Experimental Investigations for Curling Stress in Self Compacting Concrete Pavements

THESIS

Submitted in partial fulfilment
of the requirements for the degree of
DOCTOR OF PHILOSOPHY

By

GANDAGE ABHIJEET SIDDAPPA
ID. No. 2011PHXF411H

Under the Supervision of
Prof. V. Vinayaka Ram

BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI
2015

BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI

CERTIFICATE

This is to certify that the thesis entitled **"Experimental Investigations for Curling Stress in Self Compacting Concrete Pavements"** and submitted by **Gandage Abhijeet Siddappa** ID No **2011PHXF411H** for the award of Ph. D. of the institute embodies original work done by him under my supervision.

Signature of the Supervisor: ________________________________

Name: **Prof. V. VINAYAKA RAM**

Designation: **Associate Professor**
Department of Civil Engineering
BITS Pilani – Hyderabad Campus

Date:

ACKNOWLEDGEMENTS

I am deeply indebted to my revered thesis supervisor **Prof. V. Vinayaka Ram**, Associate Professor, Dept. of Civil Engineering, BITS Pilani, Hyderabad campus for his valuable guidance, suggestions, encouragement and moral support throughout the period of this research work. It has been a privilege for me to work under his valuable guidance. Apart from his super scholastic proficiency, I am greatly influenced by his humane personality and noble character.

My sincere thanks to **Prof. P. N. Rao**, Professor, Dept. of Civil Engg. BITS Pilani, Hyderabad Campus and **Prof. A. Vasan**, Associate Professor, Dept. of Civil Engg. BITS Pilani Hyderabad Campus, who are the members of Doctoral Advisory Committee (DAC), for their valuable suggestions, moral support and kind assistance from time to time.

I am thankful to **Prof. K. Srinivasa Raju,** Professor, Dept. of Civil Engg. BITS Pilani, Hyderabad Campus, **Prof. A. Jagadeesh**, Head, Dept. of Civil Engg. BITS, Pilani-Hyderabad campus and **Dr. Murari R. R. Varma**, Convener Department Research Committee (DRC), Dept. of Civil Engg. BITS Pilani Hyderabad Campus for their encouragement, moral support and kind assistance from time to time.

Gratitude is also accorded to BITS, Pilani-Hyderabad campus, for providing all the necessary facilities to complete this research work. My special thanks to, **Prof. V. S. Rao,** Acting Vice Chancellor, BITS Pilani and Director, BITS, Pilani-Hyderabad campus, for allowing me to pursue my research work successfully. My sincere thanks to **Prof. Bijendra Nath Jain**, former Vice-Chancellor, BITS Pilani, **Prof. Sanjay Kumar Verma**, Dean, Academic Research, (Ph.D Program) BITS, Pilani, **Prof. Vidya Rajesh,** Associate Dean, Academic Research Division, BITS, Pilani-Hyderabad campus, **Prof. P. Yogeeswari,** Associate Dean, SRCD, BITS Pilani-Hyderabad campus, for providing the necessary infrastructure and other facilities.

I am thankful to **Prof. V. D. Karad**, Executive President and Managing Trustee, MAEER's Maharashtra Institute of Technology (MIT), Pune, **Prof. L. K. Kshirsagar**, Principal, MAEER's MIT, Pune and **Prof. S. S. Pimplikar,** Head, Dept. of Civil Engg., MIT Pune, for permitting me to undertake my doctoral studies at BITS, Pilani, Hyderabad Campus.

I would like to express my sincere thanks to **Prof. P. B. Jadhav**, Professor and **Mr. Rahul Joshi**, Assistant Professor, Dept. of Petroleum Engineering, MIT Pune for their help, support and guidance.

I am also thankful to **Dr. D. V. Morankar**, Associate Professor, College of Military Pune, and **Mr. Nitin Kotkunde,** Lecturer, Dept. of Mechanical Engg. BITS Pilani Hyderabad Campus, for their valuable inputs during the thesis writing stage.

I express my sincere thanks to **Prof. (Mrs.) P. R. Adavi, Prof. (Mrs.) A. S. Dhariwal, Prof. (Mrs.) N. G. Gogate,** & **Prof. G. S. Ingle**, Dept. of Civil Engg. MIT Pune, for their support and encouragement throughout the research work.

I am grateful to all my colleagues at MIT Pune and friends at BITS Pilani Hyderabad Campus for their help and support in completion of my research work.

I would take this opportunity to express my heartfelt gratitude to my mother **Mrs. Prabha S. Gandage**, father **Dr. Siddappa G. Gandage**, and brother **Dr. Dhananjay S. Gandage**, for their continual inspiration, strong moral & emotional support and perpetual encouragement during my endeavor to complete this research work.

My humble thanks to one and all who helped me in many ways to complete my research work.

Abhijeet S. Gandage

ABSTRACT

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade. In India, flexible pavements are preferred for road construction due to lower construction costs and speedy construction as compared to rigid pavements. However, the maintenance costs of the rigid pavements are relatively lower as compared to the maintenance costs of flexible pavements. The rigid pavements are constructed by casting cement concrete slabs over dry lean concrete or granular sub-bases. The cement concrete pavements are designed to withstand traffic loads and environmental loads during its service life. The environmental factors that are considered in the concrete pavement analysis are temperature, humidity, precipitation and frost/heave. The stresses induced in the concrete pavements on account of daily temperature variation are termed as curling stress. The curling stresses are as important as axle loads in the concrete pavement analysis as they alone can trigger the failure of the cement concrete pavements.

The rigid pavements are constructed with normally vibrated concrete. Self-compacting concrete (SCC) is preferred over normal concrete mainly due to improved mechanical properties and speed of construction. Due to environmental regulations and concerns, the use of natural river sand in concrete manufacture is becoming impractical and obsolete. Nowadays crushed sand is widely used in concrete manufacturing process. Hence, the properties of SCC mix prepared with natural sand and crushed sand were tested in the present research. SCC is a concrete with high binder content, which poses a challenge from the point of view of sustainability. Thus, use of pozzolanic materials like fly ash and its effect on the properties of SCC were also investigated. In the present study, 20% Class C fly ash dosage as a cement replacement material was obtained through experimental trials.

The thermal properties of concrete are influenced by the thermal properties of the matrix and aggregate phase. The coarse and fine aggregates used in the present study were of granitic origin. The thermal properties of concrete manufactured with granite based aggregates are relatively high when compared to concrete manufactured with aggregates of different minerals. The influence of perlite, a proven insulating material, as a replacement for fine aggregate, on the

properties of SCC mix was also examined. In the present study, 5% perlite dosage as a fine aggregate replacement material was determined experimentally.

The present study is aimed at exploring the possibility of use of SCC with crushed sand and appropriate dosage of powder additions as a possible pavement construction material. A slab prototype of M-40 grade SCC with crushed sand was constructed. SCC mix with crushed sand, without any additions was considered as the control mix. Additional slabs of M-40 grade SCC with addition of fly ash (as a cement replacement material) and perlite (as a crushed sand replacement material) were also constructed. The slabs were embedded with sensors of appropriate lengths to measure the temperature differential developed across the slab thickness.

The replacement of cement by 20% fly ash reduced the compressive strength of SCC mix by 8.34%, while 5% perlite addition as a fine aggregate replacement material along with 20% fly ash dosage resulted in a decrease of 8.93%. The thermal conductivity (k) values of SCC mix with fly ash were 9% less than the k value of control mix. The k value of SCC mix with fly ash and perlite combination was 28% less as compared to control mix. The development of temperature differential across concrete cross section was influenced by the mix composition, properties and ambient conditions. The temperature differential (ΔT) for SCC mix with fly ash addition was observed to be 20.62% more than the control mix. This resulted in 50% increase in the curling stress as compared to the control mix. In case of SCC mix with fly ash and perlite combination, the ΔT value was 29.69% more. However, this resulted reduction of the curling stress by 47%.

Thus, from the present study it was inferred that the SCC mix with crushed sand had relatively lower ΔT developed across the thickness resulting in lower magnitude of the curling stress. Additions, if any, to the SCC mix need to be carefully considered based on the prior testing of the material properties and using these properties to estimate the curling stresses.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ACPA	American Concrete Pavement Association
ASCE	American Society of Civil Engineers
ASTM	American Society of Testing and Materials
Austroads	Association of Australian and New Zealand Road Transport and Traffic Authorities
BIS	Bureau of Indian Standards
BSE	Back-Scattered Electrons
CRCP	Continuously Reinforced Concrete Pavements
CS	Crushed Sand
CTE	Coefficient of Thermal Expansion
DLC	Dry Lean Concrete
EFNARC	European Federation of Producers and Contractors of Specialist Products for Structures
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GFRP	Glass Fibre Reinforced Polymers
HCP	Hydrated Cement Paste
HRWR	High Range Water Reducing (Admixtures)
HSC	High Strength Concrete
IRC	Indian Roads Congress
JPCP	Jointed Plain Concrete Pavements
JSCE	Japanese Society of Civil Engineers
Max.	Maximum
Min.	Minimum
MEPDG	Mechanistic-Empirical Pavement Design Guide
MPa	Mega Pascal
NCHRP	National Cooperative Highway Research Programme
NDT	Non-Destructive Testing
NRMCA	National Ready Mixed Concrete Association
NS	Natural Sand
OPC	Ordinary Portland Cement

PCA	Portland Cement Association
PCC	Portland Cement Concrete
PCE	Polycarboxylate ether
PCCP	Portland Cement Concrete Pavement
PCI	Precast/Prestressed Concrete Institute
RILEM	International Union of Testing and Research Laboratories of Materials and Structures
RTD	Resistance Temperature Detector
SCC	Self-Compacting Concrete
SEM	Scanning Electron Microscopy
TC	Technical Committee
T and F	Taylor and Francis
UPV	Ultrasonic Pulse Velocity
VMA	Viscosity Modifying Agents/Admixtures

Chapter 1

INTRODUCTION

1.1 Background of the Study:

For an emerging economy like India, development of efficient and sustainable transportation infrastructure is the key to achieve development and prosperity. A typical transportation system involves fixed facilities, flow entities and control mechanisms that allow people and freight to move in an efficiently planned geographical space ensuring timely delivery of desired activity (Papacostas, 2006). Surface transportation is the most widely used mode of transportation in the world and a country's development is measured in terms of total length of paved roads.

A pavement is an engineered structure whose function is to withstand the load applied from the vehicles without excessive deformation. Pavements can be classified as flexible (bituminous) pavements and rigid (concrete) pavements. The choice of the type of pavement to be constructed depends on type of traffic and availability of funds.

Over a period of time, it has been observed that the concrete pavements have several benefits as compared to bituminous pavements as listed below (Kadiyali, 2013):

1. The service life of concrete pavements is 30 to 40 years as compared to 15 to 20 years for bituminous pavements.
2. Concrete pavements offer maintenance free service, good riding quality and good abrasion resistance.
3. The concrete pavements reduce fuel consumption for commercial vehicles by 14 to 20%.
4. The construction of bituminous pavements requires 25% extra fuel, which is not required in concrete pavement construction.

Pavement life cycle costs mainly depend on the cost of materials used at the time of construction (Delatte, 2008). In comparison to bituminous pavements, the initial cost of construction of concrete pavements is higher, but the subsequent maintenance costs are lower for concrete pavements. As per a recent report on the status of urban roads in Pune city, (September 2014), the cost of concrete pavement construction is Rs. 2200/m^2. In comparison, the construction of bituminous pavements costs Rs. 1200/m^2 for a service life of 20 years. However, the bituminous pavements need resurfacing at an interval of three years till the end of the life of the pavement. Also, the maintenance works for 2000 km long bituminous pavements in Pune city cost Rs. 400 crores annually. In light of the above mentioned points, concrete pavements are a preferred choice of pavement construction.

One of the limiting factors of concrete pavement construction is excessive traffic stoppage time as compared to the bituminous pavement construction. However, the recent advances in the road construction technologies, like slip form paving, help to reduce the overall construction time of concrete pavement construction. One such enabling technology is the use of Self Compacting Concrete (SCC) for road construction. Since its evolution, SCC found large scale application in various surface transportation elements like highway bridges and tunnel construction. One of the major applications of SCC in the initial years was the Sodra Lanken Project in Sweden (1998-2004). The project utilized 15000 m^3 of SCC (Ouchi et al., 2003). In India, SCC was mainly used by Nuclear Power Corporation of India, for the Tarapur, Kaiga and Rajasthan Atomic Power Plant (RAPP) projects. More recently, SCC with fly ash and micro silica was used in Delhi Metro project (Sood et al., 2009). Due to various merits of SCC as compared to normal concrete, it is a preferred construction material.

1.2 Concrete pavements:

Concrete pavements have been used for construction of highways, runways, city roads, parking lots, industrial flooring and similar other infrastructure. A properly designed and constructed concrete pavement, made from durable materials, can serve the intended function for many years with practically insignificant maintenance. The first concrete pavement was constructed in Bellefontaine, Ohio in 1891 (Delatte, 2008). In India, concrete road construction was initiated in the decade of 1920-30. The famous Marine Drive in Mumbai was built in 1939 (Kadiyali, 2013).

Concrete pavements, like bituminous pavements, are designed as all weather, long lasting structures to cater to high speed traffic (Fwa, 2006). However, the load distribution mechanism in both the type of pavements is different. The bituminous pavement is designed to provide sufficient thickness to distribute the applied load with depth, whereas concrete pavements rely on the slab action to spread the load over a large area. The stresses in concrete pavements are induced on account of the interaction amongst various factors, which can be categorized as under (Papagiannakis, 2008):

1. Environmental (effect of temperature and moisture changes in the pavement slab)
2. Traffic loading

3. Base or subgrade support of slab (volume change or erosion of subgrade)

The stresses induced in the concrete pavements on account of temperature differential across the thickness of the pavement slab, are termed as curling stress. At times, the magnitude of the curling stress can be equal to the stresses induced by the traffic wheel loads. These stresses are tensile in nature. Hence, the curling stresses are of critical importance in the design of a low tensile strength material like concrete (Fwa, 2006).

1.3 Self Compacting Concrete (SCC):

The concept of SCC originated from the research related to underwater placement of concrete (Mehta, et al. 2006 and Gaimster et al. 2003). According to the European guidelines (EFNARC, 2005), SCC is defined as a concrete that is able to flow and consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, while retaining its homogeneity without any need of any additional compaction. The present day SCC was developed in Japan. The first mix design model was developed by Ozawa et al. in 1989 (Gaimster et al. 2003). Various research teams, Okamura et al., (1989), Yurugi et al. (1993), Domone and Chai (1996), later improvised the initial SCC mix design to establish better SCC mixes (Gaimster et al. 2003).

SCC is characterized by high binder content and adequate fluidity. It is also termed as a High Performance Concrete (HPC), on account of the ease of it's placement in heavily reinforced sections and compaction under its own self weight without segregation (Naik et al., 2012, Ghafoori et al. 2010, Kwan et al, 2010 and Sideris, 2007). As compared to conventional concrete, SCC is ensures quiet, safe and speedy completion of the construction activity (Lomboy et al. 2011). Large scale construction operations prefer SCC over normal concrete due to various advantages it offers that can be categorized as technical, economic and environmental (Gandage et al., 2014 and Domone, 2006). The various advantages of SCC have been summarized in Table 1.1.

Table 1.1: Advantages of SCC

Technical	Economic	Environmental
Concreting in heavily reinforced sections	Reduced construction time	Safe work environment
Thin section precast units can be manufactured	Reduced labour costs and safer operations	Large scope for use of waste materials
Structures of any geometry can be cast	Use of industrial waste help offset high input costs	Improved carbon footprint of concrete

1.4 Organization of the Thesis:

The thesis presents the details of the study undertaken and results obtained from the experimental and numerical/analytical investigations undertaken during the current research activity. The thesis is organized as explained below;

Chapter 1 presents the brief introduction about importance of pavements, concrete pavements and Self Compacting Concrete (SCC).

Chapter 2 reviews and summarizes the relevant literature related to the thermal properties of concrete, the methods of measurement of the thermal properties, its influence on the development of temperature gradient in concrete pavements, the measurement and subsequent analysis of the temperature gradient. Further, a review on the SCC mix with various additions, its properties and micro-structure analysis of the SCC has been presented. The chapter presents the problem statement and objectives of the proposed research. In conclusion, the research methodology adopted to achieve the research objectives is discussed.

Chapter 3 presents the details of experimental investigations Part 1, comprising material properties and test results. The chapter discusses the procedure of microstructure analysis to understand the morphology of various materials considered in the SCC mix using intermediate Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Analysis (EDXA). Thin Section Petrographic Analysis undertaken to study the morphology of the coarse aggregate used in the investigations has also been presented in this chapter.

Chapter 4 discusses the details of experimental investigations Part 2. This stage presents the mix design details as well as the test results for fresh and hardened state properties of SCC mix with natural sand (NS) and crushed sand (CS) along with the micro structure analysis. It also presents the test results of experimental procedures undertaken to determine the appropriate dosage of fly ash as a cement replacement additive and perlite as a fine aggregate replacement. The microstructure analysis of the SCC mix with fly ash and perlite additions are also presented and discussed.

Chapter 5 presents the details of experimental investigations Part 3. The initial part of the chapter details the procedure and results to determine laboratory measurement of thermal conductivity (k) for SCC mixes finalized in the earlier chapter. The relation between k values of the concrete mixes with microstructure and the properties of the mixes has also been discussed. In the later part of the chapter, the laboratory setup developed for measurement of temperature differential across cube specimen and slab section for specific case conditions are discussed in detail. The chapter also presents the magnitude of temperatures determined using numerical equations.

Chapter 6 discusses the computation of theoretical values of curling stresses using Westergaard's equations with Bradbury's coefficients.

Chapter 7 presents the conclusions of the research study undertaken.. This chapter also includes the future scope of the work as well as contributions from the research study.

Fig. 1.1 presents the outline of the organization of thesis.

Chapter 1: Introduction

- Background of the Study.
- Concrete pavements.
- Self-Compacting Concrete.
- Organization of Thesis.

↓

Chapter 2: Literature Review

- Rigid or Concrete Pavements. (Environmental Load Analysis of Concrete Pavements, Curling stress analysis in Concrete pavements, Built-in curl of concrete slabs, MEPDG, Thermal properties of Concrete, Field Studies to measure Temperature Differential across concrete pavement slabs).
- Self-Compacting Concrete (Origin, Mix Design, SCMs, SCC for pavement construction).
- Findings from Literature Review.
- Gaps identified in Literature Review.
- Problem Statement for Research.
- Objectives of Research.
- Research Methodology.

↓

Chapter 3: Experimental Investigations (Part 1): Material Properties & Morphology

- Overview of materials used in the research study.
- Properties of the materials and test results (Cement, Aggregates, fly ash, perlite, admixture).
- Morphology studies of concrete ingredients using intermediate SEM & EDXA (cement, fly ash, perlite, pan dust).
- Thin Section Petrographic Analysis of Coarse Aggregate.

↓

Chapter 4: Experimental Investigations (Part 2): SCC Mix Design, Properties & SEM Analysis

- Overview of Mix Design methods for SCC.
- Fresh & hardened state properties of SCC mix with NS and CS with SEM Image analysis.
- Fresh & hardened state properties of SCC mix with SEM image analysis to determine appropriate dosage of fly ash as a cement replacement additive.
- Fresh & hardened state properties of SCC mix with SEM image analysis to determine appropriate dosage of perlite as a fine aggregates replacement additive.

↓

Chapter 5: Experimental Investigations (Part 3): Thermal Conductivity, Temperature Gradient

- Overview of Thermal conductivity studies.
- Temperature gradient measurement in cube specimen and Slab section.
- Temperature results using Choubane Tia Model and Fourier Biot Eqn.

↓

Chapter 6: Computation of Curling Stress

↓

Chapter 7: Conclusions & Future Scope of Work

Fig. 1.1: Overview of Organization of Thesis

Chapter 2

LITERATURE REVIEW

The chapter comprises two main sections. In the initial section, review of literature related to concrete pavements, environmental loads on concrete pavements and temperature effects on concrete pavements is presented. The second section discusses the findings from the literature survey related to SCC. The chapter concludes with the key findings from the literature review that helped define the research problem and objectives.

2.1 Rigid or Concrete pavements:

A pavement is an engineering system. Its analysis and design includes interaction of naturally available supporting layers, the constructed layers and nature and magnitude of the applied loads (**Ioannides, 2006**). Rigid pavements are essentially made of Portland cement concrete. The use of cement concrete as a construction material is on account of economic reasons and ease in availability of the concrete ingredients. The concrete pavement is designed as a long lasting all weather structure for modern day high speed traffic. As per Tayabji and Lim 2007 (**Van Dam et al. 2012**), the design of long lasting concrete pavement includes:

1. Adequate structural slab thickness
2. Strong erosion resistant bases
3. Doweled transverse joints.

For the concrete pavement to achieve its functional requirement, following aspects related to design and construction of the pavements are important:

1. Determination of soil properties, design, traffic loads and environmental parameters
2. Selection of appropriate materials for various pavement layers
3. Structural design to determine adequate thickness of pavement layer
4. Design of drainage system
5. Safety and geometric design.

2.1.1 Environmental Load analysis of Concrete Pavements:

The concrete pavement is designed for repeated traffic loading that influences the fatigue life of the material. The daily traffic load is a major design factor considered for concrete pavements. The fatigue failure of the concrete pavement occurs on the account of repetitive action of wheel loads, whose magnitude may be less than the failure load of the material (**Fwa, 2006**). Apart from traffic loads, environmental loads are also to be considered in the design of concrete pavements. These loads determine the plan dimensions of the pavement slab, design of the temperature reinforcement to control crack width & crack spacing and joint & joint reinforcement for effective load transfer between adjacent slab panels.

The environmental factors that affect the performance of concrete pavements include temperature, humidity, precipitation and frost/heave (**Mahboub et al. 2003**). The environmental factors induce various types of stresses/strains in the concrete pavements. The stresses developed in the concrete pavements on account of temperature can be of two types, curling stress and thermal expansion stress (**Masad et al. 1996**). The curl induces stress in the slab which is restrained by its self-weight and the slab sub-base or sub-grade interaction. Based on the location of traffic load and time of the day, the magnitude of the curling stress can be high enough to cause failure of the slab. The non-linear temperature distribution causes higher tensile stresses than the linear temperature distribution. This difference was in the range of 3% to 13.5% of the modulus of rupture of concrete (**Masad et al. 1996**).

Temperature stresses can also occur in concrete slabs due to variations in the uniform temperature. The variation in the uniform temperature causes the slab to expand and contract. If this movement of slab is resisted on account of friction between the concrete slab and sub-grade or sub-base, then it induces tensile stresses. These stresses are dependent on the friction factor between slab and the sub-base as well as slab geometry (**Masad et al. 1996**).

2.1.2 Curling Stress in Concrete Pavements:

The curling stress results from temperature differential between the top and bottom of the concrete slab. Temperature gradients in the concrete pavement slabs cause the slabs to curl upwards and downwards on daily basis as well as seasonally. The moisture gradients cause the slab to curl upwards (**Asbahan, 2011; Jeong et al. 2005**). The stresses developed in concrete pavement slab on account of temperature differential are termed as curling stress. The deflection in slab on account of moisture differential is termed as warping (**Jeong et al. 2005**).

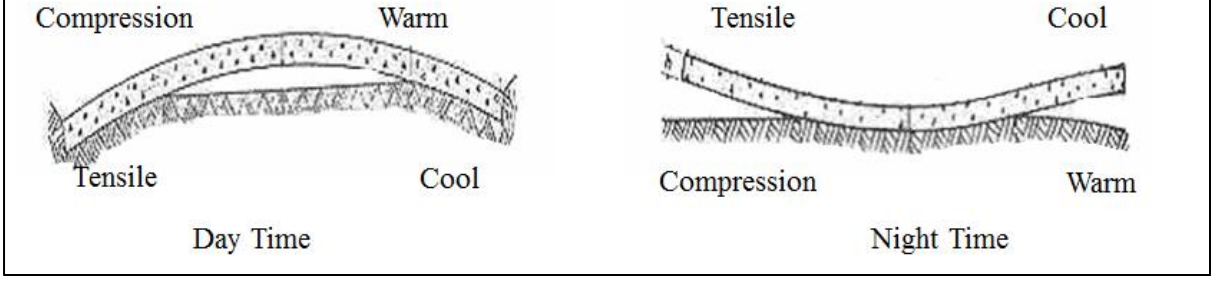


Fig. 2.1: Curling Stress in Rigid Pavements

(Fwa, 2006; Huang, 2004)

The temperature effects on concrete pavements were studied since 1920s. Westergaard (1927), proposed the solution for temperature curling. These equations were based on simplified boundary conditions and linear temperature profile in the slab. Bradbury (1938), suggested correction factors, assumed linear temperature differential for curling stress analysis. However, it was Teller and Sutherland (1935) who reported non-linear temperature profiles. According to them, the stresses arising from restrained temperature warping are as important as those produced by the heaviest legal loads. Mirambell (1990), Choubane and Tia (1992, 1995), Lee and Darter (1993), Harik et al (1994), Masad et al (1996), Mohamed and Hansen (1997), Ioannides and Khazanovich (1998) and Ioannides and Salsilli-Murua (1999), have reported the non-linearity of temperature profile across slab thickness (**Hiller et al. 2010**). Thomlinson (1940), addressed the curling stress problem due to non-linear temperature profile for the first time. It was proposed that the total non-linear temperature profile across concrete pavement slab comprised three parts viz. uniform axial, linear curling and self-equilibrating non-linear (Fig. 2.2).

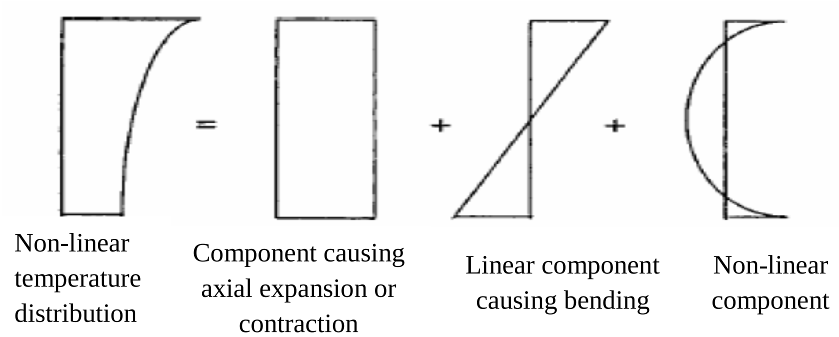


Fig. 2.2: Stress components due to non-linear temperature profile (Siddique et al. 2005, Hiller et al. 2010)

The axial component represents the uniform temperature factor that leads to slab expansion or contraction. This movement is resisted by the friction between slab and underlying layer or neighbouring slabs. The resistance offered generates stresses in the pavement slab, whose magnitude is minimum in case of matured slabs. For a freshly laid slab, this factor is not applicable as the tensile stresses developed are countered by the material strength. The second component is the equivalent linear bending stress which gives the same moment as the non-linear temperature profile. The third component is the self-equilibrating internal stress component that is non-linear in nature. The nature of this component can be tensile or compressive across the depth of the slab. However, it does not affect the deflection profile of the slab. The third component is usually not considered in the slab analysis as it is difficult to determine the magnitude of the temperature related stress (Ioannides et al. 1998).

Choubane and Tia (1992), proved that the assumption of linear temperature profile led to an error of 30% in the computation of warping stresses. **Zhang et al. (2003)** have analyzed the data regarding environmental loads for pavement slabs constructed in Florida and Illinois. They concluded that for the pavement slabs in Florida, the maximum tensile and maximum compressive stresses evaluated in the upper part of the slab assuming linear temperature distribution were 12.9% and 24.3% lower than the corresponding stresses computed using non-linear temperature profile. The maximum tensile and maximum compressive stresses evaluated in the lower part of the slab were 47.2% and 15.9% higher than the corresponding stresses computed using non-linear temperature profile. For the pavements in Illinois, adopting linear temperature profile, the maximum tensile and compressive stresses computed were 55.9% and 29.3% lower than the stresses computed assuming non-linear profile in the upper part of the slab. For the lower part of the slab, the maximum tensile and compressive stresses calculated with linear temperature profile were 74.9% and 100% higher respectively as compared to stresses computed using non-linear temperature profile.

Research studies were undertaken to present the actual temperature profile developed in the pavement slab and the related stresses. Khazanovich, 1994; Mohamed and Hansen, 1997; Jeong and Zollinger, 2005 proposed third order polynomial equation of the following form for measuring the temperature gradient in the concrete slab (**Hiller et al. 2010**) as given below,

$$\Delta T = A + Bz + Cz^2 + Dz^3 \qquad (2.1)$$

where;

z: zero at mid-depth of the slab and +ve in the downward direction and –ve in the upward direction of the slab.

A, B, C and D: regression coefficients.

However, the limitation of use of third order polynomial equation is that it fails to predict the temperature stress component at intermediate depths (**Hiller et al. 2010**).

According to Choubane and Tia (1995), a simple quadratic function is sufficient to present the daily temperature profile throughout the depth of the pavement slab. The equation is as under;

$$T(z) = A + Bz + Cz^2 \qquad (2.2)$$

where;

z: distance from the bottom of the slab.

A, B and C: regression coefficients based on measured slab temperature profile.

$$A = T_{bot} \quad (2.3)$$

$$B = \frac{4T_{mid} - 3T_{bot} - T_{top}}{h} \quad (2.4)$$

$$C = \frac{2(T_{bot} + T_{top} - 2T_{mid})}{h^2} \quad (2.5)$$

where;

T_{top}, T_{mid} and T_{bot} are temperatures at top, middle and bottom of the slab

h is slab thickness

Further, the study concluded that assumption of linear temperature profile led to higher values of maximum tensile stresses for day time condition and lower values for night time condition.

The daily and seasonal variations in the temperature and moisture influence curling stress as well as the slab-subgrade contact. A partial loss with the underlying subgrade affects the stresses that are induced in concrete slabs. Masad (1996) and Ahmad (1998) have reported that the temperature gradient developed in concrete slab may be related to fatigue failure to some extent. It was reported that a temperature gradient of 1^{o}F/in. in the concrete slab increases its fatigue damage on account of truck traffic by a factor of 10 when compared to zero temperature gradient condition (**Masad, 1996 and Belshe et al. 2011**). The effects of moisture fluctuations are insignificant. As per field and model studies, performed on Gene Snyder freeway, Louisville, Ky., undertaken by **Mahboub et al. (2004)**, the change in traffic load induced strain was 20% less than the change due to temperature for a particular day and time. The study proved that environmental factors (temperature) produce a significant response in concrete pavements than traffic loads.

As per **Liu et al. (2000)**, the temperature distribution across pavement thickness is governed by Fourier-Biot heat conduction equation as mentioned below,

$$\frac{\partial^2 T}{\partial z^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} = \frac{1}{\frac{k}{\rho c}}\frac{\partial T}{\partial t} \quad (2.6)$$

where;

α: thermal diffusivity coefficient of the material, T: Temperature, k: thermal conductivity of material, ρ: density of material, c: specific heat of material, z: depth of the layer or thickness of section. This temperature distribution is transient in nature (**Vandenbossche et al. 2011a**). In the transient system, the temperature changes with time as well as position in the slab.

2.1.3 Built-in Curl of Concrete Pavement Slabs:

During the paving of concrete roads, a shrinkage gradient is developed due to difference in the moisture content between the top and bottom of the slab. The moisture differential causes a curling moment in the slab causing it to lift upwards at the corners and edges (**Rao et al. 2005**). As this curling is observed during the construction phase of the pavement slab, this is termed as built-in curl. **Rao et al. 2005** undertook a study on State Route 14, Palmdale California, and proposed an effective built in temperature difference (EBITD). EBITD is a result of built-in temperature gradient, shrinkage and creep. The tests were performed on pavement slabs cast with fast setting high-early strength concrete under desert conditions.

The occurrence of curling in a concrete pavement slab comprises of five factors viz. (**Rao et al. 2005**):

1. Temperature gradient through the slab (ΔT_{tg})
2. Moisture gradient through the slab (ΔT_{mg})
3. Built-in temperature gradient (ΔT_{bi})
4. Differential drying shrinkage (ΔT_{shr})
5. Creep (ΔT_{crp})

The curling in slab due to the above mentioned factors is expressed as total effective linear temperature difference (TELTD) (ΔT_{tot}).

$$\Delta T_{tot} = \Delta T_{tg} + \Delta T_{mg} + \Delta T_{bi} + \Delta T_{shr} - \Delta T_{crp} \qquad (2.7)$$

The above mentioned components are influenced by material properties such as coefficient of thermal expansion, thermal conductivity, permeability etc. as well as mix design parameters like aggregate type, cement content and type, water content, admixtures etc. (**Rao et al. 2005**).

Asbahan et al. (2011) undertook a study on effects of temperature and moisture gradients on slab deformation for a JPCP at early age. The curvature in slab, on account of curling and/or warping stress is its response to the environmental loads. The research team studied 14 instrumented JPCP slab panels on State Route 22, Murrysville, Pennsylvania for a period of 2 years, to measure the variations in temperature and moisture in a newly laid pavement as well as contribution of built-in and transient environmental effects over time. The slab panels were instrumented with thermocouples, moisture sensors and vibrating wire (VW) static strain gauges. As per the findings, the slab curvature developed on account of transient temperature and moisture conditions are influenced by following factors:

1. Temperature and moisture conditions at the time of construction of slab (built-in gradients which affect the long term performance of slab)
2. Concrete materials properties like CTE, drying shrinkage, creep and elastic modulus of concrete
3. Restraints to the slab deformation in form of self-weight, friction at slab sub-base interface and restraints to joint movements (dowel bars, tie bars and aggregate interlock).

The built-in temperature gradient in the pavement slab not only depends on the CTE of concrete but also on temperature conditions at the time of casting and curing practices and conditions adopted (**Asbahan et al. 2011; Vandenbossche et al. 2011a**). As compared to the unrestrained slabs, the curvature of restrained slabs was 60% lower. The restraint of temperature and moisture related deformation can result in higher levels of environmental slab stress which decrease over time with creep and stress relaxation. Its magnitude may also decrease because of reduced load related stresses.

As per studies undertaken in Michigan (**Hansen et al. 2006**), the built-in curl in concrete slabs (due to temperature differential between slab top and bottom during setting of the slab) will be high in case of paving in hot weather. Early morning paving limits the temperature differential developed due to combined heat of hydration and solar radiation effects. If the temperature difference between the slab top and bottom is in the range of 10^{o}C to 12^{o}C, then the slab profile during the setting phase is flat and it remains in full contact with the underlying layer. This minimizes the occurrence of the tensile stresses in the pavement slab during setting.

Wells et al. (2006), attempted to quantify the built-in construction gradients in concrete pavement slabs. Construction curling and warping generates a built-in temperature gradient due to the changes in the temperature and moisture in a hardening cement concrete slab. Due to insignificant stiffness in the fresh concrete, the slab remains flat in presence of the gradient. A 30 cm thick instrumented concrete slab laid over 10 cm thick open graded asphalt stabilized base, a 13 cm thick dense graded sub-base and 61 cm thick backfill was investigated in Murrysville, Pennsylvania. At the time of final set, a linear temperature gradient of 0.2^{o}C/cm was recorded at the slab edge and a near zero gradient at the mid panel.

The joints in the pavement cracked after 17 to 19 hours of paving. This was on account of a large negative temperature gradient of -0.2^{o}C/cm.

A similar study to investigate the effect of environmental loads on the early behaviour of concrete slabs was undertaken at Texas A & M University by **Jeong et al. (2005)**. The slab dimensions were 9.2 m long, 3.7 m wide and 30.5 cm thick, laid on a 10.2 cm thick lean concrete sub-base with plan dimensions of 10.4 m and 4.3 m. The slab was observed for a period of 2 years. According to the study, the early behaviour of the slab is influenced by moisture, temperature and creep. Creep is a time-dependent deformation of concrete observed during the early age. It reduces the effect of tensile stresses developed due to temperature or moisture differential caused during the early age of concrete. It is related to viscous movement in the hydrated cement paste characterized by loss of moisture and shrinkage. Creep is influenced by the amount of shrinkage, quantity of aggregate, water-cement ratio, age at loading, temperature & humidity conditions and amount of curling & warping stresses.

2.1.4 Mechanistic Empirical Pavement Design Guide (MEPDG):

One of the important aspects in pavement analysis and design is the adoption of MEPDG (**Asbahan et al. 2011 and Breakah et al. 2011**). MEPDG is a transition state between empirical methods of pavement design and mechanistic design procedures. MEPDG inputs considered for pavement analysis and design includes material properties, support conditions, traffic and climate data as well as slab geometry, edge support and joint load transfer (**Van Dam et al. 2012**). The climate data affects the overall pavement performance as material properties change with temperature and moisture conditions (**Breakah et al. 2011**). The temperature induced warping stress can be of equal magnitude as wheel loads and is a major factor in the mechanistic design of concrete pavements (**Shi et al. 2000**).

The output of the new pavement analysis guideline gives the predicted quantities of distress, (like cracking, spalling and faults) as well as ride quality (roughness index). It is a comprehensive guide to understand the pavement performance under various load mechanisms (**Vandenbossche et al. 2011b**). The fault and crack models proposed in MEPDG consider the built-in temperature gradient as well as modulus of rupture of concrete. As per studies undertaken in Minnesota, one of the important factors related to MEPGD observed was, the predicted parameters of pavement performance were over estimated as compared to the actual field test data. This is on account of difference in the design pavement and the as-built pavement.

2.1.5 Thermal Properties of Concrete:

The response of the concrete pavement to environmental loads, in particular temperature loads, mainly depends on the thermal properties of concrete as well as its constituents. The thermal properties of concrete influence its service life performance like fire resistance and development of temperature gradients. Important thermal properties of concrete that should be considered in the analysis of environmental loads are specific heat, coefficient of thermal expansion (CTE), and thermal conductivity (k). Depending on the application of the concrete, specific thermal property is expected. For insulation purposes, concrete with low thermal conductivity is required. In case of concrete components exposed to high temperature differential which causes tensile stresses in the concrete, high thermal conductivity is preferred (**Xu et al. 2000**).

Dehdezi (2014), states that the thermophysical properties of concrete govern the temperature distribution and stresses in concrete pavement slabs. The thermophysical properties of construction materials that influence its long term performance are thermal conductivity, specific heat capacity, density, thermal diffusivity and thermal effusivity. In case of concrete, the thermophysical properties of aggregates significantly influence the thermal behaviour of concrete. Apart from these properties, the type of aggregate, porosity (inter-particle contact) and moisture content of the aggregates also influence the thermal response of concrete. The analysis of field data related to temperature differential in pavements in Arizona and Montana (**Dehdezi, 2014**), proved that 25% reduction in the thickness of pavement slab can be achieved if concrete with quartzite aggregates (thermal conductivity 3.6 W/m/^{o}K for concrete with quartzite aggregates) is used as compared to concrete with limestone aggregates (thermal conductivity 1.2 W/m/^{o}K for concrete with limestone aggregates),

Naik et al. (2011), investigated the influence of type of coarse aggregate particle on the coefficient of thermal expansion (CTE) values of concrete. CTE is defined as the unit change in length per degree of temperature change. In simple terms, CTE measures the expansion or contraction of the material with temperature. CTE of concrete plays an important role in the design and service life performance of pavements as it affects the critical slab stresses as well as joint and crack openings. CTE of aggregates influences the performance of concrete as it affects the change in dimensions due to variation in temperature. High values of CTE adversely affect the durability of concrete because of the thermal incompatibility amongst the constituent materials. Pavement distresses like early age or premature cracking, faulting, blow-ups, corner breaks, joint spalling and large joint openings during adverse seasons are related to CTE. CTE of concrete depends on material factors like cement paste, aggregates, moisture conditions, age and environmental factors like temperature fluctuations and relative humidity. Of all the ingredients in the normal concrete, coarse aggregates constitute 75% of the total volume. Thus, the coarse aggregates influence the CTE values of concrete. CTE of aggregates is influenced by type, origin and geographic location of the parent rock. The CTE of concrete manufactured with different types of aggregates are listed in Table 2.1.

Table No. 2.1: CTE of concrete with different aggregates (Fwa, 2006)

Concrete with aggregate type	Coefficient of Thermal Expansion (α_c)
Concrete with limestone aggregate	6 x 10^{-6} to 8 x 10^{-6} per ^{o}C.
Concrete with granite aggregate	8 x 10^{-6} to 10 x 10^{-6} per ^{o}C.
Concrete with sandstone aggregate	10 x 10^{-6} to 12 x 10^{-6} per ^{o}C.
Concrete with blast furnace slag aggregate	9 x 10^{-6} to 12 x 10^{-6} per ^{o}C.

As per **Shin et al. (2011)**, the CTE of concrete is an important design parameter in estimating pavement performance for cracking, faulting and international roughness index (IRI). Based on the studies undertaken to assess the CTE values of concrete using different aggregates, it was observed that for an increase of 8% in the CTE values of concrete at 63% relative humidity, the tensile stresses in the top surface of PCC pavement slab, on account of curling, would increase by 12% during morning hours.

Khaliq et al. (2011), investigated the thermal and mechanical properties of self-compacting concrete (SCC) and fibre reinforced self-compacting concrete (FRSCC) at varying temperatures. As per the study, concrete contains different forms of moisture (moisture in the voids of concrete, adsorbed moisture and capillary moisture) which evaporates at different rates depending on the temperature condition. This physical and chemical change in the microstructural phenomenon leads to variation in the thermal conductivity of concrete with temperature. The thermal conductivity values decrease with increase in the temperature (20^{o}C to 800^{o}C). Addition of steel or propylene fibres does not alter the thermal conductivity values significantly.

Kodur et al. (2011) undertook a laboratory investigation to assess effect of high temperature (20^{o}C to 800^{o}C) on the thermal properties of HSC, SCC and fly ash concrete (FAC). From the studies it was concluded that, the thermal conductivity of SCC mix was highest as compared to HSC and FAC mixes. This is attributed to the use of HRWR admixture in SCC as the higher concentration of the admixture ions increase the thermal conductivity values of SCC.

Xing et al. (2011), performed an experimental study to assess the influence of type of aggregates on concrete behaviour at high temperatures. The aggregates used in the study were siliceous, crushed calcareous and semi-crushed silico-calcareous. It was inferred that the thermal conductivity of HSC mix with siliceous aggregates was more as compared to the other mixes. The silico-calcareous aggregates contained 70% of siliceous aggregates (flint). Yet the thermal conductivity values of the HSC mix with silico-calcareous aggregates was not equal to the thermal conductivity values of HSC mix with siliceous aggregates. This is on account of low thermal conductivity values of flint as the quartz in flint is cryptocrystalline as compared to quartz in the siliceous aggregates which is macrocrystalline. Further, with increase in temperature, the values of the thermal properties reduce due to the deterioration of the micro-structure interface and limited heat transfer in the voids.

As per the experimental investigations undertaken by **Bentz et al. (2010)**, the addition of fly ash to cement mortar or concrete decreases the thermal conductivity values on account of decrease in the density of the matrix phase. The addition of fly ash does not influence the specific heat property of the concrete or mortar as the specific heat capacities of fly ash and cement are approximately same. The type of aggregates also influences the thermal properties.

Wang et al. (2008), investigated the thermal properties of materials in Iowa state used for pavement construction. As per the findings noted in the study, the thermal properties of the material, CTE and thermal conductivity have an important role in MEPDG. The CTE of concrete is generally higher in dry condition than in wet conditions. The thermal conductivity of cement concrete is influenced by mineral character of the aggregates, water content, air void content & structure and the temperature & moisture condition of concrete. The studies were performed on concrete specimens prepared using quartzite, dolomite and limestone aggregates. The CTE values of concrete with quartzite were more ($12.35 \times 10^{-6}/^{o}C$) than the CTE values of concrete with dolomite ($12.03 \times 10^{-6}/^{o}C$) and limestone ($10.25 \times 10^{-6}/^{o}C$). As per investigations undertaken jointly by Iowa Dept. of Transportation and FHWA, with increase in the thermal conductivity of concrete, the faulting and cracking of PCC pavements decreases.

Buch et al. (2008) have undertaken laboratory investigations to determine CTE values of concrete mixes with various aggregates (limestone, dolomite, gravel, slag and trap rock) in Michigan. The studies concluded that the aggregate geology, age of the specimen and the number of heating and cooling cycles have a significant impact on CTE values. The temperature observations are crucial in arriving at suitable conclusions regarding the thermal performance of concrete specimens. Automated temperature observations at a rate of one reading per minute ensures reliable data for further analysis.

As per studies undertaken by **Al-Ostaz (2007)** on 20 different concrete mixes to analyse the effect of aggregate type, moisture content and temperature on CTE of concrete, the humidity or moisture control factor is less significant in influencing the CTE of concrete. The type of aggregate used in concrete mix was a major influencing factor. The studies were undertaken on concrete specimen prepared using chert and limestone based aggregates. The concrete mixes with chert aggregates exhibited higher CTE values than limestone aggregate concrete mixes.

Demirboğa et al. (2003) have experimented with the use of expanded perlite aggregates on light weight concrete mixes containing fly ash and silica fume as a cement replacement additive. From the studies undertaken, it was observed that the addition of fly ash, silica fume and expanded perlite aggregate decreased the thermal conductivity of the light weight concrete mix by 43.5%. The addition of fly ash and silica fume affected the density of the concrete mix, which in turn influenced the thermal conductivity values. 30% addition of fly ash and silica fume as a replacement of cement led to a maximum reduction in thermal conductivity values. The thermal conductivity (k) value of the concrete mix with fly ash is 18.6% less than the k value of the concrete mix with silica fume.

Kodur et al. (2003) investigated that the type of aggregates used in the concrete mix significantly influenced the thermal properties of High Strength Concrete (HSC). The thermal properties of HSC mixes with siliceous and carbonate aggregates were tested at a temperature range of $0^{o}C$ to $1000^{o}C$. The thermal conductivity of HSC mix with siliceous aggregates is more than HSC mix with carbonate aggregates on account of high crystallinity of the siliceous aggregates. Due to the high crystallinity of the siliceous aggregates, the rate of decrease of thermal conductivity with temperature is also high as compared to carbonate aggregates. The specific heat values of the HSC mix with siliceous aggregates is less as compared to the concrete mix with carbonate aggregates.

Studies undertaken by **Xu et al. (2000)**, have proved that the addition of sand decreases the specific heat and increases the thermal conductivity of concrete. Addition of sand to cement paste without any mineral admixtures reduced the specific heat by 13% and increased the thermal conductivity by 9%. Cement mortar with silica fume showed that the specific heat decreased by 11% and thermal conductivity increased by 65% on sand addition. As compared the mineral admixture, the interface area between sand particle and cement paste is small. This reduces the specific heat values and increases the thermal conductivity values.

2.1.6 Field Studies to measure the Temperature Differential across Concrete Pavement Slabs:

According to **Huang (2004)**, curling stress in concrete pavements vary with the temperature differential between the top and bottom of the slab. Unless actual field measurements are recorded, it is reasonable to assume a maximum temperature differential of 2.5^{o}F/in. to 3.5 ^{o}F/in. (0.055 ^{o}C/mm to 0.077 ^{o}C/mm) during day and about half the above values at night. As per the findings of the Arlington Road Test reported by Teller and Sutherland (1935), the maximum temperature differential between the top and bottom of the concrete slab was measured in the months of April and May. On averaging the largest five measurements, the maximum temperature differential in a 6 in. (152 mm) slab was 22 ^{o}F (12.2 ^{o}C) and for a 9 in. (229 mm) slab the temperature differential was 31 ^{o}F (17.2 ^{o}C). These values correspond to temperature gradients of 3.7 ^{o}F/in. (0.080 ^{o}C/mm) and 3.4 ^{o}F/in. (0.074 ^{o}C/mm) respectively.

As per the AASHTO road test, temperatures were measured in a 6.5 in. (165 mm) concrete slab. The temperatures were measured between a point 0.25 in. (6.4 mm) below the top surface and 0.5 in. (12.7 mm) above the bottom surface of the slab. This temperature difference was referred to as standard temperature differential. The maximum temperature differential for the months of June and July were averaged to 18.5 ^{o}F (10.2 ^{o}C) when the slab curled down and -8.8 ^{o}F (-4.9 ^{o}C) when the slab curled up. The above values correspond to temperature gradients of 3.2 ^{o}F/in. (0.07 ^{o}C/mm) and 1.5 ^{o}F/in. (0.03 ^{o}C/mm) respectively. The temperature differentials measured in slabs of other thickness at AASHTO test site showed that the temperature differential was not proportional to the slab thickness. The rate of increase in the temperature differential was not as rapid as the increase in the slab thickness. Hence, greater temperature gradient should be used for thinner slabs (**Huang, 2004**).

As per **Suresh Kumar et al. (2013)**, the performance of the rigid pavements is influenced by environmental factors like humidity, precipitation, amount of solar radiation along with temperature. The research team presented the data on temperature differential obtained in a high volume fly ash concrete pavement (HVFAC) section (4.4 m x 3.3 m x 300 mm) in Bangalore. The slab was embedded with thermocouples to monitor temperature in the top, middle and bottom sections of the slab. The study period duration was seven days (in summer, winter and monsoon season) in which hourly temperature data were recorded. As per the study undertaken, the minimum surface temperature for the slab during summer, winter and monsoon season was 22.80 ^{o}C, 21.30 ^{o}C and 21.10 ^{o}C respectively. The maximum surface temperature for the slab during summer, winter and monsoon season recorded was 53.90 ^{o}C, 42.30 ^{o}C and 38.60 ^{o}C respectively. The maximum temperature differential recorded for the HVFAC slab was 13.5 ^{o}C, 13 ^{o}C and 8.8 ^{o}C for summer, winter and monsoon season respectively.

Binod Kumar et al. (2012) studied the response of concrete pavements to environmental loads with instrumented test sections at NH-2 (Allahabad by-pass), NH-76 (Kota, Rajasthan) and NH-31 (Siliguri, West Bengal). Vibrating wire temperature sensors were embedded at different depths in the test sections. The slab thicknesses investigated were of 320 mm (NH-2), 310 mm (NH-76) and 300 mm (NH-31). The positive temperature differential recorded was 19.2 ^{o}C (on NH-2), 17.1 ^{o}C (on NH-76) and 18.9 ^{o}C (on NH-31). The IRC:58 prescribed values for positive temperature differential at Allahabad, Kota and Siliguri are 16.4 ^{o}C, 15.8 ^{o}C and 16.84 ^{o}C respectively. This temperature differential was observed between 1300 hrs. to 1500 hrs. (IST).

According to **Belshe et al. (2011)**, Arizona Department of Transportation (ADOT) laid a layer of thin open graded asphalt rubber friction course over existing Portland cement concrete pavement (PCCP). This layer helped in redeveloping skid resistance of the pavement surface, ensured reduction in tyre pavement noise by 4 dB to 6 dB and minimized the tendency of reflective cracking. Apart from above listed merits, one of the important advantage of having such a layer is, the lowering of curling stresses caused by thermal gradients thereby ensuring longer pavement life. The temperature variations in PCCP cause one of the following effects:

1. Uniform temperature changes cause expansion and contraction of the whole slab

2. Temperature gradient between the top and bottom of the slab causes the slab to curl. As the slabs are restrained to curl, they crack on account of temperature induced stresses.

Siddique et al. (2005), measured the development of temperature differential across concrete slab. As per their investigations, the profile of the temperature differential was non-linear, with rapid change in temperature in the upper half of the slab and a gradual change in the lower half. Based on this study, **Belshe et al. (2011)** undertook a field investigation on Interstate 10 (I-10) at Ray Road, Phoenix. The pavement section consisted of 343 mm PCC slab and 150 mm aggregate sub-base. The temperature change occurring in the pavement slab was measured for peak ambient air summer temperature (45 ^{o}C) and minimum winter temperature (1.7 ^{o}C). In this study, the temperature change in the upper part of the pavement slab recorded was 20 ^{o}C for a period of 24 hours, while in the lower part of the slab the temperature change recorded was 4.5 ^{o}C during summer time. For the winter observations, the temperature change for a period of 24 hours in the upper part of the slab was 12.5 ^{o}C and 3 ^{o}C for lower part of the slab. The provision of open graded friction course reduced the temperature changes by 2 ^{o}C to 4 ^{o}C in the upper part of the slab and by 1 ^{o}C in the lower part of the slab, due to shield effect. The overall reduction in the temperature differential due to provision of the friction course is 1 ^{o}C to 3 ^{o}C. This is on account of the aeration produced by the open texture of the friction course which reduced the temperature fluctuations.

Studies undertaken by **Shoukry et al. (2003)**, on instrumented Robert Byrd Highway (Route 33) Elkins, West Virginia, proved that the temperature gradient profile is non-linear and had its maximum effect on the longitudinal stresses 0.28 m away from the transverse joint (near embedded dowel joints). The uniform temperature component of temperature gradient profile causes a large magnitude of tensile thermal stress in the centre of the slab. This stress is dependent on the magnitude of the temperature drop and the difference between top and bottom temperatures of the slab. It is not influenced by the non-linearity of the temperature gradient profile.

Choubane et al. (1995), undertook an experimental and analytical study to determine realistic thermal load induced stresses in concrete pavements. A six slab pavement was constructed at Florida Department of Transportation for the investigation. Each slab was 6.1 m (20 ft.) long, 3.7 m (12 ft.) wide and 23 cm (9 in.) thick. Thermocouples were embedded in the slab at 2.54 cm, 6.1cm, 11.4 cm, 16.5 cm and 20 cm (1, 2.5, 4.5, 6.5 and 8 in.) below the top surface of the slab. Temperatures were recorded at an interval of 15 minutes. The findings of the study proved that the temperature distribution within the concrete slab is essentially non-linear. The temperature distribution throughout the slab thickness can be represented by a quadratic equation.

As per **Chen et al. (2011)**, distresses occurring in CRCP, due to the corrosion of reinforcement, can be attributed to the environmental factors. The corrosion of reinforcement in CRCPs in Wisconsin led to delamination, spalling and steel rupture. The research team explored the possibility of use of GFRP rebars as a replacement to steel reinforcement in CRCP and its impact on the development of thermal stresses and shrinkage in concrete slabs. Shrinkage and thermal stresses due to environmental loads, lead to cracking in pavement slabs. The shrinkage in concrete causes tensile stresses (**Zhang et al. 2000**). The temperature variation in concrete causes tensile or compressive stresses depending on the CTE of concrete and reinforcement bars (**Chen et al. 2002**). The CTE of concrete primarily depends on the CTE and type of coarse aggregates used (**Chen et al. 2011 and Naik et al. 2011**).

2.2 Self Compacting Concrete (SCC):

Cement concrete is a preferred construction material of our times. The ease of manufacture of concrete with locally available raw materials, ease in deforming the plastic material to achieve different shapes and forms and its versatile applications makes it a priority material over other alternative construction materials. The advancements in construction technology demand for high rise and lean structures and concern for environment and sustainability pose a challenge to the concrete technologists to design and manufacture a performance oriented sustainable material. With increased capital outlay and strict time schedules of construction projects, there is a growing trend for use of High Performance Concrete (HPC). According to American Concrete Institute (ACI 1998), HPC is defined as a concrete meeting special combination of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing and curing practices (**Mehta et al. 2006**). The high performance characteristics of such a concrete may be in form of ease of placement, compaction without segregation, early age strength, long term strength and mechanical properties, improved resistance to permeability, high density, improved toughness, long life in severe environments and volume stability (**Mehta et al. 2006**) In simple terms, a concrete can be categorized as HPC if it possesses high strength, durability and reliability (**Golaszewski et al. 2004**). In terms of water cement ratio, HPC is one which has water/cementitious ratio of 0.25 and sometimes below 0.2 (**Neville, 2010**). This concrete has typically high dosage of superplasticizer to achieve desired workability.

Self-Compacting Concrete (SCC), also known as Self Consolidating Concrete (**Türkel et al. 2010**), is a type of High Performance Concrete (HPC) (**Ghafoori et al. 2010; Sideris, 2007**). Khayat et al. defined SCC as a highly flowable, yet stable concrete that can spread readily into place and fill the formwork without any consolidation and without undergoing any significant separation (**Gaimster et al. 2003**). **EFNARC, 2005** defines SCC as a concrete that is able to flow and consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, while maintaining homogeneity and without the need for any additional compaction.

2.2.1 Origin of SCC:

The concept of SCC originated from the research in underwater placement of concrete (**Mehta et al. 2006; Gaimster et al. 2003**). Simultaneous but independent research was undertaken in Europe, North America and Japan since 1970s (**EFNARC, 2005**) to develop high workability concrete mixes that were alternatively called as self-compacting concrete, self-consolidating concrete, self-leveling concrete or rheoplastic concrete. It was in the mid-1980s that the concept of present day SCC was first initiated and developed in Japan. The first model of SCC mix design was developed by Ozawa et al. in 1989 (**Gaimster et al. 2003**). Many researchers have attempted modifying the mix design process for establishing better SCC mixes and the notable ones are Okamura et al. (1989), Ozawa et al. (1989), Yurugi et al. (1993), Domone and Chai (1996) (**Gaimster et al. 2003**). **Domone 2006,** noted that SCC was first introduced to the construction industry during 1990s and by 2003, it had large scale applications in precast and prestressed concrete industry.

2.2.2 SCC Mix Design:

The main differentiating factor of SCC with respect to normal cement concrete is its superior rheological properties. From material composition point of view, SCC has high binder content (cement along with additives in the range of 450 to 550 kg/m^3), coarse aggregates, limited to 50 % of solid volume of concrete, fine aggregates, limited to 40% of mortar volume and admixtures - superplasticizers (High Range Water Reducing Admixture HRWR) to increase workability and viscosity modifying agents (VMA) to control segregation in the mix (**Gaimster et al. 2003**). The enhanced rheology of SCC is on account of use of HRWR and high powder content. In simple terms, SCC comprises two major components, cohesive particle group (cement grains) and cohesionless particle group (sand and gravel grains).

The important rheological terms related to the flow of SCC are yield stress and plastic viscosity (**Wallevik et al. 2011**). The mortar phase of SCC is considered as an example of

Bingham rheological model which states that a linear relation exists between variation of shear rate and shear stress (**Banfill, 2011; Zhang et al. 2010; Li, 2007; Vikan et al. 2007; Felekoğlu et al. 2006 and Li et al. 2004**). SCC has to satisfy two contrasting objectives viz. high fluidity (related to yield stress) and adequate segregation resistance (related to plastic viscosity). The flow in the SCC mix is achieved by a combination of forces listed below (**Li et al. 2004**):

1. Inter-particle friction that follow Coulomb's law of solid friction
2. Van der Waals force of attraction
3. Static electric repulsive forces between cement particles when naphthalene sulphonate based super plasticizers are used or the steric hindrance effect caused when polycarboxylate based super plasticizer is used
4. Interparticle potential energy between cement particles.

The fluidity in concrete is achieved by addition of HRWR, whereas segregation resistance is obtained with adjustment of powder content and/or addition of VMA. This leads us to the methods of mix design of SCC. The growing awareness of SCC and its advantages, motivated researchers to undertake studies to arrive at appropriate and economical mix design methods for the SCC mix. Based on the material combinations selected, the mix design method proposed by various researchers can be classified into three major categories (**Türkel et al. 2010; Hodgson et al., 2005**):

A. Powder method – high fines content with addition of supplementary cementitious materials (SCM) to improve viscosity of the mix.
B. Admixture method – use of HRWR to increase workability (fluidity) of the mix as well as VMA to ensure adequate segregation stability of the concrete.
C. Combination method – a balance between amount of fines and quantity of VMA added to the mix so as to achieve desired segregation stability.

As per studies undertaken by **Gurjar (2004)**, for Florida Dept. of Transportation, to assess the suitability of Florida based materials for mix design of SCC, the SCC mix design is influenced by the following factors:

1. High volume of paste to maintain aggregate separation
2. High volume of fine particles to reduce the risk of segregation and bleeding
3. High dosage of HRWR to impart adequate fluidity

4. Lower coarse aggregate content and smaller maximum size of aggregate (MSA) to improve passing ability.

The mix design of SCC mixes is affected by fixed factors, variable factors and nuisance factors. The fixed and variable factors can be controlled in the experiment stage. Important nuisance factors are:

1. Mid experiment changes in instrument, equipment, environment conditions, measuring devices
2. Variations or changes in the test procedures and protocols
3. Day of the week and time of the day
4. Operator skill and efficiency.

According to RILEM Report 35 (**Skarendahl et al. 2006**), the fluidity and properties of SCC are greatly influenced by the fillers and admixtures. At microscopic level – micrometer and nanometer – colloidal forces and surface chemistry influence the performance of SCC. Most of the colloidal particles – cement, fillers, smallest aggregate particles – flocculate to different degrees spontaneously when immersed in mixing water. They have to be dispersed to free the entrapped water and to break the solid structure so as to enable the suspension flow thus reducing the yield stress as described by Bingham model. Addition of superplasticizers (HRWR) leads to dispersion of this water. However, the dosage of superplasticizer has to be decided carefully as the suspension may become unstable and segregate. In such cases, instead of decreasing water cement ratio, mineral fillers are added or viscosity modifying agents (VMA) are added so as to bind surplus water and prevent segregation. Thus, important mechanisms that govern flow of SCC are dispersion of flocculated particles and binding of water. First generation and second generation superplasticizers are by-products of lignin, melamine and naphthalene. The third generation of superplasticizer used in SCC is polycarboxylate ether based (**Wallevik et al. 2011; Girish et al. 2010)**. The lignin or naphthalene based admixture impart workability to concrete mix by electrostatic repulsion, while the polycarboxylate ether based admixtures impart fluidity to the concrete mix on account of steric hindrance effect.

2.2.3 Supplementary Cementitious Materials (SCMs) or Powder Additions in SCC:

The use of SCMs in SCC is necessary from economic and environmental perspective. SCC is a concrete with high cement content. Cement is an energy intensive material. Cement industry accounts for 7 % of global CO_2 emissions (**Madandoust et al. 2012**). To reduce the carbon footprint of SCC, it is advisable to use the powder additions so as to reduce the cement content which in turn reduces the CO_2 emissions. Further, to achieve desired workability (slump flow) at lower water cement ratio, there is a need to use HRWR. With high cement content and superplasticizer dosage, the fluidized concrete has a high risk of segregation and bleeding. This necessitates the use of VMA. Both HRWR and VMA, being costly constituents, will make the SCC mix costlier by 20% to 40% more than the normal concrete (**Nehdi et al. 2004**). However, contrasting cost differences have been observed by various researchers due to variety of reasons. According to **Ho et al. 2002**, SCC is 80 % to 150 % costlier than normal concrete in Singapore, 10 % to 15 % in Sweden and around 50 % to 100 % more costly in France. The increase in cost of SCC, is primarily attributed to materials cost as reported by **Ouchi et al**. **2003,** is hardly 4 % costlier than the normal concrete while, saving 33 % of operational costs of making SCC. To make SCC an affordable option, SCMs are added to the mix as a cement replacement. High powder content in the SCC mix ensures reduced risk of segregation and bleeding (**Yahia et al. 2005**). Powdered materials apart from ordinary Portland cement added in concrete mix to improve the fresh as well as hardened state properties of concrete are termed as mineral additions or supplementary cementitious materials. Cementitious materials can also be defined as all the materials that contribute to the strength of concrete either by chemical or physical action (**Neville et al. 2010**).

As regards SCC, the mineral additions can be classified in three main categories (**Nepomuceno et al., 2012; Uysal et al, 2012; Türkel et al. 2010; Felekoğlu et al. 2006)**:

a. Type 1 addition: Inert or inactive
b. Type 2 addition: Pozzolanic or reactive
c. Type 3 addition: Industrial waste

Different types of mineral additions used in the SCC mix by various researchers have been listed in Table No. 2.2:

Table No. 2.2: Type of Powder Additions in SCC

Type 1 addition (inert or inactive)	**Type 2 addition (Pozzolanic)**	**Type 3 addition (Industrial Waste)**
Limestone powder	Flyash, Silica fume, Blast furnace slag, Metakaolin, Volcanic ash	Granite dust, Marble dust, Basalt dust, Rice Husk Ash, Bagasse Ash

The basic objective of adding SCMs in any concrete mix is to improve its workability and strength economically. At microstructure level, mineral additions help in creating a dense, highly impermeable hydrated cement paste and a strong paste aggregate interface. The matrix densification ensures reduction in pores and improved impermeability. The additives to cement concrete can be classified as inert or pozzolanic based on their chemical action.

Inert additions are chemically inert and do not take part in the cement hydration reactions. However, their physical properties have beneficial effects in form of improved workability and denser impermeable concrete. At microstructure level, the inert additions provide nucleation site to enhance hydration of Portland cement.

Pozzolanic additions aid in gain of strength of concrete by a combination of physical and chemical processes. Calcium hydroxide, formed as a result of hydration of cement, has no cementing value. In the pozzolanic reaction, the siliceous compounds of the pozzolan react with calcium hydroxide to form compounds possessing cementitious properties (**Price, 1975**).

The performance of the mineral additions depends on the physical and physico-chemical properties of the powder or addition, which in turn affect the fresh state properties of the SCC. These properties include particle shape, surface texture, rate of superplasticizer adsorption, surface energy, finest fraction content, Blaine fineness and particle size distribution (**Felekoğlu et al. 2006**).

On account of high cement content in the SCC mixes, there will be pronounced shrinkage and creep. As per **NCHRP report 628**, at 300 days age, precast concrete segments made with SCC exhibited 30% higher drying shrinkage and 20% higher creep as compared to normal high performance concrete. Addition of SCMs helps to reduce the drying shrinkage and creep. As per **Gurjar (2004)**, the high cement content based SCC mixes warrant the use of supplementary cementitious materials. For water cement ratio below 0.33, cement can be substituted by 10% fly ash or 40% slag or 6% silica fume. The high cost of production of SCC is offset by the following factors which help in improving the overall efficiency of the concrete operation:

1. Reduced pumping times lead to faster work cycles. SCC mixes reduce the pouring times by 20% to 30%
2. No use of vibrators, thereby reduces the subsequent vibrator maintenance costs
3. Reduced cost of maintenance of formworks and long life of formwork elements
4. Improved worker safety.

SCC mixes with inert fillers have better fresh state properties, excellent surface finish and higher strength as compared to SCC mixes with pozzolanic fillers. This is due to improved particle packing and water retention in the mixes with inert fillers (**Türkel et al. 2010**).

2.2.4 SCC Applications for Pavement Construction:

SCC ensures safe, quiet and efficient construction. However, its flowable nature is not suitable for slip form applications. For paving applications a mix that is flowable yet can hold its shape right after casting is preferred. **Lomboy et al. (2011)** experimented with the concept of semi-flowable SCC (SFSCC) for possible pavement applications. A SFSCC has a slump flow of 250mm to 330mm. SFSCC can be obtained by increasing the powder content of the mix with addition of fly ash, water reducers, clay additives and/or fibres.

2.3 Findings from the Literature Review:

Based on the Literature Review undertaken, following points can be summarized:

1. The environmental loads (temperature) are as important as vehicular loads in the design and analysis of concrete pavements.
2. The periodic variations in temperatures lead to bending of the slabs. This introduces curling stresses which are tensile in nature. This stress is observed during the service life of the concrete pavement.
3. The variations in the moisture and differential setting process across the pavement thickness results in built-in curl, consequently observed in the form of crack development affecting its long term durability.
4. MEPDG analysis of pavements recommends that material properties play a significant role in pavement design and performance. As per MEPDG recommendations, the measured or investigated properties of materials should form the input for pavement analysis.
5. The response of the concrete pavements to temperature variation is dependent on the thermal properties (CTE and thermal conductivity) of concrete. These thermal properties depend on the ambient condition (moisture, temperature) as well as material properties (mix composition, thermal properties of constituent materials, aggregate type and size).
6. SCC is a High Performance Concrete that ensures safe and speedy construction operations. The SCC mixes exhibit superior mechanical and durability performance as compared to normal concrete.

7. SCC mix design can be admixture based, powder based or combination based. The choice of a particular mix design method depends on the specific application of the mix. From economics and sustainability point of view, powder mix design is preferred.
8. Powder additions to SCC mixes can ensure a segregation free and environmentally sustainable concrete mix.
9. Due to its fluid nature, it may be difficult to use SCC for on-site paving operation. However, its paving applications can be improved with the addition of suitable powders which make the concrete mix viscous and impart sufficient holding strength.

2.4 Gaps identified from the Literature Review:

Based on the findings from the literature review, following gaps were identified;

1. The temperature gradient observations for peak summer temperatures were measured and evaluated. The effect of varying environmental conditions on the development of temperature gradient has minimum reference.
2. The fine aggregates used for preparation of pavement slab were not clearly identified as natural sand or crushed sand. The effect of use of crushed sand on the thermal properties of SCC and its bearing on the thermal performance of SCC pavement slabs was not clearly experimented.
3. IRC guidelines (IRC 44:2008) recommend the use of 20% fly ash as a cement replacement additive in concrete mix adopted for pavement application. However, its effect on the thermal properties and performance of the pavement slab has not been reported in the pavement design guidelines.
4. The use of microstructure analysis of the pavement material to understand its particular behaviour pattern has not been considered in the earlier studies.

The present research work aims to address the above mentioned gaps identified from the literature.

2.5 Problem Statement for Research:

The present research aims at:

1. Assessing the performance of crushed sand in SCC as a pavement material.
2. Evaluation of thermal properties (thermal conductivity) of the SCC mix with crushed sand along with various additions (fly ash as a cement replacement material and perlite as a fine aggregate replacement material).

3. Measurement of temperature differential across semi-field scale slabs of SCC mix with crushed sand and SCC mix with various additions (fly ash as a cement replacement material and perlite as a fine aggregate replacement material).
4. Computation of theoretical values of curling stress with Westergaard equations using the temperature differential observations measured experimentally for varying environment conditions.

2.6 Objectives of the Research:

Based on the literature review undertaken, following objectives were set to address the research problem:

1. Mix Design of M-40 grade SCC for possible pavement applications as per standard guidelines (EFNARC, IRC and BIS standards).
2. Measurement of fresh state and hardened state properties of M-40 grade SCC with natural sand (NS) and crushed sand (CS) as well as microstructure examination of a representative specimen.
3. Measurement of fresh state and hardened state properties of M-40 grade SCC with powder additions (fly ash and perlite) along with microstructure analysis of a representative specimen.
4. Measurement of thermal conductivity values, by steady state method, for M-40 grade SCC mix without any powder additions as well as mix with appropriate dosage of the powder combinations finalized experimentally.
5. Measurement of temperature differential and estimation of temperature gradient across 15 cm cube specimens for the M-40 grade SCC mixes finalized.
6. Measurement of temperature differential and estimation of temperature gradient across 30 cm thick slab section for the M-40 grade SCC mixes finalized.
7. Numerical validation of temperature values measured experimentally with the Choubane Tia Model and Fourier Biot Equation.
8. Computation of theoretical values of curling stress, by the Westergaard equations, using the measured temperature differential values and comparing the values for different mixes.

2.7 Research Methodology:

The research study was aimed at investigating the effect of environmental loads (temperature) on SCC specimen as a proposed pavement material. Based on the findings of the literature review and objectives set for the research study, this section discusses the research methodology adopted.

As per the recommended guidelines in IRC 58: 2011, cement concrete pavements are designed on the basis of flexural strength. Further, it has been mentioned that in no case, the 28 day flexural strength of pavement quality concrete (PQC) should be less than 4.5MPa. The flexural strength of concrete is measured as per IS: 516-1959 or as per the relationship prescribed in IS: 456-2000,

$$F_{cr} = 0.7\sqrt{f_{ck}} \quad (2.8)$$

where,

F_{cr}: flexural strength of concrete (modulus of rupture) MPa.

f_{ck}: characteristic compressive cube strength of concrete MPa.

By substituting the 28 day flexural strength of 4.5MPa, it is found that the characteristic strength is around 41MPa. Hence, for pavement applications, it can be deduced that the minimum grade of concrete has to be M-40. As per the mix design procedure, prescribed by IS: 10262-2009, the target compressive strength for M-40 grade of concrete is 48.25MPa. Thus, the concrete mix considered for the present study is M-40 grade SCC mix.

The research methodology adopted comprised following steps:

1. Experimental Investigations (Part 1): Determination of properties of materials considered for M-40 grade SCC mix. The experimental trials were undertaken as per guidelines prescribed by relevant IS codes. The experimental investigations were supplemented by morphological studies undertaken with the aid of intermediate Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy Analysis (EDXA). The studies undertaken helped in determining the various physical and mechanical properties of materials as well as composition and morphological structure.
2. Experimental Investigations (Part 2): at this stage, mix design process of SCC mix as per EFNARC guidelines was carried out. On finalization of the mix design, the following laboratory trials were undertaken;
    a. M-40 grade SCC mix with natural sand (NS) as well as crushed sand (CS).
    b. Determination of appropriate dosage of fly ash as a cement replacement material in M-40 grade SCC mix.

c. Determination of appropriate dosage of perlite as a fine aggregate replacement material.

As per EFNARC guidelines (2005), fresh state properties viz. filling ability, passing ability and segregation resistance were verified with the standard testing protocols. The cured samples were subjected to non-destructive evaluation with Schmidt Hammer and Ultrasonic Pulse Velocity equipment. Subsequently, compressive strength of the cube specimen (3 days, 7 days, 28 days and 90 days) and flexural strength of the beam specimen (7 days and 28 days) (as specified by IRC 58:2011 and IS 516:1959) were determined in the laboratory. At the end of the experimental trials, three SCC mixes satisfying the fresh state as well as hardened state properties, were obtained as listed below:

a. SCC mix with appropriate fine aggregate material (Mix A).
b. SCC mix with appropriate fly ash dosage (Mix B).
c. SCC mix with appropriate fly ash and perlite dosage (Mix C).

3. Experimental Investigations (Part 3): at this stage, thermal conductivity (k) of the mixes listed above was determined by the steady state method (two slab guarded hot plate method as per IS 3346:1980). The temperature differential (ΔT) across cube specimen and slab sections, prepared for various case considerations, exposed to varying open atmospheric conditions, embedded with series of temperature sensors across various depths as well as areal extent, were monitored.
4. The ΔT values obtained in the preceding step were compared with the temperature values obtained numerically using Choubane Tia Model and Fourier Biot Equation. The temperature values obtained using Finite Element (FE) software ANSYS were also compared with the ΔT values measured.
5. The ΔT values measured experimentally were substituted in the Westergaard's equations to determine the theoretical values of the curling stress.

In conclusion, this chapter presents the literature review, findings from the literature review, identification of research objectives and research methodology. The upcoming chapter discusses the details of the experimentation carried out to find the basic material properties of all the materials being used in the present study along with the morphology of these materials.

Chapter 3

EXPERIMENTAL INVESTIGATIONS (PART 1): PROPERTIES AND MORPHOLOGY OF MATERIALS

This chapter presents the first stage of experimental investigations undertaken to determine various properties of the materials used in the present study for the mix design of M-40 grade SCC mix. The experimental tests are also supported by the morphological studies of the materials undertaken with the help of intermediate SEM and EDXA studies.

3.1 Cement:

53 grade Ordinary Portland Cement (OPC) (IS 12269: 1987) was used for all the laboratory trials performed in the present study. Various properties of the cement (as per test certificate from cement plant) have been tabulated in Table 3.1.

Table 3.1: Properties of Cement

Physical properties of Cement		
Property	**Test Result**	**IS 12269: 1987 requirement**
Fineness (m^2/kg)	290	225
Standard Consistency (%)	29	--
Initial Setting time (minutes)	180	30 (Min.)
Final Setting time (minutes)	250	600 (Max.)
Le-Chatelier Expansion (mm)	0.5	10 (Max.)
Chemical Composition of Cement		
$\frac{CaO - 0.7SO_3}{2.8SiO_3 + 1.2Al_2O_3 + 0.65\ Fe_2O_3}$	0.88	0.8 (Min.) 1.02 (Max.)
Al_2O_3/Fe_2O_3	1.24	0.66 (Min.)
Insoluble residue (% by mass)	1.88	2.00 (Max.)
Magnesia (% by mass)	0.90	6.00 (Max.)
Sulphuric Anhydride (% by mass)	1.80	3.00 (Max.)
Total loss on ignition (% by mass)	1.80	4.00 (Max.)
Total Chlorides (% by mass)	0.008	0.10 (Max.)
Mechanical Property of Cement (Compressive Strength MPa)		
3 days (72 hrs. ± 1 hr.)	38.0	27 (Min.)
7 days (168 hrs. ± 1 hr.)	51.0	37 (Min.)
28 days (672 hrs. ± 1hr.)	71.5	53 (Min.)

3.2 Fly ash:

Fresh Class C fly ash, obtained directly from a local thermal power plant, was used in the present study. The chemical composition of the fly ash sample (as per the test certificate received from the supplier) is presented in Table 3.2.

Table 3.2: Chemical Composition of Fly ash

Component	Percentage	Component	Percentage
SiO_2	56.54%	Fe_2O_3	4.65%
Al_2O_3	23.66%	Mn_3O_4	0.13%
CaO	11.61%	TiO_2	1.37%
Na_2O	2.18%	P_2O_5	1.58%
K_2O	2.85%	SO_3	0.48%
MgO	0.92%		

As per IS: 3812 (Part I) 2003, fly ash can be classified as a calcareous pulverized fuel ash (reactive CaO not less than 10% by mass) and siliceous pulverized fuel ash (reactive CaO less than 10% by mass). As per ASTM standards, fly ash is classified as Class C fly ash (obtained from combustion of lignite or sub-bituminous coal) and Class F fly ash (obtained from combustion of bituminous coal). Class C fly ash possesses pozzolanic as well as hydraulic properties, while Class F fly ash exhibits pozzolanic properties only. Both the classes of fly ash help in improving the workability of the concrete mix. However, Class C flyash contributes to the gain in later age (beyond 28 days) strength on account of its hydraulic properties (Berry et al. 1980, Price, 1975). The reactivity of fly ash and its contribution in strength development of concrete depends on flyash properties, its chemical composition, particle size along with temperature and curing conditions. Apart from workability improvement and reduction in HRWR dosage, addition of flyash also helps in reducing the heat of hydration and minimizes the adverse effect of alkali aggregate reaction (Malhotra, 2008, *Gandage*, *2014*).

3.3 Aggregates (Coarse and Fine):

The aggregates were procured from a local quarry. Various tests prescribed in IS 2386 (Part I to IV), 1963, were performed on the sample considered in the study. The coarse as well as fine aggregates were of granite origin. Thin section Petrographic analysis of a coarse aggregate specimen from the given sample was also undertaken in addition to all the other prescribed tests.

Natural sand (NS) and crushed sand (CS) were considered as fine aggregates in the present study. NS was obtained from Manjira river, flowing near Hyderabad. CS was obtained from the local quarry. The quarry dust powder obtained with the crushed sand was analysed for its microstructure using intermediate SEM. The summary of test results is summarized and presented in Table 3.3.

Table 3.3: Properties of Aggregates

Properties of Coarse Aggregates			
Property	**IS Code**	**Test Result**	
Flakiness Index (%)	IS 2386 (Part I) – 1963	7.87	
Elongation Index (%)	IS 2386 (Part I) – 1963	30.71	
Specific Gravity	IS 2386 (Part III) – 1963	2.62	
Water Absorption (%)	IS 2386 (Part III) – 1963	0.8	
Bulk Density (Loose) kg/m^3	IS 2386 (Part III) – 1963	1472.83	
Bulk Density (Compacted) kg/m^3	IS 2386 (Part III) – 1963	1489.13	
Aggregate Impact Value (%)	IS 2386 (Part IV) – 1963	25.02	
Aggregate Crushing Value (%)	IS 2386 (Part IV) – 1963	30.24	
Los Angeles Abrasion Value (%)	IS 2386 (Part IV) – 1963	19.41	
Properties of Fine Aggregates			
Property	**IS Code**	**Test Result**	
		NS	**CS**
Specific Gravity	IS 2386 (Part III) – 1963	2.68	2.70
Bulk Density (Loose) kg/m^3	IS 2386 (Part III) – 1963	1630.44	1648.23
Bulk Density (Compacted) kg/m^3	IS 2386 (Part III) – 1963	1739.31	1751.14
Fineness Modulus		2.56	2.67

3.4 Perlite:

Perlite is an amorphous volcanic glass with pearly vitreous lustre characterized by onion skin structure (Bektas et al. 2005). Perlite is a generic name for naturally occurring siliceous rock. It can be distinguished from other volcanic glasses due to its property of rapid expansion (4 to 20 times its original volume) on heating. It is a light weight material with excellent thermal and acoustic insulation properties. In construction industry, it is commonly used as a light weight aggregate. Perlite possesses pozzolanic reactivity due to its volcanic origin and high silica and alumina content. Perlite has a low thermal conductivity and is relatively stable over a wide range of temperature (service temperature to 800^oC).

In the present study, perlite was trued as a partial replacement for crushed sand. The effect of insulating perlite on the thermal response of M-40 grade SCC with fly ash dosage was investigated. Various properties of perlite (as provided by the supplier) are presented in Table 3.4.

Table 3.4: Properties of Perlite

Physical properties of Perlite	
Property	**Test Result**
Loose weight density (kg/m^3)	120 - 150
Compacted density (kg/m^3)	140 – 180
Moisture content (%)	< 0.5
Thermal conductivity (W/m/^{o}K)	0.044
Colour	Grey
Sieve Analysis of Perlite	
Sieve size	**% Passing**
1.18 mm	2
0.6mm	98
0.3mm	20 – 40
0.15mm	15 – 25
Chemical Composition of Perlite	
pH	7
Silicon di oxide (%)	71 – 76
Aluminum oxide (%)	10 – 14
Ferric oxide (Max) (%)	0.4
Ferrous oxide (Max) (%)	0.5
Calcium oxide (%)	0.5
Magnesium oxide (%)	0.2
Sodium oxide (%)	3 – 4
Potassium oxide (%)	4 – 5
Organic matter	Traces

3.5 HRWR Admixture or Superplasticizer:

Polycarboxylate Ether (PCE) based high performance superplasticizer (Glenium 233) was used in the present study. This admixture is used for high performance rheodynamic concrete. The traditional chemical admixtures are melamine or naphthalene sulphonate based (Zhang et al. 2010).

These admixtures impart workability (slump) to the concrete mix through the principle of electrostatic repulsion. The polymers of this admixture adsorb on cement particles by wrapping around it at early stage of concrete mixing process. They impart negative charge to the cement particles agglomerates thereby leading to repulsion amongst the flocks. The negative charges disperse the cement particles by electrical repulsion. This admixture improves workability of concrete and reduces the water requirement upto 20%.

The PCE superplasticizer consists of long side chains of carboxylic ether. The polymer adsorbs on the cement particles and initiates the electrostatic repulsion in the early stage of mixing. With the progress in the mixing the long side chains stabilize the cement particles ability to disperse and separate. This is steric hindrance effect which provides a physical barrier between cement grains. This renders the concrete flowable whose workability is measured as slump flow. Use of PCE superplasticizers can lead to water reduction upto 40%.

The addition of superplasticizers retards the cement setting time. It is on account of residual sugars and salts present in the admixture. The retardation occurs on account of adsorption, complexation (formation of flocks), precipitation and nucleation (Zhang et al. 2010).

The properties of HRWR superplasticizer used in the present study as received from the supplier are summarized and tabulated below in Table 3.5.

Table 3.5: Properties of Superplasticizer

Property	Test Result
Colour	Light brown
Relative density	1.08 ± 0.01 at 25 ^{o}C
pH	≥ 6
Chloride ion content	< 0.2%

3.6 Microstructure Studies:

Microstructure is defined as the type, amount, shape, size and distribution of various phases present in a solid (Mehta et al. 2006). Concrete is a composite material. The properties of concrete are influenced by the interaction between individual constituents and their final arrangement in the hardened mix. Concrete, is primarily a two phase material, comprising aggregate phase (coarse aggregates) and the mortar or matrix phase (cement, fine aggregates, and water) (Gandage et al. 2013a).

In the present study, the microstructure of powder ingredients of SCC mix (cement, fly ash, perlite and pan dust) were studied using intermediate SEM and energy dispersive X-ray analysis (EDXA). The microstructure properties of the coarse aggregate particle was observed using Thin Section Petrographic Analysis. The following sections describe SEM and EDXA analysis of powder constituents of the concrete mix, along with the petrographic analysis of coarse aggregate particles.

3.6.1 Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Analysis (EDXA):

A microscope is a device that magnifies the details of an object finer than what can be observed with naked eyes. Optical microscope was used since 16th century (Ramachandran et al. 2001). The development of scanning electron microscopy was based on the discoveries during 1920s regarding wave nature of particle stream by L. de Broglie and focusing of electrons in magnetic field by H. Busch. Due to shorter wavelength of the incident electron beam, the electron microscope is able to produce distinctly high resolution images compared to optical microscope. When a beam of primary electrons strike a bulk solid, the electrons are either reflected (scattered) or absorbed producing various signals. The striking of the electron beam on a solid specimen leads to production of many responses like secondary electrons, back scattered electrons (BSE), X-rays, Auger electrons and other responses (Ramachandran et al. 2001). The most frequent mode of SEM image analysis is capture of secondary electrons or BSE, while the microanalytical technique (elemental composition studies) is undertaken using EDXA or wavelength dispersive analysis.

In the present study, BSE imaging mode was adopted for the microstructure evaluation of the powder materials as well as concrete. The elemental composition of powder additions was also analysed using EDXA. The EDXA adopted in the present study was spot mode, where a small spot in a constituent particle was analysed for its elemental composition. Fig. 3.1 presents the Scanning Electron Microscope and the sample used during the study.

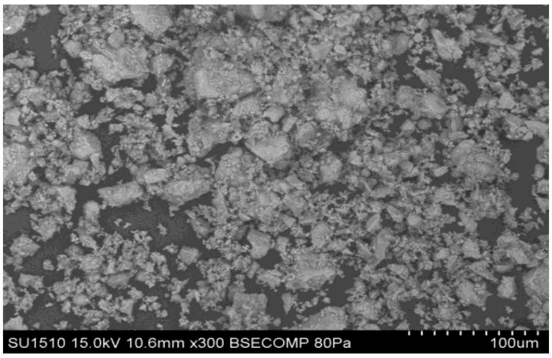
Scanning Electron Microscope (SEM)

Sample placed on metal stub.

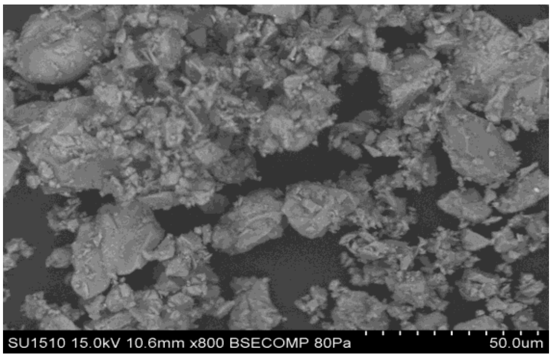
Fig. 3.1: Scanning Electron Microscope and Sample for SEM analysis

3.6.1.1 SEM image and EDXA of Cement:

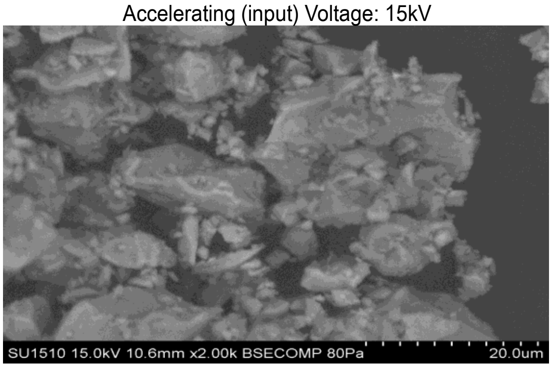
The SEM image of cement particle highlights its morphology i.e. solid or porous structure , shape, size of the particle, pore shape and pore size. If the cement particle is exposed to moisture then the initial phase of hydration products may also be visible. Fig. 3.2 presents the SEM image of cement particle at 300x, 800x and 2000x magnification levels.



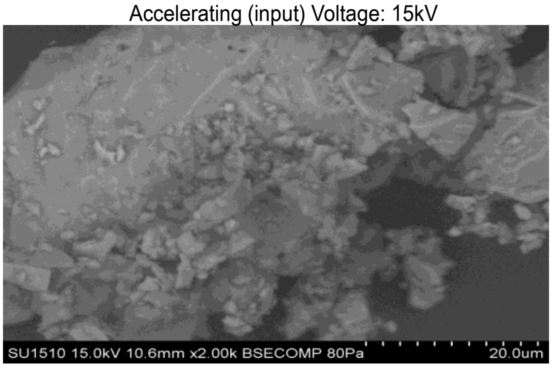
Magnification Level: 300x, Scale: 100μm, Accelerating (input) Voltage: 15kV



Magnification Level: 800x, Scale: 50μm, Accelerating (input) Voltage: 15kV



Magnification Level: 2000x, Scale: 20μm, Accelerating (input) Voltage: 15kV



Magnification Level: 2000x, Scale: 20μm, Accelerating (input) Voltage: 15kV

Fig. 3.2: SEM image of cement particles

From the image (2000x magnification level) it can observed that the cement particles are having regular shape with well-defined edges. As the SEM setup was placed in an air conditioned enclosure, during the sample preparation stage, the cement particles absorbed moisture. As a result of this, hydration reaction was initiated. This is evident from the small froth like agglomerates that are adsorbed on the particle surface. Along with the SEM image, EDXA was also investigated for the cement particle. Fig 3.3 presents the EDXA plot of the cement particle. Table 3.6 presents the elemental composition of cement particle as obtained from the EDX analysis of cement particle. In the absence of chemical composition data regarding the material, the EDXA presents approximate representation of the constituents in the material being investigated. The elemental composition of cement obtained from EDXA validates the chemical composition of cement particles (Table 3.1).

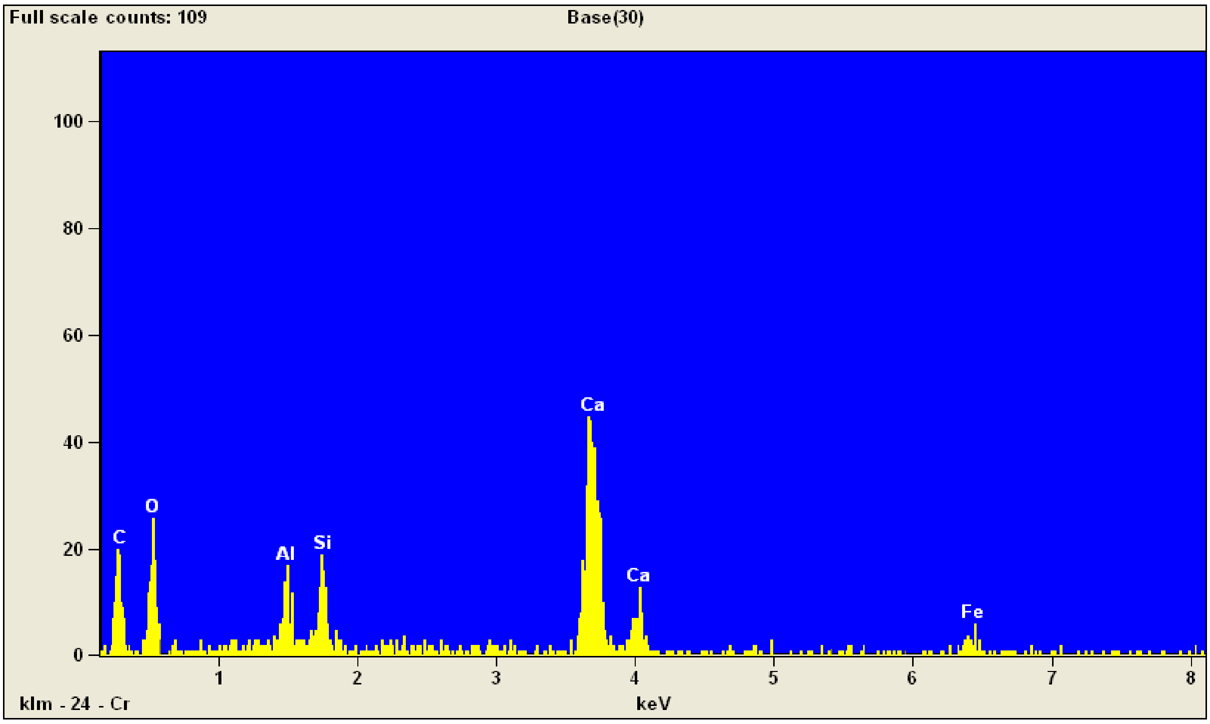


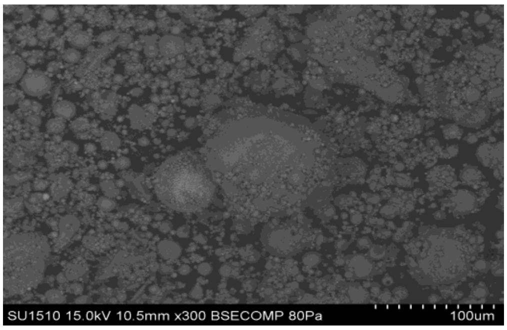
Fig. 3.3: EDX analysis of cement particle

Table 3.6: Elemental composition of cement particle as obtained from EDX analysis

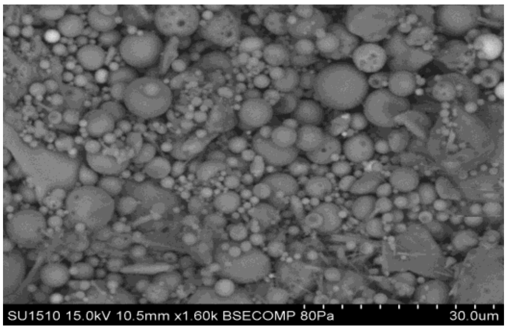
Element Line	Weight %	Atom %
C (K)	24.40	38.78
O (K)	34.08	40.65
Al (K)	3.35	2.37
Si (K)	4.50	3.06
Si (L)	---	---
Ca (K)	26.97	12.85
Ca (L)	---	---
Fe (K)	6.70	2.29
Fe (L)	---	---
Total	**100.00**	**100.00**

3.6.1.2 SEM image and EDXA of Fly ash:

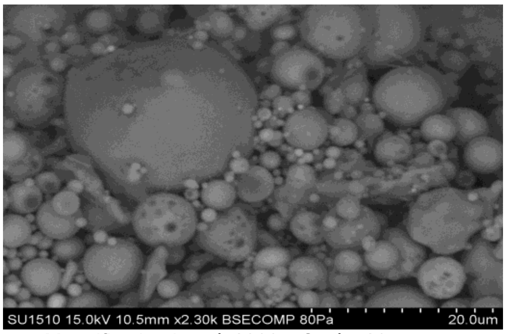
In a typical SEM image, fly ash particles mostly appear as solid glassy spheres. It may also comprise hollow spheres called as cenospheres (completely empty) and plenospheres (several small spheres packed around single sphere) (Ramachandran et al. 2001). Fig. 3.4 presents the SEM image of fly ash.



Magnification Level: 300x, Scale: 100μm, Accelerating (input) Voltage: 15kV



Magnification Level: 1600x, Scale: 30μm, Accelerating (input) Voltage: 15kV



Magnification Level: 2300x. Scale: 20μm. Accelerating (input) Voltage: 15kV

Fig. 3.4: SEM image of fly ash particles

The SEM image (2300x magnification level) shows spherical fly ash particles with distribution of cenospheres as well as plenospheres. Fig. 3.5 presents the EDX analysis of fly ash.

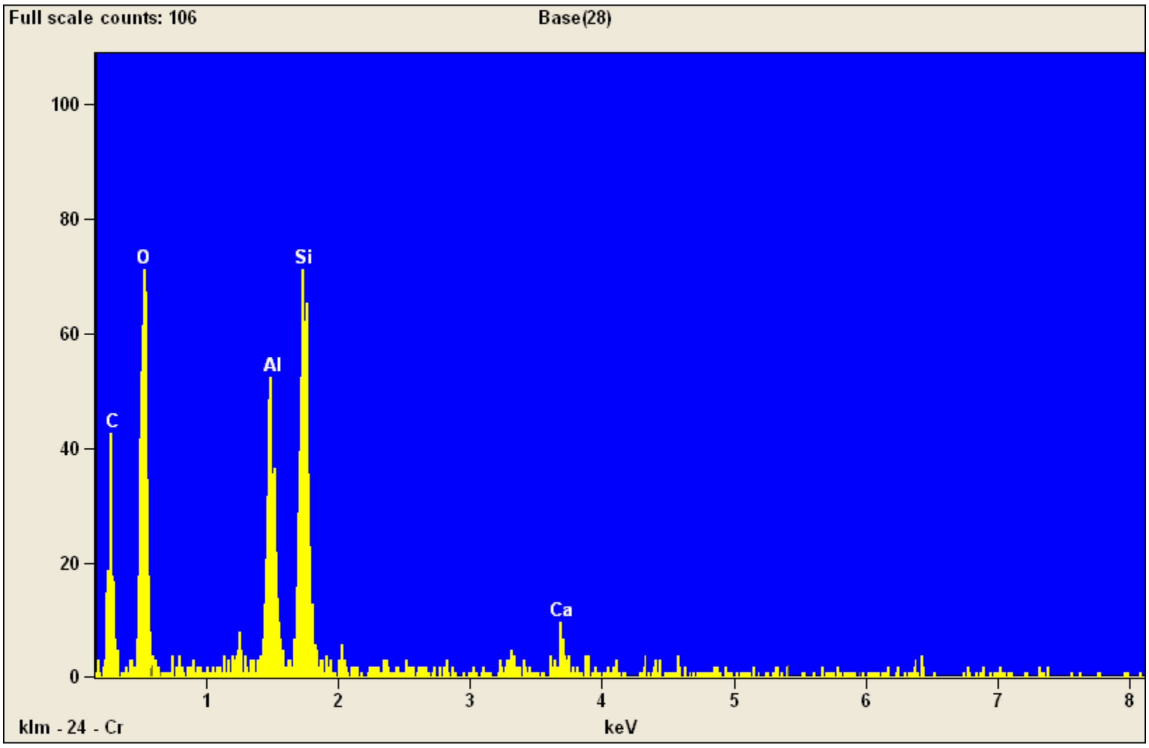


Fig. 3.5: EDX analysis of fly ash particle

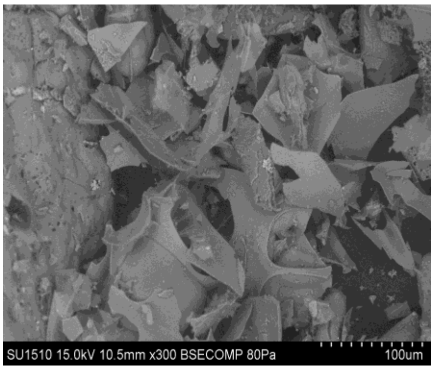
Table 3.7 presents the elemental composition of fly ash. The element composition analysis given by EDXA is in line with the chemical composition of fly ash. The presence of calcium peak in the EDXA suggests that the fly ash considered in the study is Class C fly ash.

Table 3.7: Elemental composition of fly ash particle as obtained from EDX analysis

Element Line	Weight %	Atom %
C (K)	34.35	44.83
O (K)	44.46	43.57
Al (K)	6.40	3.72
Si (K)	12.59	7.03
Si (L)	---	---
Ca (K)	2.21	0.86
Ca (L)	---	---
Total	**100.00**	**100.00**

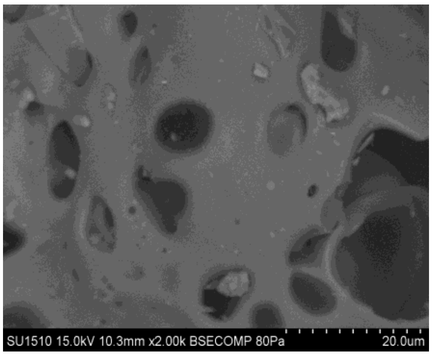
3.6.1.3 SEM image and EDXA of Perlite:

Perlite is a volcanic glass with onion skin like structure. The structure is observed clearly in the SEM images of perlite. Fig. 3.6 presents the SEM image of perlite at 300x and 2000x magnification levels.



Magnification Level: 300x, Scale: 100μm,
Accelerating (input) Voltage: 15kV

Magnification Level: 2000x, Scale: 20μm,
Accelerating (input) Voltage: 15kV



Magnification Level: 2000x, Scale: 20μm,
Accelerating (input) Voltage: 15kV

Fig. 3.6: SEM image of perlite particles

As observed from the SEM images, perlite has a very thin cross section and the surface of the material is porous. The porous particle structure renders it as an insulating material.

Fig. 3.7 presents the EDXA plot for perlite used in the present study. Table 3.8 presents the elemental composition of perlite as obtained from EDXA.

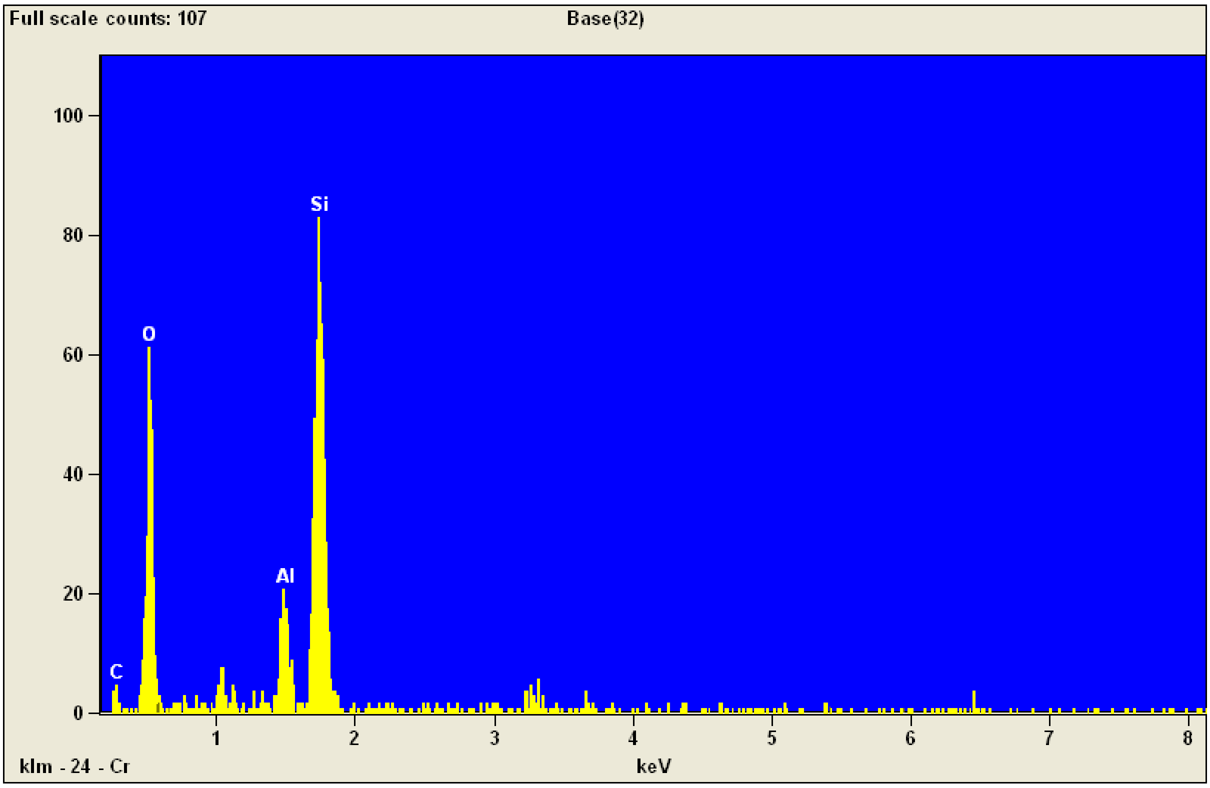


Fig. 3.7: EDX analysis of perlite particle

Table 3.8: Elemental composition of perlite particle as obtained from EDX analysis

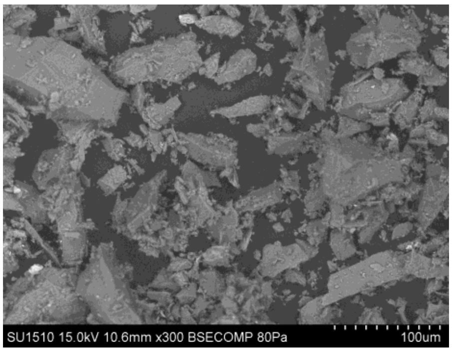
Element Line	**Weight %**	**Atom %**
C (K)	15.25	22.49
O (K)	50.23	55.61
Al (K)	5.18	3.40
Si (K)	29.34	18.50
Si (L)	---	---
Total	**100.00**	**100.00**

The EDXA suggests the composition of perlite is similar to pozzolanic material like fly ash. However, the calcium peak is missing in the perlite. This suggests that perlite can be pozzolanic but not hydraulic.

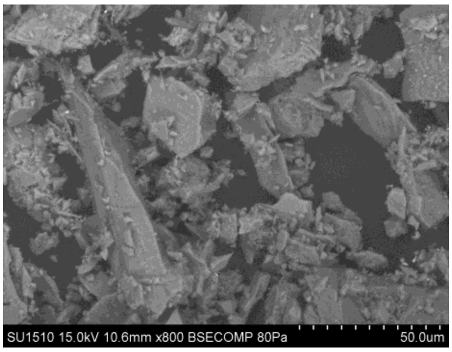
3.6.1.4 SEM image and EDXA of CS dust:

Crushed sand was used as fine aggregates used in the SCC mix during the present study. The crushed sand specimen obtained from local quarry was manufactured by the crushing of granite rock. Along with the solid particles, dust was also present in the specimen. Excess amount of dust in concrete mix affects the water cement ratio. As per the provisions of IS

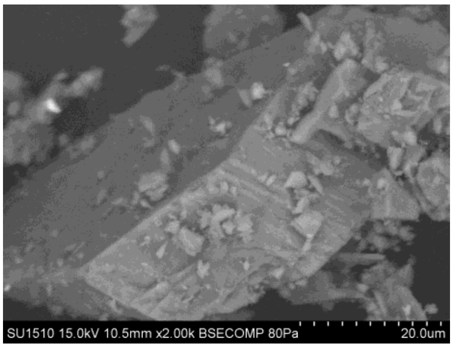
383, the limit recommended for fines passing 150µm IS sieve is 20%. In the present study, the amount of fines passing 150µm IS sieve was observed to be 9%. The dust in the fine aggregate, within prescribed limits, helps to densify the matrix phase of the SCC mix. It also helps in improving the mechanical performance of the hardened mix. Fig. 3.8 presents the SEM images of dust at 300x, 800x and 2000x magnification level.



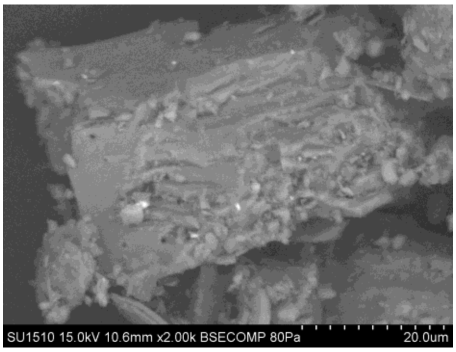
Magnification Level: 300x, Scale: 100µm,
Accelerating (input) Voltage: 15kV



Magnification Level: 800x, Scale: 50µm,
Accelerating (input) Voltage: 15kV



Magnification Level: 2000x, Scale: 20µm,
Accelerating (input) Voltage: 15kV



Magnification Level: 2000x, Scale: 20µm,
Accelerating (input) Voltage: 15kV

Fig. 3.8: SEM image of dust particles

It ca be clearly seen from the SEM images of the CS dust (2000x magnification level), that the individual particles present a solid structure with regular geometry. It has well defined sharp edges. Particles with such geometry are expected to aid in better interlocking and improved mechanical performance of the concrete.

Fig. 3.9 presents the EDXA plot for dust particle. Table 3.9 presents the element composition obtained from EDXA.

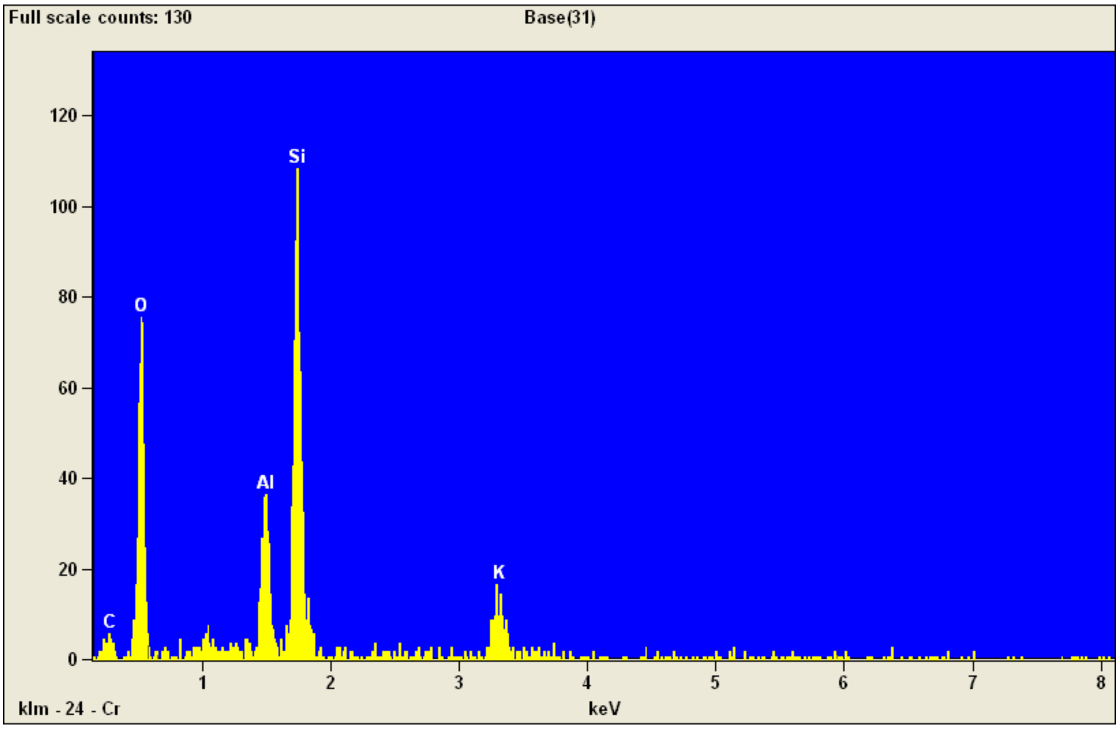


Fig. 3.9: EDX analysis of dust particle

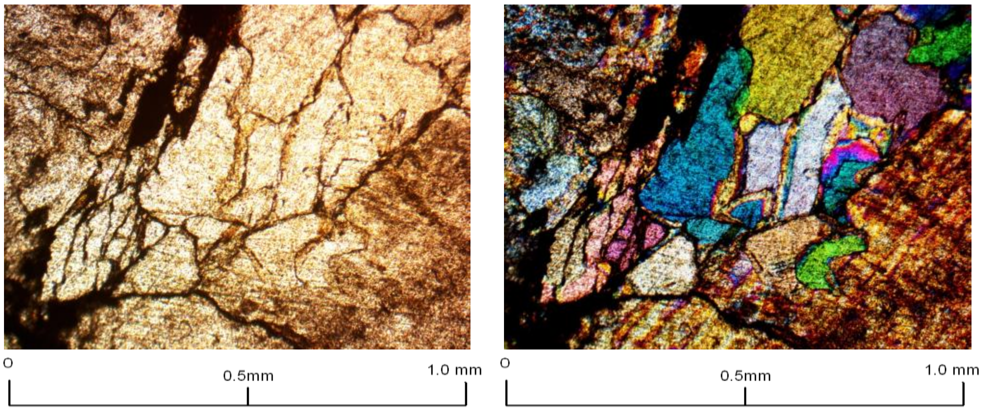
Table 3.9: Elemental composition of dust particle as obtained from EDX analysis

Element Line	Weight %	Atom %
C (K)	15.56	22.94
O (K)	51.92	57.46
Al (K)	5.54	3.63
Si (K)	21.07	13.28
Si (L)	---	---
K (K)	5.92	2.68
K (L)	---	---
Total	**100.00**	**100.00**

From the EDXA plot it can be inferred that the dust particle predominantly consists of SiO_2. It is also composed of alumina and potassium oxide. This indicates the siliceous nature of the fine aggregate.

3.6.2 Thin Section Petrographic Analysis of coarse aggregate particle:

The coarse aggregates used in the present study were obtained from local quarry. The microstructure properties of the specimen sample were studied using Thin Section Petrographic Analysis. Photomicrograph of granite based coarse aggregates, used in the present study is being presented in Fig. 3.10.



PPL BCN

Thin Section Petrographic Analysis of Coarse Aggregate particle.

Fig. 3.10: Thin Section Petrographic Analysis of Coarse Aggregate particle in Plane Polarized Light (PPL) and Between Cross Nichols (BCN)

Various properties inferred from the photomicrograph are presented in Table 3.10.

Table 3.10: Properties of granite coarse aggregate

Texture	Equigranular, granitic.
Mineral composition	1. Quartz – colourless, anhedral, cleavages absent, cracks present, low relief (PPL), anisotropic, dull double refraction (DR) colours (BCN). 2. K-Feldspars – colourless (turbid), anhedral, cleavages absent, cracks present, low relief (PPL), anisotropic, dull double refraction (DR) colours (BCN). 3. Biotite – brown colour, platy/flaky, one set of perfect cleavage, cracks present, high relief, pleochroic in shades of brown (PPL). Anisotropic, high DR colours, straight/parallel extinction
Weathering of mineral grains	Mineral borders are sharp, do not show any kind of altered material. Cleavage planes are also free of any clay like coatings. Rock appeared to be fresh in condition.
Identification	Granite
Classification	Igneous, plutonic, acidic series

In summary, the properties and morphology of various materials adopted for SCC mix have been studied and presented in this chapter. The next chapter presents second stage of experimentation highlighting the details of the mix design process, fresh and hardened state properties of SCC mix with microstructure studies.

Chapter 4

EXPERIMENTAL INVESTIGATIONS (PART 2): MIX DESIGN, PROPERTIES AND MICROSTRUCTURE OF SCC

This chapter presents the experimental procedures undertaken for the mix design of M-40 grade SCC. Various properties (fresh and hardened states) along with the microstructure studies are also discussed in this chapter. Fresh state and hardened state properties of the SCC mix were correlated with the microstructure of the concrete mix.

At the end of the this stage of experimentation, three mixes of M-40 grade SCC were finalized as under;

1. M-40 grade SCC with appropriate fine aggregate (NS or CS): Mix A.
2. M-40 grade SCC with appropriate dosage of fly ash as a cement replacement additive: Mix B.
3. M-40 grade SCC with appropriate perlite dosage as a replacement for fine aggregate: Mix C.

4.1 Mix Design for M-40 grade SCC:

SCC is a rheodynamic concrete that flows under its own weight with minimal segregation, ensuring a uniform, defect free and quality product (EFNARC, 2005; Domone, 2006; Mehta & Monteiro, 2006). SCC differs from normal concrete in three aspects, viz. high cement content, high fines content and use of high range water reducing admixtures (HRWR) or superplasticizers. As per the mix design proposed by Okamura (Naik et al. 2012), the mix proportioning of SCC is done in such a way that:

1. The coarse aggregate content is limited to 50% of the solid volume
2. The fine aggregate content is fixed at 40% of the mortar fraction
3. Water cement ratio by volume is in the range of 0.9 to 1 depending on the properties of the cementitious mix
4. The HRWR dosage is determined on the basis of the degree of self-compactibility desired.

As per EFNARC guidelines, the mix design of SCC differs from normal concrete in following aspects:

1. Comparatively lower coarse aggregate content (28% to 35% by volume of the mix)
2. Increased paste content
3. Water powder ratio 0.8 to 1.0 by volume.

4. Water content limited to a maximum of 200 litres/m^3
5. Total powder content 160 to 240 litres (400 to 600 kg/m^3)
6. Increased superplasticizer dosage
7. Possible use of VMA
8. Sand content balances the volume of the other constituents.

Based on the mix designs experimented by various research groups, EFNARC formulated specific guidelines for SCC mix design as summarized in Table 4.1. However, these are not restrictive guidelines and the actual mix composition may vary from the prescribed range based on the desired workability and intended applications.

Table 4.1: EFNARC Guidelines for SCC Mix Design (source: EFNARC, 2005)

Constituent	**Typical range by mass (kg/m^3)**	**Typical range by volume (litres/m^3)**
Powder	380 – 600	--
Paste	--	300 – 380
Water	150 – 210	150 – 210
Coarse aggregates	750 – 1000	270 – 360
Fine aggregates (sand)	Content balances the volume of the other constituents, typically 45% to 55% of total aggregate mass.	
Water powder ratio by volume	--	0.85 to 1.10

Using the above guidelines, the mix design calculations were performed and the quantities of the different ingredients were estimated and presented in Table 4.2.

Table 4.2: Mix Design for M-40 Grade SCC

Constituent	Cement	Fine Agg.	Coarse Agg.	Water	HRWR*
Quantity	430 kg/m^3	1130 kg/m^3	630 kg/m^3	200 kg/m^3	0.95

(*: lit/100 kg. of binder)

With the above mentioned mix design, trials were performed to measure the fresh state as well as hardened state properties of the M-40 grade SCC mix with natural sand (NS) as well as crushed sand (CS).

4.2 Fresh state properties of SCC mix:

The requirements for various fresh state properties of concrete mix are specified in the standard guidelines. SCC mixes have high proportion of fines as compared to the conventional mixes. The self compactibility of SCC mixes depends on physical characteristics of the mix materials and mix proportioning. The underlying principle of SCC mix design is to have high flowability at lower water cement ratio (Naik et al. 2012). The important fresh state properties of SCC mix are filling ability, segregation resistance and passing ability.

Filling ability is the ability of the SCC mix to flow under its own weight, without any external vibration, and fill completely all the voids in the formwork section with all possible obstacles (reinforcement). Segregation resistance or stability of the SCC mix in fresh state is its ability to remain homogenous during transport as well as during the placement of the mix. Passing ability is the ability of SCC mix to flow through openings of all sizes.

As per EFNARC guidelines, the filling ability and stability of the SCC mixes, in fresh state, is defined by four characteristics as tabulated in Table 4.3. It also prescribes the testing protocols suitable to measure these characteristics.

ASTM also prescribes tests to measure the fresh state properties (Filling ability, passing ability and segregation resistance) of SCC mix. The ASTM prescribed tests are also listed in Table 4.3.

Table 4.3: Characteristics and test methods for fresh state properties of SCC mixes

Characteristic	Preferred test method(s)	
	EFNARC	ASTM
Flowability	Slump flow test	Slump flow, T_{50} (ASTM C 1611)
Viscosity (rate of flow)	T_{50}, Slump flow test or V-funnel test	--
Passing ability	L-box test	J-Ring Test (ASTM C 1621)
Segregation	Segregation resistance (Sieve) test	Column segregation test, Visual Stability Index (VSI).

In the present study, slump flow, T_{50}, J-Ring Test, V-funnel test and VSI were performed to assess the fresh state properties of various SCC mixes.

4.3 Hardened state properties of SCC mix:

The testing of hardened concrete aims at confirming the quality of the concrete. Basic aim of the tests is to ensure that the concrete used on site has developed sufficient strength. The strength of concrete is its resistance to rupture. The hardened state properties measured for the SCC mixes proposed in the present study include;

1. Non-destructive tests (Schmidt rebound hammer test & Ultrasonic Pulse Velocity test)
2. Cube compression test
3. Beam flexure test

4.3.1 Non-Destructive Tests on SCC mix:

Non-destructive testing (NDT) was undertaken to assess the quality of the hardened concrete without damaging it. Apart from quality of workmanship and structural integrity, NDT can be undertaken to detect voids, cracking and delamination. The NDT tests undertaken in the present study include Schmidt rebound hammer test and Ultrasonic Pulse Velocity (UPV) test.

The Schmidt rebound hammer test is a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The procedure for Schmidt rebound hammer test was undertaken as per the guidelines mentioned in IS 13311 (Part 2) 1992. The rebound hammer test provides an easy and rapid indication of compressive strength of concrete by means of correlation between the rebound index and the compressive strength of the concrete mix.

The UPV test helps to determine the uniformity of concrete, presence of cracks, voids and other imperfections and changes in the structure that occur with respect to time. The test procedure was performed as per the guidelines mentioned in IS 13311 (Part 1), 1992. Direct transmission method was adopted for the UPV test on prepared cube specimens. Fig. 4.1 illustrates the Schmidt rebound hammer and UPV test.

Fig. 4.1: NDT (Schmidt Rebound Hammer & UPV) on a cube specimen

4.3.2 Cube Compression Test:

Compressive strength is one of the most important and useful property of concrete. Compressive strength of concrete is considered as a qualitative measure for other properties of hardened concrete. In the present study, the compressive strength test has been conducted on cube specimen of 15cm side. The compression strength test is undertaken as per the provisions mentioned in IS: 516–1959. For given water cement ratio, the compressive strength for SCC mix will be higher as compared to normally vibrated concrete. This is on account of improved interface between aggregate and hardened paste. Fig. 4.2 shows the test setup used for measurement of compressive strength of the cube specimen. The compressive strength of the hardened SCC mix was measured at 3 days, 7 days, 28 days and 90 days. A batch of three cube specimens was tested at each age. A total of 4 batches (3 cube specimen for each age) were tested and the average compressive strength obtained from the test result of each batch has been reported.

Fig. 4.2: Test setup for compressive strength test of a cube specimen

4.3.3 Beam Flexure Test:

For the pavement application of concrete, flexural strength has to be performed on concrete. This test helps to determine the extreme fibre tensile strength of concrete in pure bending. This test is important for pavement slab especially in case of unequal settlement or loss of contact with the founding strata due to continuous movement of vehicular traffic on surface. In the present study, third point loading pattern as discussed in IS: 516–1959, was adopted. The specimen size adopted for the test was 50cm x 10cm x 10cm as the maximum size of aggregate used in the mix was 16mm. Fig 4.3 illustrates the test setup for flexural strength test. The specimens were tested immediately on removal from water in wet condition. A batch of 6 specimens was cast out of which three test specimens were tested for each age. In total 3 batches were cast (9 beam specimens for each age) and the average flexural strength measured for the three batches has been reported.

Fig. 4.3: Test setup for flexural strength test of a beam specimen

4.4 Microstructure Studies of SCC:

The micro-level material arrangement plays an important role in the concrete behaviour under loading. The study of the micro level layout of concrete ingredients is possible with the microstructure studies. The microstructure of a material helps to identify general (volume and shape) as well as, specific (voids, cracks, evidence of degradation) details of the material (Poole et al. 1998). Concrete is a two phase material, comprising aggregate phase (coarse aggregates) and the mortar or matrix phase (cement, fine aggregates and water) (Gandage et al. 2013a). The mechanical and durability performance of the hardened concrete mix depends on the arrangement and interaction between the two phases. The concrete microstructure studies can be undertaken at different magnification levels as tabulated below,

Table 4.4: Magnification levels of concrete (Li, 2011)

Level	Optical Magnification Range	Usual method of observation	Structures revealed
Visual	1x – 10x	Unaided eye or hand lens	Details of coarse aggregate and air voids
Petrographic	25x – 250x	Optical microscope	Fine aggregates, air voids, some paste details and some cracks.
Intermediate SEM	250x – 2000x	SEM backscatter mode on plane polished surfaces	Arrangement and juxtaposition of cement paste particles, sand, capillary voids
High magnification SEM	2000x – 20000x	SEM secondary electron mode on fractured surfaces	Details of internal structure of individual cement particles and masses
Nanostructure	1000000x	Atomic Force Microscopy (AFM), High Voltage Transmission Electron Microscope (TEM)	Some details of C-S-H gel

The microstructure of the hardened concrete mix was studied using Petrographic analysis and intermediate SEM.

The following section describes the sample preparation procedure for microstructure analysis of hardened concrete specimens thin section Petrographic analysis and intermediate SEM.

4.4.1 Sample preparation procedure for microstructure studies of hardened concrete:

Specimen samples of hardened concrete mixes used in the present study were prepared as per guidelines mentioned in IS 2386 (Part VIII) 1963. These prepared samples were used for petrographic examination as well as SEM images of hardened concrete mix. The instruments required for sample preparation include concrete saws, thin section CL-50 precision lapping machine, microscope slides, ultrasonic cleaning machine, oven and petrographic microscope (Gandage et al. 2013b). Consumables like abrasive silicon carbide grit as an abrasive agent, epoxy resin and hardener for impregnation of specimen cracks, acetone, water and dye were also used in the specimen preparation. Fig. 4.4 presents the CL-50 lapping machine and petrographic microscope.

Thin Section Lapping Machine Petrographic Microscope

Fig. 4.4: Thin section CL-50 precision lapping machine (L) and Petrographic microscope (R)

The important steps involved in the specimen preparation are;

1. *Preliminary cutting and dressing:* The concrete core or block is held tightly in the jack of the cutting machine having diamond blade saw. Chips of approximately 10mm x 20mm size and 2mm – 5mm thickness are cut.
2. *Initial Lapping:* Prior to next step the chips obtained from the above step is ground and lapped to remove any damage caused in the cutting process. The combination of grinding and lapping action will ensure high quality, optically flat surface that can be properly bonded to the glass microscope slide. The thickness of these dressed chips is 1mm.
3. *Cleaning and drying:* After the initial lapping process the samples are cleaned in ultrasonic cleaner setup for 10 minutes to clear off abrasive agent (silicon carbide) and other dust particles. The samples are dried in laboratory oven for 10 minutes at 45^{o}C.
4. *Mounting of specimen on glass slides:* The flattened polished surface of the specimen cleaned by ultrasonic method is further cleaned with the help of acetone (solvent). The solvent cleaned specimen is bonded on the glass slide with the help of epoxy resin hardener. While applying the epoxy resin hardener care is taken about the thickness of the layer of the hardener being applied. To control the thickness of the epoxy resin hardener small amount of acetone can be used. Also while applying the hardener a few drops of coloured dye is added.
5. *Final Lapping:* Once the specimens are mounted on the glass slide they are allowed to set for 12 – 16 hours. After this setting period each specimen is lapped so as to achieve a thickness of up to 30 microns.

6. *Covering:* After the final lapping, the specimen is thoroughly cleaned with distilled water and covered using glass cover slip. This is to prevent carbonation and damage to the sample after its preparation and is also important to reduce light scattering during the examination of the thin section.

Important precautions to be considered during sample preparation are;

1. Excessive heating is to be avoided during the preparation of thin sections. Excessive heating means temperature more than 45^{o}C. Tests performed at 38^{o}C produce reliable results.
2. Exposure to air should be minimized as carbonation may take place in freshly ground and polished concrete surfaces and carbonation may lead to loss of valuable information in the finished thin section.
3. Exposure to water should be completely avoided as it may result in secondary hydration and loss of water soluble compounds from the cement paste.

Fig. 4.5 depicts different stages of laboratory procedures adopted for preparation of thin section specimens for microstructure analysis.

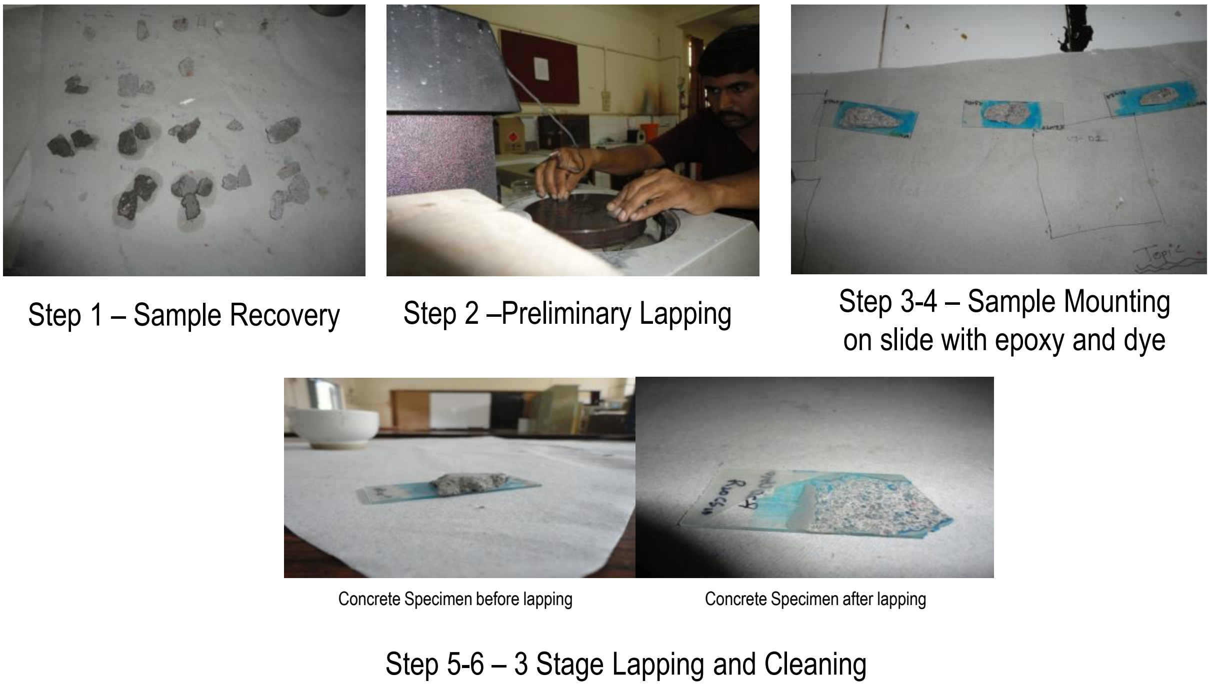


Fig. 4.5: Laboratory procedure for preparation of thin section specimens

4.4.2 Thin Section Petrographic Analysis:

Thin section petrographic analysis has been practiced by geologists since more than 200 years (Roy et al. 1993). The origin of concrete petrography dates backs to 1915 (Jana, 2005).

The test setup required for thin section petrographic analysis is similar to the requirement for petrographic analysis of coarse aggregates as prescribed in IS 2386 (Part VIII): 1963. The petrographic examination of concrete specimens helps in understanding morphology of the concrete, surface bonding and determination of relative proportion. Petrographic analysis involves use of optical microscope to examine plane polished surface or specially ground petrographic thin section (25μm to 30 μm thick) which are transparent to light. The thin section specimens are prepared by impregnation of the empty spaces like cracks, air voids and capillary pore by a fluorescent dye dissolved in a low viscosity epoxy resin (Gandage et al. 2013b). When the prepared specimens are observed under optical microscope equipped with fluorescent light attachments, crack patterns and degree of inhomogeneity can be observed.

4.4.3 SEM investigations of hardened concrete:

The microstructure of concrete is an integrated term applied for the hydrated cement paste (HCP), coarse as well as fine aggregates and the interface between the aggregate and the hydrated cement paste known as interfacial transition zone (ITZ) or paste aggregate interface. The microstructure examination helps to analyse the extent of hydration taken place in the HCP, mineral composition of the aggregates and the bond between the matrix phase and the aggregate phase. The interface between paste and aggregate is one of the weak area in the concrete microstructure due to its porous nature. The microstructure studies of different phases in the hardened concrete specimens give an idea about the engineering behaviour (strength, dimensional stability and durability) of the specimen (Mehta et al. 2006).

Fig. 4.6 presents the process of sample placement on metal stub and arrangement of the specimens in the SEM for examination.

Ground prepared concrete sample placed on metal stub.

Specimen inside Scanning Electron Microscope

Fig. 4.6: Concrete specimen for microstructure studies using SEM

4.5 Laboratory Trial for determination of appropriate fine aggregate sample for M-40 grade SCC:

With a view to decide about the type of fine aggregate to be used for further investigations, experimentation was undertaken. Two types of fine aggregates NS and CS confirming to zone 2 (as prescribed in IS 383:1970) were adopted in this study. The mix design as tabulated in Table 4.2 was used for both the SCC mixes. As discussed in the preceding section, the fresh state and hardened state properties of the SCC mixes were evaluated. The following sections present the results of the tests undertaken.

4.5.1 Fresh state properties of SCC mix with NS and CS:

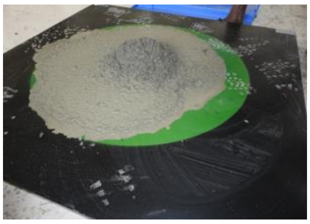
The fresh state properties of the SCC mix are determined to evaluate its flowability and stability. Fig. 4.7 highlights the various tests performed to measure the fresh state properties of SCC mixes with NS and CS.

Slump flow Test

J-Ring Test

V-Funnel Test

Slump Flow for SCC mix with NS



Slump Flow for SCC mix with CS

J-Ring Flow for SCC mix with NS

J-Ring Flow for SCC mix with CS

Fig. 4.7: Tests for measuring fresh state properties of SCC mix with NS and CS

From the above figure, it can be observed that the slump flow and J-ring spread for SCC mix with NS is cohesive and uniform. The mortar halo (bleed water) at the periphery of the spread is negligible. On the contrary, for SCC mix with CS, the slump flow and J-ring spread is segregated with pronounced mortar halo at the periphery. The V-funnel test also showed a relatively cohesive mix at the end of the test indicating negligible segregation. Table 4.5 presents the results of fresh state properties of SCC mixes with NS and CS.

Table 4.5: Fresh state properties of SCC mixes with NS and CS

Property	SCC mix with NS	SCC mix with CS
Slump flow (mm)	610	590
T_{50} (s)	5.2	5.6
V-Funnel time (s)	13	14.5
VSI	0	2
J-ring flow (mm)	605	580

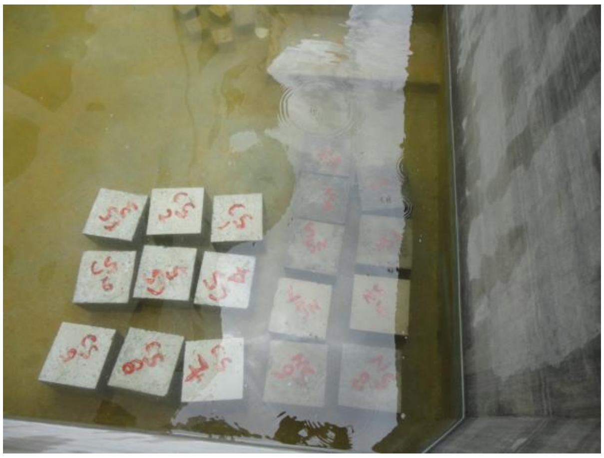
From the results of the fresh state properties it was observed that,

1. The slump flow of SCC mix with CS was 3.28% less than the slump flow for SCC mix with NS.
2. The T_{50} times were almost comparable. Due to round shape and smooth texture of NS particles, the T_{50} time required for SCC mix with NS was lower than CS mixes.
3. The V-funnel emptying time was 11.5% more for SCC mix with CS than SCC mix with NS.
4. VSI indicates SCC mix with CS had a pronounced mortar halo.
5. With the introduction of J-ring, the flow of the concrete reduced due to the obstructions. However the, rate of flow reduction was low in SCC mix with NS (0.8%) as compared to CS mixes (2.59%). This was attributed to the particle shape and texture of the fine aggregates used in the respective mix. The NS was mainly composed of rounded smooth particles. These particles aid in uniform spread of the mix without segregation. The CS particles were angular and have rough surface texture leading to inter-particle friction (Sideris. 2007) which affects the flow spread.

4.5.2 Hardened state properties of SCC mix with NS and CS:

The objective of the research study is to assess the response of SCC mix as a pavement material to environmental loads. For pavement applications, the concrete mix should satisfy the flexural strength requirement (4.5MPa) as prescribed by IRC 58: 2011. Further, this study proposes to use M-40 grade of SCC mix with average compressive strength requirement of

48.25MPa as per mix design calculations recommended in IS 10262: 2009. As discussed earlier, the cube specimens were first subjected to NDT tests and then tested for compressive strength. The tests were performed at 3 days, 7 days, 28 days and 90 days. The flexural strength tests were performed at 7 days and 28 days. The cube and beam specimens were subjected to wet curing by submerging the sections in the water tank as shown in Fig. 4.8.



Wet curing of Specimen

Fig. 4.8: Curing of SCC mix specimens

Table 4.6 summarizes the test results for various properties evaluated.

Table 4.6: Summary of test results for hardened state properties of SCC mix with NS and CS

Description	SCC mix with NS	SCC mix with CS
Density of the cube specimen (kg/m^3)		
Demoulded specimen	2315.06	2331.69
3 day cured cube specimen	2336.30	2355.02
7 day cured cube specimen	2369.88	2395.56
28 day cured cube specimen	2392.10	2439.51
90 day cured cube specimen	2415.81	2455.58
Schmidt Hammer Test (MPa)		
3 day cube specimen	12.80	13.97
7 day cube specimen	15.00	17.40
28 day cube specimen	20.20	23.80
90 day cube specimen	21.35	27.69

Table 4.6: Summary of test results for hardened state properties of SCC mix with NS and CS (contd.)

Description	SCC mix with NS	SCC mix with CS
Ultrasonic Pulse Velocity (km/s)		
3 day cube specimen	3.88	3.97
7 day cube specimen	3.98	3.99
28 day cube specimen	4.12	4.21
90 day cube specimen	4.24	4.30
Cube Compressive Strength (MPa)		
3 day cube specimen	35.19	43.78
7 day cube specimen	38.34	47.86
28 day cube specimen	43.96	55.31
90 day cube specimen	49.85	63.26
Beam Flexural Strength (MPa)		
7 day beam specimen	5.2	6.47
28 day beam specimen	6.6	7.34

Fig. 4.9 a, 4.9 b, 4.9 c, 4.9 d and 4.9 e presents the graphs for the test results on the experimental trial undertaken.

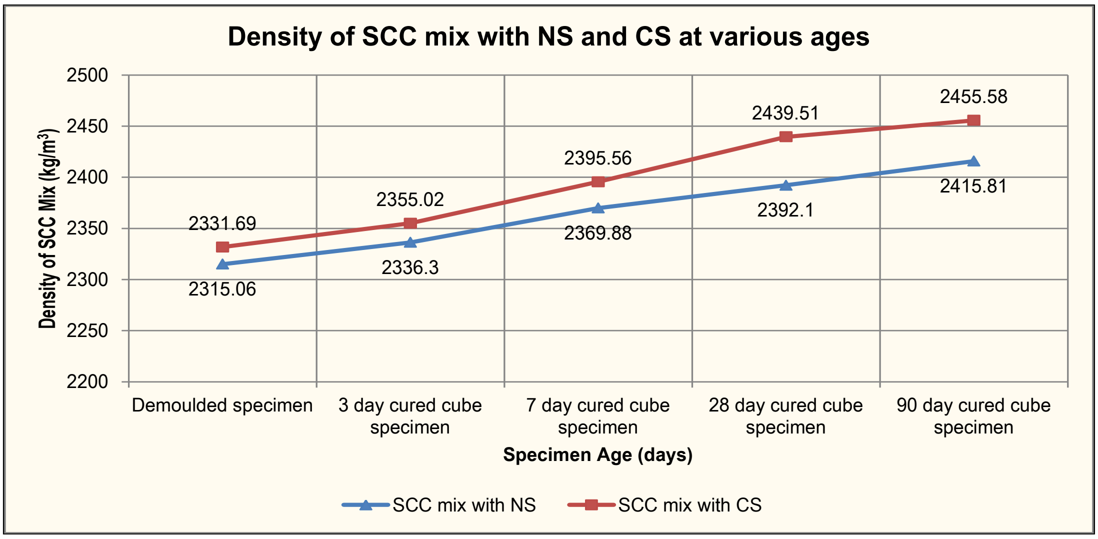


Fig. 4.9a: Variation in the density of the SCC mixes with NS & CS at various ages

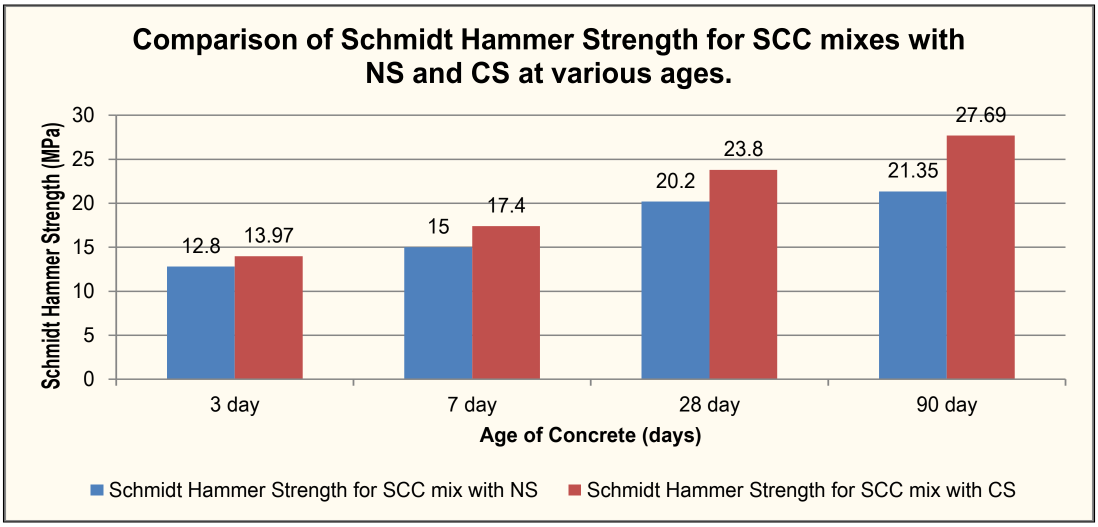


Fig. 4.9b: Variation in the Schmidt Hammer Strength for the SCC mixes with NS & CS at various ages

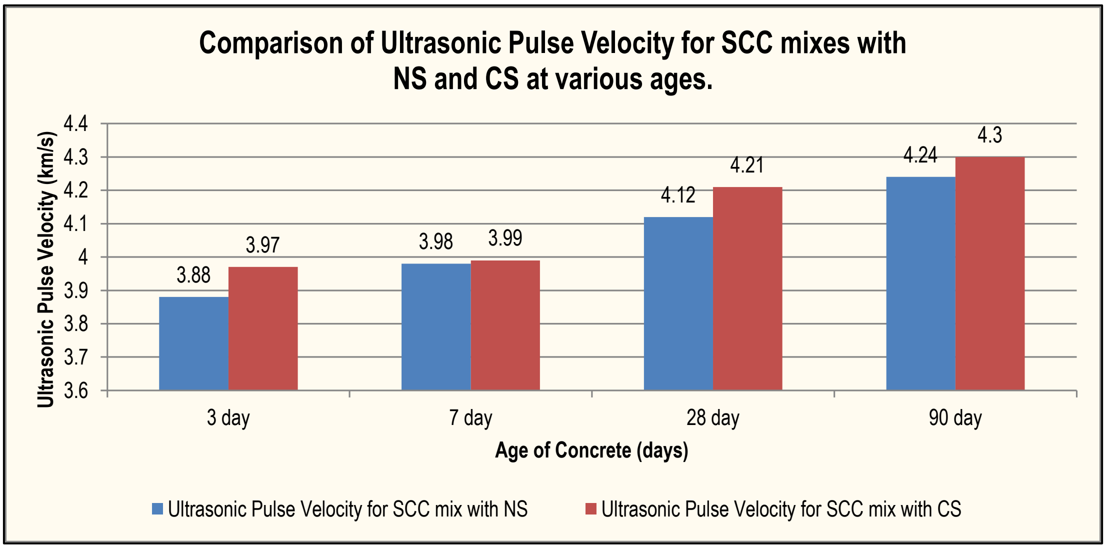


Fig. 4.9c: Variation in the Ultrasonic Pulse Velocity for the SCC mixes with NS & CS at various ages

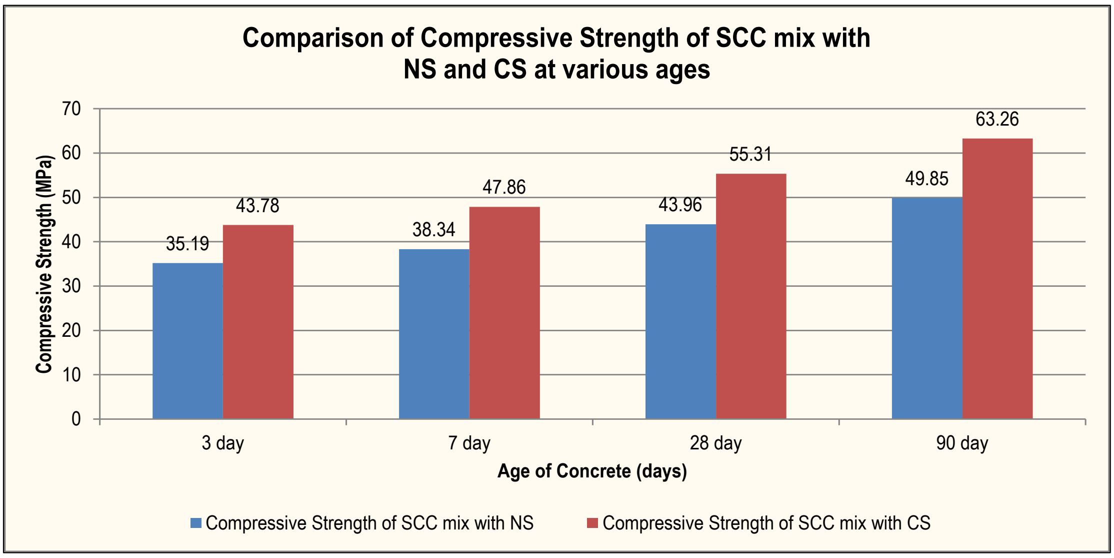


Fig. 4.9d: Variation in the Compressive Strength of the SCC mixes with NS & CS at various ages

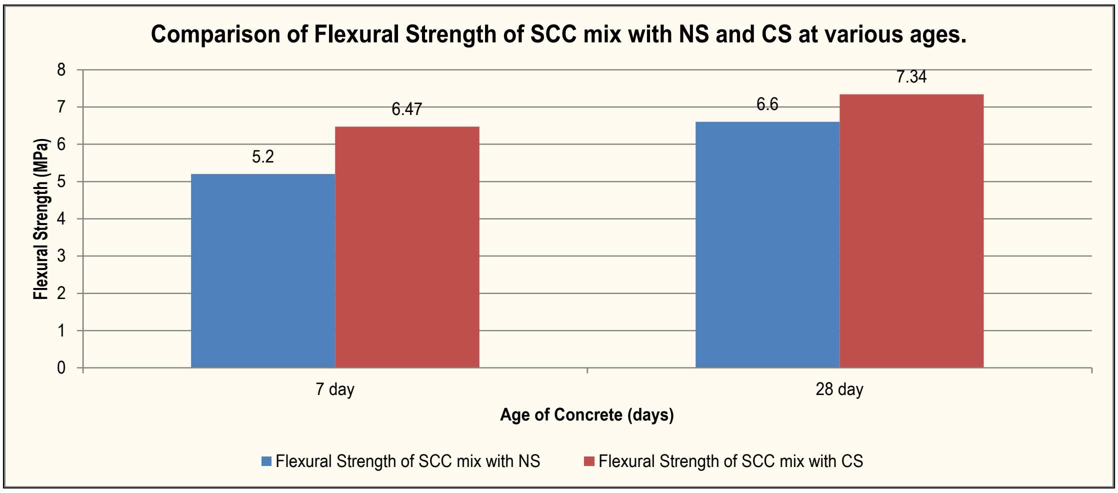


Fig. 4.9e: Variation in the Flexural Strength of the SCC mixes with NS & CS at various ages

From the above test results, following points were inferred,

A. *Density:*

1. SCC mixes with CS were denser than the NS mixes. The density of the demoulded cube specimen for the SCC mix with CS was 0.72% more than the density of the demoulded cube specimen for the SCC mix with NS. The density of the CS mixes cured at 3, 7, 28 and 90 days was 0.8%, 1.08%, 1.98%, and 1.67% more than the NS mixes cured at the same ages.
2. With respect to the density of the demoulded cube specimen for NS mix, the rate of increase in density for the NS mix cube specimen at 3 days, 7 days, 28 days and 90 days was 0.92%, 2.37%, 3.33% and 4.35% respectively. Similarly, for the CS mix cube specimen, the density increase at 3, 7, 28 and 90 days was 1%, 2.72%, 4.63% and 5.32% with respect to the density of the demoulded CS cube specimen. Thus, the rate of increase in the cube density for CS mixes is relatively more than the rate of increase in the cube density for NS mixes.
3. The variation in the densities of the NS and CS mixes is attributed to the particle shape, size and packing of the fine materials in the matrix phase of the concrete mixes. For the given mix design, the NS mixes exhibited lower densities due to large sized, round shaped and smooth textured particles of the fine aggregates. This reduced the density of the matrix phase and overall density of the concrete. On the contrary, in the CS mixes, the fine aggregate particles were uniform sized, angular and rough textured leading to efficient particle packing arrangement in the matrix phase. This resulted in overall denser matrix leading to higher densities for the cube specimen.

4. Apart from the particle shape and size, the packing of the particles in the matrix phase affects its overall service life performance also. Fig. 4.10 presents the cross section of tested beam specimen of NS and CS mix. The NS mix beam specimen shows voids in the cross section, while the CS mix beam showed a denser matrix with negligible voids.

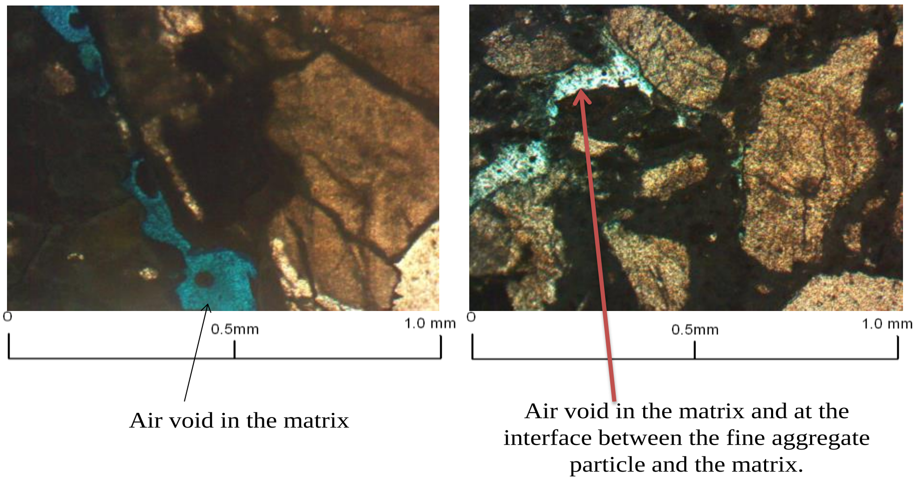
c/s of beam specimen for SCC mix with NS

c/s of beam specimen for SCC mix with CS

Fig. 4.10: Cross section of beam specimens of SCC mix with NS and CS

The representative specimens were subjected to microstructure examination as per the procedure discussed in Section 4.4.1 and 4.4.2.

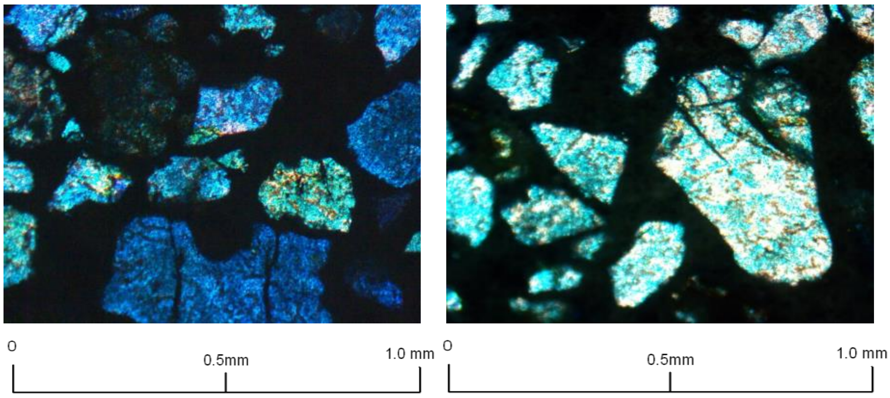
Fig. 4.11 (a) & 4.11 (b) presents the petrographic image of NS and CS mixes respectively.



Petrographic image of SCC mix with NS.

Fig. 4.11 (a): Thin Section Petrographic image of SCC mix with NS

From the thin section petrographic image of a representative cube specimen of SCC mix with NS and CS, it is observed that the matrix phase of NS mixes has air voids (Fig. 4.11 a). The voids are also seen at the interface between the aggregate particle and matrix phase.



Specimen with denser matrix and angular shaped fine aggregate particles
Petrographic image of SCC mix with CS.

Fig. 4.11 (b): Thin Section Petrographic image of SCC mix with CS

In case of the CS mixes, efficient particle packing arrangement in the matrix is observed. This is observed by the dark coloured matrix without any air voids (Fig. 4.11b). Thus the density of the CS mixes is more than the NS mixes.

B. *Schmidt Hammer test:*

For the Schmidt hammer test, the compressive strength values obtained (by correlating the rebound index and compressive strength values from the calibration chart supplied by the equipment supplier) for CS mixes was 8.38%, 16%, 17.82% and 29.69% more than the NS mixes at 3, 7, 28 and 90 days respectively. The rebound hammer or Schmidt hammer test results indicated that the CS mixes had a hard surface as compared to the NS mixes.

C. *Ultrasonic Pulse Velocity:*

The test results for the ultrasonic pulse velocity tests indicated that the test results were relatively comparable. As per IS 13311 (Part 1) 1992, both the concrete mixes (NS as well as CS) can be termed as good quality.

D. *Cube Compressive Strength:*

1. The compressive strength values recorded for the CS mix was more than the NS mix.
2. The compressive strength values for the SCC mix with CS was 24.41%, 18.09%, 23.02% and 22.01% more than the compressive strength values for NS mixes at 3, 7, 28 and 90 days. This was attributed to the better particle packing arrangement observed in CS mixes (Fig. 4.11a & 4.11b).

3. With respect to the 3 day compressive strength, the rate of increase in the compressive strength at 7, 28 and 90 days for the SCC mix with NS was 8.95%, 24.92% and 41.66% respectively. Similarly for the CS mixes, the rate of strength gain for CS mixes at 7, 28 and 90 days, was 9.32%, 26.34% and 44.49% respectively.

E. *Beam Flexural Strength:*

The flexural strength performance of the SCC mix with CS was better than the NS mix. The 7 and 28 day flexural strengths for CS mixes were 24.42% and 11.21% more than the NS mixes.

From the above observations it was inferred that the compressive strengths of the SCC mix with CS was higher than the compressive strength of the SCC mix with NS. This was supported by the microstructure images obtained from the thin section petrographic analysis.

Thus, it was observed that though SCC mix with NS satisfied the flexural strength criteria for pavement application, it did not conform to the compressive strength requirement prescribed. Hence, from the above experiment trial, it was concluded that the SCC mix with CS satisfied the flexural strength as well as compressive strength requirement for pavement application and hence, for the subsequent experimental studies, M-40 grade SCC mix with CS was adopted. This mix was termed as Mix A.

4.6 Laboratory Trial for determination of appropriate dosage of fly ash as a cement replacement material:

The next stage of laboratory trials was aimed at determination of appropriate dosage of fly ash as a cement replacement material. M-40 grade SCC mix with CS was only considered in this stage of experimentation. SCC mix with NS was not considered as per the findings from the laboratory studies discussed in the preceding section.

The mix design considered for fly ash dosage trials is summarized in Table 5.7. In the present study, Class C fly ash has been adopted as a replacement for cement. A total of 9 mixes were tested in which the fly ash dosages were varied from 0% to 40% cement replacement, at an increment of 5% for each batch. Fly ash addition to SCC mixes reduces the superplasticizer dosage to achieve same workability. This is observed up to 40% replacement level. Beyond 40%, the reduction in superplasticizer dosage is insignificant (Liu, 2010). In the present study, the upper limit of fly ash as a cement replacement additive has been limited to 40%. At this stage, Mix 1 was considered as the control mix and all the properties of the remaining mixes were compared with respect to the control mix. The retrospective effect of the increase in the fly ash dosage on the fresh state and hardened state properties of M-40 grade SCC mix with CS was investigated. Mix proportions of all the combinations tried with varying replacement dosage of fly ash have been summarized and presented in Table 4.7.

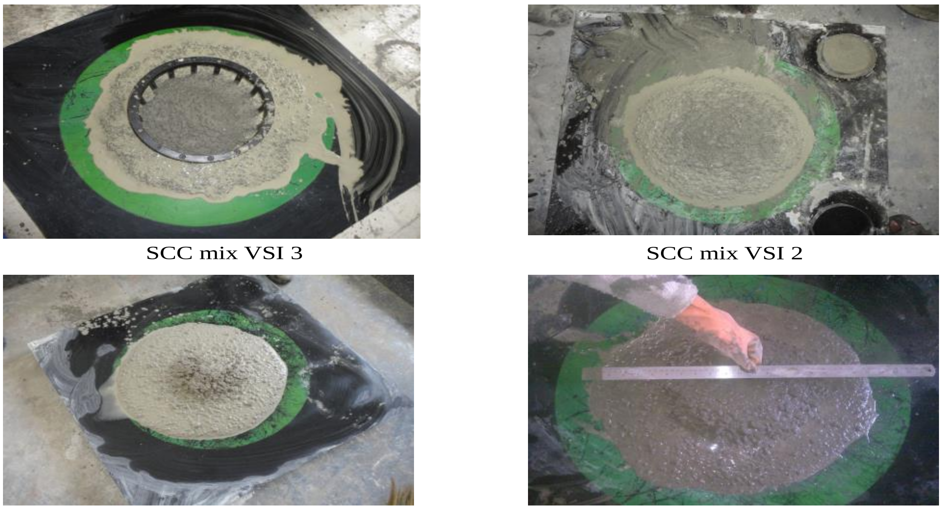
Table 4.7: Mix Design for M-40 grade SCC to determine appropriate dosage of fly ash as a cement replacement material

Constituent	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
Cement (kg/m^3)	430	408.5	387	365.5	344	322.5	301	279.5	258
Fly ash (kg/m^3)	0	21.5	43	64.5	86	107.5	129	150.5	172
Fly ash dosage (% of cement)	0	5	10	15	20	25	30	35	40
Fine Aggregates (kg/m^3)	1135	1135	1135	1135	1135	1135	1135	1135	1135
Coarse Aggregates (kg/m^3)	630	630	630	630	630	630	630	630	630
Water (kg/m^3)	200	200	200	200	200	200	200	200	200
HRWR (lit/100 kg of binder)	0.95	0.9	0.85	0.85	0.8	0.8	0.75	0.75	0.7

Each mix was tested for the fresh as well as mechanical properties.

4.6.1 Fresh state properties:

As per EFNARC guidelines, the fresh mix of SCC should be flowable as well as possess enough stability (resistance to segregation). Mineral admixtures (inert as well as pozzolanic) help improve the stability of the mix without affecting the flow. The addition of fly ash helped in improving the fresh state properties. It improved the slump flow with reduction in the mortar halo (VSI). The fly ash addition also ensured decrease in the HRWR dosage (Table 4.7). Fig. 4.12 presents the effect of addition of fly ash on the reduction of mortar halo.



SCC mix VSI 3 SCC mix VSI 2

SCC mix VSI 1 SCC mix VSI 0

Fig. 4.12: Reduction of mortar halo in SCC mix with CS due to step by step increase in fly ash dosage

Table 4.8 presents the fresh state properties for the 9 mixes tested.

Table 4.8: Summary of fresh state properties of SCC mixes for fly ash dosage trials

Mix Details	Slump flow (mm)	T_{50} (s)	V-Funnel (s)	VSI	J-ring flow (mm)
Mix 1	590	5.6	14.5	2	580
Mix 2	590	5.6	14.5	1	580
Mix 3	595	5.6	14.2	1	585
Mix 4	596	5.6	14.1	1	585
Mix 5	597	5.5	14	0	590
Mix 6	598	5.5	14	0	590
Mix 7	600	5.2	13.7	0	596
Mix 8	603	5.2	13.5	0	597
Mix 9	610	5	13.0	0	600

Based on the above results, following points were inferred for the fresh state properties of SCC mix with CS and varying fly ash dosages;

1. The addition of fly ash to the SCC mix helped in reducing the HRWR dosage (Table 4.7). This is on account of improved particle size distribution in the cement fly ash mix which improves paste fluidity and decreases its viscosity.
2. It was observed that the effect of addition of fly ash on the improvement of the fresh state properties was observed from 10% dosage levels (Mix 3).

3. With the increase in fly ash dosages, the slump flow values increased steadily. With respect to Mix 1 (0% fly ash), the increase in slump flow values were 0.85%, 1.02%, 1.2%, 1.36%, 1.7%, 2.2% and 3.4% from Mix 3 to Mix 9 respectively.
4. The J-ring flow patterns were also similar to the slump flow pattern.
5. The T_{50} time was comparable up to Mix 5. At 30% and 35% addition level (Mix 7 and 8), the decrease in T_{50} time was 7.14% with respect to Mix 1. For Mix 9, this decrease was 10.7%. The fly ash addition also helps in reducing the V-funnel emptying time.
6. The improvement in the fresh state properties of the SCC mix was on account of the spherical shape (Hanneson et al. 2012 and Burgos-Montes et al. 2012) of the fly ash particles (Fig. 3.4) which impart lubrication effect to the matrix phase during the flow of the mix. This reduces the friction between the particles and ensures uniform, cohesive and speedy flow.
7. The addition of fly ash, in stages, helped to minimize the mortar halo (VSI = 0) from Mix 5 onwards. The addition of fly ash absorbs the excess bleed water thereby decreasing the tendency of segregation (Gurjar, 2004).

Graphical representation of variation in the slump flow values and T_{50} time with increase in fly ash dosage from Mix 1 to Mix 9 in presented through Fig. 4.13.

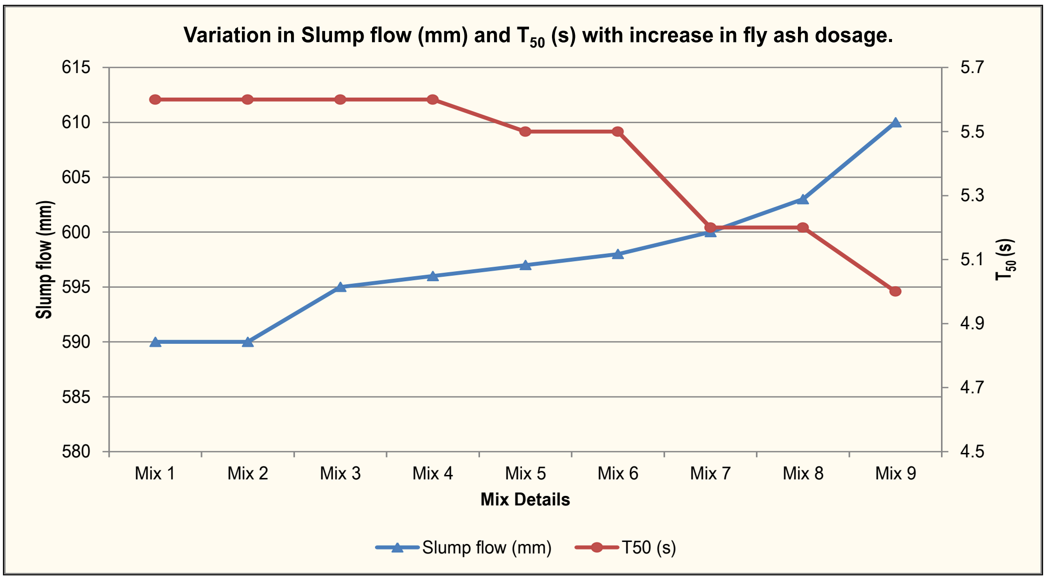


Fig. 4.13: Variation in slump flow and T_{50} time for SCC mix with CS and varying fly ash dosage

Thus, the addition of fly ash to SCC mix offers a dual advantage of reduced cement usage and lower dosage of HRWR admixture for achieving a particular degree of workability and other fresh state properties of the SCC mix.

4.6.2 Hardened state properties:

The influence of varying dosage of Class C fly ash on the hardened state properties of SCC mix has been discussed below. The various properties considered include,

1. Density (3, 7, 28 & 90 days)
2. NDT-Schmidt Hammer Test (3, 7, 28 & 90 days)
3. NDT-Ultrasonic Pulse Velocity Test (3, 7, 28 & 90 days)
4. Cube compression strength (3, 7, 28 & 90 days)
5. Beam flexural strength (3, 7, 28 & 90 days)

4.6.2.1 Density:

Table 4.9 (a) presents the summary of density of the SCC mixes tested for determination of appropriate dosage of fly ash as a cement replacement additive.

Table 4.9 (a): Summary of density of SCC mixes for variation in fly ash dosage

Mix Details	**Fly ash dosage (%)**	**Density of Cube Specimen (kg/m^3)**				
		Demoulded	**3 days**	**7 days**	**28 days**	**90 days**
Mix 1	0	2331.69	2355.02	2395.56	2439.51	2455.58
Mix 2	5	2329.30	2354.57	2392.27	2413.32	2424.34
Mix 3	10	2321.48	2345.34	2380.12	2409.34	2412.11
Mix 4	15	2318.52	2334.82	2378.15	2398.54	2409.34
Mix 5	20	2316.07	2326.92	2375.29	2396.72	2409.07
Mix 6	25	2310.12	2322.93	2369.34	2388.64	2396.54
Mix 7	30	2307.66	2320.18	2363.83	2388.64	2396.54
Mix 8	35	2306.76	2317.64	2359.22	2375.81	2385.34
Mix 9	40	2306.16	2312.09	2354.81	2365.34	2382.22

Fig. 4.14 presents the graphical trend of variation in the density of SCC mix with CS and varying dosage of fly ash as a cement replacement additive.

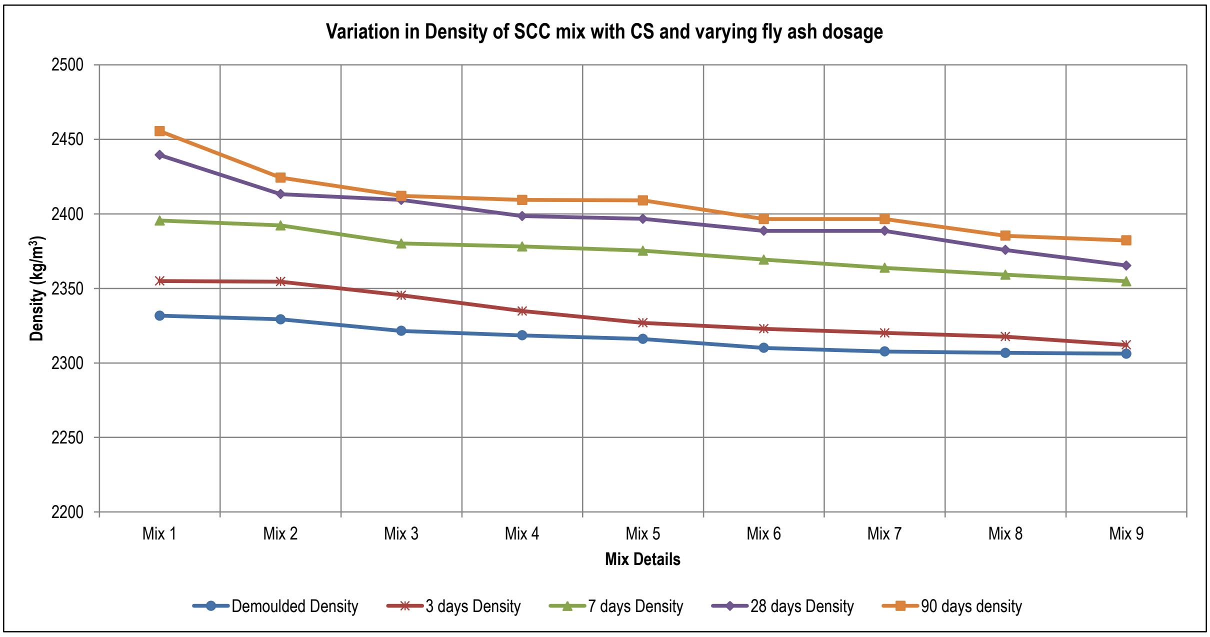


Fig. 4.14: Variation in density for SCC mix with CS and varying fly ash dosage

Table 4.9 (b) presents the comparison of demoulded density values for SCC mixes with varying fly ash dosage (Mix 2 to Mix 9) with respect to the demoulded density of Mix 1. It highlights the trend of decrease in the demoulded densities with increase in the fly ash dosage.

Table 4.9 (c) presents the comparison of gain in the 28 day and 90 day densities with respect to the demoulded density of each mix.

Table 4.9 (b): Comparison of demoulded densities of SCC mix with varying fly ash dosage with respect to the control mix

Mix Details	Fly ash dosage (%)	% drop in demoulded density with respect to Mix 1	Mix Details	Fly ash dosage (%)	% drop in demoulded density with respect to Mix 1
Mix 1	0	--	Mix 6	25	0.93
Mix 2	5	0.11	Mix 7	30	1.03
Mix 3	10	0.44	Mix 8	35	1.07
Mix 4	15	0.57	Mix 9	40	1.09
Mix 5	20	0.67			

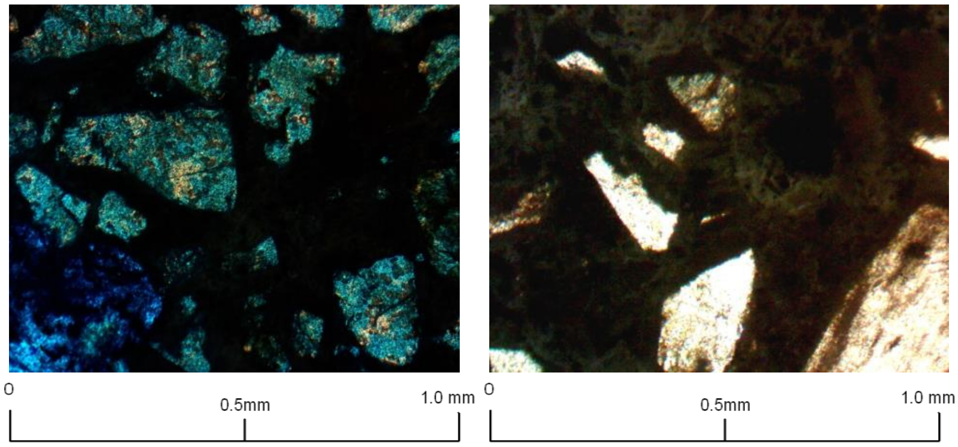
Table 4.9 (c): Comparison of 28 day and 90 day densities with demoulded density

Mix Details	Fly ash dosage (%)	% gain in 28 day density with demoulded density	% gain in 90 day density with demoulded density	Mix Details	Fly ash dosage (%)	% gain in 28 day density with demoulded density	% gain in 90 day density with demoulded density
Mix 1	0	4.62	5.32	Mix 6	25	3.40	3.74
Mix 2	5	3.61	4.08	Mix 7	30	3.12	3.6
Mix 3	10	3.78	3.91	Mix 8	35	2.99	3.41
Mix 4	15	3.45	3.91	Mix 9	40	2.57	3.29
Mix 5	20	3.48	4.02				

From the above test results following points were concluded,

1. Increment in the fly ash dosage has resulted in the decrease in the density of test specimen.
2. Comparing the demoulded densities of the SCC mixes with fly ash dosages with the demoulded density of Mix 1, the reduction in the demoulded densities was steady up to 20% fly ash dosage. At 25% fly ash dosage a significant reduction was observed which remains steady up to 40% fly ash dosage.
3. The gain in 28 day density of cube specimen with respect to the demoulded density, was maximum in case of Mix 1. The rate of gain in 28 day density dropped steadily up to 25% fly ash dosage (Mix 6). Further, the rate of gain in 28 day density for remaining mixes (Mix 7, 8 and 9) dropped significantly.
4. In case of 90 day density, the rate of gain in density with respect to the demoulded density was high in case of Mix 1. With increasing fly ash dosage, the rate of gain in the 90 day density dropped at a steady rate up to Mix 5. From Mix 6 onwards, again a steady decrease in the rate of density gain was observed.
5. The replacement of cement with light weight additive like fly ash (Khaleel et al. 2012) decreased the density of the matrix phase.
6. Thin section petrographic image of SCC mix is presented in Fig. 4.15. The specimens used for the petrographic analysis were cured for 28 days. Two representative specimens were selected viz. specimen without any fly ash addition (Mix 1) and the specimen containing 20% fly ash as a cement replacement additive. The image on the left side represents SCC mix without any fly ash (Mix 1). The matrix is dark coloured and dense. The image on the right side represents the specimen with 20% fly ash in

the matrix. The colour of the matrix is brown coloured. It indicates the relative effect of replacing the cement with fly ash leading to lighter matrix as reflected from the density values.



M-40 grade SCC with CS and 0% fly ash – dense dark coloured matrix

M-40 grade SCC with CS and 20% fly ash – dense brown coloured matrix

Petrographic image of SCC mix with and without fly ash.

Fig. 4.15: Thin section petrographic image of SCC mix with and without fly ash

4.6.2.2 Schmidt Hammer Test:

Before the samples were subjected to the destructive testing, they were subjected to Schmidt Hammer test. The test observations for all the mixes were are summarized in Table 4.10 (a).

Table 4.10 (a): Summary of Schmidt Hammer test for SCC mixes with CS and variation in fly ash dosage

Mix Details	Fly ash dosage (%)	Schmidt Hammer test (MPa)			
		3 days	7 days	28 days	90 days
Mix 1	0	13.97	17.40	23.80	27.69
Mix 2	5	13.70	16.47	20.34	23.00
Mix 3	10	12.67	15.10	20.20	22.80
Mix 4	15	12.30	14.70	19.17	22.67
Mix 5	20	11.70	14.30	18.73	21.80
Mix 6	25	11.63	13.67	17.23	21.57
Mix 7	30	11.34	13.27	16.47	20.70
Mix 8	35	11.02	12.80	15.47	19.20
Mix 9	40	10.98	11.53	15.00	18.34

Fig. 4.16 presents the graphical interpretation of the test results.

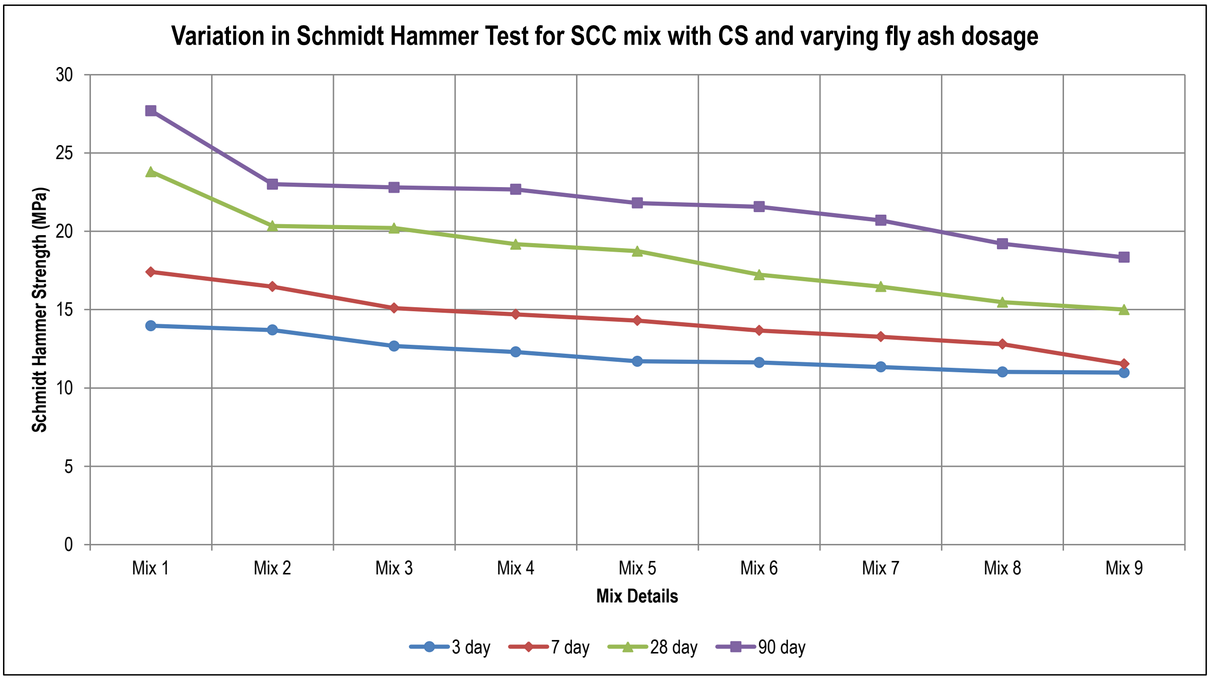


Fig. 4.16: Variation in Schmidt Hammer Test for SCC mix with CS and varying fly ash dosage

Table 4.10 (b) presents the % drop in the 28 day and 90 day Schmidt Hammer test results for SCC mix with varying fly ash dosage with respect to the corresponding Schmidt hammer test results for Mix 1 (control mix).

Table 4.10 (b): Comparison of 28 day and 90 day Schmidt Hammer test for SCC mix with varying fly ash dosage with respect to the control mix

Mix Details	Fly ash dosage (%)	% drop in 28 day Schmidt Hammer test with respect to Mix 1	% drop in 90 day Schmidt Hammer test with respect to Mix 1	Mix Details	Fly ash dosage (%)	% drop in 28 day Schmidt Hammer test with respect to Mix 1	% drop in 90 day Schmidt Hammer test with respect to Mix 1
Mix 1	0	--	--	Mix 6	25	27.61	22.10
Mix 2	5	14.54	16.94	Mix 7	30	30.79	25.24
Mix 3	10	15.13	17.66	Mix 8	35	35	30.55
Mix 4	15	19.45	18.13	Mix 9	40	36.98	33.77
Mix 5	20	21.30	21.27				

From the above test results it was observed that,

1. With increasing dosage of fly ash, the Schmidt Hammer strength is decreasing.

2. A steady drop in 28 day Schmidt hammer values was observed up to Mix 5 (20% fly ash dosage).
3. With further increase in fly ash dosage, the drop was more pronounced (27.61% less) with respect to the Schmidt Hammer values for the control mix. This indicated that the appropriate fly ash dosage as a cement replacement was in the range of 20% to 25% cement replacement level.
4. The trend in the drop of the 90 day Schmidt Hammer values was uniform with respect to the 90 day Schmidt Hammer values for the control mix (Mix 1).
5. The results indicated that the SCC mixes with fly ash require more time to develop hard surface. This is an indicator of later age (beyond 28 days) strength gain of concrete mixes with fly ash addition.

4.6.2.3 Ultrasonic Pulse Velocity (UPV) test:

The test specimens with varying fly ash dosages were subjected to the UPV test. The test results are summarized and presented in Table 4.11 (a).

Table 4.11 (a): Summary of Ultrasonic Pulse Velocity test for SCC mixes with CS and variation in fly ash dosage

Mix Details	Fly ash dosage (%)	Ultrasonic Pulse Velocity (km/s)			
		3 days	7 days	28 days	90 days
Mix 1	0	3.97	3.99	4.21	4.30
Mix 2	5	3.88	3.93	4.09	4.11
Mix 3	10	3.79	3.86	4.01	4.08
Mix 4	15	3.71	3.77	3.96	4.06
Mix 5	20	3.65	3.73	3.94	4.01
Mix 6	25	3.62	3.67	3.79	3.98
Mix 7	30	3.54	3.65	3.76	3.89
Mix 8	35	3.48	3.61	3.73	3.87
Mix 9	40	3.32	3.59	3.63	3.85

Fig. 4.17 presents the graphical summary of the test results.

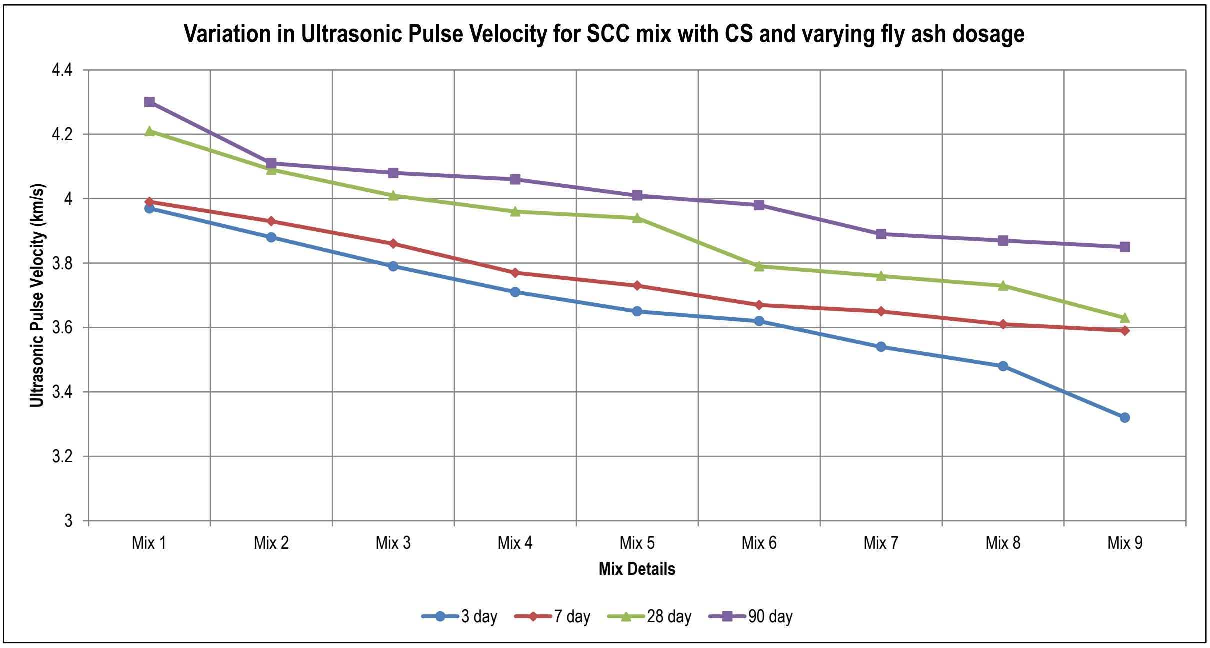


Fig. 4.17: Variation in Ultrasonic Pulse Velocity for SCC mix with CS and varying fly ash dosage

Table 4.11 (b) presents the % drop in the 28 day and 90 day ultrasonic pulse velocity values for SCC mixes with varying fly ash dosages when compared to the corresponding ultrasonic pulse velocity values of control mix (Mix 1).

Table 4.11 (b): Comparison of 28 day and 90 day Ultrasonic Pulse Velocity for SCC mix with CS and varying fly ash dosage with respect to the control mix

Mix Details	Fly ash dosage (%)	% drop in 28 day UPV with respect to Mix 1	% drop in 90 day UPV with respect to Mix 1	Mix Details	Fly ash dosage (%)	% drop in 28 day UPV with respect to Mix 1	% drop in 90 day UPV with respect to Mix 1
Mix 1	0	--	--	Mix 6	25	9.98	7.44
Mix 2	5	2.85	4.42	Mix 7	30	10.69	9.53
Mix 3	10	4.75	5.12	Mix 8	35	11.40	10
Mix 4	15	5.94	5.58	Mix 9	40	13.78	10.47
Mix 5	20	6.41	6.75				

Comparing the experimental test results for Ultrasonic Pulse Velocity for 28 days and 90 days with respect to the recommendations of IS 13311 (Part 1): 1992 provision, it can be inferred,

1. All the 9 mixes were good quality concretes, as the 28 day and 90 day UPV values measured were in the range of 3.5 km/s to 4.5 km/s.

2. As compared to the 28 day UPV values of control mix, the % drop in the 28 day UPV values was steady up to Mix 5 (20% fly ash dosage). In case of Mix 6 (25% fly ash dosage), a steep drop of 9.98% was observed as compared to Mix 1. The 28 day UPV test also indicated that the appropriate fly ash dosage was in the range of 20% and 25% cement replacement levels.
3. The 90 day UPV test results indicated a gradual drop in the UPV values with increase in the fly ash dosage as compared with the control mix.

4.6.2.4 Cube Compression Strength Test:

The cube compression strength test was performed on 15cm size cubes, tested in 3000kN compression testing machine. At the end of the specified curing period, the cubes were allowed to dry, away from direct sunlight. The cured cubes were weighed and subjected to NDT tests. These cubes were then tested in the compression testing machine.

Table 4.12 (a) presents the test results for the cube compression test performed on the cube specimens corresponding to the nine mixes at 3 days, 7 days, 28 days and 90 days.

Table 4.12 (a): Summary of cube compression strength test for SCC mixes with CS and variation in fly ash dosage

Mix Details	Fly ash dosage (%)	Cube compression strength (MPa)			
		3 days	**7 days**	**28 days**	**90 days**
Mix 1	0	43.78	47.86	55.31	63.26
Mix 2	5	36.14	43.07	53.00	63.02
Mix 3	10	35.39	39.02	51.04	60.30
Mix 4	15	33.11	37.56	50.98	59.70
Mix 5	20	30.21	34.90	50.70	58.63
Mix 6	25	27.47	32.56	46.37	55.08
Mix 7	30	24.23	30.73	43.98	50.62
Mix 8	35	23.15	29.85	41.93	48.59
Mix 9	40	22.86	28.85	40.34	47.23

Fig. 4.18 presents the graphical trend of the cube compression test results.

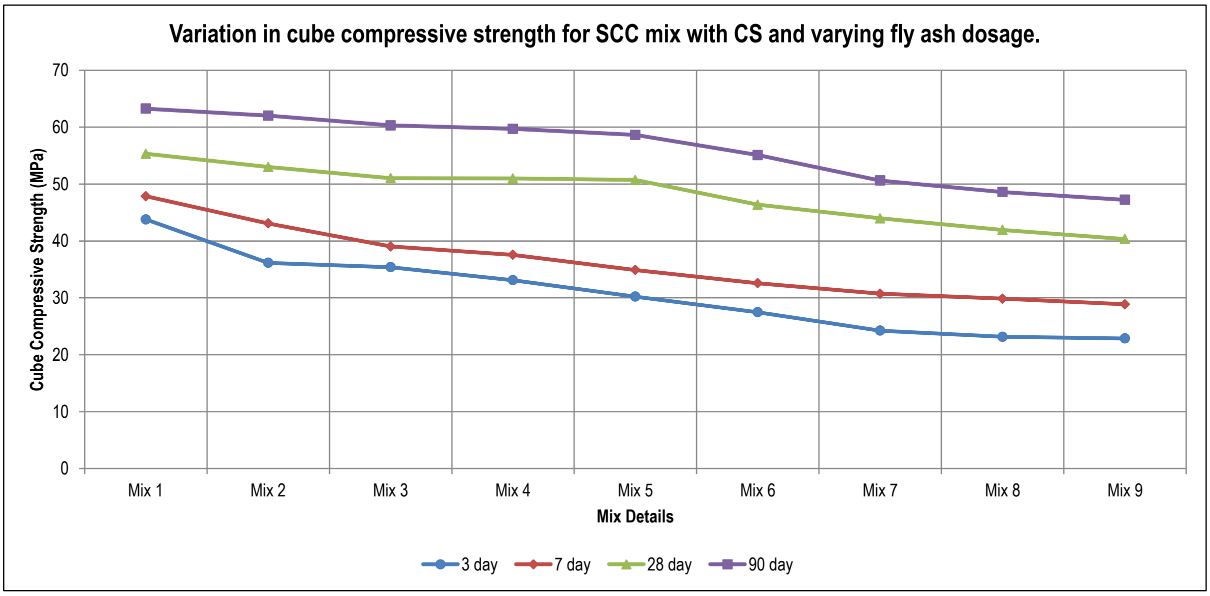


Fig. 4.18: Variation in cube compressive strength for SCC mix with CS and varying fly ash dosage

Table 4.12 (b) presents the variation in the 28 day and 90 day cube compression test results with respect to the control mix.

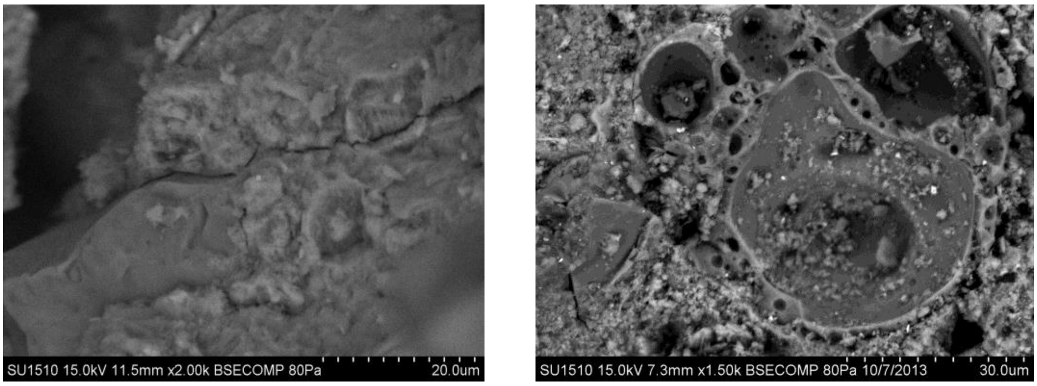
Table 4.12 (b): Comparison of 28 day and 90 day cube compression strength test results with control mix

Mix Details	Fly ash dosage (%)	% drop in 28 day comp. str. with respect to Mix 1	% drop in 90 day comp. str. with respect to Mix 1	Mix Details	Fly ash dosage (%)	% drop in 28 day comp. str. with respect to Mix 1	% drop in 90 day comp. str. with respect to Mix 1
Mix 1	0	--	--	Mix 6	25	16.16	12.93
Mix 2	5	4.18	1.96	Mix 7	30	20.49	19,98
Mix 3	10	7.72	4.68	Mix 8	35	24.19	23.19
Mix 4	15	7.83	5.63	Mix 9	40	27.07	25.34
Mix 5	20	8.34	7.32				

From the above test results, following points were inferred;

1. With an increase in the fly ash dosage, the cube compressive strength decreases at 28 days as well as 90 days.
2. The decrease in the 28 day compressive strengths was gradual up to Mix 5 (20% fly ash dosage). A sudden drop of 16.16% was observed in the 28 day compression strength for Mix 6 (25% fly ash dosage).

3. As observed from the test results, the increase in the fly ash dosage resulted in the reduction of cube compressive strength of the SCC mix. This observation is in line with the observation reported by Hannesson et al. (2012). This is attributed to the slower rate of hydration reaction at higher dosage of fly ash.
4. In the present study, it was observed that the 28 day compression strength requirement (48.25 MPa) was achieved up to 20% fly ash dosage level (Mix 5). Beyond 20% dosage level, the strength requirement was not fulfilled.
5. The drop in the 90 day compressive strengths were gradual, with significant drop observed in case of Mix 7 onwards (30% fly ash dosage).
6. As the hydration reaction nears completion, the pozzolanic reaction starts. The fly ash combines with calcium hydroxide (by product of hydration reaction) to form secondary hydration products. This influences the 90 day cube compression strength. However, with increase in the fly ash dosage, the quantity of calcium hydroxide formation is reduced significantly and this lead to lowering of the 90 day compression strength.
7. One of the influencing factors of the mechanical properties of the hardened concrete is the relative arrangement of matrix and the aggregates with respect to each other. Fig. 4.19 presents a representative SEM image of SCC mix with 0% fly ash (Mix 1) and 20% fly ash dosage (Mix 5).



SCC mix with 0% fly ash: Matrix phase enveloping the aggregate particle

SCC mix with 20% fly ash: Matrix phase with hollow fly ash particles

Fig. 4.19: SEM image of SCC mix with 0% and 20% fly ash dosage

From the SEM image it can be observed that in case of Mix 1, the matrix phase appears dense and envelopes the aggregate particle adequately. This arrangement improved the mechanical performance of the concrete mix which is reflected by high 28 day compressive strength (55.31 MPa). As discussed earlier, the addition of fly ash in the concrete mix as a cement replacement lowered the density of the matrix phase.

Also fly ash particles are hollow, with presence of voids (cenospheres), as seen in the figure. Hence, the cube compression strength of SCC mixes with fly ash was lower as compared to control mix.

4.6.2.5 Beam Flexural Strength:

The beam flexural strength test was performed on beam specimens of 500mm length and 100mm cross section. The beams were tested for 7 day and 28 day flexural strength performance. All the test results for the nine mixes are summarized and presented in Table 4.13 (a).

Table 4.13 (a) : Summary of beam flexural strength for SCC mixes with CS and variation in fly ash dosage

Mix Details	Fly ash dosage (%)	Beam flexural strength (MPa)	
		7 day	28 day
Mix 1	0	6.74	7.34
Mix 2	5	5.67	7.20
Mix 3	10	5.67	7.07
Mix 4	15	5.47	6.74
Mix 5	20	5	6.54
Mix 6	25	4.67	6.54
Mix 7	30	4.67	6.50
Mix 8	35	4.60	6.50
Mix 9	40	4.53	6.30

Table 4.13 (b) presents the variation in the 7 day and 28 day beam flexural strength for SCC mixes with varying fly ash dosage in comparison to the control mix.

Table 4.13 (b): Comparison of 7 day and 28 day beam flexural strength test with control mix

Mix Details	Fly ash dosage (%)	% drop in 7 day flex. str. with respect to Mix 1	% drop in 28 day flex. str. with respect to Mix 1	Mix Details	Fly ash dosage (%)	% drop in 7 day flex. str. with respect to Mix 1	% drop in 28 day flex. str. with respect to Mix 1
Mix 1	0	--	--	Mix 6	25	30.71	10.90
Mix 2	5	15.88	1.91	Mix 7	30	30.71	11.45
Mix 3	10	15.88	3.68	Mix 8	35	31.75	11.45
Mix 4	15	18.85	8.17	Mix 9	40	32.79	14.17
Mix 5	20	25.82	10.90				

The trend of the test results has been represented graphically in Fig. 4.20.

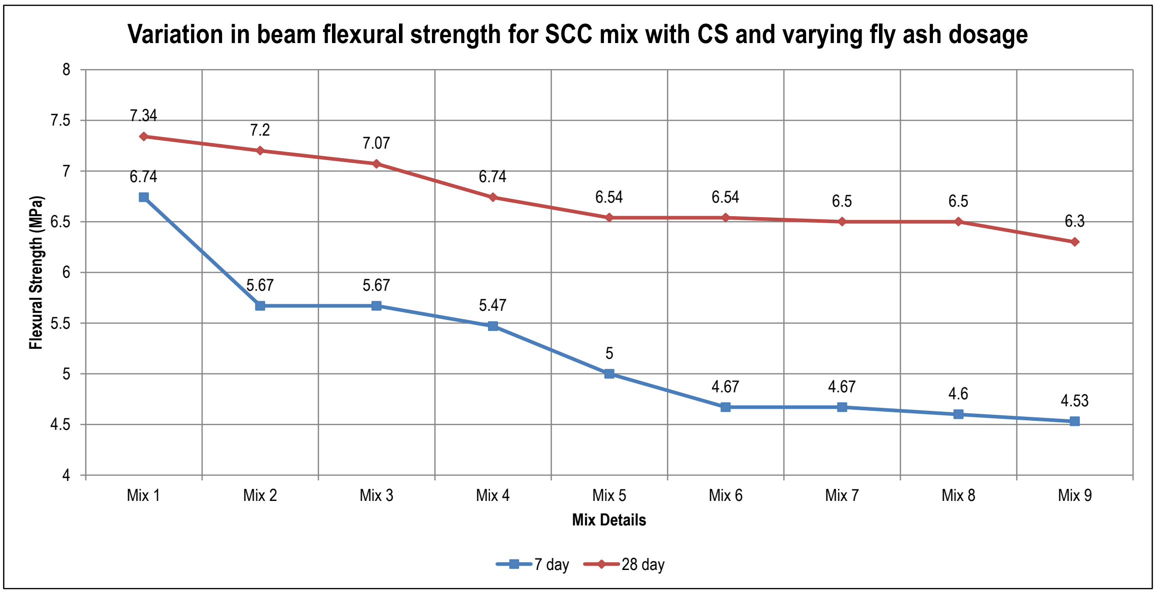


Fig. 4.20: Variation in beam flexural strength for SCC mix with CS and varying fly ash dosage

From the above experimental results, it was observed that;

1. The 7 day flexural strength results exhibited marked fluctuations. This was on account of the slowing down of hydration reaction with increase in the fly ash dosage.
2. The drop in the 28 day flexural strength values was relatively uniform and showed a steady pattern from Mix 5 (20% fly ash dosage) onwards.
3. All the mixes satisfied the flexural strength requirement of 4.5MPa as prescribed by IRC 58:2011.

From the above discussed experimental trials, it was concluded that Mix 5 i.e. M-40 grade SCC mix with CS having 20% fly ash dosage as a cement replacement, satisfied the 28 day compressive strength as well as 28 day flexural strength requirement for possible pavement application. This mix exhibited satisfactory fresh state as well as hardened state properties. Also, the 20% fly ash dosage arrived through the laboratory trial was in line with the recommendations of IRC 44:2008.

Hence, 20% fly ash dosage was considered as an appropriate cement replacement dosage in the present study. This mix was termed as Mix B and was further subjected to the laboratory trials to determine appropriate dosage of perlite as a fine aggregate replacement material.

4.7 Laboratory Trials for determination of appropriate dosage of perlite as a fine aggregate replacement material:

At the end of the earlier stage of experiments it was observed that 20% fly ash dosage was the appropriate dosage as it satisfies the compressive as well as flexural strength requirements for the pavement application.

The SCC mix finalized with 20% fly ash dosage was subjected to trials to determine appropriate dosage of perlite as a crushed sand replacement material. Perlite is a volcanic glass with insulating properties. The objective of adding perlite as crushed sand replacement material is to study the effect of an insulating material on the response of the SCC mix to the temperature variations. The aggregates (coarse as well as fine) used in the SCC mixes were of granite origin. Granite based aggregates are predominantly siliceous and are crystalline in nature. As per Naik et al (2011), the thermal properties of concrete are influenced by the thermal properties of aggregates. Crystalline siliceous aggregates have high CTE which in turn increase the CTE of the hardened concrete. With this background, the effect of addition of an insulating material (perlite) as a replacement to fine aggregates on the thermal performance of the SCC mix has been investigated. The mix design adopted to determine appropriate dosage of perlite as a fine aggregate replacement material is tabulated in Table 4.14.

Table 4.14: Mix Design for M-40 grade SCC to determine appropriate dosage of perlite as a fine aggregate replacement material

Constituent	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Cement (kg/m^3)	430	344	344	344	344	344
Fly ash (kg/m^3)	0	86	86	86	86	86
Fly ash dosage (% of cement)	0	20	20	20	20	20
Fine Aggregates (kg/m^3)	1135	1135	1106.625	1078.25	1049.875	1021.5
Perlite (kg/m^3)	0	0	28.375	56.75	85.125	113.5
Perlite dosage (% of Fine Agg.)	0	0	2.5	5	7.5	10
Coarse Aggregates (kg/m^3)	630	630	630	630	630	630
Water (kg/m^3)	200	200	200	200	200	200
HRWR (lit/100 kg of binder)	0.95	0.8	0.95	0.8	0.95	0.8

M-40 grade SCC mix with CS and 20% fly ash as a cement replacement additive was adopted for the trials. In all 6 mixes (2 control mixes viz. Mix A and Mix B and 4 trial mixes) were studied. The perlite dosages were tried from 2.5% up to 10%. The perlite dosage was increased at an interval of 2.5%. The upper limit of perlite dosage was fixed at 10%. However, it was observed that the perlite dosages beyond 5% were resulting in inadequate target strength requirements and hence the replacement levels were limited to 10%.

4.7.1 Fresh state properties:

Table 4.15 presents the summary of fresh state properties for the trials undertaken to determine appropriate dosage of perlite.

Table 4.15: Summary of fresh state properties of SCC mix with CS and 20% fly ash for perlite dosage trials

Mix Details	Slump flow (mm)	T_{50} (s)	V-Funnel (s)	VSI	J-ring flow (mm)
Mix 1	590	5.6	14.5	2	580
Mix 2	597	5.5	14	0	590
Mix 3	598	5.5	14	0	590
Mix 4	600	5.2	13.7	0	588
Mix 5	600	5.2	13.6	0	588
Mix 6	599	5.4	13.9	0	590

Fig. 4.21 presents the slump flow images of SCC mix with perlite.

Mix on withdrawal of slump cone

Flow of the mix

Final flow of the mix

Fig. 4.21: Slump flow of SCC mix with perlite

From the fresh state properties of the SCC mix with varying perlite dosages, following points were observed,

1. The slump flow spread in the SCC mix was nearly same as Mix 2 (SCC mix with 20% fly ash dosage and 0% perlite) or slightly more.
2. The T_{50} time required was comparable for all mixes except Mix 6 which required slightly more time.
3. The V-funnel emptying time for the SCC mixes with perlite were comparable to Mix 2.
4. From the figure it can be observed that the flow had absence of mortar halo.
5. The J-ring spread had slight variations.
6. The slowing down of the flow spread (indicated by increase in T_{50} time) was attributed to the replacement of fine aggregate component by perlite. The specific gravity of perlite was 1.06. In comparison, the specific gravity of fine aggregates used in the mix was 2.70. Replacing the fine aggregates with light weight material led to gap formation in the combined gradation of fine aggregates and perlite. This gap influenced the flow of the mix. However, the flow of the mix was not adversely affected as, the presence of fly ash in the matrix ensured adequate flow. Hence, the fresh state properties of SCC mixes with perlite were comparable to the fresh state properties of Mix 2. The presence of gap in the matrix is supported by Fig. 4.22 presents the thin section petrographic image of a representative specimen of SCC mix with perlite in the matrix phase.

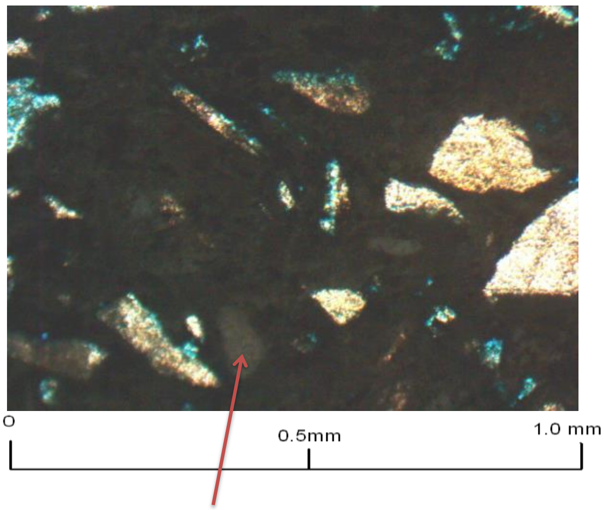


Fig. 4.22: Thin section petrographic image of SCC mix with perlite and voids in the matrix

4.7.2 Hardened state properties:

4.7.2.1 Density:

Table 4.16 (a) presents the density of various SCC mixes considered for perlite trials.

Table 4.16 (a): Summary of density of SCC mixes with CS and 20% fly ash for variation in perlite dosage

Mix Details	Fly ash dosage (%)	Perlite dosage (%)	Density of Cube Specimen (kg/m^3)				
			Demoulded	**3 days**	**7 days**	**28 days**	**90 days**
Mix 1	0	--	2331.69	2355.02	2395.56	2439.51	2455.58
Mix 2	20	0	2316.07	2326.92	2375.29	2396.72	2409.07
Mix 3	20	2.5	2307.16	2325.46	2374.56	2388.15	2390.12
Mix 4	20	5.0	2305.68	2322.67	2372.32	2386.22	2388.14
Mix 5	20	7.5	2303.21	2321.98	2370.08	2382.71	2384.47
Mix 6	20	10.0	2297.34	2313.09	2364.67	2378.67	2381.42

Fig. 4.23 presents the graphical trend of density variation in the SCC mix considered for perlite dosage trials.

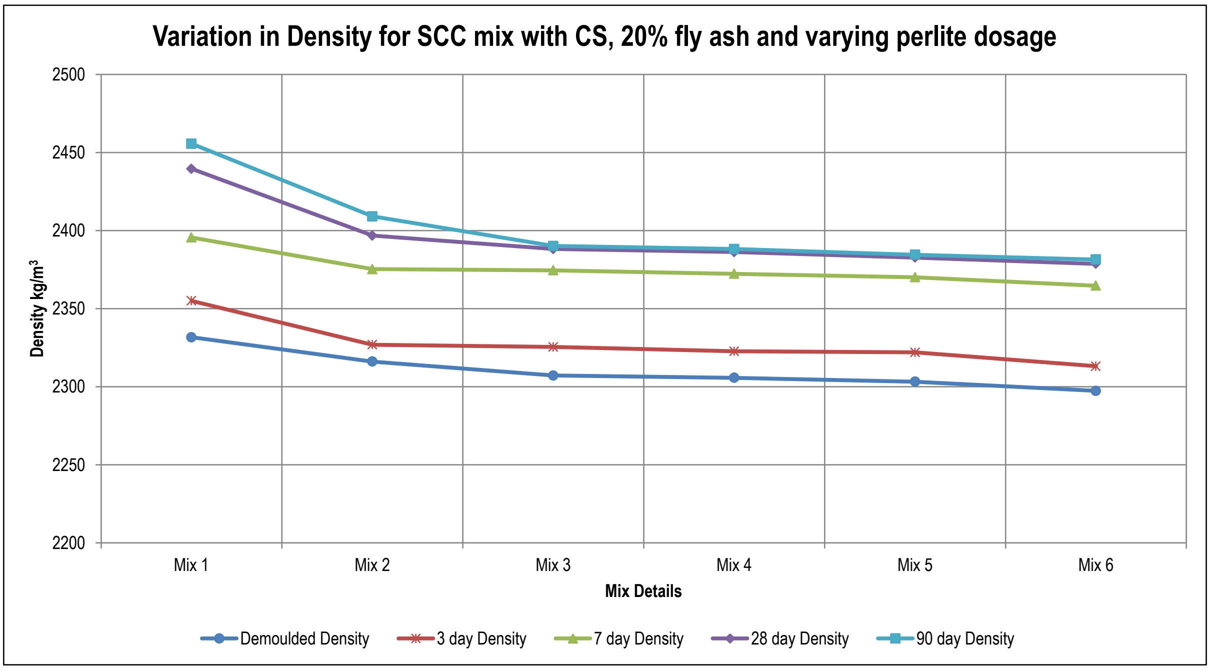


Fig. 4.23: Variation in density for SCC mixes with CS, 20% fly ash and varying perlite dosage

The comparison of demoulded densities of the varying dosage of perlite in SCC mixes has been compared with the control mixes and presented in Table 4.16 (b).

Table 4.16 (b): Comparison of demoulded densities of SCC mix with CS, 20% fly ash dosage and varying perlite dosage with respect to the control mix

Mix Details	Fly ash dosage (%)	Perlite dosage (%)	% drop in demoulded density with respect to Mix 1	% drop in demoulded density with respect to Mix 2
Mix 1	0	0	--	--
Mix 2	20	0	0.67	--
Mix 3	20	2.5	1.05	0.39
Mix 4	20	5	1.14	0.45
Mix 5	20	7.5	1.22	0.56
Mix 6	20	10	1.47	0.81

Table 4.16 (c) presents the comparison of gain in 28 day and 90 day density for the above considered mixes.

Table 4.16 (c): Comparison of gain in 28 day and 90 day density of SCC mix with CS, 20% fly ash dosage and varying perlite dosage with respect to the control mix

Mix Details	Fly ash dosage (%)	Perlite dosage (%)	% gain in 28 day density compared with demoulded density	% gain in 90 day density compared with demoulded density
Mix 1	0	0	4.62	5.32
Mix 2	20	0	3.48	4.02
Mix 3	20	2.5	3.51	3.47
Mix 4	20	5	3.49	3.58
Mix 5	20	7.5	3.45	3.53
Mix 6	20	10	3.54	3.67

From the above results it is observed that,

1. The reduction in the demoulded density of the SCC mixes with perlite dosage, as compared to Mix 1, was 1.05%, 1.14%, 1.22% and 1.47% at 2.5%, 5%, 7.5% and 10% perlite dosage levels respectively.
2. Comparing the demoulded density of the SCC mixes with perlite to that of Mix 2, the drop in density was less than 1%. This was attributed to the same mix composition of the concrete mix except, for the addition of perlite at 2.5% increment in each trial.

3. The gain in the 28 day density of perlite mixes, when compared to the corresponding demoulded density, was less than the gain observed in Mix 1. But it was comparable to the gain observed in Mix 2.
4. The addition of perlite does not significantly improve the gain in 90 day density of the SCC mixes. The gain in 90 day density was almost same as the gain in 28 day density when compared to the respective demoulded density of the perlite mixes. The lack of significant gain in the 90 day density for perlite mixes can be attributed to the lack of availability of the nucleation site for the secondary hydration reaction due to replacement of fine aggregate by light weight perlite.

4.7.2.2 Schmidt Hammer Test:

Table 4.17 (a) presents the experimental test results for Schmidt hammer test performed on the cube specimens for M-40 grade SCC with crushed sand and 20% fly ash dosage with varying perlite additions.

Table 4.17 (a): Summary of Schmidt Hammer test results for SCC mixes with CS and 20% fly ash for variation in perlite dosage

Mix Details	**Fly ash dosage (%)**	**Perlite dosage (%)**	**Schmidt Hammer test (MPa)**			
			3 days	**7 days**	**28 days**	**90 days**
Mix 1	0	--	13.97	17.40	23.80	27.69
Mix 2	20	0	11.70	14.30	18.73	21.80
Mix 3	20	2.5	11.60	13.34	17.56	18.94
Mix 4	20	5	11.30	13.03	17.53	18.23
Mix 5	20	7.5	11.00	12.34	16.74	17.27
Mix 6	20	10	11.00	12.29	15.50	16.35

Fig. 4.24 presents the graphical variation in the Schmidt hammer test results for the various mixes discussed above.

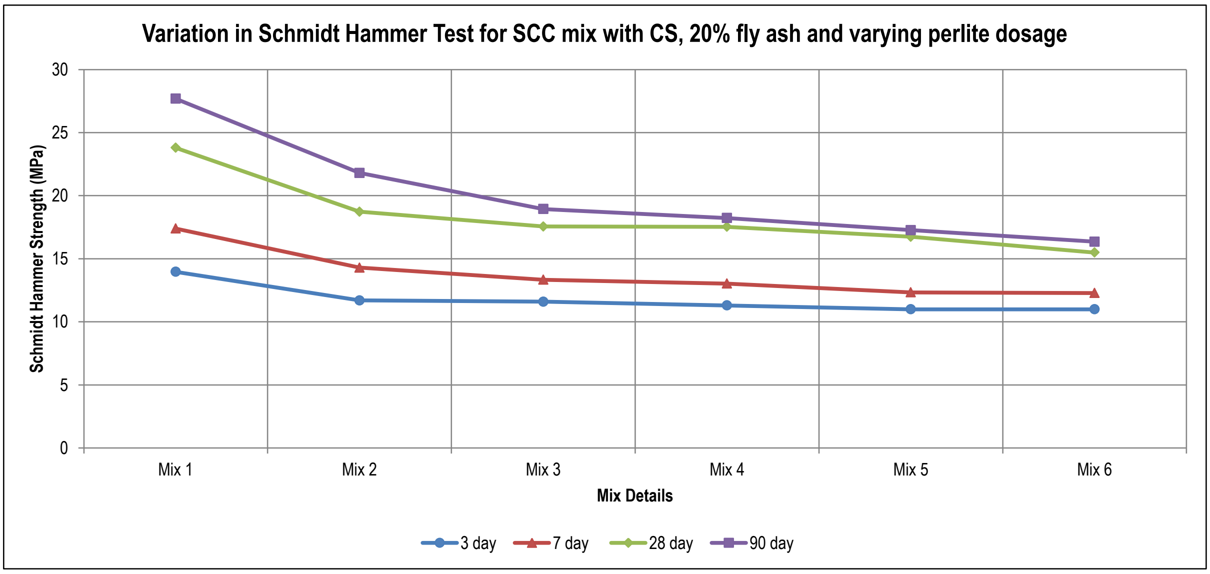


Fig. 4.24: Variation in Schmidt Hammer Test for SCC mixes with CS, 20% fly ash and varying perlite dosage

Table 4.17 (b) presents the % drop in the 28 day and 90 day Schmidt hammer test results in SCC mixes with varying perlite dosage when compared to the control mixes.

Table 4.17 (b): Comparison of 28 day and 90 day Schmidt hammer test for SCC mix with CS, 20% fly ash and varying perlite dosage with respect to the control mix

Mix Details	Fly ash dosage (%)	Perlite dosage (%)	% drop in 28 day Schmidt hammer test with respect to Mix 1	% drop in 90 day Schmidt hammer test with respect to Mix 1	% drop in 28 day Schmidt hammer test with respect to Mix 2	% drop in 90 day Schmidt hammer test with respect to Mix 2
Mix 1	0	0	--	--	--	--
Mix 2	20	0	21.30	21.27	--	--
Mix 3	20	2.5	26.22	31.60	7.01	13.12
Mix 4	20	5.0	26.35	34.16	7.18	16.38
Mix 5	20	7.5	29.66	37.63	11.67	20.78
Mix 6	20	10.0	34.87	40.95	18.74	25

From the above trend of results it can be inferred that,

1. With increasing perlite dosage, the magnitude of % drop in 28 day and 90 day Schmidt hammer test was more when compared to Mix 1.
2. Comparing to Mix 2, the magnitude of % drop in 28 day and 90 day Schmidt hammer test was relatively low. However at higher perlite dosage the % drop values were

significant, indicating that the addition of lightweight materials like fly ash and perlite decreases the overall density of the matrix phase in the concrete mix.

3. The % drop in the 28 day Schmidt hammer test results for perlite mixes was in line to the % drop observed for Mix 2.
4. The drop in the Schmidt hammer values indicated that the concrete cube surfaces were relatively less hard as compared to the cube surface of Mix 1.
5. For Mix 4 onwards, no major difference was observed in the 28 day and 90 day Schmidt hammer test results. This indicated that the addition of perlite did not have any significant contribution in development of hardened state properties of the SCC mix.

4.7.2.3 Ultrasonic Pulse Velocity:

Table 4.18 (a) presents the ultrasonic pulse velocity values measured for the cube specimens for various mixes considered in the perlite dosage trials.

Table 4.18 (a): Summary of Ultrasonic Pulse Velocity for SCC mixes with CS and 20% fly ash for variation in perlite dosage

Mix Details	Fly ash dosage (%)	Perlite dosage (%)	Ultrasonic Pulse Velocity (km/s)			
			3 days	7 days	28 days	90 days
Mix 1	0	--	3.97	3.99	4.21	4.30
Mix 2	20	0	3.65	3.73	3.94	4.01
Mix 3	20	2.5	3.58	3.69	3.89	3.91
Mix 4	20	5	3.53	3.63	3.81	3.86
Mix 5	20	7.5	3.48	3.59	3.77	3.83
Mix 6	20	10	3.48	3.51	3.67	3.80

Fig. 4.25 presents the graphical trend of the experimental values measured for the ultrasonic pulse velocity test.

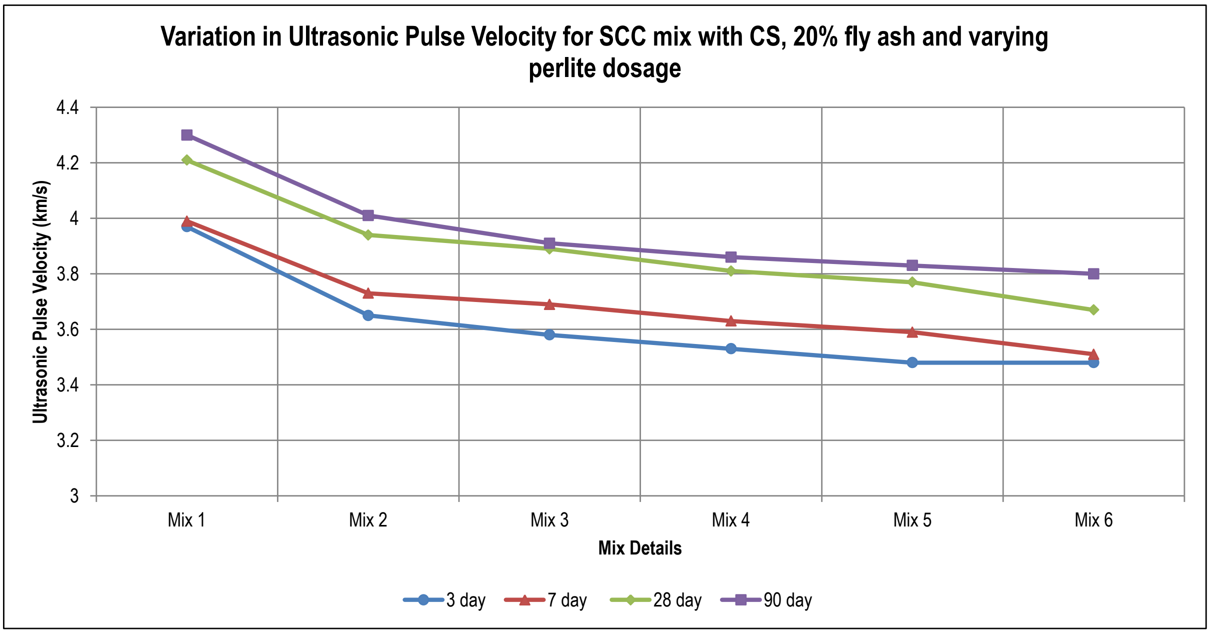


Fig. 4.25: Variation in Ultrasonic Pulse Velocity for SCC mixes with CS, 20% fly ash and varying perlite dosage

Table 4.18 (b) presents the comparative trend of % drop in the UPV values with variation in the perlite dosage.

Table 4.18 (b): Comparison of 28 day and 90 day Ultrasonic Pulse Velocity for SCC mix with CS, 20% fly ash and varying perlite dosage with respect to the control mix

Mix Details	Fly ash dosage (%)	Perlite dosage (%)	% drop in 28 day UPV with respect to Mix 1	% drop in 90 day UPV with respect to Mix 1	% drop in 28 day UPV with respect to Mix 2	% drop in 90 day UPV with respect to Mix 2
Mix 1	0	0	--	--	--	--
Mix 2	20	0	6.41	6.75	--	--
Mix 3	20	2.5	7.60	9.07	1.27	2.49
Mix 4	20	5.0	9.50	10.23	3.30	3.74
Mix 5	20	7.5	10.45	10.93	4.31	4.49
Mix 6	20	10.0	12.83	11.63	6.85	5.24

From the above set of results it was observed that,

1. The SCC mixes with varying perlite dosage were of good quality on comparing the ultrasonic pulse velocity values measured in the test with IS 13311 Part 1 recommendations.

2. As compared to the 28 day UPV values of Mix 1, there is a steep drop in the UPV values with increase in the perlite dosage. This indicates that the addition of perlite decreases the density of the paste matrix thereby leading to lower velocity values.
3. With the ageing process (90 days), there is a marginal drop in the UPV values when compared to the 28 day values for corresponding perlite mixes.
4. Comparing the UPV values of perlite mixes with Mix 2, the % drop values are relatively lower. But at higher perlite dosage these values % drop values increase significantly indicating that the perlite and fly ash addition decreases the density of the matrix phase.

4.7.2.4 Cube Compression Strength Test:

Table 4.19 (a) presents the summary of cube compression strength test for the cube specimens of SCC mixes with varying perlite dosage.

Table 4.19 (a) : Summary of cube compression strength test for SCC mixes with CS and 20% fly ash for variation in perlite dosage

Mix Details	Fly ash dosage (%)	Perlite dosage (%)	Cube Compressive Strength Test (MPa)			
			3 days	**7 days**	**28 days**	**90 days**
Mix 1	0	--	43.78	47.86	55.31	63.26
Mix 2	20	0	30.21	34.90	50.70	58.63
Mix 3	20	2.5	28.85	33.89	50.61	57.34
Mix 4	20	5	27.46	32.34	50.37	56.59
Mix 5	20	7.5	27.13	32.02	47.02	55.41
Mix 6	20	10	26.93	31.56	46.89	52.88

Fig. 4.26 presents the graphical pattern of the variation in the cube compressive strength for the SCC mixes with varying perlite dosage.

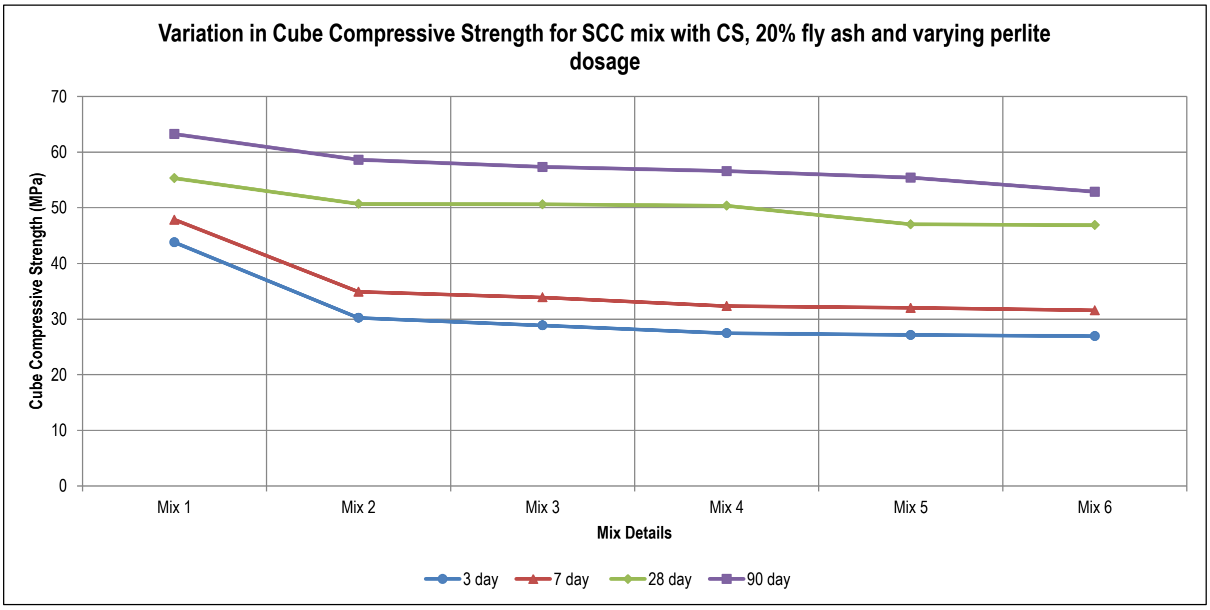


Fig. 4.26: Variation in cube compressive strength for SCC mixes with CS, 20% fly ash and varying perlite dosage

Table 4.19 (b) presents a trend of % drop in 28 day and 90 day cube compressive strengths for SCC mixes with varying perlite dosage in comparison to the control mixes.

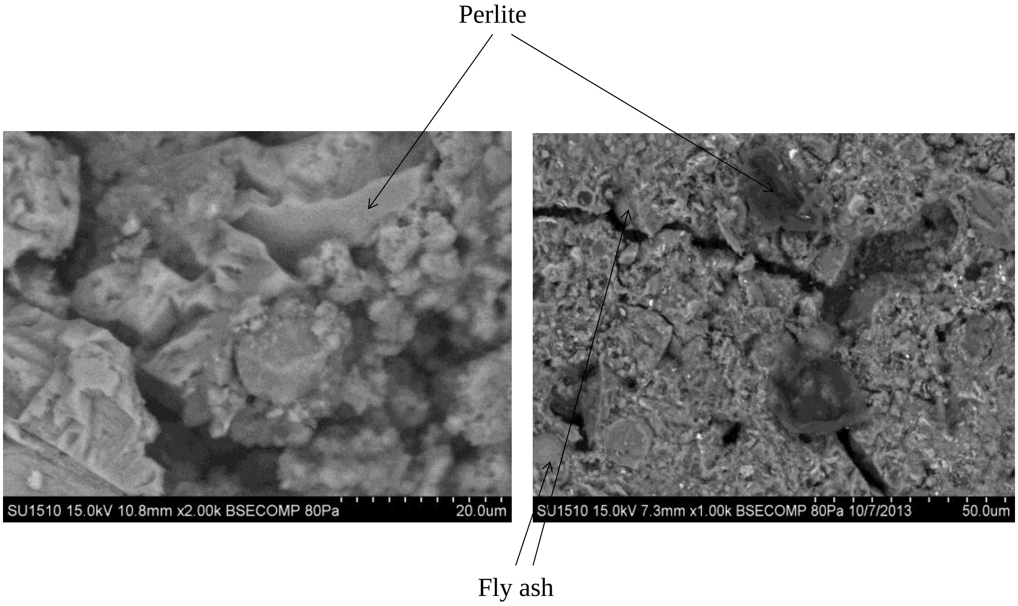
Table 4.19 (b): Comparison of 28 day and 90 day cube compression strength test results with control mix

Mix Details	Fly ash dosage (%)	Perlite dosage (%)	% drop in 28 day comp. str. with respect to Mix 1	% drop in 90 day comp. str. with respect to Mix 1	% drop in 28 day comp. str. with respect to Mix 2	% drop in 90 day comp. str. with respect to Mix 2
Mix 1	0	0	--	--	--	--
Mix 2	20	0	8.33	7.32	--	--
Mix 3	20	2.5	8.50	9.36	0.18	2.20
Mix 4	20	5.0	8.93	10.54	0.66	3.48
Mix 5	20	7.5	14.99	12.41	7.26	5.49
Mix 6	20	10.0	15.22	16.41	7.52	9.81

From the above trend of results it was observed that,

1. The cube compression strength for SCC mixes with perlite decrease with an increase in the perlite dosage.

2. The % drop in the 28 day cube compressive strength as compared to Mix 1 is relatively equal for Mix 2, 3 and 4. In case of Mix 5 (7.5% perlite dosage), the cube compressive strength drops significantly. Also the magnitude of the 28 day compressive strength (47.02 MPa) is less than the standard requirement of 48.25 MPa.
3. In comparison to Mix 1, the 90 day compressive strengths for the perlite mixes recover (lower values of % drop) due to the secondary hydration reaction on account of Class C fly ash addition in the mix.
4. In comparison to Mix 2, the % drop in the 28 day strength was insignificant upto 5% perlite dosage (Mix 4). However, a sharp drop in the strength values is observed at 7.5% dosage level.
5. The % drop in the 90 day compressive strength as compared to Mix 2 was steady upto 7.5% perlite dosage. On further increase in the dosage, a significant drop in the strength values was observed.
6. Fig. 4.27 presents SEM image of a representative sample having fly ash and perlite.



SCC mix with fly ash and perlite in the matrix phase

Fig. 4.27: SEM image of SCC mix with fly ash and perlite

From the microstructure image it can be deduced that the thickness of the matrix phase enveloping the aggregate particle is less which impacts the load carrying capacity of the matrix-aggregate composite. This was observed in case of SCC mix with higher perlite dosage (at 7.5% and 10% dosage level).

4.7.2.5 Beam Flexural Strength:

Table 4.20 (a) presents the summary of 7 day and 28 day beam flexural strength results.

Table 4.20 (a): Summary of beam flexural strength test for SCC mixes with CS and 20% fly ash for variation in perlite dosage

Mix Details	Fly ash dosage (%)	Perlite dosage (%)	Beam Flexural Strength Test (MPa)	
			7 days	28 days
Mix 1	0	--	6.74	7.34
Mix 2	20	0	5.00	6.54
Mix 3	20	2.5	6.53	7.93
Mix 4	20	5	6.87	8.34
Mix 5	20	7.5	6.83	7.87
Mix 6	20	10	6.00	7.60

Fig. 4.28 presents the graphical profile of the beam flexural strength test results.

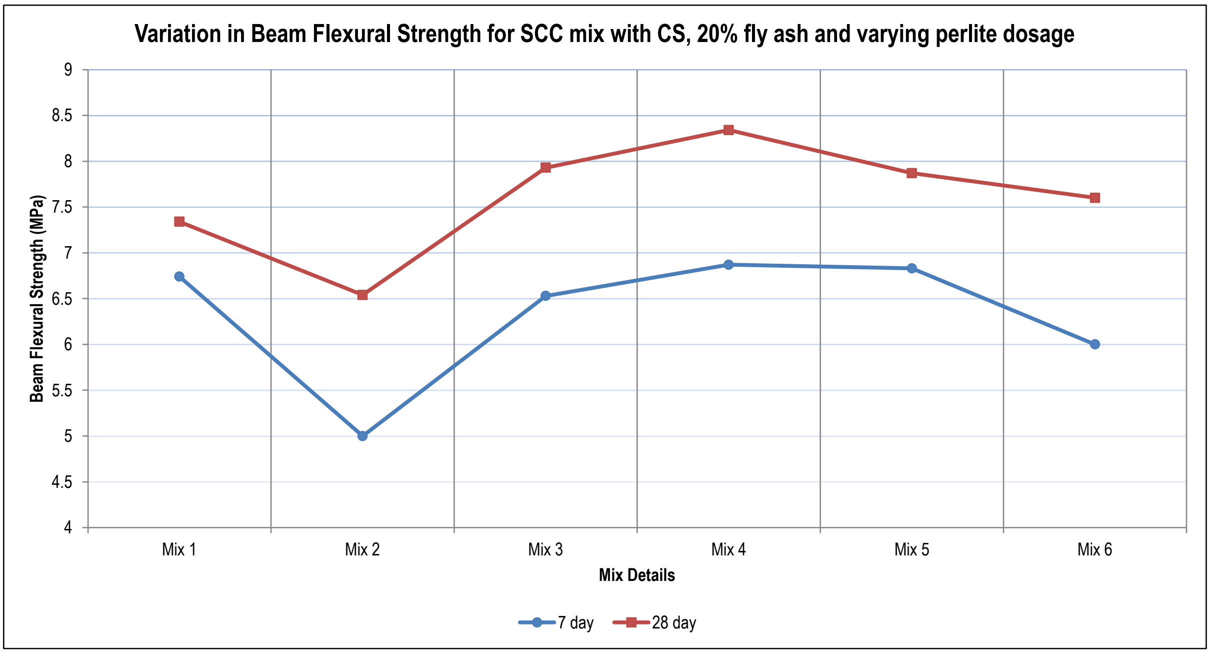


Fig. 4.28: Variation in beam flexural strength for SCC mixes with CS, 20% fly ash and varying perlite dosage

Table 4.20 (b) presents the % variation in beam flexural strength observed in the test specimen for SCC mixes with varying perlite dosage.

Table 4.20(b): Comparison of 7 day and 28 day beam flexural strength test results with control mix

Mix Details	Fly ash dosage (%)	Perlite dosage (%)	% changes in 7 day flex. str. with respect to Mix 1	% changes in 28 day flex. str. with respect to Mix 1	% changes in 7 day flex. str. with respect to Mix 2	% changes in 28 day flex. str. with respect to Mix 2
Mix 1	0	0	--	--	--	--
Mix 2	20	0	25.81 less	10.89 less	--	--
Mix 3	20	2.5	3.12 less	8.04 more	30.60 more	21.25 more
Mix 4	20	5.0	1.93 more	13.63 more	37.40 more	27.53 more
Mix 5	20	7.5	1.34 more	7.22 more	36.60 more	20.34 more
Mix 6	20	10.0	10.98 less	3.54 more	20 more	16.21 more

From the above test results it was observed that,

1. The addition of perlite as a fine aggregate replacement material improved the 7 day as well as 28 day flexural strength performance of the beam specimen when compared to Mix 1 and Mix 2 results.
2. As compared to the 28 day flexural strength values for Mix 1, the mixes with perlite dosages show slightly more 28 day flexural strength.
3. The 7 day flexural strength values of the SCC mix with perlite dosages are excessively high when compared to the 7 day flexural strength of Mix 2. This is due to the fact of incomplete hydration reaction on account of fly ash and perlite addition. The addition of fly ash, as a cement replacement material, retards the hydration reaction. The addition of perlite, as a fine aggregate replacement material, reduces the nucleation sites for hydration reaction. As a result the matrix is relatively soft and light weight imparting enough flexibility to the test section.
4. In case of comparison with Mix 2, the 28 day flexural strength values for the SCC mixes with perlite show substantially high values. This can be attributed to the light weight additions of fly ash and perlite that lower the density of the matrix phase. As a result the overall density of the hardened concrete is less and it becomes more flexible.

Thus from the above experimental trials, it was concluded that Mix 4, M-40 graded SCC mix with crushed sand having 20% Class C fly ash as a cement replacement and 5% perlite as a fine aggregate replacement, was the appropriate mix for perlite dosage to be adopted for further investigations. This combination of additives satisfied the 28 day flexural strength and 28 day compressive requirement prescribed by IRC 58:2011. This mix was termed as Mix C.

Thus, at the end of this trial, following mixes were finalized for the next stage of experiments;

1. Mix A: M-40 grade SCC with crushed sand having no additions.
2. Mix B: M-40 grade SCC with crushed sand, with 20% Class C fly ash as a cement replacement material.
3. Mix C: M-40 grade SCC with crushed sand, with 20% Class C fly ash as a cement replacement material and 5% perlite as a fine aggregate replacement material.

These mixes were considered for the next stage of experiments to determine the thermal conductivity. Cube specimens and slab sections corresponding to the above mentioned SCC mixes were prepared for measurement of the temperature gradient developed across the thickness of the specimen for varying environmental conditions. The details of these investigations are presented in the next chapter.

Chapter 5

EXPERIMENTAL INVESTIGATIONS (PART 3): MEASUREMENT OF THERMAL CONDUCTIVITY AND TEMPERATURE GRADIENT

In the previous chapter, based on the laboratory investigations of fresh state and hardened state properties, SCC mixes with various additives were finalized. These mixes were subjected to experimental investigations to determine their thermal properties. In the present chapter, the laboratory procedure to measure the thermal conductivity (k) values of the three SCC mixes has been discussed in the initial part. The next section discusses the detailed procedure adopted for measurement of temperature gradient developed across cube specimen and slab sections for the proposed three SCC mixes. The results obtained for particular case studies have been discussed in detail. The experimental values of the temperature, measured in the cube specimen and slab section, were validated using the Choubane Tia Model and Fourier Biot Equation.

5.1 Thermal conductivity studies:

As discussed in Chapter 2, the objective of the research project is to study the response of SCC as a pavement material to environmental loads (temperature). The temperature studies of any material and its response depends on its thermal properties and the temperature gradient. The thermal properties of concrete influence its durability, fire resistance property and development of temperature related stresses. The thermal properties like specific heat, coefficient of thermal expansion and thermal conductivity of the concrete specimen bear a significant impact on the application of the concrete in a particular environment. In the present study, of all the thermal properties listed above, thermal conductivity of the three SCC mixes (Mix A, Mix B and Mix C) were measured.

Thermal conductivity (k) of a material is its ability to conduct heat. It is a specific property of the material and is a measure of the rate at which the heat passes perpendicularly through a unit area of a homogenous material of unit thickness for a temperature difference of one degree. The k value of concrete is a time dependent property, influenced by the variation in temperature as well as boundary conditions (Howlader et al. 2012). Depending on the application of concrete a specific thermal conductivity value is desired. Concrete having application as an insulating material (furnace walls) require a low k value. A high k value for concrete is desirable for reducing thermal stresses developed on account of temperature differential across the concrete cross section (pavement applications). The k value of concrete depends on its composition and structure (Tuson et al. 2012). It governs the rate of heat flow through the concrete. The k value of concrete is influenced by mineralogical character of aggregates, cement content, water content, air void content and ambient moisture and temperature conditions (Wang et al. 2008).

The k values of concrete can be measured in the laboratory either by steady state or unsteady (transient) state method (Bindiganavile et al. 2012). Steady state methods are adopted for homogeneous materials. In this method, the flux is proportional to the temperature gradient along the direction of flow. The experimental procedures are time consuming. However, the thermal conductivity values obtained by this method are accurate. The methods of steady state thermal conductivity analysis include, guarded hot plate method, unguarded hot plate method and cylindrical probe method to name a few. The transient analyses are the non-steady methods adopted for heterogeneous materials with moisture. Though the test procedures are relatively fast, the accuracy of the k value is less. The common methods adopted for transient analysis are laser flash method, step method, transient line, transient strip and transient plane method.

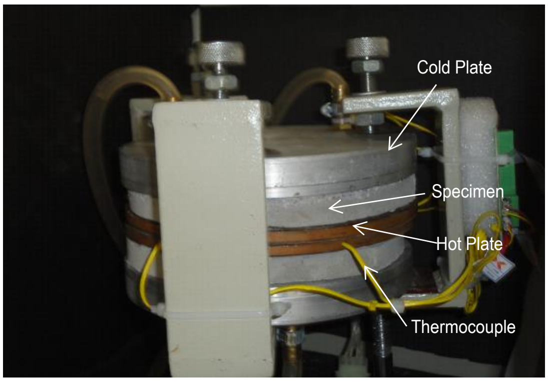
In the present study, the k values of the SCC mixes have been determined by the steady state method using two slab guarded hot plate method. In the steady state method, the heat flux is proportional to the temperature gradient developed in the direction of flow. This constant of proportionality is known as thermal conductivity (Callister, 2007). The two slab guarded hot plate method (IS 3346:1980 and ASTM C177:2013) was used to determine k values of the test specimens as recommended in ACI 122R:2002. This is a commonly used test method for measuring thermal conductivity of cement concrete for pavement applications (Wang et al. 2008).

5.1.1 Guarded Hot Plate Method for Thermal Conductivity Measurement:

Fig. 5.1 represents the guarded hot plate method for the measurement of k values of the SCC mixes.

IS 3346:1980 and ASTM C177:2013, specifies the test procedure for laboratory measurement of the steady state heat flux through flat, homogenous specimens with their specimens in contact with solid, parallel boundaries held at constant temperature using the guarded hot plates.

Concrete Specimen for k value measurement



Two Slab Guarded Hot Plate Method

Fig. 5.1: Two slab guarded hot plate method and specimens used for k value measurement

In the test setup, the heat flux is applied to two identical specimens (180 mm dia. and 16 mm thick) held between the hot and cold plates, ensuring unidirectional heat flow through the specimen. Thermocouples were provided to measure the temperature at each face of the specimen. The heat transferred through the specimen was equal to the power supplied to the heater. Thermal equilibrium (steady state) was achieved when the temperature and voltage observations remained constant. The stabilization time depends on the apparatus, control system, test temperatures and the thermal diffusivity and thickness of the specimen. In the present study, the average stabilization time observed was 30 minutes to 45 minutes. The observations were recorded at an interval not less than 30 minutes, until four successive observations gave the k values differing not more than 1%. The specimens were cured for 28 days in curing tank and air dried before the test.

The k values were measured at three temperature ranges 30^oC-40^oC, 40^oC-50^oC and 50^oC-60^oC. The said temperature ranges were adopted based on the fact that the concrete pavement surface would be subjected to these temperature ranges throughout the day for its entire service life. Tuson et al. (2012) have reported that the k values of concrete have not been evaluated at normal service temperature. It was further observed that most of the research studies have determined the k value using transient methods and for temperatures excess of 200^oC. The objective of these studies was to assess the fire resistance of the concrete mix.

In the present study, two identical test specimens of 180 mm diameter and 16 mm thickness were prepared corresponding to the three SCC mixes, from the same batch of concrete used for testing of the mechanical properties. The specimens were cured for 28 days.

Table 5.1 presents the k values determined for the three SCC mixes for the temperature range listed above.

Table 5.1: Thermal conductivity values for SCC mixes with various powder additives

Mix Details	Density of the concrete mix (kg/m³)	Thermal Conductivity (k) W/m/°C		
		30°C – 40°C	40°C – 50°C	50°C – 60°C
Mix A	2439.51	3.115	2.554	1.800
Mix B	2396.72	2.879	2.197	1.652
Mix C	2386.22	2.355	1.944	1.498

Fig. 5.2 presents the graph for experimental results obtained for the thermal conductivity investigations.

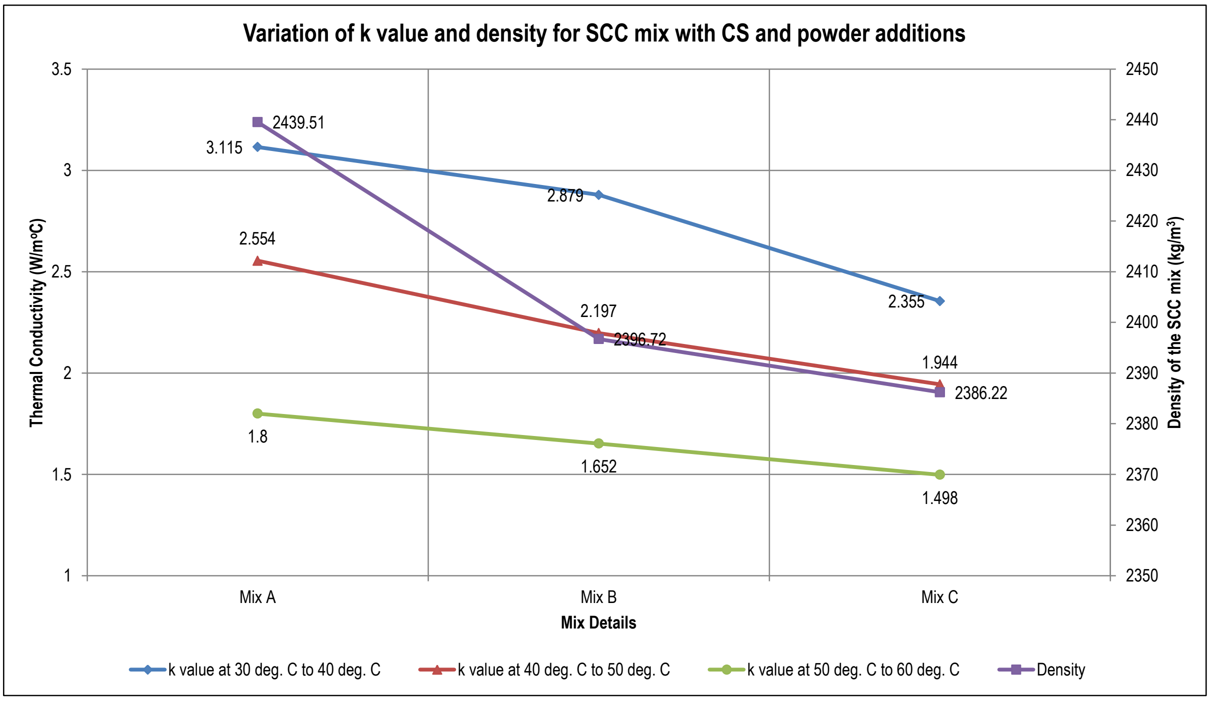


Fig. 5.2: Variation in thermal conductivity (k) values and density for SCC mixes with CS and powder additions

From the above test results the following points were inferred;

1. With an increase in the test temperature, the k values of all mixes decreased.
2. As compared to the k values of Mix A, the k values of Mix B and Mix C were 7.58% and 25.04% lower at a test temperature of 30°C to 40°C. At 40°C to 50°C, the k values were 13.98% and 23.88% lower while, at 50°C to 60°C the k values were 8.23% and 16.78% lower, when compared to the k values of Mix A.
3. The k values at test temperature of 30°C to 40°C were highest as compared to the k values at other temperature range for all the three mixes. This is due to the presence of

physically bound moisture present at the microstructure level. Though completely dried specimens were used, some amount of capillary moisture influences the k value.

4. With an increase in the temperature, the residual moisture if present in the concrete specimen evaporates. Thus, the voids in the specimen occupied by water are now occupied by air. As air is a poor conductor of heat, the air voids lead to reduction in the k value.
5. The k value is also dependent on the mix composition. Mix A does not have any powder additions. Also the matrix phase in Mix A is denser leading to overall high density of Mix A.. Thus, the k value of Mix A is high as compared to the other two mixes.
6. The addition of fly ash in Mix B, led to reduction in the density of the matrix phase of the SCC mix. This lowered the overall density of the SCC mix, in turn reducing the k value of Mix B.
7. Mix C had fly ash as well as perlite as additives. The addition of the two insulating materials led to substantial reduction in the k value of Mix C.
8. The reaction between cement and powder additions creates a thermal barrier which increases thermal resistance, thereby reducing the k value.

5.2 Temperature gradient studies:

The temperature difference between the top and bottom of the concrete pavement slab develops a gradient leading to tensile stresses in the pavement. The objective of this project was to assess the temperature gradient developed over a laboratory prototype of a pavement slab made using SCC. From the experimental investigations undertaken, it was observed that SCC mixes with CS (Mix A) had better strength performance as compared to NS mixes. Further, the influence of powder additives like fly ash (Mix B) and perlite (Mix C) on the development of temperature gradient for SCC mix with CS was also investigated. This section presents the experimental process adopted for the temperature gradient studies.

The experimental study was undertaken on 15 cm cube specimens corresponding to the three SCC mixes (Mix A, B and C). Also, three slabs of 30 cm thickness, corresponding to the three mixes, were cast on a 10 cm thick Dry Lean Concrete (DLC) layer. The DLC had an average 7 day compressive strength of 25 MPa.

Due to limitations of space and infrastructure, the plan dimensions of the slabs were reduced. A normal concrete pavement slab has a plan dimension of 5.5 m x 3.5 m. The aspect ratio (l/b) for this geometry works out to be 1.57. Using this aspect ratio, the plan dimension of the laboratory prototype adopted for the three slabs was 1 m x 0.63 m.

Fig. 5.3 (a), (b) and (c) present the stages in slab construction procedure.

(i) Site Clearance

(ii) Leveling

(iii) Compaction

Fig. 5.3 (a): Site clearance and preliminary operations

(i) Formwork layout for DLC

(ii) Casting of DLC

(iii) Covering of freshly laid DLC layer

(iv) Curing of DLC layer

Fig. 5.3 (b): Formwork setup, casting, curing and covering of DLC layer

(i) Formwork layout for SCC with sensors

(ii) Freshly cast SCC

(iii) Curing of SCC Slab

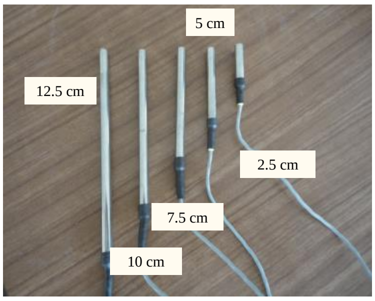
(iv) Sensor and Data Logger unit fixed to slab

Fig. 5.3 (c) : Formwork setup with sensors, casting, curing and data recording of SCC slab section

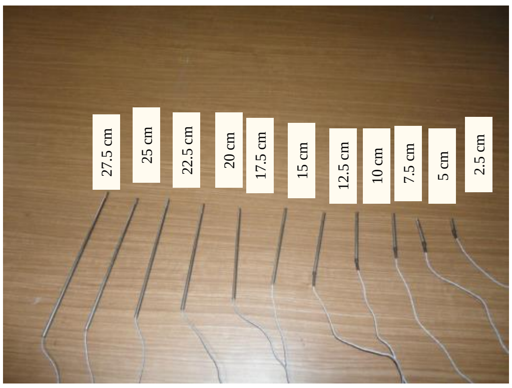
5.2.1 Test Setup for the experimental study:

The temperature gradient developed across the specimen cross section was measured using Resistance Temperature Detector (RTD) sensors. RTDs of varying lengths were adopted for the cube specimen as well as slab sections. The temperatures were recorded at every 2.5 cm depth measured from the top of the cube and slab respectively. Along with the respective RTD sensors embedded in the cube specimen and slab section, the surface temperature was recorded using sticker sensors attached on the cube and slab surface respectively. Fig. 5.4 presents the various RTD sensors used in the present experimental study.

(i) Sticker Sensors



(ii) RTD Sensors for cube specimen



(iii) RTD Sensors for slab section

Fig. 5.4: RTD Sensors used in the experimental study

The sensors were embedded in the respective specimen during the plastic state (fresh state). Fig. 5.5 shows the layout of the sensors placed in the cube specimen, while Fig. 5.6 shows the layout of the RTD sensors in the slab section.

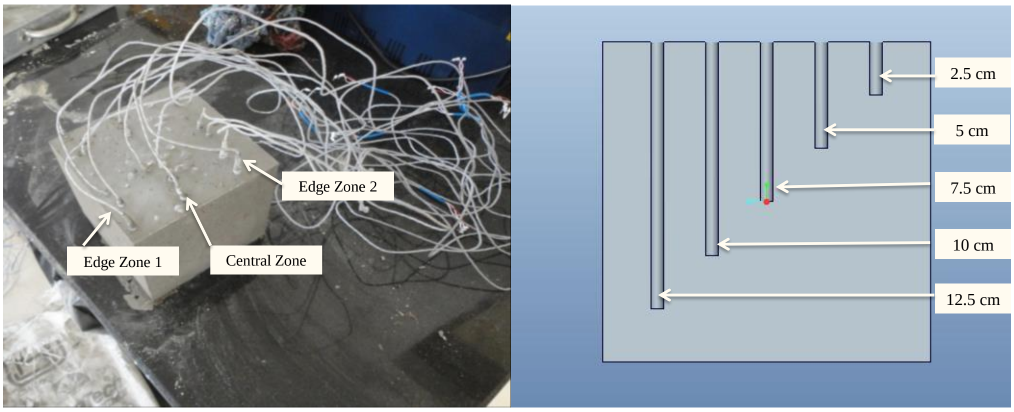


Fig. 5.5: RTD Sensor arrangement in the cube specimen

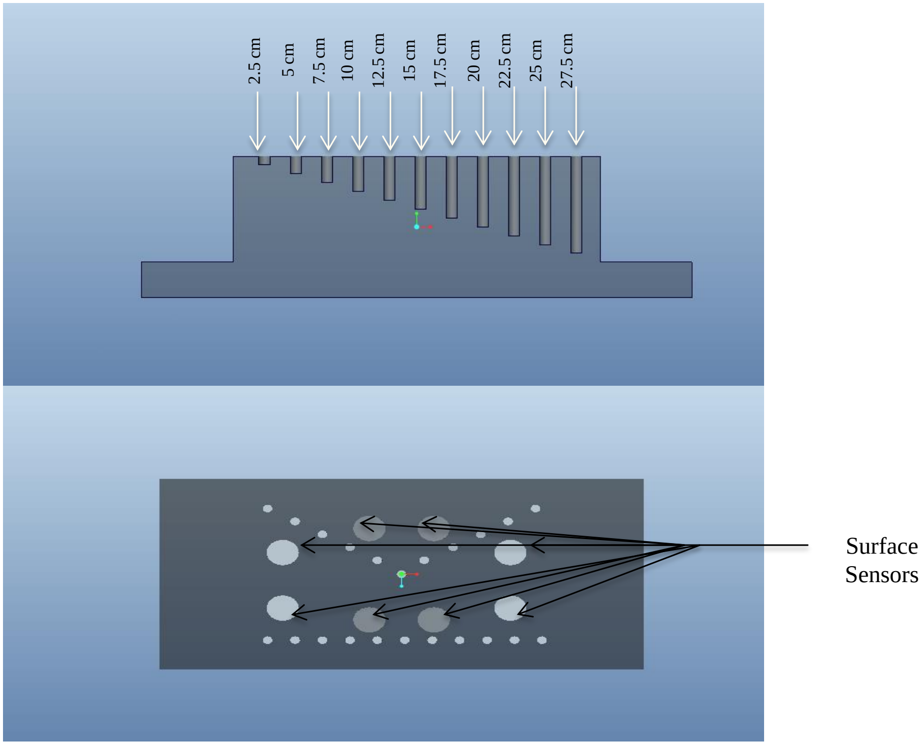


Fig. 5.6: RTD Sensor arrangement in slab section

The sensors were in turn attached to a 16-channel data logger. The data logger scanned and saved the temperature recorded by the sensors at an interval of 60 seconds. The data logger had an on-board memory for storing 3000 observations. The temperature data recorded in the loggers was retrieved at every 48 hour interval.

Fig. 5.7 (a) & (b) presents the instrumented test setup for measurement of temperature gradient across cube specimens for all the three concrete mixes.

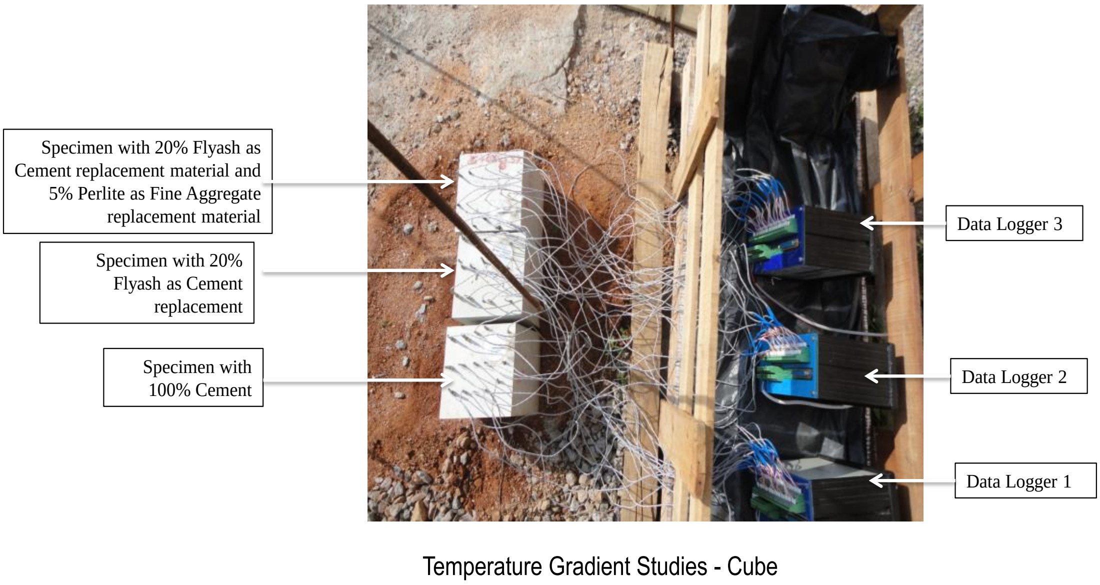


Fig. 5.7 (a) : Test setup for measurement of temperature gradient in cube specimen

Fig. 5.7 (b): Test setup for measurement of temperature gradient in slab section

5.2.2 Case Considerations:

A concrete pavement is subjected to varying environmental conditions in its service life. In the present study, the cube specimens were subjected to the temperature gradient measurement for a period of 180 days. The slab sections were investigated for temperature gradient studies for a period of 32 days. Table 5.2 (a) presents the specific cases considered for the temperature gradient measurement of cube specimen.

Table 5.2 (a): Case considerations for the Temperature Gradient Studies for the cube specimen

S. No.	Case Detail	SCC Concrete Mix		
		Mix A	**Mix B**	**Mix C**
Period for observations		4 October 2013 to 1 May 2014	8 October 2013 to 1 May 2014	10 October 2013 to 1 May 2014
1.	Max. Ambient Air Temp.	28 to 29 April 2014	28 to 29 April 2014	28 to 29 April 2014
2.	Min. Ambient Air Temp.	13 to 14 November 2013	13 to 14 November 2013	13 to 14 November 2013
3.	24 hours. Precipitation	23 to 24 October 2013	25 to 26 October 2013	25 to 26 October 2013
4.	Part humid and part rainy condition	22 to 23 October 2013	26 to 27 October 2013	22 to 23 October 2013
5.	24 hour cloudy and humid condition	1 to 2 November 2013	1 to 2 November 2013	1 to 2 November 2013
6.	2 hr. sudden precipitation	9 to 10 October 2013	9 to 10 October 2013	10 to 11 October 2013

For the case of maximum ambient air temperature, the temperature record obtained from the institute weather station was 39^{o}C. Corresponding to this temperature, the maximum cube surface temperature recorded for Mix A, Mix B and Mix C was 54.90^{o}C, 58.16^{o}C and 51.08^{o}C respectively. Similarly, for the minimum ambient air temperature of 17.3^{o}C, the minimum temperature recorded on the surface of the cube was 15.13^{o}C, 14.9^{o}C and 15.35^{o}C respectively for Mix A, Mix B and Mix C respectively. Adequate precautions for the data loggers were taken for recording the temperature during precipitation.

Table 5.2 (b) presents the cases considered for slab section. For the slab section, 24 hr. precipitation observation was not recorded. During the time span of 32 days, only 4 hours precipitation was recorded in March 2014 and the observations for the same were recorded and analysed. For the case of maximum ambient air temperature, the value obtained from the weather station was 41^{o}C, 39^{o}C and 37^{o}C for Mix A, Mix B and Mix C respectively. The corresponding maximum slab surface temperature recorded for the three mixes were 50.39^{o}C, 51.39^{o}C and 52.51^{o}C respectively. For the case of minimum ambient air temperature of 19^{o}C, 19^{o}C and 17^{o}C for Mix A, Mix B and Mix C respectively, the minimum slab surface temperatures recorded for the respective slabs were 17.60^{o}C, 16.59^{o}C and 16.58^{o}C. In case of

Mix C, the minimum ambient air temperature and 4 hour precipitation observation were recorded on the same day i.e. 4 to 5 March 2014.

Table 5.2 (b): Case considerations for the Temperature Gradient Studies for the slab section

S. No.	Case Detail	SCC Concrete Mix		
		Mix A	**Mix B**	**Mix C**
Period for observations		23 January 2014 to 1 May 2014	25 January 2014 to 3 May 2014	27 January 2014 to 5 May 2014
1.	Max. Ambient Air Temp.	23 to 24 April 2014	02 to 03 April 2014	22 to 23 April 2014
2.	Min. Ambient Air Temp.	23 to 24 February 2014	25 to 26 February 2014	04 to 05 March 2014
3.	Part humid and part rainy condition (4 hrs. of precipitation)	17 –18 April 2014	02 – 03 March 2014	04 – 05 March 2014
4.	24 hr. cloudy and humid conditions	07 – 08 March 2014	09 – 10 March 2014	05 – 06 March 2014

The temperature observations recorded in the cube specimen and slab sections were analysed with the Choubane Tia model and Fourier Biot Eqn. analysis. The trend of temperature variations for various case considerations and the comparison of experimental observations with the temperature values obtained from the two models are discussed in the following section.

5.3 Analysis of Temperature Gradient studies:

The curling stress developed in the cement concrete pavement section depends on the temperature gradient developed between the top and bottom surfaces of the pavement slab. The temperature distribution is transient in nature i.e. its magnitude changes with time.

As discussed in the preceding section, the temperature distribution across cube specimen and slab section corresponding to the three SCC mixes (viz. Mix A, Mix B and Mix C) for the specific case studies was measured. The temperatures are measured with the help of RTD sensors of varying length embedded in the respective cube and slab specimens. The temperature data at every 2.5 cm depth in the section was recorded using a 16 channel data logger

.

As per literature studies (Choubane et al. 1995), the temperature profile across the depth of the pavement slab can be determined by the Choubane Tia equation as;

$$T(z) = A + Bz + Cz^2 \tag{5.1}$$

where;

z: distance from the bottom of the slab.

A, B and C: regression coefficients based on measured slab temperature profile.

$$A = T_{bot} \tag{5.2}$$

$$B = \frac{4T_{mid} - 3T_{bot} - T_{top}}{h} \tag{5.3}$$

$$C = \frac{2(T_{bot} + T_{top} - 2T_{mid})}{h^2} \tag{5.4}$$

where;

T_{top}, T_{mid} and T_{bot} are temperatures at top, middle and bottom of the slab.

h: slab thickness.

Further, as per Liu et al. (2000), the temperature distribution across pavement thickness is governed by Fourier-Biot heat conduction equation as mentioned below,

$$\frac{\partial^2 T}{\partial z^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} = \frac{1}{\frac{k}{\rho c}}\frac{\partial T}{\partial t} \tag{5.5}$$

where;

α: thermal diffusivity coefficient of the material, T: Temperature, k: thermal conductivity of material, ρ: density of material, c: specific heat of material, z: depth of the layer or thickness of section.

Assuming a constant heat flux, the solution for the above equation is;

$$T = T_i + \frac{2q_o\sqrt{\frac{\alpha\tau}{\pi}}}{kA} exp\left(\frac{-z^2}{4\alpha\tau}\right) - \frac{q_o z}{kA}\left(1 - erf\,\frac{z}{2\sqrt{\alpha\tau}}\right) \tag{5.6}$$

where,

T: temperature (^oC)

T_i: initial temperature (^oC)

z: distance or depth (m)

α: thermal diffusivity (m^2/s)

τ: time (s)

q_o/A: surface heat flux (W/m^2)

k: thermal conductivity ($W/m^o C$)

Apart from the numerical determination of the temperature profile, an attempt to determine the temperature distribution using finite element simulation model was undertaken. ANSYS software package was used for the study. 20-node brick element, with SOLID 90 geometry was adopted for thermal transient module. The hourly temperature profiles obtained using ANSYS simulation have been tabulated in the experimental result table.

Important properties of the SCC mixes, adopted in the present study, considered in numerical analysis are tabulated below.

Table 5.3: Properties of SCC mixes considered for numerical analysis

Property	Mix A	Mix B	Mix C	Remarks
Density (kg/m^3)	2439.51	2396.72	2386.22	28 day cured density measured experimentally.
Thermal Conductivity (W/m^o C)	3.115	2.879	2.355	Measured at 30^{o}C – 40^{o}C
	2.554	2.197	1.944	Measured at 40^{o}C – 50^{o}C
	1.800	1.652	1.498	Measured at 50^{o}C – 60^{o}C
Coefficient of convective heat transfer (W/m^2 ^{o}C)	25			Assumed (Neville, 2010)
Specific heat capacity of concrete (J/g^{o}C)	0.88			Assumed (Neville, 2010)

5.4 Results for Temperature Gradient Studies on Cube Specimen:

Table 5.4 presents a representative result table for the temperature values measured experimentally, computed using the two equations (Choubane Tia model and Fourier Biot equation) and from the FEA simulation at various depths for 15 cm cube specimen.

Fig. 5.8 presents representative comparative plot of the measured and computed temperature values, while Fig. 5.9 presents the X-Y Scatter plot for temperature values measured experimentally and computed numerically at various depths for a particular case study. The results table and corresponding graphs related to other specific case studies for 15 cm cube specimen are appended as Appendix A.

Table 5.4 (a): 24 hr. cube temperature values (measured and calculated) for Mix A for maximum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (^{o}C) at 2.5 cm				Temperature (^{o}C) at 5 cm				Temperature (^{o}C) at 7.5 cm			
		(^{o}C)	(^{o}C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	0930 to 1030	35	37.03	33.52	34.02	33.79	33.66	31.79	32.08	31.20	31.49	31.21	31.21	31.15	31.18
2	1030 to 1130	37	43.70	38.25	39.65	38.85	38.55	36.31	36.78	36.57	36.44	35.08	35.08	35.45	35.26
3	1130 to 1230	38	50.41	43.47	46.10	43.95	43.71	41.22	42.70	41.61	41.41	40.18	40.18	40.46	40.32
4	1230 to 1330	39	53.64	46.70	49.84	47.16	46.93	44.74	46.58	45.33	45.04	43.87	43.87	43.87	43.87
5	1330 to 1430	39	54.90	48.62	51.93	48.95	48.78	47.03	49.08	47.60	47.32	46.36	46.36	46.46	46.41
6	1430 to 1530	39	54.25	49.15	52.25	50.56	49.86	48.02	50.03	48.77	48.39	47.59	47.59	47.98	47.79
7	1530 to 1630	38	49.68	48.11	49.83	47.25	47.68	47.69	49.14	47.17	47.43	47.61	47.61	47.19	47.40
8	1630 to 1730	37	43.16	44.44	45.23	44.80	44.62	45.02	46.06	42.20	43.61	45.66	45.66	45.04	45.35
9	1730 to 1830	36	40.04	41.47	42.20	40.80	41.13	42.21	43.22	40.20	41.21	43.12	43.12	43.76	43.44
10	1830 to 1930	34	36.75	38.67	39.25	38.62	38.65	39.63	40.56	38.44	39.04	40.69	40.69	40.29	40.49
11	1930 to 2030	33	35.19	36.68	37.27	36.14	36.41	37.48	38.38	37.21	37.34	38.50	38.50	38.24	38.37
12	2030 to 2130	32	34.02	35.38	35.90	35.15	35.27	36.05	36.88	36.23	36.14	36.99	36.99	36.26	36.62
13	2130 to 2230	31	32.73	34.18	34.59	34.12	34.15	34.79	35.59	35.18	34.98	35.73	35.73	35.20	35.47
14	2230 to 2330	30	31.44	32.88	33.29	32.09	32.48	33.53	34.31	34.14	33.84	34.49	34.49	34.15	34.32
15	2330 to 0030	29	30.50	31.82	32.24	31.13	31.48	32.43	33.18	33.20	32.82	33.33	33.33	33.23	33.28
16	0030 to 0130	28	29.75	30.95	31.44	30.15	30.55	31.53	32.33	32.24	31.88	32.44	32.44	32.26	32.35
17	0130 to 0230	28	28.51	29.92	30.22	29.03	29.48	30.56	31.21	31.05	30.80	31.48	31.48	31.05	31.27
18	0230 to 0330	27	27.51	28.96	29.27	28.03	28.49	29.61	30.29	30.04	29.82	30.57	30.57	30.04	30.31
19	0330 to 0430	26	27.04	28.32	28.67	28.06	28.19	28.85	29.58	29.09	28.97	29.77	29.77	29.10	29.43
20	0430 to 0530	26	26.65	27.80	28.11	27.04	27.42	28.34	28.95	28.07	28.20	29.16	29.16	29.07	29.11
21	0530 to 0630	27	26.33	27.37	27.57	27.14	27.25	27.86	28.36	28.10	27.98	28.70	28.70	28.07	28.39
22	0630 to 0730	29	26.12	26.99	27.00	25.57	26.28	27.42	27.73	27.40	27.41	28.29	28.29	28.27	28.28
23	0730 to 0830	31	27.46	27.43	27.50	26.74	27.09	27.54	27.77	27.23	27.39	28.25	28.25	28.82	28.54
24	0830 to 0930	34	33.02	30.17	30.85	30.68	30.43	29.19	29.62	29.30	29.24	29.32	29.32	29.21	29.26

Table 5.4 (b): 24 hr. cube temperature values (measured and calculated) for Mix A for maximum ambient air temperature at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (ºC) at 10 cm				Temperature (ºC) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn	ANSYS
1	0930 to 1030	30.36	31.41	30.77	30.57	30.22	32.67	30.62	30.42
2	1030 to 1130	33.94	34.55	33.29	33.61	33.27	35.19	33.87	33.57
3	1130 to 1230	39.01	38.56	39.95	39.48	38.03	37.83	38.20	38.12
4	1230 to 1330	42.77	41.70	43.17	42.97	41.99	40.08	41.29	41.64
5	1330 to 1430	45.29	43.78	45.95	45.62	44.76	41.32	44.20	44.48
6	1430 to 1530	46.57	44.94	46.69	46.63	46.01	42.08	46.09	46.05
7	1530 to 1630	46.73	45.25	47.13	46.93	46.25	42.04	46.78	46.51
8	1630 to 1730	45.19	44.01	45.23	45.21	45.13	41.12	45.70	45.41
9	1730 to 1830	42.88	41.88	42.46	42.67	43.17	39.51	43.26	43.22
10	1830 to 1930	40.57	39.64	40.20	40.38	41.07	37.41	41.11	41.09
11	1930 to 2030	38.44	37.65	38.22	38.33	39.07	35.81	39.19	39.13
12	2030 to 2130	36.91	36.21	36.24	36.58	37.56	34.55	37.21	37.39
13	2130 to 2230	35.65	35.02	35.19	35.42	36.30	33.44	36.16	36.23
14	2230 to 2330	34.43	33.83	34.14	34.29	35.09	32.33	35.12	35.10
15	2330 to 0030	33.28	32.68	33.21	33.25	34.01	31.24	34.18	34.10
16	0030 to 0130	32.38	31.75	32.24	32.31	33.03	30.27	33.21	33.12
17	0130 to 0230	31.44	31.04	31.05	31.24	32.20	29.88	32.04	32.12
18	0230 to 0330	30.56	30.12	30.04	30.30	31.28	28.93	31.03	31.16
19	0330 to 0430	29.75	29.23	29.09	29.42	30.52	27.98	30.08	30.30
20	0430 to 0530	29.11	28.73	29.07	29.09	29.88	27.68	30.06	29.97
21	0530 to 0630	28.65	28.59	28.05	28.35	29.32	28.02	30.03	29.68
22	0630 to 0730	28.23	28.69	28.18	28.21	28.90	28.93	29.11	29.00
23	0730 to 0830	28.11	28.95	27.55	27.83	28.76	29.87	28.32	28.54
24	0830 to 0930	28.92	29.94	28.48	28.70	29.30	31.51	29.86	29.58

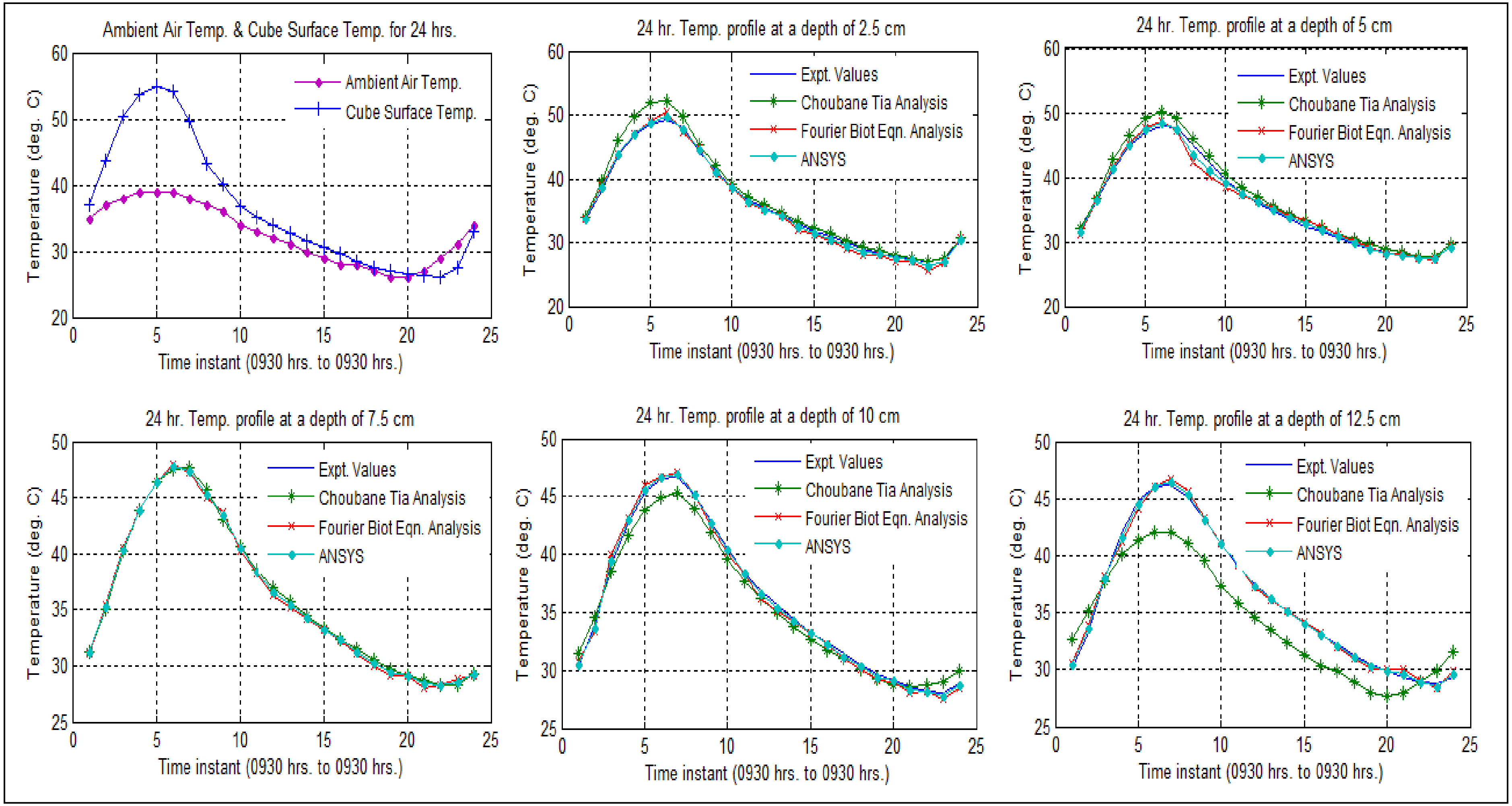


Fig. 5.8 : 24 hour cube temperature profile (measured and calculated) at various depths for Mix A for maximum ambient air temperature

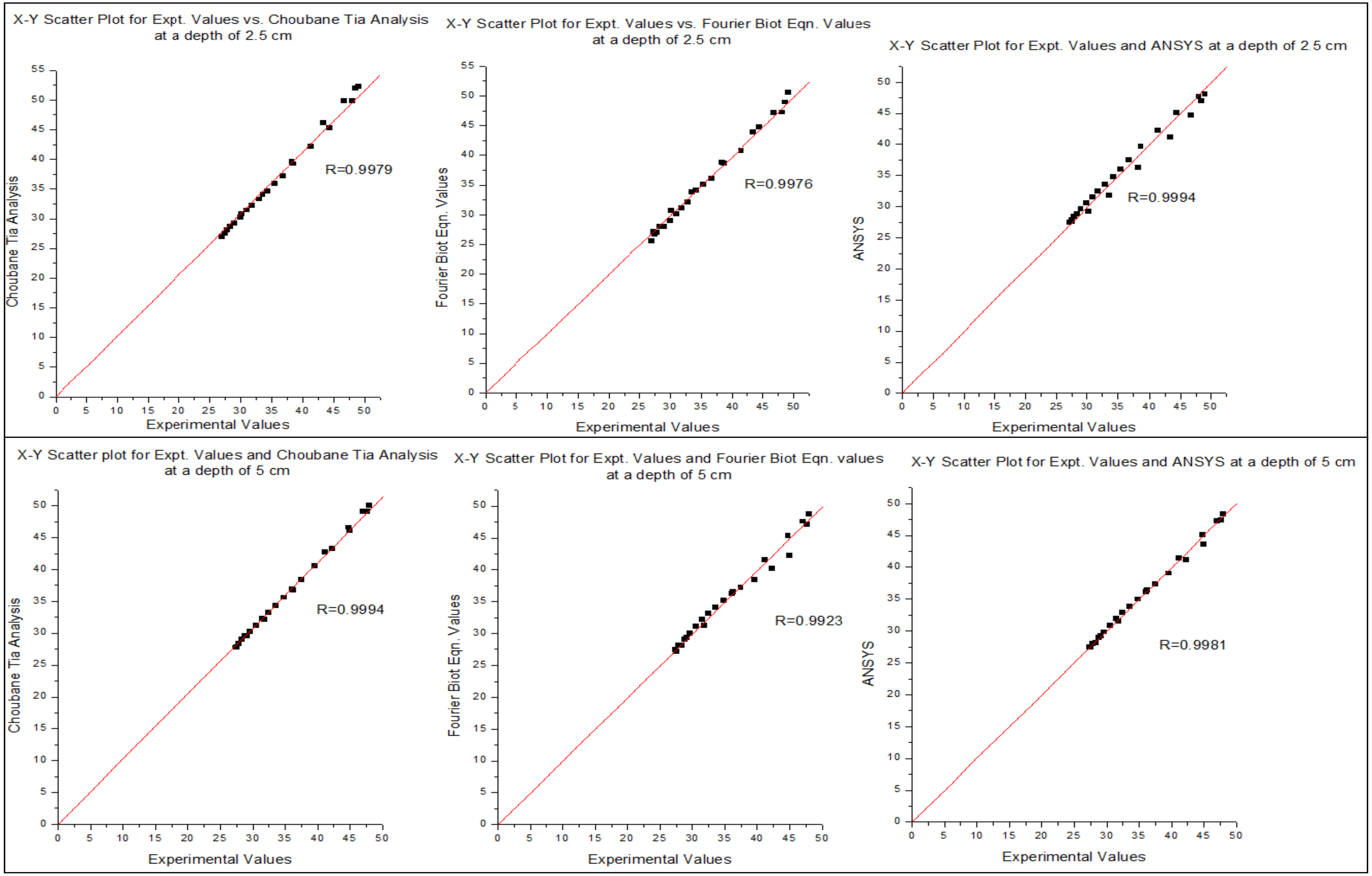


Fig. 5.9 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

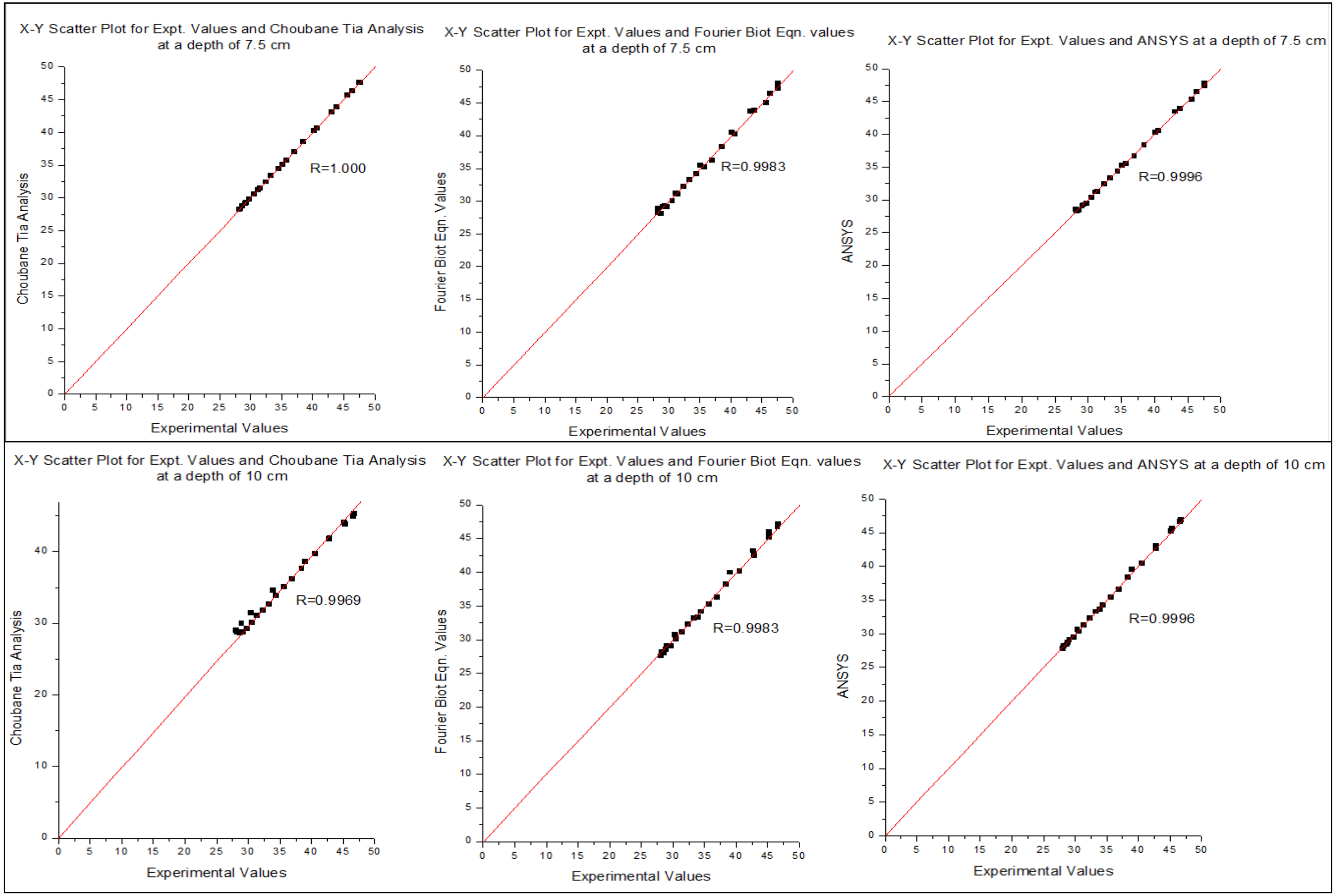


Fig. 5.9 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

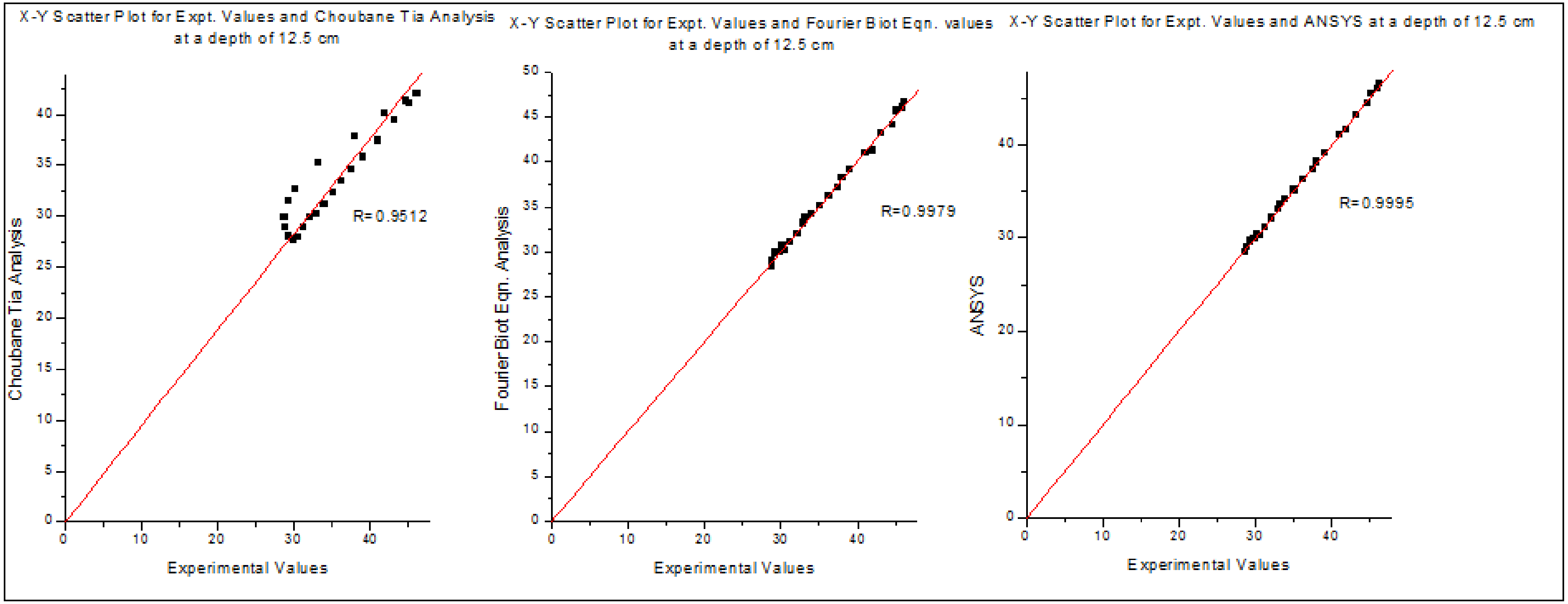


Fig. 5.9 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table 5.5 presents the temperature differential (ΔT) and gradient (ΔT/thickness) developed during day as well as night time for the various cases corresponding to the three SCC mixes.

Table 5.5: Temperature differential and gradient across cube specimens for the three SCC mixes

S. No.	Case Detail	SCC Concrete Mix											
		Mix A				Mix B				Mix C			
		Day time		Night time		Day time		Night time		Day time		Night time	
		ΔT (^{o}C)	ΔT/t (^{o}C/mm)	ΔT (^{o}C)	ΔT/t (^{o}C/mm)	ΔT (^{o}C)	ΔT/t (^{o}C/mm)	ΔT (^{o}C)	ΔT/t (^{o}C/mm)	ΔT (^{o}C)	ΔT/t (^{o}C/mm)	ΔT (^{o}C)	ΔT/t (^{o}C/mm)
1.	Max. Ambient Air Temp.	10.14	0.068	-2.78	-0.018	17.74	0.118	-3.52	-0.024	8.91	0.059	-2.57	-0.017
2.	Min. Ambient Air Temp.	4.81	0.032	-3.1	-0.021	7.75	0.052	-3.46	-0.023	7.24	0.048	-3.63	-0.024
3.	24 hours. Precipitation	1.03	0.0069	-1.08	-0.0072	0.06	0.0004	-0.4	-0.027	0.04	0.0003	-0.48	-0.0032
4.	Part humid and part rainy condition	3	0.02	-1.45	-0.0097	2.07	0.014	-0.67	-0.0045	3.2	0.021	-1.38	-0.0092
5.	24 hour cloudy and humid condition	4.81	0.032	-1.46	-0.0097	9.05	0.06	-1.46	-0,0097	8.37	0.056	-1.45	-0.0097
6.	2 hr. sudden precipitation	2.82	0.019	-1.55	-0.010	3.73	0.025	-1.26	-0.0084	5.84	0.039	-1.59	0.011

t: thickness of the cube specimen (150mm).

The values tabulated are the experimental values. Based on the observations, following points were inferred,

1. It was observed that the cube (15cm side) temperature differential developed corresponding to maximum ambient air temperature was 10.14^{o}C, 17.74^{o}C and 8.91^{o}C for Mix A, B and C respectively. The cube temperature differential values for Mix A and Mix C is less than the IRC recommended value of 17.3^{o}C for a 15 cm thick slab. The cube temperature differential for Mix B exceeded the recommended value.
2. In case of Mix A, the ΔT value is less than the recommended value due to its high thermal conductivity and dense structure. This leads to quick dissipation of heat across the thickness resulting in lower differential.
3. In case of Mix B, the addition of insulating fly ash to the concrete mix reduced its density and k value thereby increasing the temperature differential.
4. For mix C, the addition of light weight insulators like perlite and addition of fly ash reduced the density as well as k value of the concrete mix. In case of SCC mix due to higher proportion of the matrix, perlite was uniformly spread all over the specimen geometry. This improved overall insulation of the specimen (evident from the low k values as compared to Mix A and Mix B values). Thus, the temperature differential developed for mix C was less.
5. Corresponding to the minimum ambient air temperature, the negative cube temperature differential developed in the cube specimens corresponding to the three concrete mixes was comparable.
6. For the case of 24 hr. precipitation, a cube temperature differential of 1.03^{o}C was observed for Mix A. The high value of density of Mix A indicated lesser proportion of voids and made the cube specimen relatively impermeable to water. Thus, a temperature differential was observed for Mix A.
7. For the remaining mixes, the cube temperature differential was tending to zero value. Water is 25 time more conductive than air. The addition of fly ash (in mix B) and fly ash with perlite (in mix C) made the matrix phase of the SCC mix porous. The pores developed in the hardened concrete are usually occupied by air. With presence of moisture, the specimen becomes relatively more conductive, as a result of which the cube temperature differential for Mix B and C was less than 1^{o}C.
8. In case of sudden 2 hr. precipitation, a temperature drop of 4.95^{o}C was observed in the cube surface temperature for Mix A. For Mix B, a temperature drop of 7.12^{o}C was

observed in the cube surface temperature. In case of Mix C, the cube surface temperature reflected a drop of 3.5^{o}C. This indicated that the presence of moisture led to rapid decrease in the surface temperature for Mix B on account of its porous matrix due to replacement of cement by light weight fly ash.

9. The temperature values computed using Choubane Tia model consider only the temperature values at top, bottom and middle portion of the specimen geometry. It does not consider any of the material properties for the computations.
10. The temperature values computed using Fourier Biot equation were nearly same as the experimental values measured. The Fourier Biot equation considers the thermal conductivity of the specimen in the computations. So the values were nearly equal to the experimental values. However, the thermal conductivity values of the three SCC mixes considered in the present study were determined in dry state. The k value of the specimen in presence of moisture for different temperature conditions was not determined experimentally. Hence, a variation in the temperature values is observed between the measured and computed values especially for wet conditions (humid, 24 hour precipitation and part cloudy and part rainy conditions).

The next set of tables present the temperature values (measured as well as computed) for the slab sections corresponding to the three SCC mixes.

5.5 Results for Temperature Gradient Studies on Slab Section:

In case of slab sections, the sensors were arranged in the two patterns. One line of sensors was laid in a straight line along the edge of the slab, while the other line was arranged in a D-shape (Fig. 5.6). Thus, for the slab section, for each case observation, there will be two sets of temperature values measured viz. along the edge section and along the D-pattern.

Table 5.6 (a), 5.6 (b), 5.6 (c) & 5.6 (d) presents a representative result table for the temperature values measured experimentally (in the edge section), computed using the two equations (Choubane Tia model and Fourier Biot equation) and from the FEA simulation at various depths for 30 cm slab section.

Fig. 5.10 (a), 5.10 (b), & 5.10 (c) presents representative comparative plot of the measured and computed temperature values, while Fig. 5.11 (a), 5.11 (b), 5.11 (c), 5.11 (d), 5.11 (e), 5.11 (f) & 5.11 (g) presents the X-Y Scatter plot for temperature values measured experimentally (along the edge section) and computed numerically at various depths for a particular case study.

Table 5.7 (a), 5.7 (b), 5.7 (c) & 5.7 (d) presents the representative result table for temperature values measured experimentally (in the D-profile) along with the computed values.

Fig. 5.12 (a), 5.12 (b), & 5.12 (c) presents representative comparative plot of the measured and computed temperature values, while Fig. 5.13 (a), 5.13 (b), 5.13 (c), 5.13 (d), 5.13 (e), 5.13 (f) & 5.13 (g) presents the X-Y Scatter plot for temperature values measured experimentally (along the D-profile) and computed numerically at various depths for a particular case study. The results table and corresponding graphs related to other specific case studies for 30 cm slab section are appended as Appendix B.

Table 5.6 (a) : 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for maximum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	36	43.97	37.43	41.05	37.52	37.47	35.72	38.49	35.88	35.80	33.90	36.30	33.63	33.76
2	1200 to 1300	38	46.08	41.58	43.37	41.70	41.64	40.44	40.98	40.56	40.50	38.25	38.91	38.38	38.31
3	1300 to 1400	39	50.35	44.35	47.18	44.41	44.38	43.14	44.37	43.27	43.21	40.94	41.91	40.82	40.88
4	1400 to 1500	41	48.37	46.59	46.18	46.28	46.44	45.54	44.21	45.69	45.61	43.40	42.48	43.15	43.27
5	1500 to 1600	40	43.25	42.93	42.46	43.01	42.97	43.28	41.72	43.40	43.34	42.57	41.03	42.74	42.65
6	1600 to 1700	39	41.60	40.84	41.15	40.73	40.79	41.50	40.72	41.40	41.45	41.24	40.29	41.39	41.32
7	1700 to 1800	37	38.99	38.39	39.01	38.36	38.37	39.42	39.00	39.37	39.40	39.76	38.94	39.89	39.82
8	1800 to 1900	36	36.64	36.60	37.01	36.46	36.53	37.61	37.32	37.73	37.67	38.18	37.55	38.17	38.17
9	1900 to 2000	35	34.46	34.78	35.06	34.58	34.68	35.80	35.56	35.91	35.86	36.54	35.98	36.39	36.46
10	2000 to 2100	34	33.45	33.44	34.01	33.58	33.51	34.34	34.51	34.46	34.40	35.14	34.92	35.25	35.19
11	2100 to 2200	33	32.47	32.47	33.04	32.59	32.53	33.23	33.53	33.36	33.30	34.10	33.96	34.18	34.14
12	2200 to 2300	32	31.65	31.61	32.23	31.76	31.68	32.34	32.75	32.46	32.40	33.14	33.20	33.23	33.18
13	2300 to 0000	31	30.98	30.83	31.54	30.00	30.42	31.50	32.04	31.60	31.55	32.36	32.48	32.40	32.38
14	0000 to 0100	30	30.33	30.20	30.88	30.09	30.14	30.79	31.37	30.90	30.85	31.64	31.82	31.73	31.69
15	0100 to 0200	29	29.76	29.62	30.32	29.86	29.74	30.20	30.82	30.11	30.15	30.97	31.28	31.03	31.00
16	0200 to 0300	29	29.26	29.10	29.80	29.15	29.13	29.64	30.29	29.89	29.77	30.49	30.74	30.58	30.53
17	0300 to 0400	28	28.81	28.78	29.32	28.86	28.82	29.19	29.80	29.28	29.24	29.99	30.24	29.94	29.96
18	0400 to 0500	27	28.36	28.34	28.87	28.50	28.42	28.75	29.33	28.79	28.77	29.49	29.76	29.57	29.53
19	0500 to 0600	27	28.25	28.12	28.70	28.25	28.19	28.47	29.12	28.56	28.51	29.12	29.51	29.24	29.18
20	0600 to 0700	28	27.97	27.84	28.40	27.91	27.88	28.17	28.80	28.21	28.19	28.84	29.17	28.92	28.88
21	0700 to 0800	29	28.83	28.34	29.01	28.41	28.37	28.40	29.21	28.77	28.59	28.94	29.40	29.01	28.97
22	0800 to 0900	32	30.23	29.60	30.17	29.62	29.61	29.35	30.13	29.26	29.30	29.71	30.13	29.88	29.80
23	0900 to 1000	34	31.82	31.18	31.51	31.28	31.23	30.72	31.25	30.66	30.69	30.82	31.05	30.91	30.87
24	1000 to 1100	36	34.79	33.00	33.96	33.12	33.06	32.27	33.25	32.89	32.58	32.14	32.64	32.27	32.21

Table 5.6 (b): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for maximum ambient air temperature at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	32.93	34.47	32.79	32.86	31.94	33.01	32.05	31.99	31.92	31.92	32.01	31.96
2	1200 to 1300	36.66	37.15	36.59	36.63	34.91	35.71	34.44	34.67	34.58	34.58	34.64	34.61
3	1300 to 1400	39.18	39.81	39.29	39.23	37.19	38.07	37.27	37.23	36.69	36.69	36.73	36.71
4	1400 to 1500	41.56	40.98	41.33	41.45	39.35	39.71	39.46	39.41	38.68	38.68	38.71	38.69
5	1500 to 1600	41.56	40.39	41.26	41.41	40.02	39.79	40.12	40.07	39.24	39.24	39.28	39.26
6	1600 to 1700	40.79	39.88	40.69	40.74	39.70	39.47	39.81	39.76	39.07	39.07	39.11	39.09
7	1700 to 1800	39.83	38.85	39.31	39.57	39.08	38.71	39.00	39.04	38.54	38.54	38.51	38.52
8	1800 to 1900	38.60	37.70	38.74	38.67	38.26	37.79	38.45	38.35	37.80	37.80	37.84	37.82
9	1900 to 2000	37.20	36.32	37.18	37.19	37.13	36.56	37.11	37.12	36.71	36.71	36.75	36.73
10	2000 to 2100	35.97	35.27	36.02	36.00	36.08	35.54	36.02	36.05	35.73	35.73	35.78	35.76
11	2100 to 2200	34.92	34.33	35.00	34.96	35.14	34.62	35.22	35.18	34.86	34.86	34.91	34.88
12	2200 to 2300	34.07	33.59	34.02	34.05	34.39	33.91	34.41	34.40	34.17	34.17	34.21	34.19
13	2300 to 0000	33.24	32.87	33.33	33.28	33.66	33.20	33.72	33.69	33.48	33.48	33.52	33.50
14	0000 to 0100	32.57	32.21	32.64	32.60	32.98	32.55	32.99	32.98	32.84	32.84	32.89	32.87
15	0100 to 0200	31.94	31.69	31.96	31.95	32.43	32.04	32.52	32.47	32.35	32.35	32.37	32.36
16	0200 to 0300	31.33	31.14	31.41	31.37	31.87	31.49	31.92	31.90	31.80	31.80	31.85	31.83
17	0300 to 0400	30.82	30.63	30.90	30.86	31.35	30.98	31.42	31.38	31.29	31.29	31.33	31.31
18	0400 to 0500	30.38	30.16	30.46	30.42	30.86	30.51	30.94	30.90	30.83	30.83	30.88	30.85
19	0500 to 0600	29.97	29.87	29.93	29.95	30.52	30.20	30.65	30.58	30.49	30.49	30.54	30.52
20	0600 to 0700	29.62	29.52	29.71	29.67	30.15	29.84	30.28	30.22	30.14	30.14	30.20	30.17
21	0700 to 0800	29.57	29.60	29.65	29.61	30.01	29.81	30.16	30.08	30.01	30.01	30.05	30.03
22	0800 to 0900	30.04	30.15	30.08	30.06	30.26	30.21	30.31	30.29	30.29	30.29	30.32	30.31
23	0900 to 1000	30.80	30.90	30.68	30.74	30.78	30.81	30.75	30.76	30.78	30.78	30.83	30.81
24	1000 to 1100	31.83	32.15	31.81	31.82	31.54	31.77	31.43	31.49	31.50	31.50	31.47	31.49

Table 5.6 (c): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for maximum ambient air temperature at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	31.68	31.18	31.58	31.63	31.70	30.82	31.66	31.68	32.17	30.82	32.10	32.14
2	1200 to 1300	33.60	33.77	33.65	33.63	33.51	33.27	33.48	33.49	34.30	33.09	34.18	34.24
3	1300 to 1400	35.14	35.66	35.26	35.20	34.86	34.99	34.91	34.88	35.91	34.68	36.00	35.95
4	1400 to 1500	36.64	37.87	36.66	36.65	36.22	37.29	36.27	36.25	37.38	36.95	37.46	37.42
5	1500 to 1600	37.36	38.74	37.34	37.35	36.87	38.29	36.91	36.89	37.94	37.88	38.01	37.97
6	1600 to 1700	37.64	38.67	37.62	37.63	37.25	38.29	37.31	37.28	38.15	37.91	38.24	38.19
7	1700 to 1800	37.52	38.33	37.48	37.50	37.22	38.08	37.29	37.25	37.95	37.79	38.03	37.99
8	1800 to 1900	37.15	37.74	37.16	37.15	36.92	37.60	37.02	36.97	37.42	37.39	37.51	37.47
9	1900 to 2000	36.49	36.78	36.54	36.51	36.35	36.76	36.42	36.39	36.60	36.65	36.62	36.61
10	2000 to 2100	35.79	35.85	35.81	35.80	35.73	35.89	35.81	35.77	35.85	35.86	35.91	35.88
11	2100 to 2200	35.13	35.02	35.18	35.16	35.10	35.12	35.15	35.13	35.09	35.15	35.14	35.12
12	2200 to 2300	34.56	34.37	34.60	34.58	34.57	34.50	34.61	34.59	34.48	34.56	34.51	34.50
13	2300 to 0000	34.03	33.69	34.10	34.07	34.06	33.85	34.11	34.08	33.87	33.95	33.93	33.90
14	0000 to 0100	33.49	33.08	33.50	33.49	33.53	33.27	33.59	33.56	33.29	33.41	33.33	33.31
15	0100 to 0200	32.97	32.60	32.99	32.98	33.02	32.80	33.00	33.01	32.75	32.95	32.82	32.78
16	0200 to 0300	32.54	32.06	32.59	32.56	32.58	32.27	32.64	32.61	32.33	32.44	32.40	32.36
17	0300 to 0400	32.11	31.56	32.16	32.14	32.18	31.79	32.22	32.20	31.83	31.98	31.90	31.87
18	0400 to 0500	31.68	31.11	31.72	31.70	31.74	31.35	31.79	31.76	31.37	31.56	31.42	31.39
19	0500 to 0600	31.27	30.76	31.33	31.30	31.35	31.00	31.40	31.37	30.97	31.20	31.05	31.01
20	0600 to 0700	30.93	30.41	31.00	30.97	30.99	30.65	31.00	31.00	30.70	30.87	30.76	30.73
21	0700 to 0800	30.73	30.22	30.77	30.75	30.81	30.44	30.86	30.84	30.63	30.65	30.70	30.67
22	0800 to 0900	30.84	30.41	30.90	30.87	30.88	30.55	30.91	30.89	30.73	30.73	30.80	30.77
23	0900 to 1000	31.13	30.80	31.17	31.15	31.15	30.88	31.20	31.18	31.12	31.01	31.16	31.14
24	1000 to 1100	31.64	31.35	31.70	31.67	31.62	31.30	31.69	31.66	31.76	31.37	31.82	31.79

Table 5.6 (d): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for maximum ambient air temperature at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	32.16	31.18	32.20	32.18	34.02	31.91	34.03	34.02	33.01	33.01	33.08	33.04	31.56	31.56	31.59	31.57
2	1200 to 1300	34.64	33.22	34.71	34.68	36.54	33.67	36.63	36.58	34.43	34.43	34.49	34.46	32.97	32.97	33.00	32.98
3	1300 to 1400	36.23	34.73	36.31	36.27	37.46	35.14	37.52	37.49	35.90	35.90	35.95	35.93	33.74	33.74	33.77	33.75
4	1400 to 1500	37.68	36.83	37.73	37.71	38.38	36.95	38.43	38.40	37.29	37.29	37.32	37.31	34.38	34.38	34.43	34.41
5	1500 to 1600	38.23	37.52	38.31	38.27	38.33	37.21	38.41	38.37	36.94	36.94	36.97	36.96	34.76	34.76	34.79	34.78
6	1600 to 1700	38.32	37.55	38.40	38.36	38.17	37.19	38.23	38.20	36.84	36.84	36.87	36.85	35.01	35.01	35.05	35.03
7	1700 to 1800	38.04	37.47	38.05	38.04	37.63	37.10	37.72	37.68	36.70	36.70	36.74	36.72	35.15	35.15	35.19	35.17
8	1800 to 1900	37.46	37.11	37.52	37.49	36.88	36.75	36.91	36.89	36.32	36.32	36.36	36.34	35.18	35.18	35.21	35.20
9	1900 to 2000	36.59	36.45	36.66	36.63	35.87	36.17	35.94	35.90	35.79	35.79	35.82	35.81	35.03	35.03	35.05	35.04
10	2000 to 2100	35.73	35.76	35.81	35.77	34.98	35.58	35.00	34.99	35.32	35.32	35.37	35.35	34.77	34.77	34.80	34.78
11	2100 to 2200	34.94	35.12	35.00	34.97	34.29	35.02	34.33	34.31	34.85	34.85	34.88	34.87	34.56	34.56	34.60	34.58
12	2200 to 2300	34.29	34.57	34.35	34.32	33.59	34.51	33.64	33.62	34.38	34.38	34.43	34.41	34.32	34.32	34.36	34.34
13	2300 to 0000	33.65	34.00	33.71	33.68	33.02	33.98	33.06	33.04	33.91	33.91	33.95	33.93	34.02	34.02	34.04	34.03
14	0000 to 0100	33.06	33.49	33.11	33.08	32.55	33.53	32.59	32.57	33.51	33.51	33.54	33.52	33.72	33.72	33.76	33.74
15	0100 to 0200	32.57	33.05	32.62	32.59	32.09	33.10	32.14	32.12	33.09	33.09	33.13	33.11	33.42	33.42	33.45	33.44
16	0200 to 0300	32.09	32.56	32.16	32.13	31.61	32.64	31.68	31.64	32.67	32.67	32.70	32.68	33.09	33.09	33.13	33.11
17	0300 to 0400	31.59	32.12	31.65	31.62	31.12	32.22	31.17	31.15	32.29	32.29	32.32	32.30	32.76	32.76	32.81	32.79
18	0400 to 0500	31.12	31.73	31.20	31.16	30.70	31.86	30.76	30.73	31.95	31.95	32.00	31.98	32.53	32.53	32.60	32.57
19	0500 to 0600	30.76	31.38	30.84	30.80	30.41	31.53	30.46	30.44	31.64	31.64	31.69	31.67	32.26	32.26	32.30	32.28
20	0600 to 0700	30.48	31.06	30.55	30.51	30.09	31.22	30.15	30.12	31.36	31.36	31.41	31.38	31.99	31.99	32.02	32.00
21	0700 to 0800	30.32	30.87	30.41	30.37	30.11	31.10	30.17	30.14	31.32	31.32	31.37	31.35	31.76	31.76	31.80	31.78
22	0800 to 0900	30.55	30.94	30.61	30.58	30.48	31.17	30.53	30.50	31.44	31.44	31.49	31.47	31.70	31.70	31.74	31.72
23	0900 to 1000	30.94	31.20	31.03	30.98	31.07	31.45	31.05	31.06	31.75	31.75	31.80	31.78	31.74	31.74	31.79	31.76
24	1000 to 1100	31.63	31.55	31.71	31.67	31.94	31.84	32.02	31.98	32.24	32.24	32.28	32.26	31.90	31.90	31.92	31.91

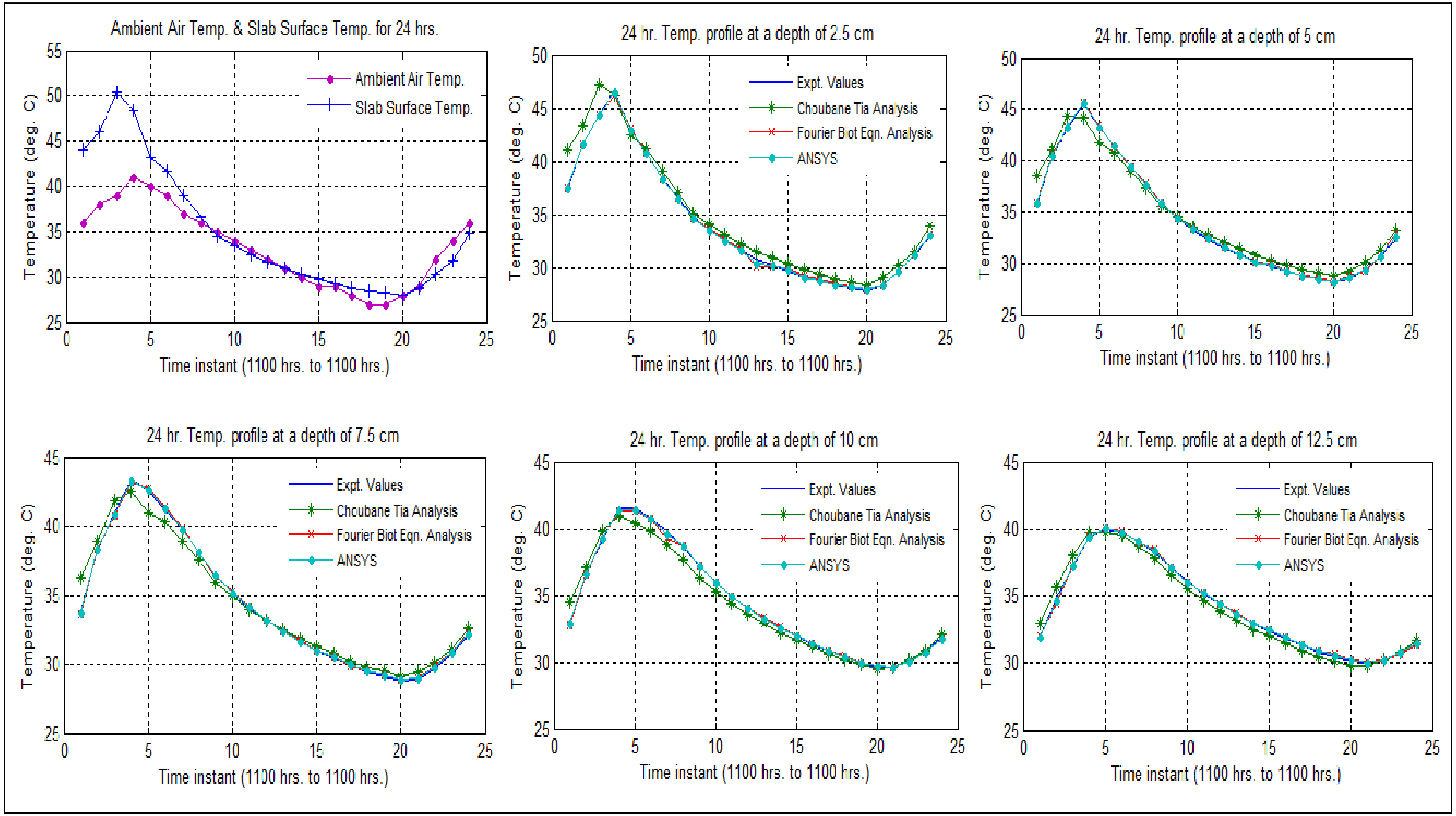


Fig. 5.10 (a): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix A for maximum ambient air temperature (surface to 12.5 cm)

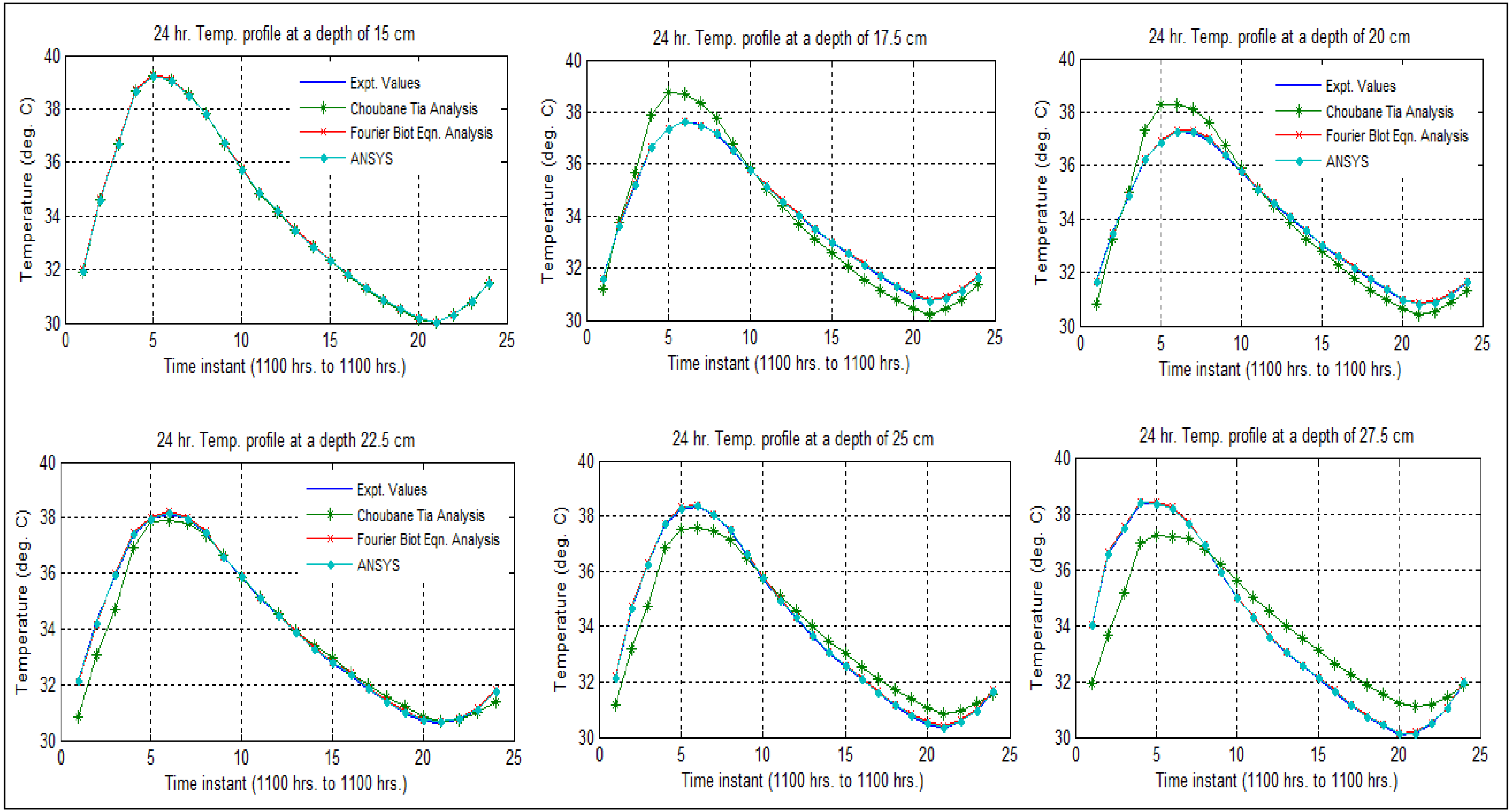


Fig. 5.10 (b): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix A for maximum ambient air temperature (15 cm to 27.5 cm)

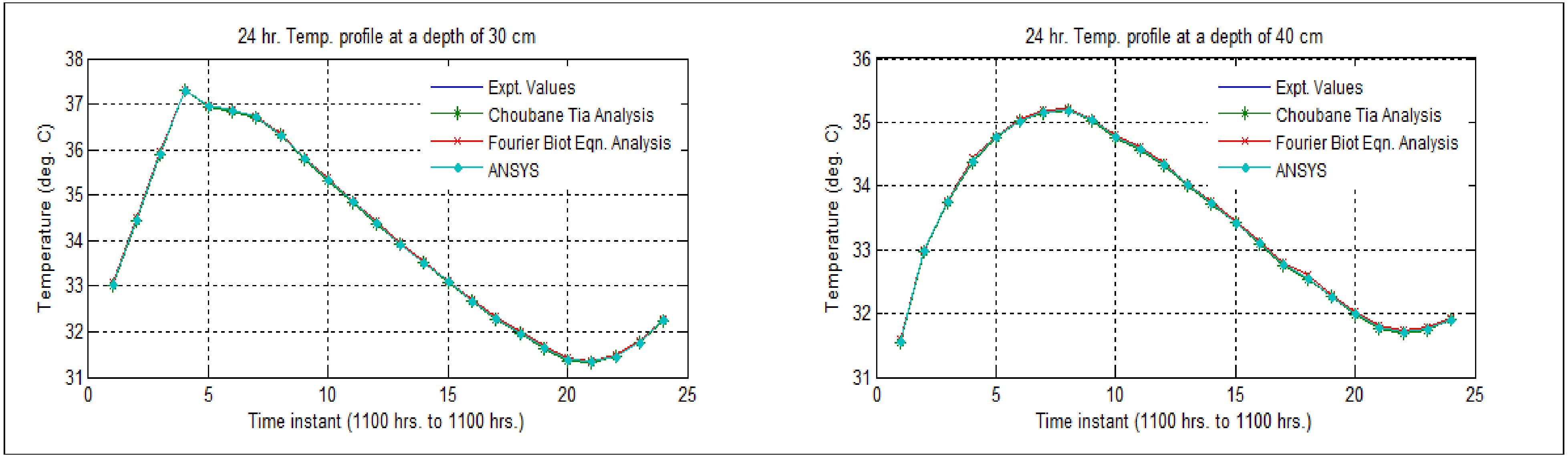


Fig. 5.10 (c): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix A for maximum ambient air temperature (30 cm & 40 cm)

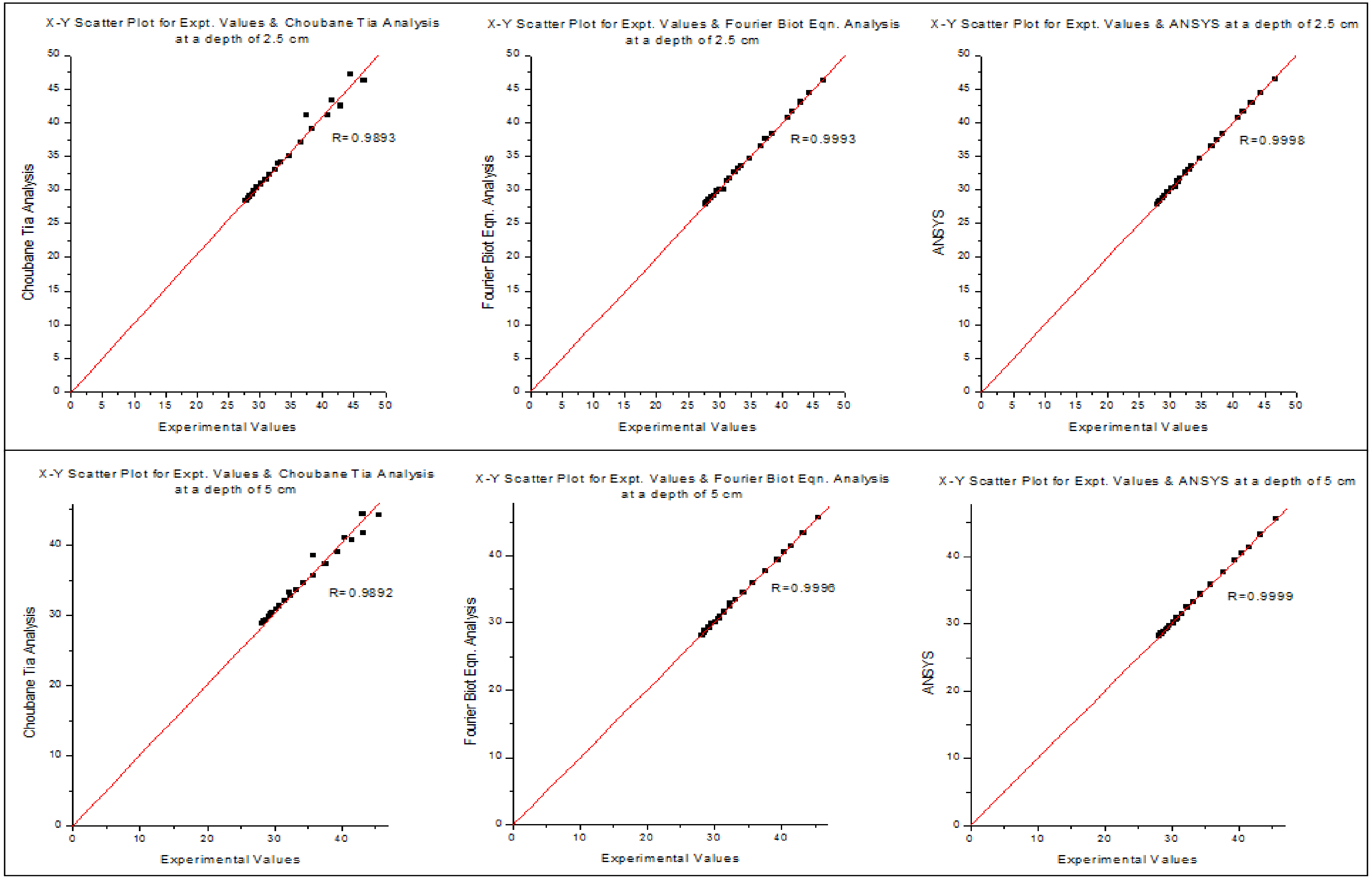


Fig. 5.11 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

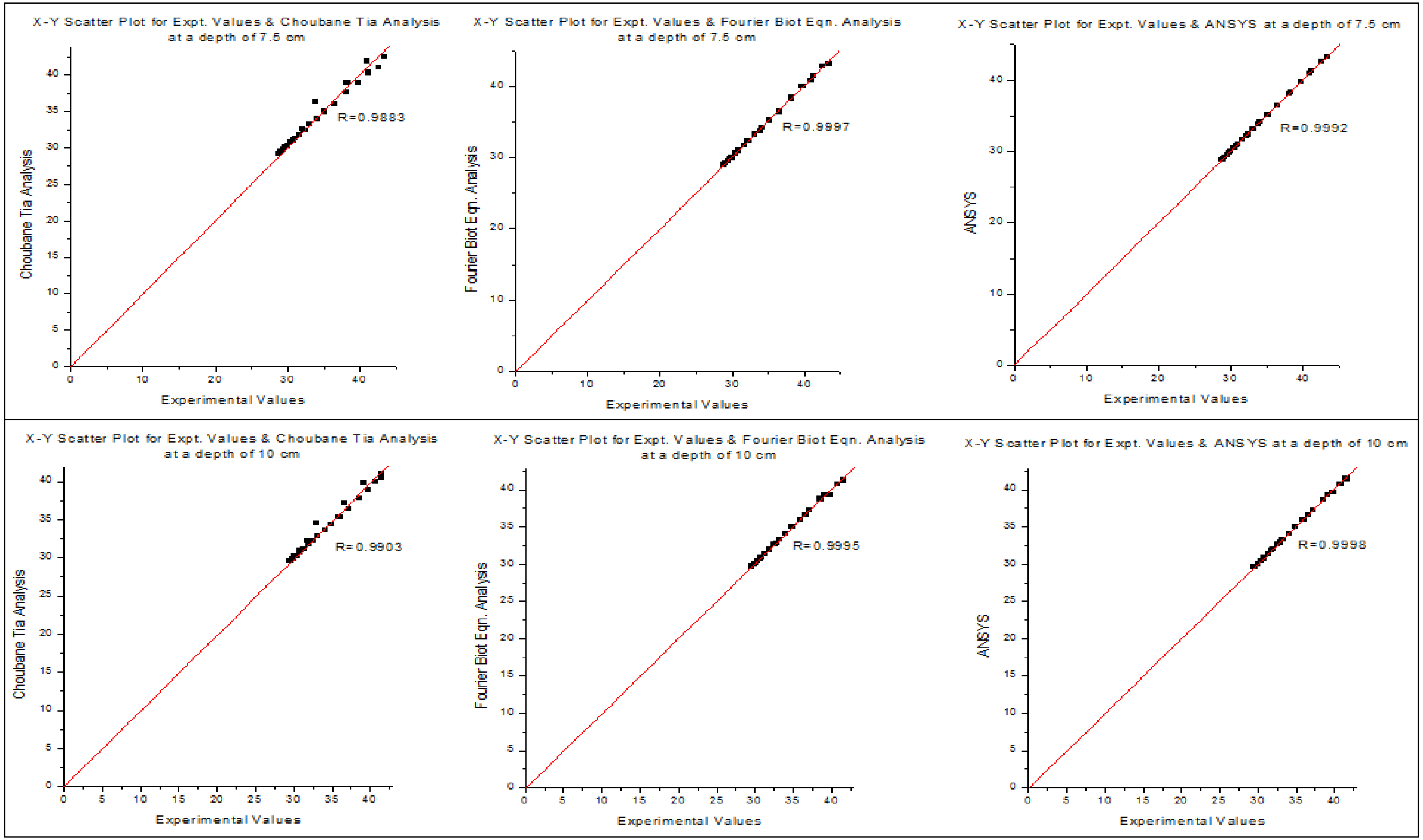


Fig. 5.11 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

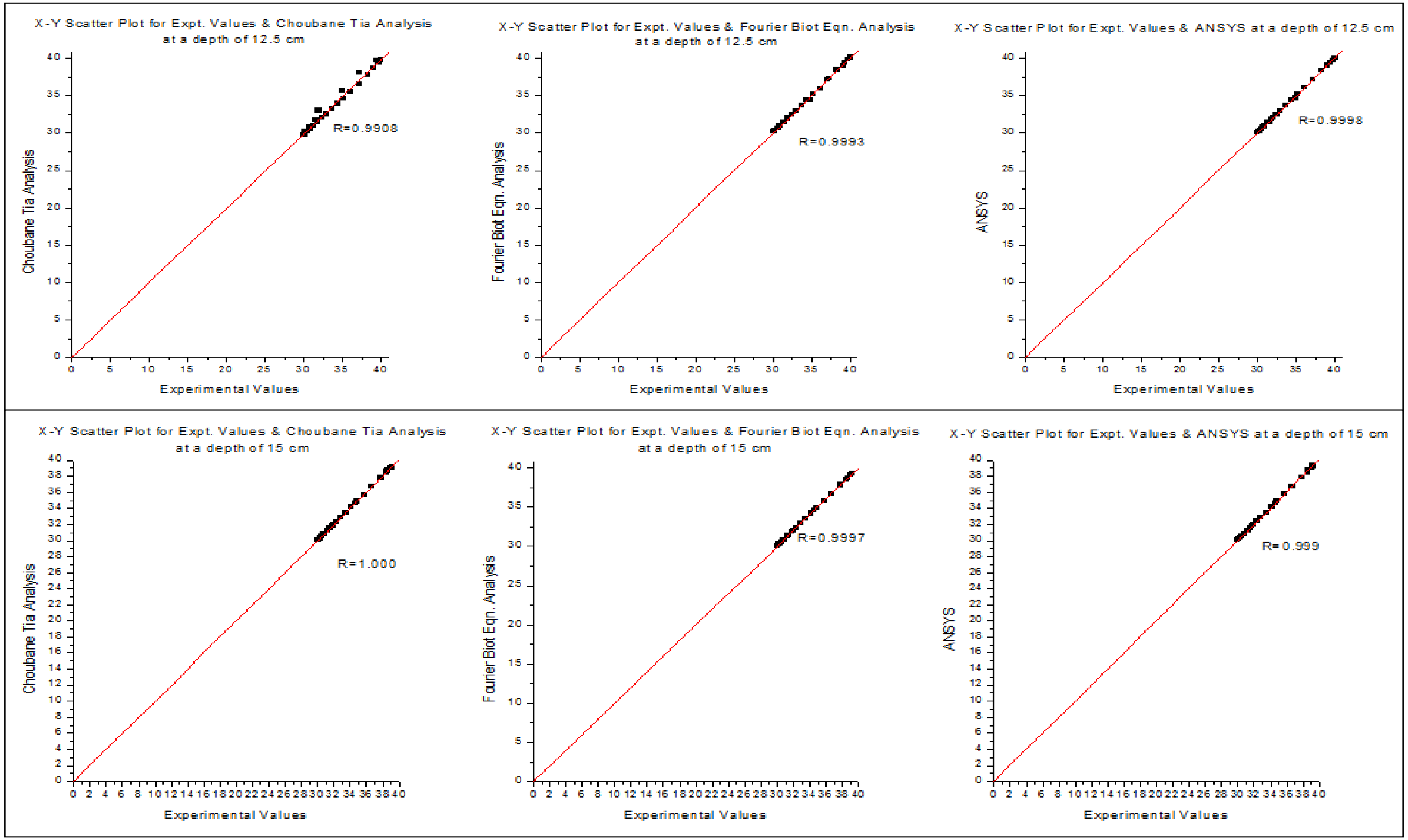


Fig. 5.11 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

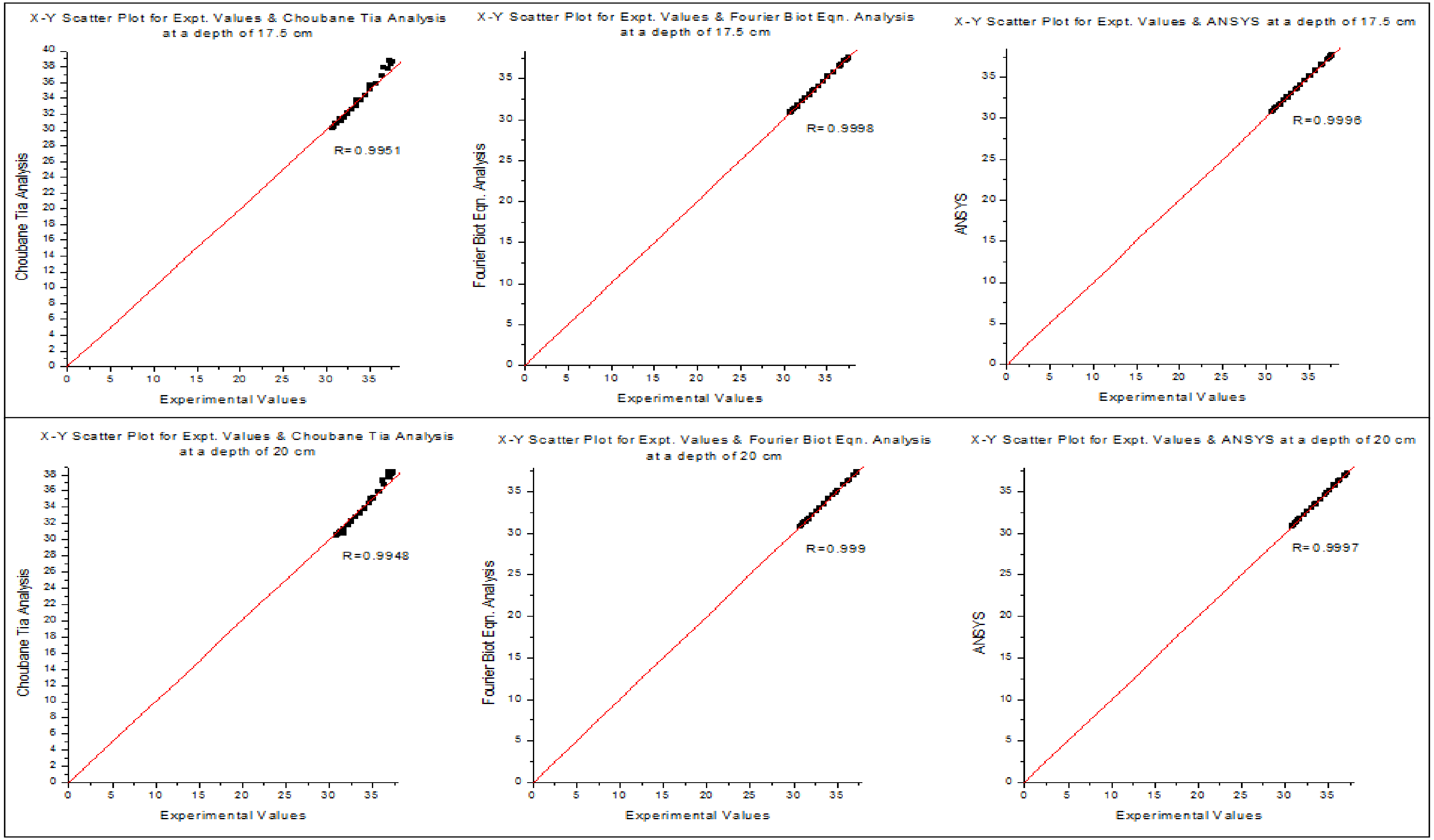


Fig. 5.11 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

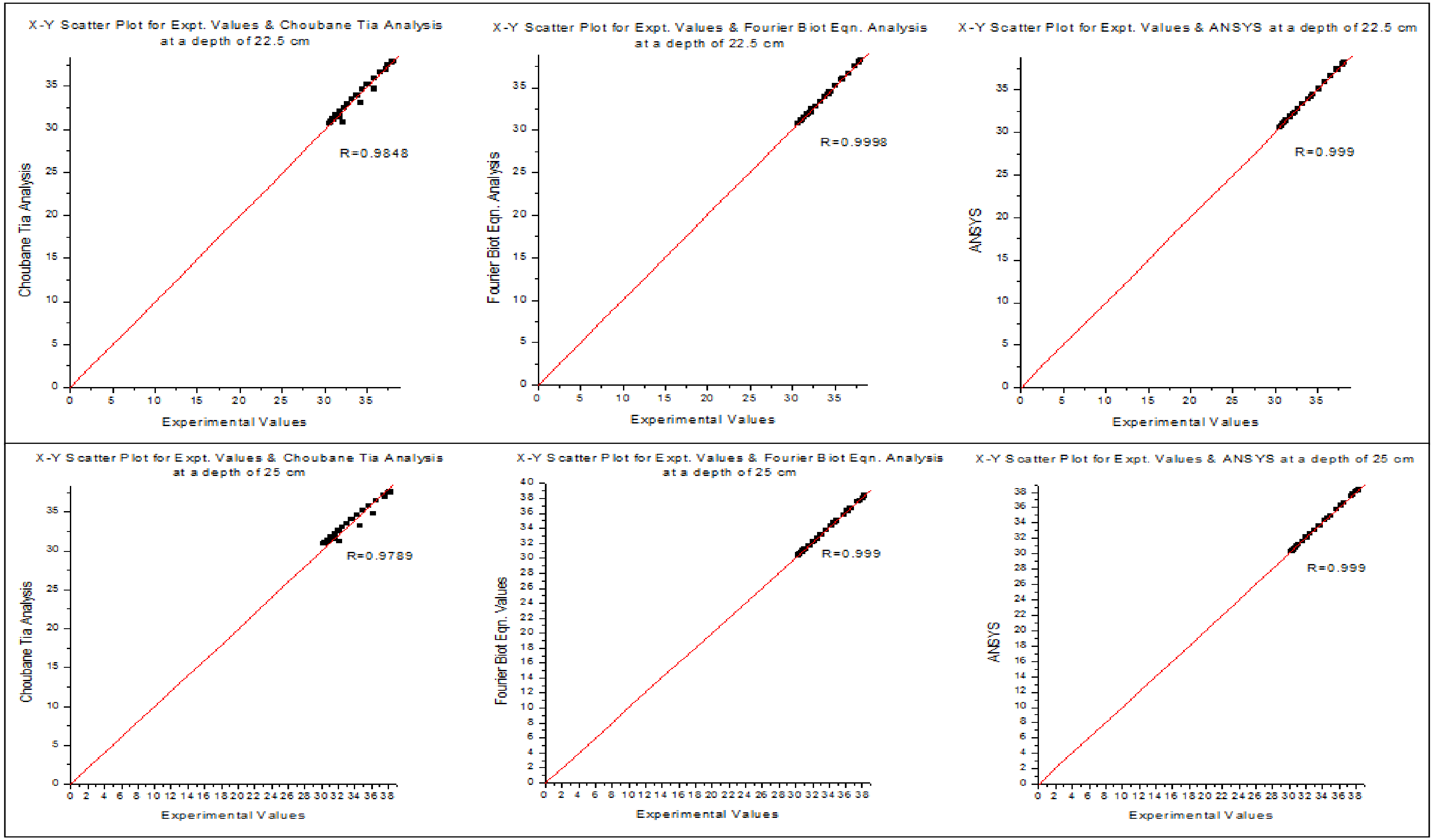


Fig. 5.11 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

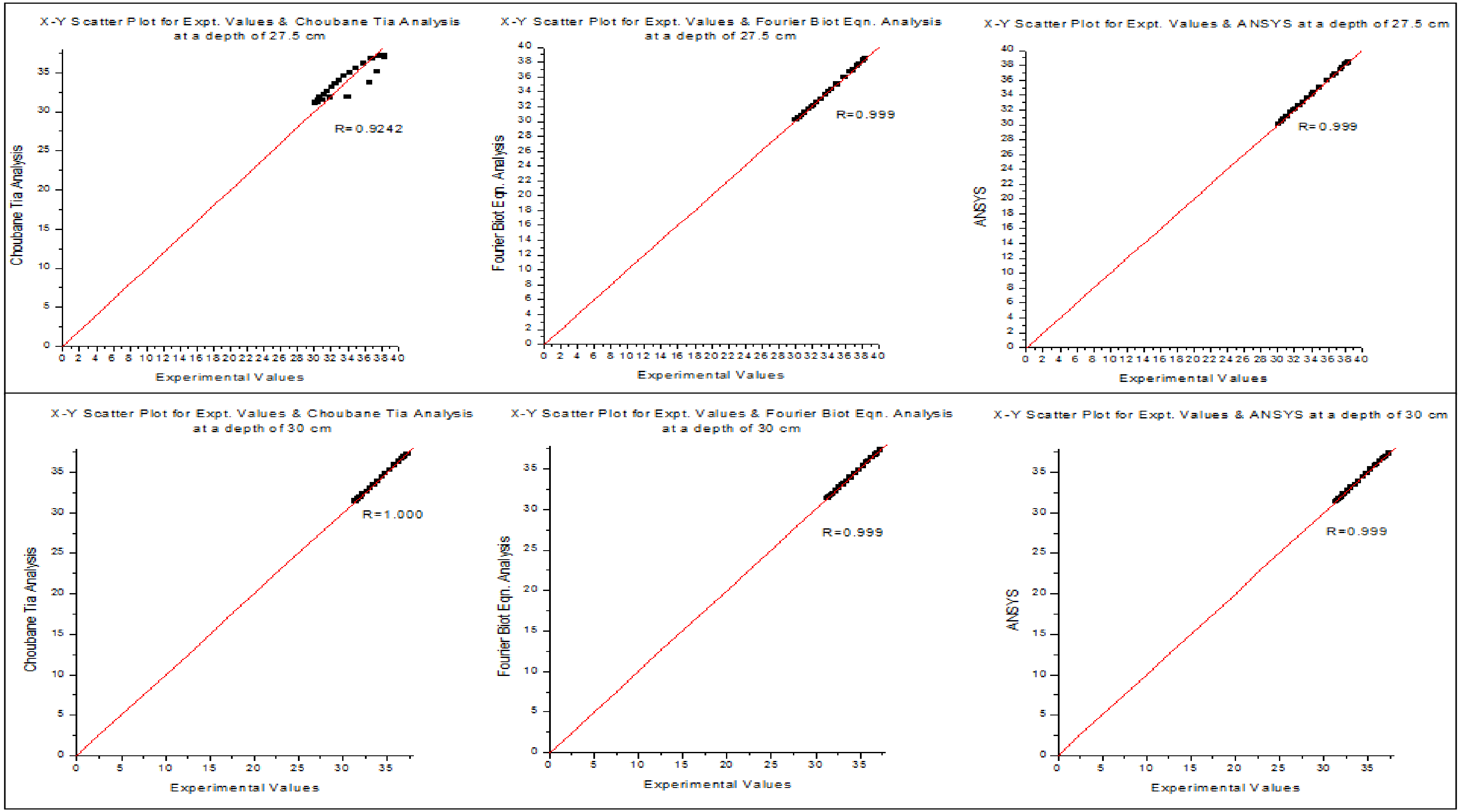


Fig. 5.11 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

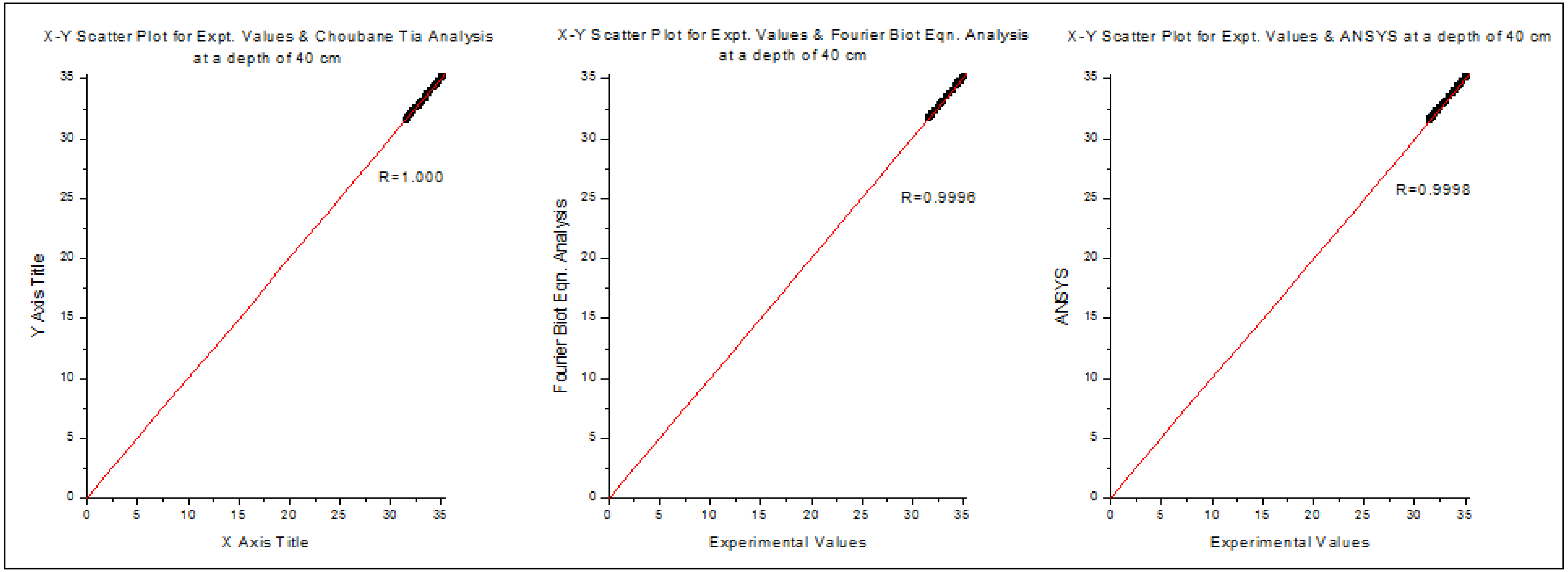


Fig. 5.11 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table 5.7 (a): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for maximum ambient air temperature at 2.5 cm, 5 cm, & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	36	40.60	37.43	38.15	37.53	37.48	30.65	36.01	30.36	30.51	30.47	34.15	30.56	30.52
2	1130 to 1230	38	44.90	42.25	41.42	42.03	42.14	33.94	38.38	33.36	33.65	33.05	35.78	33.19	33.12
3	1230 to 1330	39	48.81	44.94	44.58	44.23	44.58	36.81	40.88	36.82	36.82	35.66	37.71	35.59	35.63
4	1330 to 1430	41	50.39	48.24	46.05	48.42	48.33	39.53	42.25	39.95	39.74	38.29	39.00	38.93	38.61
5	1430 to 1530	40	44.03	45.47	41.53	45.68	45.57	41.29	39.36	41.79	41.54	40.23	37.51	40.67	40.45
6	1530 to 1630	39	42.34	43.44	40.55	43.44	43.44	40.92	38.98	40.30	40.61	40.33	37.64	40.72	40.53
7	1630 to 1730	37	40.24	41.50	39.16	41.11	41.30	40.30	38.22	40.19	40.25	40.10	37.41	39.95	40.02
8	1730 to 1830	36	37.61	38.84	37.29	38.29	38.56	39.27	37.01	39.41	39.34	39.37	36.76	39.28	39.32
9	1830 to 1930	35	35.06	35.94	35.40	35.48	35.71	37.94	35.70	38.04	37.99	38.33	35.95	38.23	38.28
10	1930 to 2030	34	33.57	33.88	34.27	33.67	33.77	36.40	34.88	36.25	36.33	37.06	35.38	37.03	37.05
11	2030 to 2130	33	32.42	32.67	33.34	32.80	32.73	35.15	34.14	35.17	35.16	36.01	34.82	36.05	36.03
12	2130 to 2230	32	31.47	31.70	32.55	31.60	31.65	34.20	33.49	34.17	34.18	35.03	34.27	35.05	35.04
13	2230 to 2330	31	30.64	30.81	31.82	30.71	30.76	33.28	32.84	33.23	33.25	34.25	33.71	34.17	34.21
14	2330 to 0030	30	29.96	30.16	31.19	30.21	30.19	32.52	32.26	32.45	32.48	33.47	33.17	33.40	33.44
15	0030 to 0130	29	29.36	29.58	30.66	29.63	29.60	31.88	31.78	31.95	31.92	32.82	32.73	32.91	32.86
16	0130 to 0230	29	28.84	29.06	30.16	29.03	29.04	31.22	31.30	31.12	31.17	32.27	32.27	32.11	32.19
17	0230 to 0330	28	28.45	28.76	29.75	28.82	28.79	30.73	30.89	30.95	30.84	31.71	31.85	31.96	31.84
18	0330 to 0430	27	27.94	28.36	29.25	28.49	28.43	30.30	30.40	30.55	30.43	31.18	31.37	30.90	31.04
19	0430 to 0530	27	27.83	28.07	29.06	28.14	28.10	29.85	30.13	29.89	29.87	30.76	31.05	30.65	30.71
20	0530 to 0630	28	27.46	27.84	28.70	27.82	27.83	29.53	29.79	29.48	29.50	30.47	30.72	30.56	30.51
21	0630 to 0730	29	27.99	27.99	29.02	27.95	27.97	29.20	29.91	29.08	29.14	30.09	30.66	29.95	30.02
22	0730 to 0830	32	29.31	29.15	29.92	29.18	29.17	29.21	30.45	29.17	29.19	29.94	30.90	29.86	29.90
23	0830 to 0930	34	30.91	30.76	31.06	30.60	30.68	29.69	31.19	29.55	29.62	30.21	31.30	30.31	30.26
24	0930 to 1030	36	32.72	32.59	32.39	32.59	32.59	30.49	32.09	30.35	30.42	30.69	31.84	30.55	30.62

Table 5.7 (b): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for maximum ambient air temperature at 10 cm, 12.5 cm, & 15 cm

S. No.	Time Instant	Temperature (ºC) at 10 cm				Temperature (ºC) at 12.5 cm				Temperature (ºC) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	30.10	32.60	30.57	30.34	30.21	31.34	30.26	30.23	30.38	30.38	30.20	30.29
2	1130 to 1230	31.71	33.62	31.66	31.69	31.45	31.89	31.48	31.46	30.60	30.60	30.52	30.56
3	1230 to 1330	33.78	35.07	33.49	33.64	33.25	32.97	33.31	33.28	31.40	31.40	31.33	31.37
4	1330 to 1430	35.87	36.29	35.50	35.68	35.09	34.13	35.15	35.12	32.51	32.51	32.47	32.49
5	1430 to 1530	37.82	35.97	37.72	37.77	36.87	34.76	36.62	36.74	33.87	33.87	33,78	33.87
6	1530 to 1630	38.50	36.53	38.65	38.57	37.71	35.63	37.84	37.78	34.97	34.97	34.50	34.73
7	1630 to 1730	38.64	36.72	38.44	38.54	38.05	36.17	38.12	38.09	35.75	35.75	35.65	35.70
8	1730 to 1830	38.43	36.54	38.69	38.56	38.00	36.36	38.07	38.03	36.21	36.21	36.36	36.29
9	1830 to 1930	37.91	36.15	38.06	37.99	37.61	36.30	37.59	37.60	36.40	36.40	36.46	36.43
10	1930 to 2030	37.06	35.80	37.02	37.04	36.97	36.11	37.01	36.99	36.33	36.33	36.31	36.32
11	2030 to 2130	36.28	35.37	36.23	36.25	36.34	35.79	36.22	36.28	36.08	36.08	36.01	36.05
12	2130 to 2230	35.50	34.92	35.43	35.46	35.71	35.41	35.52	35.61	35.76	35.76	35.61	35.69
13	2230 to 2330	34.77	34.41	34.62	34.70	35.05	34.96	35.01	35.03	35.35	35.35	35.41	35.38
14	2330 to 0030	34.15	33.91	34.10	34.12	34.49	34.49	34.41	34.45	34.91	34.91	35.00	34.96
15	0030 to 0130	33.55	33.51	33.48	33.51	33.95	34.11	33.99	33.97	34.55	34.55	34.49	34.52
16	0130 to 0230	32.94	33.07	32.88	32.91	33.38	33.70	33.20	33.29	34.15	34.15	34.06	34.10
17	0230 to 0330	32.47	32.64	32.51	32.49	32.87	33.26	32.99	32.93	33.71	33.71	33.99	33.85
18	0330 to 0430	31.98	32.17	31.94	31.96	32.45	32.80	32.56	32.50	33.26	33.26	33.49	33.38
19	0430 to 0530	31.49	31.80	31.30	31.39	31.99	32.39	31.97	31.98	32.82	32.82	32.98	32.90
20	0530 to 0630	31.11	31.48	31.15	31.13	31.58	32.08	31.42	31.50	32.52	32.52	32.60	32.56
21	0630 to 0730	30.75	31.29	30.38	30.56	31.17	31.78	31.23	31.20	32.13	32.13	32.15	32.14
22	0730 to 0830	30.55	31.27	30.44	30.50	30.87	31.55	30.88	30.88	31.76	31.76	31.62	31.69
23	0830 to 0930	30.54	31.38	30.75	30.64	30.80	31.44	30.68	30.74	31.48	31.48	31.36	31.42
24	0930 to 1030	30.74	31.62	30.92	30.83	30.90	31.45	30.79	30.84	31.31	31.31	31.51	31.41

Table 5.7 (c): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for maximum ambient air temperature at 17.5 cm, 20 cm, & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	30.47	29.72	30.55	30.51	30.34	29.36	30.26	30.30	30.16	29.29	30.10	30.13
2	1130 to 1230	30.71	29.74	30.61	30.66	30.56	29.33	30.38	30.47	30.70	29.35	30.61	30.66
3	1230 to 1330	31.65	30.36	31.47	31.56	31.38	29.85	31.22	31.30	32.01	29.88	32.08	32.05
4	1330 to 1430	32.82	31.43	32.58	32.70	32.57	30.90	32.27	32.42	33.64	30.92	33.50	33.57
5	1430 to 1530	34.31	33.29	34.31	34.31	34.07	33.04	34.14	34.11	35.62	33.10	35.55	35.58
6	1530 to 1630	35.49	34.52	35.23	35.36	35.37	34.31	35.11	35.24	36.95	34.31	36.84	36.90
7	1630 to 1730	36.26	35.46	36.27	36.26	36.27	35.30	36.14	36.20	37.73	35.27	37.77	37.75
8	1730 to 1830	36.58	36.10	36.34	36.46	36.71	36.02	36.58	36.64	38.08	35.98	38.04	38.06
9	1830 to 1930	36.70	36.45	36.67	36.68	36.90	36.45	36.78	36.84	37.87	36.41	37.71	37.79
10	1930 to 2030	36.57	36.45	36.42	36.49	36.78	36.47	36.65	36.71	37.32	36.40	37.35	37.33
11	2030 to 2130	36.32	36.25	36.21	36.27	36.47	36.29	36.51	36.49	36.65	36.21	36.58	36.61
12	2130 to 2230	35.93	35.97	36.01	35.97	36.06	36.03	36.00	36.03	36.04	35.94	36.00	36.02
13	2230 to 2330	35.47	35.59	35.50	35.48	35.57	35.66	35,69	35.57	35.39	35.58	35.44	35.42
14	2330 to 0030	35.01	35.17	35.00	35.00	35.06	35.26	35.00	35.03	34.77	35.19	34.59	34.68
15	0030 to 0130	34.60	34.82	34.78	34.69	34.61	34.91	34.71	34.66	34.27	34.84	34.31	34.29
16	0130 to 0230	34.19	34.42	34.10	34.15	34.19	34.53	34.00	34.10	33.72	34.45	33.67	33.70
17	0230 to 0330	33.75	33.99	33.80	33.78	33.71	34.10	33.54	33.63	33.21	34.03	33.19	33.20
18	0330 to 0430	33.31	33.55	33.19	33.25	33.26	33.67	33.19	33.22	32.74	33.61	32.68	32.71
19	0430 to 0530	32.86	33.09	32.99	32.92	32.81	33.20	32.99	32.90	32.35	33.15	32.29	32.32
20	0530 to 0630	32.55	32.80	32.41	32.48	32.49	32.91	32.54	32.51	31.94	32.87	32.00	31.97
21	0630 to 0730	32.17	32.35	32.08	32.13	32.08	32.44	32.04	32.06	31.54	32.40	31.32	31.43
22	0730 to 0830	31.80	31.88	31.31	31.56	31.73	31.93	31.61	31.67	31.20	31.89	31.08	31.14
23	0830 to 0930	31.53	31.49	31.59	31.56	31.44	31.48	31.31	31.37	31.03	31.45	31.10	31.06
24	0930 to 1030	31.40	31.21	31.34	31.37	31.30	31.15	31.44	31.37	31.02	31.13	31.09	31.05

Table 5.7 (d): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for maximum ambient air temperature at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	30.52	29.52	30.37	30.44	31.38	30.04	31.23	31.31	30.87	30.87	30.75	30.81	31.11	31.11	30.98	31.04
2	1130 to 1230	31.38	29.81	31.27	31.33	33.60	30.70	33.53	33.56	32.03	32.03	32.10	32.07	33.79	33.79	33.87	33.83
3	1230 to 1330	32.98	30.44	33.06	33.02	36.24	31.53	36.32	36.28	33.15	33.15	33.05	33.10	36.04	36.04	35.91	35.98
4	1330 to 1430	35.05	31.48	35.07	35.06	39.69	32.58	39.73	39.71	34.23	34.23	34.14	34.19	38.33	38.33	38.28	38.30
5	1430 to 1530	37.01	33.49	37.04	37.02	40.47	34.19	40.52	40.49	35.21	35.21	35.38	35.30	38.33	38.33	38.30	38.31
6	1530 to 1630	37.92	34.55	37.73	37.82	40.27	35.00	40.41	40.34	35.68	35.68	35.97	35.83	37.27	37.27	37.50	37.38
7	1630 to 1730	38.39	35.37	38.45	38.42	40.10	35.60	40.02	40.06	35.97	35.97	36.02	35.99	36.51	36.51	36.97	36.74
8	1730 to 1830	38.37	35.97	38.23	38.30	38.79	35.99	38.80	38.80	36.05	36.05	36.02	36.04	35.85	35.85	35.97	35.91
9	1830 to 1930	37.87	36.31	37.71	37.79	37.48	36.16	37.56	37.52	35.97	35.97	36.00	35.98	35.14	35.14	35.21	35.18
10	1930 to 2030	37.10	36.23	37.00	37.05	36.37	35.96	36.51	36.44	35.60	35.60	35.70	35.65	34.40	34.40	34.50	34.45
11	2030 to 2130	36.40	36.00	36.28	36.34	35.44	35.66	35.56	35.50	35.20	35.20	35.40	35.30	33.79	33.79	33.88	33.84
12	2130 to 2230	35.73	35.71	35.60	35.66	34.73	35.33	34.61	34.67	34.81	34.81	35.00	34.90	33.26	33.26	33.33	33.30
13	2230 to 2330	35.09	35.34	35.00	35.04	34.10	34.94	34.00	34.05	34.38	34.38	34.50	34.44	32.78	32.78	32.69	32.73
14	2330 to 0030	34.52	34.95	34.41	34.46	33.46	34.55	33.51	33.49	33.99	33.99	34.00	34.00	32.42	32.42	32.49	32.45
15	0030 to 0130	34.00	34.59	34.00	34.00	32.91	34.18	33.00	32.95	33.59	33.59	33.65	33.62	32.03	32.03	32.00	32.02
16	0130 to 0230	33.48	34.21	33.51	33.49	32.50	33.79	32.60	32.55	33.20	33.20	33.22	33.21	31.64	31.64	31.80	31.72
17	0230 to 0330	32.99	33.80	33.00	33.00	32.05	33.39	32.00	32.02	32.82	32.82	33.00	32.91	31.27	31.27	31.40	31.34
18	0330 to 0430	32.58	33.38	32.70	32.64	31.59	32.99	31.48	31.54	32.42	32.42	32.61	32.51	30.91	30.91	31.00	30.96
19	0430 to 0530	32.18	32.94	32.29	32.24	31.18	32.57	31.09	31.13	32.03	32.03	32.12	32.08	30.66	30.66	30.75	30.70
20	0530 to 0630	31.80	32.66	31.70	31.75	30.88	32.29	30.70	30.79	31.76	31.76	31.81	31.78	30.44	30.44	30.55	30.49
21	0630 to 0730	31.42	32.22	31.31	31.37	30.70	31.91	30.58	30.64	31.46	31.46	31.54	31.50	30.22	30.22	30.30	30.26
22	0730 to 0830	31.17	31.77	31.08	31.13	30.73	31.57	30.61	30.67	31.29	31.29	31.12	31.20	30.23	30.23	30.37	30.30
23	0830 to 0930	31.10	31.40	31.10	31.10	30.95	31.32	30.75	30.85	31.22	31.22	31.04	31.13	30.49	30.49	30.64	30.57
24	0930 to 1030	31.20	31.15	31.15	31.18	31.43	31.21	31.37	31.40	31.31	31.31	31.25	31.28	30.90	30.90	30.92	30.91

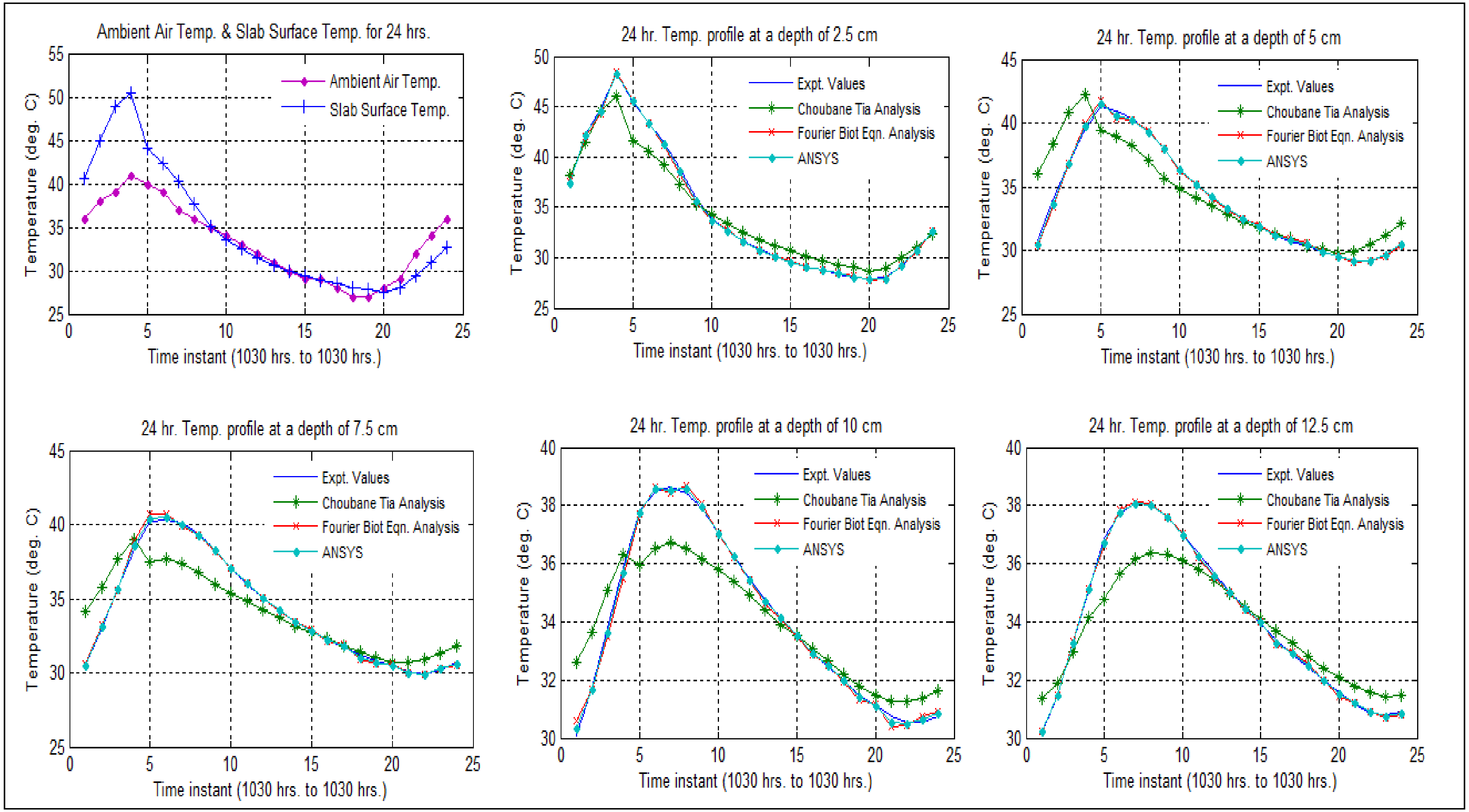


Fig. 5.12 (a): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix A for maximum ambient air temperature (surface to 12.5 cm)

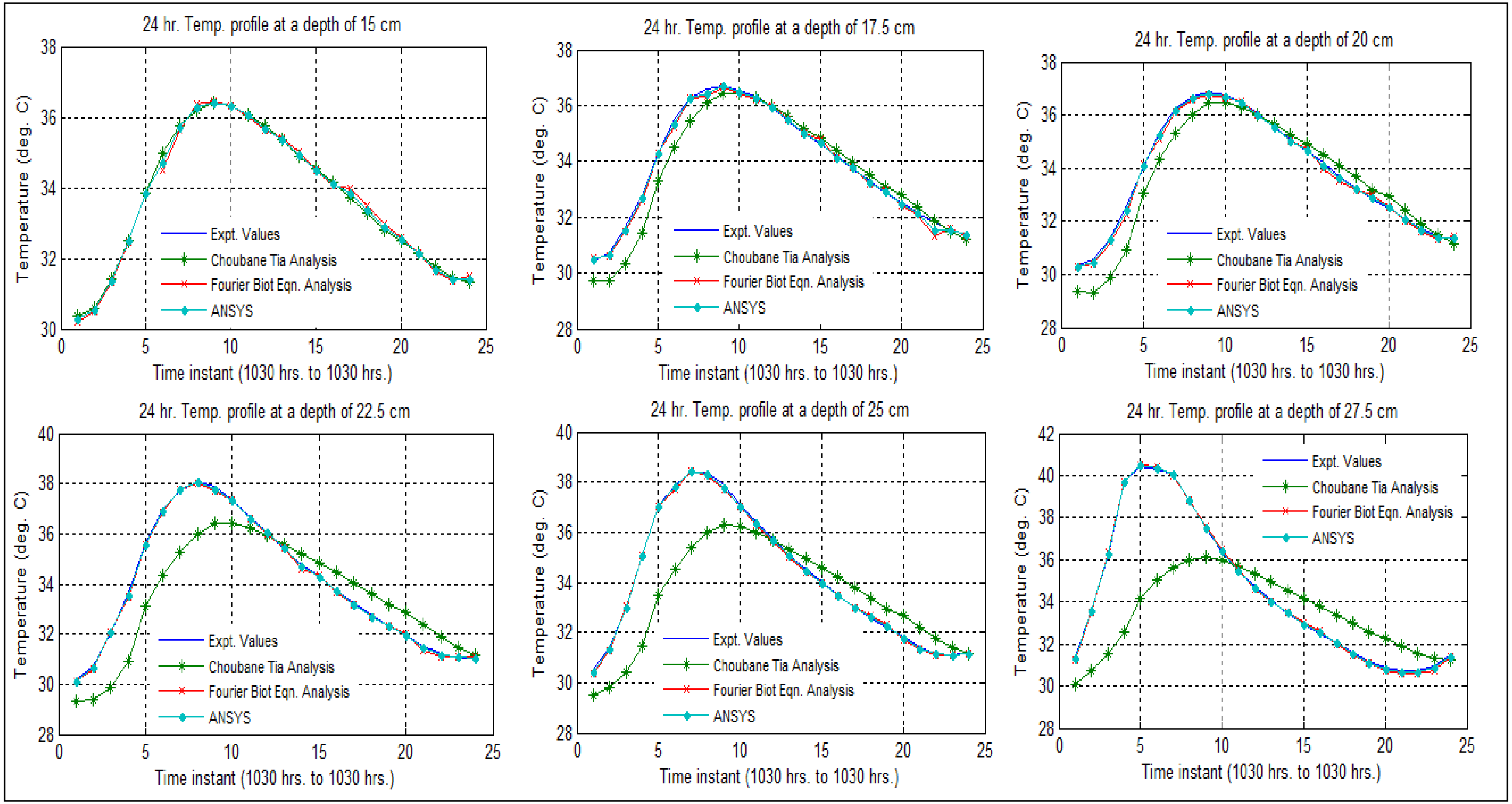


Fig. 5.12 (b): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix A for maximum ambient air temperature (15 cm to 27.5 cm)

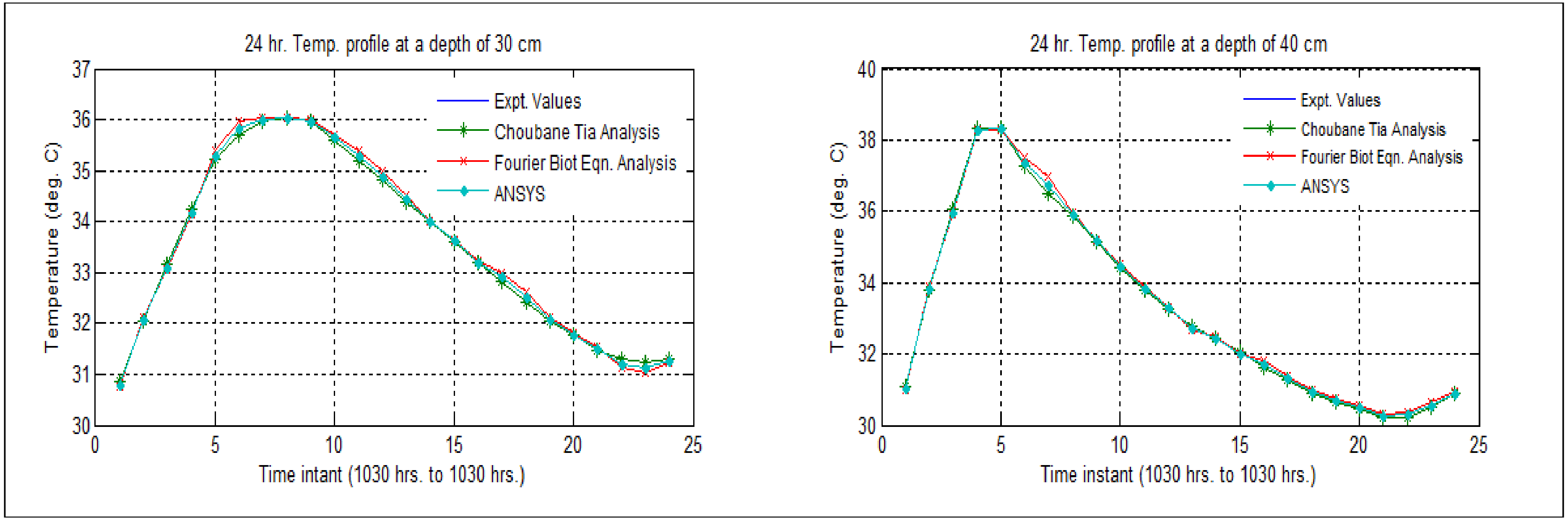


Fig. 5.12 (c): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix A for maximum ambient air temperature (30 cm & 40 cm)

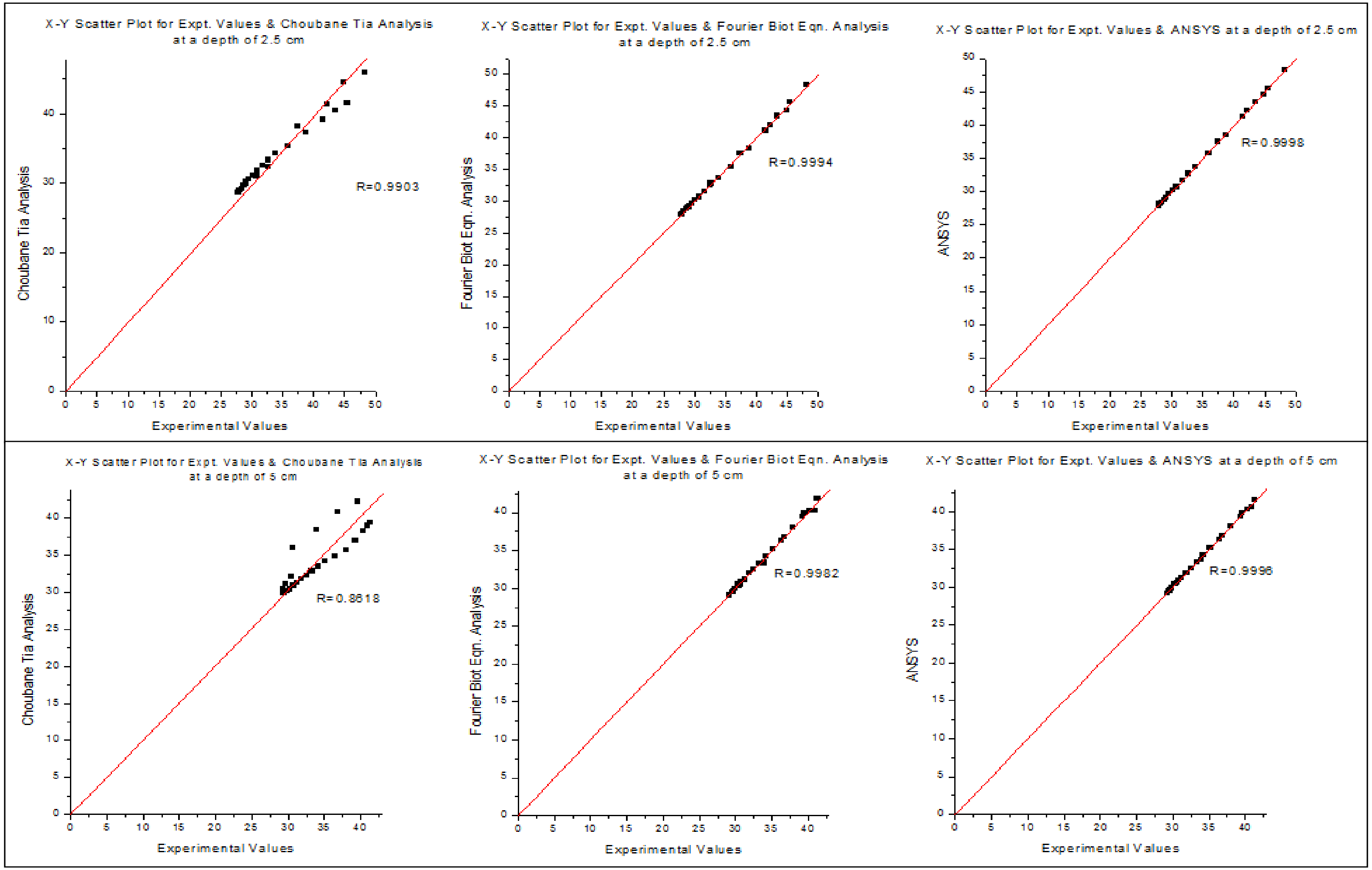


Fig. 5.13 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

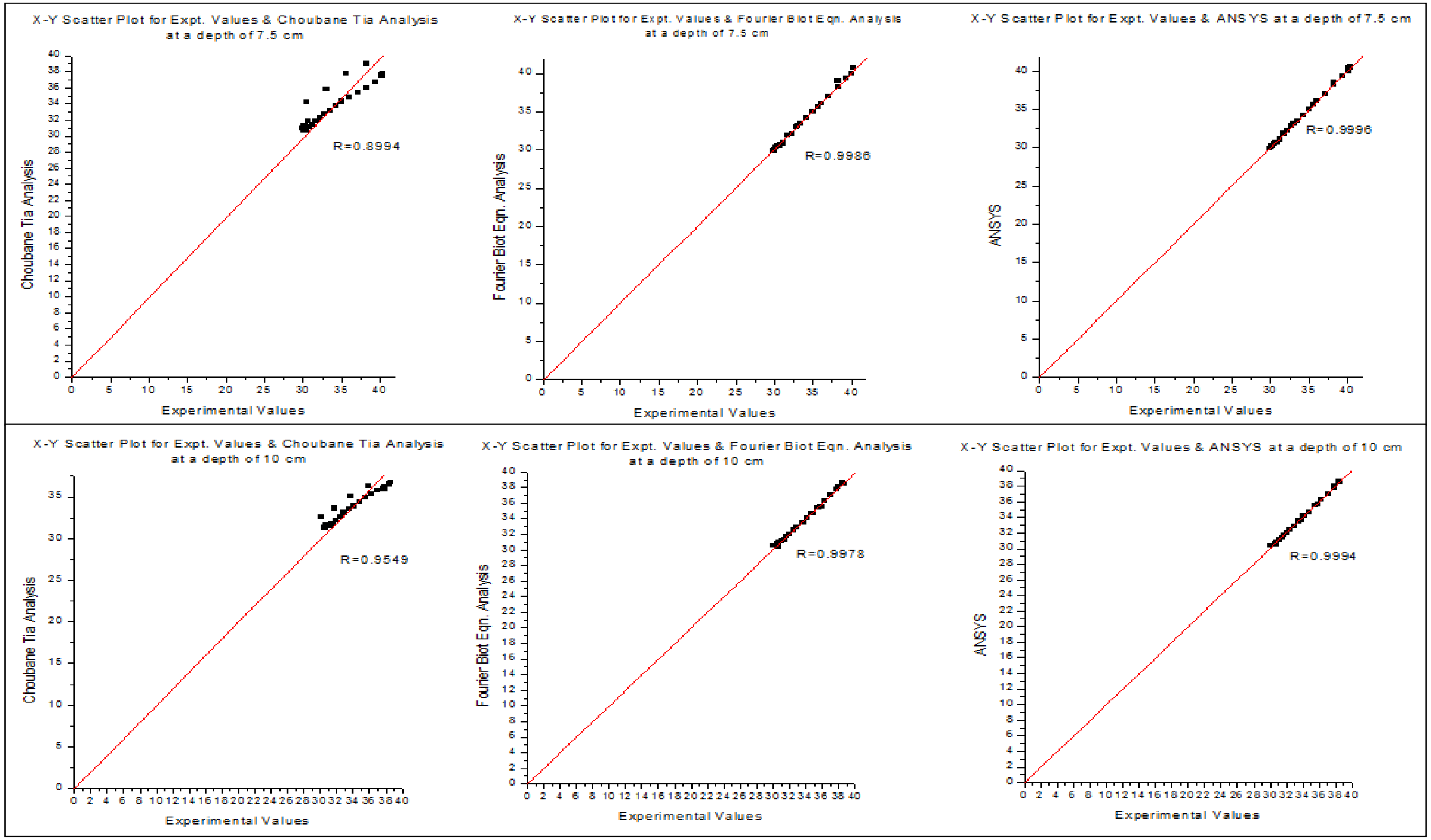


Fig. 5.13 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

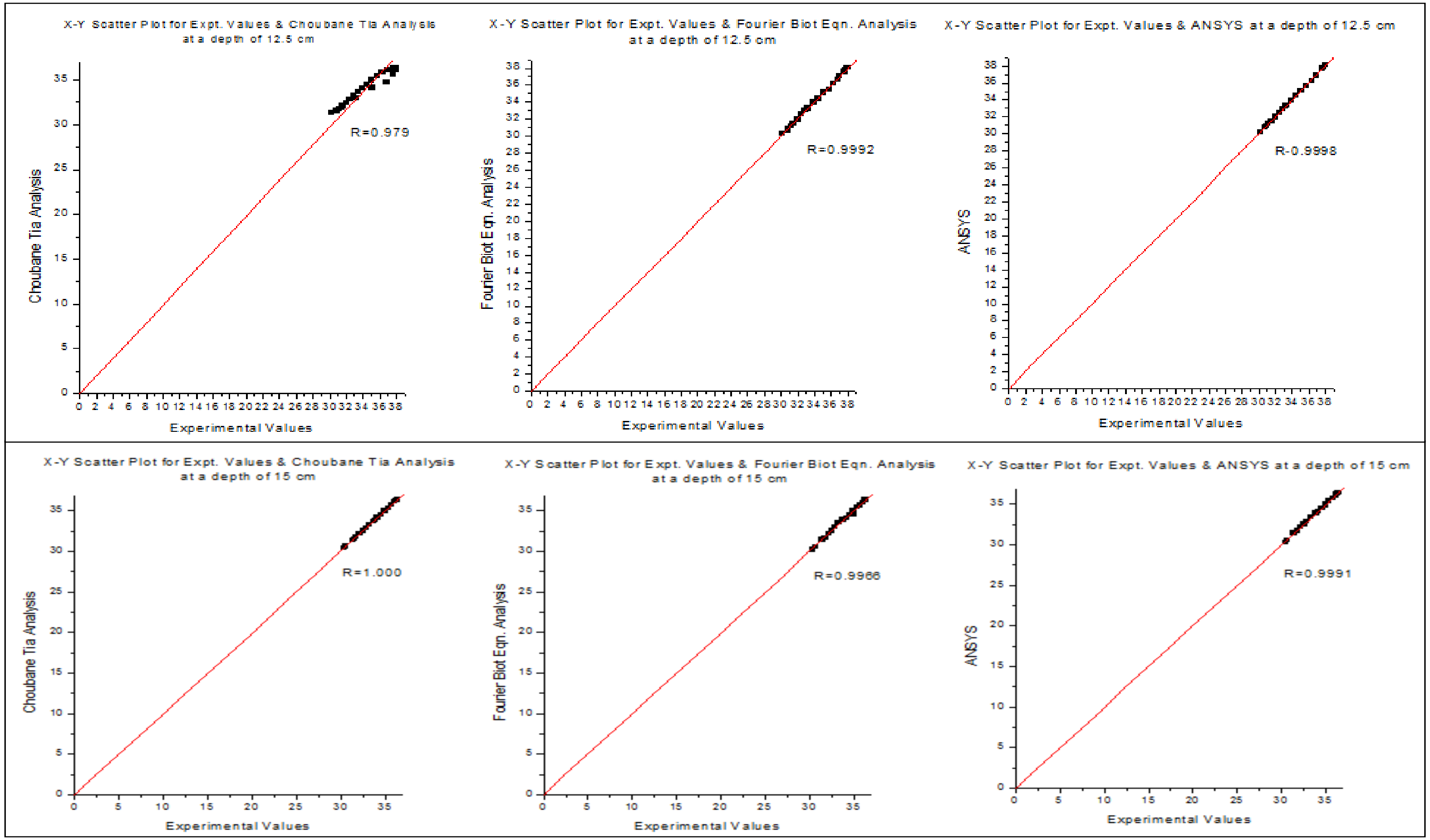


Fig. 5.13 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

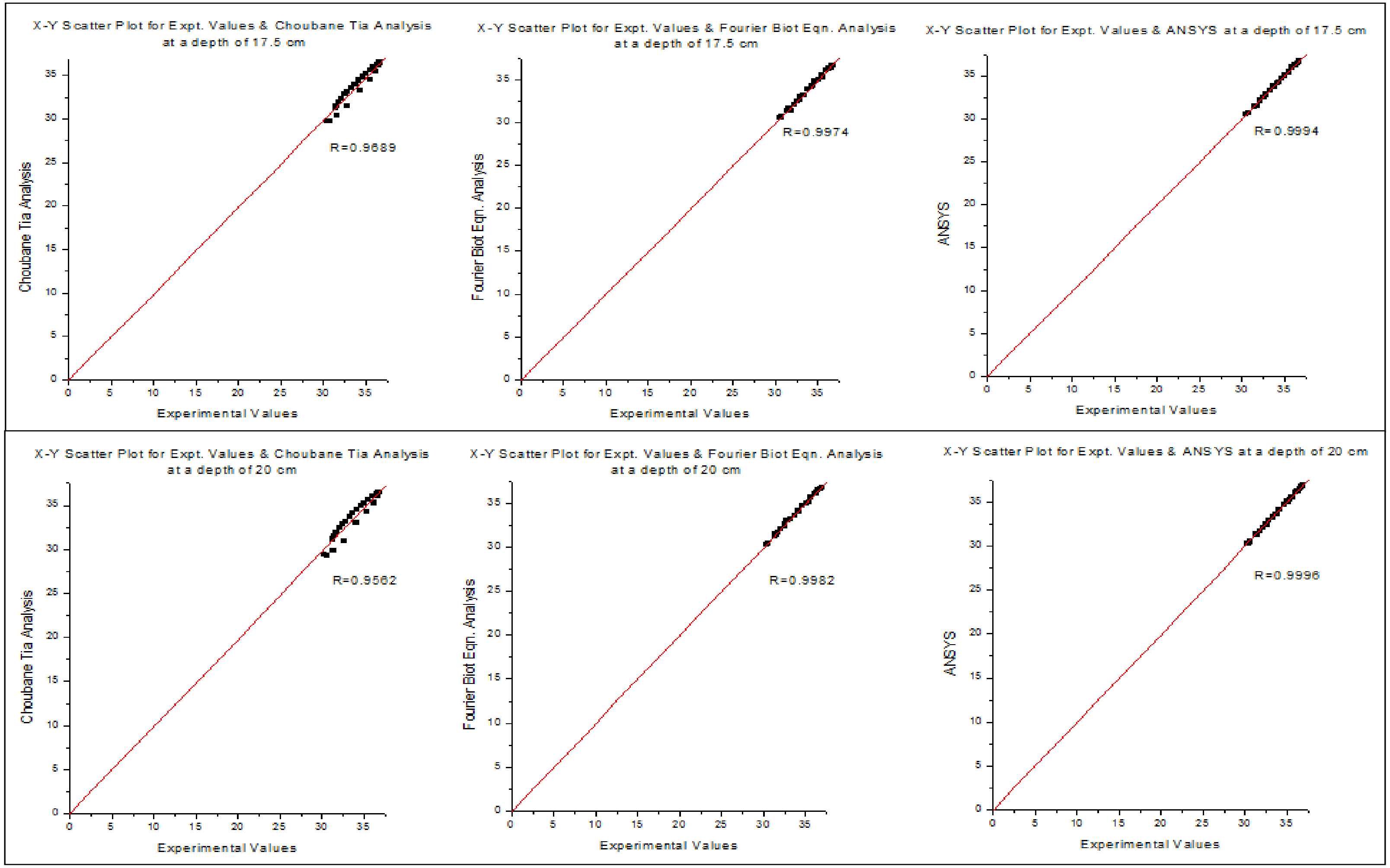


Fig. 5.13 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

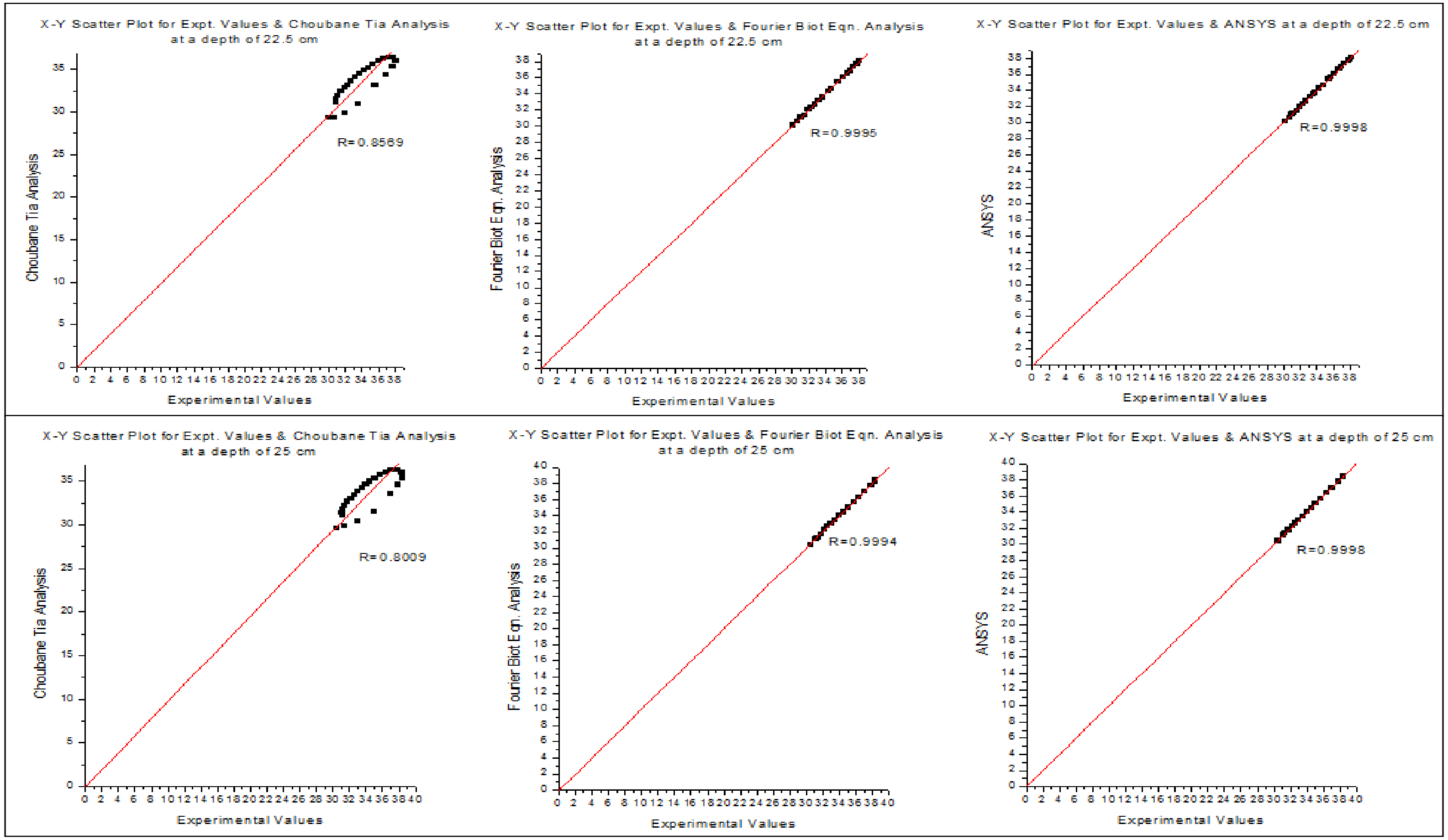


Fig. 5.13 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

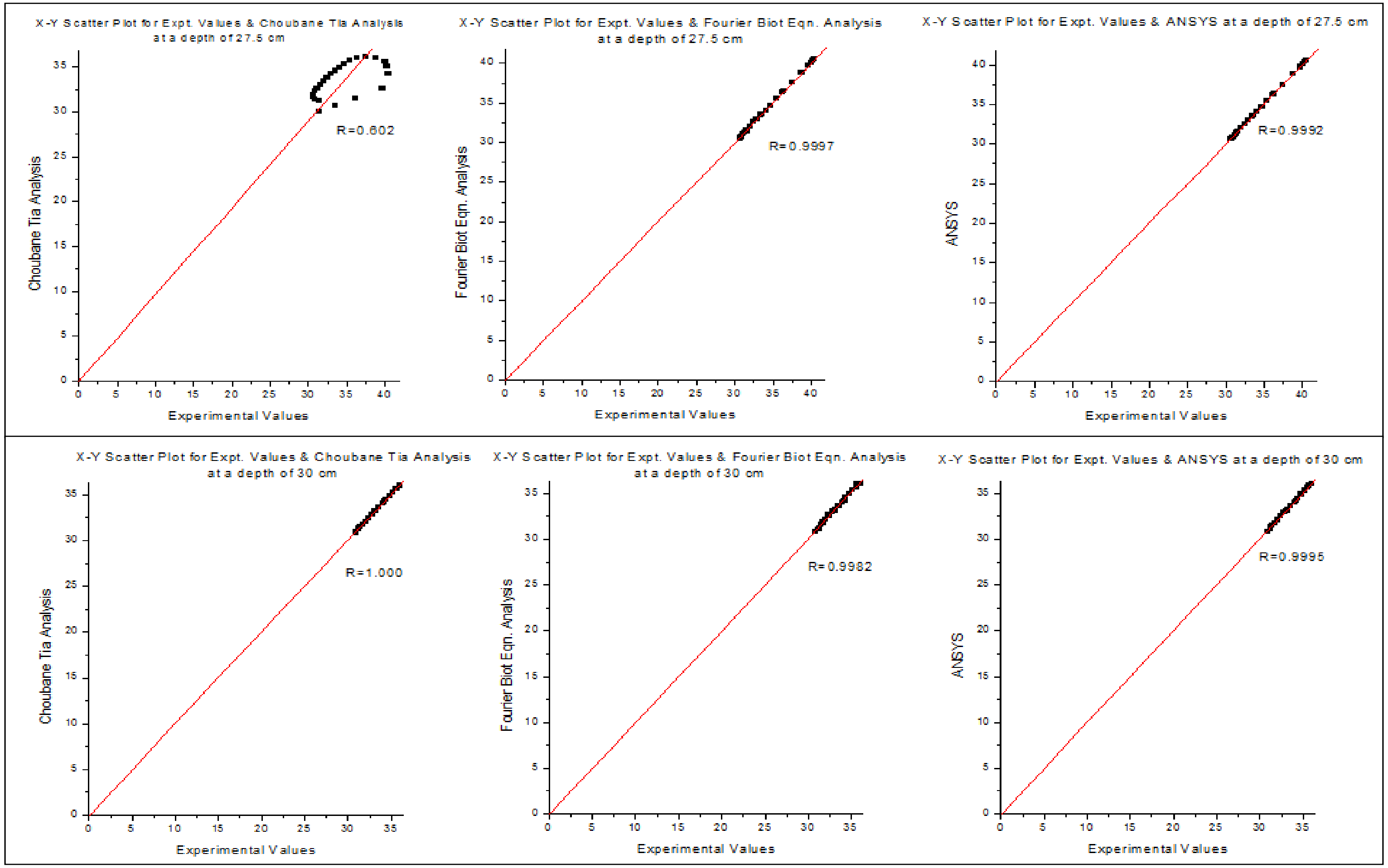


Fig. 5.13 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

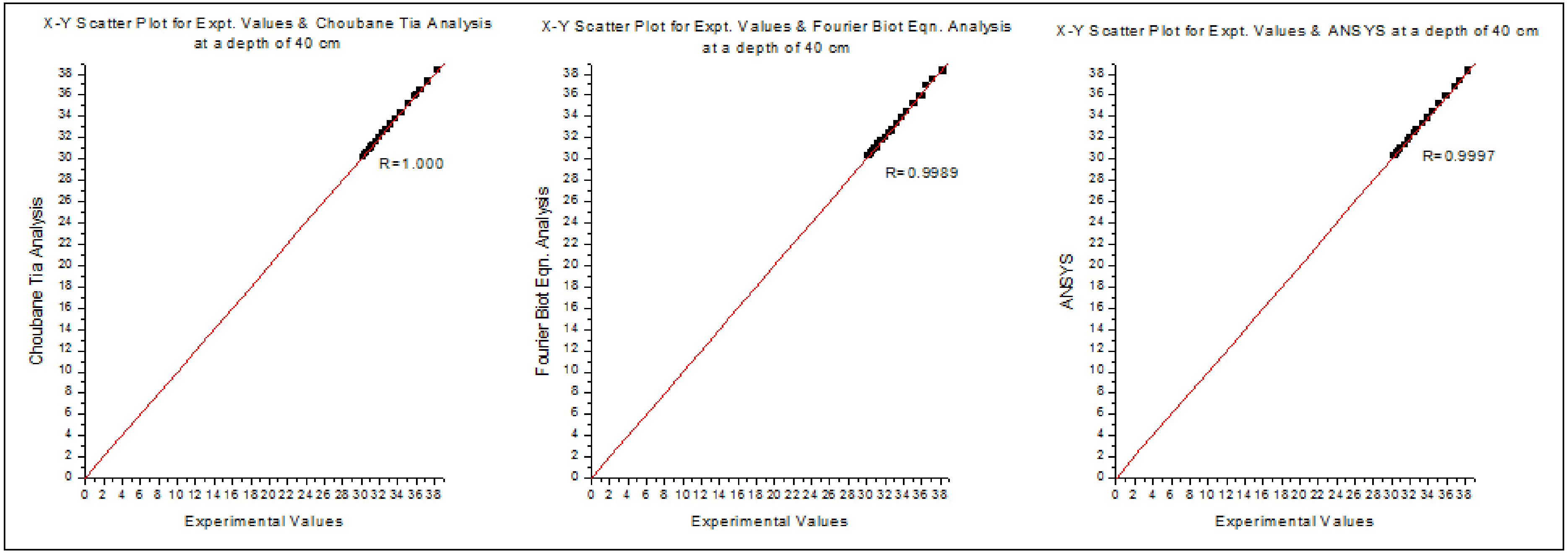


Fig. 5.13 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

The summary of the temperature differential (ΔT) and temperature gradient (ΔT/t) for the slab sections have been presented in in Table 5.8.

Table 5.8: Temperature differential and gradient across slab section (edge) for the three SCC mixes

S. No.	Case Detail	SCC Concrete Mix																							
		Mix A (Edge)				Mix A (D)				Mix B (Edge)				Mix B (D)				Mix C (Edge)				Mix C (D)			
		Day time		Night time		Day time		Night time		Day time		Night time		Day time		Night time		Day time		Night time		Day time		Night time	
		ΔT (°C)	ΔT/t (°C/mm)	ΔT (°C)	ΔT/t (°C/mm)	ΔT (°C)	ΔT/t (°C/mm)	ΔT (°C)	ΔT/t (°C/mm)	ΔT (°C)	ΔT/t (°C/mm)	ΔT (°C)	ΔT/t (°C/mm)	ΔT (°C)	ΔT/t (°C/mm)	ΔT (°C)	ΔT/t (°C/mm)	ΔT (°C)	ΔT/t (°C/mm)	ΔT (°C)	ΔT/t (°C/mm)	ΔT (°C)	ΔT/t (°C/mm)	ΔT (°C)	ΔT/t (°C/mm)
1.	Max. Ambient Air Temp.	14.45	0.048	-3.39	-0.011	16.16	0.054	-4.3	-0.014	17.43	0.058	-6.27	-0.021	14.4	0.048	-4.99	-0.017	18.74	0.063	-5.91	-0.0197	14.49	0.048	-4.2	-0.014
2.	Min. Ambient Air Temp.	16.25	0.054	-5.35	-0.018	12.69	0.042	-5.04	-0.017	15.77	0.053	-5.59	-0.019	13.6	0.045	-4.6	-0.015	6.36	0.0212	-4.68	-0.016	5.19	0.017	-3.51	-0.012
3.	Part humid and part rainy condition	11.29	0038	-3.10	-0.01	11.54	0.038	-3.8	-0.013	16.22	0.054	-3.17	-0.011	13.32	0.045	-2.6	-0.0087	6.36	0.0212	-4.68	-0.016	5.19	0.017	-3.51	-0.012
4.	24 hour cloudy and humid condition	16.56	0.055	-4.06	-0.014	14.15	0.047	-3.43	-0.011	9.86	0.033	-3.77	-0.013	9.86	0.033	-3.77	-0.013	7.98	0.027	-2.74	-0.0091	6.63	0.022	-2.05	-0.007

t: thickness of the slab section (300 mm).

The ΔT and $\Delta T/t$ values presented above represent the experimental data. From the above observations, following points were inferred;

1. Two sets of ΔT and $\Delta T/t$ values for each slab section based on the layout and arrangement of the sensors have been measured.
2. The peak positive temperature differential occurred between 1200 hrs. to 1400 hrs. The maximum negative temperature differential was observed, early morning, between 0430 hrs. to 0700 hrs.
3. For the case of maximum ambient air temperature, the maximum positive value of ΔT was measured in the edge section of Mix C (18.74^{o}C). This was on account of the addition of fly ash and perlite as cement and fine aggregate replacement additives. The insulating properties of these additions created a thermal barrier for the transmission of heat from slab top to bottom resulting in high day time ΔT values. The lowest value of day time ΔT for the case of maximum ambient air temperature was measured in the edge zone of Mix A (14.45^{o}C). This was on account of dense structure and high k value of the Mix A section that led to relatively quick dissipation of heat from the top to the bottom of the slab.
4. The maximum value of the day time ΔT measured in the present study was less than the IRC 58:2011 recommended value of 21^{o}C for a 30 cm thick slab section for the state of Andhra Pradesh.
5. For the case of minimum ambient air temperature, the maximum negative ΔT value was observed in the edge section of Mix B (-5.59^{o}C). This is on account of the addition of insulating material (fly ash) which reduced the density of the mix creating a relatively porous structure as compared to Mix A.
6. In case of part humid and part rainy condition, the values for day time ΔT measured were lowest for Mix C in edge and D section. This can be attributed to the lower density (porous matrix structure) of the concrete mix due to addition of perlite and fly ash. When the voids in the concrete are filled with moisture/water, the conductivity relatively increases as compared to the dry air voids. As the k value of water is 25 time that of air, the temperature dissipation, between the top and bottom of the slab section, in case of Mix C takes place at a rapid rate. Hence the ΔT values are lower than those measured for Mix A and Mix B. In case of Mix A and Mix B, the ΔT values are more due to dense structure as compared to Mix C which is relatively impermeable.

7. In case of 24 hr. cloudy and humid conditions, the ΔT values for Mix B and Mix C are relatively less than Mix A. This is on account of porous structure of the concrete mix which absorbs moisture from the ambient atmosphere thereby increasing the k value of the section. This led to faster dissipation of heat and lower ΔT values. In case of Mix A, higher density values indicate a dense structure which is relatively impermeable to moisture ingress. Hence, the ΔT value of Mix A for the 24 hr. cloudy and humid conditions was high.

Chapter 6

COMPUTATION OF CURLING STRESS

The chapter presents the computations of the theoretical value of the curling stress, in each of the concrete mix for the specific case study, using Westergaard's equations along with Bradbury's coefficients. The temperature gradients measured experimentally for each specific case study for the cube specimen and slab section were used in the curling stress computation.

6.1 Curling Stress Computation:

The daily variation in the concrete slab temperature develops temperature stresses in the pavement section. The temperature variation develops two types of stresses in the concrete pavement;

1. Curling stress due to temperature differential between the top and the bottom section of the pavement slab due to daily variation in the temperature at a particular location.
2. Frictional stresses due to overall increase or decrease in temperature of the pavement slab due to seasonal variation in the temperature at a particular location.

The frictional stresses between pavement slab and underlying DLC layer are not considered in the present study.

The magnitude of curling stresses due to temperature differential was first proposed by Westergaard (1927) assuming linear temperature differential. Bradbury (1938) corrected the Westergaard solution for curling stress by introducing the Bradbury coefficients.

Thus, the equations to determine curling stress for concrete pavement are;

$$\sigma_{ci} = \frac{E\alpha\Delta t}{2}\left(\frac{C_x+\mu C_y}{1-\mu^2}\right) \tag{6.1}$$

$$\sigma_{ce} = \frac{E\alpha\Delta t C_x}{2} \tag{6.2}$$

Or

$$\sigma_{ce} = \frac{E\alpha\Delta t C_y}{2} \tag{6.3}$$

where;

σ_{ci}: curling stress in the slab interior (MPa)

σ_{ce}: curling stress in the edge section (maximum of the two equations is to be considered) (MPa)

E: modulus of elasticity of concrete specimen (kg/cm^2)

α: coefficient of thermal expansion of concrete specimen (/^{o}C)

Δt: temperature differential measured between the top and bottom of the slab (^oC)

μ: Poisson's ratio of concrete

C_x: coefficient in the X direction depends on the ratio of L_x/l

C_y: coefficient in the Y direction, depends on the ratio of L_y/l

l: radius of relative stiffness (cm)

L_x: interval of transverse joints (cm)

L_y: interval of longitudinal joints (cm)

The radius of relative stiffness is determined as;

$$l = \left[\frac{Eh^3}{12K(1-\mu^2}\right]^{1/4} \quad (6.4)$$

h: slab thickness (cm)

k: modulus of subgrade reaction (kg/cm^3).

In the present study, using the above mentioned Westergaard equations, theoretical value of curling stress was determined. As the temperature differential values for cube specimen (15cm) and slab sections (30cm) were determined, the curling stress values (theoretical) were computed for 15cm thick and 30cm thick slabs for the three SCC mixes. The material properties considered for the computation of theoretical curling stresses are summarized and presented in Table 6.1;

Table 6.1: Material properties and slab geometry considered for computation of theoretical curling stresses.

Material property	Mix A	Mix B	Mix C
Modulus of elasticity of concrete (kg/cm^2)	3.14×10^5	2.70×10^5	1.96×10^5
Modulus of subgrade reaction (kg/cm^3)	6.9 (for a soaked CBR of 20%)		
Poisson's ratio	0.15		
Plan dimensions of the slab	5.5 m x 3.5 m		
Slab thickness	15cm and 30cm		

The modulus of elasticity considered in the computation of the curling stress was determined mathematically by using the relation between ultrasonic pulse velocity and density of the concrete specimen (Lamond et al. 2006). The equation is as below,

$$E_d = \frac{v^2\rho(1+\mu)(1-2\mu)}{(1-\mu)} \quad (6.5)$$

where;

E_d: dynamic modulus of elasticity (kg/cm^2)

ρ: density of concrete (kg/m^3)

μ: dynamic Poisson's ratio (0.22)

v: ultrasonic pulse velocity (m/s)

As per Neville (2010), the static elastic modulus is determined by the following empirical relation

$$E = 0.83E_d \tag{6.6}$$

The values of modulus of elasticity tabulated above are calculated using above formulae. As per Lamond et al. (2006), the Poisson's ratio for all types of concrete can be considered between 0.15 to 0.20. A value of 0.15 was adopted in the present study.

Table 6.2 (a) and 6.2 (b) presents the curling stress values (theoretical) computed using Westergaard equations along with Bradbury's coefficients for slab thickness of 15 cm and 30 cm.

Table 6.2 a: Curling Stress for 15 cm thick slab

Case consideration	Curling stress (MPa) for 15 cm thick slab											
	Mix A (Edge)		**Mix A (Interior)**		**Mix B (Edge)**		**Mix B (Interior)**		**Mix C (Edge)**		**Mix C (Interior)**	
	Day	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
Max. ambient air temp.	1.64	-0.45	1.87	-0.51	2.47	-0.49	2.84	-0.56	0.87	-0.25	1.02	-0.29
Min. ambient air temp.	0.78	-0.50	0.89	-0.57	1.08	-0.48	1.24	-0.55	0.71	-0.36	0.83	-0.42
24 hr. precipitation	0.17	-0.17	0.19	-0.2	0.01	-0.06	0.01	-0.06	0.00	-0.05	0.00	-0.05
Part humid and part rainy condition	0.49	-0.23	0.55	-0.27	0.29	-0.09	0.33	-0.11	0.31	-0.14	0.37	-0.16
24 hr. Cloudy and humid condition	0.78	-0.24	0.89	-0.27	1.26	-0.20	1.45	-0.23	0.82	-0.14	0.96	-0.17
2 hr. sudden precipitation	0.46	-0.25	0.52	-0.29	0.52	-0.18	0.60	-0.20	0.57	-0.16	0.67	-0.16

Table 6.2 b: Curling Stress for 30 cm thick slab

Case consideration	Curling stress (MPa) for 30 cm thick slab											
	Mix A (Edge)		Mix A (Interior)		Mix B (Edge)		Mix B (Interior)		Mix C (Edge)		Mix C (Interior)	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Max. ambient air temp.	1.78	-0.42	2.17	-0.58	1.89	-0.68	1.72	-0.60	1.62	-0.51	1.39	-0.40
Min. ambient air temp.	2.00	-0.66	1.70	-0.68	1.71	-0.61	1.62	-0.55	0.55	-0.40	0.50	-0.34
Part humid and part rainy condition	1.39	-0.38	1.55	-0.51	1.76	-0.34	1.59	-0.31	0.55	-0.40	0.50	-0.34
24 hr. Cloudy and humid condition	2.04	-0.50	1.90	-0.42	1.49	-0.51	1.18	-0.45	0.69	-0.24	0.64	-0.20

6.2 Discussion on Results:

From the results of the curling stress computations, following points were observed,

1. The theoretical curling stress values computed using Westergaard equations were less than the minimum flexural strength requirement of 4.5MPa as prescribed by IRC 58:2011. The magnitudes of these stresses computed, were also less than the 28 day flexural strength (7.34MPa for Mix A, 6.54MPa for Mix B and 8.34MPa for Mix C) of specimens measured.
2. In case of 15cm thick slab,
    a. A general trend observed in the curling stress results, for all three mixes, was that the magnitude of day time curling stress in the slab interior was more than the magnitude of the curling stresses in the slab edge section.
    b. For maximum ambient air temperature condition, the day time slab interior stress was more than the curling stress in slab edge section by 14.02% for Mix A, 14.98% for Mix B and 17.24% for Mix C respectively. For night time, the slab interior stress was more than the slab edge stress by, 13.34% for Mix A, 14.29% for Mix B and 13.79% for Mix C respectively.
    c. As compared to Mix A, the day time slab edge stress for Mix B was 50.61% more and for Mix C it was 46.95% less for the case of maximum ambient air temperature. The slab interior stress for Mix B was 51.87% more and 45.45% less as compared to the interior stresses for Mix A.
    d. The night time edge stresses for maximum ambient air temperature, in case of Mix B were 8.89% more as compared to Mix A, while the interior stresses were 9.80% more. In case of Mix C, these stresses were 44.44% and 43.14% less in the edge and interior region respectively.
    e. The magnitude of the day time curling stress (edge as well as interior) was maximum for Mix B as compared to the other mixes. Mix B comprises 20% fly ash as a cement replacement material. Mix B had relatively lower k values as compared to Mix A as a result of which temperature differential developed across the cross section was more as compared to Mix A. This resulted in higher values of curling stresses.
    f. The magnitude of, day time as well as night time, curling stress (edge as well as interior) in case of Mix C was the least of the corresponding values as compared to the other mixes. This can be attributed to the insulating nature of

fly ash (added as cement replacement) and perlite (added as a fine aggregate replacement). The insulating envelope created over the slab geometry by these two additions prevent heat transmission through the slab resulting in relatively lower magnitude of temperature differential being created across the slab cross section.

g. For the case of minimum ambient air temperature, the trend of higher values of slab interior stresses as compared to slab edge stresses was observed. The slab interior stresses were 14.10% more for Mix A, 14.82% more for Mix B and 16.9% more for Mix C than the slab edge stresses for day time

h. The night time slab interior curling stresses were 14% (Mix A), 14.58% (Mix B) and 16.67% (Mix C) more than the slab edge stresses.

i. As compared to day time edge and interior curling stresses for Mix A, the corresponding values were 38.46% and 39.32% more in case of Mix B and 8.97% & 6.74% less for Mix C.

j. The night time edge and interior curling stress values in case of Mix B were 4% & 3.51% less as compared to the corresponding values for Mix A. For Mix C these values were 28% and 26.32% lower.

3. In case of 30cm thick slab,

a. For the case of maximum ambient air temperature, the magnitude of the day time slab interior curling stress was 21.91% more than the edge stress for Mix A. For Mix B and Mix C, the slab interior stresses were 8.99% and 14.20% lower than the slab edge stresses during the day. The night time slab interior stress was 38% more, 11.77% less and 21.57% less than the edge stress for Mix A, B and C respectively.

b. As compared to Mix A, the day time slab edge stresses of Mix B and Mix C were 6.18% more and 8.98% less respectively. The slab interior stresses for Mix B and Mix C were 20.74% and 35.95% lower as compared to the slab interior stresses for Mix A.

c. The night time edge stresses for Mix B and Mix C were 61.90% and 21.43% higher as compared to the corresponding value of Mix A. The interior stress for Mix B was 3.45% more while for Mix C it was 31.04% less as compared to Mix A.

d. For the case of minimum ambient air temperature, the day time slab edge stresses in Mix B and Mix C were 14.5% and 72.5% less than Mix A. The day time slab interior stresses for Mix B and Mix C were 4.71% and 70.59% lower as compared to Mix A. The night time slab edge and interior stresses for Mix B were 7.58% and 19.12% lower as compared to Mix A. In case of Mix C these values were 39.39% and 50% lower in comparison to respective curling stresses in Mix A.

4. The magnitude of the slab interior stress was more than the slab edge stress. As seen in Fig. 4.10, SCC is mainly comprised of matrix phase uniformly distributed around the aggregate phase. The edge portion of the geometry essentially comprises of matrix phase. From the literature it was noted that the thermal properties and behaviour of concrete are influenced by the thermal properties of the aggregate phase as well as matrix phase. Due to uniform structure of the matrix phase, relative thermal conductivity will be high in the edge section as compared to the slab interior section. In the interior section, the interaction of aggregate phase and matrix phase, as well as difference in the thermal properties of these phases, leads to slower conduction of heat through the cross section. This leads to higher values of ΔT resulting in higher magnitude of curling stress in the slab interior. Thus, difference in the magnitude of curling stresses was observed in the edge section as well as central section for all the slab sections for all case considerations.
5. The additions to the concrete mix (fly ash and perlite) not only alter the density of the matrix phase, but also the thermal properties of the overall mix. The powder additions reduce the overall density of the hardened concrete making it more permeable thereby improving its thermal conductivity. Hence, as compared to Mix A, Mix B and Mix C show drop in the ΔT value which gets reflected in the computed values of curling stresses.
6. In wet and humid conditions, the magnitude of the edge stresses were more than the interior due to denser matrix composition in the edge zone of the slab which is relatively impermeable to moisture ingress. This creates a ΔT between slab top and bottom in the edge zone. Due to matrix-aggregate interaction and difference in the properties of each phase, relatively temperature dissipation occurs more quickly and with presence of moisture it is more accelerated. So the ΔT value is relatively less as compared to the ΔT value in the edge section. This results in lower value of the curling stress in the slab interior section in wet and humid condition.

Chapter 7

CONCLUSIONS AND FUTURE SCOPE

7.1 Summary of findings from the present study:

Based on the experimental investigations and results obtained following conclusions were drawn;

A. SCC mixes with NS and CS:

1. The fresh state properties of SCC mixes with NS are a shade better than the fresh state properties of SCC mixes with CS. This is attributed to the rounded shape and smooth texture of NS fine particles as compared to angular shaped and rough textured CS particles.
2. SCC mixes with crushed sand (CS) have resulted in better mechanical properties as compared to the SCC mixes with natural sand (NS). This is on account of excellent particle packing and arrangement in the matrix phase as compared to the SCC mixes with NS. This is evident from high values of the density of the SCC mixes with CS at all ages. It was also reflected from the higher values of ultrasonic pulse velocities observed in the cube specimens of SCC mixes with CS.
3. The use of CS as a fine aggregate material is crucial from environmental sustainability point of view. Due to harmful effects of NS mining on riverine ecology, legislations are formulated to ban the use of NS for concrete manufacture. Under such circumstances, use of CS is a viable alternative as it lead to better mechanical and durability properties as well as ensures conservation of valuable natural resource.
4. One potential drawback of use of CS for SCC mix preparation is higher dosage of superplasticiser required to achieve desired fresh state properties which increases the risk of segregation and bleeding. However, it can be offset by appropriate powder additions.
5. The microstructure studies provide an important avenue to validate the particular performance or behaviour of the material based on the relative arrangement of ingredients in the hardened mix.

B. Fly ash addition to SCC mixes:

1. SCC mix design can be powder based or admixture based or a combination of both. Use of pozzolanic or inert additions as cement replacement materials helps to improve fresh state properties of SCC mix at lower HRWR dosage and does not

require VMAs to stabilize the fresh mix. In the present study, powder based mix design was adopted with use of Class C fly ash as a cement replacement material.

2. The addition of fly ash as a cement replacement material in SCC mixes helps in improving the carbon foot print of the SCC mix. Conceptually SCC mixes are characterized as high cement content mixes (cement content in excess of 500kg/m^3). Addition of fly ash as a cement replacement material ensures conservation of environment due to reduced emissions in cement manufacture as well as recycling of an environmental hazard.
3. Class C fly ash exhibits pozzolanic as well as hydraulic reactivity. This is evident from the gain in 90 day cube compressive strengths for SCC mixes. Though its addition slows down the gain of 28 day cube compressive strength.
4. Fly ash addition improves the fresh state properties of SCC mixes with CS at lower superplasticizer dosage. Hence, the addition of fly ash helps in economizing the SCC mix due to reduced HRWR dosage.

C. Perlite addition to SCC mixes:

1. Perlite is a light weight insulating material commonly used as a light weight additive for replacing aggregates. The addition of perlite helps to improve the thermal and acoustic performance of hardened concrete.
2. In the present study, addition of perlite, as a fine aggregate replacement material, reduced the density of the SCC mix. It lowered the hardened state performance of the concrete mix, though there was no significant impact on the thermal performance of the mix.

D. Thermal conductivity studies:

1. The investigations were undertaken on SCC. It is characterized by high fines content as compared to normal concrete. Due to higher proportion of fines and dense particle packing arrangement, the k value of the SCC mix was comparatively high.
2. Another reason for high thermal conductivity values of Mix A as compared to the other SCC mixes with powder additions was the use of granite aggregates. The granite based aggregates have high values of thermal properties which reflect in the thermal properties of concrete mix.

3. The addition of insulating materials like fly ash and perlite creates a thermal barrier in the concrete specimen lowering its k value and significantly influencing the thermal properties of the hardened concrete mix.

E. Temperature gradient studies:

1. The ΔT values measured were dependent on the mix composition and k values in the present study. From the experimental observations it was observed that the ΔT values were lower for Mix A specimens due to high density and k values.
2. The powder additions (fly ash as well as perlite) increase the ΔT values for SCC mix due to the insulating properties of these additions. Hence, the dosage of these powders needs to be experimentally analysed to ensure that the ΔT values are not exceeding the recommended limits.
3. With the increase in the thickness of the pavement slab, the magnitude of the temperature differential (ΔT) values are more, but the temperature gradient (ΔT/t) developed is less.
4. The presence of moisture makes the pavement slab highly conductive which is reflected by a near zero temperature differential.
5. The temperature values obtained using Choubane Tia model were varying widely from the experimental values as the model considered only the temperature values and did not consider the material properties that also influence its thermal performance.
6. Fourier Biot equation gave a series of results close to the experimental values as this equation considers, the density, specific heat and thermal conductivity values of the concrete mix for computations.

F. Curling stress computations:

1. The magnitude of curling stress follows the trend observed in the temperature differential measurement.
2. The addition of fly ash in the SCC mix lowered the k value of the SCC mix turning it into an insulating material, thereby increasing the magnitude of temperature differential and curling stresses.
3. The addition of perlite as a fine aggregate replacement material lowered the k values of the SCC mix significantly as compared to Mix A and Mix B. The magnitude of temperature differential developed in SCC mix with fly ash and perlite addition increased however, it resulted in lowering of the curling stress

value. This can be attributed to the insulating nature of perlite which prevented transmission of temperature differential across the slab thickness.

7.2 Conclusions from the present study:

1. The SCC mix with CS are preferred over SCC mix with NS due to better hardened state properties (28 day cube compressive strength for SCC mix with CS was 23.02% more than the corresponding value for SCC mix with NS).
2. M-40 grade SCC mix with CS can be adopted for pavement applications as it satisfies the requirement of compressive strength (55.31MPa against target value of 48.25MPa) and flexural strength (7.34MPa against target value of 4.5MPa) for M-40 grade pavement quality concrete .
3. The powder based SCC mix design resulted in homogeneous SCC mix from the point of view of fresh state properties observed during the laboratory investigations. It resulted in dense and homogenous matrix phase as observed in the microstructure images of the hardened concrete.
4. The appropriate fly ash dosage as a cement replacement material recommended from the present study is 20%. The 28 days compressive strength values (50.70 MPa) and flexural strength (6.54 MPa) at 20% dosage level satisfy the target values of 48.25 MPa and 4.5 MPa respectively. The findings also validate the 20% fly ash dosage guideline recommended in IRC 44:2008.
5. The present study concludes that, perlite can be adopted as a fine aggregate replacement material. The study inferred that 5% replacement levels are appropriate as they satisfy the 28 days compressive strength (50.37MPa>48.25MPa) and flexural strength (8.34MPa>4.5MPa) requirement for pavement application.
6. The k values of the SCC mixes measured in the present study were influenced by the density of the specimen, mix composition and test temperature conditions. The SCC mix with higher density had higher k values. With increase in the magnitude of the test temperature, the k values reduced by 7% to 25% depending on the type of mix.
7. The development of the temperature gradient across the slab cross section is influenced by the material composition (powder additions), properties (density, k values) and ambient conditions (temperature, humidity, precipitation).
8. The maximum value of temperature differential was observed in the day time between 1200 hrs. to 1400 hrs. This is also the duration when maximum value of curling stress occurs in the slab section. However, it was observed in the present study, that the

magnitude of the curling stress was not uniform throughout the 24 hr. observation period. The assumption in the design code of practice to consider uniform magnitude of curling stress in the design of rigid pavements leads to conservative magnitudes. It is recommended to consider the varying magnitude of the temperature gradient and curling stress in the design process of rigid pavements.

7.3 Limitations of the Research:

The research study undertaken is based on the following assumptions,

1. The study is focused only on determination of temperature gradients developed in the test sections in M-40 grade SCC mix. The vehicle or traffic loads are not considered in the study.
2. The SCC slabs were cast over dry lean concrete layer in the present study. This study does not consider the interaction at the bottom of the SCC slab and the top surface of DLC layer.
3. The effects of the thermal property of the soil subgrade and its impact on the slab investigations are not considered.
4. The study is limited to the measurement of the temperature gradient developed on account of transient environmental conditions. The study does not consider and assess the built-in curl developed in the test sections.
5. The study does not consider the moisture gradient developed in the test sections.
6. Of the various thermal properties discussed in the literature review, the study measured the thermal conductivity values only.
7. The thermal conductivity values in the present study were measured using steady state test set up. However, in practice the concrete sections are subjected to transient environmental conditions. The thermal conductivity values in transient state were not measured.
8. The study does not measure the thermal properties (CTE) of the constituent materials (cement, coarse aggregates and fine aggregates) in the mix considered. The values mentioned in the literature were considered in the present study.

7.4 Future Scope:

The following points have been identified as a possible scope for future research;

1. In the present study, a binary combination of cement fly ash mixture was investigated in SCC mixes. Investigations into use of ternary or quaternary powder combinations

on the fresh state, hardened state and thermal properties of SCC mixes for pavement applications can be investigated.

2. The scope of present study was limited to measurement of temperature gradient and evaluation of theoretical values of curling stresses was undertaken. However, detailed instrumentation of full scale slab prototype to measure stresses and strains on account of temperature loads and vehicular loads needs to be undertaken and the field investigations can be validated by appropriate mathematical models.
3. In the present study, only k values of the SCC mixes (with possible powder combinations) were investigated. However, the measurement of CTE, specific heat values of the SCC mix with powder combinations also needs to be undertaken to understand the field behaviour of these mixes for various environmental and traffic loading conditions.
4. Measurement of thermal conductivity values of SCC mix (with additions as well) under moist conditions and in transient state. In the present study, the k values were determined by steady state on dried specimens. However, in practice, the specimens are subjected to transient environmental conditions (moisture and temperature variations in particular).
5. The slab prototypes cast in the present study were below the surrounding ground level. It simulates the condition of a pavement in cut section (Fig. 5.3 b). The effect of temperature loads on the SCC pavement slab laid on embankment can also be investigated.
6. The ΔT values were measured for the slabs laid in the east-west orientation (along the length). The effect of the layout of slabs in the other orientation directions on its thermal behaviour can also be investigated.
7. Use of Magnesium oxy-chloride cement (MOC) in SCC mixes. MOC is high strength quick setting cement that does not require humid curing. This cement has low specific gravity (2.4), low coefficient of thermal expansion, excellent fire resistance and good abrasion resistance. Possible applications of this cement in pavement construction and its influence on the thermal performance of the pavement concrete can be investigated.

Contributions from the present study:

1. The study presents an experimental methodology to measure temperature differential across the pavement slab.
2. It highlights the importance of microstructure analysis and investigations of the hardened concrete mix to correlate the mechanical properties with the arrangement of the ingredients in the material.
3. The study suggests that, thermal properties (thermal conductivity in the present study) influences the development of the temperature gradient across the pavement cross section along with the other factors like topography, altitude, latitude, proximity to sea, land use patterns, road side avenues and facilities.
4. The study recommends that actual temperature differential values to be considered in estimation of curling stresses rather than uniform temperature differential as recommended in IRC 58-2011 code of practice.
5. The addition of fly ash (as a cement replacement material) in the concrete mix ensures a sustainable mix. However, the present study suggests that the addition of fly ash influences the properties and performance of the hardened concrete, especially when subjected to environmental loads. This aspect has to be considered in case of mix design of pavement concrete with fly ash. This study also suggests that addition of perlite can help offset the negative impact of fly ash on the thermal properties of pavement concrete.

REFERENCES:

Ahmad, I., Rahman, M. H., Seraj, S. M., and Hoque, A. M. (1998). “Performance of plain concrete runway pavement.” *Journal of Performance of Constructed Facilities*, 12(3), 145-157.

Al-Ostaz, A. (2007). “Effect of Moisture Content on the Coefficient of Thermal Expansion of Concrete.” *University of Mississippi and Mississippi Dept. of Transportation*, MS.

Asbahan, R. E., and Vandenbossche, J. M. (2011). “Effects of Temperature and Moisture Gradient on Slab Deformation for Jointed Plain Concrete Pavements.” *Journal of Transportation Engineering*, 137(8), 563-570.

Banfill P.F.G. (2011). “Additivity effects in the rheology of fresh concrete containing water-reducing admixtures.” *Construction and Building Materials*, 25, 2955–2960.

Bektas, F., Turanli, L., and Monteiro, P. J. M. (2005). “Use of perlite powder to suppress the alkali–silica reaction.” *Cement and Concrete Research*, 35(10), 2014–2017.

Belshe, M., Mamlouk, M. S., Kaloush, K. E., and Rodenzo, M. (2011). “Temperature Gradient and Curling Stresses in Concrete Pavement with and without Open-Graded Friction Course.” *Journal of Transportation Engineering*, 137(10), 723-729.

Bentz, D. P., Peltz, M. A., Duran-Herrera, A., Valdez, P., and Jaurez, C. A. “Thermal properties of high-volume fly ash mortars and concrete.” *Journal of Building Physics*, 34(3), 263-275.

Berry, E. E., and Malhotra, V. M. (1980). “Fly ash for use in Concrete – A Critical Review.” *ACI Journal*, 77(2), 59-73.

Bindiganavile, V., Batool, F., and Suresh, N. (2012). “Effect of fly ash on thermal properties of cement based foams evaluated by transient plane heat source.” *The Indian Concrete Journal*, 86(11), 7-14.

Binod Kumar, Mathur Renu, and Gangopadhyay, S. (2012). “Rigid Pavement Response to Environmental and Traffic Loading Investigated Through Instrumentation.” *Highway Research Journal*, Indian Roads Congress, 5(2), 1-8.

Breakah, T. M., Williams, C. R., Herzmann, D. E., and Takle, E. S. (2011). “Effects of Using Accurate Climatic Conditions for Mechanistic-Empirical Pavement Design.” *Journal of Transportation Engineering*, 137(1), 84-90.

Buch, N., and Jahangirnejad, S., (2008). “Quantifying Coefficient of Thermal Expansion Values of Typical Hydraulic Cement Concrete Paving Mixtures.” *Michigan Dept. of Transportation and Michigan State University*, MI.

Burgos-Montes, O., Palacios, M., Rivilla, P., and Puertas, F. (2012). “Compatibility between superplasticizer admixtures and cements with mineral additions.” *Construction and Building Materials*, Elsevier Ltd, 31, 300–309.

Callister (Jr.), W. D. (2007). *Materials Science and Engineering*, John Wiley & Sons, 7th Ed., USA.

Chen, H. L., and Choi, J. H. (2011). “Analysis of Shrinkage and Thermal Stresses in Concrete Slabs Reinforced with GFRP Rebars.” *Journal of Materials in Civil Engineering*, 23(5), 612-627.

Chen, H. L., and Choi, J. H. (2002). “Effects of GFRP reinforcing rebars on shrinkage and thermal stresses in concrete.” *Proceedings 15th ASCE Engineering Mechanics Conference*, New York.

Choubane, B., and Tia, M. (1992). “Non-Linear Temperature Gradient Effect on Maximum Warping Stresses in Rigid Pavements.” *Transportation Research Record 1370,* Washington, TRB, National Research Council, 11-19.

Choubane, B., and Tia, M. (1995). “Analysis and Verification of Thermal Gradient Effects on Concrete Pavements.” *Journal of Transportation Engineering*, 121(1), 75-81.

Dehdezi, P. K. (2014). “Impact of Concrete Thermophysical Properties on Pavement Structural Design.” *Journal of Materials in Civil Engineering,* 26, 1-6.

Delatte, N. (2008). “Concrete Pavement Design, Construction and Performance.” Taylor and Francis, Oxon, UK, pp. 1-2.

Demirboğa, R., and Gul, R. “The effects of expanded perlite aggregate, silica fume and fly ash on thermal conductivity of lightweight concrete.” *Cement and Concrete Research*, 33, 723-727.

Domone, P. L. (2006). “Self-compacting concrete: An analysis of 11 years of case studies.” *Cement and Concrete Composites*, 28(2), 197-208.

European Federation of National Associations Representing producers and applicators of specialist building products for Concrete (EFNARC), “The European Guidelines for Self Compacting Concrete – Specification, Production and Use”, May 2005.

Felekoğlu B., Tosun K., Baradan B., Altun A., and Uyulgan B. (2006). “The effect of fly ash and limestone fillers on the viscosity and compressive strength of self-compacting repair mortars.” *Cement and Concrete Research*, 36, 1719–1726.

Fwa, T. F. (2006). *The Handbook of Highway Engineering,* Taylor and Francis, Boca Raton.

Gaimster, R., and Dixon, N. (2003) “Self Compacting Concrete”, in Newman, J., Choo, B. S. (Eds.) *Advanced Concrete Technology, Process,* Elsevier Butterworth Heinemann, Oxford, pp. 9-1 to 9-23.

Gandage, A. S., and Ram, V. V. (2014). "Role of Supplementary Cementitious Materials in Self Compacting Concrete : A Review." *The Indian Concrete Journal*, 88(6), 42-59.

Gandage, A. S., Ram, V. V., and Joshi, R. A. (2013a). "Comparative Study of Thin Section Petrographic Analysis for Normal Concrete and Self-Compacting Concrete." *Proceedings of International Conference on Advances in Science and Technology of Concrete,* organized by India Chapter of American Concrete Institute (IC-ACI), Mumbai, 290-293.

Gandage, A. S., Narsale, V. D., and Joshi, R. A. (2013b). "Study of Alkali Aggregate Reactivity using Thin Section Petrographic Analysis." *Highway Research Journal*, Indian Roads Congress, 6(2), 8-16.

Ghafoori, N., and Diawara, H. (2010). "Influence of temperature on fresh performance of self-consolidating concrete." *Construction and Building Materials,* Elsevier Ltd, 24(6), 946–955.

Girish, S., Ranganath, R. V., and Vengala, J. (2010). "Influence of powder and paste on flow properties of SCC." *Construction and Building Materials*, 24(12), 2481-2488.

Gołaszewski, J., and Szwabowski, J. (2004). "Influence of superplasticizers on rheological behaviour of fresh cement mortars." *Cement and Concrete Research,* 34(2), 235–248.

Gurjar, A. H. (2004). "Mix Design and Testing of Self-Consolidating Concrete Using Florida Materials." *Report submitted to Florida Dept. of Transportation,* US.

Hannesson, G., Kuder, K., Shogren, R., and Lehman, D. (2012). "The influence of high volume of fly ash and slag on the compressive strength of self-consolidating concrete." *Construction and Building Materials*, 30, 161–168.

Hansen, W., Wei, Y., Smiley D. L., Peng, Y., and Jansen, E. A. (2006). "Effects of paving conditions on built-in curling and pavement performance." *International Journal of Pavement Engineering*, 7(4), 291-296.

Hiller, J. E., and Roesler, J. R. (2010). "Simplified Nonlinear Temperature Curling Analysis of Jointed Concrete Pavements." *Journal of Transportation Engineering*, 136(7), 654-663.

Ho D., Sheinn A., and Ng C. (2002). "The use of quarry dust for SCC applications." *Cement and Concrete Research*, 32, 505–511.

Hodgson, D. III, Schindler A.K., Brown D.A., and Stroup-Gardiner M. (2005). "Self-Consolidating Concrete for Use in Drilled Shaft Applications." *Journal of Materials in Civil Engineering*, 17(3), 363–369.

Howlader, M., Rashid, M. H., Mallick, D., and Haque, T. (2012). "Effect of Aggregate Types on Thermal Properties of Concrete." *ARPN Journal of Engineering and Applied Sciences*, 7(7), 900-907.

Huang, Y. H. (2004). *Pavement Analysis and Design*, 2nd Ed., Pearson Prentice Hall, Upper Saddle River, NJ.

Ioannides, A. M. (2006). "Concrete pavement analysis: the first eighty years." *International Journal of Pavement Engineering*, 7(4), 233-249.

Jana, D. (2005). "Concrete Petrography – Past, Present and Future." *10th Euroseminar on Microscopy Applied to Building Materials*, Scotland.

Jeong, J. H., and Zollinger, D. G. (2005). "Environmental Effects on the Behaviour of Jointed Plain Concrete Pavements." *Journal of Transportation Engineering*, 131(2), 140-148.

Kadiyali, L. R. (2013). "Latest Developments in Concrete Roads: The Way Ahead." *Proceedings of the International Conference on Innovations in Concrete, Universities Press*, pp. 34-38.

Khaleel, O. R., and Abdul Razak, H. (2012). "The effect of powder type on the setting time and self compactability of mortar." *Construction and Building Materials*, Elsevier Ltd, 36, 20–26.

Khaliq, W., and Kodur, V. (2011). "Thermal and mechanical properties of fibre reinforced high performance self-consolidating concrete at elevated temperatures." *Cement and Concrete Research*, 41, 1112-1122.

Kodur, V., and Khaliq, W. (2011). "Effect of Temperature on Thermal Properties of Different Types of High-Strength Concrete." *Journal of Materials in Civil Engineering*, 23(6), 793-801.

Kodur, V. K. R., and Sultan, M. A. (2003). "Effect of Temperature on Thermal Properties of High-Strength Concrete." *Journal of Materials in Civil Engineering*, 15(2), 101-107.

Kwan, A. K. H., and Ng, I. Y. T. (2010). "Improving performance and robustness of SCC by adding supplementary cementitious materials." *Construction and Building Materials*, Elsevier Ltd, 24(11), 2260–2266.

Lamond, J., and Pielert, J. (2006). "Significance of Tests and Properties of Concrete and Concrete making materials." *ASTM STP 169D.*

Li, Z. (2011). *Advanced Concrete Technology*. John Wiley & Sons Pub. New York, US.

Li, Z. (2007). "State of workability design technology for fresh concrete in Japan." *Cement and Concrete Research*, 37, 1308–1320.

Li Z., Ohkubo T., and Tanigawa Y. (2004). "Flow Performance of High-Fluidity Concrete." *Journal of Materials in Civil Engineering*, 16(6), 588–596.

Liu, M. (2010). “Self-Compacting Concrete with different levels of pulverized fuel ash.” *Construction and Building Materials.* 24(7), 1245-1252.

Liu, C., and Yuan, D., (2000). “Temperature Distribution in Layered Road Structures.” *Journal of Transportation Engineering*, 126(1), 93-95.

Lomboy, G., Wang, K., and Ouyang, C. (2011a). “Shrinkage and Fracture Properties of Semiflowable Self-Consolidating Concrete.” *Journal of Materials in Civil Engineering*, 23(11), 1514–1524.

Madandoust R., and Mousavi S.Y. (2012). “Fresh and hardened properties of self-compacting concrete containing metakaolin.” *Construction and Building Materials*, 35, 752–760.

Mahboub, K. C., Liu, Y., and Allen, D. L. (2004). “Evaluation of Temperature Responses in Concrete Pavements.” *Journal of Transportation Engineering*, 130(3), 395-401.

Malhotra, V. M. (2008). “Mineral Admixtures.” in *Concrete Construction Engineering Handbook*, Nawy E. G. (Eds.), 2nd Ed., CRC Press, Boca Raton.

Masad, E., Taha, R., and Muhunthan, B. (1996). “Finite Element Analysis of Temperature Effects on Plain-Jointed Concrete Pavements.” *Journal of Transportation Engineering*, 122(5), 388-398.

Mehta, P. K., and Monteiro P. J. M. (2006). *Concrete Microstructure, Properties and Materials*. McGraw Hill, San Francisco, US, pp. 475-476.

Naik, T. R., Kumar, R., Ramme, B. W., and Canpolat, F. (2012). “Development of high-strength, economical self-consolidating concrete.” *Construction and Building Materials*, Elsevier Ltd, 30, 463–469.

Naik, T. R., Kraus, R. N., and Kumar, R. (2011). “Influence of Types of Coarse Aggregates on the Coefficient of Thermal Expansion of Concrete.” *Journal of Materials in Civil Engineering*, 23(4), 467-472.

NCHRP Report 628, (2009). *Self Consolidating Concrete for Precast, Prestressed Concrete Bridge Elements*, K. H. Khayat, D. Mitchell (Eds.), Transportation Research Board, US, 2-3.

Nehdi M., Pardhan M., and Koshowski S. (2004). “Durability of self-consolidating concrete incorporating high-volume replacement composite cements.” *Cement and Concrete Research*, 34, 2103–2112.

Nepomuceno M., Oliveira L., and Lopes S.M.R. (2012). “Methodology for mix design of the mortar phase of self-compacting concrete using different mineral additions in binary blends of powders.” *Construction and Building Materials*, 26, 317–326.

Neville A. M., and Brooks J. J. (2010). *Concrete Technology*, Prentice Hall (Pearson), Essex.

pp. 408-410.

Ouchi, M., Nakamura, S., Osterberg, T., Hallberg, S., and Lwin, M. (2003). "Applications of Self Compacting Concrete in Japan, Europe and The United States." *Proceedings of International Symposium on High Performance Concrete (ISHPC)*, pp. 1-20.

Papacostas, C. S., and Prevedouros P. D. (2006). *Transportation Engineering & Planning*. Prentice Hall Publishers, New Delhi, India, pp. 1-4.

Papagiannakis, A. T., and Masad E. A. (2008). *Pavement Design and Materials*. John Wiley & Sons Inc., pp. 207-208.

Poole, A. B., St John, D. A., and Sims, I. (1998). *Concrete Petrography: A handbook of Investigative Technique*. 1st Ed., Arnold Publishers, London, UK.

Price, W. H. (1975). "Pozzolan: A Review." *ACI Journal*, 225-232.

Ramachandran, V. S., and Beaudoin, J. J. (2001). *Handbook of Analytical Techniques in Concrete Science and Technology*, Noyes Publications, New Jersey, USA.

Rao, S. S., and Roesler, J. R. (2005). "Characterizing Effective Built-in Curling from Concrete Pavement Field Measurements." *Journal of Transportation Engineering*, 131(4), 320-327.

Roy, D. M., Grutzeck, M. W., and Scheetz, B. E. (1993). "Concrete Microscopy." *Strategic Highway Research Program (SHRP-C-662)*, Washington DC, pp. 1-10.

Shi, X. P., Fwa, T. F., and Zhang, J. (2000). "Thick-Plate Model for Warping Stress in Concrete Pavements." *International Journal of Pavement Engineering*, 1(2), 107-117.

Shin, H. C., and Chung, Y. (2011). "Determination of Coefficient of Thermal Expansion Effects on Louisiana PCC Pavement Design." *Louisiana Dept. of Transportation & Development, Louisiana State University*, LA.

Shoukry, S. N., William, G. W., and Riad, M. (2003). "Nonlinear Temperature Gradient Effects in Dowel Jointed Concrete Slabs." *International Journal of Pavement Engineering*, 4(3), 131-142.

Siddique, Z. Q., Hossain, M., and Meggers, D. (2005). "Temperature and Curling measurements on concrete pavements." *Proceedings, 2005 Mid-Continent Transportation Research Symposium*, Iowa State University, Ames, IA.

Sideris, K. (2007). "Mechanical characteristics of self-consolidating concretes exposed to elevated temperatures." *Journal of Materials in Civil Engineering*, 19(8), 648-654.

Skarendahl, A., and Billberg, P. (2006). "RILEM Report 35: Casting of Self Compacting Concrete." *RILEM Technical Committee 188-CSC*, France.

Sood, H., Khitoliya, R. K., and Pathak, S. S., "Incorporating European Standards for Testing

Self Compacting Concrete in Indian Conditions." *International Journal of Recent Trends in Engineering*, 1(6), 41-45.

Srinivasa Kumar R., Textbook of Highway Engineering, First Ed., Universities Press, Hyderabad, 2011, pp. 282-283.

Suresh Kumar, K. S., Amarnath, M. S., and Avinash, G. B. (2013). "Influence of Environmental Factors on Temperature Differential in High Performance Cement Concrete Pavements." *Indian Highways*, 41(5), 17-23.

The Times of India, Pune Edition, September 2014.

Türkel S., and Kandemir A. (2010). "Fresh and Hardened Properties of SCC Made with Different Aggregate and Mineral Admixtures." *Journal. of Materials. in Civil Engineering*, 22(10), 1025–1032.

Tuson, A., and Charman, R. (2012). "Thermal Material Properties for Modelling of the 2-Metre Box." *NDA-RWMD Report*. pp. 1-2.

Uysal M., Yilmaz K., and Ipek M. (2012). "The effect of mineral admixtures on mechanical properties, chloride ion permeability and impermeability of self-compacting concrete." *Construction and Building Materials*, 27, 263–270.

Van Dam, T., Taylor, P., Fick, G., Gress, D., VanGeem, M., and Lorenz, E. (2012). "Sustainable Concrete Pavements: A Manual for Practice." *Federal Highway Authority and National Concrete Pavement Technology Centre, Iowa State University*, Ames, IA.

Vandenbossche, J. M., Mu, F., Gutierrez, J. J., and Sherwood, J. (2011a). "An evaluation of the built-in temperature difference input parameter in the jointed plain concrete pavement cracking model of the Mechanistic-Empirical Pavement Design Guide." *International Journal of Pavement Engineering*, 12(3), 215-228.

Vandenbossche, J. M., Mu, F., and Burnham, T. R. (2011b). "Comparison of measured vs. predicted performance of jointed plain concrete pavements using the Mechanistic-Empirical Pavement Design Guideline." *International Journal of Pavement Engineering*, 12(3), 239-251.

Vikan H., Justnes H., Winnefeld F., and Figi R. (2007). "Correlating cement characteristics with rheology of paste." *Cement and Concrete Research*, 37, 1502–1511.

Wallevik, O. H., and Wallevik, J. E. (2011). "Rheology as a tool in concrete science: The use of rheographs and workability boxes." *Cement and Concrete Research,* 41, 1279-1288.

Wang, K., Hu, J., and Ge, Z. (2008). "Material Thermal input for Iowa Materials." *Iowa State Department and Centre for Transportation Research & Education, Iowa State University*, IA.

Wells, S. A., Phillips, B. M., and Vandenbossche, J. M. (2006). "Quantifying built-in construction gradients and early age slab deformation caused by environmental loads in a jointed plain concrete pavement." *International Journal of Pavement Engineering*, 7(4), 275-289.

Xing, Z., Beaucour, A. L., Hebert, R., Noumowe, A., Ledesert, B. (2011). "Influence of the nature of aggregates on the behaviour of concrete subjected to elevated temperatures." *Cement and Concrete Research*, 41, 392-402.

Xu, Y., and Chung, D. D. L. (2000). "Effect of sand addition on the specific heat and thermal conductivity of cement." *Cement and Concrete Research*, 30, 59-61.

Yahia A., Tanimura M., and Shimoyama Y. (2005). "Rheological properties of highly flowable mortar containing limestone filler-effect of powder content and W/C ratio." *Cement and Concrete Research*, 35, 532–539.

Zhang, J., Fwa, T. F., Tan, K. H., and Shi, X. P. (2003). "Model for Nonlinear Thermal Effect on Pavement Warping Stresses." *Journal of Transportation Engineering*, 129(6), 695-702.

Zhang, J., Li, V. C., and Wu, C. (2000). "Influence of reinforcing bars on shrinkage stresses in concrete slabs." *Journal of Engineering Mechanics*, 126(12), 1297-1300.

Zhang M.-H., Sisomphon K., Ng T.S., and Sun D.J. (2010). "Effect of superplasticizers on workability retention and initial setting time of cement pastes." *Construction and Building Materials*, 24, 1700–1707.

Publications from the present Research:

Journal Papers:

1. **Gandage, Abhijeet S**., and Ram, V. V. (2014). "Role of Supplementary Cementitious Materials in Self Compacting Concrete: A Review." *The Indian Concrete Journal*, 88(6), 42-59, pp.
2. **Gandage, Abhijeet S**., Ram, V. V., Yaswanth, A. B., Thota Pawan Kumar, and Gupta, Sankalp. (2014). "Thermal Conductivity Studies for Self Compacting Concrete with Sand & Fly ash variation." *ACI Materials Journal* (**Accepted for Publication**)
3. **Gandage, Abhijeet S**., Ram, V. V., Yaswanth, A. B., Thota Pawan Kumar, (2014). "Hydration Temperature profile in Self Compacting Concrete with fly ash and perlite." *International Journal of Pavement Engineering* (**Under Review**)

Conference Papers:

1. **Gandage, Abhijeet S**., Ram, V. V., and Joshi, R. A. (2013). "Comparative Study of Thin Section Petrographic Analysis for Normal Concrete and Self-Compacting Concrete." *Proceedings, International Conference on Advances in Science and Technology of Concrete*, organized by India Chapter of American Concrete Institute (IC-ACI), Mumbai, 290-293.
2. **Gandage, Abhijeet S**., Ram, V. V., Sivakumar, M. V. N., Vasan, A., Venu, M., and Yaswanth, A. B. (2013). "Effect of Perlite on Thermal Conductivity of Self Compacting Concrete." *Proceedings, 2^{nd} Conference of Transportation Research Group of India*, 188-197, pp.
3. **Gandage, Abhijeet S**., Ram, V. V., Sivakumar, M. V. N., Vasan, A., Venu, M., and Yaswanth, A. B. (2013). "Optimization of Class C Fly ash in Self Compacting Concrete for Pavement Application." *Proceedings, International Conference on Innovations in Concrete for Meeting Infrastructure Challenges*, 213-226 pp.

RESUME

Supervisor: **Prof. V. Vinayaka Ram.**

Prof. V. Vinayaka Ram is an Associate Professor at Dept. of Civil Engg. Birla Institute of Technology & Science (BITS) Pilani-Hyderabad Campus. His research interests include pavement material characterization, pavement instrumentation and material evaluation, traffic engineering, and accelerated pavement testing. He has published and presented several research papers related to his research expertise in various national and international journals and conferences of repute. He is Life Member, Indian Roads Congress, Institute of Urban Transport, Indian Society of Technical Education, Indian Concrete Institute and Member, Institution of Engineers (India).

Candidate: **Gandage Abhijeet Siddappa**

Gandage Abhijeet Siddappa is working as an Assistant Professor at Dept. of Civil Engg. MAEER;s Maharashtra Institute of Technology, Pune. He has a Post Graduate degree (M-Tech) in Construction & Management. His area of expertise is Construction Planning, Resource Management, Construction Techniques, Concrete Technology & Transportation Engineering. He has an industrial experience of 2 years and academic experience of 7 years. He took a sabbatical to pursue doctoral studies at Dept. of Civil Engg. BITS Pilani Hyderabad Campus. He is Associate Member, Institution of Engineers (India), Life Member, Indian Concrete Institute, Indian Roads Congress and American Concrete Institute (India Chapter).

APPENDIX A

Observations Tables and Graphs for Temperature values measured and computed at different depths in cube specimen

Table A-1 (a): 24 hr. cube temperature values (measured and calculated) for Mix A for minimum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	0930 to 1030	25	28.49	27.35	27.04	27.53	27.31	25.87	25.94	25.40	25.74	25.18	25.18	24.97	25.11
2	1030 to 1130	27	33.39	30.25	31.20	30.80	30.75	28.85	29.45	28.99	29.10	28.16	28.16	28.04	28.12
3	1130 to 1230	28	34.97	32.50	33.25	32.85	32.87	31.11	31.75	31.73	31.53	30.48	30.48	30.54	30.50
4	1230 to 1330	28	37.57	34.76	35.90	34.92	35.19	33.35	34.26	34.08	33.90	32.65	32.65	32.10	32.47
5	1330 to 1430	28	37.98	36.07	37.01	36.03	36.37	34.82	35.76	34.45	35.01	34.24	34.24	33.68	34.05
6	1430 to 1530	28	36.48	35.55	36.41	35.44	35.80	34.89	35.80	34.63	35.11	34.66	34.66	34.46	34.59
7	1530 to 1630	27	33.23	33.75	34.35	32.54	33.55	33.82	34.61	33.59	34.01	34.00	34.00	34.09	34.03
8	1630 to 1730	26	29.22	30.68	31.15	30.08	30.64	31.44	32.10	31.17	31.57	32.05	32.05	31.46	31.85
9	1730 to 1830	24	25.82	27.40	27.99	27.21	27.53	28.45	29.17	28.15	28.59	29.37	29.37	29.10	29.28
10	1830 to 1930	22	23.45	24.90	25.53	24.74	25.06	25.93	26.68	25.82	26.14	26.90	26.90	26.88	26.89
11	1930 to 2030	21	21.70	23.05	23.57	23.84	23.49	23.97	24.65	23.89	24.17	24.93	24.93	24.93	24.93
12	2030 to 2130	21	20.40	21.62	21.99	21.11	21.57	22.46	22.98	22.08	22.51	23.38	23.38	24.05	23.60
13	2130 to 2230	20	19.39	20.49	20.85	20.12	20.49	21.29	21.77	21.08	21.38	22.15	22.15	22.06	22.12
14	2230 to 2330	20	18.49	19.64	19.83	19.33	19.60	20.32	20.73	20.23	20.43	21.20	21.20	21.16	21.18
15	2330 to 0030	20	17.87	18.87	19.02	18.44	18.78	19.57	19.85	19.31	19.58	20.36	20.36	20.21	20.31
16	0030 to 0130	19	17.36	18.33	18.50	18.36	18.40	18.93	19.30	19.25	19.16	19.75	19.75	20.17	19.89
17	0130 to 0230	19	16.81	17.84	17.89	17.37	17.70	18.39	18.68	18.26	18.44	19.18	19.18	19.18	19.18
18	0230 to 0330	18	16.36	17.27	17.43	17.24	17.31	17.89	18.19	18.17	18.08	18.62	18.62	19.11	18.78
19	0330 to 0430	17	15.85	16.79	17.01	17.18	16.99	17.40	17.79	18.13	17.77	18.18	18.18	19.08	18.48
20	0430 to 0530	17	15.40	16.38	16.50	16.25	16.38	16.91	17.28	17.17	17.12	17.71	17.71	18.12	17.85
21	0530 to 0630	18	15.13	16.06	16.01	16.41	16.16	16.59	16.73	17.28	16.87	17.30	17.30	17.19	17.26
22	0630 to 0730	19	15.56	16.12	16.02	16.70	16.28	16.48	16.52	16.49	16.50	17.07	17.07	16.33	16.82
23	0730 to 0830	22	20.44	18.88	19.00	19.12	19.00	18.07	18.24	18.19	18.17	18.16	18.16	18.47	18.27
24	0830 to 0930	23	26.39	23.96	24.24	23.18	23.79	22.37	22.72	22.05	22.38	21.84	21.84	21.39	21.69

Table A-1 (b): 24 hr. cube temperature values (measured and calculated) for Mix A for minimum ambient air temperature at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (^oC) at 10 cm				Temperature (^oC) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	0930 to 1030	24.53	24.77	24.31	24.54	24.62	24.71	23.94	24.42
2	1030 to 1130	27.46	27.33	27.03	27.27	27.47	26.94	27.10	27.17
3	1130 to 1230	29.77	29.43	29.36	29.52	29.58	28.60	29.69	29.29
4	1230 to 1330	31.84	31.07	31.06	31.33	31.53	29.52	31.17	30.74
5	1330 to 1430	33.42	32.43	33.78	33.21	33.08	30.36	32.67	32.04
6	1430 to 1530	34.09	32.98	34.97	34.01	33.74	30.76	33.24	32.58
7	1530 to 1630	33.63	32.53	33.06	33.07	33.45	30.20	33.63	32.43
8	1630 to 1730	31.99	31.02	31.97	31.66	32.04	29.01	32.71	31.25
9	1730 to 1830	29.49	28.57	29.07	29.04	29.76	26.78	29.12	28.55
10	1830 to 1930	27.11	26.19	26.92	26.74	27.57	24.56	27.86	26.66
11	1930 to 2030	25.16	24.41	25.95	25.17	25.71	23.10	25.91	24.91
12	2030 to 2130	23.61	23.18	23.04	23.28	24.25	22.39	24.06	23.56
13	2130 to 2230	22.40	21.98	22.04	22.14	23.07	21.26	23.06	22.46
14	2230 to 2330	21.43	21.23	21.10	21.25	22.10	20.83	22.18	21.70
15	2330 to 0030	20.60	20.56	20.14	20.43	21.32	20.44	21.25	21.00
16	0030 to 0130	19.96	19.85	20.11	19.97	20.64	19.60	20.20	20.15
17	0130 to 0230	19.42	19.40	19.12	19.31	20.10	19.34	19.21	19.55
18	0230 to 0330	18.85	18.73	19.07	18.89	19.59	18.53	19.13	19.08
19	0330 to 0430	18.37	18.18	19.06	18.53	19.09	17.78	19.10	18.66
20	0430 to 0530	17.95	17.81	18.08	17.95	18.64	17.57	18.14	18.12
21	0530 to 0630	17.53	17.69	17.13	17.45	18.23	17.93	17.22	17.80
22	0630 to 0730	17.24	17.66	16.92	17.28	18.02	18.31	18.39	18.24
23	0730 to 0830	18.10	18.76	18.98	18.61	18.85	20.04	19.73	19.54
24	0830 to 0930	21.38	21.59	21.26	21.41	21.87	21.98	21.99	21.95

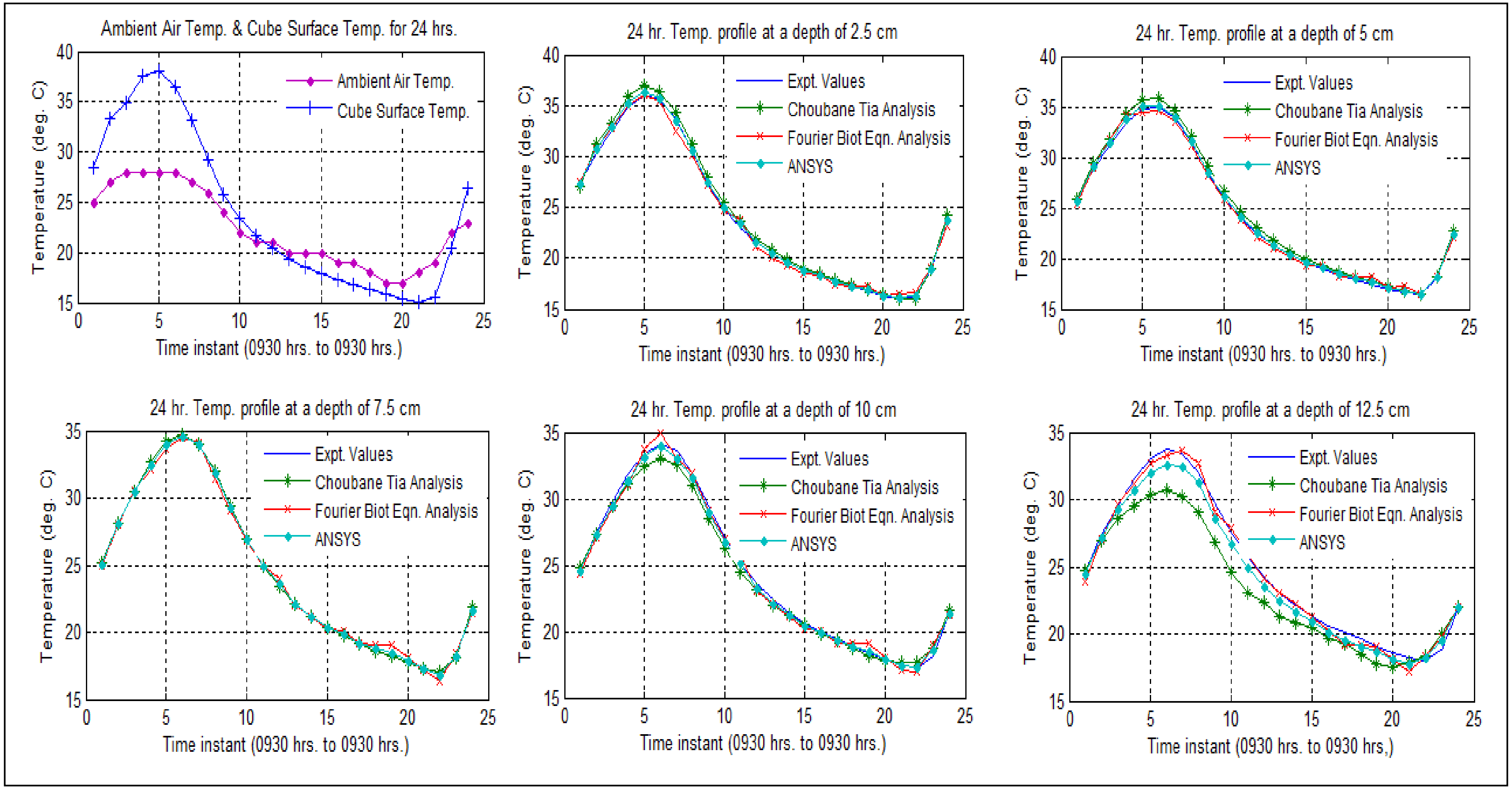


Fig. A-1: 24 hour cube temperature profile (measured and calculated) at various depths for Mix A for minimum ambient air temperature

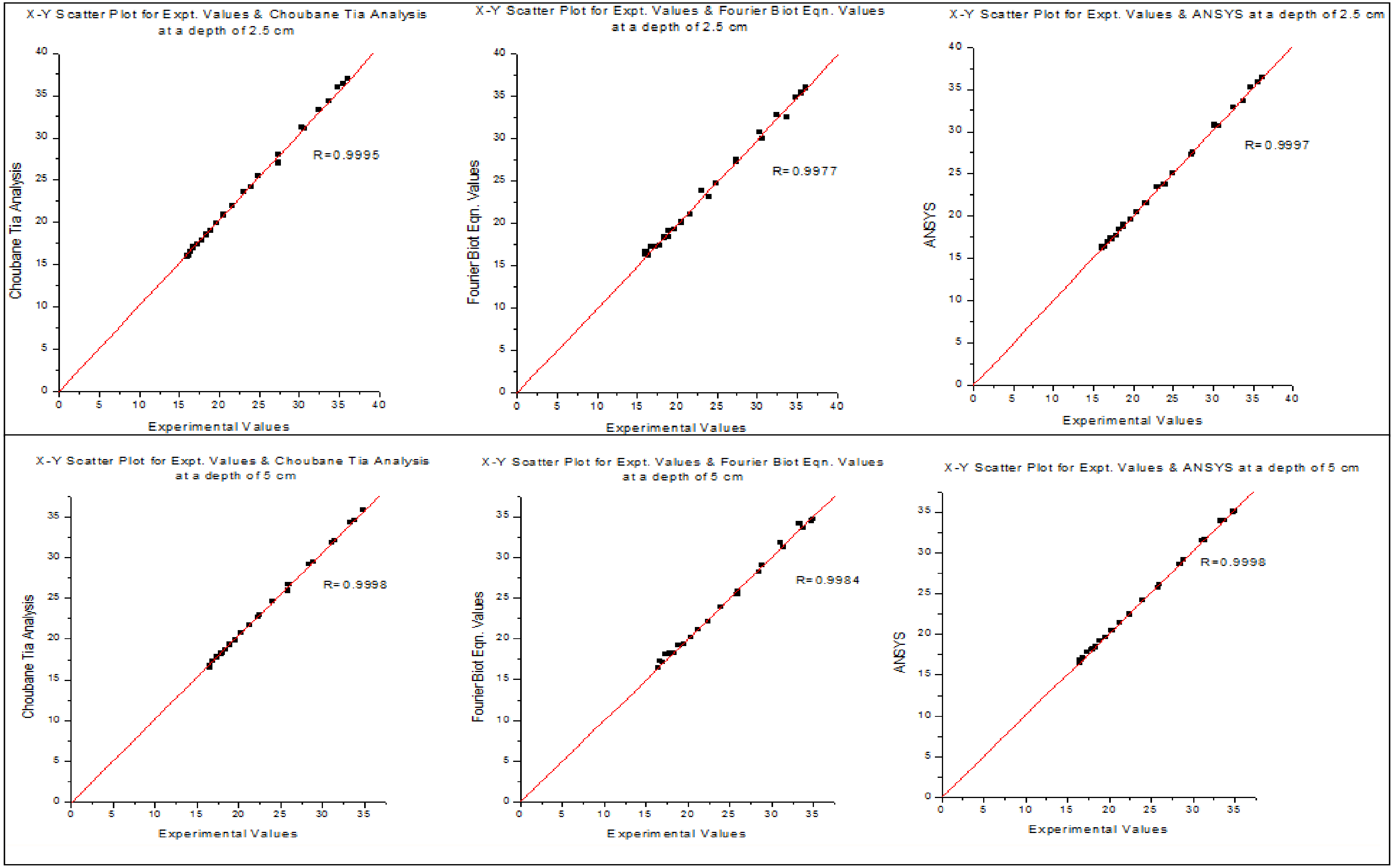


Fig. A-2 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

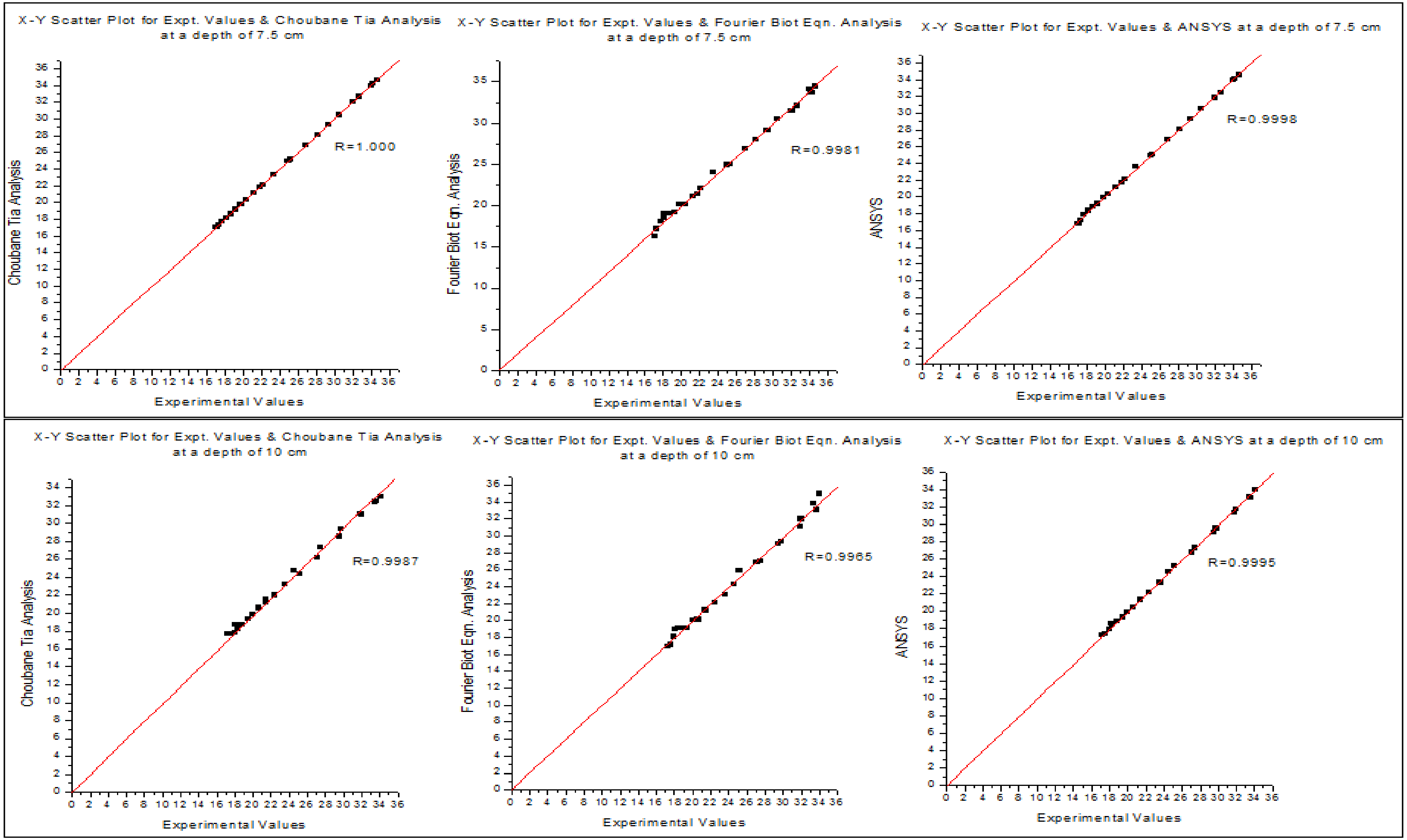


Fig. A-2 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

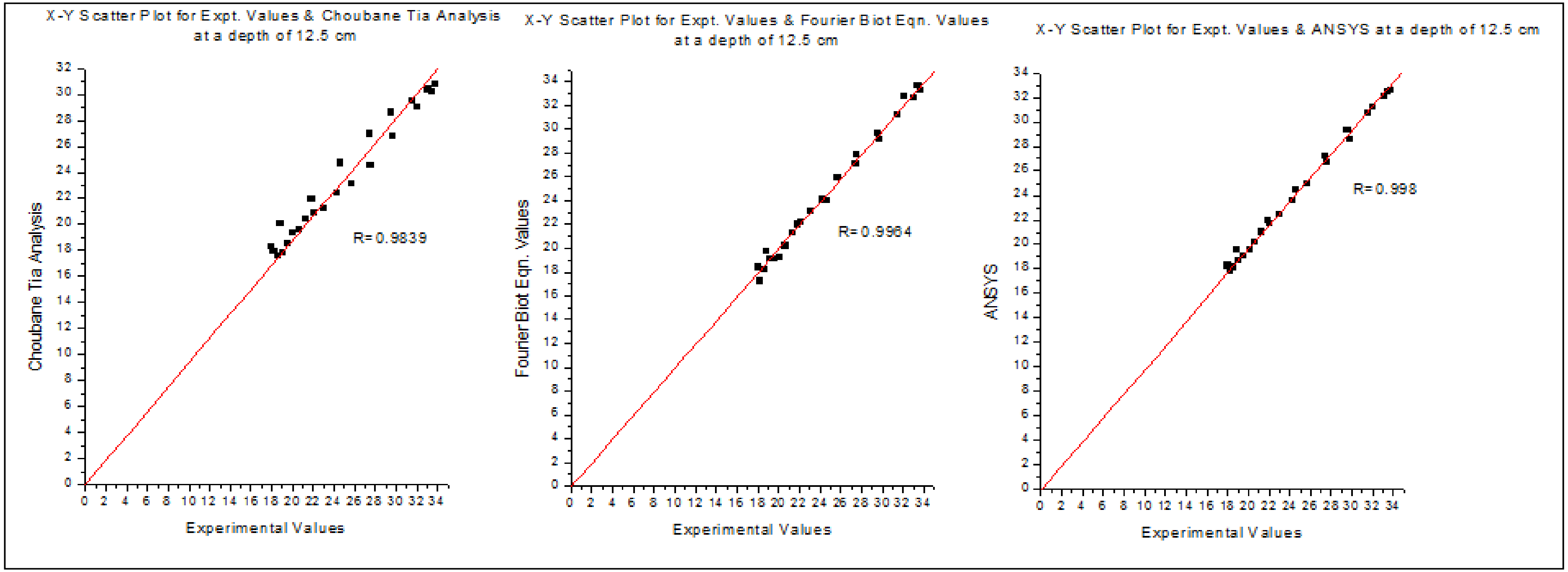


Fig. A-2 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-2(a): 24 hr. cube temperature values (measured and calculated) for Mix A for 24 hr. precipitation 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (^{o}C) at 2.5 cm				Temperature (^{o}C) at 5 cm				Temperature (^{o}C) at 7.5 cm			
		(^{o}C)	(^{o}C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	0930 to 1030	26	26.41	25.69	25.81	25.11	25.54	25.22	25.42	25.18	25.28	25.24	25.24	25.47	25.32
2	1030 to 1130	26	27.02	26.29	26.53	26.10	26.31	25.88	26.17	25.58	25.88	25.94	25.94	25.41	25.76
3	1130 to 1230	27	26.96	26.54	26.60	26.78	26.64	26.22	26.39	26.17	26.26	26.32	26.32	26.15	26.26
4	1230 to 1330	27	26.93	26.63	26.65	26.62	26.63	26.31	26.48	26.65	26.48	26.43	26.43	26.12	26.33
5	1330 to 1430	27	26.68	26.62	26.64	26.25	26.50	26.47	26.64	26.10	26.40	26.67	26.67	26.43	26.59
6	1430 to 1530	27	25.05	25.68	25.50	25.41	25.53	25.84	25.90	25.21	25.65	26.25	26.25	26.50	26.33
7	1530 to 1630	27	22.81	23.46	23.48	23.31	23.42	24.13	24.16	24.43	24.24	24.86	24.86	24.98	24.90
8	1630 to 1730	26	22.25	22.63	22.62	22.98	22.74	23.06	23.09	23.09	23.08	23.67	23.67	23.41	23.58
9	1730 to 1830	26	22.20	22.46	22.37	22.32	22.38	22.73	22.73	22.93	22.80	23.27	23.27	23.62	23.39
10	1830 to 1930	25	22.12	22.36	22.33	22.51	22.40	22.55	22.64	22.36	22.52	23.07	23.07	23.24	23.13
11	1930 to 2030	25	22.02	22.26	22.18	22.57	22.34	22.42	22.48	22.40	22.43	22.92	22.92	22.27	22.70
12	2030 to 2130	24	22.08	22.27	22.29	22.38	22.31	22.39	22.55	22.27	22.40	22.84	22.84	22.18	22.62
13	2130 to 2230	24	22.10	22.27	22.30	22.35	22.31	22.38	22.54	22.25	22.39	22.83	22.83	22.17	22.61
14	2230 to 2330	24	22.08	22.27	22.27	22.34	22.29	22.36	22.52	22.24	22.37	22.82	22.82	22.16	22.60
15	2330 to 0030	24	22.04	22.22	22.18	22.32	22.24	22.29	22.39	22.22	22.30	22.68	22.68	22.15	22.50
16	0030 to 0130	24	22.23	22.38	22.32	22.51	22.40	22.36	22.49	22.36	22.40	22.74	22.74	22.24	22.57
17	0130 to 0230	23	22.30	22.43	22.52	22.16	22.37	22.46	22.70	22.11	22.42	22.83	22.83	22.07	22.58
18	0230 to 0330	23	22.21	22.39	22.47	22.19	22.35	22.43	22.68	22.13	22.41	22.83	22.83	22.09	22.59
19	0330 to 0430	23	22.07	22.29	22.35	22.17	22.27	22.35	22.58	22.12	22.35	22.76	22.76	22.08	22.53
20	0430 to 0530	23	21.86	22.07	22.12	22.22	22.13	22.16	22.35	22.15	22.22	22.55	22.55	22.10	22.40
21	0530 to 0630	23	21.92	22.05	22.09	22.32	22.16	22.08	22.26	22.23	22.19	22.44	22.44	22.15	22.35
22	0630 to 0730	23	22.26	22.32	22.35	22.24	22.30	22.26	22.46	22.17	22.30	22.58	22.58	22.11	22.43
23	0730 to 0830	23	22.63	22.67	22.70	22.71	22.69	22.56	22.77	22.50	22.61	22.84	22.84	22.33	22.67
24	0830 to 0930	24	22.90	22.90	22.85	22.40	22.72	22.77	22.89	22.98	22.88	23.03	23.03	23.66	23.24

Table A-2(b): 24 hr. cube temperature values (measured and calculated) for Mix A for 24 hr. precipitation at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (ºC) at 10 cm				Temperature (ºC) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	0930 to 1030	25.06	25.28	24.98	25.11	25.30	25.53	25.57	25.47
2	1030 to 1130	25.75	25.83	25.60	25.73	25.99	25.85	25.94	25.93
3	1130 to 1230	26.14	26.40	26.76	26.43	26.36	26.63	26.62	26.54
4	1230 to 1330	26.27	26.50	26.08	26.28	26.54	26.69	26.22	26.48
5	1330 to 1430	26.54	26.74	26.28	26.52	26.77	26.85	26.33	26.65
6	1430 to 1530	26.23	26.55	26.33	26.37	26.58	26.80	26.36	26.58
7	1530 to 1630	25.05	25.56	25.98	25.53	25.50	26.27	25.16	25.65
8	1630 to 1730	23.87	24.34	23.94	24.05	24.49	25.12	24.55	24.72
9	1730 to 1830	23.39	24.00	23.42	23.60	23.96	24.91	23.24	24.04
10	1830 to 1930	23.17	23.60	23.16	23.31	23.64	24.25	23.09	23.66
11	1930 to 2030	23.01	23.48	23.18	23.22	23.48	24.17	23.10	23.59
12	2030 to 2130	22.93	23.19	22.12	22.74	23.40	23.57	23.07	23.35
13	2130 to 2230	22.90	23.17	22.11	22.73	23.34	23.56	23.06	23.32
14	2230 to 2330	22.86	23.16	22.11	22.71	23.29	23.56	23.06	23.30
15	2330 to 0030	22.74	23.05	22.10	22.63	23.11	23.49	23.06	23.22
16	0030 to 0130	22.75	23.08	22.16	22.66	23.15	23.50	23.09	23.25
17	0130 to 0230	22.83	22.93	22.05	22.60	23.23	22.99	23.03	23.08
18	0230 to 0330	22.83	22.94	22.06	22.61	23.26	22.99	23.03	23.10
19	0330 to 0430	22.78	22.89	22.05	22.57	23.16	22.97	23.03	23.05
20	0430 to 0530	22.55	22.73	22.07	22.45	22.94	22.88	22.04	22.62
21	0530 to 0630	22.44	22.63	22.10	22.39	22.87	22.81	22.06	22.58
22	0630 to 0730	22.55	22.71	22.07	22.44	22.94	22.85	22.04	22.61
23	0730 to 0830	22.76	22.90	22.22	22.63	23.12	22.95	23.13	23.07
24	0830 to 0930	22.92	23.26	22.44	22.87	23.26	23.58	23.26	23.37

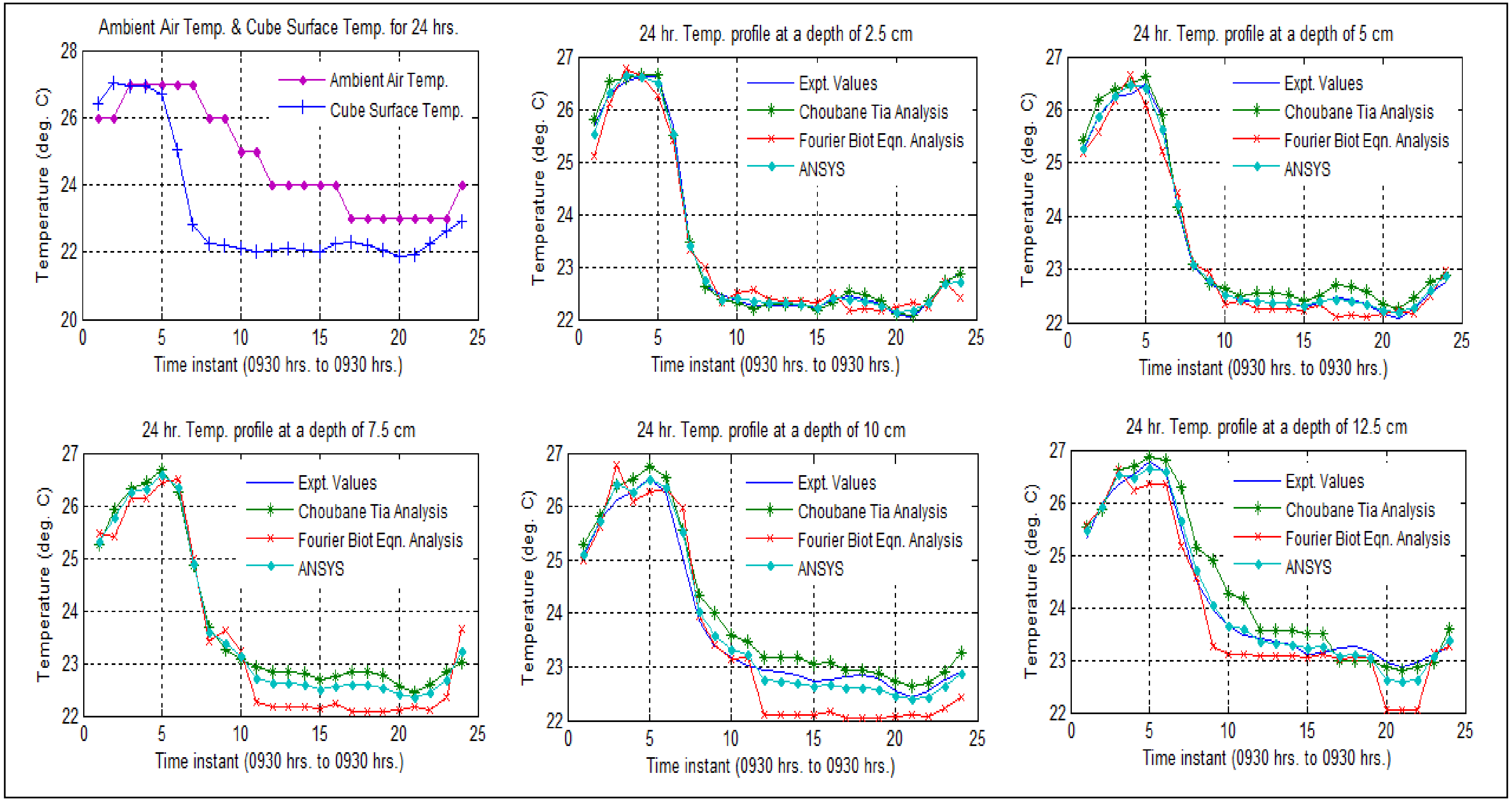


Fig. A-3: 24 hour cube temperature profile (measured and calculated) at various depths for Mix A for 24 hour precipitation

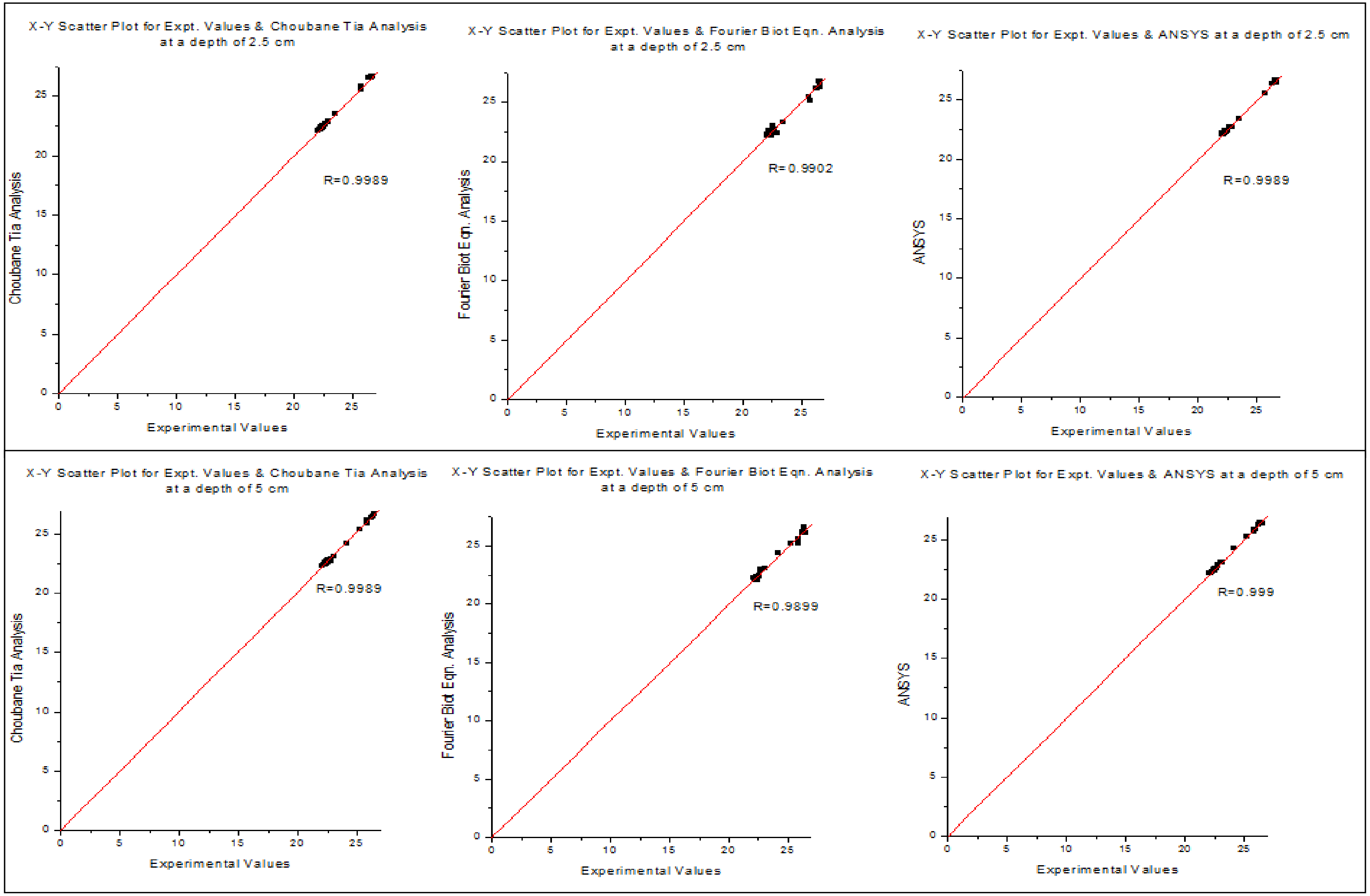


Fig. A-4 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

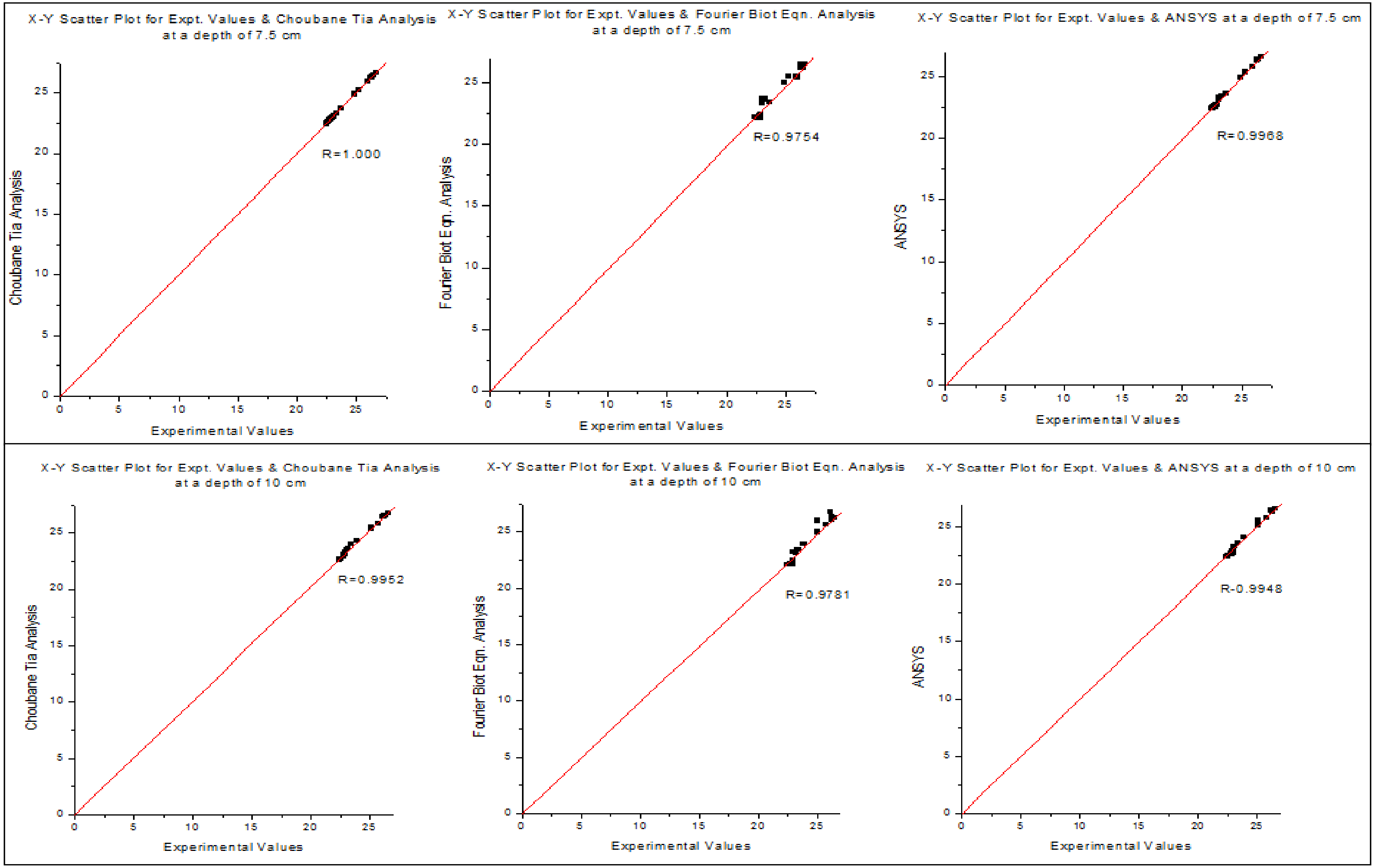


Fig. A-4 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

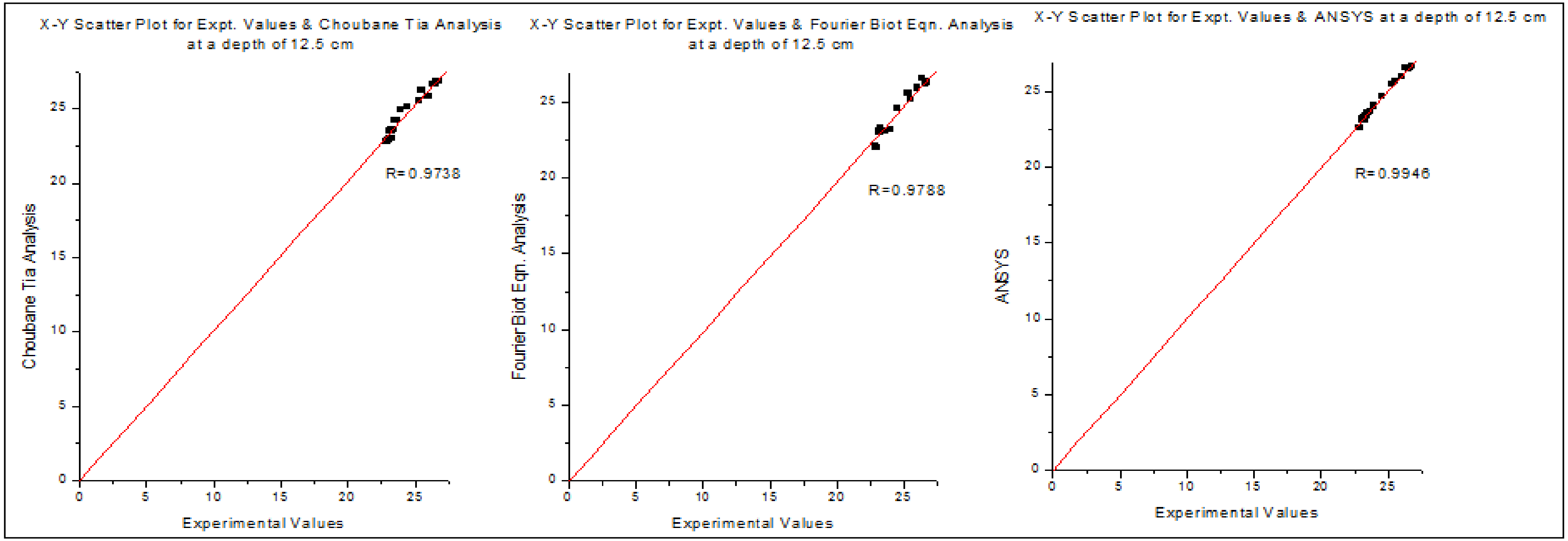


Fig. A-4 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-3 (a): 24 hr. cube temperature values (measured and calculated) for Mix A for part humid & part rainy condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	0930 to 1030	27	30.16	28.68	28.84	28.79	28.77	27.55	27.84	27.96	27.78	27.16	27.16	27.32	27.21
2	1030 to 1130	28	32.06	31.00	31.14	31.69	31.28	30.02	30.33	30.00	30.12	29.60	29.60	29.69	29.63
3	1130 to 1230	28	31.30	30.87	31.18	30.26	30.77	30.47	30.89	30.81	30.72	30.42	30.42	30.90	30.58
4	1230 to 1330	28	31.09	30.89	31.19	30.60	30.89	30.62	31.05	30.04	30.57	30.66	30.66	30.06	30.46
5	1330 to 1430	28	30.22	30.42	30.67	30.17	30.42	30.34	30.79	30.63	30.59	30.59	30.59	30.44	30.54
6	1430 to 1530	27	27.92	29.05	29.16	29.28	29.17	29.45	29.85	29.71	29.67	29.98	29.98	29.49	29.82
7	1530 to 1630	27	27.98	28.18	28.65	28.63	28.48	28.48	28.98	28.25	28.57	28.98	28.98	28.18	28.72
8	1630 to 1730	27	26.75	27.33	27.61	27.36	27.43	27.73	28.15	27.66	27.85	28.36	28.36	28.11	28.28
9	1730 to 1830	26	26.08	26.60	26.91	26.19	26.57	26.95	27.41	26.54	26.97	27.56	27.56	27.04	27.39
10	1830 to 1930	26	24.94	25.58	25.83	25.69	25.70	26.10	26.44	26.49	26.34	26.76	26.76	25.33	26.28
11	1930 to 2030	25	24.13	24.74	25.00	25.13	24.95	25.16	25.57	25.09	25.28	25.86	25.86	25.06	25.60
12	2030 to 2130	25	23.73	24.27	24.42	24.19	24.29	24.64	24.93	24.13	24.57	25.24	25.24	25.09	25.19
13	2130 to 2230	25	23.58	23.99	24.15	24.23	24.12	24.28	24.58	24.16	24.34	24.88	24.88	24.11	24.63
14	2230 to 2330	25	23.17	23.55	23.70	23.31	23.52	23.87	24.14	23.22	23.74	24.49	24.49	24.14	24.37
15	2330 to 0030	24	22.81	23.21	23.36	23.21	23.26	23.45	23.78	23.15	23.46	24.05	24.05	24.10	24.07
16	0030 to 0130	24	22.55	22.91	23.03	22.28	22.74	23.18	23.42	23.20	23.27	23.71	23.71	23.13	23.52
17	0130 to 0230	24	22.56	22.85	22.91	22.32	22.69	23.02	23.22	23.23	23.15	23.48	23.48	23.15	23.37
18	0230 to 0330	24	22.47	22.80	22.82	22.27	22.63	22.97	23.13	22.19	22.76	23.40	23.40	23.13	23.31
19	0330 to 0430	24	22.50	22.81	22.81	22.25	22.62	22.91	23.10	22.18	22.73	23.36	23.36	23.12	23.28
20	0430 to 0530	23	22.42	22.76	22.83	22.10	22.56	22.87	23.12	22.07	22.69	23.28	23.28	23.05	23.20
21	0530 to 0630	23	22.53	22.82	22.89	22.08	22.59	22.89	23.13	22.05	22.69	23.27	23.27	23.04	23.19
22	0630 to 0730	23	22.71	22.93	23.00	22.05	22.66	22.94	23.19	22.03	22.72	23.28	23.28	23.02	23.19
23	0730 to 0830	24	23.63	23.56	23.55	23.19	23.43	23.34	23.52	23.13	23.33	23.56	23.56	23.09	23.40
24	0830 to 0930	24	24.88	24.60	24.70	24.52	24.60	24.26	24.53	24.36	24.39	24.38	24.38	24.24	24.33

Table A-3 (b): 24 hr. cube temperature values (measured and calculated) for Mix A for part humid & part rainy condition at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	0930 to 1030	26.83	26.79	26.88	26.83	26.86	26.74	26.51	26.70
2	1030 to 1130	29.14	28.97	29.79	29.30	29.06	28.44	29.05	28.85
3	1130 to 1230	30.11	29.79	30.60	30.17	30.16	28.98	30.52	29.89
4	1230 to 1330	30.46	30.02	30.71	30.39	30.59	29.13	30.58	30.10
5	1330 to 1430	30.46	30.05	30.63	30.38	30.68	29.19	30.95	30.27
6	1430 to 1530	30.00	29.55	30.66	30.07	30.37	28.55	30.97	29.96
7	1530 to 1630	29.08	28.66	29.46	29.06	29.58	27.99	29.85	29.14
8	1630 to 1730	28.48	28.24	28.74	28.48	28.92	27.78	28.43	28.38
9	1730 to 1830	27.71	27.38	27.69	27.60	28.27	26.86	27.40	27.51
10	1830 to 1930	26.93	26.79	26.22	26.65	27.49	26.54	27.13	27.05
11	1930 to 2030	26.09	25.86	26.04	26.00	26.73	25.58	27.02	26.44
12	2030 to 2130	25.44	25.35	26.06	25.62	26.09	25.27	26.03	25.80
13	2130 to 2230	25.02	25.06	25.07	25.05	25.61	25.09	26.04	25.58
14	2230 to 2330	24.66	24.75	25.10	24.84	25.17	24.92	25.06	25.05
15	2330 to 0030	24.23	24.18	24.07	24.16	24.81	24.16	25.04	24.67
16	0030 to 0130	23.87	23.90	23.09	23.62	24.47	24.00	24.05	24.18
17	0130 to 0230	23.62	23.70	23.10	23.47	24.20	23.87	24.06	24.04
18	0230 to 0330	23.50	23.64	23.09	23.41	24.06	23.84	24.05	23.98
19	0330 to 0430	23.43	23.60	23.08	23.37	23.95	23.81	24.05	23.93
20	0430 to 0530	23.39	23.31	23.03	23.24	23.87	23.22	24.02	23.70
21	0530 to 0630	23.34	23.29	23.02	23.22	23.83	23.20	23.01	23.35
22	0630 to 0730	23.34	23.28	23.02	23.21	23.78	23.19	23.01	23.33
23	0730 to 0830	23.53	23.65	23.06	23.41	23.95	23.80	23.03	23.59
24	0830 to 0930	24.24	24.24	24.16	24.21	24.58	24.11	24.09	24.26

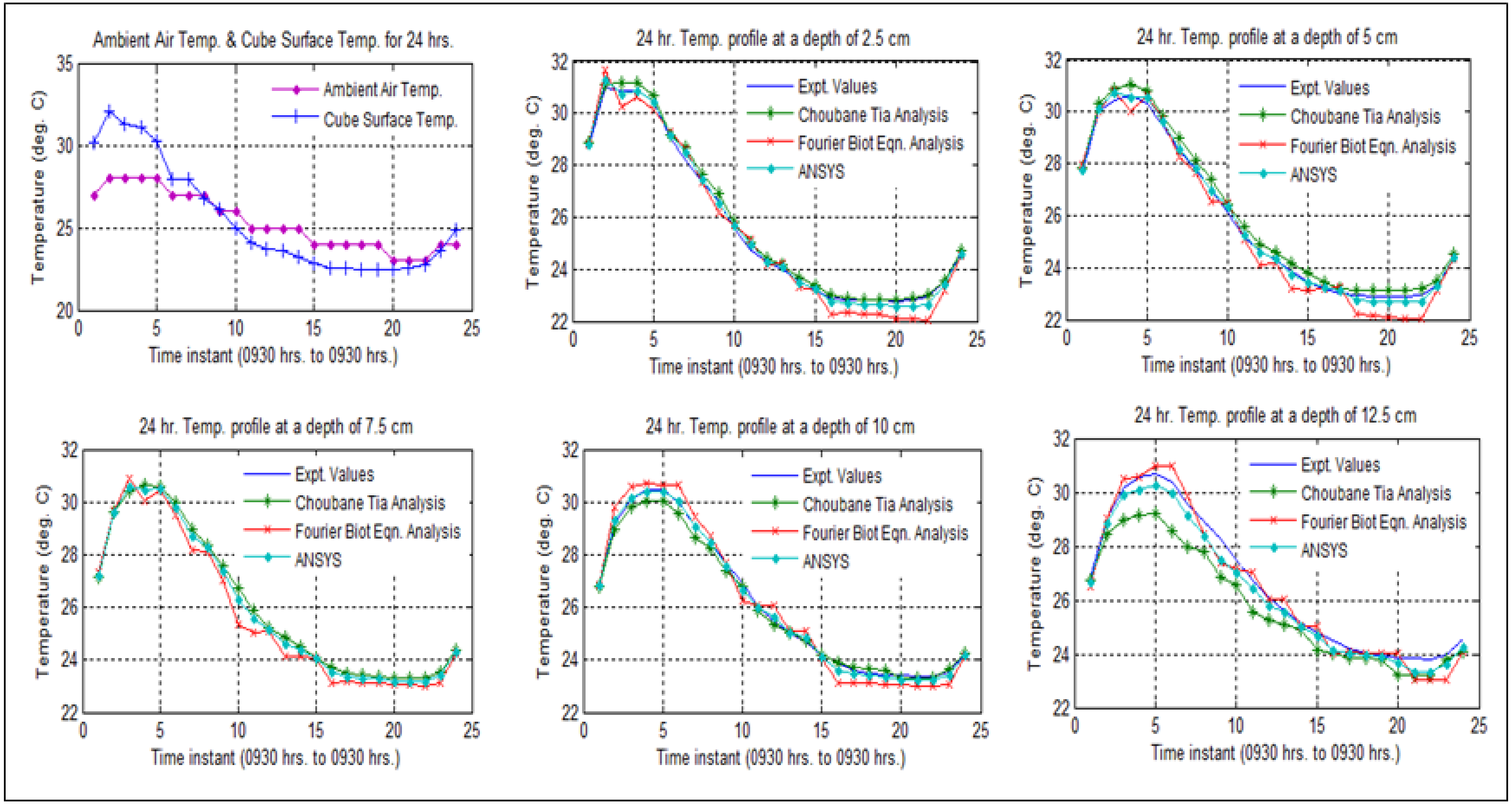


Fig. A-5: 24 hour cube temperature profile (measured and calculated) at various depths for Mix A for part humid and part rainy condition

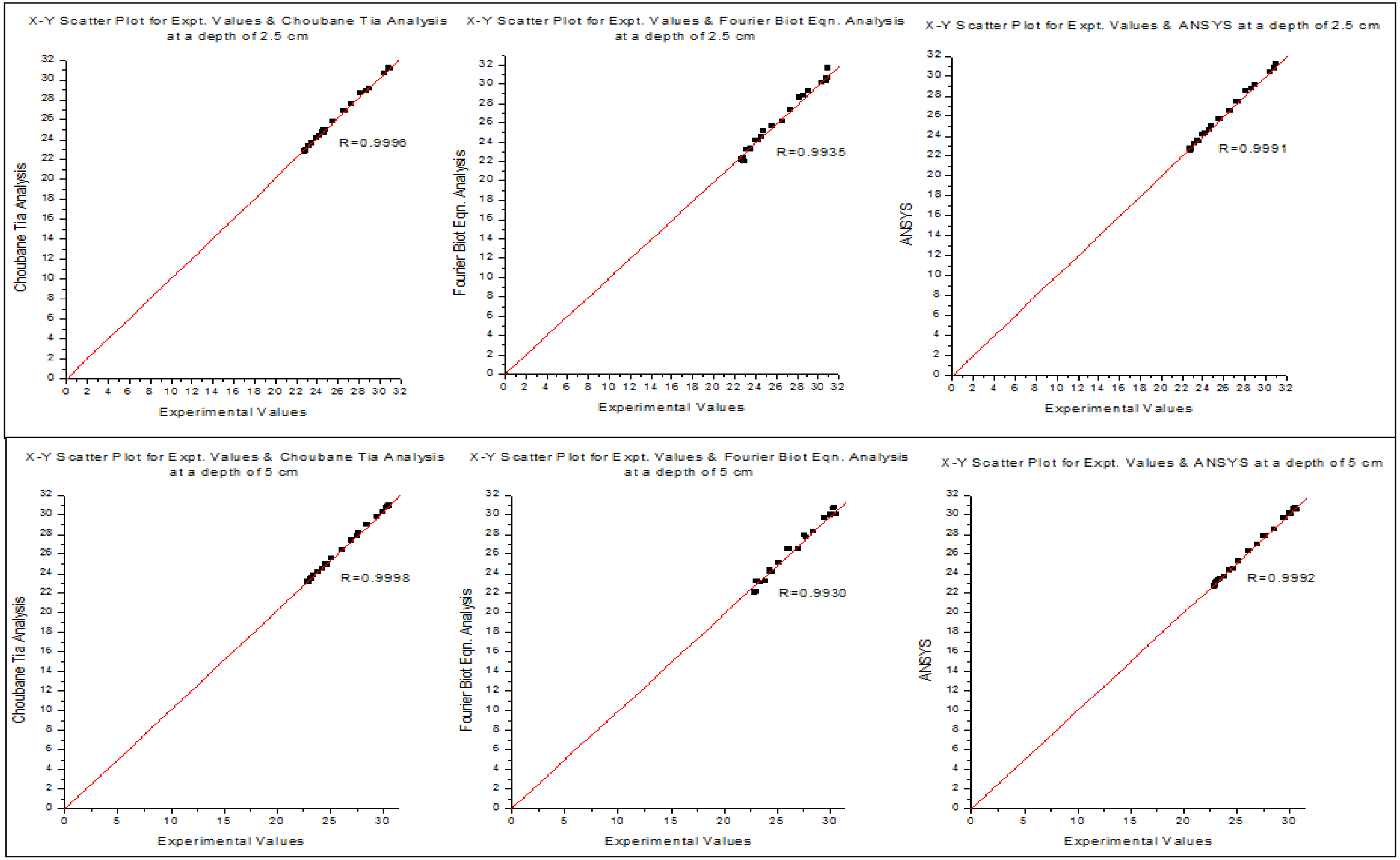


Fig. A-6 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

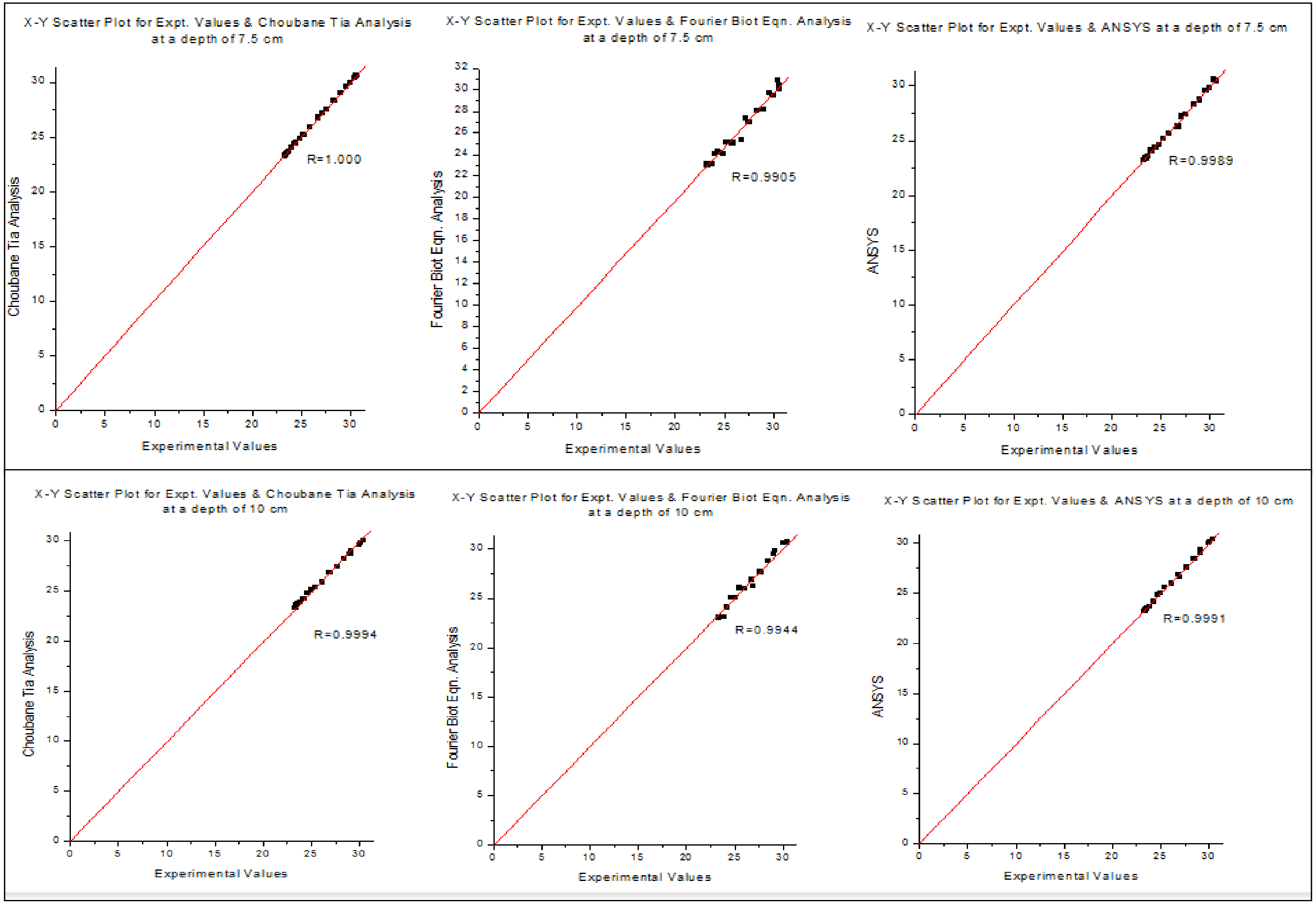


Fig. A-6 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

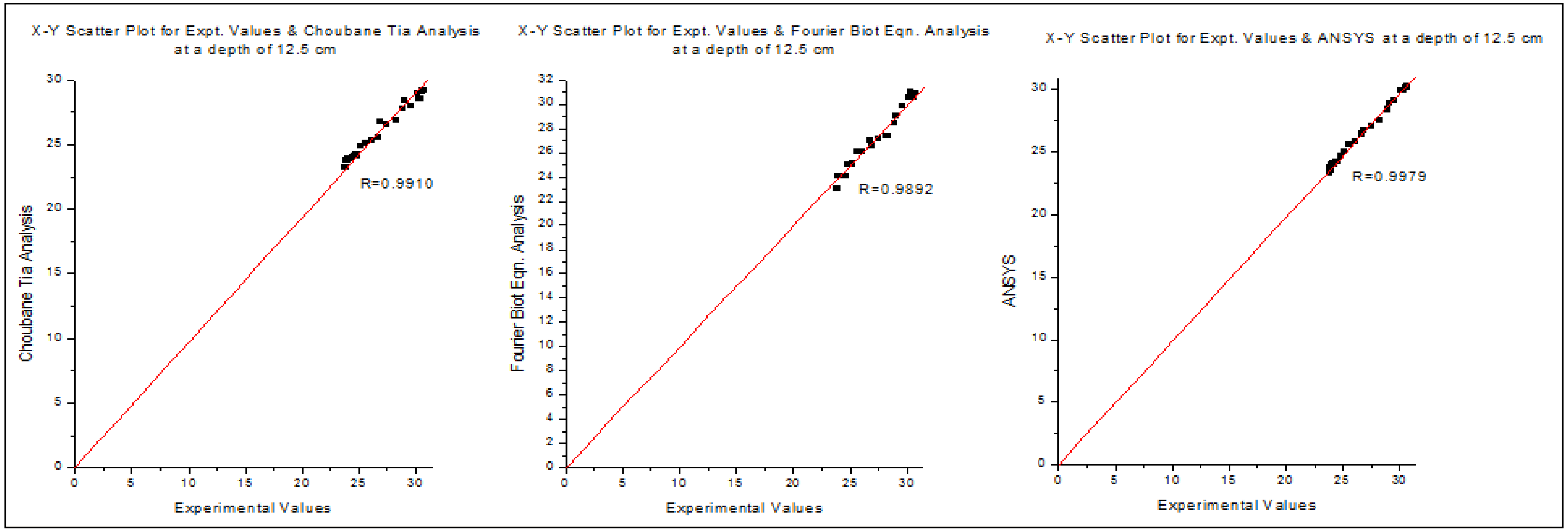


Fig. A-6 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-4 (a): 24 hr. cube temperature values (measured and calculated) for Mix A for 24 hr. cloudy & humid condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	0930 to 1030	27	33.85	31.25	31.77	31.07	31.36	29.50	30.07	29.07	29.55	28.74	28.74	28.75	28.75
2	1030 to 1130	28	36.81	34.36	35.10	34.68	34.71	32.78	33.49	32.21	32.83	31.98	31.98	31.52	31.83
3	1130 to 1230	29	39.99	36.93	38.20	36.70	37.28	35.33	36.40	35.22	35.65	34.58	34.58	34.52	34.56
4	1230 to 1330	30	40.43	38.59	39.54	38.32	38.81	37.38	38.30	37.06	37.58	36.73	36.73	36.76	36.74
5	1330 to 1430	30	36.95	36.71	37.51	36.51	36.91	36.56	37.39	36.98	36.98	36.58	36.58	36.02	36.39
6	1430 to 1530	29	34.71	34.91	35.74	34.57	35.07	35.10	35.98	35.21	35.43	35.42	35.42	35.16	35.33
7	1530 to 1630	29	32.74	33.10	33.83	33.40	33.45	33.45	34.24	33.69	33.79	33.96	33.96	33.13	33.68
8	1630 to 1730	28	30.99	31.57	32.20	31.13	31.63	32.01	32.73	32.80	32.51	32.57	32.57	32.54	32.56
9	1730 to 1830	27	29.53	30.18	30.76	30.76	30.57	30.63	31.33	30.83	30.93	31.24	31.24	31.89	31.46
10	1830 to 1930	26	28.32	28.95	29.57	28.60	29.04	29.42	30.16	29.72	29.77	30.10	30.10	29.81	30.01
11	1930 to 2030	24	27.55	28.09	28.80	28.40	28.43	28.51	29.32	28.58	28.80	29.09	29.09	29.72	29.30
12	2030 to 2130	24	26.80	27.32	27.99	27.48	27.60	27.73	28.51	27.64	27.96	28.37	28.37	28.75	28.50
13	2130 to 2230	23	25.85	26.54	27.13	26.38	26.68	26.95	27.71	26.57	27.08	27.59	27.59	27.71	27.63
14	2230 to 2330	23	25.53	26.01	26.60	26.38	26.33	26.37	27.08	26.57	26.67	26.95	26.95	26.71	26.87
15	2330 to 0030	23	25.01	25.53	26.07	25.53	25.71	25.90	26.58	25.67	26.05	26.52	26.52	26.78	26.61
16	0030 to 0130	22	24.29	24.88	25.44	24.56	24.96	25.24	25.98	24.69	25.30	25.90	25.90	25.79	25.87
17	0130 to 0230	22	24.11	24.58	25.07	24.57	24.74	24.88	25.51	24.70	25.03	25.42	25.42	25.80	25.55
18	0230 to 0330	22	23.88	24.30	24.76	24.62	24.56	24.59	25.17	24.73	24.83	25.10	25.10	25.82	25.34
19	0330 to 0430	21	23.98	24.29	24.88	24.40	24.52	24.49	25.22	24.58	24.76	25.00	25.00	25.72	25.24
20	0430 to 0530	22	23.96	24.29	24.73	24.60	24.54	24.46	25.06	24.72	24.74	24.95	24.95	24.81	24.90
21	0530 to 0630	22	23.78	24.13	24.56	24.69	24.46	24.32	24.91	24.78	24.67	24.83	24.83	24.85	24.83
22	0630 to 0730	23	24.29	24.34	24.72	24.10	24.39	24.38	24.89	24.07	24.45	24.80	24.80	24.05	24.55
23	0730 to 0830	24	25.89	25.18	25.68	25.20	25.36	24.92	25.43	24.55	24.97	25.14	25.14	25.04	25.11
24	0830 to 0930	26	29.17	27.63	28.12	27.53	27.76	26.77	27.27	26.59	26.88	26.64	26.64	26.08	26.46

Table A-4 (b): 24 hr. cube temperature values (measured and calculated) for Mix A for 24 hr. cloudy & humid condition at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (ºC) at 10 cm				Temperature (ºC) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	0930 to 1030	28.05	27.79	28.17	28.00	28.22	27.21	28.85	28.09
2	1030 to 1130	31.19	30.56	31.68	31.14	31.14	29.23	31.15	30.51
3	1130 to 1230	33.77	32.74	33.68	33.40	33.63	30.88	33.15	32.55
4	1230 to 1330	35.94	34.82	35.51	35.42	35.62	32.58	35.63	34.61
5	1330 to 1430	36.15	35.07	36.68	35.97	36.06	32.88	36.57	35.17
6	1430 to 1530	35.17	34.07	35.44	34.89	35.25	31.93	35.84	34.34
7	1530 to 1630	33.84	32.99	33.76	33.53	34.09	31.34	34.44	33.29
8	1630 to 1730	32.53	31.73	32.36	32.20	32.83	30.21	32.21	31.75
9	1730 to 1830	31.24	30.49	31.92	31.22	31.66	29.07	31.96	30.90
10	1830 to 1930	30.14	29.39	30.87	30.13	30.57	28.02	30.93	29.84
11	1930 to 2030	29.13	28.13	29.81	29.02	29.61	26.43	29.89	28.65
12	2030 to 2130	28.41	27.58	28.84	28.27	28.85	26.12	28.90	27.96
13	2130 to 2230	27.64	26.76	27.81	27.40	28.16	25.23	27.89	27.09
14	2230 to 2330	26.99	26.23	26.81	26.67	27.50	24.91	26.89	26.43
15	2330 to 0030	26.56	25.90	26.85	26.44	27.01	24.73	26.91	26.22
16	0030 to 0130	25.97	25.21	25.86	25.68	26.51	23.91	26.92	25.78
17	0130 to 0230	25.47	24.81	25.86	25.38	26.03	23.67	26.92	25.54
18	0230 to 0330	25.12	24.54	25.88	25.18	25.66	23.51	25.93	25.03
19	0330 to 0430	24.97	24.22	24.81	24.67	25.45	22.89	25.89	24.74
20	0430 to 0530	24.94	24.40	24.87	24.74	25.32	23.42	25.93	24.89
21	0530 to 0630	24.81	24.31	24.90	24.68	25.24	23.37	25.94	24.85
22	0630 to 0730	24.76	24.46	24.03	24.42	25.19	23.86	25.02	24.69
23	0730 to 0830	25.03	24.80	25.69	25.17	25.44	24.42	25.40	25.09
24	0830 to 0930	26.32	26.22	26.06	26.20	26.67	26.00	26.20	26.29

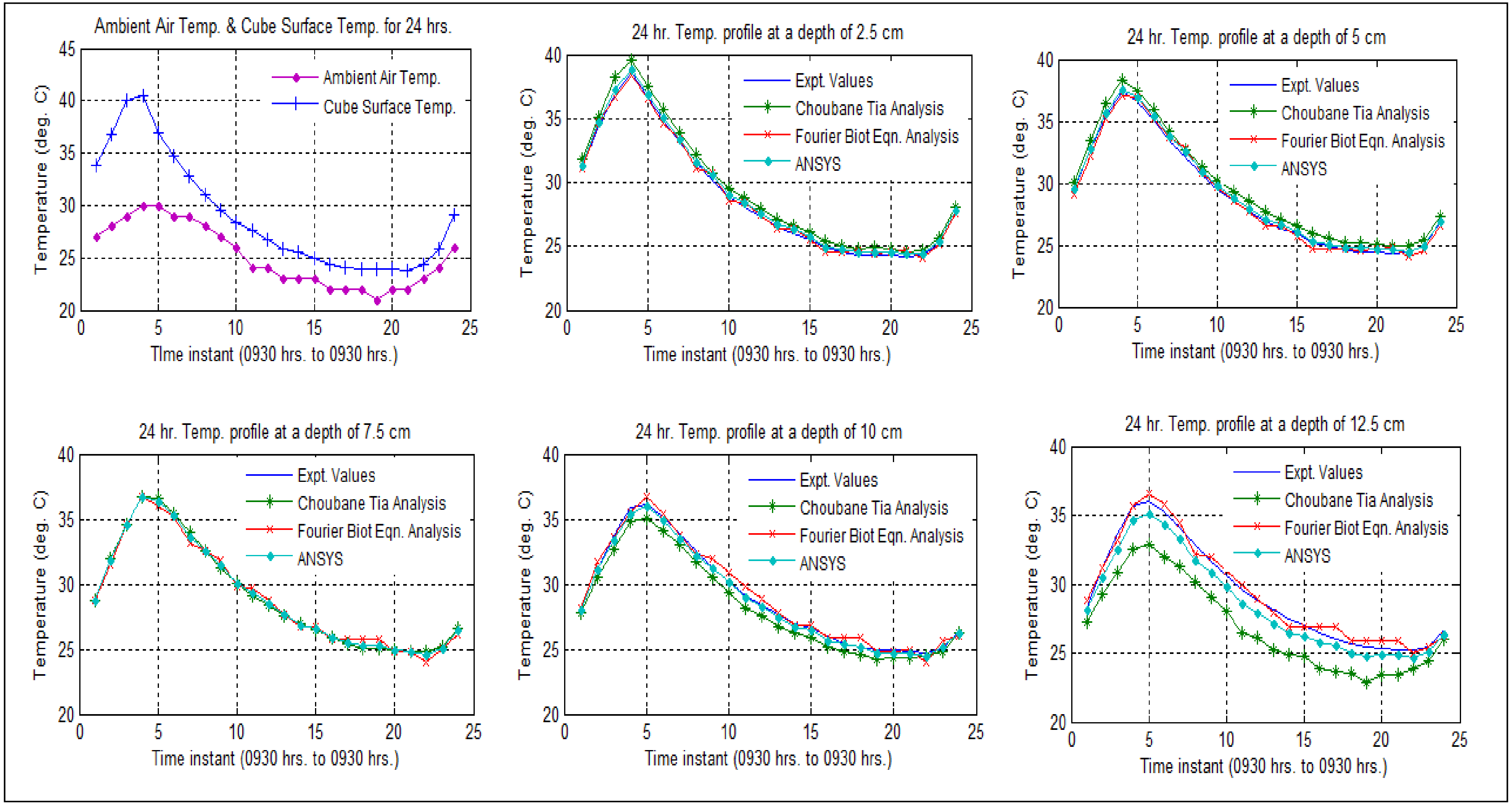


Fig. A-7: 24 hour cube temperature profile (measured and calculated) at various depths for Mix A for 24 hr. cloudy and humid condition

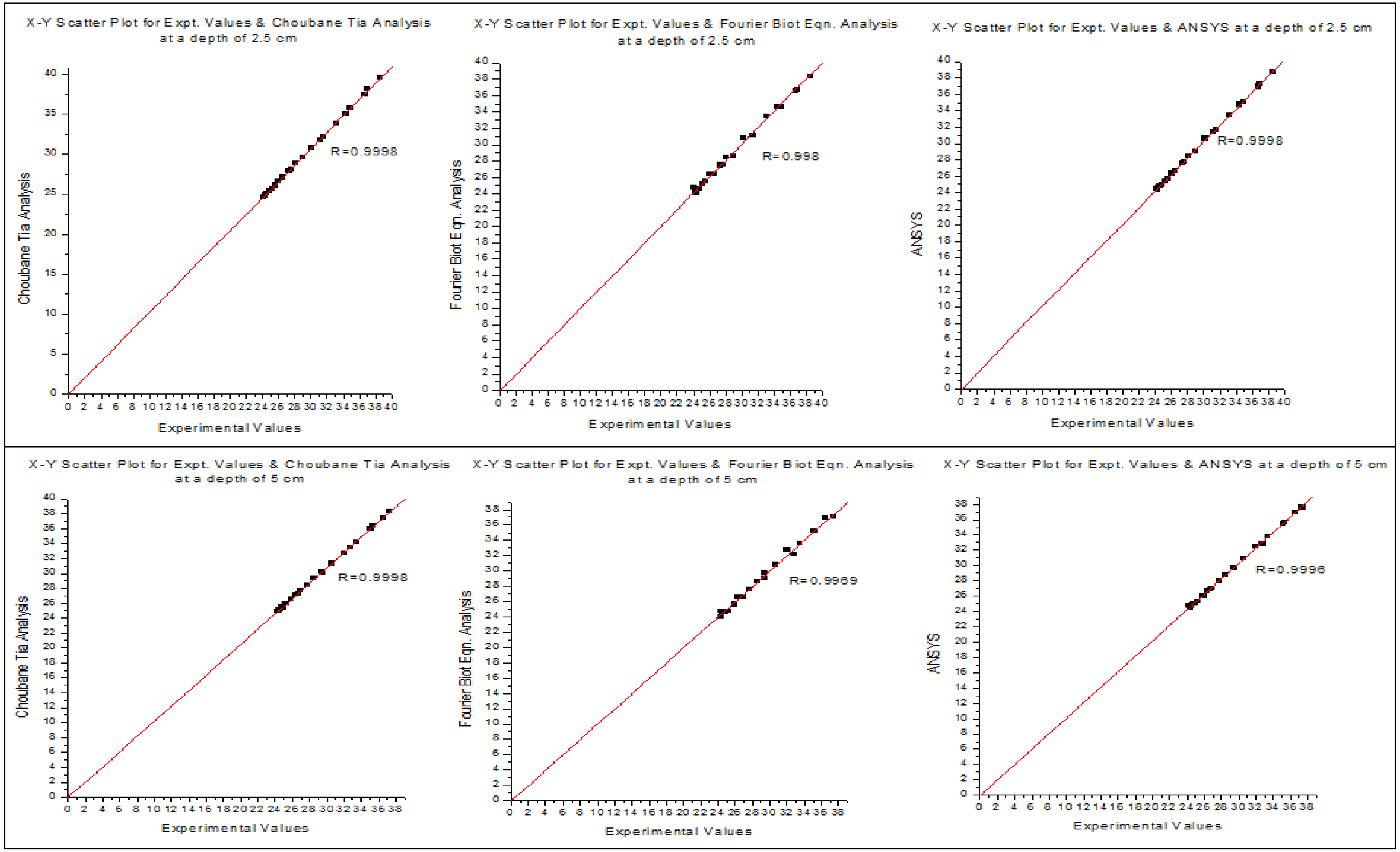


Fig. A-8 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

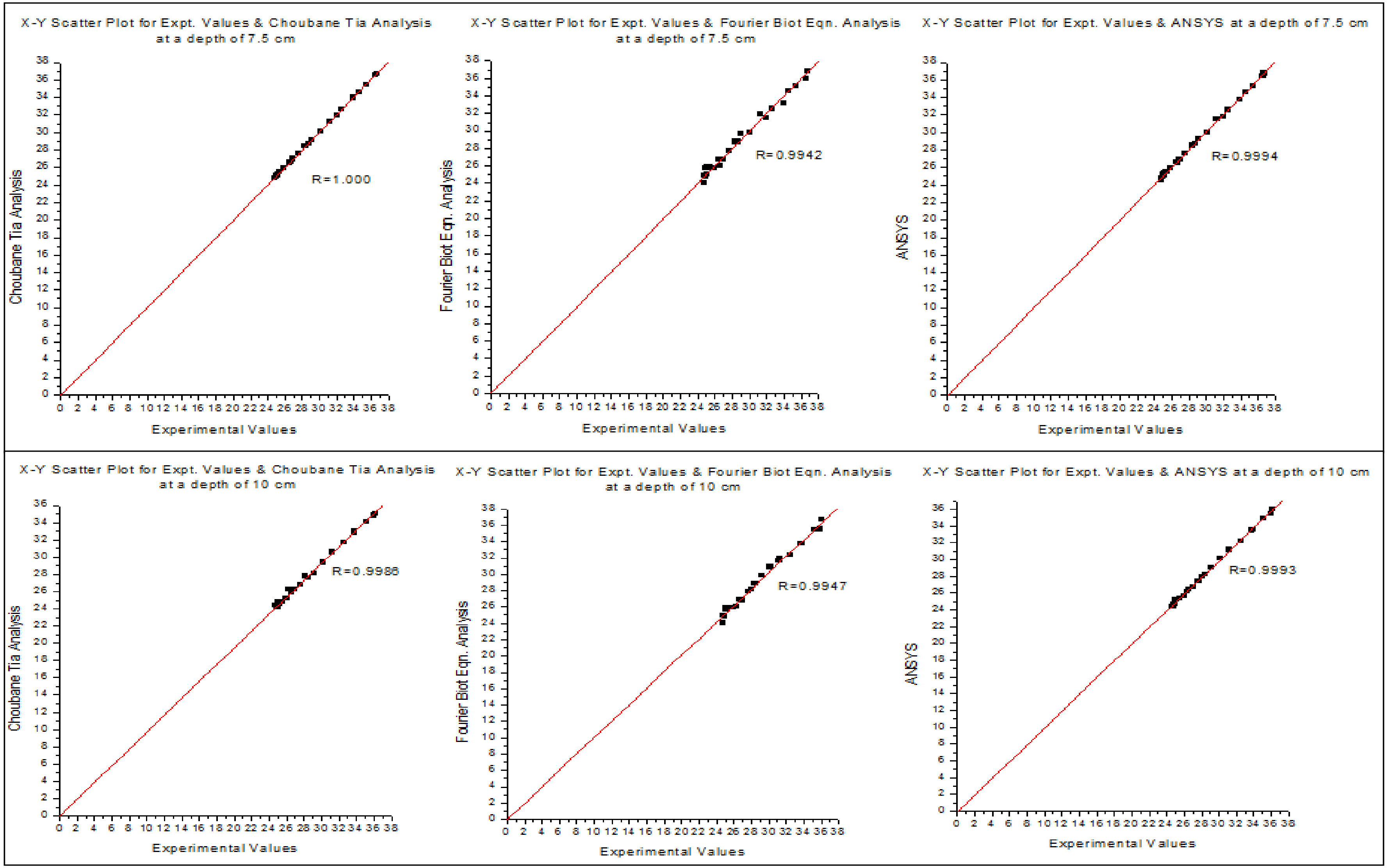


Fig. A-8 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

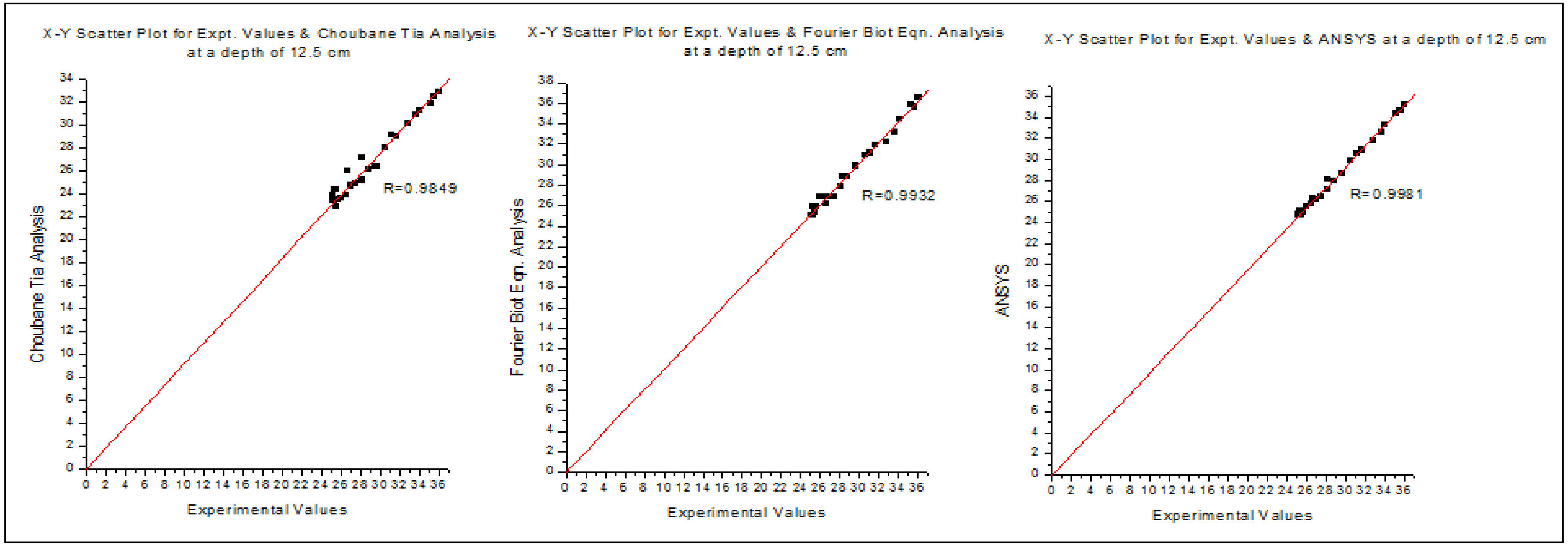


Fig. A-8 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-5 (a): 24 hr. cube temperature values (measured and calculated) for Mix A for 2 hr. sudden precipitation at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	0930 to 1030	28	27.83	26.60	26.43	26.94	26.66	25.47	25.60	25.18	25.42	25.34	25.34	25.81	25.50
2	1030 to 1130	30	31.39	29.94	29.62	29.41	29.65	28.42	28.47	28.72	28.53	27.93	27.93	27.86	27.90
3	1130 to 1230	31	32.28	31.43	31.13	31.93	31.49	30.32	30.35	30.68	30.45	29.95	29.95	30.16	30.02
4	1230 to 1330	31	35.21	33.51	33.67	33.24	33.47	32.06	32.47	32.90	32.48	31.60	31.60	31.31	31.51
5	1330 to 1430	31	35.88	35.13	35.10	34.50	34.91	33.93	34.30	34.49	34.24	33.50	33.50	33.38	33.46
6	1430 to 1530	31	36.27	35.64	35.71	35.21	35.52	34.51	35.03	34.77	34.77	34.22	34.22	34.87	34.43
7	1530 to 1630	30	33.72	33.93	34.23	33.76	33.97	33.73	34.30	33.45	33.83	33.90	33.90	33.66	33.82
8	1630 to 1730	29	31.31	32.15	32.39	32.04	32.19	32.33	32.88	31.14	32.11	32.79	32.79	32.43	32.67
9	1730 to 1830	28	28.76	29.71	30.07	29.34	29.71	30.23	30.81	30.24	30.43	30.97	30.97	30.16	30.70
10	1830 to 1930	27	23.80	25.71	25.57	25.84	25.71	26.58	26.84	26.59	26.67	27.62	27.62	27.40	27.55
11	1930 to 2030	26	22.73	23.65	23.46	24.53	23.88	23.80	24.11	24.37	24.09	24.70	24.70	24.25	24.55
12	2030 to 2130	26	22.29	23.10	22.73	23.58	23.14	23.12	23.24	23.41	23.26	23.83	23.83	23.27	23.64
13	2130 to 2230	26	22.10	22.86	22.42	22.59	22.62	22.83	22.88	22.41	22.71	23.46	23.46	23.28	23.40
14	2230 to 2330	26	21.62	22.34	21.88	22.42	22.21	22.28	22.33	22.00	22.20	22.96	22.96	22.67	22.86
15	2330 to 0030	25	21.50	22.10	21.69	21.90	21.90	21.94	22.04	21.63	21.87	22.55	22.55	22.43	22.51
16	0030 to 0130	25	21.52	22.12	21.65	21.70	21.82	21.87	21.96	21.49	21.77	22.45	22.45	22.33	22.41
17	0130 to 0230	24	21.60	22.24	21.82	22.44	22.17	21.97	22.12	21.31	21.80	22.48	22.48	22.21	22.39
18	0230 to 0330	24	21.60	22.28	21.84	22.40	22.17	22.00	22.15	22.28	22.14	22.52	22.52	22.19	22.41
19	0330 to 0430	24	21.47	22.05	21.64	21.51	21.73	21.75	21.90	21.36	21.67	22.27	22.27	22.24	22.26
20	0430 to 0530	24	21.26	21.92	21.45	21.67	21.68	21.66	21.74	21.47	21.62	22.14	22.14	22.32	22.20
21	0530 to 0630	24	21.02	21.70	21.23	21.61	21.51	21.49	21.55	21.43	21.49	21.98	21.98	21.29	21.75
22	0630 to 0730	24	20.80	21.45	20.97	21.55	21.32	21.30	21.29	21.39	21.33	21.75	21.75	21.26	21.59
23	0730 to 0830	25	20.96	21.47	20.86	22.39	21.57	21.18	21.08	20.98	21.08	21.60	21.60	20.66	21.29
24	0830 to 0930	27	23.67	23.30	22.61	23.61	23.17	22.37	22.19	22.83	22.46	22.42	22.42	22.23	22.36

Table A-5 (b): 24 hr. cube temperature values (measured and calculated) for Mix A for 2 hr. sudden precipitation at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (ºC) at 10 cm				Temperature (ºC) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	0930 to 1030	25.15	25.66	24.87	25.23	25.33	26.54	25.09	25.66
2	1030 to 1130	27.46	28.00	27.90	27.79	27.40	28.69	27.28	27.79
3	1130 to 1230	29.48	29.92	29.44	29.61	29.33	30.27	29.01	29.54
4	1230 to 1330	31.09	31.07	31.54	31.23	30.90	30.87	31.07	30.94
5	1330 to 1430	32.93	32.68	32.25	32.62	32.61	31.84	32.48	32.31
6	1430 to 1530	33.73	33.27	33.58	33.53	33.45	32.20	33.51	33.05
7	1530 to 1630	33.64	33.06	33.44	33.38	33.53	31.76	33.43	32.90
8	1630 to 1730	32.73	32.11	32.96	32.60	32.84	30.85	32.56	32.08
9	1730 to 1830	31.10	30.55	31.11	30.92	31.35	29.57	31.06	30.66
10	1830 to 1930	27.90	27.91	28.27	28.03	28.09	27.70	28.16	27.98
11	1930 to 2030	25.00	25.20	25.17	25.12	25.66	25.64	26.10	25.80
12	2030 to 2130	24.11	24.48	24.18	24.26	24.80	25.20	25.11	25.04
13	2130 to 2230	23.68	24.18	24.19	24.01	24.28	25.02	24.11	24.47
14	2230 to 2330	23.14	23.78	23.45	23.46	23.66	24.80	23.26	23.91
15	2330 to 0030	22.72	23.21	22.28	22.74	23.25	24.03	23.17	23.48
16	0030 to 0130	22.61	23.12	22.22	22.65	23.14	23.97	23.13	23.41
17	0130 to 0230	22.60	22.92	22.14	22.55	23.13	23.42	23.08	23.21
18	0230 to 0330	22.61	22.95	22.13	22.56	23.08	23.44	23.07	23.20
19	0330 to 0430	22.36	22.74	22.16	22.42	22.82	23.32	23.09	23.08
20	0430 to 0530	22.23	22.65	22.21	22.36	22.73	23.27	22.12	22.71
21	0530 to 0630	22.09	22.54	22.19	22.27	22.62	23.21	22.11	22.65
22	0630 to 0730	21.88	22.36	21.17	21.80	22.35	23.11	22.10	22.52
23	0730 to 0830	21.68	22.43	21.44	21.85	22.08	23.56	21.26	22.30
24	0830 to 0930	22.31	23.30	22.82	22.81	22.59	24.83	22.48	23.30

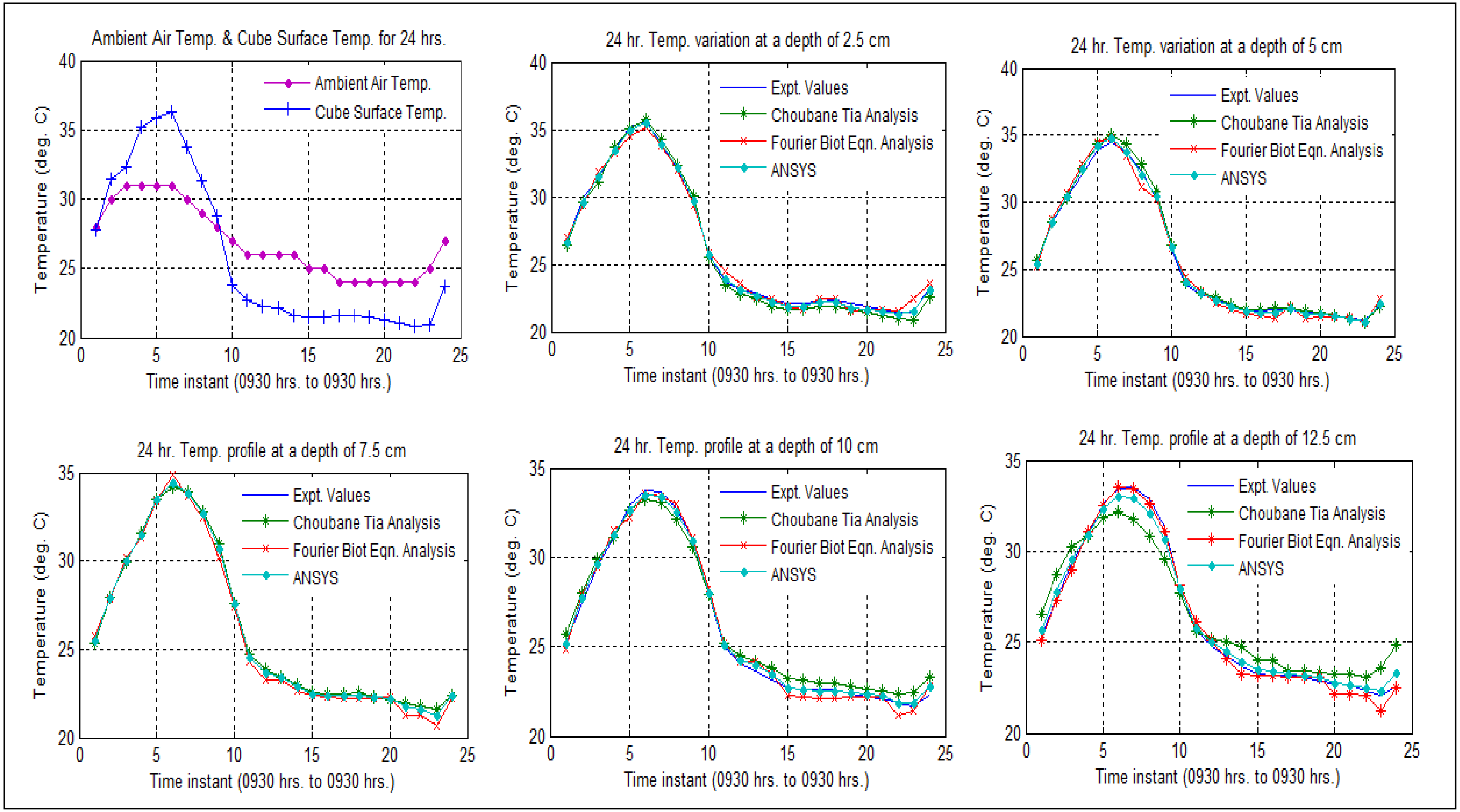


Fig. A-9: 24 hour cube temperature profile (measured and calculated) at various depths for Mix A for 2 hr. sudden precipitation

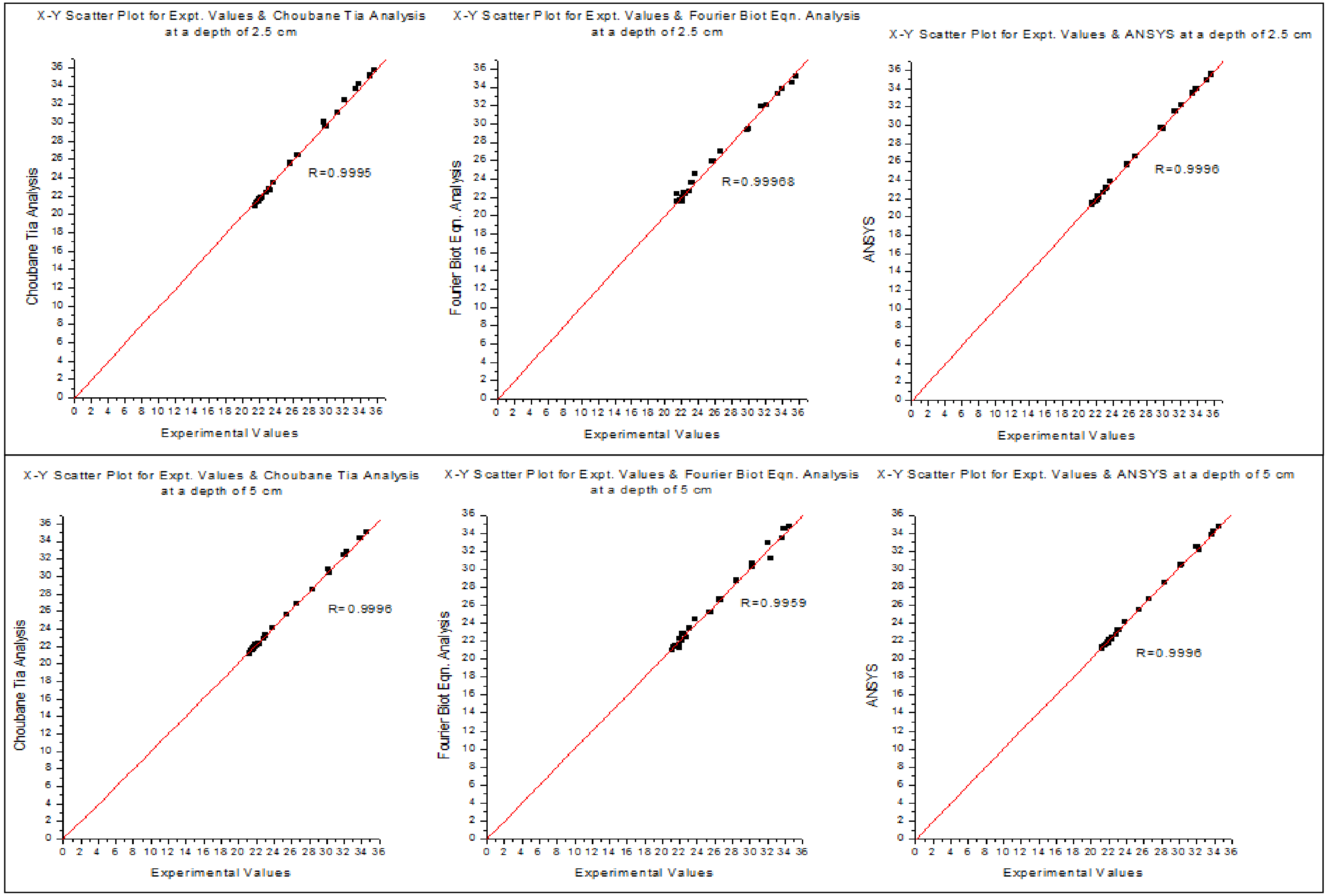


Fig. A-10 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

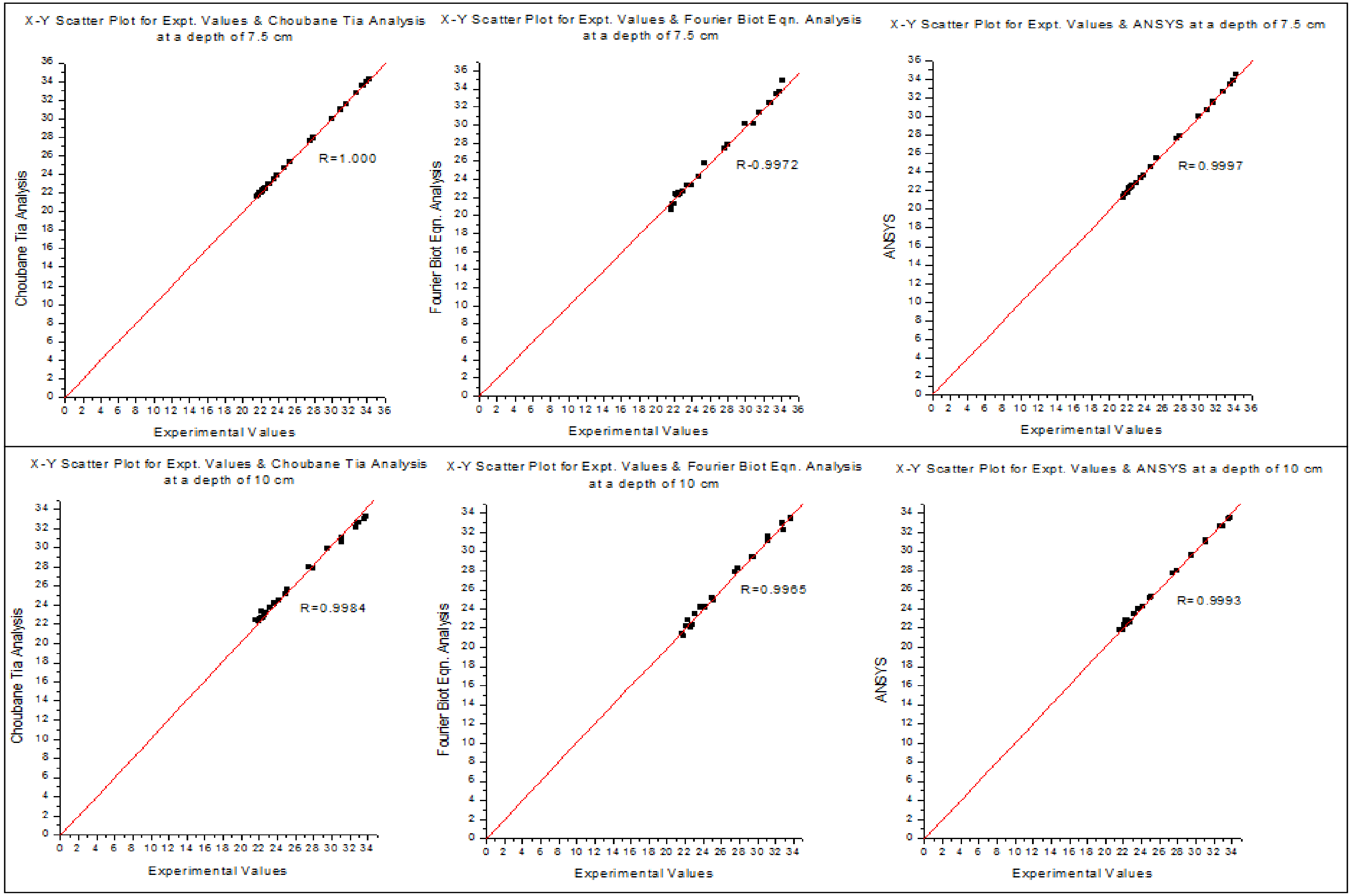


Fig. A-10 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

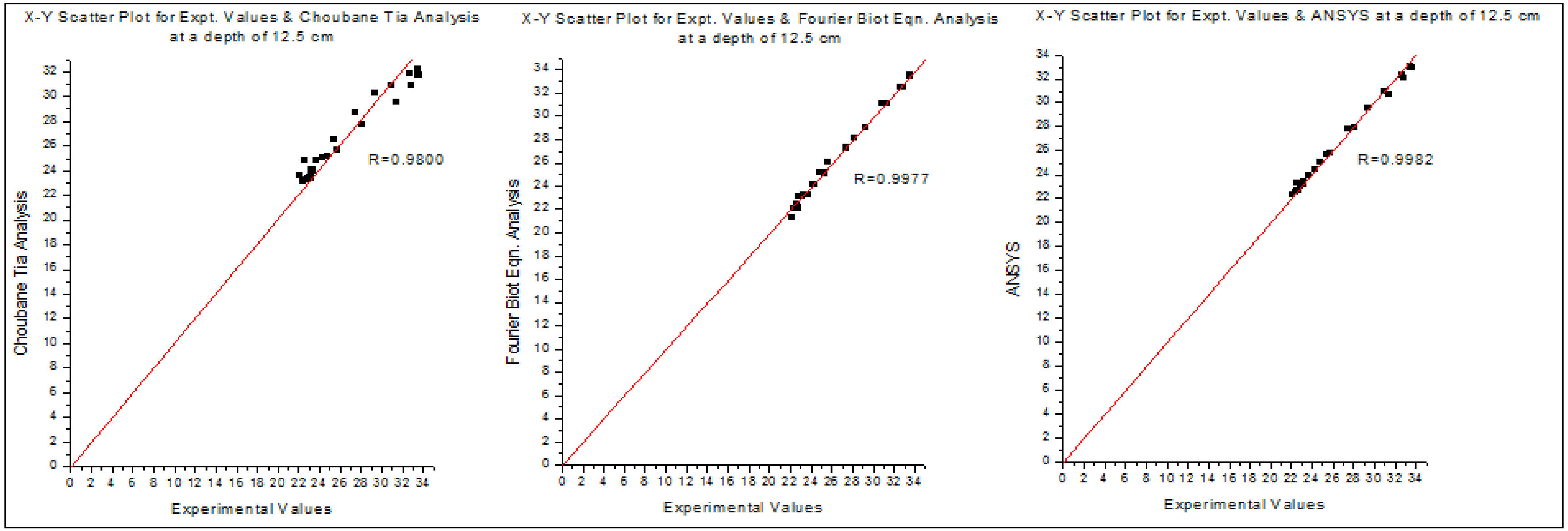


Fig. A-10 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-6 (a): 24 hr. cube temperature values (measured and calculated) for Mix B for maximum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (^oC) at 2.5 cm				Temperature (^oC) at 5 cm				Temperature (^oC) at 7.5 cm			
		(^oC)	(^oC)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	37	48.17	37.72	41.48	37.40	37.56	35.74	36.72	35.02	35.38	33.90	33.90	34.10	34.00
2	1130 to 1230	38	56.50	42.85	48.64	42.85	42.85	40.88	42.70	40.42	40.65	38.66	38.66	38.12	38.39
3	1230 to 1330	39	58.16	45.75	51.38	45.09	45.42	44.17	46.03	44.57	44.37	42.11	42.11	42.20	42.16
4	1330 to 1430	39	57.75	47.23	52.43	47.73	47.48	46.17	47.99	46.76	46.46	44.43	44.43	44.76	44.59
5	1430 to 1530	39	55.89	47.77	52.08	47.29	47.53	47.09	48.67	47.31	47.20	45.66	45.66	45.97	45.82
6	1530 to 1630	38	47.20	46.39	47.41	46.82	46.61	46.55	46.91	46.14	46.35	45.73	45.73	45.91	45.82
7	1630 to 1730	37	40.78	42.83	42.89	42.76	42.79	43.77	43.90	43.22	43.50	43.82	43.82	43.87	43.85
8	1730 to 1830	36	37.75	40.30	40.11	40.78	40.54	41.33	41.41	41.54	41.43	41.65	41.65	41.39	41.52
9	1830 to 1930	34	34.77	37.77	37.48	37.91	37.84	38.97	39.06	38.94	38.95	39.50	39.50	39.95	39.73
10	1930 to 2030	33	33.81	36.19	36.03	36.84	36.51	37.11	37.30	37.89	37.50	37.64	37.64	37.93	37.78
11	2030 to 2130	32	32.50	34.88	34.62	34.91	34.89	35.74	35.85	35.93	35.84	36.21	36.21	36.96	36.58
12	2130 to 2230	31	31.38	33.71	33.42	33.90	33.80	34.52	34.62	34.93	34.72	34.98	34.98	34.95	34.97
13	2230 to 2330	30	30.23	32.49	32.22	32.94	32.72	33.27	33.41	33.96	33.61	33.77	33.77	33.97	33.87
14	2330 to 0030	29	29.43	31.51	31.29	31.90	31.70	32.25	32.38	32.93	32.59	32.70	32.70	32.96	32.83
15	0030 to 0130	28	28.50	30.66	30.41	30.91	30.78	31.37	31.53	31.94	31.65	31.84	31.84	31.96	31.90
16	0130 to 0230	28	27.21	29.62	29.18	30.12	29.87	30.41	30.41	30.08	30.25	30.91	30.91	30.05	30.48
17	0230 to 0330	27	26.39	28.78	28.37	29.10	28.94	29.52	29.60	29.07	29.29	30.08	30.08	30.04	30.06
18	0330 to 0430	26	26.25	28.26	28.01	28.95	28.61	28.88	29.04	28.97	28.92	29.36	29.36	28.98	29.17
19	0430 to 0530	26	25.84	27.77	27.47	28.04	27.90	28.39	28.46	28.03	28.21	28.81	28.81	28.02	28.41
20	0530 to 0630	27	25.53	27.36	26.94	27.31	27.34	27.94	27.88	27.21	27.58	28.36	28.36	28.14	28.25
21	0630 to 0730	29	25.99	27.12	26.73	27.74	27.43	27.54	27.38	27.20	27.37	27.93	27.93	27.78	27.86
22	0730 to 0830	31	29.51	27.87	28.49	27.97	27.92	27.88	27.98	26.44	27.16	27.97	27.97	27.24	27.61
23	0830 to 0930	34	36.83	31.19	32.97	31.36	31.27	30.07	30.47	30.78	30.43	29.32	29.32	29.77	29.54
24	0930 to 1030	35	43.01	34.99	37.83	34.23	34.61	33.45	34.18	33.31	33.38	32.08	32.08	32.45	32.26

Table A-6 (b): 24 hr. cube temperature values (measured and calculated) for Mix B for maximum ambient air temperature at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	33.18	33.00	33.44	33.31	32.67	34.03	32.63	32.65
2	1130 to 1230	37.69	36.53	37.67	37.68	36.97	36.31	36.61	36.79
3	1230 to 1330	41.15	39.64	41.71	41.43	40.42	38.60	40.63	40.53
4	1330 to 1430	43.52	41.74	43.48	43.50	42.65	39.93	42.49	42.57
5	1430 to 1530	44.84	43.04	44.07	44.45	44.01	40.82	44.25	44.13
6	1530 to 1630	45.15	43.85	45.08	45.11	44.48	41.27	44.51	44.49
7	1630 to 1730	43.68	42.64	43.51	43.59	43.47	40.37	43.31	43.39
8	1730 to 1830	41.70	40.82	41.23	41.46	41.72	38.94	41.14	41.43
9	1830 to 1930	39.71	38.81	39.97	39.84	39.87	36.97	39.98	39.93
10	1930 to 2030	37.89	37.04	37.95	37.92	38.15	35.49	38.97	38.56
11	2030 to 2130	36.46	35.69	36.97	36.71	36.74	34.28	36.98	36.86
12	2130 to 2230	35.24	34.49	35.97	35.61	35.56	33.17	35.98	35.77
13	2230 to 2330	34.08	33.33	33.98	34.03	34.41	32.07	34.99	34.70
14	2330 to 0030	32.99	32.24	32.97	32.98	33.37	31.01	33.98	33.68
15	0030 to 0130	32.16	31.36	31.97	32.07	32.51	30.08	32.98	32.75
16	0130 to 0230	31.24	30.67	31.03	31.14	31.67	29.70	32.02	31.85
17	0230 to 0330	30.45	29.80	30.03	30.24	30.86	28.78	30.02	30.44
18	0330 to 0430	29.73	28.96	29.99	29.86	30.20	27.84	29.99	30.10
19	0430 to 0530	29.13	28.52	29.01	29.07	29.59	27.58	29.01	29.30
20	0530 to 0630	28.69	28.37	29.09	28.89	29.05	27.92	29.05	29.05
21	0630 to 0730	28.29	28.38	28.50	28.39	28.73	28.74	28.31	28.52
22	0730 to 0830	28.23	28.48	28.43	28.33	28.59	29.48	27.87	28.23
23	0830 to 0930	29.20	29.53	29.40	29.30	29.25	31.09	29.47	29.36
24	0930 to 1030	31.63	31.51	31.51	31.57	31.35	32.49	31.19	31.27

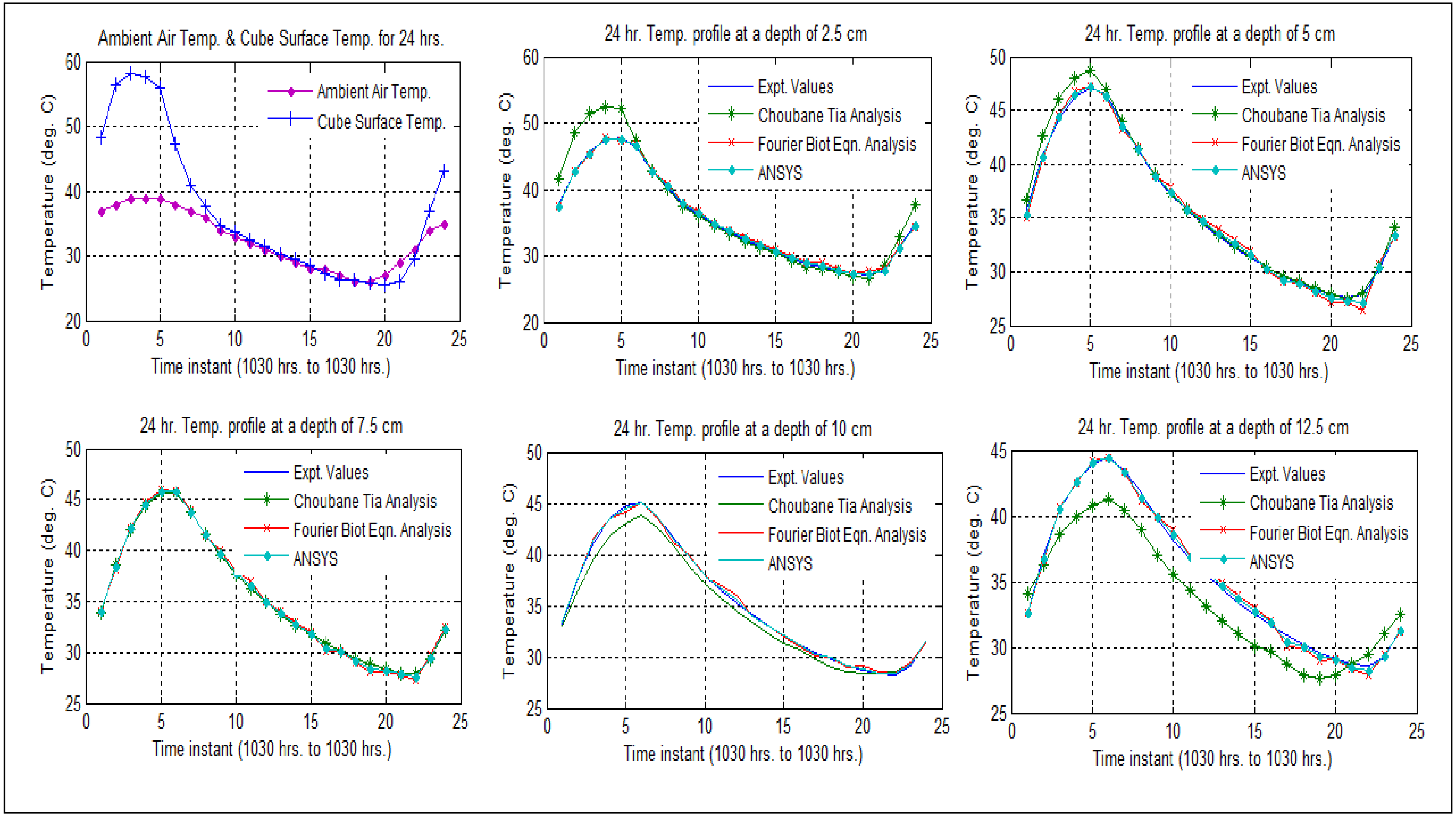


Fig. A-11: 24 hour cube temperature profile (measured and calculated) at various depths for Mix B for maximum ambient air temperature condition

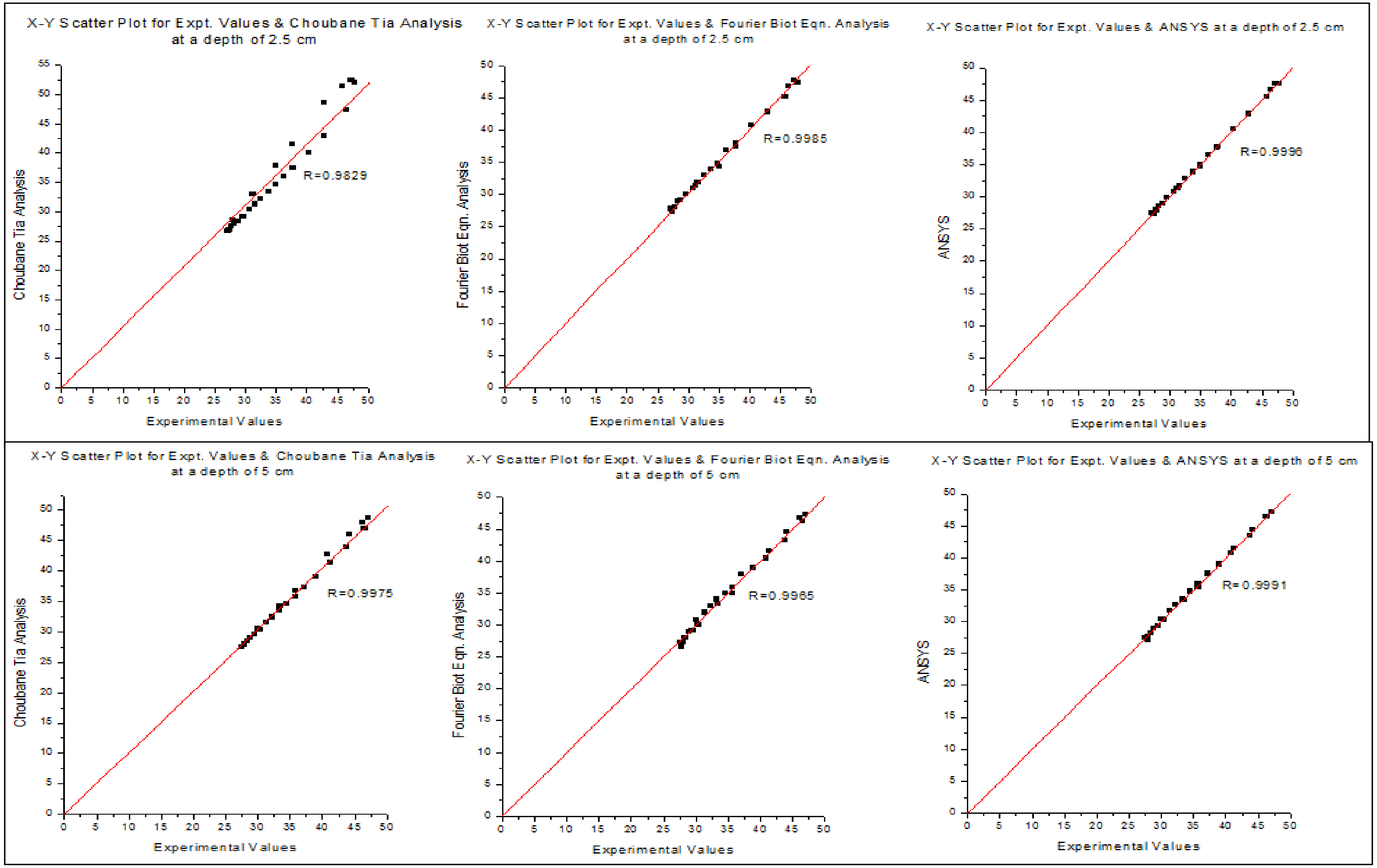


Fig. A-12 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

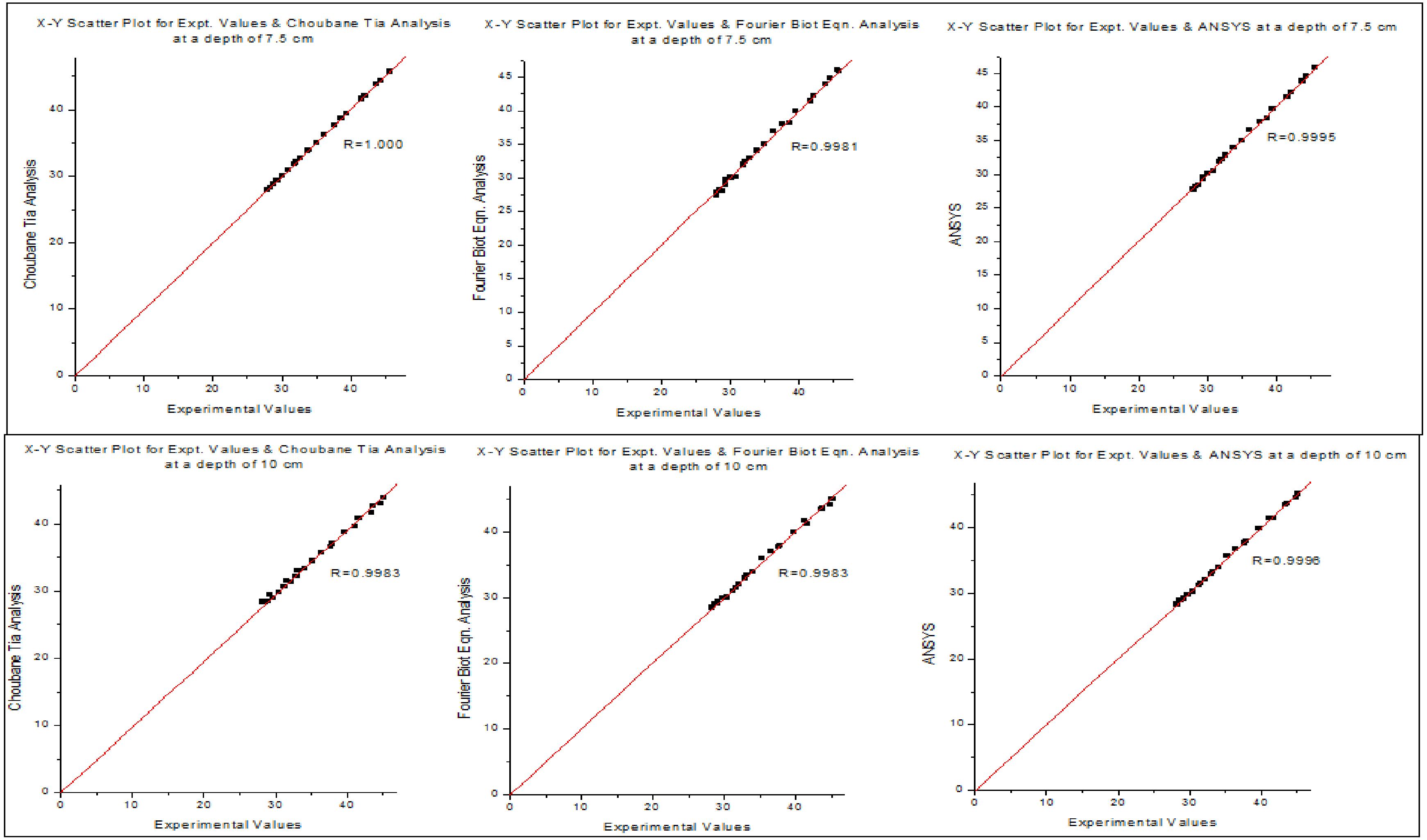


Fig. A-12 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

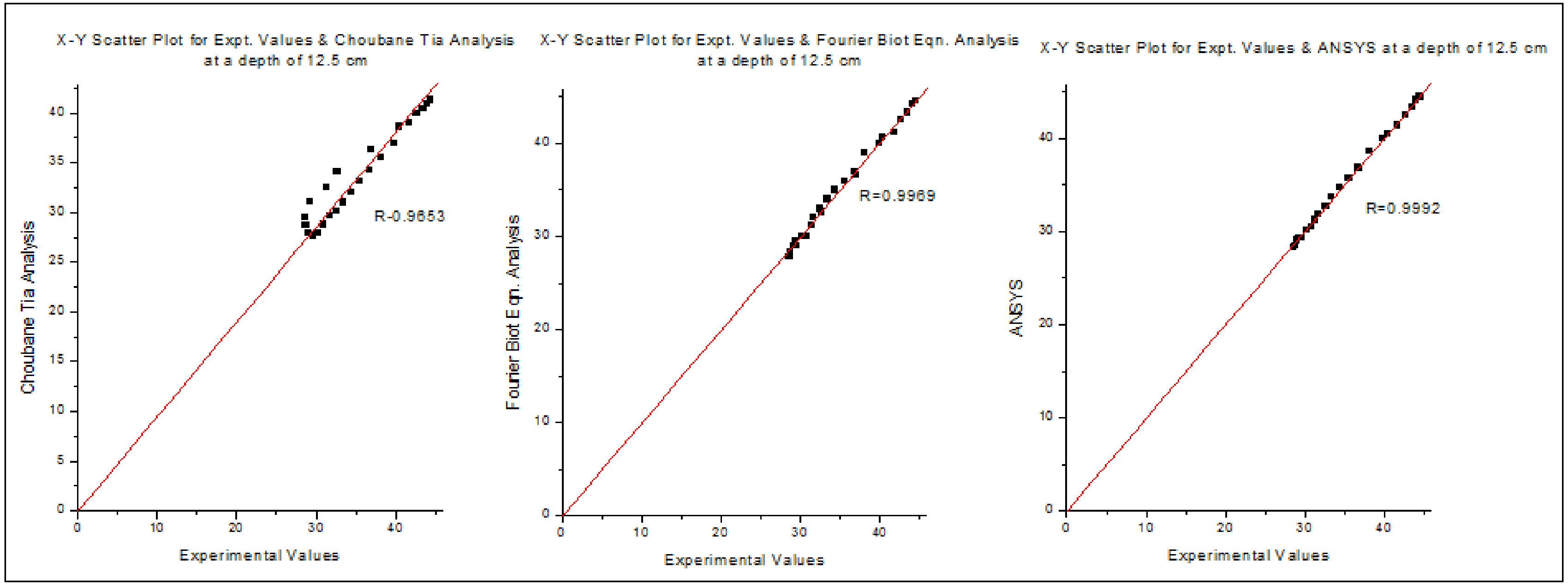


Fig. A-12 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-7(a): 24 hr. cube temperature values (measured and calculated) for Mix B for minimum ambient air temperature at 2.5 cm, 5 cm, & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (ºC) at 2.5 cm				Temperature (ºC) at 5 cm				Temperature (ºC) at 7.5 cm			
		(ºC)	(ºC)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	27	35.88	30.38	32.02	30.83	30.60	28.73	29.11	28.87	28.80	27.15	27.15	27.78	27.47
2	1130 to 1230	28	37.65	32.18	34.33	32.97	32.57	31.17	31.68	31.66	31.42	29.73	29.73	29.29	29.51
3	1230 to 1330	28	37.85	33.37	35.38	33.51	33.44	32.67	33.24	32.34	32.51	31.43	31.43	31.09	31.26
4	1330 to 1430	28	36.29	33.55	35.00	33.85	33.70	33.22	33.67	33.89	33.55	32.31	32.31	32.79	32.55
5	1430 to 1530	28	34.03	32.95	33.81	32.30	32.63	32.96	33.28	32.13	32.54	32.43	32.43	32.64	32.54
6	1530 to 1630	27	30.16	30.96	31.28	30.50	30.73	31.52	31.75	31.19	31.36	31.55	31.55	31.38	31.47
7	1630 to 1730	26	26.44	28.36	28.40	28.71	28.53	29.39	29.54	29.56	29.48	29.88	29.88	29.67	29.77
8	1730 to 1830	24	23.82	25.83	26.01	25.57	25.70	27.05	27.34	27.39	27.22	27.81	27.81	27.26	27.53
9	1830 to 1930	22	21.93	23.88	24.14	23.02	23.45	25.08	25.48	25.01	25.05	25.93	25.93	25.01	25.47
10	1930 to 2030	21	20.63	22.45	22.67	23.07	22.76	23.54	23.92	23.05	23.29	24.38	24.38	24.03	24.21
11	2030 to 2130	21	19.53	21.27	21.36	21.29	21.28	22.27	22.55	22.20	22.24	23.11	23.11	23.13	23.12
12	2130 to 2230	20	18.61	20.30	20.36	20.32	20.31	21.26	21.51	21.22	21.24	22.05	22.05	22.14	22.09
13	2230 to 2330	20	17.89	19.53	19.49	19.46	19.49	20.39	20.59	20.32	20.36	21.20	21.20	21.21	21.20
14	2330 to 0030	20	17.30	18.83	18.74	18.62	18.72	19.70	19.78	19.43	19.56	20.43	20.43	20.28	20.35
15	0030 to 0130	19	16.77	18.27	18.21	18.40	18.34	19.07	19.23	19.27	19.17	19.82	19.82	19.18	19.50
16	0130 to 0230	19	16.22	17.70	17.57	17.41	17.56	18.47	18.57	18.29	18.38	19.22	19.22	19.19	19.20
17	0230 to 0330	18	15.80	17.23	17.14	17.36	17.29	17.99	18.09	17.25	17.62	18.65	18.65	18.16	18.41
18	0330 to 0430	17	15.22	16.76	16.69	16.28	16.52	17.51	17.69	17.20	17.35	18.22	18.22	18.13	18.17
19	0430 to 0530	17	14.96	16.38	16.31	16.30	16.34	17.07	17.25	17.21	17.14	17.79	17.79	17.13	17.46
20	0530 to 0630	18	14.90	16.17	15.95	16.43	16.30	16.76	16.78	16.30	16.53	17.41	17.41	17.19	17.30
21	0630 to 0730	19	16.81	16.67	16.84	16.58	16.62	16.87	17.00	16.40	16.64	17.30	17.30	17.26	17.28
22	0730 to 0830	22	23.97	20.18	21.30	20.70	20.44	19.28	19.58	19.87	19.57	18.78	18.78	18.22	18.50
23	0830 to 0930	23	29.07	24.44	25.79	24.07	24.26	23.12	23.42	23.89	23.51	21.95	21.95	21.19	21.57
24	0930 to 1030	25	33.35	27.85	29.53	27.48	27.66	26.32	26.68	26.25	26.28	24.80	24.80	24.72	24.76

Table A-7(b): 24 hr. cube temperature values (measured and calculated) for Mix B for minimum ambient air temperature at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	26.49	26.15	26.68	26.59	25.96	26.10	25.25	25.61
2	1130 to 1230	28.97	28.47	28.01	28.49	28.34	27.89	28.45	28.40
3	1230 to 1330	30.71	29.95	30.88	30.79	30.10	28.81	30.37	30.24
4	1330 to 1430	31.77	30.91	31.69	31.73	31.37	29.47	31.26	31.31
5	1430 to 1530	32.10	31.27	32.96	32.53	31.81	29.79	31.81	31.81
6	1530 to 1630	31.43	30.70	31.15	31.29	31.38	29.18	31.32	31.35
7	1630 to 1730	30.03	29.40	30.06	30.05	30.20	28.10	30.65	30.43
8	1730 to 1830	28.15	27.40	28.16	28.15	28.48	26.13	28.10	28.29
9	1830 to 1930	26.36	25.50	26.00	26.18	26.79	24.19	26.00	26.40
10	1930 to 2030	24.84	24.04	24.02	24.43	25.31	22.92	25.01	25.16
11	2030 to 2130	23.57	23.04	23.08	23.33	24.10	22.34	24.05	24.08
12	2130 to 2230	22.54	21.97	22.09	22.32	23.09	21.29	23.06	23.07
13	2230 to 2330	21.67	21.30	21.13	21.40	22.22	20.90	22.08	22.15
14	2330 to 0030	20.94	20.68	20.18	20.56	21.50	20.54	21.11	21.30
15	0030 to 0130	20.25	19.97	20.11	20.18	20.84	19.70	21.07	20.95
16	0130 to 0230	19.72	19.50	19.12	19.42	20.23	19.43	20.07	20.15
17	0230 to 0330	19.15	18.82	19.10	19.13	19.74	18.61	19.06	19.40
18	0330 to 0430	18.66	18.28	18.08	18.37	19.26	17.87	19.05	19.16
19	0430 to 0530	18.27	17.93	18.09	18.18	18.81	17.67	18.05	18.43
20	0530 to 0630	17.90	17.82	17.12	17.51	18.39	18.01	18.07	18.23
21	0630 to 0730	17.72	17.73	17.17	17.44	18.25	18.30	18.10	18.18
22	0730 to 0830	18.83	18.92	18.77	18.80	18.99	19.99	18.47	18.73
23	0830 to 0930	21.58	21.39	21.03	21.31	21.35	21.74	21.24	21.29
24	0930 to 1030	24.20	23.89	24.01	24.10	23.75	23.96	23.84	23.79

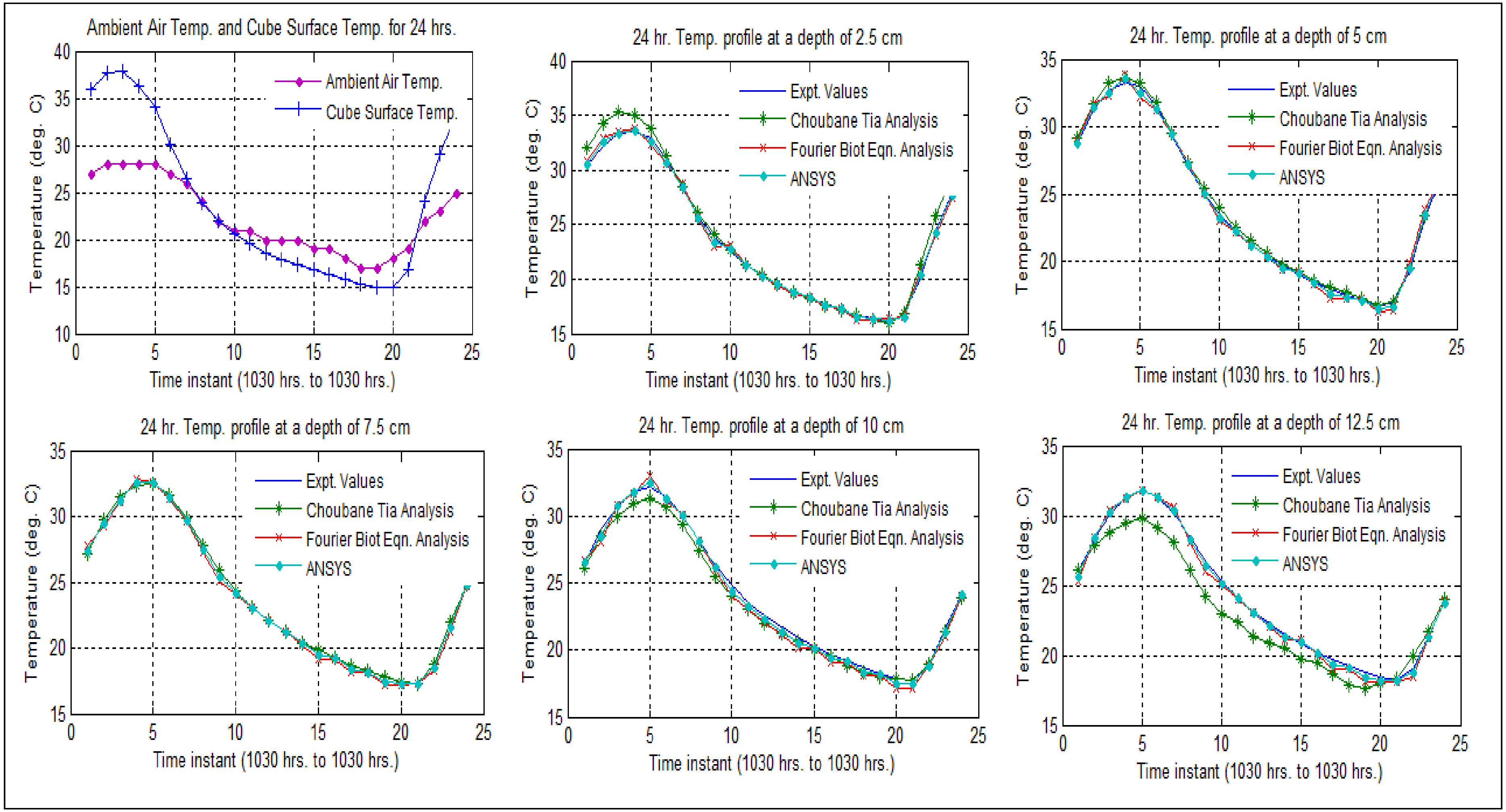


Fig. A-13: 24 hour cube temperature profile (measured and calculated) at various depths for Mix B for minimum ambient air temperature condition

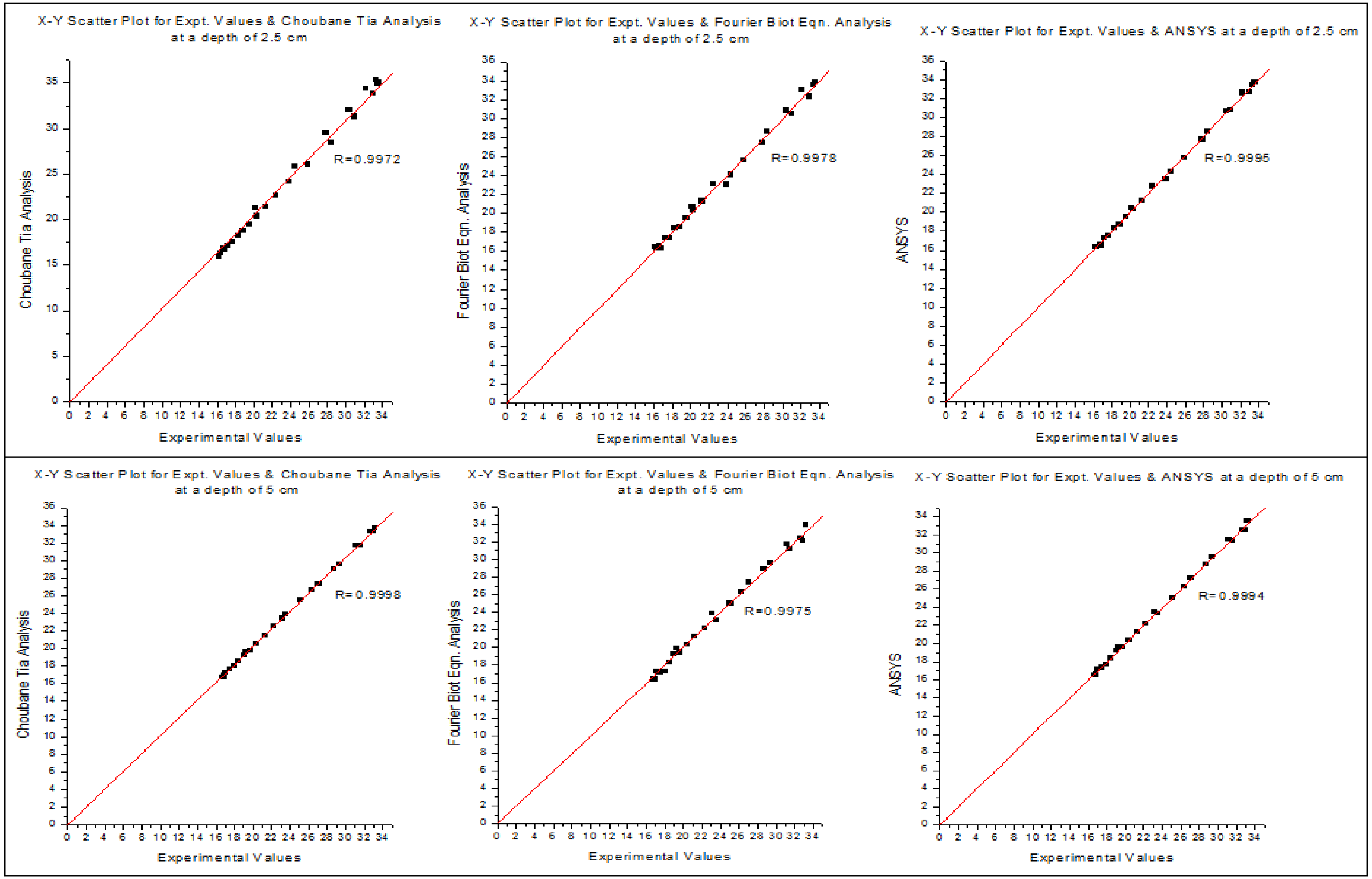


Fig. A-14 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

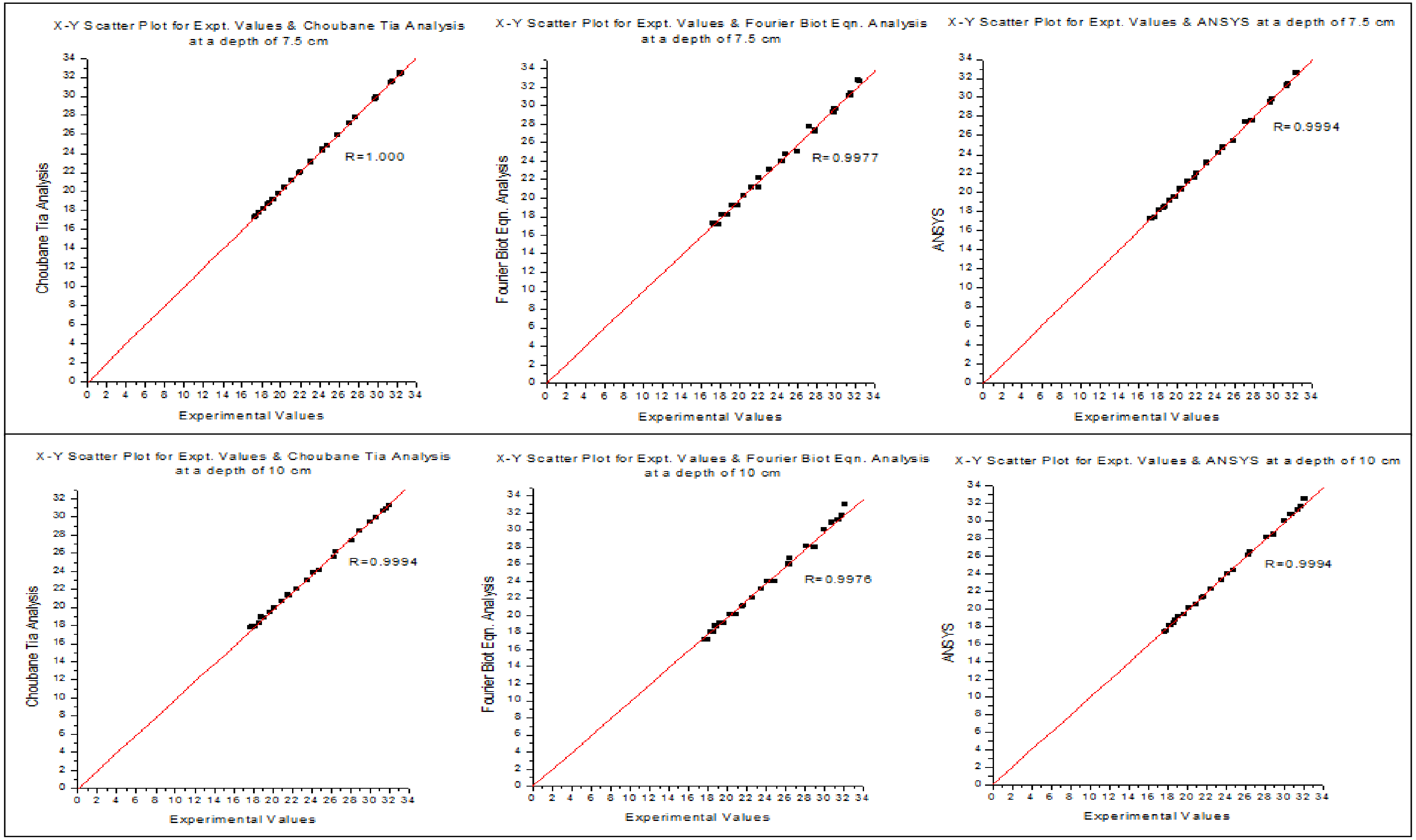


Fig. A-14 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

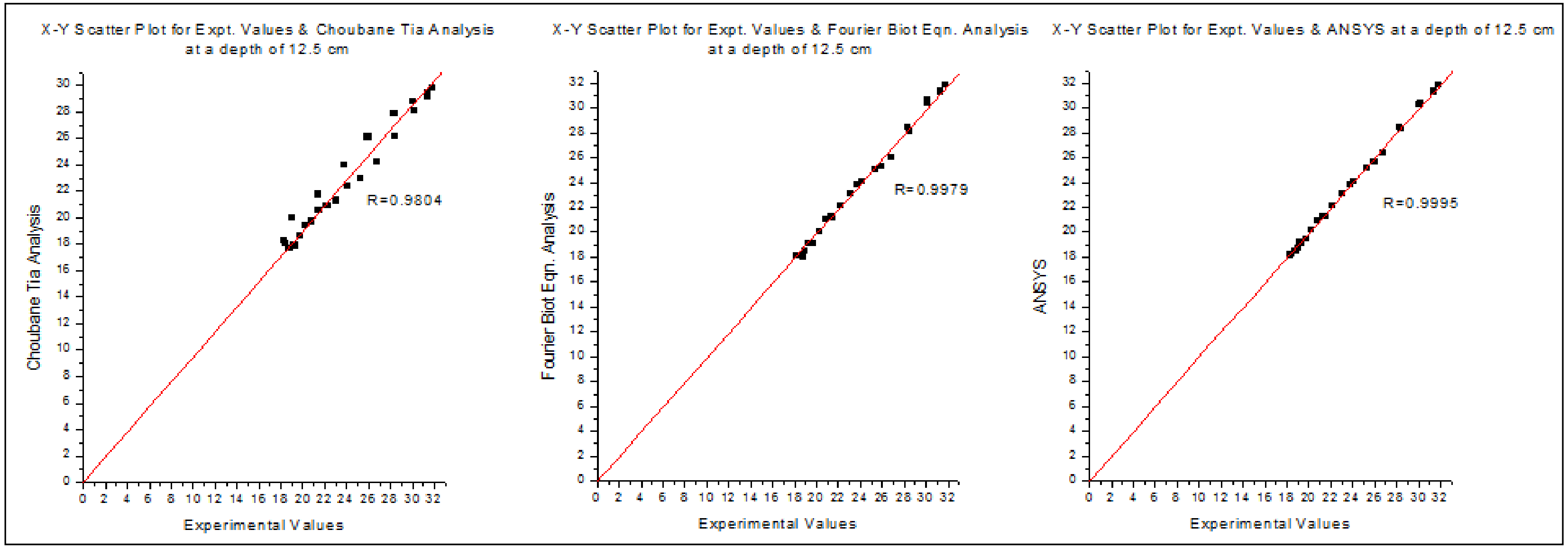


Fig. A-14 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-8 (a): 24 hr. cube temperature values (measured and calculated) for Mix B for 24 hr. precipitation at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	25	22.27	22.10	22.01	22.42	22.26	22.28	22.04	22.98	22.63	22.35	22.35	22.64	22.49
2	1130 to 1230	26	22.38	22.12	21.95	22.01	22.07	22.29	21.94	22.39	22.34	22.34	22.34	22.91	22.62
3	1230 to 1330	26	22.72	22.37	22.24	22.83	22.60	22.51	22.17	22.96	22.73	22.51	22.51	22.27	22.39
4	1330 to 1430	26	22.98	22.64	22.51	22.10	22.37	22.77	22.43	22.15	22.46	22.74	22.74	22.40	22.57
5	1430 to 1530	26	22.97	22.69	22.60	22.73	22.71	22.90	22.58	22.89	22.90	22.91	22.91	22.23	22.57
6	1530 to 1630	26	22.62	22.43	22.34	22.80	22.61	22.72	22.40	22.24	22.48	22.79	22.79	22.81	22.80
7	1630 to 1730	26	22.32	22.15	22.05	22.37	22.26	22.43	22.13	22.95	22.69	22.56	22.56	22.62	22.59
8	1730 to 1830	25	22.13	21.97	21.96	21.62	21.80	22.25	22.05	22.43	22.34	22.40	22.40	22.28	22.34
9	1830 to 1930	24	22.00	21.85	21.92	21.35	21.60	22.12	22.01	22.24	22.18	22.27	22.27	22.16	22.21
10	1930 to 2030	24	21.91	21.80	21.81	21.35	21.58	22.02	21.89	22.24	22.13	22.15	22.15	22.16	22.16
11	2030 to 2130	24	21.81	21.75	21.72	21.38	21.56	21.95	21.81	21.26	21.60	22.08	22.08	22.17	22.12
12	2130 to 2230	24	21.79	21.66	21.66	21.36	21.51	21.88	21.73	21.25	21.57	22.00	22.00	22.16	22.08
13	2230 to 2330	24	21.79	21.63	21.62	21.36	21.49	21.83	21.67	21.25	21.54	21.93	21.93	21.16	21.55
14	2330 to 0030	24	21.76	21.62	21.58	21.40	21.51	21.83	21.63	21.28	21.55	21.89	21.89	21.18	21.54
15	0030 to 0130	24	21.70	21.55	21.52	21.49	21.52	21.77	21.57	21.34	21.55	21.84	21.84	21.22	21.53
16	0130 to 0230	24	21.63	21.52	21.43	21.58	21.55	21.69	21.47	21.40	21.55	21.75	21.75	21.26	21.50
17	0230 to 0330	23	21.60	21.49	21.50	21.34	21.41	21.62	21.53	21.24	21.43	21.69	21.69	21.15	21.42
18	0330 to 0430	23	21.60	21.41	21.46	21.39	21.40	21.54	21.47	21.27	21.41	21.63	21.63	21.17	21.40
19	0430 to 0530	23	21.48	21.32	21.34	21.43	21.37	21.47	21.36	21.30	21.38	21.54	21.54	21.19	21.37
20	0530 to 0630	23	21.34	21.21	21.22	21.36	21.28	21.41	21.26	21.25	21.33	21.46	21.46	21.16	21.31
21	0630 to 0730	23	21.45	21.27	21.27	21.42	21.34	21.42	21.27	21.29	21.35	21.44	21.44	21.19	21.32
22	0730 to 0830	23	21.73	21.52	21.52	21.31	21.42	21.59	21.47	21.91	21.75	21.60	21.60	21.59	21.60
23	0830 to 0930	24	22.28	21.82	21.83	21.85	21.83	21.88	21.67	21.97	21.93	21.81	21.81	21.28	21.55
24	0930 to 1030	26	23.57	22.62	22.61	22.24	22.43	22.55	22.20	22.31	22.43	22.34	22.34	22.81	22.57

Table A-8 (b): 24 hr. cube temperature values (measured and calculated) for Mix B for 24 hr. precipitation at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	22.47	22.95	22.41	22.44	22.63	23.83	22.25	22.44
2	1130 to 1230	22.44	23.15	22.58	22.51	22.60	24.37	22.35	22.48
3	1230 to 1330	22.57	23.26	22.81	22.69	22.73	24.42	22.50	22.61
4	1330 to 1430	22.79	23.44	22.89	22.84	22.92	24.53	22.54	22.73
5	1430 to 1530	22.95	23.59	22.78	22.87	23.08	24.62	23.48	23.28
6	1530 to 1630	22.89	23.53	22.52	22.71	23.04	24.59	23.32	23.18
7	1630 to 1730	22.68	23.35	22.39	22.54	22.89	24.50	22.24	22.57
8	1730 to 1830	22.54	23.01	22.18	22.36	22.76	23.87	22.11	22.44
9	1830 to 1930	22.41	22.68	22.10	22.25	22.63	23.26	22.06	22.35
10	1930 to 2030	22.29	22.59	22.10	22.19	22.53	23.21	22.06	22.30
11	2030 to 2130	22.22	22.54	22.11	22.16	22.45	23.18	22.07	22.26
12	2130 to 2230	22.12	22.47	22.10	22.11	22.35	23.13	22.06	22.21
13	2230 to 2330	22.06	22.41	22.10	22.08	22.28	23.10	22.06	22.17
14	2330 to 0030	22.01	22.37	22.12	22.06	22.23	23.08	22.07	22.15
15	0030 to 0130	21.95	22.34	21.14	21.54	22.16	23.06	22.09	22.12
16	0130 to 0230	21.86	22.26	21.17	21.51	22.03	23.01	22.10	22.07
17	0230 to 0330	21.78	21.99	21.10	21.44	21.97	22.43	21.06	21.52
18	0330 to 0430	21.73	21.94	21.11	21.42	21.88	22.40	21.07	21.47
19	0430 to 0530	21.63	21.87	21.12	21.38	21.79	22.36	21.08	21.43
20	0530 to 0630	21.58	21.81	21.10	21.34	21.74	22.33	21.06	21.40
21	0630 to 0730	21.58	21.79	21.12	21.35	21.73	22.31	21.07	21.40
22	0730 to 0830	21.67	21.90	21.38	21.52	21.81	22.36	21.23	21.52
23	0830 to 0930	21.85	22.25	21.82	21.83	21.99	22.98	21.50	21.75
24	0930 to 1030	22.32	23.01	22.79	22.55	22.40	24.23	22.09	22.25

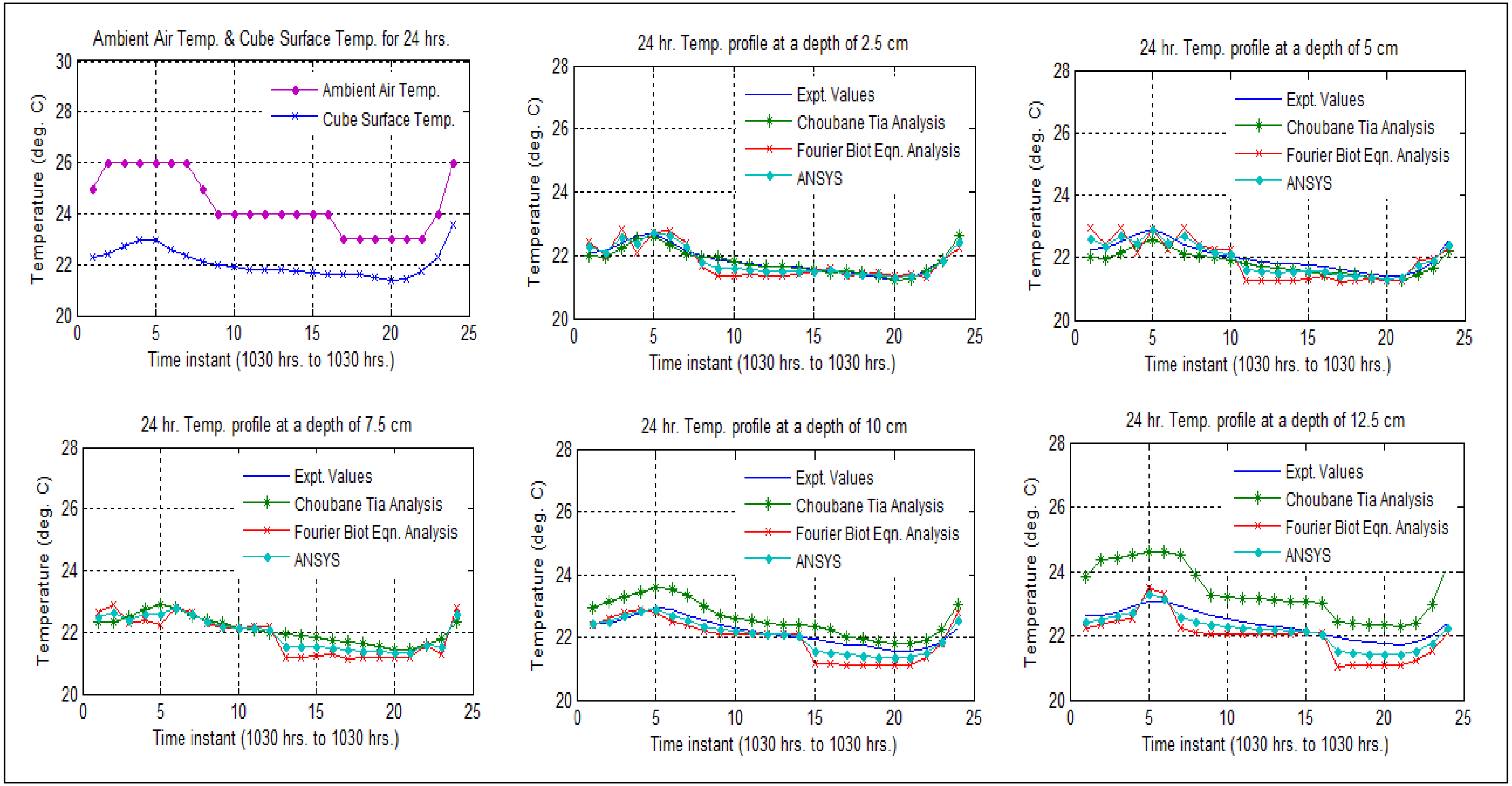


Fig. A-15: 24 hour cube temperature profile (measured and calculated) at various depths for Mix B for 24 hour precipitation

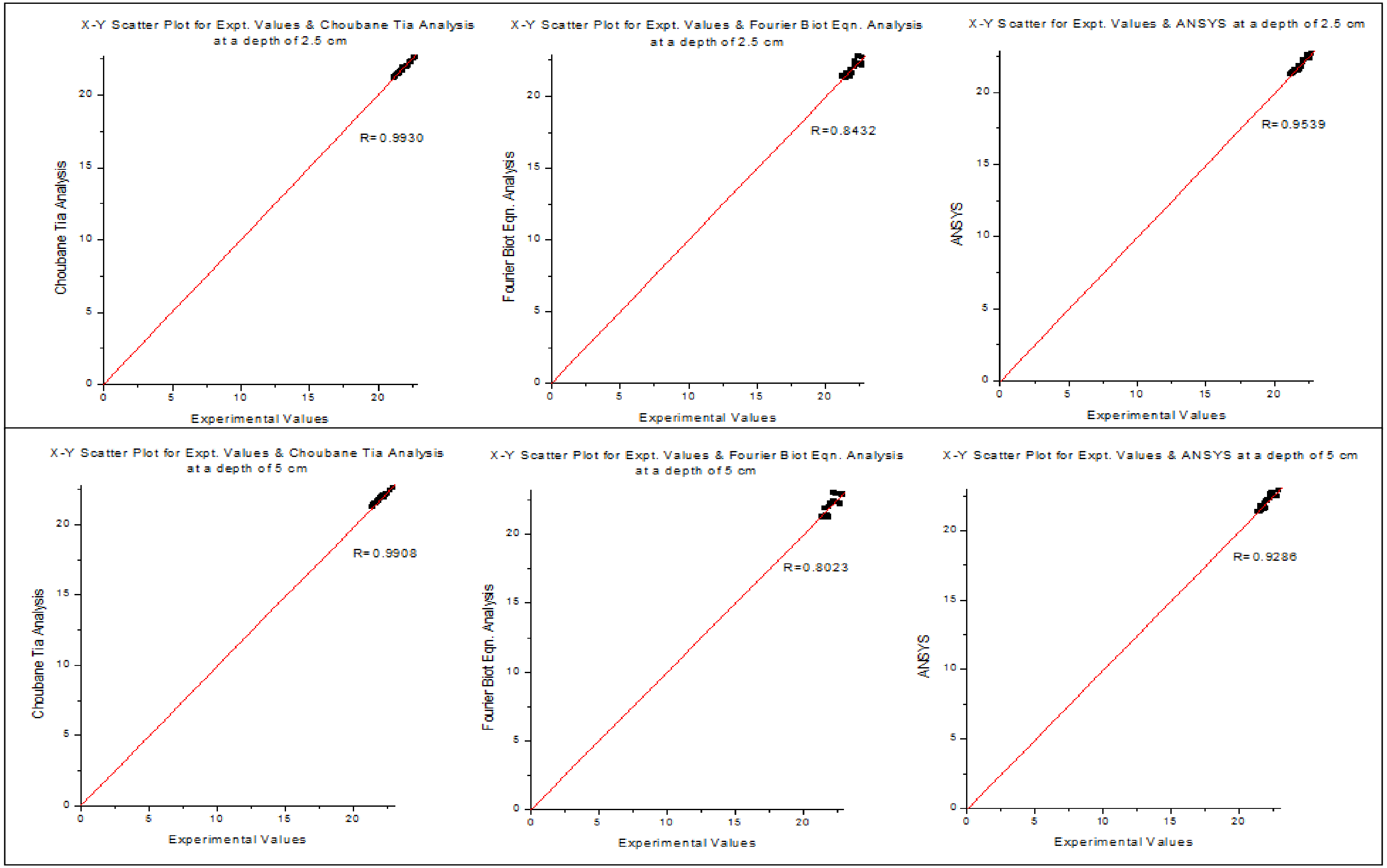


Fig. A-16 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

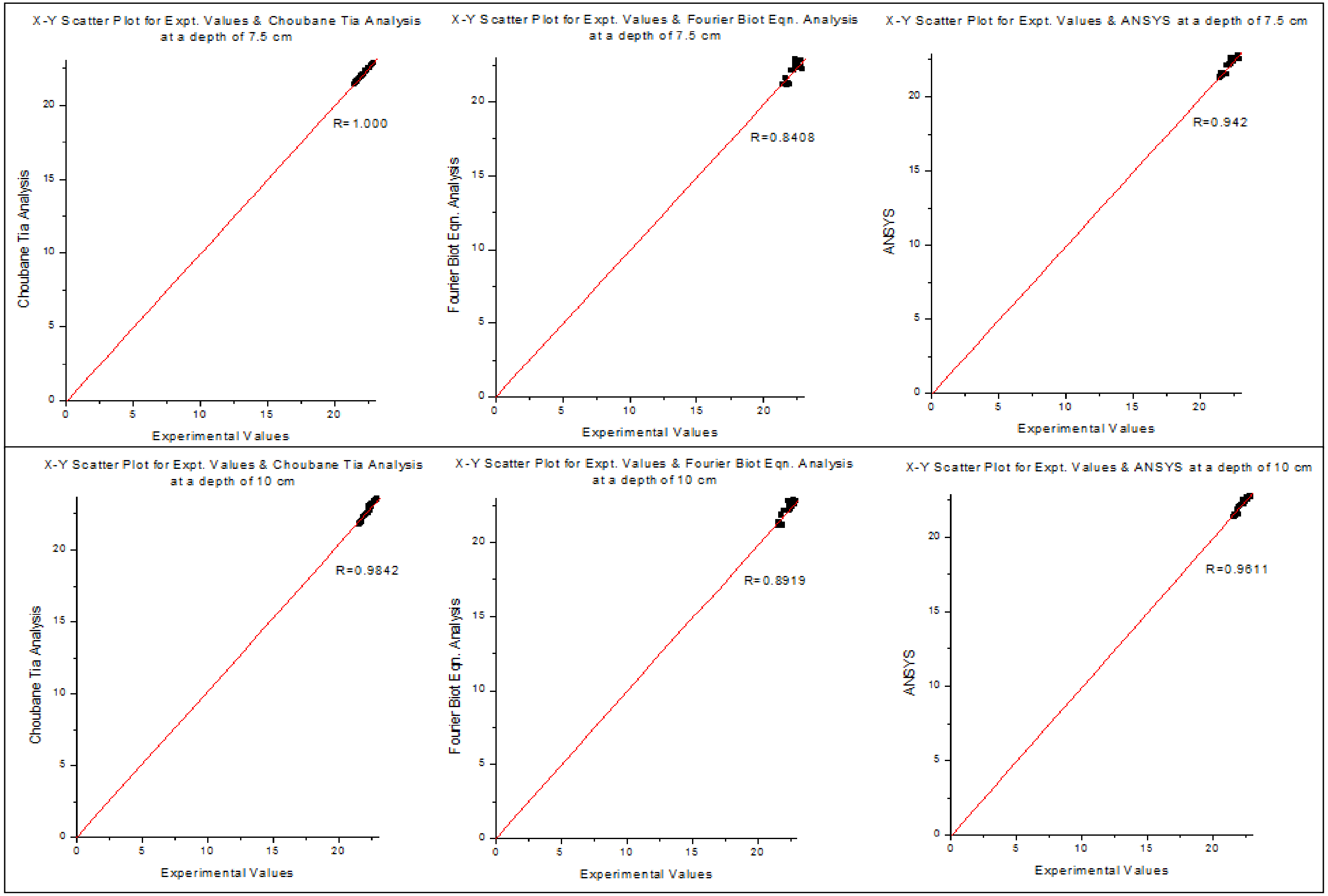


Fig. A-16 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

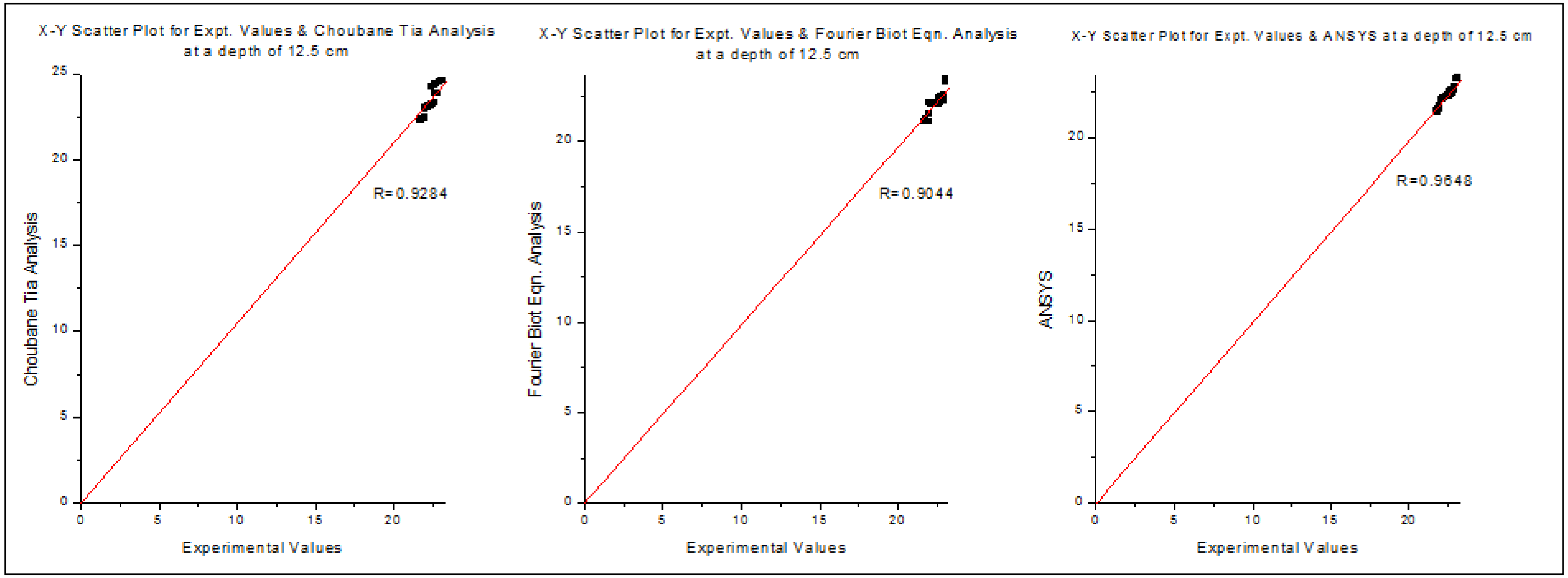


Fig. A-16 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-9 (a): 24 hr. cube temperature values (measured and calculated) for Mix B for part humid and part rainy condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	27	23.85	23.13	23.01	23.40	23.27	23.15	22.71	23.12	23.14	22.97	22.97	22.33	22.65
2	1130 to 1230	27	24.58	23.59	23.63	23.62	23.61	23.62	23.22	23.65	23.64	23.36	23.36	23.33	23.35
3	1230 to 1330	28	25.64	24.27	24.33	24.22	24.25	24.12	23.69	24.69	24.41	23.75	23.75	23.70	23.72
4	1330 to 1430	27	24.86	24.30	24.24	24.77	24.54	24.46	24.01	24.38	24.42	24.17	24.17	24.50	24.34
5	1430 to 1530	27	24.72	24.32	24.21	24.73	24.53	24.48	24.05	24.66	24.57	24.25	24.25	24.03	24.14
6	1530 to 1630	27	24.08	23.77	23.60	23.33	23.55	23.90	23.51	24.00	23.95	23.80	23.80	23.95	23.88
7	1630 to 1730	27	23.27	23.05	22.94	23.49	23.27	23.34	22.98	23.11	23.22	23.41	23.41	23.02	23.22
8	1730 to 1830	26	22.64	22.60	22.52	22.73	22.67	22.95	22.68	22.20	22.57	23.10	23.10	22.78	22.94
9	1830 to 1930	25	22.20	22.15	22.16	22.46	22.31	22.49	22.33	22.32	22.40	22.70	22.70	22.21	22.45
10	1930 to 2030	24	22.18	22.08	22.14	22.33	22.21	22.32	22.24	22.23	22.28	22.47	22.47	22.15	22.31
11	2030 to 2130	24	21.99	21.94	21.96	21.43	21.69	22.19	22.08	22.30	22.24	22.34	22.34	22.19	22.27
12	2130 to 2230	24	21.64	21.62	21.64	21.42	21.52	21.91	21.79	21.29	21.60	22.10	22.10	22.19	22.15
13	2230 to 2330	24	21.59	21.51	21.48	21.39	21.45	21.73	21.58	21.27	21.50	21.88	21.88	21.18	21.53
14	2330 to 0030	24	21.59	21.50	21.45	21.39	21.44	21.72	21.54	21.27	21.49	21.83	21.83	21.17	21.50
15	0030 to 0130	24	21.73	21.58	21.55	21.35	21.47	21.77	21.59	21.24	21.51	21.85	21.85	21.16	21.51
16	0130 to 0230	23	21.78	21.63	21.70	21.21	21.42	21.83	21.74	21.14	21.49	21.89	21.89	21.09	21.49
17	0230 to 0330	23	21.47	21.39	21.46	21.37	21.38	21.63	21.56	21.25	21.44	21.77	21.77	21.16	21.47
18	0330 to 0430	23	20.98	21.03	21.04	21.45	21.24	21.33	21.21	21.31	21.32	21.49	21.49	21.20	21.35
19	0430 to 0530	23	20.97	20.88	20.92	20.40	20.64	21.14	21.03	21.28	21.21	21.29	21.29	21.18	21.23
20	0530 to 0630	23	20.98	20.88	20.88	20.46	20.67	21.10	20.96	21.32	21.21	21.22	21.22	21.21	21.21
21	0630 to 0730	23	21.20	21.01	21.02	21.50	21.25	21.18	21.04	21.34	21.26	21.25	21.25	21.22	21.24
22	0730 to 0830	23	21.93	21.44	21.53	21.05	21.25	21.49	21.37	21.80	21.65	21.43	21.43	21.83	21.63
23	0830 to 0930	25	24.04	22.76	22.91	22.12	22.44	22.55	22.29	22.23	22.39	22.19	22.19	22.76	22.47
24	0930 to 1030	26	26.12	24.26	24.51	24.94	24.60	23.79	23.54	23.88	23.83	23.20	23.20	23.48	23.34

Table A-9 (b): 24 hr. cube temperature values (measured and calculated) for Mix B for part humid and part rainy condition at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (^oC) at 10 cm				Temperature (^oC) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	22.90	23.76	22.12	22.51	22.91	25.11	22.30	22.61
2	1130 to 1230	23.28	24.03	23.76	23.52	23.27	25.25	23.69	23.48
3	1230 to 1330	23.62	24.48	23.36	23.49	23.57	25.90	23.44	23.51
4	1330 to 1430	24.05	24.72	24.23	24.14	23.95	25.66	23.36	23.66
5	1430 to 1530	24.16	24.81	23.93	24.05	24.09	25.73	24.18	24.13
6	1530 to 1630	23.79	24.48	23.24	23.52	23.78	25.55	23.76	23.77
7	1630 to 1730	23.46	24.23	23.29	23.38	23.57	25.42	23.79	23.68
8	1730 to 1830	23.19	23.80	23.50	23.34	23.36	24.76	23.30	23.33
9	1830 to 1930	22.85	23.26	22.13	22.49	23.08	24.03	23.08	23.08
10	1930 to 2030	22.61	22.85	22.10	22.35	22.85	23.35	22.06	22.45
11	2030 to 2130	22.47	22.75	22.12	22.30	22.70	23.30	22.08	22.39
12	2130 to 2230	22.25	22.57	22.12	22.18	22.51	23.21	22.07	22.29
13	2230 to 2330	22.03	22.39	22.11	22.07	22.31	23.09	22.07	22.19
14	2330 to 0030	21.96	22.34	22.11	22.04	22.21	23.06	22.07	22.14
15	0030 to 0130	21.95	22.34	21.10	21.53	22.21	23.06	22.06	22.13
16	0130 to 0230	22.01	22.15	21.06	21.54	22.21	22.52	22.04	22.12
17	0230 to 0330	21.88	22.07	22.10	21.99	22.07	22.49	22.06	22.07
18	0330 to 0430	21.64	21.88	21.13	21.38	21.83	22.39	21.08	21.45
19	0430 to 0530	21.46	21.70	21.12	21.29	21.64	22.27	21.07	21.36
20	0530 to 0630	21.37	21.64	21.13	21.25	21.56	22.23	21.08	21.32
21	0630 to 0730	21.36	21.64	21.14	21.25	21.56	22.23	21.09	21.33
22	0730 to 0830	21.53	21.72	21.16	21.35	21.65	22.25	21.71	21.68
23	0830 to 0930	22.13	22.61	22.76	22.44	22.15	23.54	22.07	22.11
24	0930 to 1030	23.04	23.50	23.85	23.45	22.90	24.43	22.75	22.82

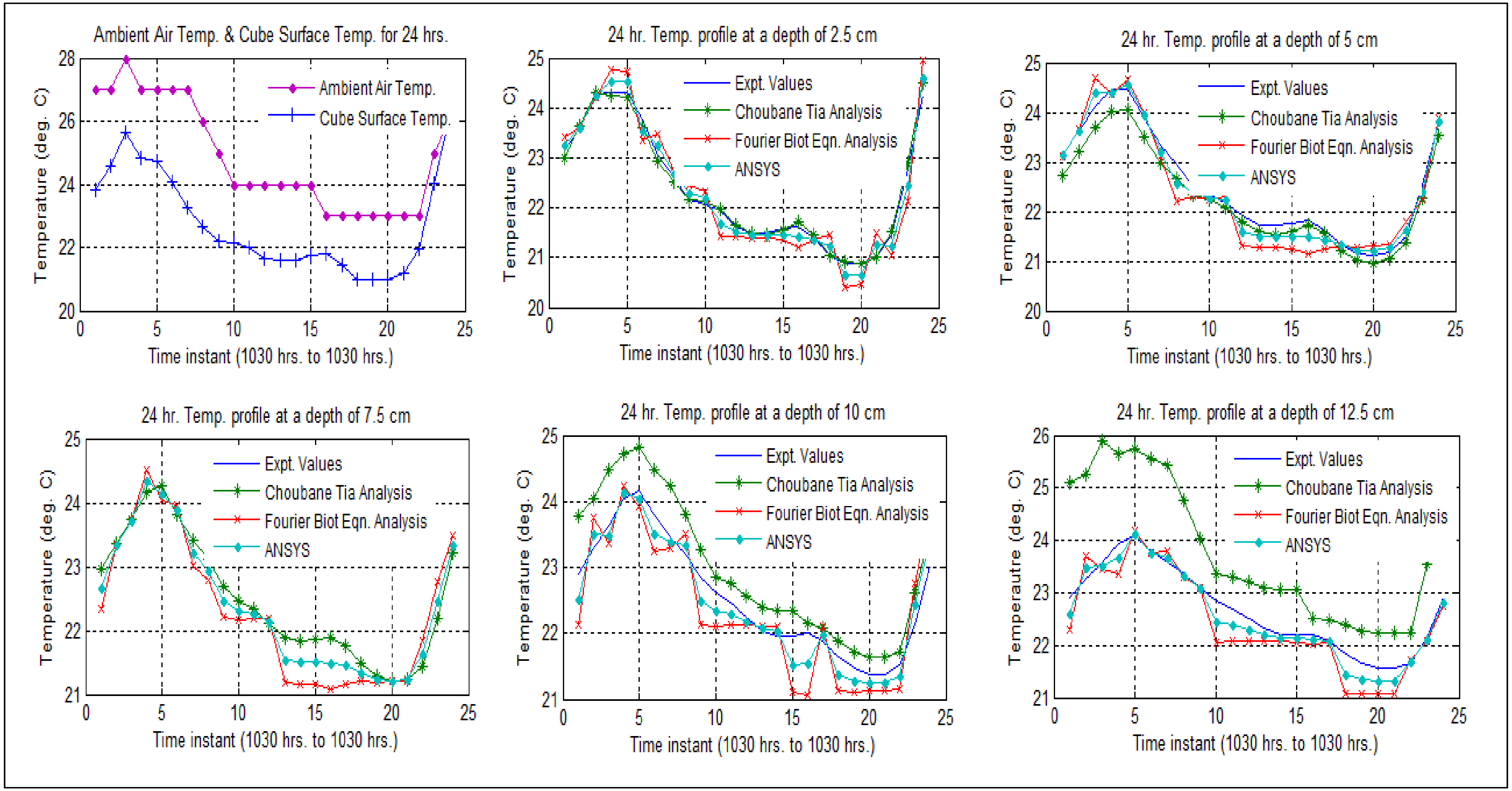


Fig. A-17: 24 hour cube temperature profile (measured and calculated) at various depths for Mix B for part humid and part rainy condition

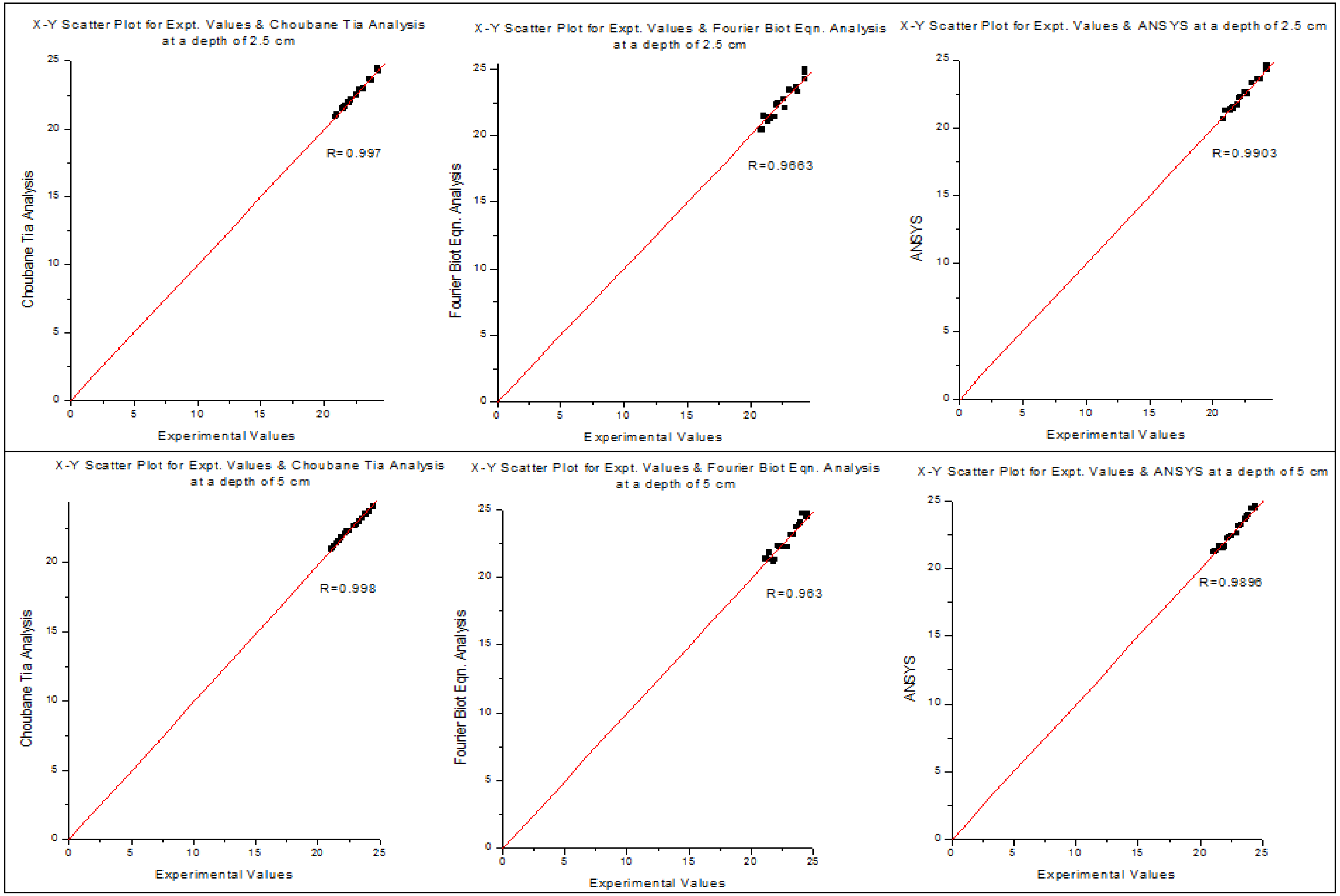


Fig. A-18 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

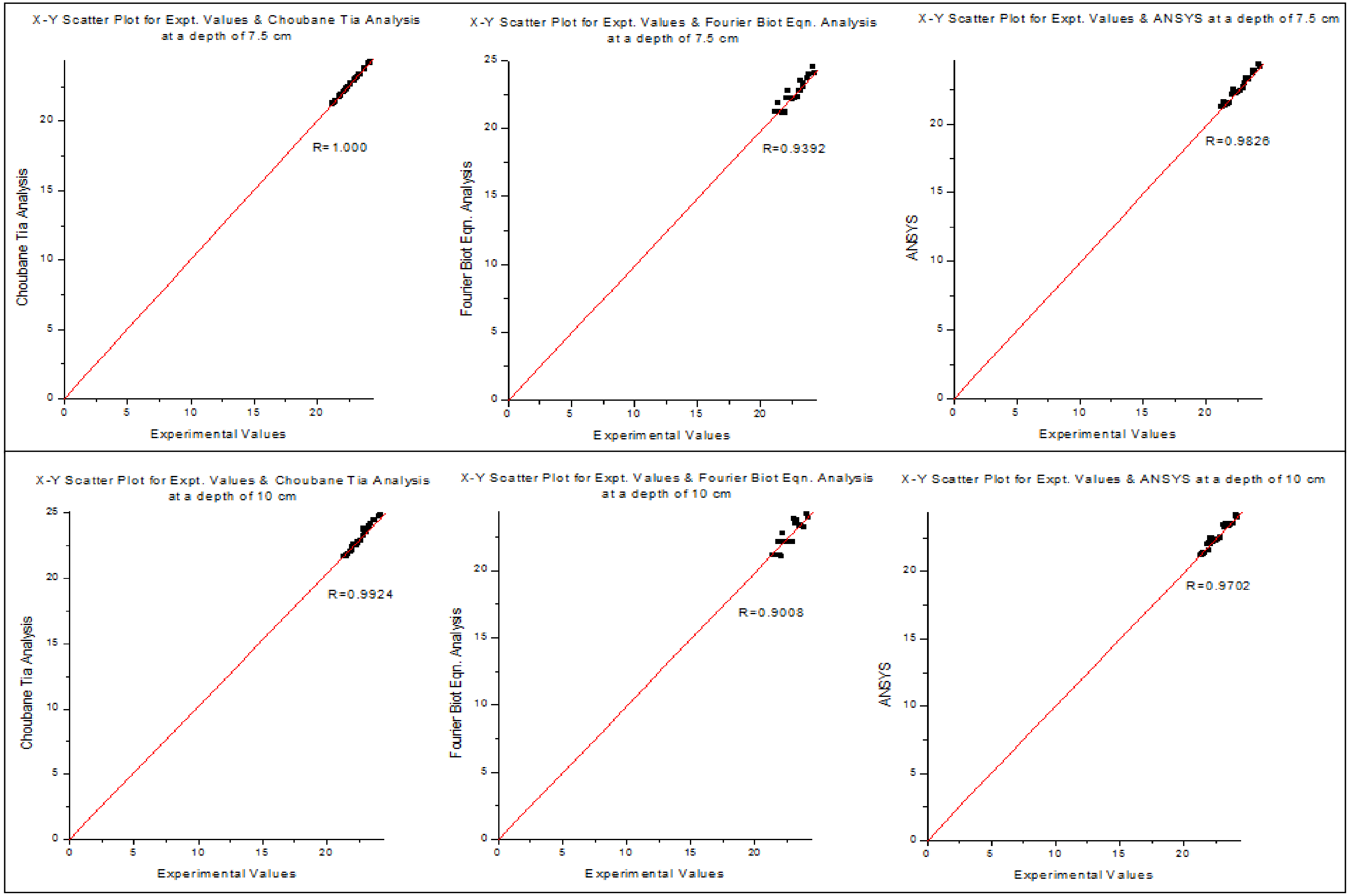


Fig. A-18 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

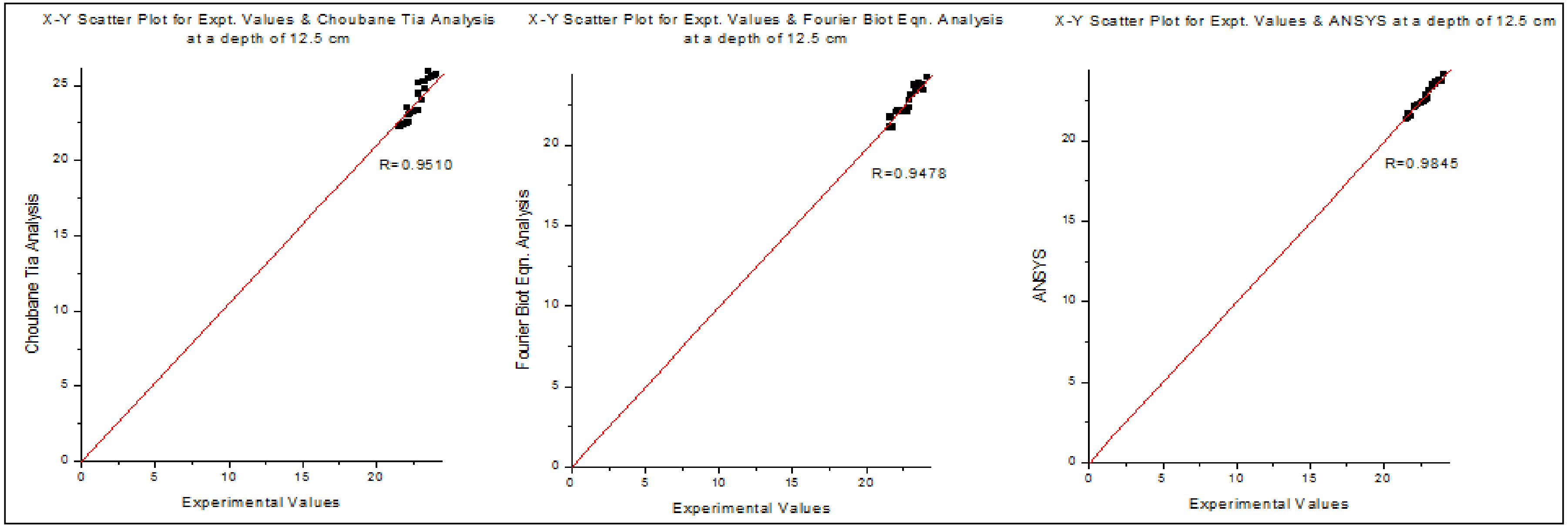


Fig. A-18 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-10 (a): 24 hr. cube temperature values (measured and calculated) for Mix B for 24 hr. cloudy and humid condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (^{o}C) at 2.5 cm				Temperature (^{o}C) at 5 cm				Temperature (^{o}C) at 7.5 cm			
		(^{o}C)	(^{o}C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	28	36.64	32.07	33.57	32.20	32.13	30.88	31.16	30.44	30.66	29.40	29.40	29.50	29.45
2	1130 to 1230	29	38.63	34.17	35.84	34.47	34.32	33.15	33.52	33.63	33.39	31.68	31.68	31.62	31.65
3	1230 to 1330	30	41.38	36.56	38.49	36.95	36.75	35.47	36.00	35.37	35.42	33.91	33.91	33.31	33.61
4	1330 to 1430	30	37.47	35.90	36.85	35.76	35.83	35.78	35.98	35.06	35.42	34.86	34.86	34.95	34.90
5	1430 to 1530	29	35.12	34.19	35.27	34.67	34.43	34.46	34.95	34.23	34.34	34.17	34.17	34.11	34.14
6	1530 to 1630	29	32.62	32.56	33.32	32.53	32.55	33.12	33.50	33.75	33.43	33.16	33.16	33.14	33.15
7	1630 to 1730	28	31.04	31.24	31.98	31.17	31.20	31.89	32.33	31.81	31.85	32.12	32.12	32.53	32.32
8	1730 to 1830	27	29.51	30.01	30.65	30.75	30.38	30.72	31.17	30.83	30.78	31.06	31.06	30.89	30.98
9	1830 to 1930	26	28.35	28.93	29.59	28.58	28.75	29.67	30.18	29.71	29.69	30.11	30.11	30.81	30.46
10	1930 to 2030	24	27.51	28.07	28.82	28.39	28.23	28.76	29.38	28.58	28.67	29.17	29.17	29.72	29.45
11	2030 to 2130	24	26.93	27.41	28.14	27.43	27.42	28.09	28.67	27.61	27.85	28.52	28.52	28.75	28.63
12	2130 to 2230	23	25.92	26.71	27.30	26.34	26.53	27.35	27.93	27.54	27.45	27.82	27.82	27.70	27.76
13	2230 to 2330	23	25.33	25.98	26.57	25.41	25.69	26.64	27.16	26.59	26.62	27.10	27.10	27.73	27.42
14	2330 to 0030	23	25.10	25.64	26.20	25.49	25.56	26.24	26.71	26.64	26.44	26.65	26.65	26.77	26.71
15	0030 to 0130	22	24.29	25.06	25.58	25.55	25.30	25.68	26.20	25.69	25.68	26.15	26.15	26.80	26.47
16	0130 to 0230	22	24.11	24.65	25.17	24.55	24.60	25.18	25.68	25.69	25.43	25.61	25.61	25.80	25.70
17	0230 to 0330	22	23.81	24.37	24.80	24.62	24.50	24.89	25.28	24.74	24.81	25.24	25.24	25.83	25.53
18	0330 to 0430	21	23.93	24.21	24.85	24.39	24.30	24.67	25.21	24.58	24.63	25.00	25.00	25.73	25.36
19	0430 to 0530	22	24.03	24.26	24.73	24.57	24.41	24.61	25.02	24.70	24.66	24.89	24.89	24.80	24.85
20	0530 to 0630	22	23.86	24.18	24.60	24.66	24.42	24.56	24.93	24.76	24.66	24.83	24.83	24.85	24.84
21	0630 to 0730	23	24.04	24.11	24.52	24.15	24.13	24.45	24.75	24.10	24.28	24.71	24.71	24.07	24.39
22	0730 to 0830	24	25.25	24.64	25.16	24.42	24.53	24.75	25.02	24.67	24.71	24.83	24.83	24.09	24.46
23	0830 to 0930	26	27.82	26.11	26.74	26.12	26.11	25.82	25.97	25.92	25.87	25.51	25.51	25.21	25.36
24	0930 to 1030	27	29.01	26.99	27.75	26.46	26.73	26.74	26.86	26.54	26.64	26.34	26.34	26.26	26.30

Table A-10 (b): 24 hr. cube temperature values (measured and calculated) for Mix B for 24 hr. cloudy and humid condition at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	27.88	28.28	27.50	27.69	28.12	27.82	28.14	28.13
2	1130 to 1230	30.21	30.32	30.58	30.39	30.25	29.42	30.19	30.22
3	1230 to 1330	32.52	32.21	32.95	32.74	32.33	30.90	32.09	32.21
4	1330 to 1430	33.88	33.49	33.51	33.70	33.69	31.87	33.54	33.61
5	1430 to 1530	33.75	32.92	33.34	33.55	33.70	31.19	33.82	33.76
6	1530 to 1630	32.93	32.29	32.73	32.83	33.13	30.91	33.44	33.29
7	1630 to 1730	32.09	31.32	32.34	32.21	32.37	29.95	32.21	32.29
8	1730 to 1830	31.15	30.33	30.93	31.04	31.51	28.98	31.96	31.73
9	1830 to 1930	30.18	29.39	30.88	30.53	30.66	28.02	30.93	30.79
10	1930 to 2030	29.22	28.21	29.82	29.52	29.83	26.48	29.89	29.86
11	2030 to 2130	28.44	27.69	28.84	28.64	29.10	26.19	28.90	29.00
12	2130 to 2230	27.73	26.96	27.81	27.77	28.50	25.35	28.88	28.69
13	2230 to 2330	26.98	26.38	26.83	26.91	27.82	25.02	27.90	27.86
14	2330 to 0030	26.41	26.01	26.85	26.63	27.27	24.80	26.91	27.09
15	0030 to 0130	25.92	25.43	25.87	25.90	26.84	24.05	26.92	26.88
16	0130 to 0230	25.41	24.97	25.87	25.64	26.36	23.77	26.92	26.64
17	0230 to 0330	25.07	24.68	25.89	25.48	25.96	23.60	25.93	25.94
18	0330 to 0430	24.84	24.23	24.83	24.83	25.62	22.90	25.89	25.76
19	0430 to 0530	24.67	24.34	24.88	24.77	25.43	23.38	25.92	25.68
20	0530 to 0630	24.60	24.31	24.90	24.75	25.32	23.36	25.94	25.63
21	0630 to 0730	24.53	24.40	24.04	24.29	25.18	23.83	25.03	25.11
22	0730 to 0830	24.59	24.60	24.69	24.64	25.18	24.32	25.42	25.30
23	0830 to 0930	25.16	25.36	25.04	25.10	25.58	25.52	25.25	25.42
24	0930 to 1030	26.20	26.19	26.72	26.46	26.17	26.41	26.66	26.41

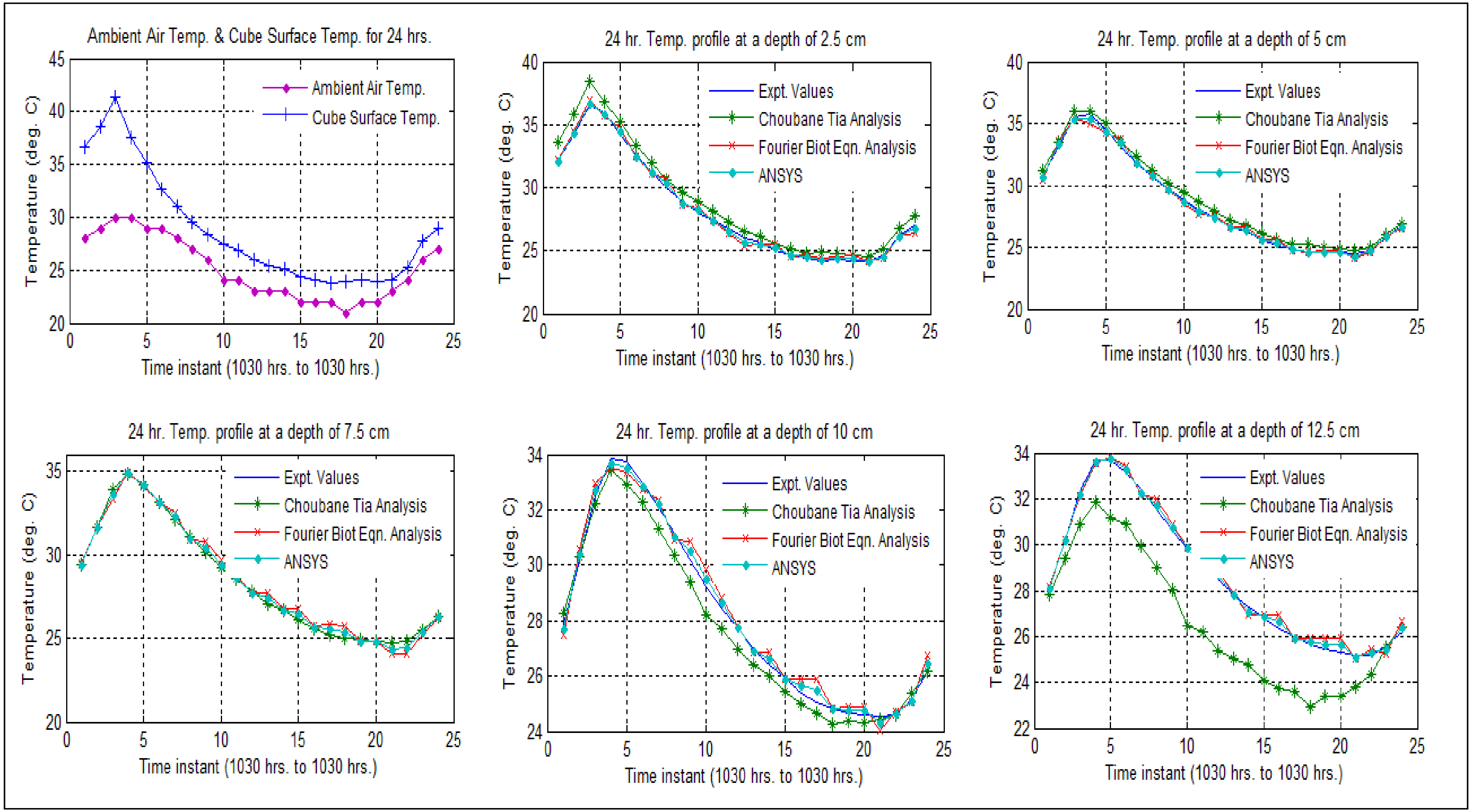


Fig. A-19: 24 hour cube temperature profile (measured and calculated) at various depths for Mix B for 24 hr. cloudy and humid condition

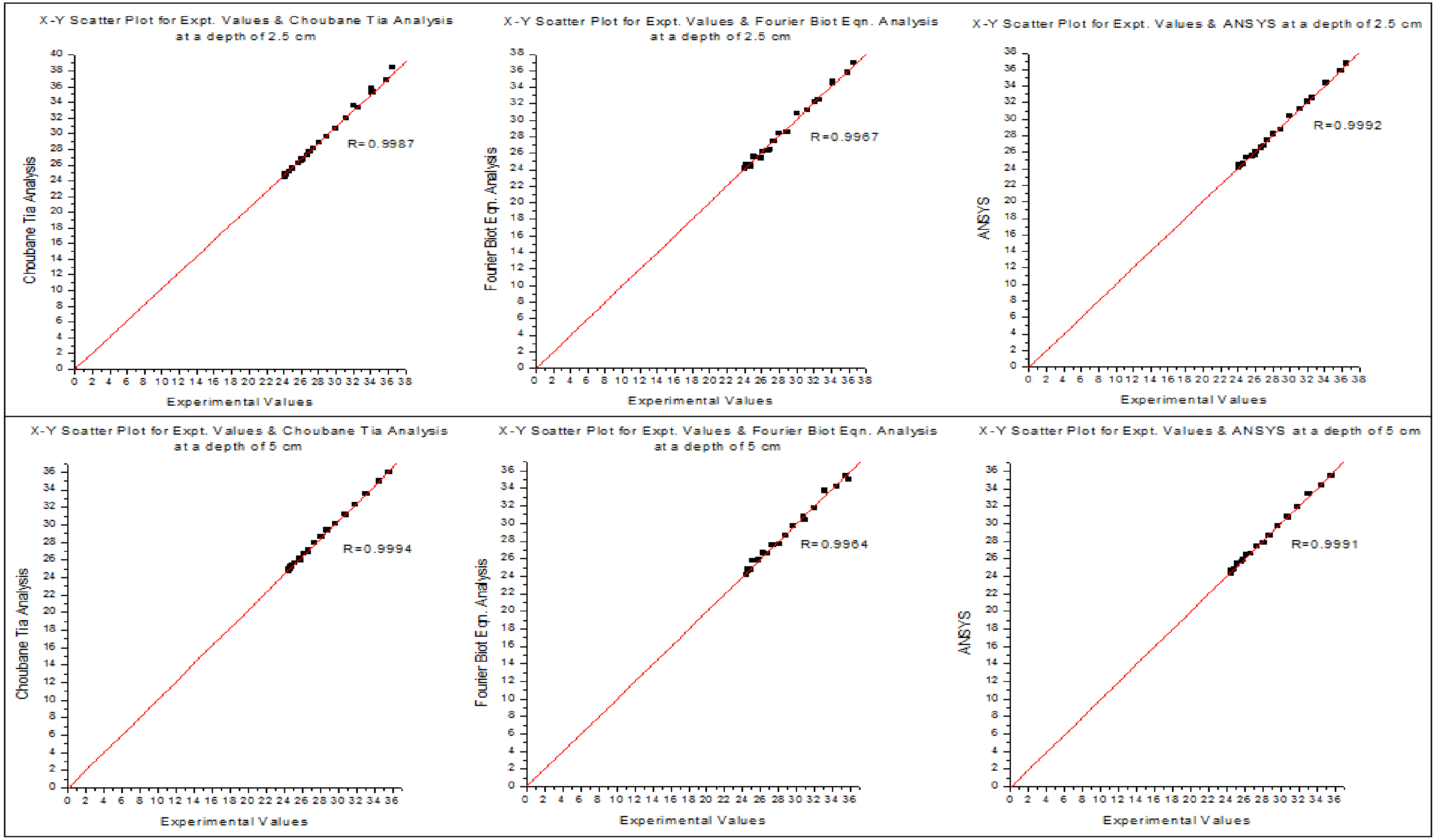


Fig. A-20 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

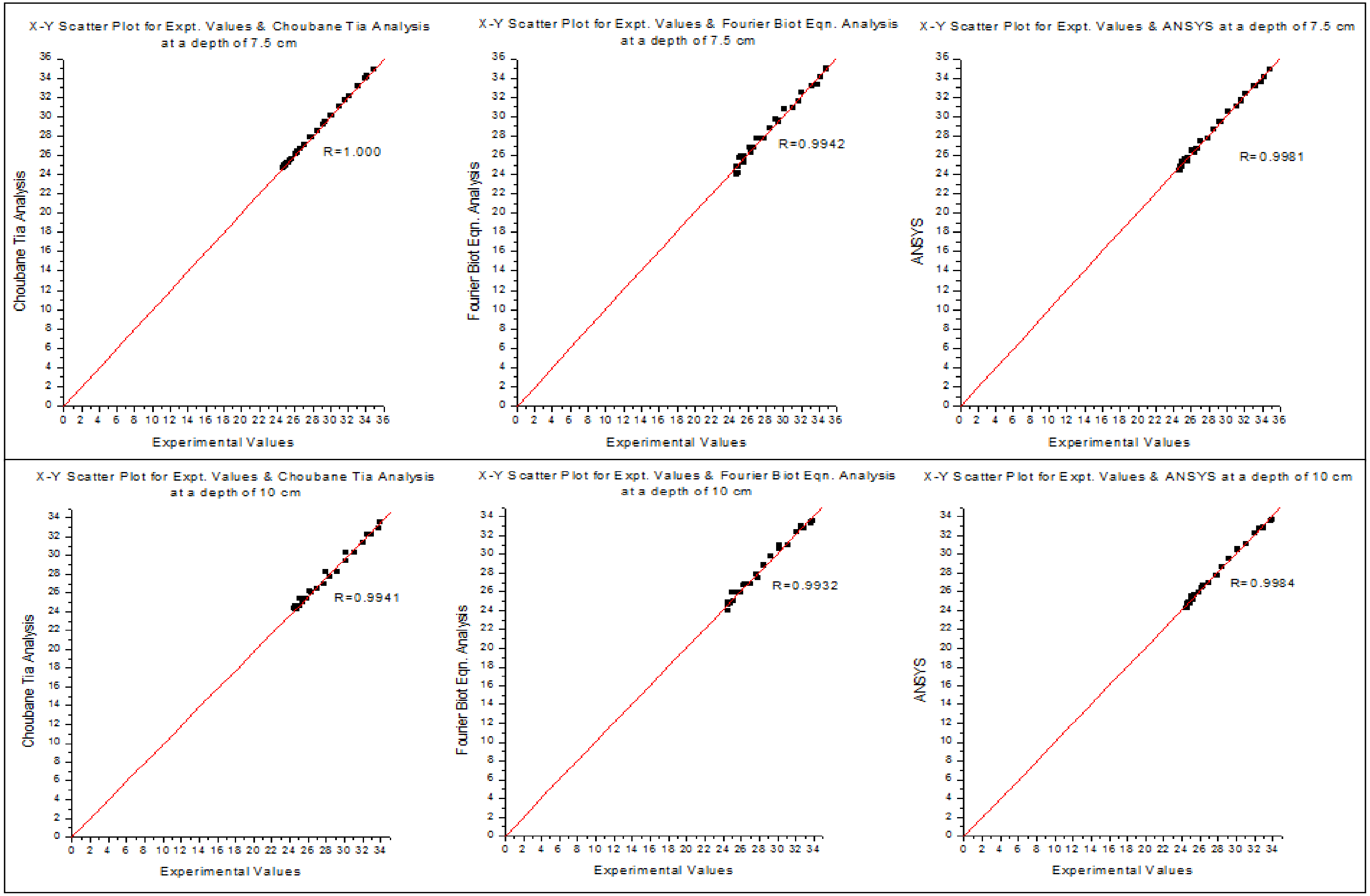


Fig. A-20 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

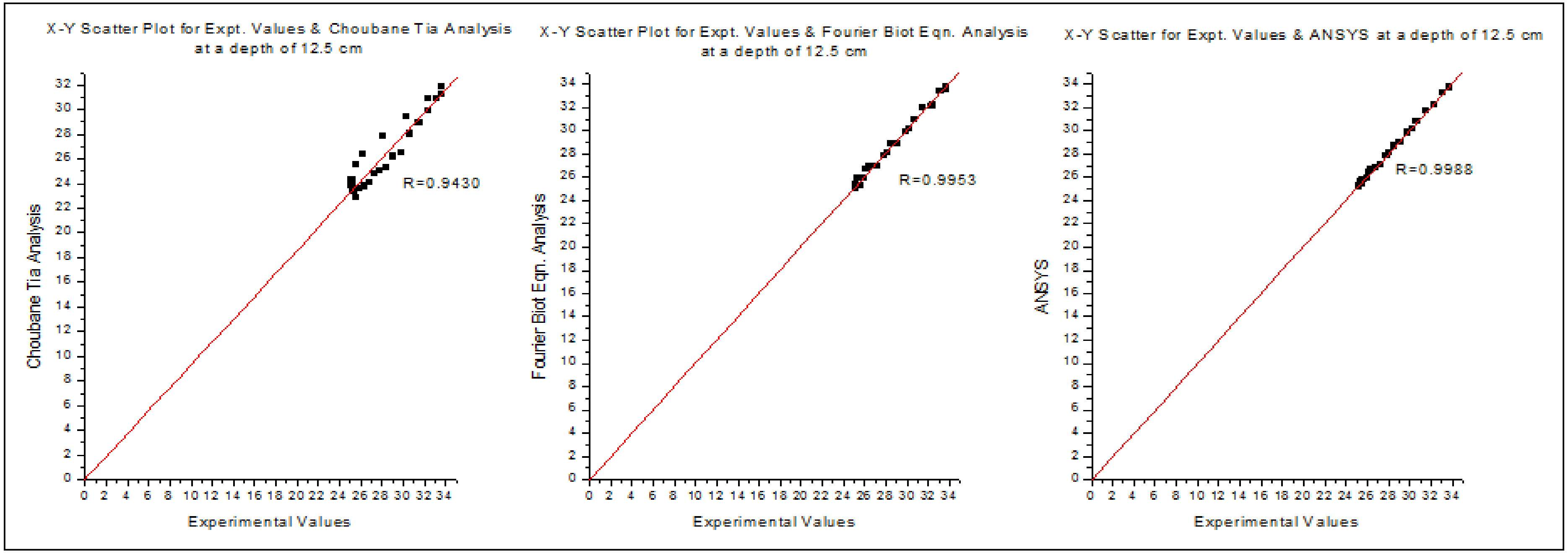


Fig. A-20 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-11 (a) : 21 hr. cube temperature values (measured and calculated) for Mix B for 2 hr. sudden precipitation at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1200 to 1300	31	32.42	32.64	32.45	32.33	32.49	31.89	32.37	31.53	31.71	32.19	32.19	32.56	32.37
2	1300 to 1400	31	35.35	34.01	35.01	34.18	34.09	33.44	34.51	33.81	33.62	33.86	33.86	33.39	33.63
3	1400 to 1500	31	35.87	34.40	35.63	34.62	34.51	33.84	35.15	33.96	33.90	34.45	34.45	34.88	34.67
4	1500 to 1600	30	36.10	32.65	35.51	32.54	32.60	32.61	34.75	32.22	32.41	33.82	33.82	33.40	33.61
5	1600 to 1700	29	33.61	30.81	33.54	30.75	30.78	31.03	33.18	30.90	30.96	32.56	32.56	32.24	32.40
6	1700 to 1800	28	31.00	28.35	31.27	28.83	28.59	28.94	31.23	28.88	28.91	30.89	30.89	30.92	30.91
7	1800 to 1900	27	23.88	24.40	25.48	24.86	24.63	24.97	26.65	24.59	24.78	27.39	27.39	27.39	27.39
8	1900 to 2000	26	22.74	22.07	23.52	22.55	22.31	22.67	24.21	22.38	22.52	24.81	24.81	24.25	24.53
9	2000 to 2100	26	22.29	21.70	22.86	21.60	21.65	22.06	23.45	22.42	22.24	24.06	24.06	24.27	24.17
10	2100 to 2200	26	21.47	21.37	22.25	21.71	21.54	21.83	23.01	21.49	21.66	23.77	23.77	23.32	23.55
11	2200 to 2300	26	20.94	20.69	21.63	20.71	20.70	21.37	22.39	21.18	21.27	23.21	23.21	23.77	23.49
12	2300 to 0000	25	20.76	20.64	21.44	20.14	20.39	21.14	22.13	21.79	21.46	22.83	22.83	22.51	22.67
13	0000 to 0100	25	21.05	20.83	21.56	20.83	20.83	21.14	22.14	21.58	21.36	22.77	22.77	22.37	22.57
14	0100 to 0200	24	20.75	21.07	21.58	21.61	21.34	21.31	22.30	21.43	21.37	22.90	22.90	22.28	22.59
15	0200 to 0300	24	20.98	21.14	21.73	21.52	21.33	21.33	22.38	21.36	21.35	22.93	22.93	22.24	22.58
16	0300 to 0400	24	20.75	21.02	21.48	21.69	21.35	21.13	22.14	21.47	21.30	22.72	22.72	22.31	22.51
17	0400 to 0500	24	20.98	20.87	21.55	20.77	20.82	21.03	22.09	21.54	21.28	22.61	22.61	22.35	22.48
18	0500 to 0600	24	20.74	20.59	21.33	20.70	20.64	20.81	21.89	20.48	20.64	22.44	22.44	22.31	22.38
19	0600 to 0700	24	20.74	20.32	21.16	20.59	20.45	20.53	21.64	20.41	20.47	22.16	22.16	22.26	22.21
20	0700 to 0800	25	20.76	20.36	20.98	21.49	20.93	20.48	21.40	20.03	20.25	22.01	22.01	22.67	22.34
21	0800 to 0900	27	22.21	21.38	21.78	21.06	21.22	21.14	21.84	21.12	21.13	22.40	22.40	22.38	22.39

Table A-11 (b) : 21 hr. cube temperature values (measured and calculated) for Mix B for 2 hr. sudden precipitation at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1200 to 1300	30.88	31.90	30.54	30.71	30.40	31.50	30.17	30.28
2	1300 to 1400	32.57	33.06	32.07	32.32	32.04	32.11	32.49	32.27
3	1400 to 1500	33.22	33.53	33.48	33.35	32.78	32.38	32.51	32.65
4	1500 to 1600	32.71	32.72	32.17	32.44	32.37	31.45	32.32	32.34
5	1600 to 1700	31.60	31.65	31.79	31.69	31.38	30.46	31.48	31.43
6	1700 to 1800	30.03	30.23	30.95	30.49	30.07	29.27	30.97	30.52
7	1800 to 1900	26.63	27.70	26.25	26.44	26.49	27.56	26.15	26.32
8	1900 to 2000	24.19	25.30	24.16	24.17	24.57	25.70	24.10	24.33
9	2000 to 2100	23.41	24.69	23.17	23.29	23.74	25.34	23.11	23.42
10	2100 to 2200	23.08	24.52	23.20	23.14	23.36	25.27	23.12	23.24
11	2200 to 2300	22.57	24.08	22.49	22.53	22.89	25.01	22.30	22.60
12	2300 to 0000	22.18	23.54	22.33	22.25	22.49	24.26	22.20	22.35
13	0000 to 0100	22.14	23.45	22.24	22.19	22.47	24.20	22.15	22.31
14	0100 to 0200	22.27	23.38	22.18	22.22	22.55	23.75	22.11	22.33
15	0200 to 0300	22.29	23.39	22.15	22.22	22.50	23.74	22.09	22.30
16	0300 to 0400	22.03	23.22	22.20	22.12	22.29	23.65	22.12	22.20
17	0400 to 0500	21.96	23.10	21.22	21.59	22.22	23.56	22.14	22.18
18	0500 to 0600	21.78	22.98	21.20	21.49	22.00	23.50	22.12	22.06
19	0600 to 0700	21.51	22.72	21.17	21.34	21.66	23.34	21.10	21.38
20	0700 to 0800	21.34	22.81	21.43	21.38	21.48	23.81	21.26	21.37
21	0800 to 0900	21.61	23.44	21.88	21.74	21.71	24.98	21.54	21.63

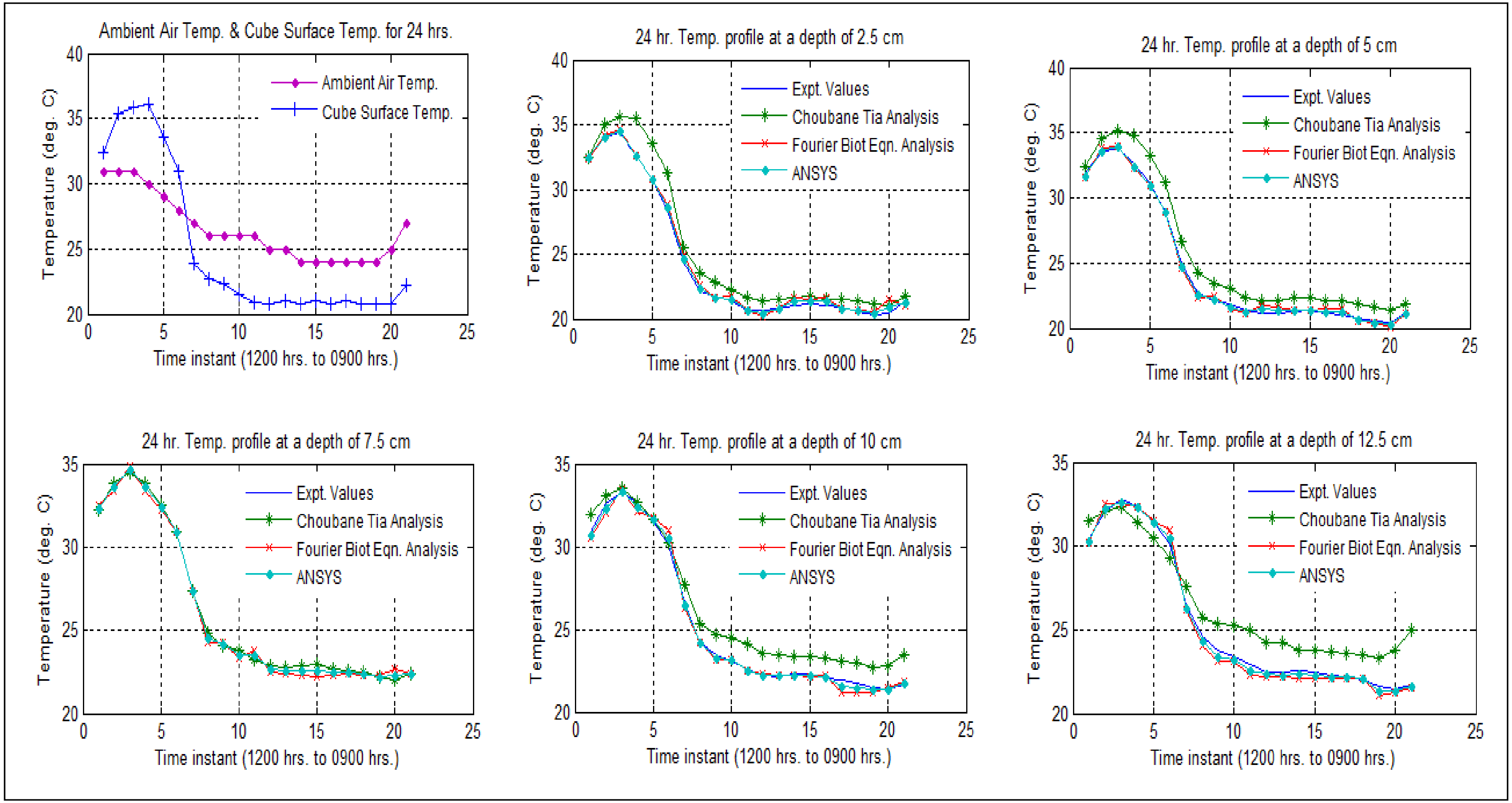


Fig. A-21: 21 hour cube temperature profile (measured and calculated) at various depths for Mix B for 2 hr. sudden precipitation

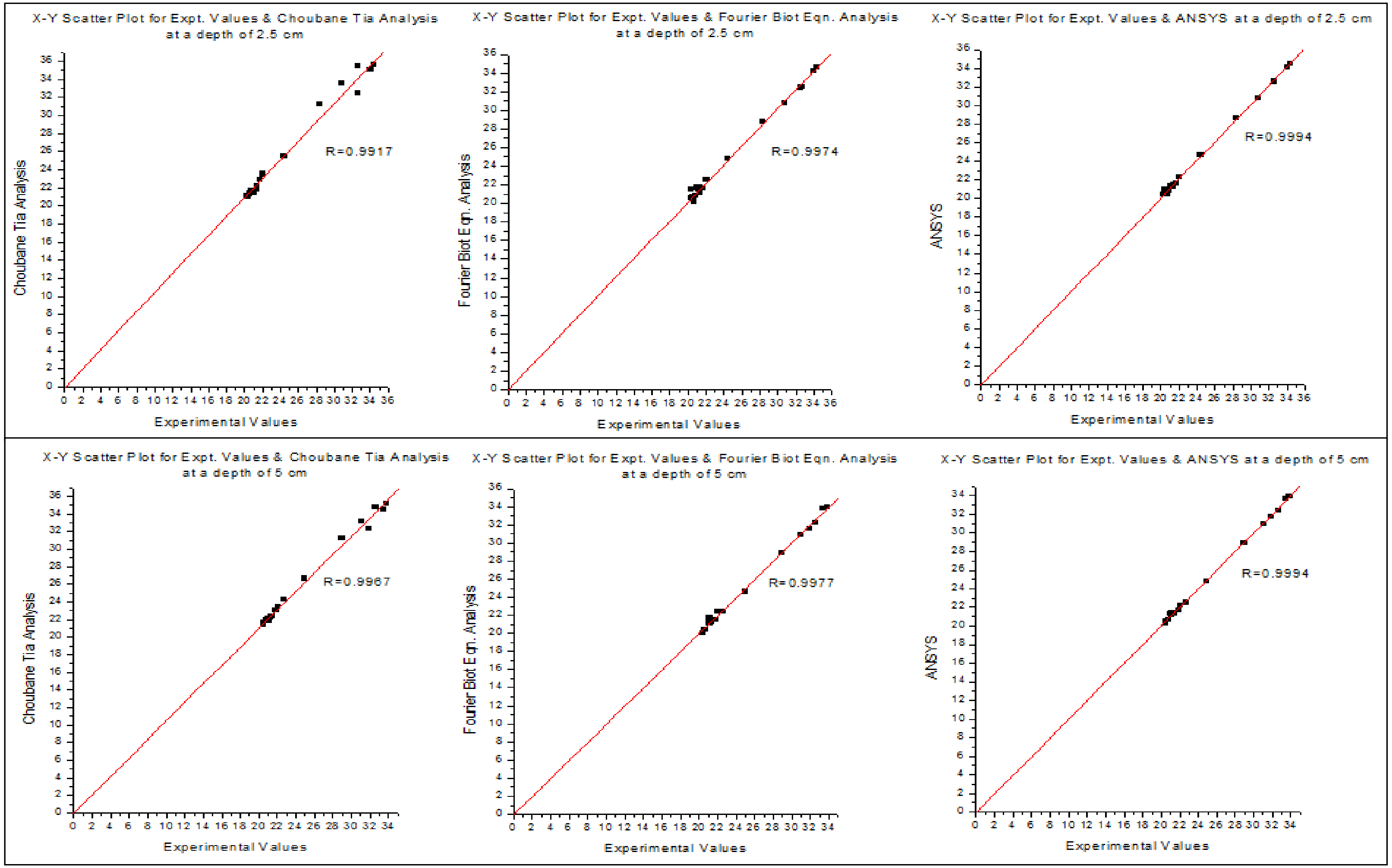


Fig. A-22 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

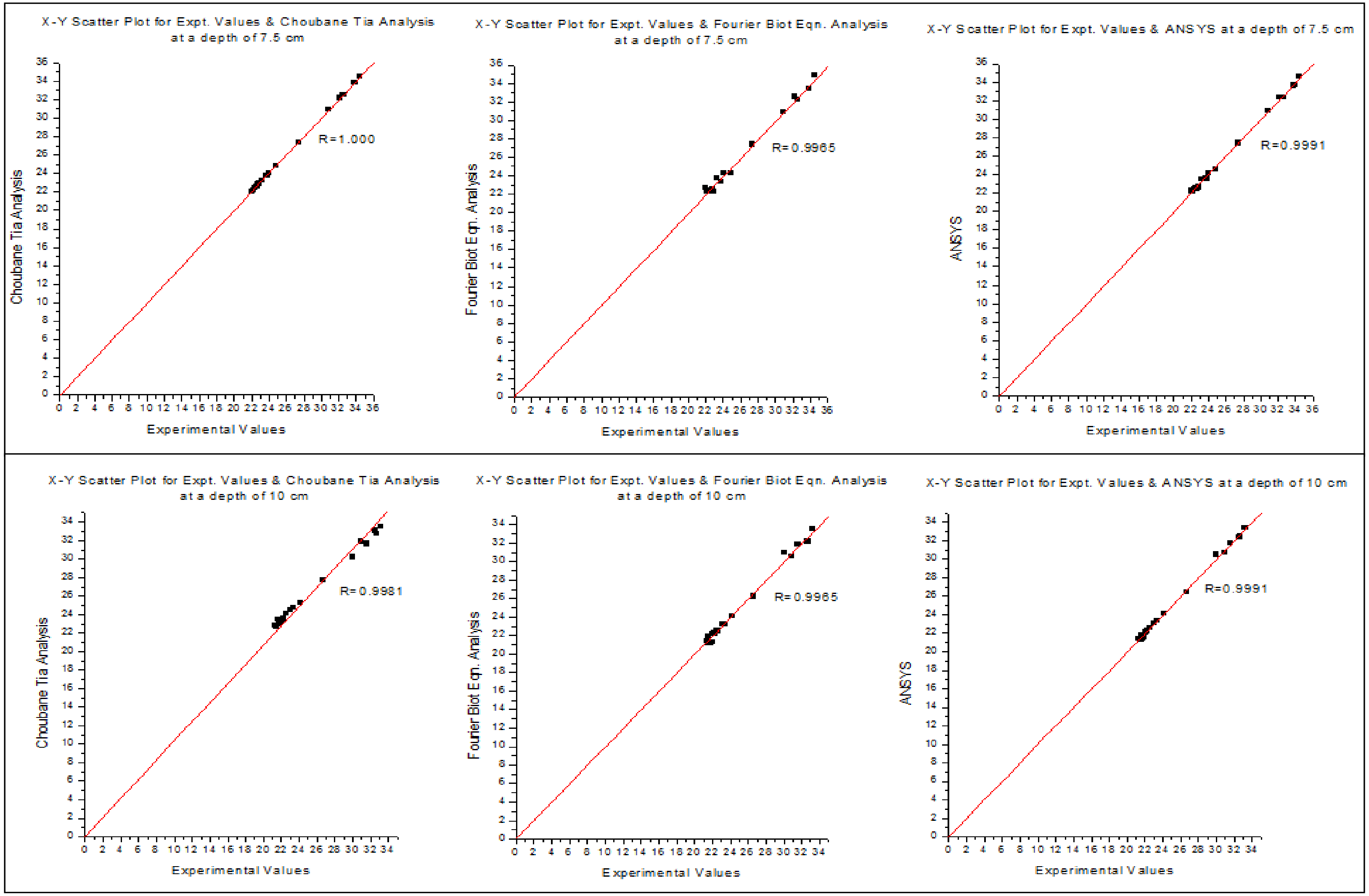


Fig. A-22 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

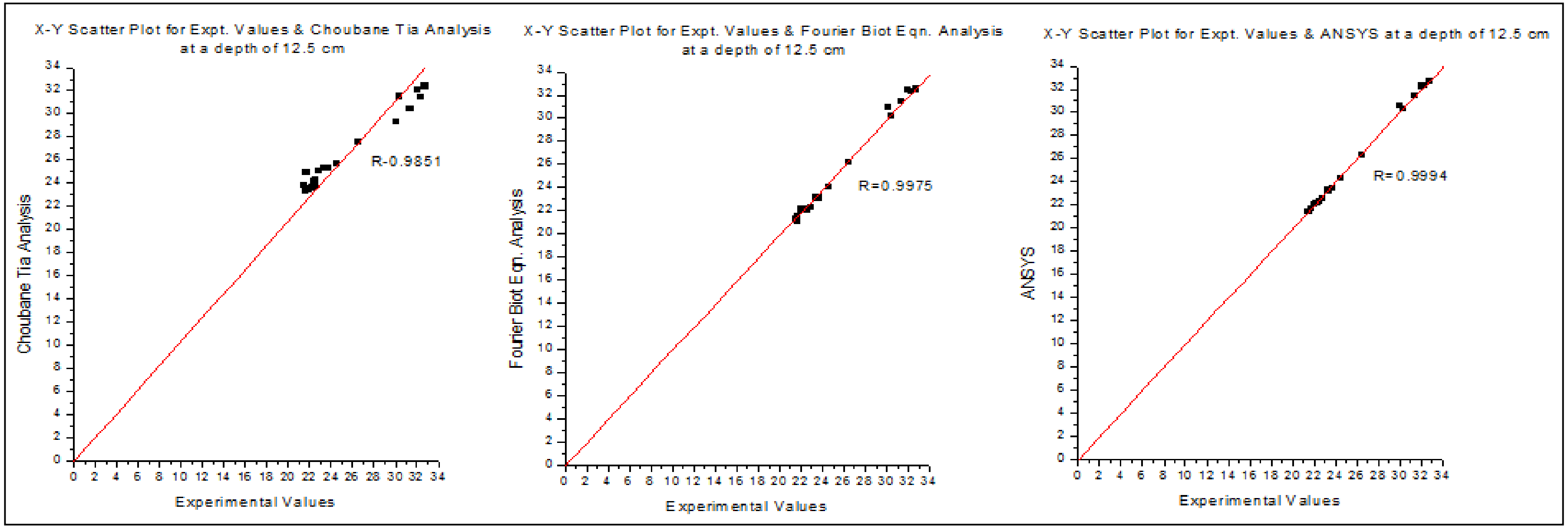


Fig. A-22 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-12 (a): 24 hr. cube temperature values (measured and calculated) for Mix C for maximum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1000 to 1100	35	39.45	35.41	36.02	35.72	35.72	33.81	33.66	34.01	33.82	32.38	32.38	32.78	32.51
2	1100 to 1200	37	46.48	40.66	42.15	40.07	40.96	38.46	38.92	38.03	38.47	36.79	36.79	36.99	36.86
3	1200 to 1300	38	49.34	44.08	45.38	44.68	44.71	41.98	42.24	41.04	41.76	39.94	39.94	39.60	39.82
4	1300 to 1400	39	50.98	46.32	47.87	46.06	46.75	44.68	45.21	44.99	44.96	42.99	42.99	42.98	42.99
5	1400 to 1500	39	51.08	47.61	49.02	47.52	48.05	46.29	46.98	46.53	46.60	44.95	44.95	44.18	44.70
6	1500 to 1600	39	49.77	47.75	48.85	48.11	48.24	46.93	47.59	46.81	47.11	45.97	45.97	45.26	45.73
7	1600 to 1700	38	43.99	44.66	45.29	44.65	44.87	45.16	45.67	45.53	45.45	45.13	45.13	45.11	45.12
8	1700 to 1800	37	40.70	41.55	42.27	41.87	41.90	42.33	42.97	42.17	42.49	42.79	42.79	42.70	42.76
9	1800 to 1900	36	37.65	38.87	39.45	38.87	39.06	39.88	40.42	39.57	39.95	40.56	40.56	40.37	40.49
10	1900 to 2000	34	35.68	36.61	37.33	36.72	36.89	37.56	38.21	37.81	37.86	38.32	38.32	38.88	38.51
11	2000 to 2100	33	34.37	35.13	35.75	35.72	35.54	35.92	36.49	35.82	36.07	36.58	36.58	36.88	36.68
12	2100 to 2200	32	33.05	33.83	34.36	33.70	33.96	34.59	35.08	34.80	34.82	35.20	35.20	35.87	35.43
13	2200 to 2300	31	31.78	32.60	33.10	32.78	32.83	33.34	33.84	33.85	33.68	34.01	34.01	33.91	33.97
14	2300 to 0000	30	30.73	31.46	31.97	31.82	31.75	32.19	32.66	32.88	32.58	32.81	32.81	32.92	32.85
15	0000 to 0100	29	29.96	30.63	31.15	30.82	30.87	31.28	31.80	31.88	31.65	31.91	31.91	31.92	31.91
16	0100 to 0200	28	28.85	29.61	30.12	29.87	29.87	30.36	30.84	30.91	30.70	30.98	30.98	30.94	30.97
17	0200 to 0300	28	27.86	28.65	29.08	28.03	28.58	29.38	29.83	29.02	29.41	30.09	30.09	30.01	30.06
18	0300 to 0400	27	27.24	27.96	28.41	27.95	28.11	28.65	29.10	28.97	28.91	29.31	29.31	29.98	29.53
19	0400 to 0500	26	26.88	27.50	28.03	27.79	27.77	28.17	28.66	28.86	28.56	28.78	28.78	28.91	28.82
20	0500 to 0600	26	26.53	27.09	27.58	26.88	27.18	27.69	28.18	27.92	27.93	28.32	28.32	27.95	28.19
21	0600 to 0700	27	26.22	26.76	27.04	26.13	26.64	27.27	27.59	27.09	27.32	27.86	27.86	27.06	27.59
22	0700 to 0800	29	26.90	26.88	27.05	26.75	26.89	27.16	27.28	27.15	27.20	27.59	27.59	27.74	27.64
23	0800 to 0900	31	30.35	28.86	29.07	28.21	28.71	28.32	28.34	28.42	28.36	28.17	28.17	28.20	28.18
24	0900 to 1000	34	35.69	32.72	32.95	32.13	32.60	31.44	31.20	31.99	31.54	30.43	30.43	30.85	30.57

Table A-12 (b): 24 hr. cube temperature values (measured and calculated) for Mix C for maximum ambient air temperature at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1000 to 1100	31.37	32.18	31.31	31.62	30.86	33.05	30.90	31.60
2	1100 to 1200	35.32	35.76	35.23	35.44	34.52	35.83	34.76	35.04
3	1200 to 1300	38.06	38.46	38.55	38.36	37.17	37.82	37.93	37.64
4	1300 to 1400	41.04	41.22	41.82	41.36	40.07	39.89	40.46	40.14
5	1400 to 1500	43.11	42.95	43.44	43.17	42.17	40.97	42.26	41.80
6	1500 to 1600	44.34	44.00	44.83	44.39	43.39	41.68	43.54	42.87
7	1600 to 1700	44.09	43.67	44.13	43.96	43.29	41.29	43.62	42.74
8	1700 to 1800	42.38	41.73	42.37	42.16	41.95	39.80	41.68	41.15
9	1800 to 1900	40.50	39.87	40.21	40.19	40.26	38.35	39.89	39.50
10	1900 to 2000	38.56	37.65	38.93	38.38	38.50	36.21	39.03	37.91
11	2000 to 2100	36.90	36.03	36.93	36.62	36.92	34.84	37.03	36.26
12	2100 to 2200	35.60	34.73	35.93	35.42	35.66	33.66	36.04	35.12
13	2200 to 2300	34.44	33.58	34.95	34.32	34.53	32.58	35.03	34.05
14	2300 to 0000	33.31	32.42	33.96	33.23	33.47	31.48	34.02	32.99
15	0000 to 0100	32.42	31.48	32.96	32.28	32.58	30.51	33.02	32.04
16	0100 to 0200	31.54	30.55	31.97	31.35	31.74	29.56	32.02	31.10
17	0200 to 0300	30.70	29.87	31.01	30.53	30.93	29.18	31.00	30.37
18	0300 to 0400	30.02	29.02	29.99	29.68	30.32	28.26	30.01	29.53
19	0400 to 0500	29.41	28.37	28.95	28.91	29.71	27.44	29.03	28.73
20	0500 to 0600	28.92	28.00	28.97	28.63	29.18	27.23	29.01	28.47
21	0600 to 0700	28.52	27.85	28.03	28.14	28.79	27.57	27.98	28.11
22	0700 to 0800	28.21	27.98	28.42	28.20	28.49	28.45	27.79	28.24
23	0800 to 0900	28.41	28.56	28.26	28.41	28.54	29.50	28.36	28.80
24	0900 to 1000	29.93	30.64	30.20	30.26	29.70	31.83	29.89	30.47

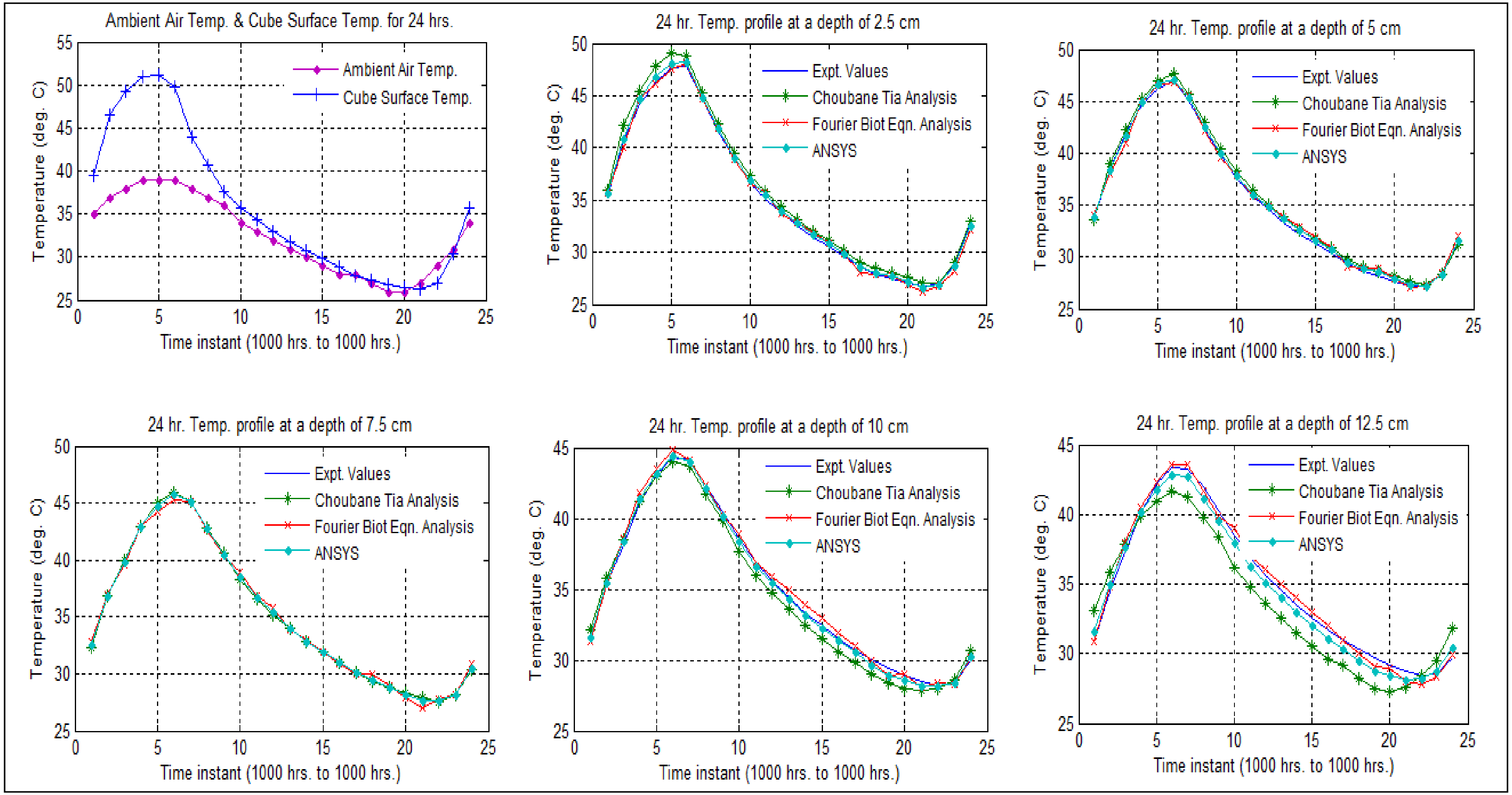


Fig. A-23: 24 hour cube temperature profile (measured and calculated) at various depths for Mix C for maximum ambient air temperature

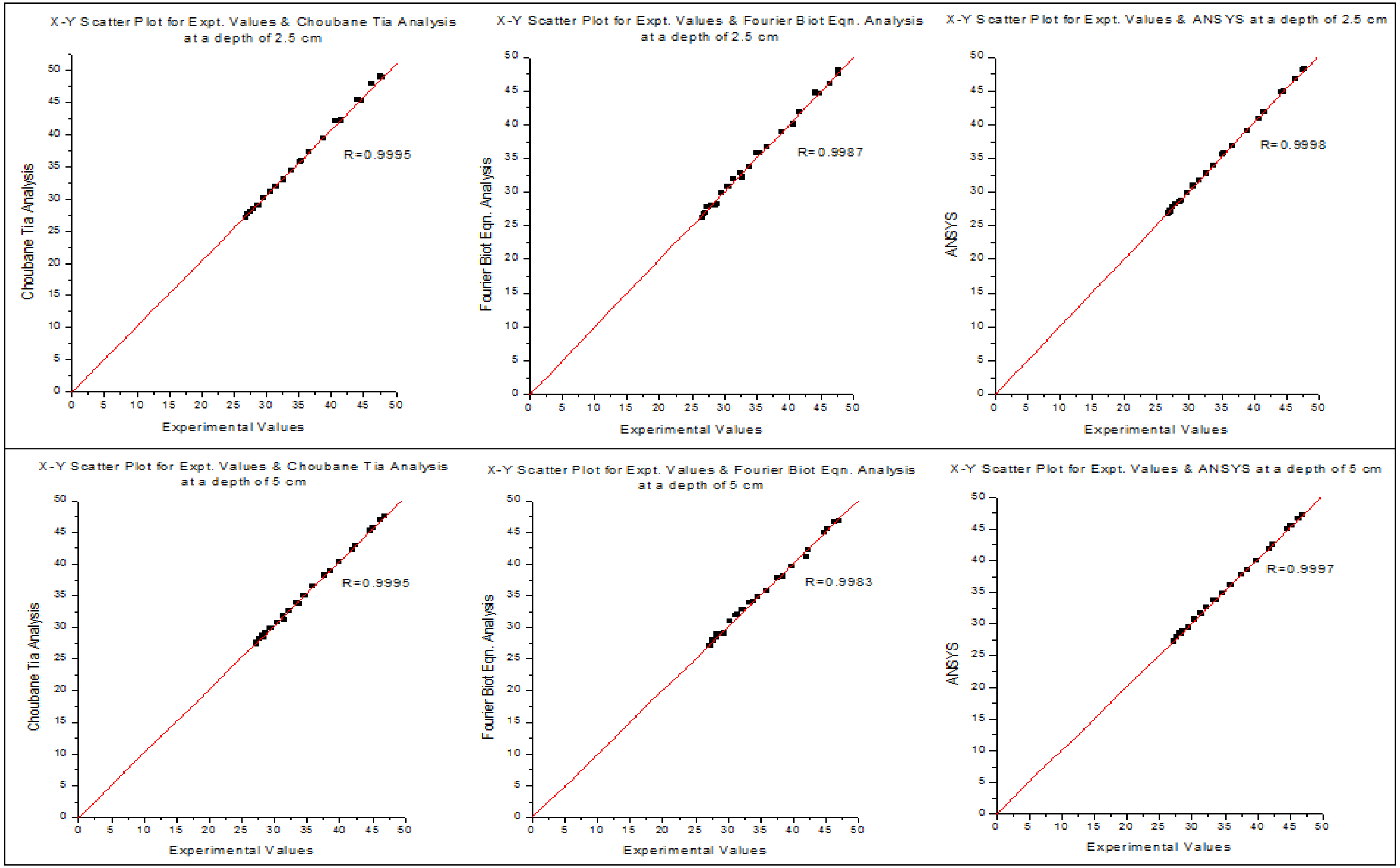


Fig. A-24 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

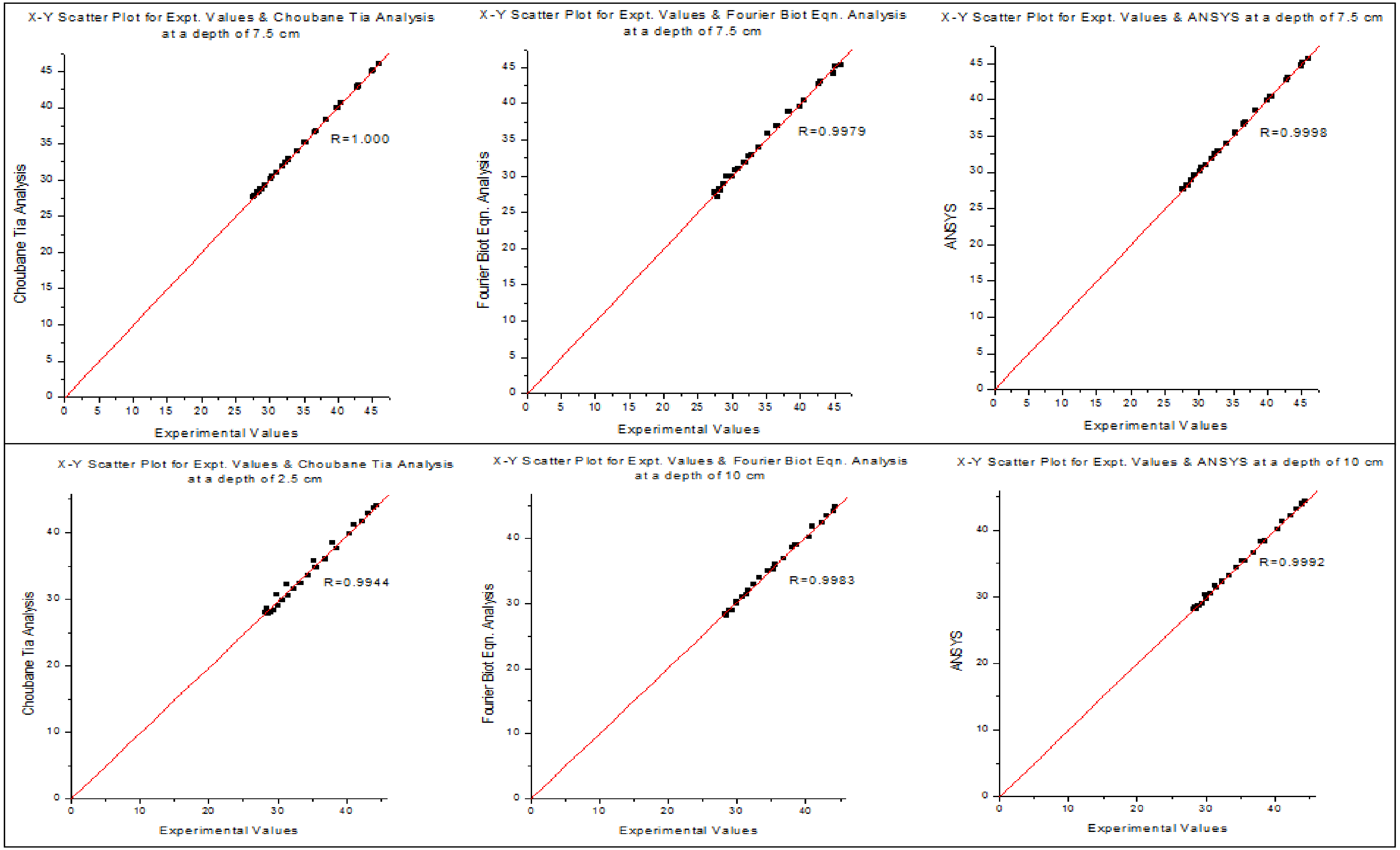


Fig. A-24 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

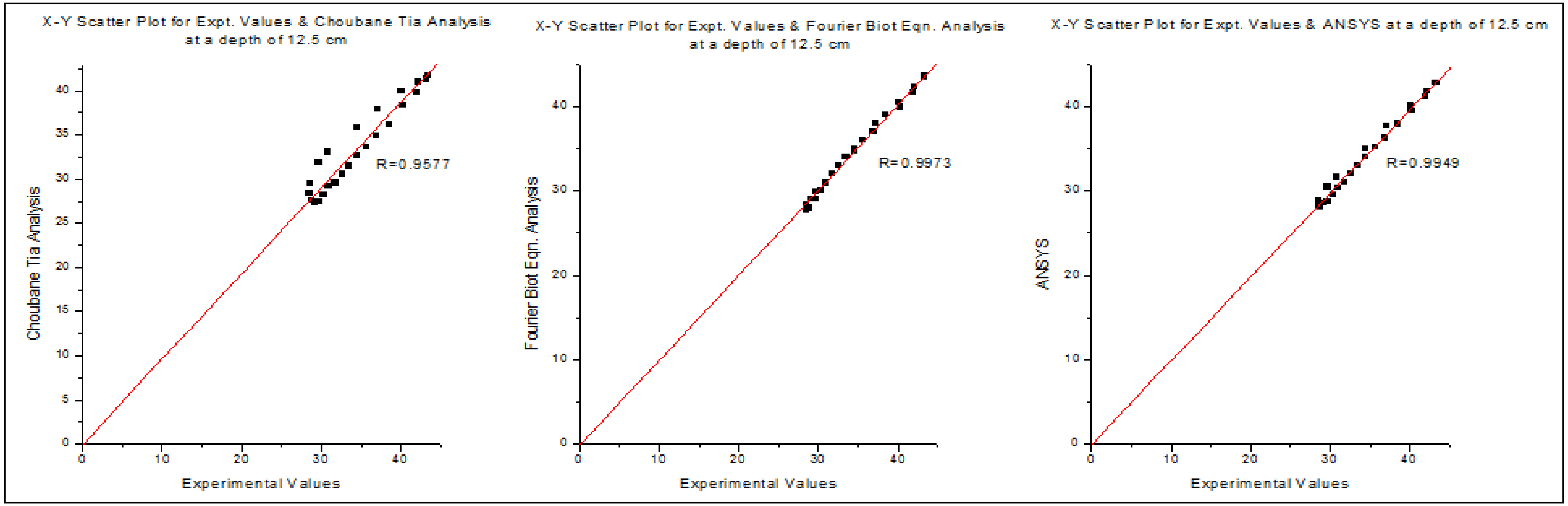


Fig. A-24 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-13 (a): 24 hr. cube temperature values (measured and calculated) for Mix C for minimum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1000 to 1100	25.00	31.66	28.65	29.02	28.89	28.85	26.99	26.99	26.15	26.71	25.58	25.58	25.53	25.56
2	1100 to 1200	27.00	34.72	31.30	32.03	31.05	31.46	29.80	29.90	29.22	29.64	28.33	28.33	28.84	28.50
3	1200 to 1300	28.00	35.35	32.61	33.29	32.52	32.80	31.40	31.56	31.18	31.38	30.17	30.17	30.45	30.27
4	1300 to 1400	28.00	35.04	33.08	33.70	33.10	33.29	32.20	32.42	32.91	32.51	31.21	31.21	31.27	31.23
5	1400 to 1500	28.00	34.29	32.98	33.58	32.22	32.93	32.38	32.74	32.33	32.48	31.76	31.76	31.91	31.81
6	1500 to 1600	28.00	31.93	31.69	32.07	31.51	31.76	31.60	31.90	31.56	31.68	31.40	31.40	31.78	31.53
7	1600 to 1700	27.00	28.94	29.41	29.89	29.29	29.53	29.93	30.33	29.44	29.90	30.27	30.27	30.44	30.32
8	1700 to 1800	26.00	26.12	26.91	27.54	26.04	26.83	27.89	28.38	27.65	27.97	28.64	28.64	28.68	28.65
9	1800 to 1900	24.00	24.04	24.77	25.59	24.56	24.97	25.87	26.51	25.37	25.92	26.82	26.82	26.23	26.62
10	1900 to 2000	22.00	22.30	23.03	23.92	23.92	23.62	24.10	24.86	24.95	24.64	25.15	25.15	24.97	25.09
11	2000 to 2100	21.00	21.03	21.69	22.53	21.99	22.07	22.82	23.43	22.00	22.75	23.72	23.72	24.00	23.81
12	2100 to 2200	21.00	19.98	20.57	21.30	20.22	20.69	21.58	22.17	21.14	21.63	22.57	22.57	22.09	22.41
13	2200 to 2300	20.00	19.10	19.68	20.37	19.22	19.76	20.64	21.20	20.15	20.66	21.58	21.58	21.09	21.41
14	2300 to 0000	20.00	18.34	18.90	19.50	18.39	18.93	19.84	20.30	19.25	19.80	20.75	20.75	20.16	20.55
15	0000 to 0100	20.00	17.74	18.25	18.76	18.55	18.52	19.14	19.53	19.36	19.34	20.04	20.04	20.23	20.10
16	0100 to 0200	19.00	17.11	17.65	18.16	17.36	17.72	18.49	18.92	18.24	18.55	19.38	19.38	19.15	19.31
17	0200 to 0300	19.00	16.58	17.04	17.52	17.39	17.32	17.93	18.25	18.25	18.15	18.77	18.77	18.16	18.56
18	0300 to 0400	18.00	16.13	16.61	17.12	16.32	16.69	17.44	17.85	17.21	17.50	18.30	18.30	18.13	18.24
19	0400 to 0500	17.00	15.66	16.20	16.75	16.23	16.39	17.01	17.49	17.15	17.22	17.88	17.88	17.10	17.62
20	0500 to 0600	17.00	15.35	15.84	16.33	15.26	15.81	16.63	17.03	16.17	16.61	17.45	17.45	17.11	17.34
21	0600 to 0700	18.00	15.43	15.74	16.08	15.38	15.74	16.42	16.65	16.25	16.44	17.13	17.13	17.16	17.14
22	0700 to 0800	19.00	18.55	17.41	17.91	17.35	17.56	17.33	17.56	17.23	17.37	17.49	17.49	17.14	17.38
23	0800 to 0900	22.00	24.28	21.60	22.06	21.84	21.83	20.65	20.58	20.86	20.70	19.83	19.83	19.18	19.61
24	0900 to 1000	23.00	28.48	25.32	25.87	25.69	25.63	23.90	23.95	23.04	23.63	22.69	22.69	22.19	22.53

Table A-13 (b): 24 hr. cube temperature values (measured and calculated) for Mix C for minimum ambient air temperature at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1000 to 1100	24.55	24.77	24.63	24.65	24.12	24.58	24.51	24.40
2	1100 to 1200	26.95	27.32	26.39	26.89	26.27	26.88	26.94	26.70
3	1200 to 1300	28.81	29.12	28.74	28.89	28.11	28.39	28.15	28.22
4	1300 to 1400	30.00	30.07	30.64	30.24	29.35	29.00	29.09	29.15
5	1400 to 1500	30.79	30.65	30.43	30.62	30.21	29.39	29.97	29.86
6	1500 to 1600	30.77	30.58	30.78	30.71	30.33	29.45	30.59	30.12
7	1600 to 1700	30.07	29.69	30.00	29.92	29.91	28.60	30.15	29.55
8	1700 to 1800	28.86	28.33	28.97	28.72	28.92	27.45	28.56	28.31
9	1800 to 1900	27.33	26.50	27.14	26.99	27.58	25.56	27.08	26.74
10	1900 to 2000	25.79	24.76	25.98	25.51	26.18	23.71	25.99	25.29
11	2000 to 2100	24.59	23.42	24.00	24.00	25.03	22.51	25.00	24.18
12	2100 to 2200	23.40	22.51	23.05	22.99	23.92	21.98	24.03	23.31
13	2200 to 2300	22.47	21.50	22.05	22.01	23.03	20.98	23.03	22.34
14	2300 to 0000	21.65	20.85	21.09	21.20	22.22	20.60	22.05	21.62
15	0000 to 0100	20.96	20.28	20.13	20.46	21.54	20.27	21.08	20.96
16	0100 to 0200	20.28	19.55	20.09	19.97	20.90	19.42	20.05	20.13
17	0200 to 0300	19.74	19.06	19.09	19.30	20.31	19.14	20.05	19.83
18	0300 to 0400	19.23	18.47	19.08	18.93	19.85	18.37	19.04	19.09
19	0400 to 0500	18.78	17.93	18.06	18.26	19.43	17.64	19.03	18.70
20	0500 to 0600	18.39	17.58	18.06	18.01	18.98	17.43	18.04	18.15
21	0600 to 0700	18.06	17.51	18.09	17.89	18.61	17.80	18.05	18.15
22	0700 to 0800	18.11	17.71	18.08	17.97	18.52	18.21	18.05	18.26
23	0800 to 0900	19.59	19.81	19.69	19.70	19.56	20.54	19.39	19.83
24	0900 to 1000	21.88	22.12	21.85	21.95	21.51	22.22	21.06	21.60

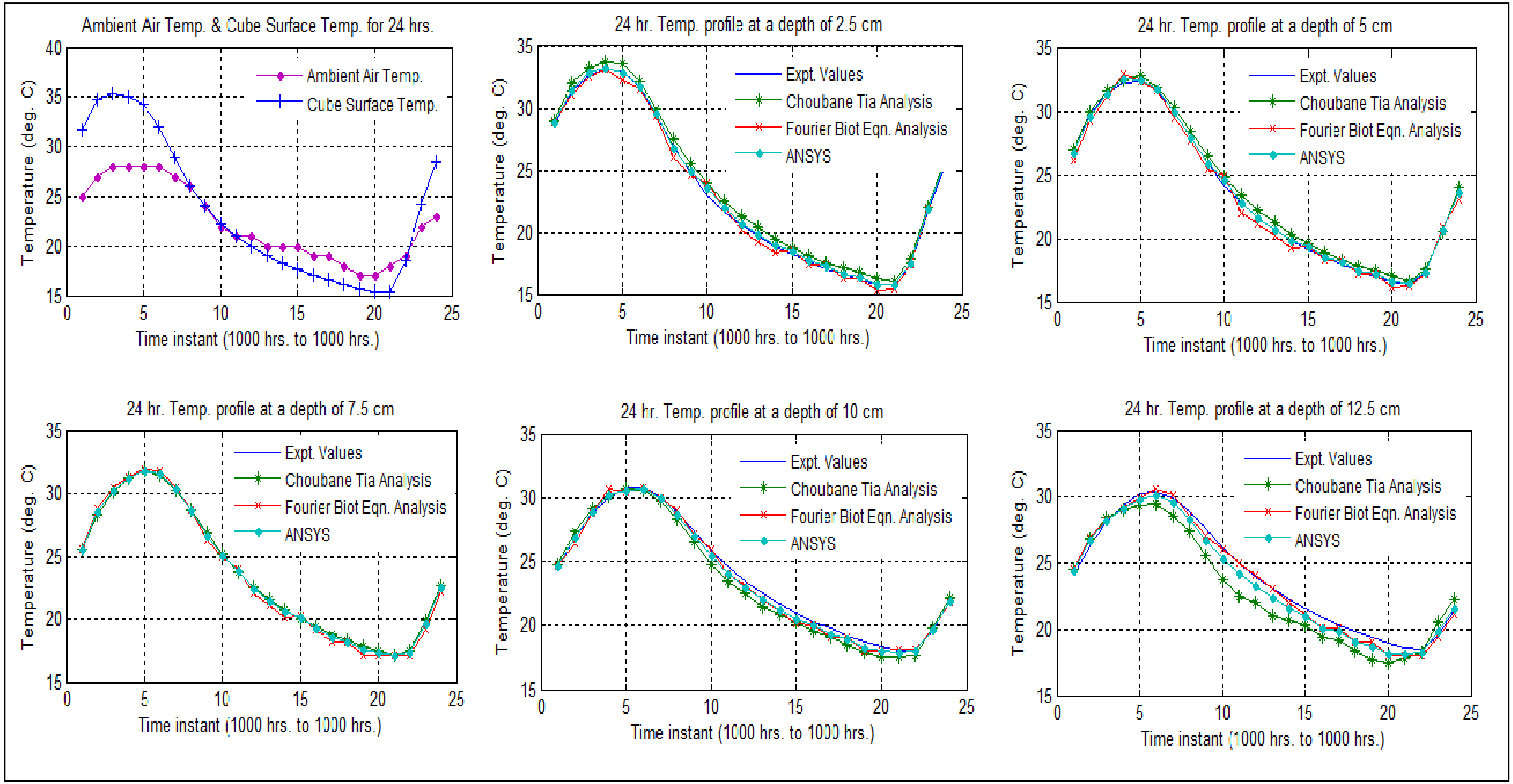


Fig. A-25: 24 hour cube temperature profile (measured and calculated) at various depths for Mix C for minimum ambient air temperature

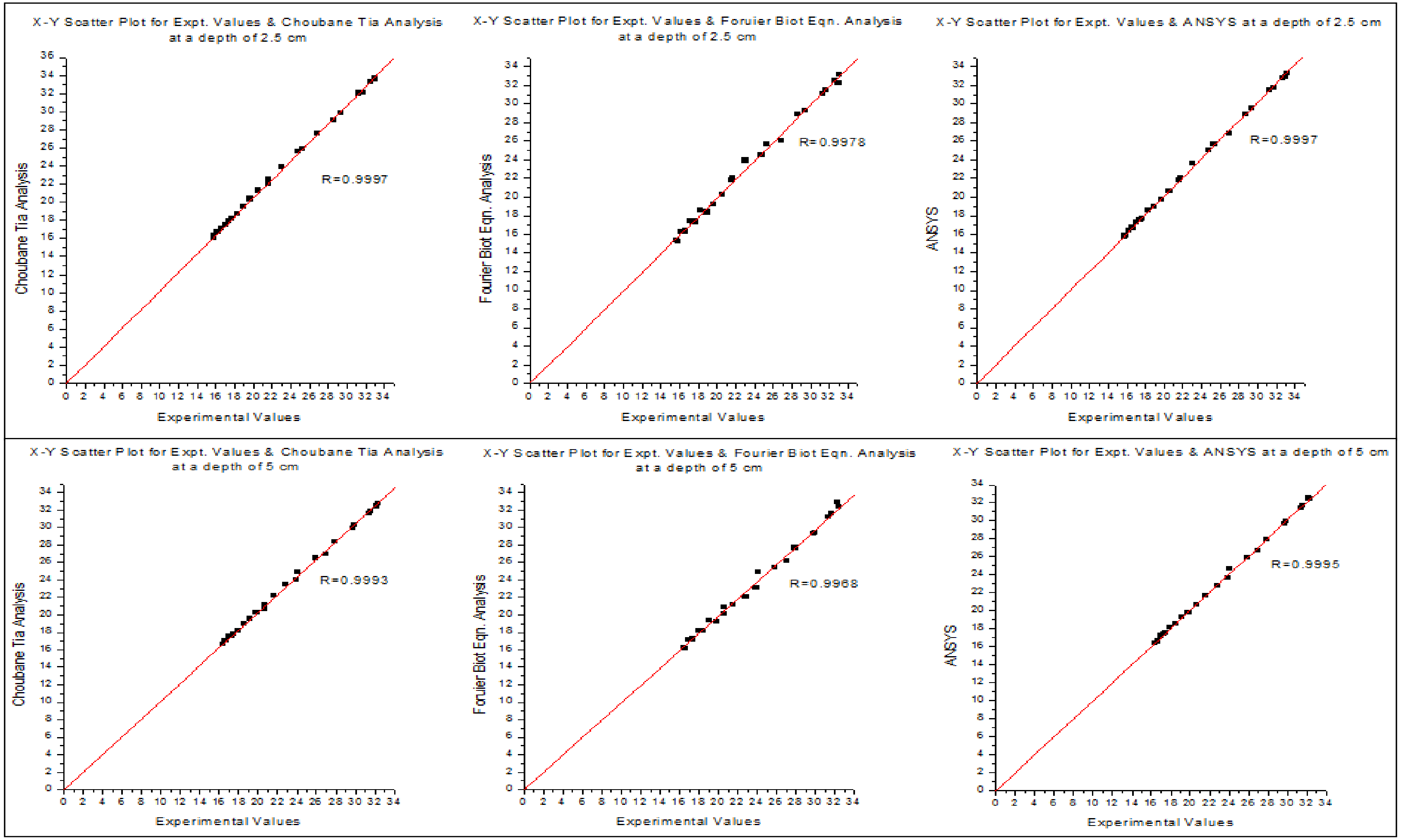


Fig. A-26 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

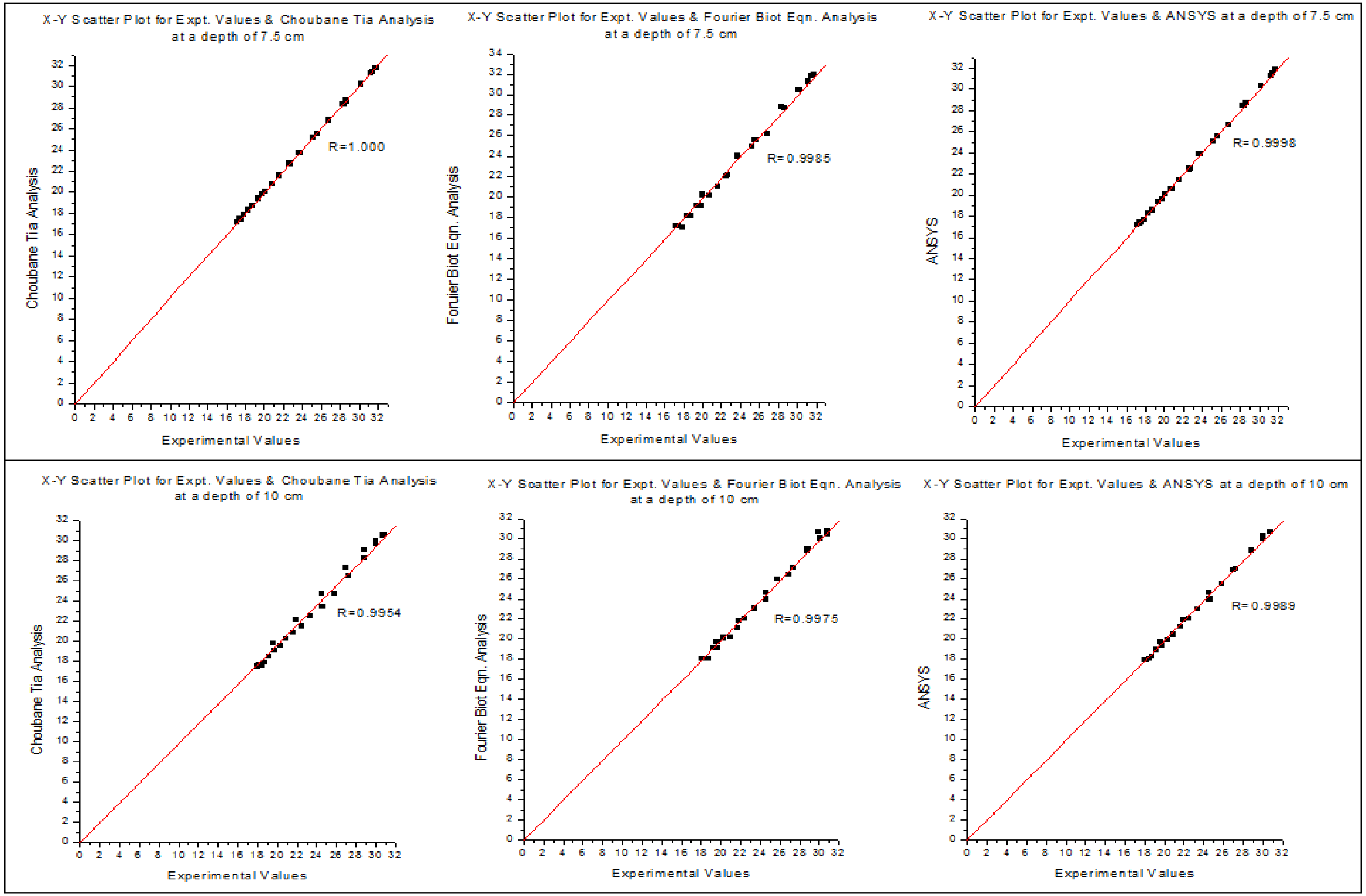


Fig. A-26 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

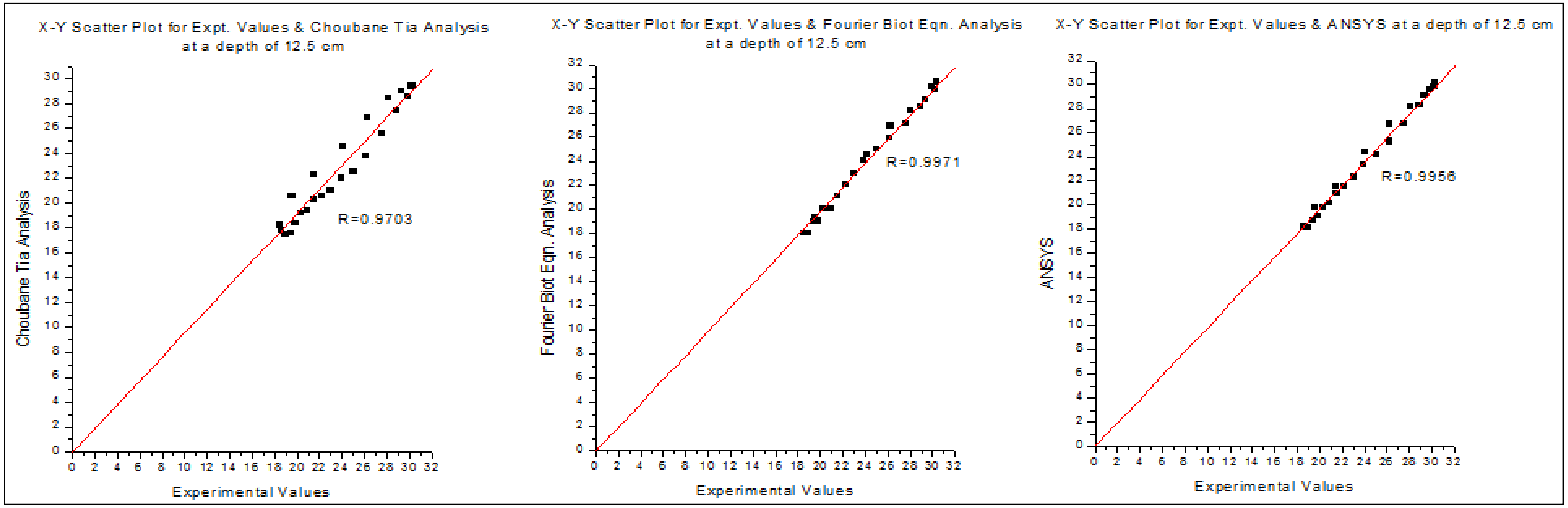


Fig. A-26 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-14 (a): 24 hr. cube temperature values (measured and calculated) for Mix C for 24 hr. precipitation at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1000 to 1100	24	22.55	22.38	22.37	22.27	22.34	22.37	22.36	22.83	22.52	22.52	22.52	22.53	22.52
2	1100 to 1200	25	22.80	22.45	22.42	22.40	22.42	22.53	22.35	22.92	22.60	22.57	22.57	22.58	22.57
3	1200 to 1300	26	22.94	22.68	22.52	22.04	22.41	22.74	22.47	22.34	22.52	22.80	22.80	22.85	22.81
4	1300 to 1400	26	22.90	22.71	22.56	23.00	22.76	22.82	22.57	22.97	22.79	22.92	22.92	22.25	22.69
5	1400 to 1500	26	22.52	22.42	22.28	22.41	22.37	22.62	22.37	22.24	22.41	22.79	22.79	22.42	22.66
6	1500 to 1600	26	22.22	22.12	21.99	22.08	22.06	22.35	22.10	22.02	22.15	22.56	22.56	22.28	22.46
7	1600 to 1700	26	21.98	22.00	21.76	22.05	21.94	22.16	21.89	22.35	22.13	22.38	22.38	22.85	22.54
8	1700 to 1800	26	21.91	21.82	21.64	21.56	21.68	22.03	21.76	22.03	21.94	22.25	22.25	22.65	22.38
9	1800 to 1900	25	21.86	21.73	21.66	21.72	21.70	21.93	21.75	21.47	21.72	22.13	22.13	22.30	22.19
10	1900 to 2000	24	21.71	21.71	21.66	21.43	21.60	21.87	21.79	21.28	21.65	22.08	22.08	22.18	22.12
11	2000 to 2100	24	21.70	21.68	21.61	21.42	21.57	21.80	21.71	21.27	21.59	22.00	22.00	22.17	22.06
12	2100 to 2200	24	21.67	21.72	21.56	21.43	21.57	21.77	21.66	21.28	21.57	21.95	21.95	21.18	21.69
13	2200 to 2300	24	21.67	21.63	21.54	21.41	21.53	21.77	21.62	21.27	21.55	21.90	21.90	21.17	21.66
14	2300 to 0000	24	21.60	21.59	21.49	21.41	21.50	21.73	21.58	21.27	21.53	21.88	21.88	21.17	21.64
15	0000 to 0100	24	21.60	21.50	21.44	21.46	21.47	21.65	21.50	21.30	21.49	21.79	21.79	21.19	21.59
16	0100 to 0200	24	21.60	21.43	21.40	21.55	21.46	21.59	21.44	21.36	21.46	21.72	21.72	21.23	21.55
17	0200 to 0300	24	21.56	21.40	21.32	21.64	21.45	21.54	21.35	21.42	21.44	21.63	21.63	21.27	21.51
18	0300 to 0400	23	21.42	21.29	21.35	21.41	21.35	21.48	21.41	21.27	21.39	21.60	21.60	21.17	21.46
19	0400 to 0500	23	21.29	21.20	21.24	21.51	21.31	21.37	21.32	21.33	21.34	21.53	21.53	21.21	21.42
20	0500 to 0600	23	21.45	21.28	21.33	21.47	21.36	21.42	21.36	21.31	21.36	21.55	21.55	21.19	21.43
21	0600 to 0700	23	21.75	21.54	21.55	21.29	21.46	21.60	21.52	21.19	21.44	21.65	21.65	21.12	21.47
22	0700 to 0800	23	22.38	21.87	22.04	21.25	21.72	21.87	21.88	21.16	21.64	21.89	21.89	21.10	21.63
23	0800 to 0900	23	23.60	22.78	23.03	22.99	22.93	22.61	22.65	22.65	22.64	22.46	22.46	22.41	22.44
24	0900 to 1000	24	23.83	23.16	23.35	23.61	23.37	23.11	23.08	23.72	23.30	23.00	23.00	23.09	23.03

Table A-14 (b): 24 hr. cube temperature values (measured and calculated) for Mix C for 24 hr. precipitation at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1000 to 1100	22.61	22.85	22.31	22.59	22.93	23.34	23.18	23.15
2	1100 to 1200	22.63	23.08	22.34	22.68	22.72	23.89	22.19	22.94
3	1200 to 1300	22.84	23.49	22.49	22.94	22.90	24.56	22.28	23.25
4	1300 to 1400	22.92	23.60	22.72	23.08	23.03	24.63	22.41	23.36
5	1400 to 1500	22.88	23.53	22.82	23.08	22.97	24.60	22.47	23.35
6	1500 to 1600	22.75	23.36	22.74	22.95	22.88	24.51	22.43	23.27
7	1600 to 1700	22.60	23.23	22.50	22.78	22.76	24.44	22.28	23.16
8	1700 to 1800	22.48	23.12	22.38	22.66	22.62	24.37	22.22	23.07
9	1800 to 1900	22.39	22.80	22.17	22.45	22.54	23.75	22.10	22.80
10	1900 to 2000	22.32	22.55	22.10	22.33	22.45	23.19	22.06	22.57
11	2000 to 2100	22.22	22.48	22.10	22.27	22.38	23.15	22.06	22.53
12	2100 to 2200	22.18	22.43	22.10	22.24	22.31	23.12	22.06	22.50
13	2200 to 2300	22.14	22.39	22.10	22.21	22.25	23.09	22.06	22.47
14	2300 to 0000	22.06	22.38	22.10	22.18	22.21	23.09	22.06	22.45
15	0000 to 0100	21.99	22.30	21.11	21.80	22.10	23.04	22.06	22.40
16	0100 to 0200	21.92	22.24	21.13	21.76	22.03	23.00	22.08	22.37
17	0200 to 0300	21.86	22.16	21.15	21.72	21.94	22.95	21.09	22.00
18	0300 to 0400	21.77	21.93	21.10	21.60	21.85	22.40	21.06	21.77
19	0400 to 0500	21.70	21.88	21.12	21.57	21.77	22.37	21.07	21.74
20	0500 to 0600	21.71	21.88	21.11	21.57	21.78	22.36	21.06	21.73
21	0600 to 0700	21.81	21.94	21.07	21.61	21.88	22.39	21.04	21.77
22	0700 to 0800	21.98	22.08	21.06	21.71	22.04	22.45	22.03	22.18
23	0800 to 0900	22.42	22.45	22.24	22.37	22.41	22.63	22.14	22.39
24	0900 to 1000	22.87	23.13	22.63	22.88	22.83	23.46	22.36	22.89

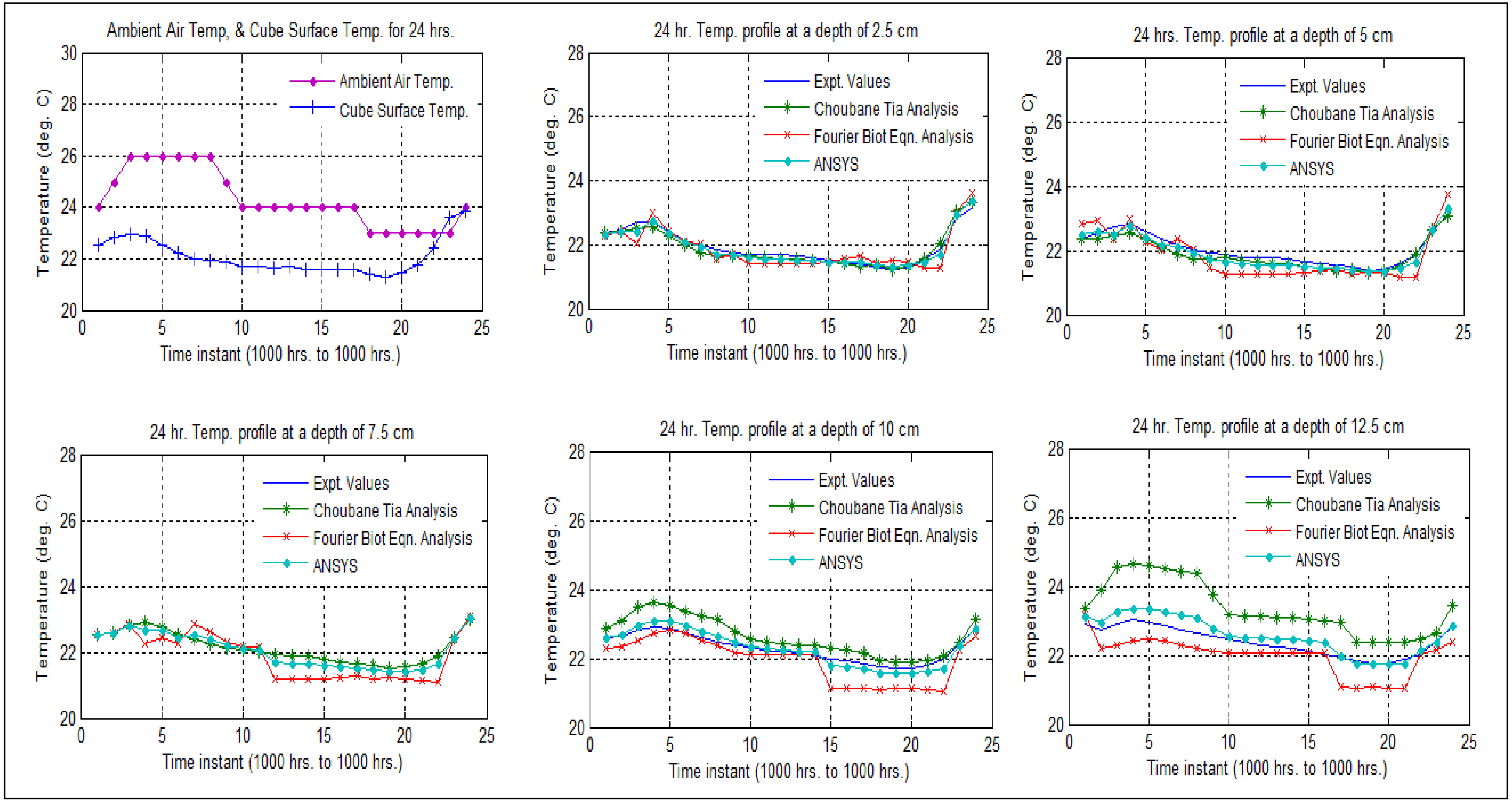


Fig. A-27: 24 hour cube temperature profile (measured and calculated) at various depths for Mix C for 24 hr. precipitation

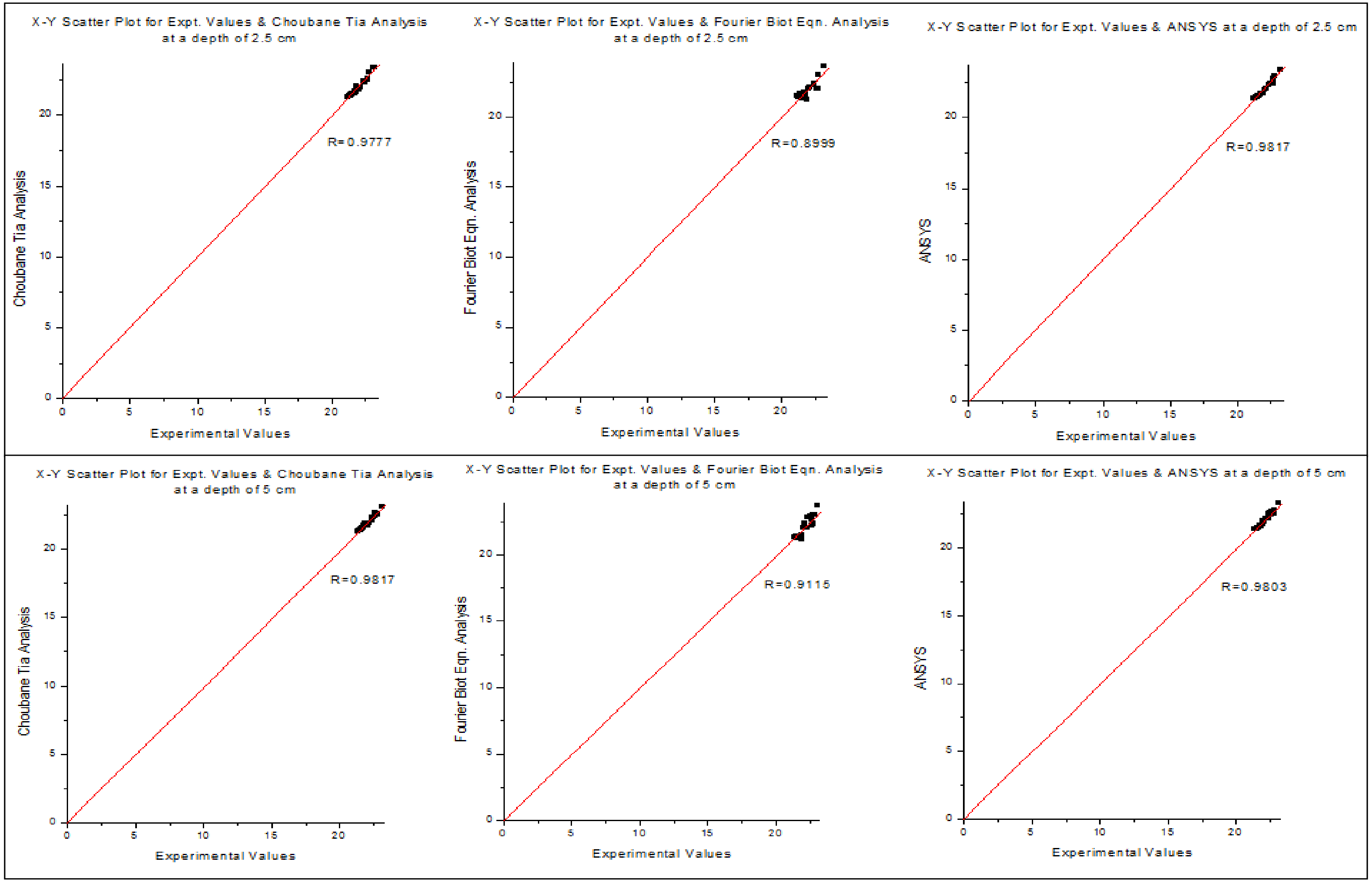


Fig. A-28 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

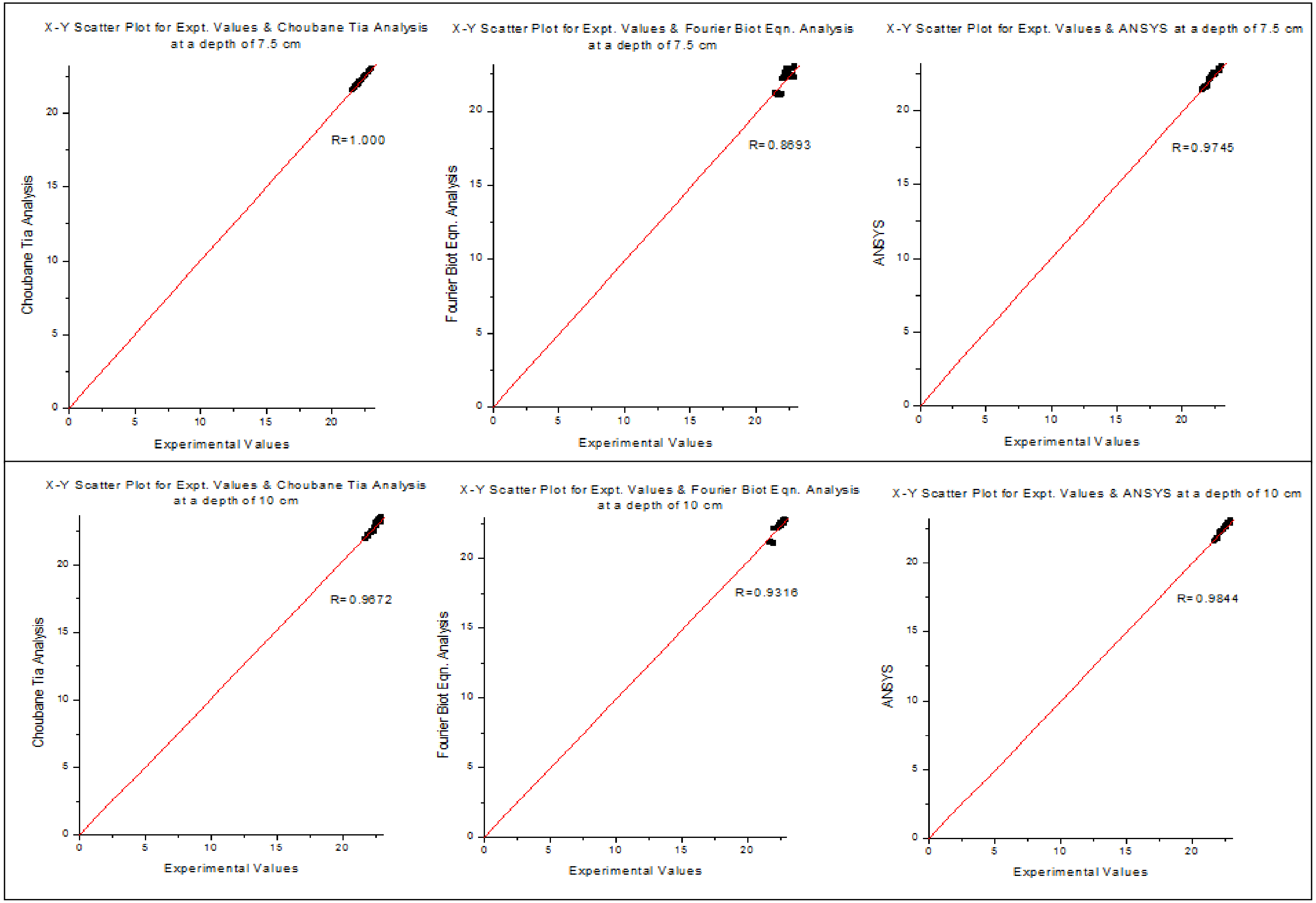


Fig. A-28 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

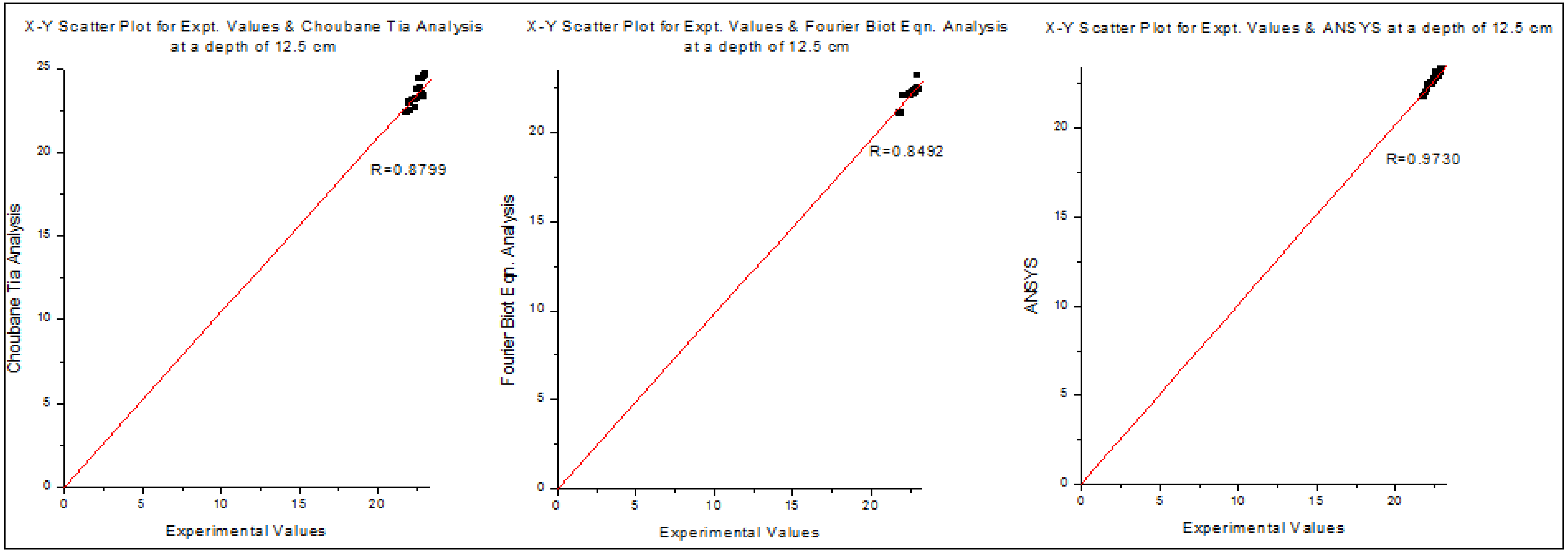


Fig. A-28 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-15 (a): 24 hr. cube temperature values (measured and calculated) for Mix C for part humid and part rainy condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1000 to 1100	27	30.18	28.56	28.80	28.56	28.64	27.64	27.76	27.30	27.57	27.06	27.06	27.72	27.28
2	1100 to 1200	28	31.34	30.48	30.47	30.22	30.39	29.79	29.73	29.05	29.52	29.11	29.11	29.83	29.35
3	1200 to 1300	28	30.80	30.38	30.53	30.69	30.53	30.12	30.19	30.36	30.22	29.76	29.76	29.03	29.51
4	1300 to 1400	28	30.32	30.30	30.38	30.74	30.47	30.17	30.26	30.77	30.40	29.96	29.96	30.38	30.10
5	1400 to 1500	28	29.93	29.90	30.11	29.60	29.87	29.90	30.09	29.68	29.89	29.87	29.87	29.33	29.69
6	1500 to 1600	27	27.57	28.38	28.55	28.28	28.40	28.89	29.10	28.47	28.82	29.22	29.22	29.19	29.21
7	1600 to 1700	27	27.47	27.63	28.08	27.43	27.71	28.08	28.42	28.60	28.36	28.48	28.48	28.01	28.32
8	1700 to 1800	27	26.19	26.59	26.93	26.62	26.71	27.17	27.43	27.72	27.44	27.68	27.68	27.09	27.49
9	1800 to 1900	26	25.37	25.66	26.13	25.66	25.82	26.31	26.63	26.44	26.46	26.87	26.87	26.28	26.67
10	1900 to 2000	26	24.04	24.52	24.86	24.33	24.57	25.24	25.49	25.22	25.32	25.92	25.92	25.14	25.66
11	2000 to 2100	25	23.31	23.63	24.04	24.28	23.99	24.31	24.59	24.18	24.36	24.96	24.96	24.12	24.68
12	2100 to 2200	25	23.08	23.33	23.61	23.35	23.43	23.83	24.06	23.23	23.71	24.42	24.42	24.15	24.33
13	2200 to 2300	25	23.02	23.18	23.40	23.37	23.32	23.60	23.76	23.24	23.53	24.10	24.10	24.15	24.12
14	2300 to 0000	25	22.63	22.72	22.95	22.46	22.71	23.22	23.30	23.30	23.27	23.68	23.68	23.19	23.52
15	0000 to 0100	24	22.27	22.35	22.65	22.37	22.46	22.86	23.00	23.25	23.04	23.31	23.31	23.16	23.26
16	0100 to 0200	24	21.99	22.01	22.31	22.50	22.27	22.47	22.64	22.33	22.48	22.97	22.97	22.21	22.71
17	0200 to 0300	24	22.11	22.08	22.33	22.37	22.26	22.46	22.59	22.25	22.43	22.89	22.89	22.16	22.64
18	0300 to 0400	24	22.11	22.14	22.34	22.35	22.28	22.51	22.60	22.23	22.45	22.90	22.90	22.15	22.65
19	0400 to 0500	24	22.18	22.18	22.38	22.34	22.30	22.56	22.62	22.22	22.47	22.90	22.90	22.14	22.65
20	0500 to 0600	23	22.14	22.15	22.46	22.16	22.26	22.53	22.72	22.10	22.45	22.90	22.90	22.06	22.62
21	0600 to 0700	23	22.27	22.25	22.54	22.14	22.31	22.58	22.75	22.09	22.47	22.91	22.91	22.06	22.62
22	0700 to 0800	23	22.46	22.34	22.64	22.24	22.41	22.60	22.79	22.16	22.52	22.90	22.90	22.10	22.63
23	0800 to 0900	24	23.50	23.03	23.24	23.85	23.37	23.04	23.12	23.56	23.24	23.14	23.14	23.35	23.21
24	0900 to 1000	24	24.83	23.99	24.35	24.38	24.24	23.87	24.00	24.22	24.03	23.80	23.80	23.40	23.67

Table A-15 (b): 24 hr. cube temperature values (measured and calculated) for Mix C for part humid and part rainy condition at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1000 to 1100	26.72	26.70	26.58	26.67	26.59	26.68	26.91	26.73
2	1100 to 1200	28.44	28.61	28.22	28.42	28.14	28.24	28.27	28.22
3	1200 to 1300	29.24	29.25	29.34	29.28	29.01	28.67	29.34	29.00
4	1300 to 1400	29.56	29.48	29.38	29.48	29.39	28.83	29.79	29.34
5	1400 to 1500	29.63	29.45	29.35	29.48	29.54	28.83	29.78	29.38
6	1500 to 1600	29.30	28.91	29.27	29.16	29.31	28.17	29.73	29.07
7	1600 to 1700	28.71	28.26	28.59	28.52	28.83	27.77	28.34	28.31
8	1700 to 1800	28.08	27.70	28.63	28.13	28.29	27.47	28.36	28.04
9	1800 to 1900	27.32	26.84	27.16	27.11	27.60	26.55	27.09	27.08
10	1900 to 2000	26.52	26.14	26.08	26.25	26.84	26.17	26.05	26.35
11	2000 to 2100	25.59	25.15	25.07	25.27	26.01	25.17	26.04	25.74
12	2100 to 2200	25.02	24.70	25.08	24.94	25.39	24.89	25.05	25.11
13	2200 to 2300	24.68	24.42	24.09	24.40	25.03	24.72	25.05	24.93
14	2300 to 0000	24.28	24.09	24.11	24.16	24.66	24.53	24.06	24.42
15	0000 to 0100	23.86	23.58	23.09	23.51	24.25	23.81	24.05	24.04
16	0100 to 0200	23.48	23.30	23.12	23.30	23.85	23.65	23.07	23.52
17	0200 to 0300	23.36	23.22	23.09	23.22	23.70	23.59	23.05	23.45
18	0300 to 0400	23.34	23.23	23.08	23.22	23.61	23.60	23.05	23.42
19	0400 to 0500	23.31	23.22	23.08	23.21	23.57	23.59	23.05	23.40
20	0500 to 0600	23.27	23.00	23.04	23.10	23.54	23.04	23.02	23.20
21	0600 to 0700	23.27	23.00	23.03	23.10	23.52	23.03	23.02	23.19
22	0700 to 0800	23.22	22.97	23.06	23.08	23.40	23.00	23.03	23.15
23	0800 to 0900	23.36	23.29	23.20	23.28	23.51	23.58	23.12	23.40
24	0900 to 1000	23.88	23.73	23.82	23.81	23.97	23.80	23.47	23.74

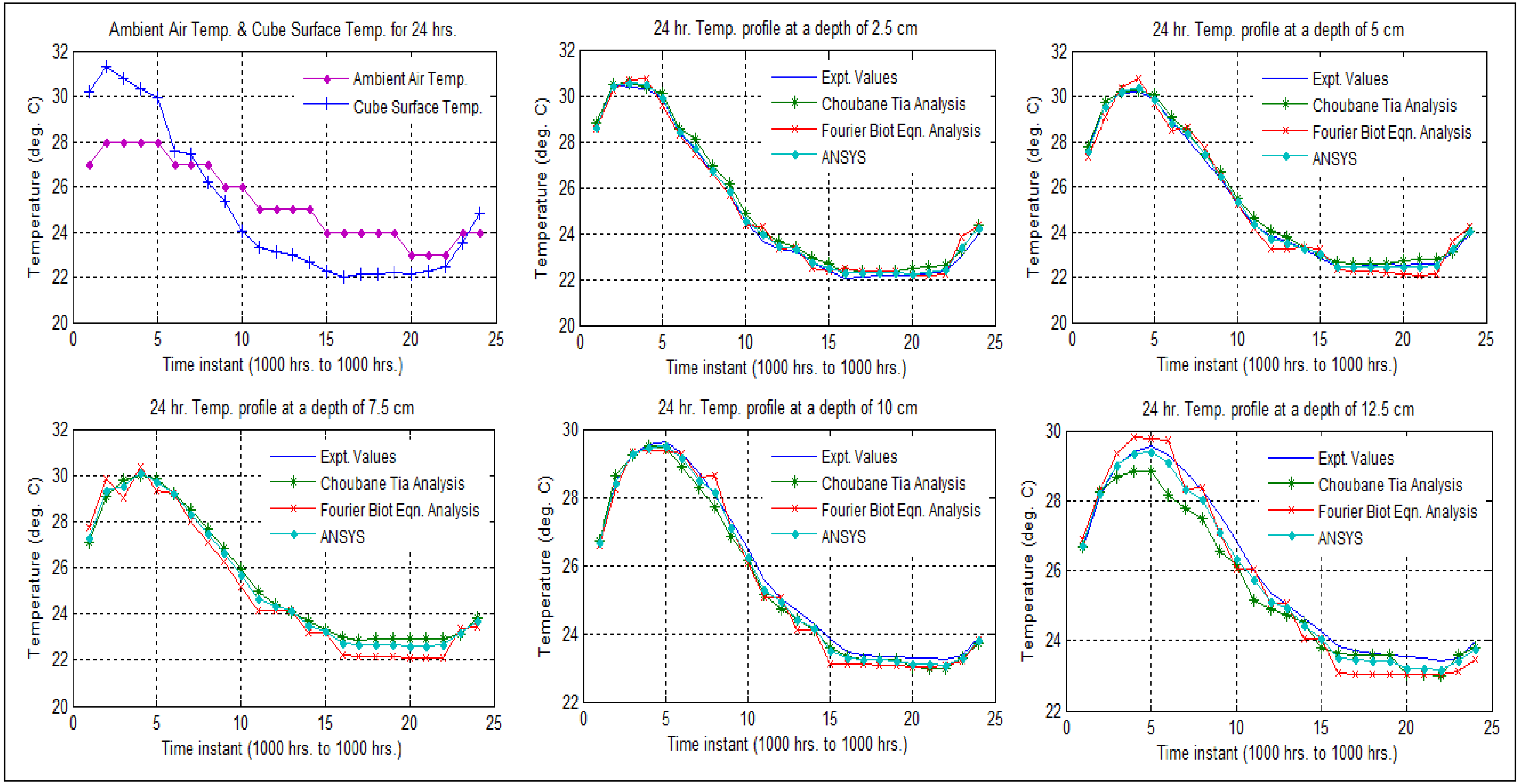


Fig. A-29: 24 hour cube temperature profile (measured and calculated) at various depths for Mix C for part humid and part rainy condition

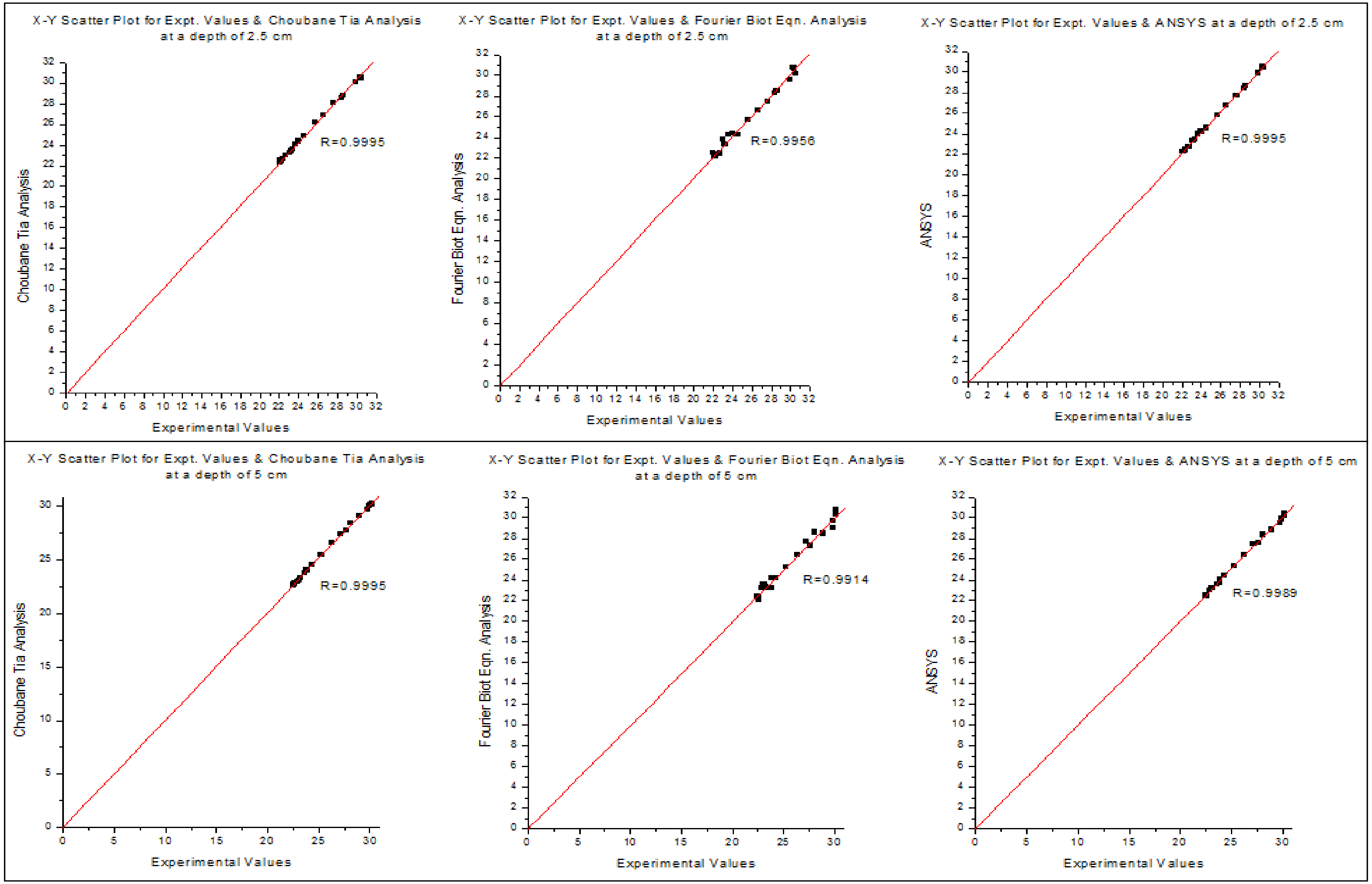


Fig. A-30 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

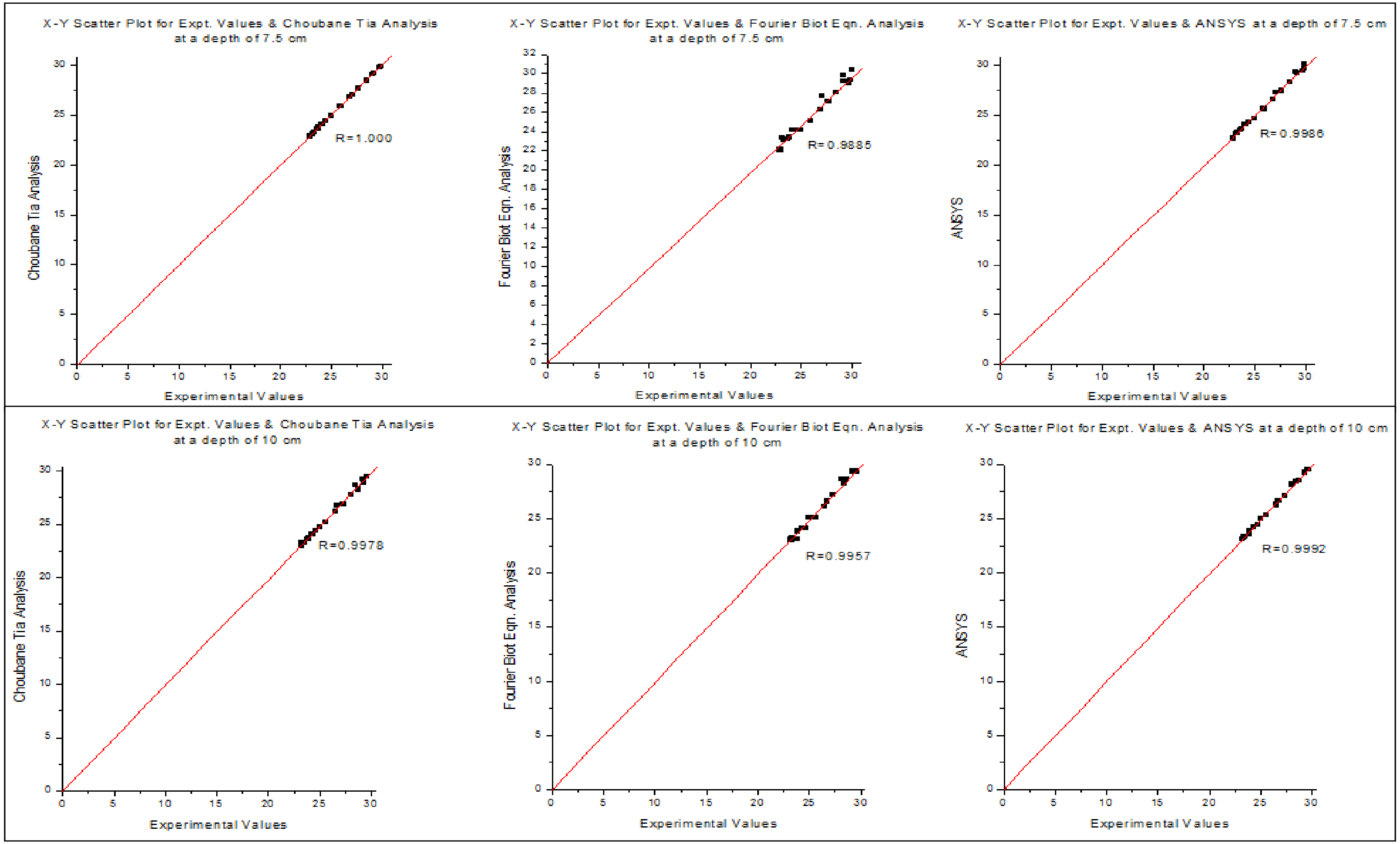


Fig. A-30 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

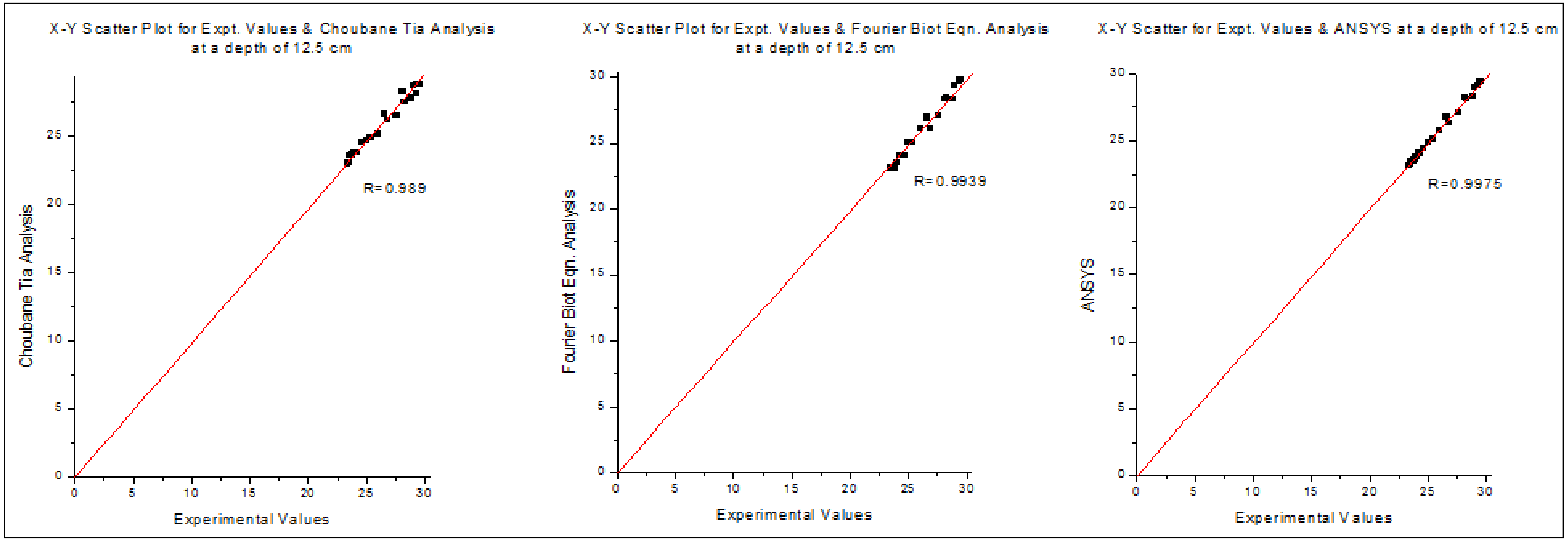


Fig. A-30 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-16 (a): 24 hr. cube temperature values (measured and calculated) for Mix C for 24 hr. cloudy and humid condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1000 to 1100	27	35.09	31.78	32.61	31.92	32.10	30.35	30.58	30.17	30.37	29.01	29.01	29.54	29.19
2	1100 to 1200	28	37.10	33.98	34.84	33.98	34.27	32.56	32.88	32.52	32.65	31.21	31.21	31.39	31.27
3	1200 to 1300	29	39.45	36.62	37.29	36.19	36.70	35.03	35.29	35.66	35.33	33.47	33.47	33.48	33.47
4	1300 to 1400	30	36.70	35.85	36.22	35.83	35.96	35.30	35.49	35.05	35.28	34.50	34.50	34.99	34.66
5	1400 to 1500	30	34.83	34.42	34.99	34.96	34.79	34.35	34.76	34.54	34.55	34.15	34.15	34.14	34.14
6	1500 to 1600	29	32.82	32.81	33.50	32.51	32.94	33.11	33.65	33.61	33.46	33.28	33.28	33.29	33.28
7	1600 to 1700	29	31.38	31.49	32.17	31.02	31.56	31.95	32.49	31.98	32.14	32.33	32.33	32.25	32.30
8	1700 to 1800	28	30.00	30.21	30.93	30.50	30.55	30.79	31.36	30.99	31.04	31.28	31.28	31.62	31.39
9	1800 to 1900	27	28.81	29.06	29.84	29.87	29.59	29.70	30.33	29.92	29.98	30.30	30.30	29.95	30.18
10	1900 to 2000	26	27.96	28.15	28.92	28.62	28.56	28.75	29.36	28.75	28.95	29.29	29.29	29.84	29.48
11	2000 to 2100	24	27.27	27.43	28.37	27.39	27.73	28.05	28.81	28.60	28.49	28.60	28.60	28.75	28.65
12	2100 to 2200	24	26.32	26.61	27.41	26.52	26.85	27.22	27.91	27.68	27.61	27.82	27.82	27.80	27.81
13	2200 to 2300	23	25.63	25.83	26.71	25.36	25.97	26.47	27.17	26.58	26.74	27.04	27.04	27.74	27.27
14	2300 to 0000	23	25.27	25.44	26.25	25.38	25.69	26.01	26.69	26.60	26.43	26.59	26.59	26.74	26.64
15	0000 to 0100	23	24.60	24.85	25.57	24.58	25.00	25.43	26.04	25.72	25.73	26.02	26.02	25.82	25.96
16	0100 to 0200	22	24.29	24.45	25.22	24.51	24.73	24.98	25.63	24.68	25.10	25.51	25.51	25.80	25.61
17	0200 to 0300	22	24.00	24.16	24.85	24.54	24.52	24.70	25.23	24.70	24.88	25.14	25.14	24.81	25.03
18	0300 to 0400	22	23.97	24.02	24.73	24.55	24.43	24.45	25.05	24.71	24.74	24.94	24.94	24.81	24.90
19	0400 to 0500	21	24.02	24.04	24.80	24.33	24.39	24.41	25.06	24.56	24.68	24.82	24.82	24.72	24.78
20	0500 to 0600	22	23.93	24.03	24.62	24.56	24.40	24.42	24.91	24.71	24.68	24.79	24.79	24.82	24.80
21	0600 to 0700	22	24.11	24.02	24.67	24.58	24.42	24.34	24.87	24.73	24.65	24.70	24.70	24.83	24.74
22	0700 to 0800	23	25.02	24.59	25.16	24.97	24.90	24.70	25.10	24.98	24.93	24.86	24.86	24.99	24.90
23	0800 to 0900	24	26.96	25.93	26.43	25.23	25.86	25.60	25.91	25.46	25.66	25.41	25.41	25.93	25.58
24	0900 to 1000	26	30.39	28.24	28.81	28.98	28.68	27.35	27.57	27.58	27.50	26.67	26.67	26.90	26.75

Table A-16 (b): 24 hr. cube temperature values (measured and calculated) for Mix C for 24 hr. cloudy and humid condition at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (^oC) at 10 cm				Temperature (^oC) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1000 to 1100	27.91	27.89	27.63	27.81	27.36	27.22	27.51	27.36
2	1100 to 1200	29.91	29.85	29.13	29.63	29.21	28.77	29.79	29.26
3	1200 to 1300	31.91	31.81	31.18	31.63	31.08	30.32	31.82	31.08
4	1300 to 1400	33.24	33.25	33.06	33.18	32.53	31.75	32.33	32.20
5	1400 to 1500	33.39	33.15	33.40	33.31	32.94	31.77	32.38	32.36
6	1500 to 1600	32.96	32.38	32.33	32.56	32.74	30.95	32.76	32.15
7	1600 to 1700	32.23	31.69	32.73	32.22	32.19	30.58	32.42	31.73
8	1700 to 1800	31.40	30.69	31.36	31.15	31.45	29.60	31.21	30.75
9	1800 to 1900	30.54	29.73	30.97	30.41	30.67	28.63	30.98	30.10
10	1900 to 2000	29.67	28.71	29.91	29.43	29.88	27.61	29.95	29.14
11	2000 to 2100	28.95	27.72	28.85	28.51	29.15	26.19	28.92	28.09
12	2100 to 2200	28.27	27.14	28.88	28.10	28.53	25.86	28.93	27.78
13	2200 to 2300	27.53	26.30	27.85	27.23	27.85	24.95	27.91	26.90
14	2300 to 0000	27.02	25.94	26.85	26.60	27.29	24.74	26.91	26.32
15	0000 to 0100	26.55	25.51	26.90	26.32	26.85	24.50	26.94	26.10
16	0100 to 0200	26.07	24.86	25.88	25.61	26.41	23.70	25.93	25.35
17	0200 to 0300	25.68	24.57	25.89	25.38	26.01	23.52	25.94	25.15
18	0300 to 0400	25.35	24.39	25.89	25.21	25.67	23.41	25.94	25.01
19	0400 to 0500	25.22	24.06	25.84	25.04	25.48	22.78	25.91	24.72
20	0500 to 0600	25.16	24.27	25.89	25.11	25.38	23.34	25.94	24.89
21	0600 to 0700	25.07	24.17	25.90	25.04	25.27	23.27	25.94	24.83
22	0700 to 0800	25.10	24.43	25.99	25.18	25.25	23.81	26.00	25.02
23	0800 to 0900	25.44	24.92	25.54	25.30	25.51	24.45	25.31	25.09
24	0900 to 1000	26.28	26.11	26.68	26.36	26.16	25.88	25.97	26.00

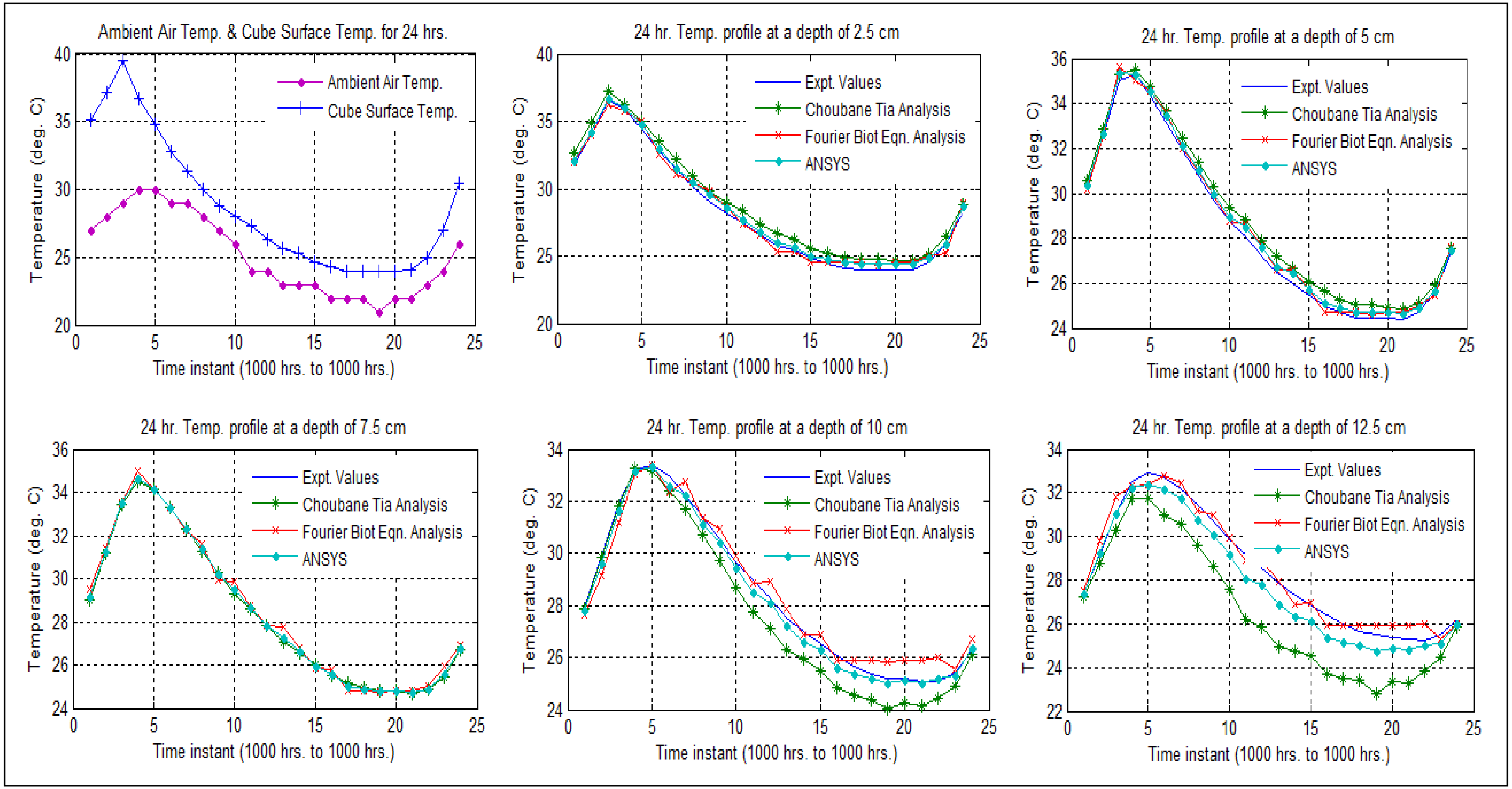


Fig. A-31: 24 hour cube temperature profile (measured and calculated) at various depths for Mix C for 24 hr. cloudy and humid condition

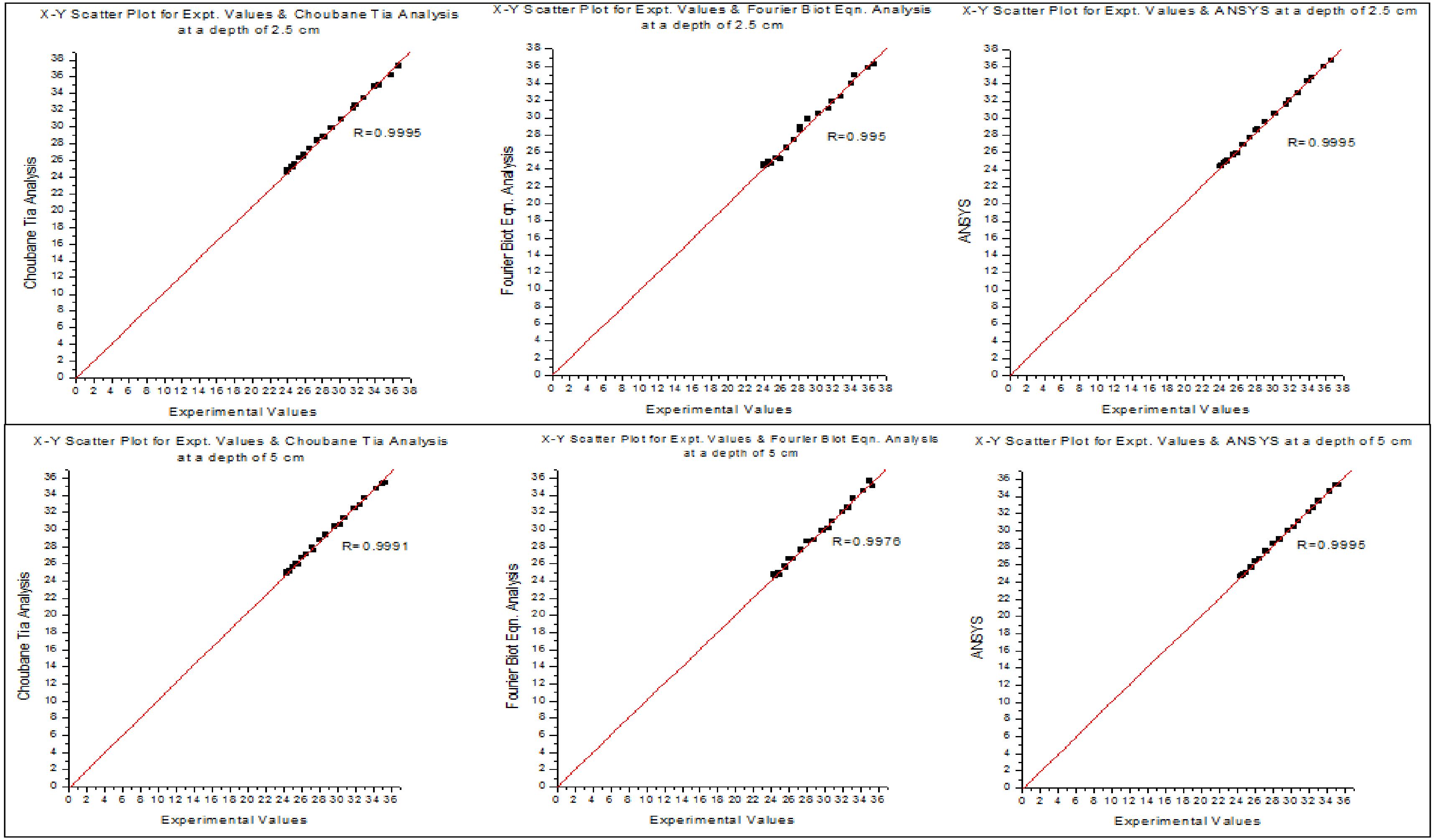


Fig. A-32 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

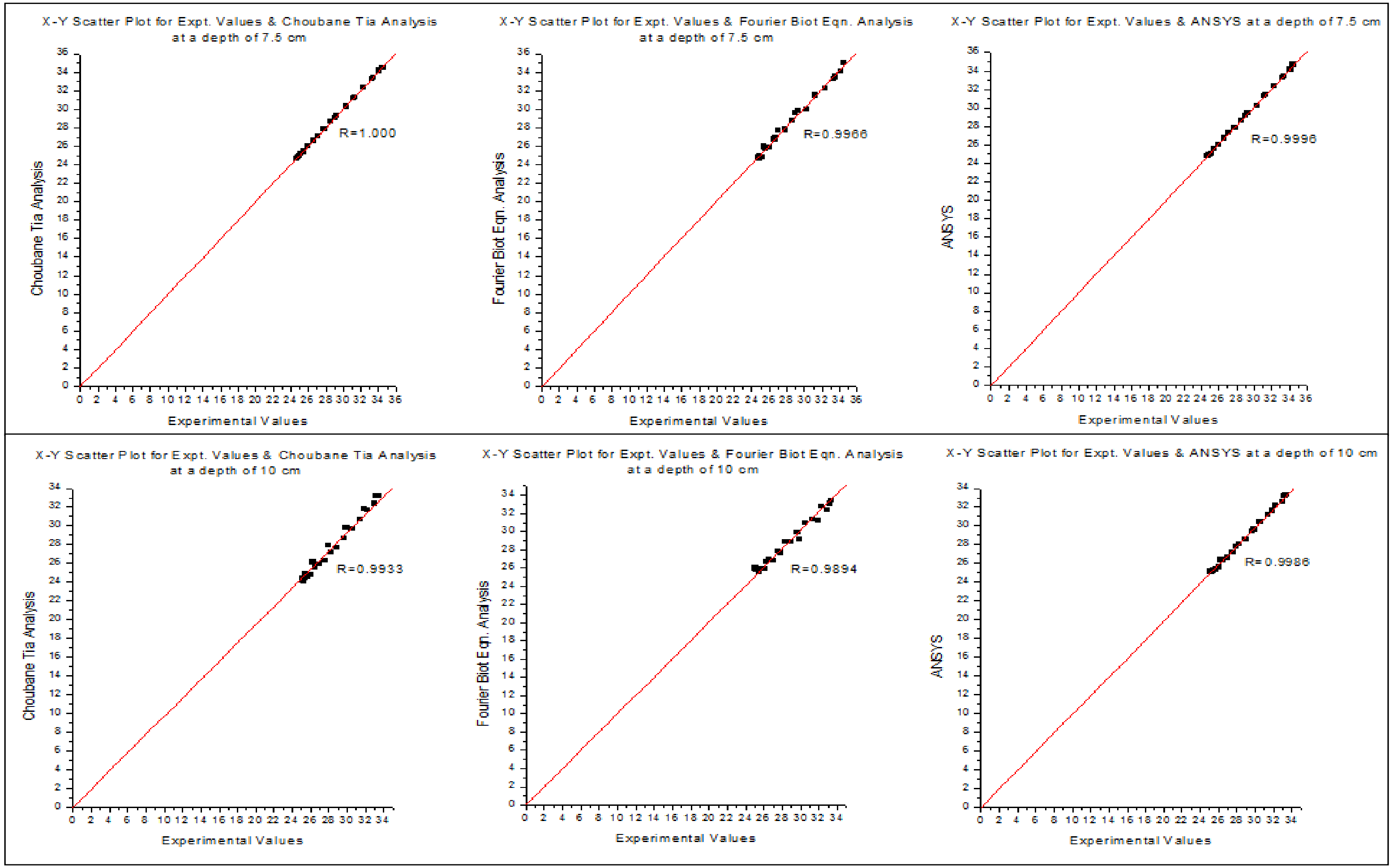


Fig. A-32 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

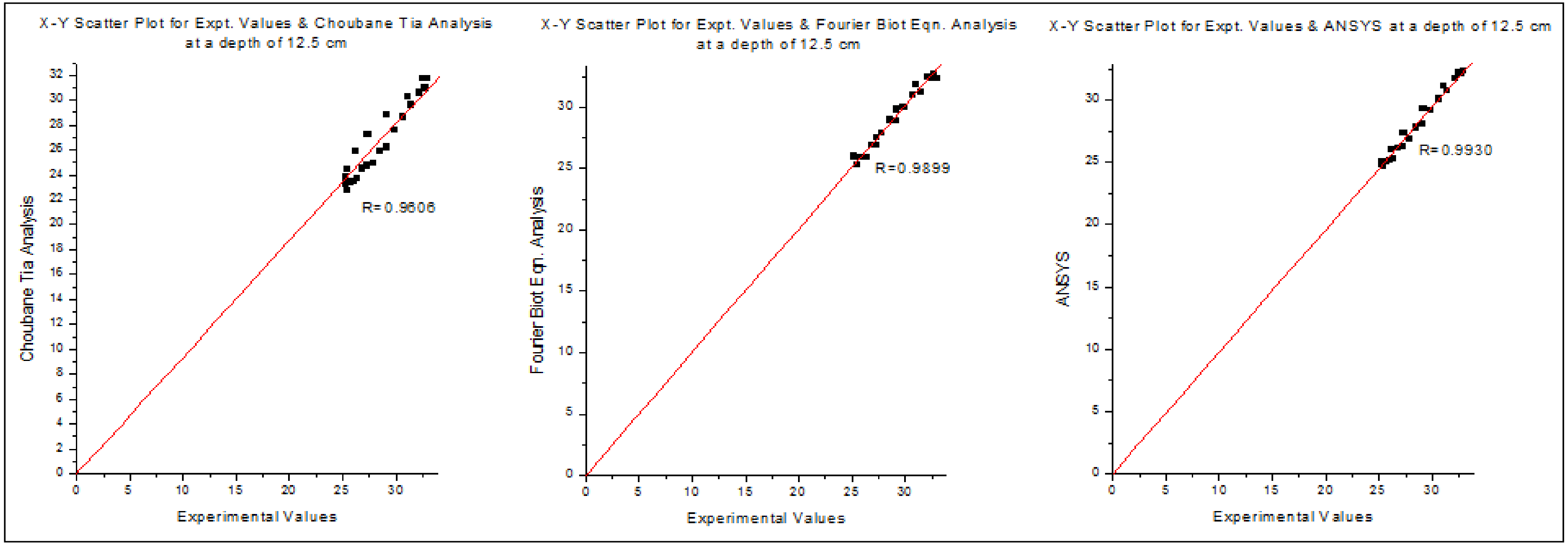


Fig. A-32 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

Table A-17(a): 24 hr. cube temperature values (measured and calculated) for Mix C for 2 hr. sudden precipitation at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Cube surface	Temperature (ºC) at 2.5 cm				Temperature (ºC) at 5 cm				Temperature (ºC) at 7.5 cm			
		(ºC)	(ºC)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1000 to 1100	28	28.75	26.40	26.75	26.88	26.68	25.46	25.50	25.11	25.36	25.00	25.00	24.77	24.92
2	1100 to 1200	29	31.67	29.54	29.55	29.43	29.51	28.39	28.09	28.79	28.42	27.31	27.31	27.83	27.48
3	1200 to 1300	30	33.80	31.63	31.62	31.32	31.52	30.34	30.06	30.40	30.27	29.12	29.12	28.95	29.06
4	1300 to 1400	30	34.67	32.92	32.97	33.06	32.98	31.82	31.64	31.54	31.67	30.68	30.68	30.67	30.68
5	1400 to 1500	30	33.74	32.65	32.74	32.95	32.78	31.94	31.89	31.81	31.88	31.19	31.19	31.21	31.20
6	1500 to 1600	30	32.15	31.70	31.77	31.24	31.57	31.39	31.41	31.03	31.28	31.04	31.04	31.09	31.06
7	1600 to 1700	29	31.35	31.18	31.28	31.02	31.16	31.01	31.09	30.61	30.90	30.76	30.76	29.92	30.48
8	1700 to 1800	29	27.33	28.14	28.31	28.33	28.26	29.02	29.01	29.50	29.17	29.43	29.43	29.21	29.35
9	1800 to 1900	28	23.83	24.18	24.66	24.49	24.44	25.32	25.43	25.98	25.58	26.15	26.15	26.62	26.31
10	1900 to 2000	27	23.34	23.49	23.81	23.72	23.67	24.27	24.33	24.48	24.36	24.91	24.91	24.30	24.71
11	2000 to 2100	26	23.13	23.28	23.49	23.74	23.50	23.81	23.89	23.49	23.73	24.35	24.35	24.31	24.33
12	2100 to 2200	26	22.97	23.16	23.23	23.80	23.40	23.61	23.59	23.53	23.57	24.05	24.05	24.33	24.14
13	2200 to 2300	26	22.70	22.92	22.93	22.85	22.90	23.36	23.28	23.56	23.40	23.77	23.77	23.35	23.63
14	2300 to 0000	25	22.60	22.77	22.83	22.45	22.68	23.18	23.13	23.29	23.20	23.50	23.50	23.19	23.40
15	0000 to 0100	24	22.59	22.74	22.88	22.23	22.62	23.12	23.14	23.15	23.14	23.38	23.38	23.10	23.29
16	0100 to 0200	24	22.42	22.61	22.74	22.33	22.56	23.02	23.03	23.22	23.09	23.30	23.30	23.14	23.25
17	0200 to 0300	24	22.20	22.41	22.54	22.42	22.46	22.83	22.87	22.28	22.66	23.18	23.18	23.18	23.18
18	0300 to 0400	23	22.03	22.22	22.47	22.19	22.29	22.67	22.80	22.13	22.53	23.02	23.02	23.08	23.04
19	0400 to 0500	23	21.96	22.12	22.34	22.21	22.22	22.51	22.64	22.14	22.43	22.85	22.85	22.09	22.60
20	0500 to 0600	23	21.76	21.93	22.14	21.27	21.78	22.36	22.45	22.18	22.33	22.70	22.70	22.11	22.50
21	0600 to 0700	23	21.56	21.68	21.88	21.30	21.62	22.06	22.17	22.20	22.14	22.43	22.43	22.13	22.33
22	0700 to 0800	24	22.60	22.18	22.33	22.96	22.49	22.27	22.27	22.63	22.39	22.40	22.40	22.40	22.40
23	0800 to 0900	24	25.35	24.07	24.45	24.20	24.24	23.74	23.82	23.75	23.77	23.46	23.46	23.74	23.55
24	0900 to 1000	26	26.10	25.11	25.27	25.37	25.25	24.86	24.77	24.15	24.59	24.59	24.59	24.89	24.69

Table A-17 (b): 24 hr. cube temperature values (measured and calculated) for Mix C for 2 hr. sudden precipitation at 10 cm & 12.5 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1000 to 1100	24.81	25.25	24.35	24.80	24.83	26.25	24.92	25.33
2	1100 to 1200	26.47	27.20	26.96	26.88	26.06	27.76	26.27	26.70
3	1200 to 1300	28.01	28.79	28.45	28.42	27.47	29.09	27.98	28.18
4	1300 to 1400	29.43	30.08	29.87	29.80	28.83	29.86	28.22	28.97
5	1400 to 1500	30.16	30.64	30.61	30.47	29.66	30.24	29.07	29.66
6	1500 to 1600	30.31	30.69	30.95	30.65	29.93	30.34	29.69	29.99
7	1600 to 1700	30.14	30.30	30.69	30.38	29.86	29.72	29.97	29.85
8	1700 to 1800	29.35	29.56	29.28	29.40	29.27	29.42	29.74	29.48
9	1800 to 1900	26.80	26.82	26.36	26.66	27.20	27.43	27.21	27.28
10	1900 to 2000	25.56	25.55	25.17	25.43	26.01	26.25	26.10	26.12
11	2000 to 2100	24.94	24.85	24.18	24.66	25.28	25.40	25.10	25.26
12	2100 to 2200	24.60	24.60	24.19	24.47	24.94	25.25	24.11	24.77
13	2200 to 2300	24.32	24.39	24.20	24.30	24.64	25.13	24.12	24.63
14	2300 to 0000	24.04	23.94	24.11	24.03	24.36	24.44	24.06	24.28
15	0000 to 0100	23.86	23.61	24.06	23.84	24.15	23.81	24.03	24.00
16	0100 to 0200	23.71	23.56	23.08	23.45	23.98	23.79	23.05	23.60
17	0200 to 0300	23.55	23.47	23.10	23.37	23.80	23.74	23.06	23.53
18	0300 to 0400	23.42	23.12	23.05	23.20	23.65	23.12	23.03	23.26
19	0400 to 0500	23.28	22.98	23.05	23.10	23.48	23.03	23.03	23.18
20	0500 to 0600	23.11	22.87	23.07	23.01	23.33	22.97	23.04	23.11
21	0600 to 0700	22.88	22.65	22.07	22.53	23.15	22.84	23.04	23.01
22	0700 to 0800	22.74	22.73	22.23	22.57	22.95	23.27	22.13	22.78
23	0800 to 0900	23.43	23.37	23.01	23.27	23.49	23.55	23.58	23.54
24	0900 to 1000	24.36	24.74	24.26	24.45	24.25	25.21	24.30	24.58

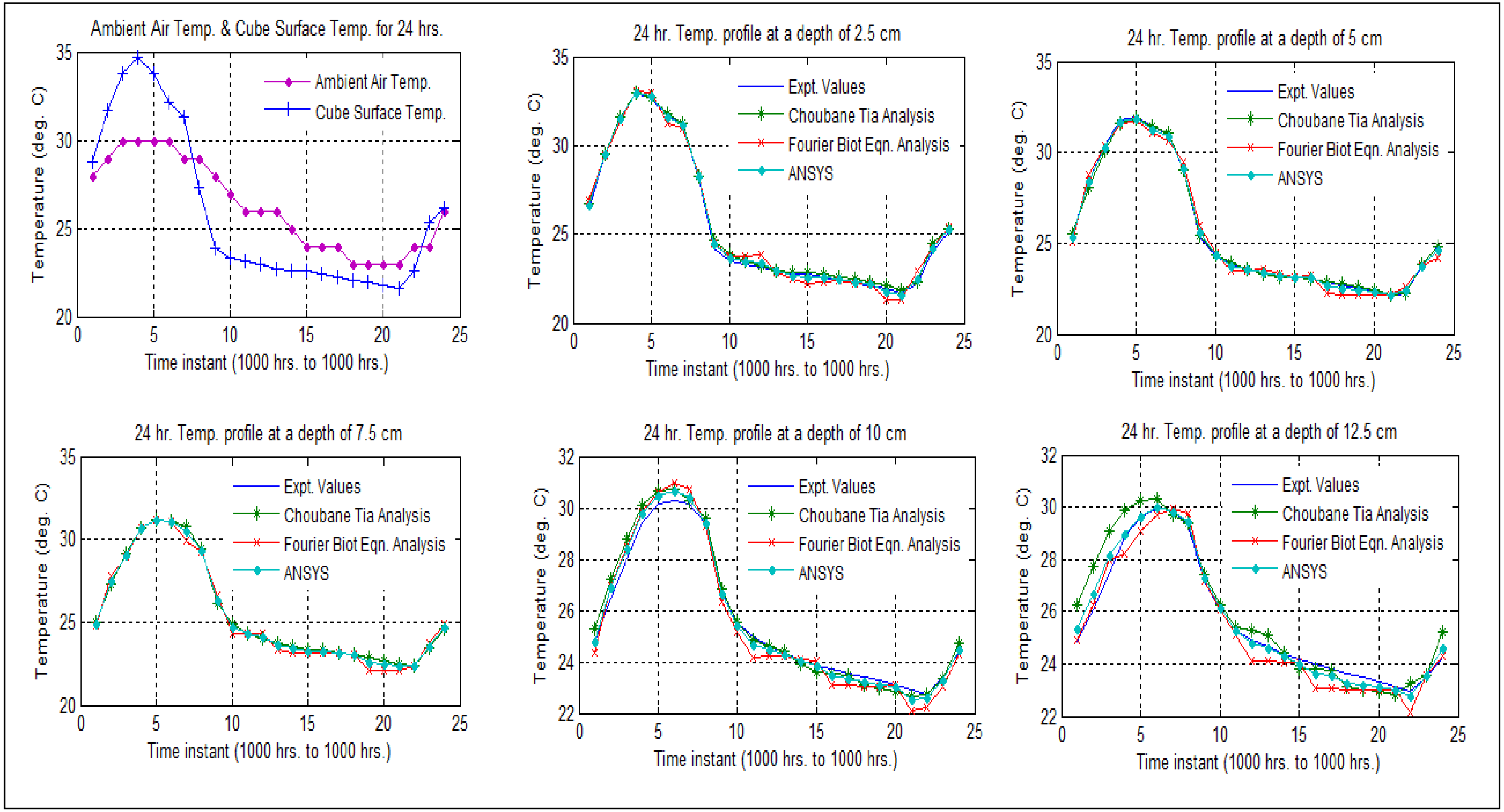


Fig. A-33: 24 hour cube temperature profile (measured and calculated) at various depths for Mix C for 2 hr. sudden precipitation

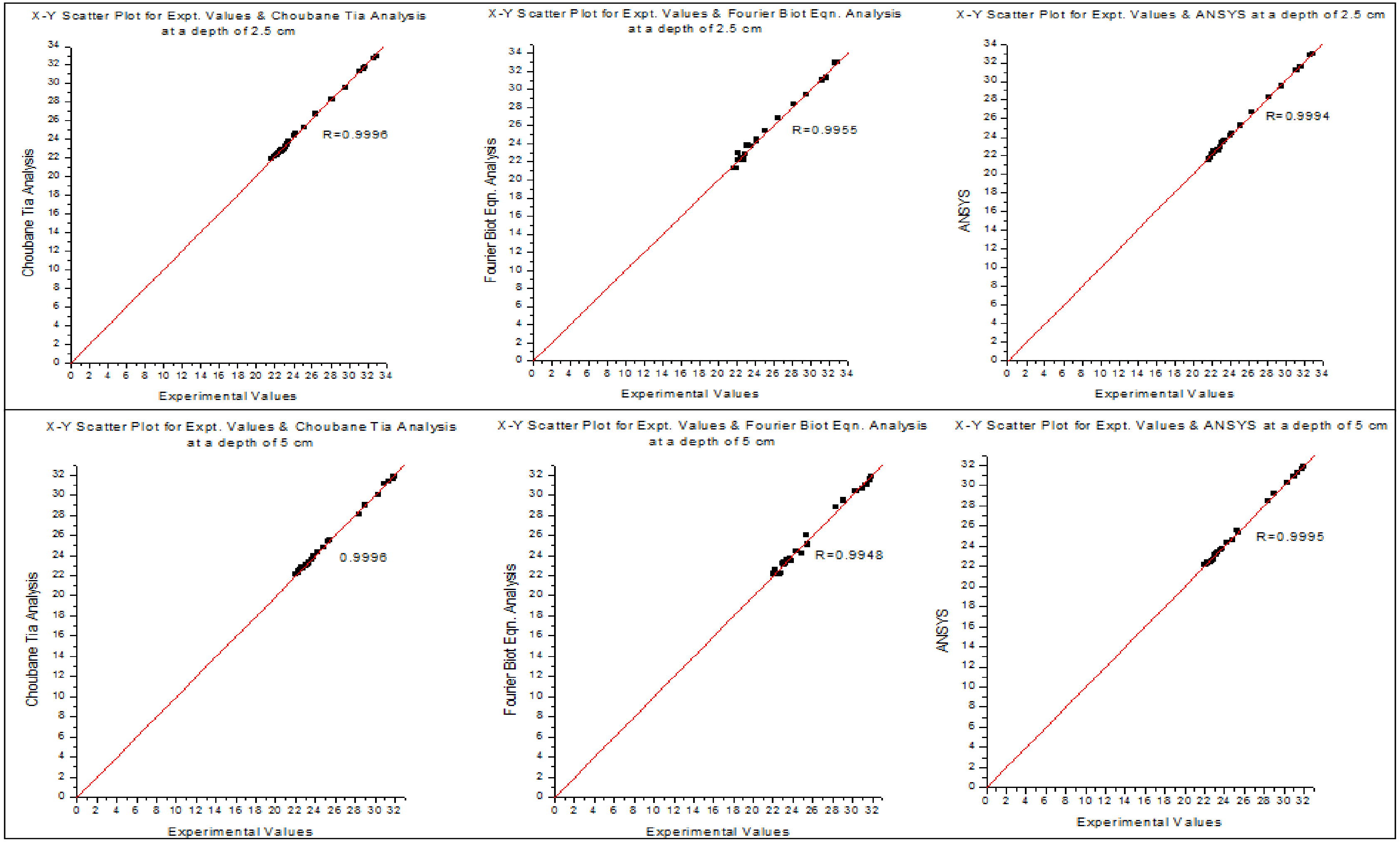


Fig. A-34 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

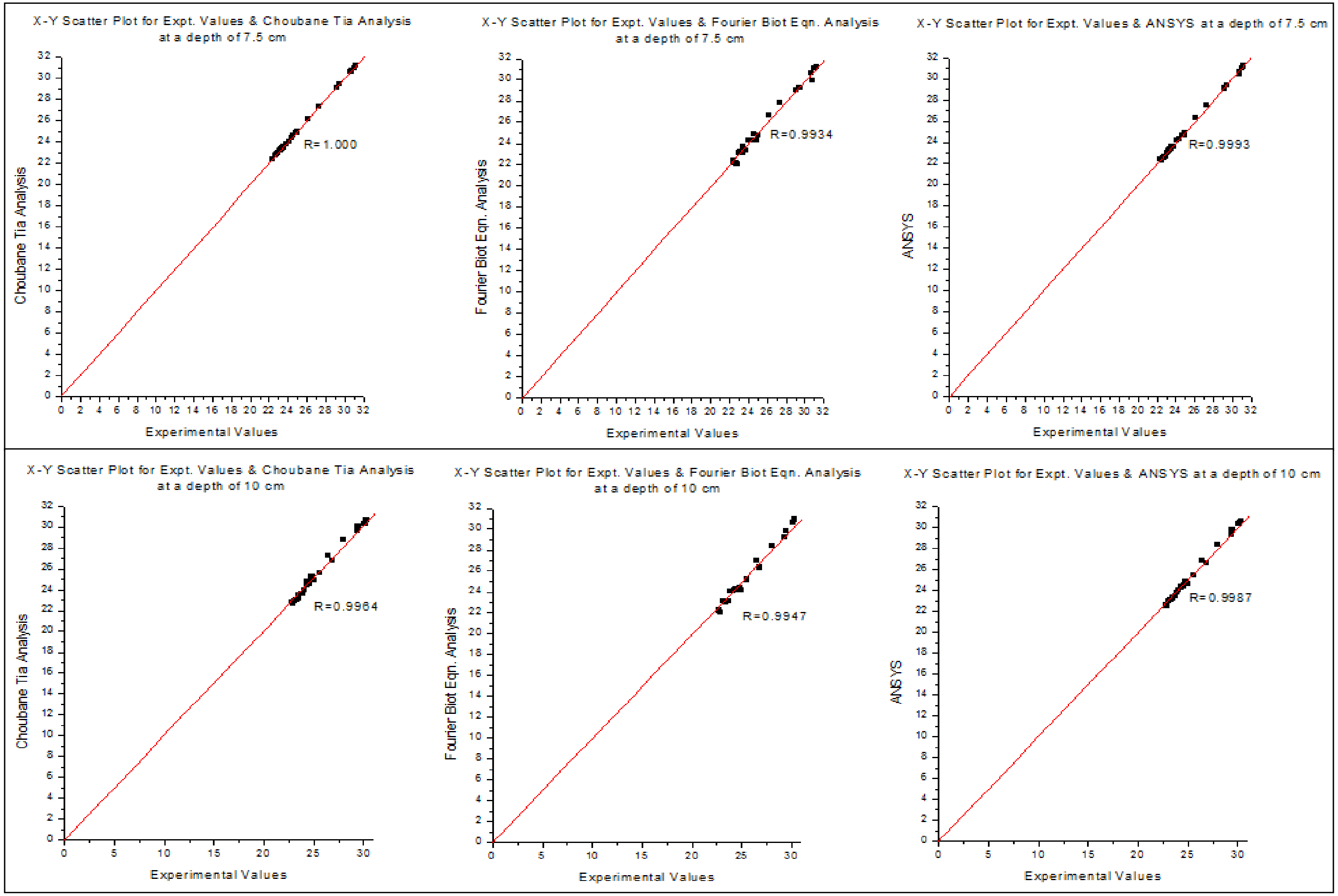


Fig. A-34 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

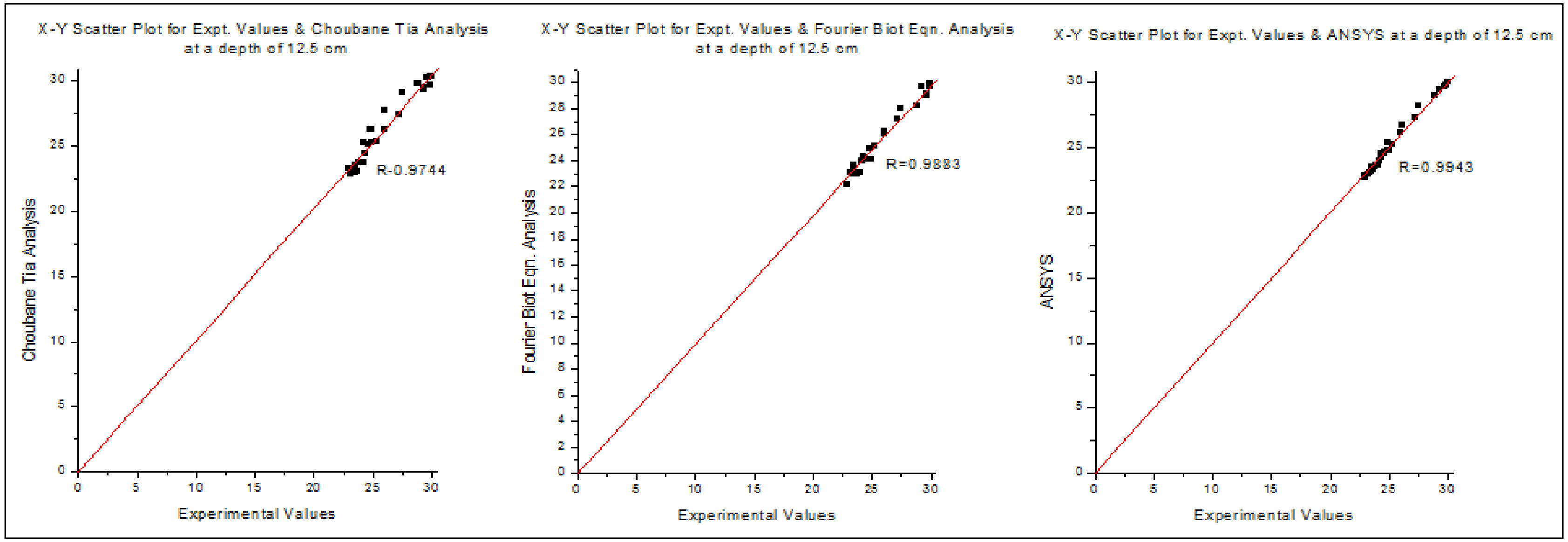


Fig. A-34 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm

APPENDIX B

Observations Tables and Graphs for Temperature values measured and computed at different depths in slab section

Table B-1 (a): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for minimum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	27	34.46	30.59	32.31	30.52	30.56	29.17	30.37	29.22	29.19	27.23	28.64	27.31	27.27
2	1200 to 1300	29	38.22	34.02	35.77	34.08	34.05	32.73	33.54	32.80	32.76	30.38	31.53	30.57	30.47
3	1300 to 1400	31	39.95	36.29	37.63	36.38	36.33	35.22	35.48	35.31	35.26	32.79	33.51	32.86	32.82
4	1400 to 1500	32	40.65	37.89	38.56	37.93	37.91	36.51	36.60	36.60	36.55	34.22	34.78	34.29	34.25
5	1500 to 1600	32	39.62	39.80	38.04	39.35	39.58	37.64	36.52	37.73	37.69	35.36	35.07	35.45	35.41
6	1600 to 1700	32	36.48	39.27	35.73	39.35	39.31	37.25	34.95	37.33	37.29	35.43	34.16	35.50	35.47
7	1700 to 1800	31	32.38	35.47	32.45	35.56	35.51	35.13	32.42	35.18	35.16	34.23	32.31	34.31	34.27
8	1800 to 1900	29	28.52	30.64	29.15	30.74	30.69	31.47	29.66	31.47	31.47	31.66	30.04	31.71	31.68
9	1900 to 2000	27	26.88	27.79	27.49	27.84	27.82	28.59	28.00	28.66	28.63	29.19	28.42	29.25	29.22
10	2000 to 2100	26	25.51	25.96	26.10	26.04	26.00	26.64	26.62	26.70	26.67	27.33	27.07	27.39	27.36
11	2100 to 2200	25	24.35	24.57	24.93	24.65	24.61	25.11	25.44	25.10	25.11	25.82	25.90	25.87	25.85
12	2200 to 2300	24	23.41	23.49	23.96	23.54	23.51	23.92	24.47	24.00	23.96	24.64	24.94	24.70	24.67
13	2300 to 0000	23	22.52	22.57	23.06	22.64	22.60	22.94	23.56	23.00	22.97	23.60	24.03	23.67	23.64
14	0000 to 0100	23	21.76	21.73	22.30	21.79	21.76	22.04	22.80	22.10	22.07	22.74	23.27	22.80	22.77
15	0100 to 0200	22	21.05	21.07	21.57	21.13	21.10	21.33	22.07	21.39	21.36	21.94	22.54	22.01	21.98
16	0200 to 0300	21	20.39	20.36	20.92	20.45	20.40	20.60	21.42	20.68	20.64	21.30	21.90	21.37	21.33
17	0300 to 0400	21	19.74	19.81	20.27	19.88	19.84	19.97	20.78	20.02	20.00	20.61	21.27	20.68	20.64
18	0400 to 0500	20	19.21	19.25	19.72	19.32	19.28	19.41	20.21	19.48	19.44	20.04	20.69	20.09	20.06
19	0500 to 0600	19	18.68	18.75	19.19	18.84	18.80	18.86	19.70	18.93	18.90	19.55	20.18	19.63	19.59
20	0600 to 0700	19	18.21	18.34	18.71	18.42	18.38	18.41	19.20	18.47	18.44	19.01	19.69	19.07	19.04
21	0700 to 0800	19	18.93	18.48	19.17	18.56	18.52	18.34	19.43	18.41	18.37	18.78	19.71	18.85	18.81
22	0800 to 0900	21	20.72	19.89	20.61	19.95	19.92	19.39	20.55	19.46	19.43	19.54	20.54	19.62	19.58
23	0900 to 1000	22	25.43	23.20	24.45	23.25	23.23	21.95	23.61	22.01	21.98	21.36	22.90	21.44	21.40
24	1000 to 1100	25	28.75	26.35	27.29	26.44	26.39	24.82	26.00	24.88	24.85	23.50	24.88	23.59	23.54

Table B-1 (b): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for minimum ambient air temperature at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	26.14	27.13	26.30	26.22	24.97	25.83	25.04	25.00	24.75	24.75	24.82	24.79
2	1200 to 1300	28.94	29.73	29.02	28.98	27.23	28.15	27.28	27.26	26.79	26.79	26.85	26.82
3	1300 to 1400	31.28	31.72	31.40	31.34	29.29	30.10	29.49	29.39	28.66	28.66	28.72	28.69
4	1400 to 1500	32.82	33.09	32.89	32.85	30.82	31.54	30.90	30.86	30.12	30.12	30.20	30.16
5	1500 to 1600	33.92	33.69	34.00	33.96	31.97	32.39	32.04	32.00	31.15	31.15	31.22	31.19
6	1600 to 1700	34.13	33.35	34.22	34.17	32.48	32.52	32.55	32.52	31.67	31.67	31.75	31.71
7	1700 to 1800	33.32	32.09	33.40	33.36	32.16	31.79	32.22	32.19	31.40	31.40	31.48	31.44
8	1800 to 1900	31.65	30.29	31.63	31.64	31.00	30.41	31.09	31.05	30.40	30.40	30.48	30.44
9	1900 to 2000	29.80	28.74	29.85	29.82	29.59	28.96	29.67	29.63	29.09	29.09	29.16	29.13
10	2000 to 2100	28.26	27.44	28.32	28.29	28.34	27.73	28.42	28.38	27.95	27.95	28.01	27.98
11	2100 to 2200	26.93	26.30	27.01	26.97	27.20	26.65	27.29	27.25	26.93	26.93	27.02	26.97
12	2200 to 2300	25.80	25.35	25.86	25.83	26.24	25.72	26.30	26.27	26.04	26.04	26.11	26.08
13	2300 to 0000	24.82	24.45	24.88	24.85	25.32	24.84	25.39	25.35	25.20	25.20	25.27	25.23
14	0000 to 0100	23.94	23.72	24.01	23.98	24.56	24.12	24.64	24.60	24.50	24.50	24.57	24.54
15	0100 to 0200	23.21	22.99	23.27	23.24	23.82	23.41	23.90	23.86	23.81	23.81	23.87	23.84
16	0200 to 0300	22.51	22.36	22.57	22.54	23.19	22.80	23.23	23.21	23.22	23.22	23.28	23.25
17	0300 to 0400	21.81	21.74	21.88	21.85	22.56	22.19	22.63	22.59	22.62	22.62	22.67	22.64
18	0400 to 0500	21.28	21.16	21.36	21.32	21.95	21.61	22.02	21.99	22.05	22.05	22.08	22.06
19	0500 to 0600	20.71	20.66	20.77	20.74	21.48	21.12	20.81	21.14	21.56	21.56	21.63	21.60
20	0600 to 0700	20.17	20.16	20.22	20.19	20.94	20.62	21.00	20.97	21.07	21.07	21.12	21.10
21	0700 to 0800	19.92	20.01	20.02	19.97	20.54	20.33	20.62	20.58	20.68	20.68	20.73	20.70
22	0800 to 0900	20.22	20.58	20.31	20.27	20.67	20.68	20.73	20.70	20.83	20.83	20.88	20.86
23	0900 to 1000	21.45	22.33	21.52	21.48	21.46	21.89	21.52	21.49	21.59	21.59	21.63	21.61
24	1000 to 1100	23.02	23.94	23.09	23.06	22.54	23.17	22.62	22.58	22.57	22.57	22.62	22.60

Table B-1 (c): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for minimum ambient air temperature at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	24.09	23.88	24.08	24.08	23.86	23.22	23.92	23.89	24.33	22.78	24.34	24.33
2	1200 to 1300	25.44	25.64	25.51	25.48	25.13	24.71	25.22	25.18	25.98	24.00	26.04	26.01
3	1300 to 1400	26.81	27.39	26.88	26.85	26.41	26.30	26.44	26.43	27.47	25.38	27.52	27.50
4	1400 to 1500	28.00	28.83	28.07	28.04	27.50	27.68	27.55	27.52	28.69	26.66	28.76	28.72
5	1500 to 1600	28.96	29.98	29.04	29.00	28.48	28.89	28.55	28.52	29.55	27.86	29.62	29.59
6	1600 to 1700	29.59	30.80	29.67	29.63	28.99	29.91	29.05	29.02	30.02	29.00	30.11	30.06
7	1700 to 1800	29.76	30.91	29.85	29.80	29.18	30.33	29.26	29.22	29.94	29.66	30.00	29.97
8	1800 to 1900	29.28	30.27	29.35	29.31	28.85	30.01	28.91	28.88	29.23	29.62	29.31	29.27
9	1900 to 2000	28.58	29.12	28.64	28.61	28.23	29.06	28.30	28.27	28.39	28.89	28.46	28.42
10	2000 to 2100	27.77	28.10	27.83	27.80	27.51	28.17	27.58	27.54	27.46	28.16	27.52	27.49
11	2100 to 2200	27.02	27.15	27.01	27.01	26.85	27.32	26.91	26.88	26.67	27.43	26.74	26.71
12	2200 to 2300	26.35	26.32	26.41	26.38	26.18	26.54	26.22	26.20	25.88	26.72	25.92	25.90
13	2300 to 0000	25.63	25.51	25.71	25.67	25.49	25.79	25.56	25.53	25.15	26.03	25.22	25.18
14	0000 to 0100	25.03	24.85	25.02	25.02	24.93	25.16	25.01	24.97	24.54	25.44	24.61	24.57
15	0100 to 0200	24.47	24.18	24.51	24.49	24.38	24.52	24.46	24.42	23.90	24.84	23.97	23.94
16	0200 to 0300	23.89	23.61	23.95	23.92	23.81	23.98	23.88	23.85	23.35	24.32	23.41	23.38
17	0300 to 0400	23.37	23.03	23.42	23.39	23.33	23.42	23.39	23.36	22.85	23.79	22.91	22.88
18	0400 to 0500	22.91	22.47	22.97	22.94	22.88	22.88	22.94	22.91	22.33	23.28	22.39	22.36
19	0500 to 0600	22.42	22.00	22.48	22.45	22.39	22.42	22.44	22.41	21.82	22.82	21.90	21.86
20	0600 to 0700	21.92	21.51	22.00	21.96	21.89	21.94	21.95	21.92	21.41	22.36	21.47	21.44
21	0700 to 0800	21.57	21.04	21.64	21.60	21.58	21.43	21.65	21.62	21.06	21.84	21.13	21.10
22	0800 to 0900	21.57	21.04	21.62	21.60	21.58	21.30	21.65	21.61	21.19	21.61	21.26	21.22
23	0900 to 1000	21.99	21.42	22.06	22.02	21.93	21.39	22.00	21.97	21.73	21.49	21.80	21.76
24	1000 to 1100	22.68	22.15	22.63	22.65	22.59	21.90	22.66	22.63	22.55	21.82	22.61	22.58

Table B-1 (d): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for minimum ambient air temperature at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	25 cm				27.5 cm				30 cm				40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	24.75	22.56	24.81	24.78	26.64	22.54	26.71	26.67	22.74	22.74	22.82	22.78	23.19	23.19	23.25	23.22
2	1200 to 1300	26.71	23.50	26.77	26.74	28.72	23.23	28.80	28.76	23.17	23.17	23.21	23.19	23.70	23.70	23.78	23.74
3	1300 to 1400	28.29	24.64	28.36	28.32	29.83	24.07	29.90	29.86	23.68	23.68	23.72	23.70	24.38	24.38	24.45	24.41
4	1400 to 1500	29.26	25.77	29.34	29.30	29.93	25.02	30.00	29.97	24.40	24.40	24.44	24.42	25.13	25.13	25.19	25.16
5	1500 to 1600	29.95	26.90	30.02	29.99	30.12	26.02	30.20	30.16	25.20	25.20	25.24	25.22	26.05	26.05	26.11	26.08
6	1600 to 1700	30.27	28.08	30.36	30.31	30.00	27.14	30.04	30.02	26.17	26.17	26.21	26.19	26.98	26.98	27.04	27.01
7	1700 to 1800	30.06	28.90	30.06	30.06	29.43	28.05	29.50	29.47	27.10	27.10	27.16	27.13	27.67	27.67	27.72	27.69
8	1800 to 1900	29.24	29.10	29.30	29.27	28.36	28.46	28.43	28.40	27.69	27.69	27.72	27.71	27.90	27.90	27.96	27.93
9	1900 to 2000	28.26	28.63	28.31	28.28	27.22	28.28	27.29	27.26	27.83	27.83	27.88	27.85	27.72	27.72	27.79	27.75
10	2000 to 2100	27.26	28.08	27.32	27.29	26.35	27.92	26.41	26.38	27.69	27.69	27.75	27.72	27.36	27.36	27.42	27.39
11	2100 to 2200	26.45	27.48	26.51	26.48	25.52	27.47	25.60	25.56	27.40	27.40	27.48	27.44	26.97	26.97	27.03	27.00
12	2200 to 2300	25.63	26.85	25.70	25.66	24.84	26.94	24.91	24.87	26.97	26.97	27.04	27.01	26.54	26.54	26.61	26.58
13	2300 to 0000	24.93	26.23	25.00	24.96	24.17	26.40	24.22	24.19	26.53	26.53	26.59	26.56	26.04	26.04	26.11	26.08
14	0000 to 0100	24.27	25.69	24.33	24.30	23.53	25.91	23.60	23.57	26.09	26.09	26.14	26.12	25.55	25.55	25.61	25.58
15	0100 to 0200	23.63	25.13	23.70	23.67	23.04	25.40	23.12	23.08	25.64	25.64	25.71	25.68	25.11	25.11	25.14	25.12
16	0200 to 0300	23.13	24.65	23.21	23.17	22.51	24.95	22.58	22.55	25.23	25.23	25.30	25.26	24.73	24.73	24.78	24.75
17	0300 to 0400	22.60	24.14	22.67	22.63	21.97	24.47	22.04	22.01	24.78	24.78	24.83	24.81	24.28	24.28	24.32	24.30
18	0400 to 0500	22.08	23.66	22.15	22.11	21.56	24.02	21.62	21.59	24.38	24.38	24.45	24.41	23.84	23.84	23.90	23.87
19	0500 to 0600	21.62	23.21	21.70	21.66	21.12	23.59	21.19	21.15	23.96	23.96	24.02	23.99	23.44	23.44	23.49	23.46
20	0600 to 0700	21.19	22.77	21.26	21.23	20.67	23.17	20.74	20.71	23.56	23.56	23.61	23.59	23.15	23.15	23.20	23.18
21	0700 to 0800	20.84	22.27	20.91	20.87	20.41	22.72	20.47	20.44	23.19	23.19	23.25	23.22	22.73	22.73	22.77	22.75
22	0800 to 0900	20.93	21.98	21.00	20.97	20.76	22.39	20.81	20.78	22.87	22.87	22.93	22.90	22.49	22.49	22.53	22.51
23	0900 to 1000	21.44	21.73	21.52	21.48	21.52	22.10	21.58	21.55	22.61	22.61	22.68	22.65	22.53	22.53	22.56	22.54
24	1000 to 1100	22.28	21.91	22.36	22.32	23.20	22.18	23.26	23.23	22.62	22.62	22.70	22.66	22.89	22.89	22.92	22.90

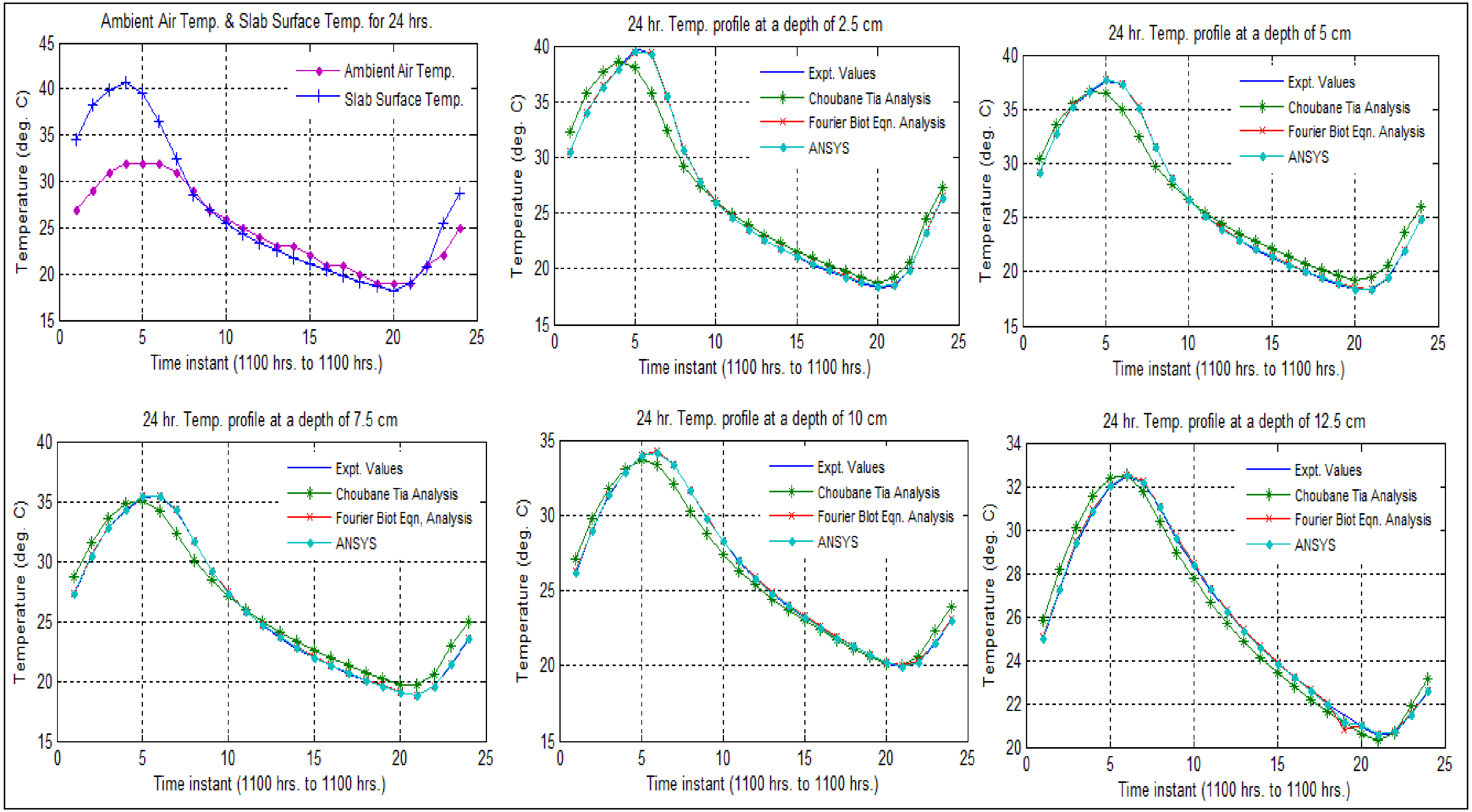


Fig. B-1 (a): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix A for minimum ambient air temperature (surface to 12.5 cm)

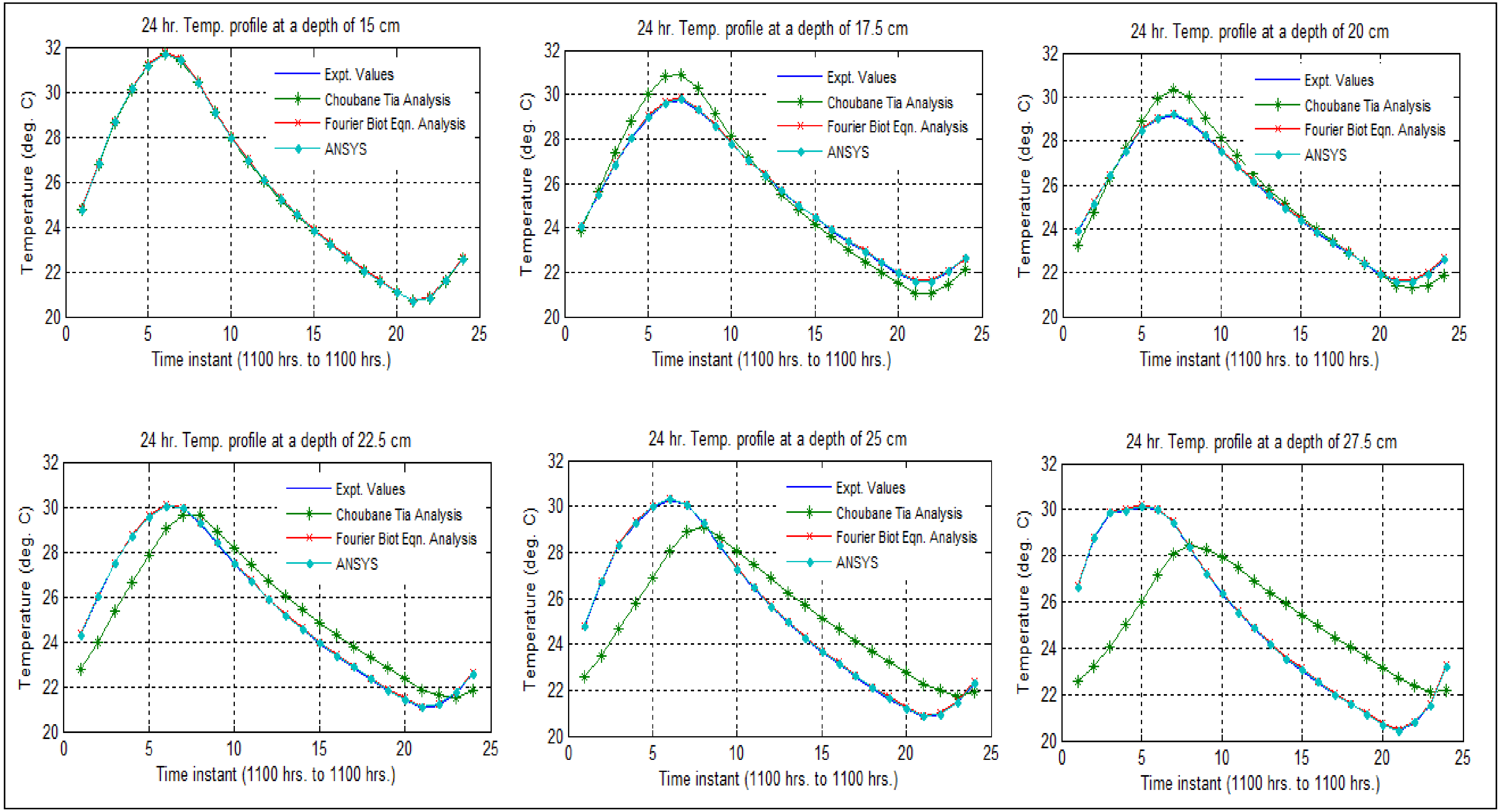


Fig. B-1 (b): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix A for minimum ambient air temperature (15 cm to 17.5 cm)

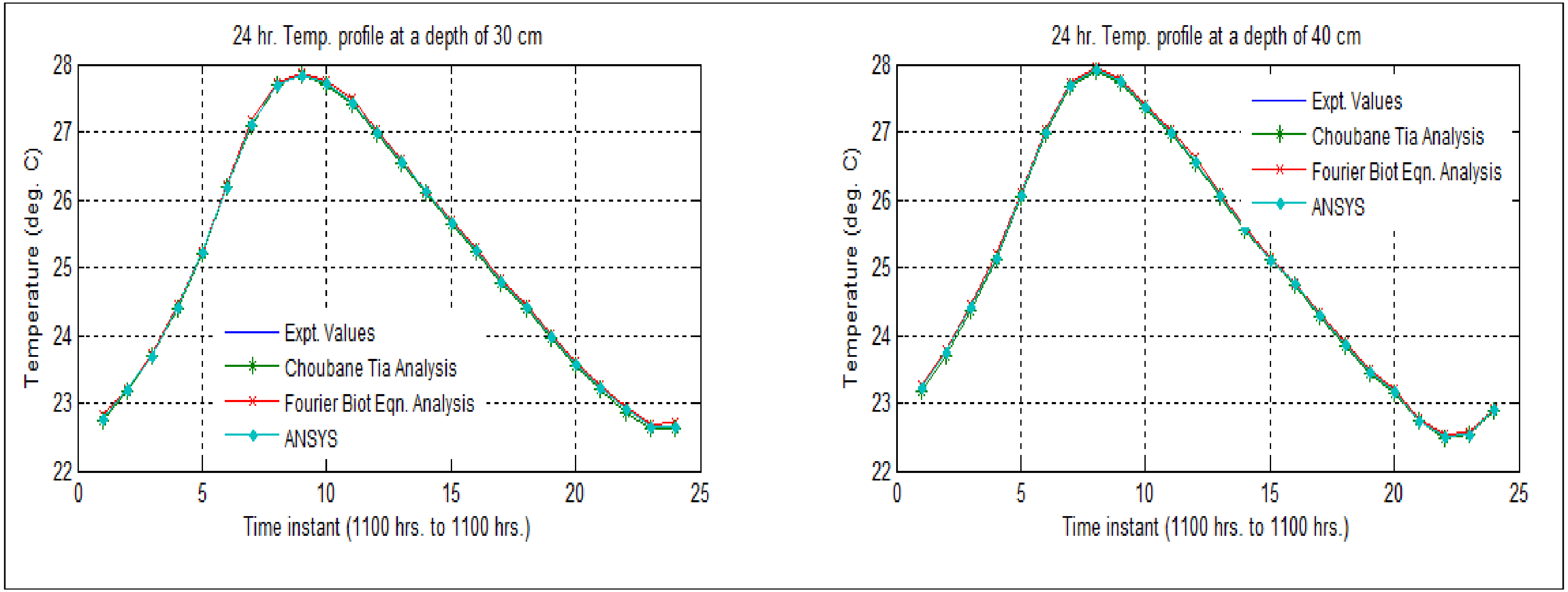


Fig. B-1 (c): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix A for minimum ambient air temperature (30 cm & 40 cm)

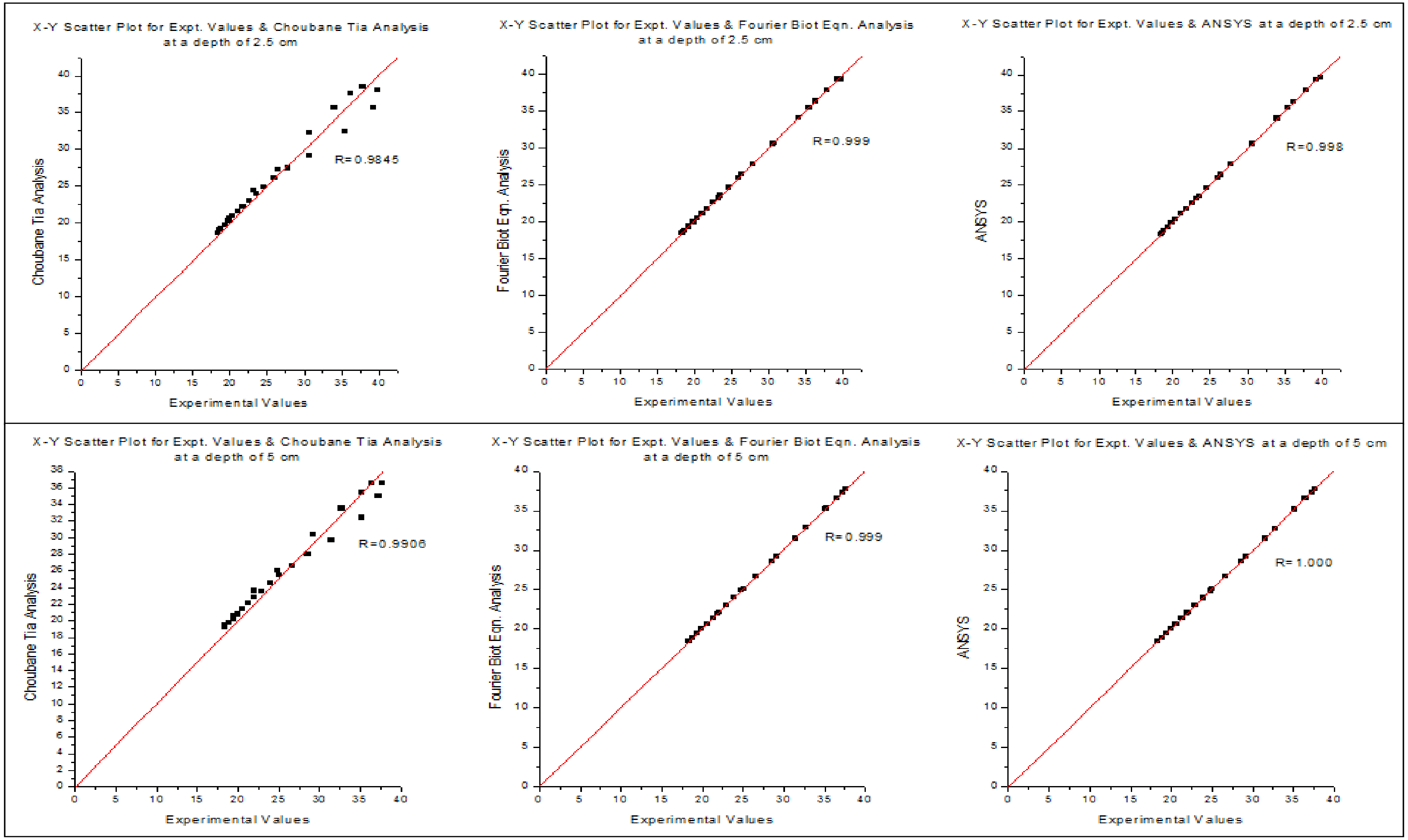


Fig. B-2 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

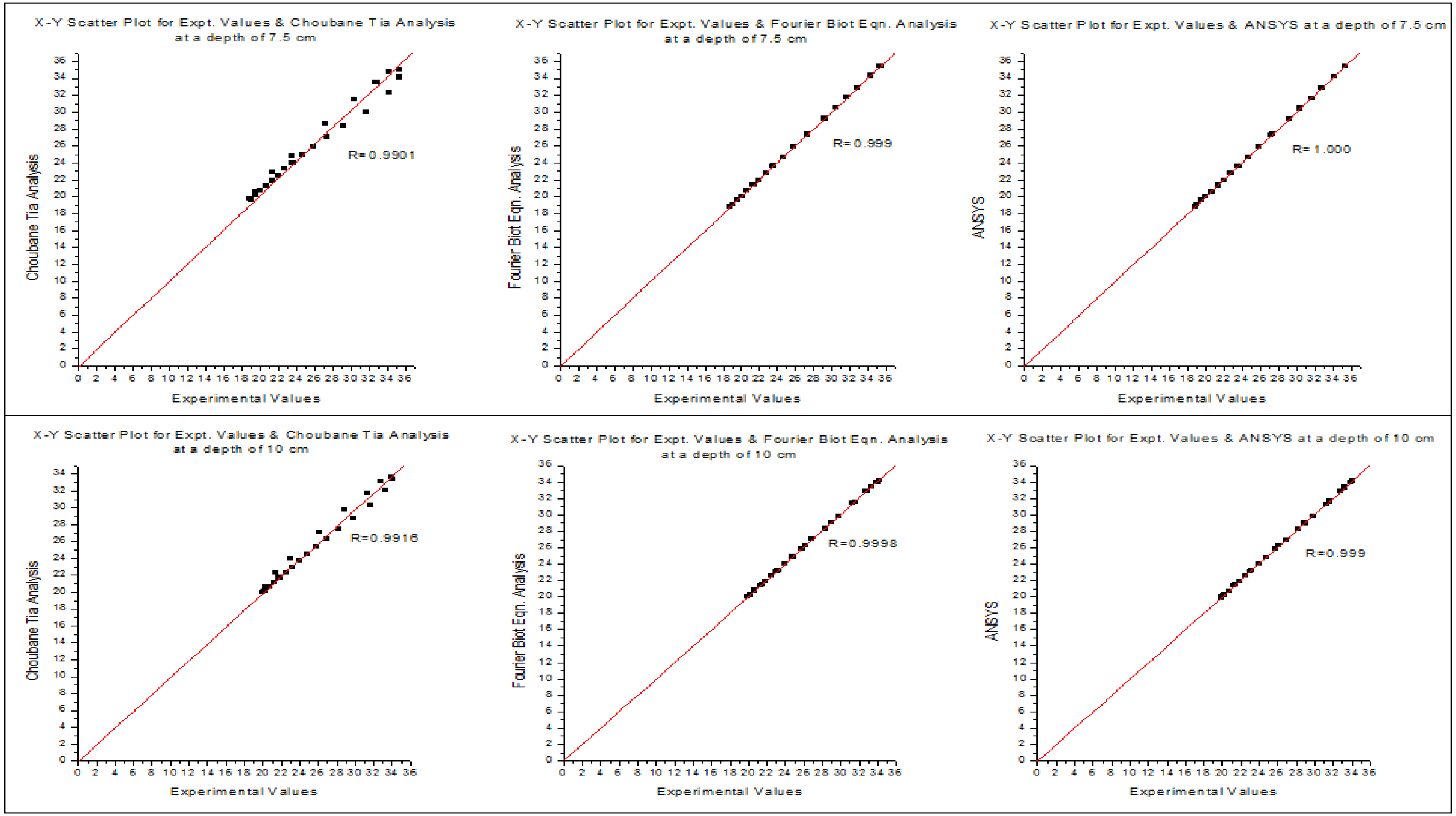


Fig. B-2 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

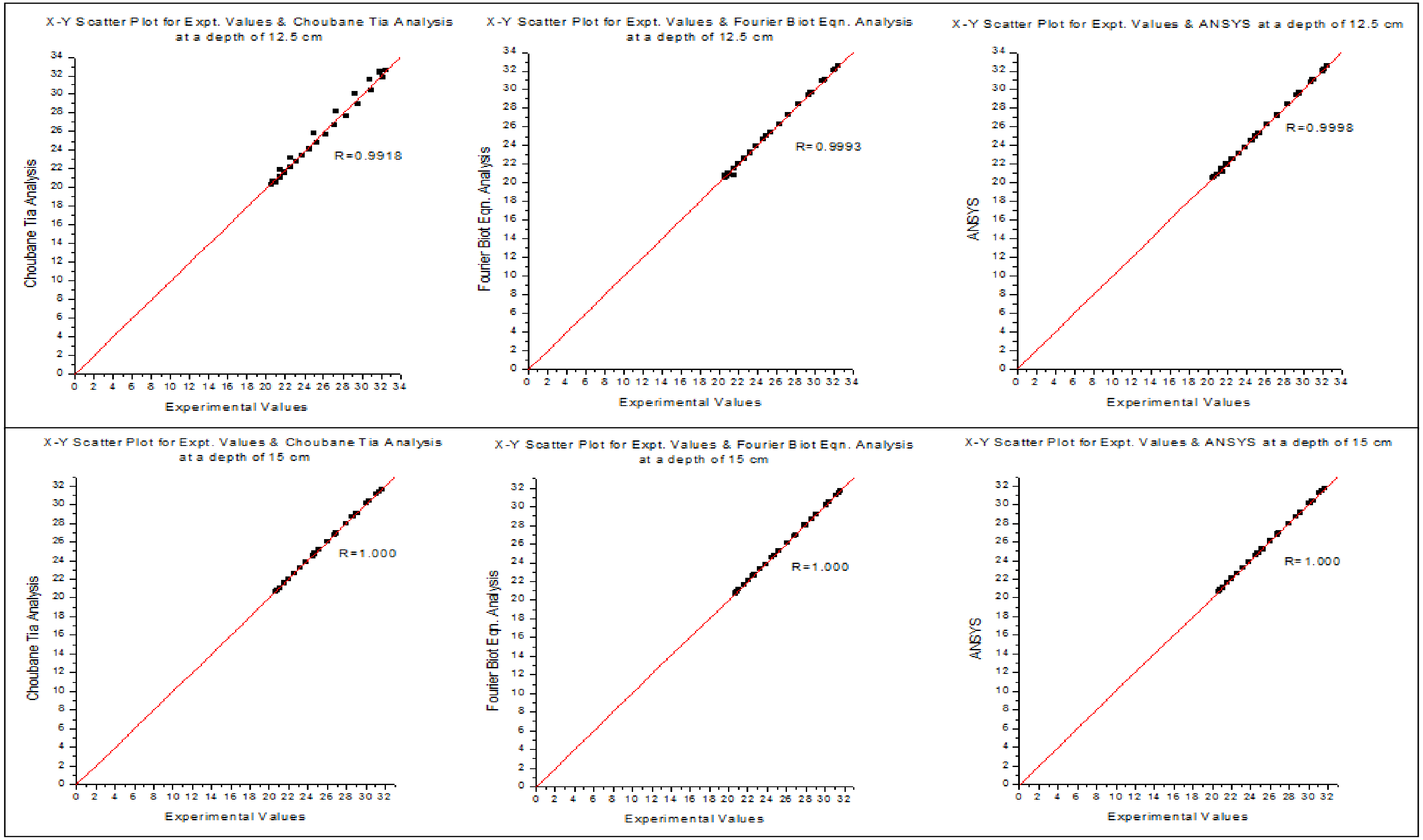


Fig. B-2 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

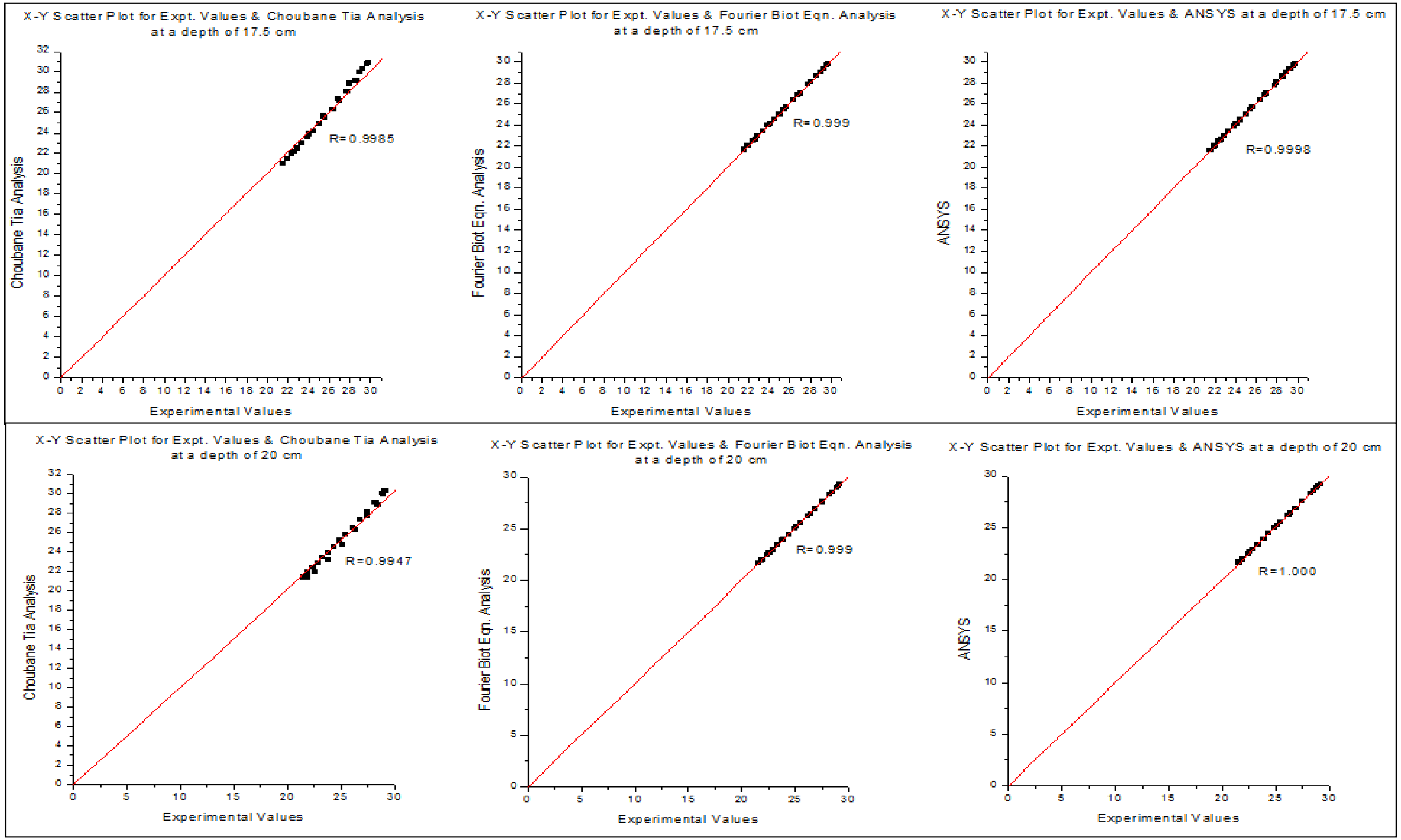


Fig. B-2 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

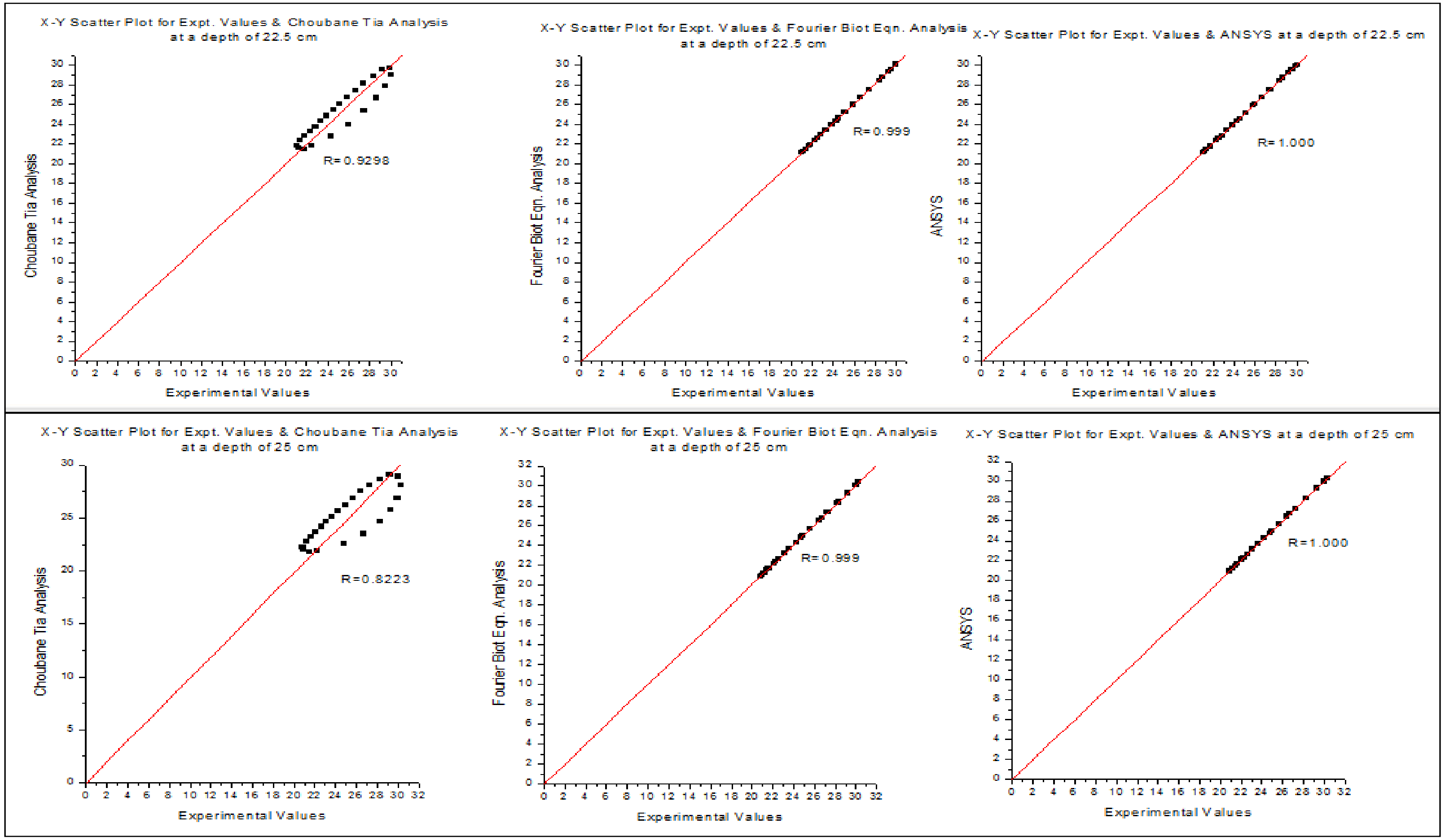


Fig. B-2 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

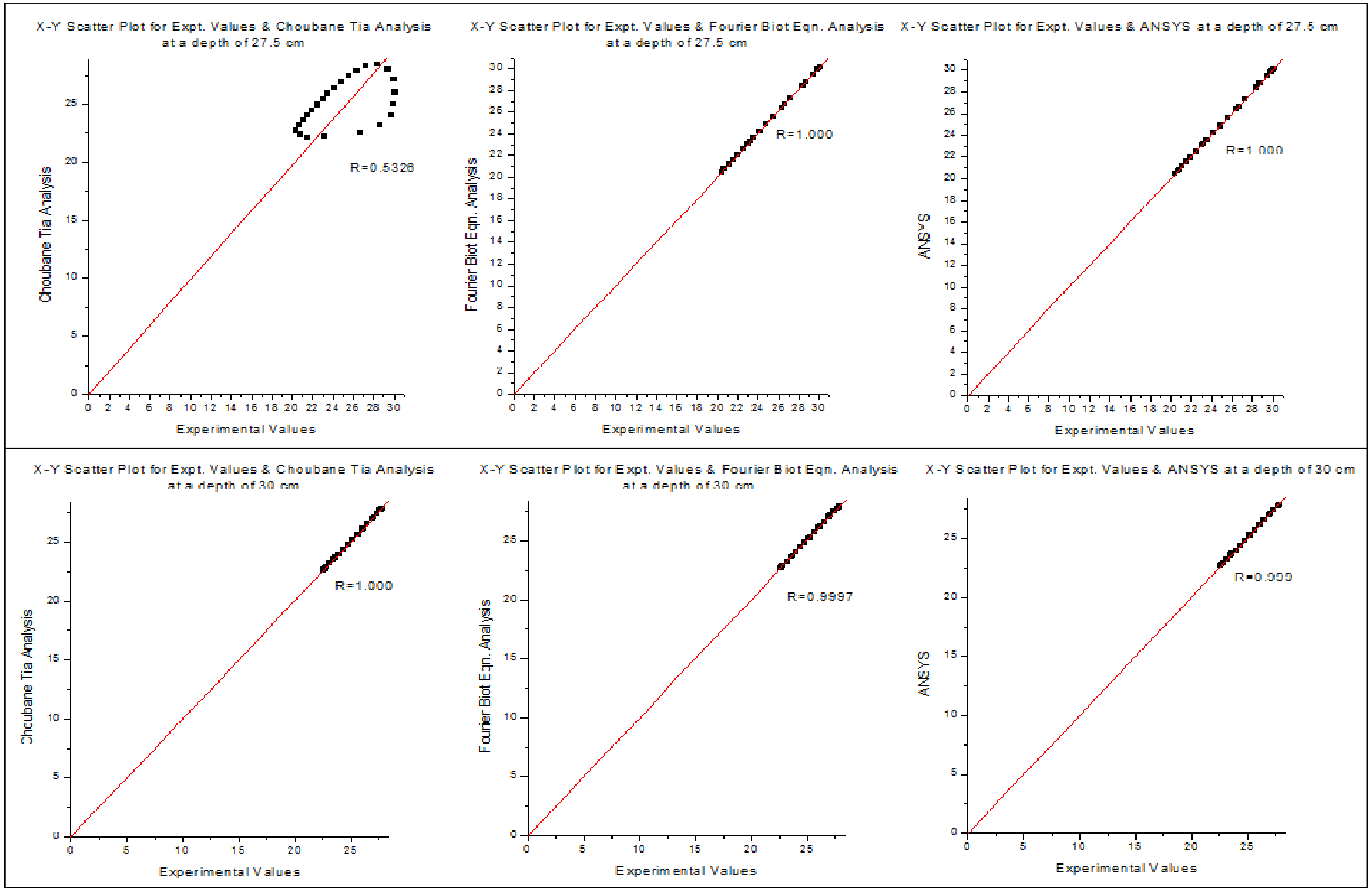


Fig. B-2 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

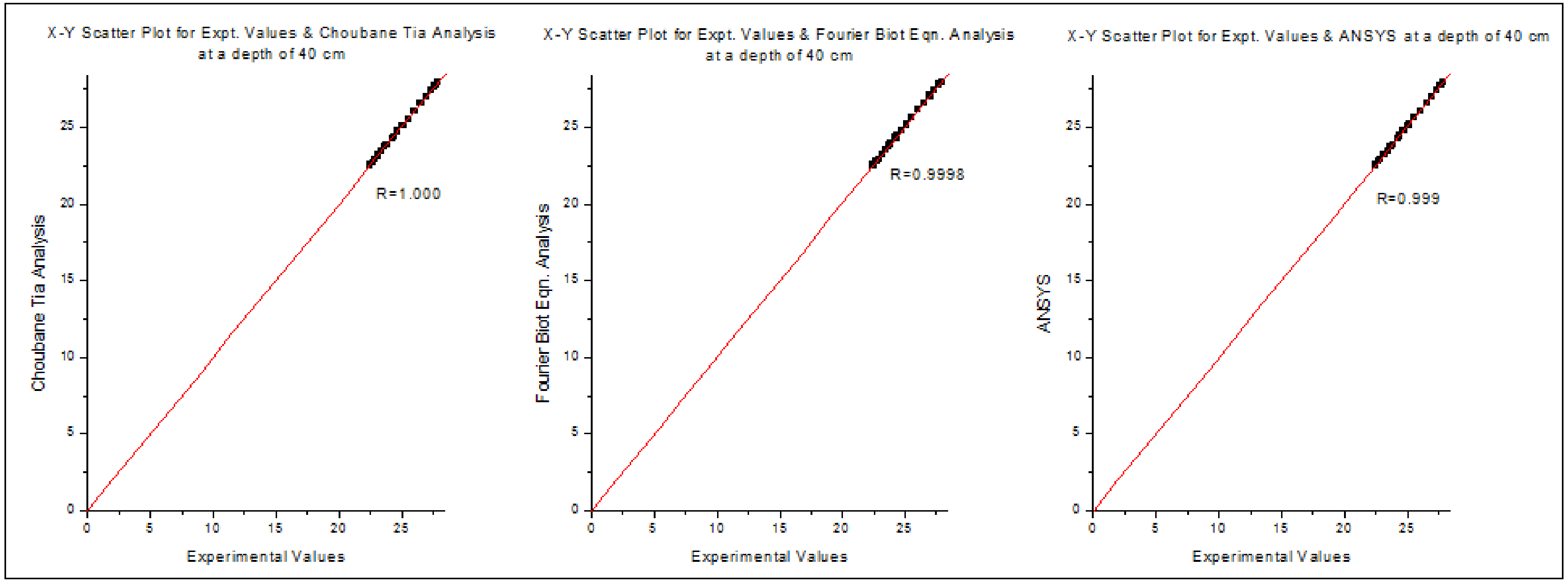


Fig. B-2 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-2 (a): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for minimum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	27	31.87	29.33	29.66	29.45	29.39	24.08	27.72	24.17	24.12	23.56	26.05	23.61	23.59
2	1130 to 1230	29	36.04	32.63	32.91	32.60	32.62	26.79	30.18	26.88	26.84	25.86	27.85	25.94	25.90
3	1230 to 1330	31	38.54	35.07	35.02	35.15	35.11	29.39	31.94	29.44	29.41	28.32	29.30	28.41	28.36
4	1330 to 1430	32	38.88	36.03	35.56	36.00	36.01	31.32	32.65	31.36	31.34	30.48	30.16	30.55	30.51
5	1430 to 1530	32	38.84	36.98	35.84	37.04	37.01	32.44	33.19	32.49	32.46	31.90	30.91	31.97	31.94
6	1530 to 1630	32	36.41	35.76	34.25	35.84	35.80	32.81	32.34	32.88	32.85	32.62	30.68	32.68	32.65
7	1630 to 1730	31	32.81	32.51	31.74	32.54	32.52	32.28	30.79	32.32	32.30	32.43	29.96	32.48	32.46
8	1730 to 1830	29	28.57	28.60	28.67	28.64	28.62	30.83	28.74	30.89	30.86	31.38	28.78	31.44	31.41
9	1830 to 1930	27	26.45	25.81	27.10	25.86	25.83	28.68	27.65	28.73	28.70	29.55	28.09	29.61	29.58
10	1930 to 2030	26	24.94	24.49	25.94	24.53	24.51	27.09	26.78	27.16	27.12	28.07	27.48	28.11	28.09
11	2030 to 2130	25	23.70	23.39	24.90	23.44	23.41	25.89	25.92	25.95	25.92	26.90	26.77	26.97	26.94
12	2130 to 2230	24	22.72	22.56	24.03	22.61	22.58	24.90	25.15	24.96	24.93	25.91	26.09	25.96	25.93
13	2230 to 2330	23	21.84	21.79	23.23	21.83	21.81	24.03	24.43	24.11	24.07	25.05	25.43	25.16	25.10
14	2330 to 0030	23	21.06	21.09	22.52	21.14	21.11	23.27	23.78	23.35	23.31	24.30	24.84	24.25	24.28
15	0030 to 0130	22	20.34	20.40	21.84	20.40	20.40	22.59	23.13	22.65	22.62	23.57	24.21	23.63	23.60
16	0130 to 0230	21	19.70	19.82	21.21	19.88	19.85	21.93	22.52	22.01	21.97	23.01	23.62	23.07	23.04
17	0230 to 0330	21	19.06	19.22	20.60	19.31	19.27	21.39	21.93	21.36	21.37	22.38	23.05	22.44	22.41
18	0330 to 0430	20	18.52	18.69	20.08	18.76	18.73	20.82	21.43	20.87	20.84	21.81	22.58	21.88	21.84
19	0430 to 0530	19	18.03	18.26	19.58	18.22	18.24	20.28	20.93	20.35	20.32	21.34	22.06	21.42	21.38
20	0530 to 0630	19	17.60	17.90	19.13	17.96	17.93	19.88	20.47	19.93	19.91	20.86	21.60	20.92	20.89
21	0630 to 0730	19	17.73	17.72	19.13	17.80	17.76	19.43	20.34	19.48	19.45	20.36	21.37	20.44	20.40
22	0730 to 0830	21	19.36	18.81	20.26	18..9	18.81	19.34	21.04	19.41	19.37	20.13	21.70	20.21	20.17
23	0830 to 0930	22	22.83	22.13	22.81	22.20	22.17	19.93	22.78	20.02	19.97	20.47	22.74	20.55	20.51
24	0930 to 1030	25	26.26	25.40	25.38	25.45	25.43	20.95	24.60	21.04	20.99	21.10	23.91	21.18	21.14

Table B-2 (b): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for minimum ambient air temperature at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (ºC) at 10 cm				Temperature (ºC) at 12.5 cm				Temperature (ºC) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	23.11	24.66	23.21	23.16	23.02	23.54	23.11	23.07	22.69	22.69	22.78	22.74
2	1130 to 1230	24.71	25.91	24.79	24.75	24.34	24.36	24.42	24.38	23.20	23.20	23.29	23.25
3	1230 to 1330	26.61	27.10	26.68	26.65	25.98	25.35	26.03	26.01	24.04	24.04	24.15	24.10
4	1330 to 1430	28.48	28.07	28.56	28.52	27.66	26.40	27.74	27.70	25.14	25.14	25.21	25.17
5	1430 to 1530	29.94	29.00	30.00	29.97	29.07	27.44	29.11	29.09	26.25	26.25	26.29	26.27
6	1530 to 1630	30.93	29.28	31.00	30.96	30.17	28.14	30.24	30.20	27.24	27.24	27.31	27.28
7	1630 to 1730	31.30	29.23	31.37	31.34	30.69	28.63	30.74	30.71	28.14	28.14	28.20	28.17
8	1730 to 1830	30.98	28.79	31.06	31.02	30.65	28.77	30.82	30.73	28.71	28.71	28.77	28.74
9	1830 to 1930	30.01	28.43	30.05	30.03	29.98	28.67	30.03	30.00	28.80	28.80	28.86	28.83
10	1930 to 2030	28.82	28.03	28.87	28.85	29.03	28.42	29.12	29.07	28.67	28.67	28.73	28.70
11	2030 to 2130	27.80	27.45	27.88	27.84	28.16	27.95	28.25	28.20	28.28	28.28	28.33	28.30
12	2130 to 2230	26.90	26.84	26.97	26.94	27.28	27.40	27.36	27.32	27.77	27.77	27.84	27.81
13	2230 to 2330	26.11	26.23	26.20	26.15	26.59	26.83	26.66	26.62	27.24	27.24	27.39	27.32
14	2330 to 0030	25.34	25.68	25.42	25.38	25.85	26.33	25.95	25.90	26.77	26.77	26.82	26.80
15	0030 to 0130	24.72	25.09	24.79	24.75	25.19	25.76	25.26	25.22	26.23	26.23	26.28	26.25
16	0130 to 0230	24.09	24.51	24.16	24.13	24.62	25.20	24.70	24.66	25.68	25.68	25.74	25.71
17	0230 to 0330	23.48	23.97	23.55	23.51	24.02	24.67	24.09	24.05	25.18	25.18	25.26	25.22
18	0330 to 0430	22.99	23.51	23.04	23.01	23.46	24.24	23.53	23.50	24.75	24.75	24.81	24.78
19	0430 to 0530	22.44	23.00	22.51	22.47	22.98	23.72	23.04	23.01	24.24	24.24	24.30	24.27
20	0530 to 0630	21.93	22.53	22.00	21.96	22.49	23.25	22.57	22.53	23.78	23.78	23.84	23.81
21	0630 to 0730	21.50	22.21	21.57	21.54	21.96	22.86	22.05	22.00	23.34	23.34	23.40	23.37
22	0730 to 0830	21.16	22.23	21.22	21.19	21.62	22.63	21.69	21.66	22.92	22.92	23.00	22.96
23	0830 to 0930	21.18	22.69	21.25	21.21	21.59	22.63	21.68	21.64	22.56	22.56	22.63	22.60
24	0930 to 1030	21.46	23.31	21.52	21.49	21.64	22.81	21.73	21.69	22.40	22.40	22.44	22.42

Table B-2 (c): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for minimum ambient air temperature at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	22.58	22.12	22.67	22.63	22.31	21.82	22.38	22.34	22.11	21.79	22.21	22.16
2	1130 to 1230	23.16	22.44	23.26	23.21	22.87	22.07	22.94	22.90	22.93	22.10	23.02	22.98
3	1230 to 1330	24.09	23.17	24.17	24.13	23.70	22.75	23.77	23.73	24.06	22.76	24.14	24.10
4	1330 to 1430	25.22	24.28	25.29	25.26	24.81	23.84	24.86	24.83	25.35	23.81	25.43	25.39
5	1430 to 1530	26.35	25.42	26.43	26.39	25.89	24.95	25.95	25.92	26.67	24.85	26.72	26.69
6	1530 to 1630	27.32	26.60	27.41	27.36	26.97	26.22	26.96	26.96	28.04	26.09	28.11	28.07
7	1630 to 1730	28.21	27.76	28.28	28.24	27.96	27.49	28.02	27.99	29.25	27.34	29.31	29.28
8	1730 to 1830	28.75	28.62	28.81	28.78	28.71	28.50	28.77	28.74	30.02	28.35	30.09	30.06
9	1830 to 1930	28.80	28.83	28.86	28.83	28.94	28.75	29.01	28.97	29.86	28.57	29.92	29.89
10	1930 to 2030	28.60	28.76	28.65	28.62	28.75	28.71	28.82	28.79	29.09	28.50	29.17	29.13
11	2030 to 2130	28.12	28.42	28.18	28.15	28.30	28.40	28.36	28.33	28.30	28.20	28.37	28.34
12	2130 to 2230	27.56	27.96	27.62	27.59	27.72	27.95	27.77	27.74	27.48	27.76	27.56	27.52
13	2230 to 2330	27.03	27.46	27.11	27.07	27.11	27.47	27.16	27.13	26.76	27.29	26.83	26.80
14	2330 to 0030	26.54	27.01	26.61	26.57	26.59	27.04	26.65	26.62	26.08	26.87	26.16	26.12
15	0030 to 0130	25.97	26.48	26.03	26.00	25.99	26.54	26.03	26.01	25.41	26.38	25.47	25.44
16	0130 to 0230	25.46	25.95	25.52	25.49	25.45	26.03	25.52	25.48	24.89	25.89	24.95	24.92
17	0230 to 0330	24.98	25.47	25.03	25.01	24.96	25.56	25.02	24.99	24.35	25.43	24.42	24.38
18	0330 to 0430	24.54	25.05	24.62	24.58	24.50	25.15	24.56	24.53	23.82	25.04	23.90	23.86
19	0430 to 0530	24.06	24.55	24.11	24.08	23.99	24.66	24.01	24.00	23.34	24.56	23.41	23.38
20	0530 to 0630	23.60	24.09	23.68	23.64	23.53	24.21	23.62	23.57	22.94	24.12	23.01	22.98
21	0630 to 0730	23.20	23.62	23.27	23.23	23.15	23.72	23.21	23.18	22.46	23.64	22.52	22.49
22	0730 to 0830	22.78	23.07	22.84	22.81	22.69	23.11	22.73	22.71	22.03	23.02	22.09	22.06
23	0830 to 0930	22.43	22.48	22.49	22.46	22.34	22.39	22.35	22.34	21.78	22.29	21.88	21.83
24	0930 to 1030	22.30	22.09	22.37	22.34	22.20	21.87	22.24	22.22	21.71	21.75	21.78	21.75

Table B-2 (d): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for minimum ambient air temperature at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (ºC) at 25 cm				Temperature (ºC) at 27.5 cm				Temperature (ºC) at 30 cm				Temperature (ºC) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	22.21	22.04	22.27	22.24	22.98	22.56	23.06	23.02	23.35	23.35	23.41	23.38	23.09	23.09	23.14	23.12
2	1130 to 1230	23.18	22.52	23.24	23.21	24.34	23.33	24.47	24.40	24.54	24.54	24.61	24.57	24.94	24.94	25.00	24.97
3	1230 to 1330	24.28	23.22	24.36	24.32	25.41	24.13	25.49	25.45	25.47	25.47	25.52	25.50	26.74	26.74	26.79	26.77
4	1330 to 1430	25.40	24.19	25.45	25.43	26.95	24.99	27.07	27.01	26.19	26.19	26.25	26.22	27.77	27.77	27.82	27.79
5	1430 to 1530	26.73	25.11	26.79	26.76	29.37	25.73	29.46	29.41	26.72	26.72	26.77	26.74	28.02	28.02	28.09	28.05
6	1530 to 1630	28.25	26.21	28.31	28.28	31.59	26.58	31.66	31.63	27.21	27.21	27.24	27.23	28.06	28.06	28.12	28.09
7	1630 to 1730	29.53	27.31	29.60	29.56	32.24	27.39	32.31	32.27	27.59	27.59	27.62	27.60	27.91	27.91	27.97	27.94
8	1730 to 1830	29.94	28.16	30.02	29.98	30.23	27.95	30.31	30.27	27.70	27.70	27.75	27.72	27.57	27.57	27.62	27.59
9	1830 to 1930	29.22	28.29	29.00	29.11	28.06	27.90	28.15	28.10	27.41	27.41	27.47	27.44	26.99	26.99	27.06	27.03
10	1930 to 2030	28.31	28.14	28.42	28.36	26.82	27.63	26.91	26.86	26.98	26.98	27.03	27.00	26.44	26.44	26.51	26.47
11	2030 to 2130	27.40	27.82	27.52	27.46	25.93	27.27	26.01	25.97	26.55	26.55	26.61	26.58	25.83	25.83	25.90	25.87
12	2130 to 2230	26.70	27.39	26.81	26.75	25.20	26.82	25.29	25.25	26.07	26.07	26.11	26.09	25.27	25.27	25.33	25.30
13	2230 to 2330	26.00	26.92	26.00	26.00	24.64	26.34	24.72	24.68	25.57	25.57	25.61	25.59	24.84	24.84	24.90	24.87
14	2330 to 0030	25.35	26.49	25.41	25.38	24.02	25.91	24.11	24.06	25.12	25.12	25.17	25.15	24.34	24.34	24.40	24.37
15	0030 to 0130	24.84	26.02	24.91	24.87	23.49	25.45	23.55	23.52	24.68	24.68	24.72	24.70	23.86	23.86	23.92	23.89
16	0130 to 0230	24.31	25.55	24.38	24.34	23.07	25.01	23.14	23.11	24.26	24.26	24.31	24.28	23.41	23.41	23.47	23.44
17	0230 to 0330	23.79	25.11	23.86	23.83	22.59	24.57	22.65	22.62	23.83	23.83	23.88	23.86	23.08	23.08	23.14	23.11
18	0330 to 0430	23.35	24.71	23.42	23.39	22.15	24.18	22.22	22.19	23.44	23.44	23.51	23.47	22.66	22.66	22.71	22.69
19	0430 to 0530	22.94	24.25	23.02	22.98	21.73	23.73	21.81	21.77	23.01	23.01	23.07	23.04	22.25	22.25	22.31	22.28
20	0530 to 0630	22.53	23.83	22.60	22.56	21.38	23.34	21.44	21.41	22.64	22.64	22.69	22.66	21.87	21.87	21.92	21.89
21	0630 to 0730	22.07	23.37	22.17	22.12	21.00	22.92	21.00	21.00	22.28	22.28	22.35	22.32	21.57	21.57	21.61	21.59
22	0730 to 0830	21.72	22.80	21.81	21.76	21.06	22.46	21.01	21.04	22.00	22.00	22.05	22.03	21.41	21.41	21.46	21.44
23	0830 to 0930	21.61	22.17	21.69	21.65	21.44	22.05	21.53	21.49	21.91	21.91	21.96	21.94	21.53	21.53	21.58	21.56
24	0930 to 1030	21.72	21.72	21.78	21.75	21.87	21.79	21.93	21.90	21.95	21.95	22.00	21.98	21.64	21.64	21.69	21.67

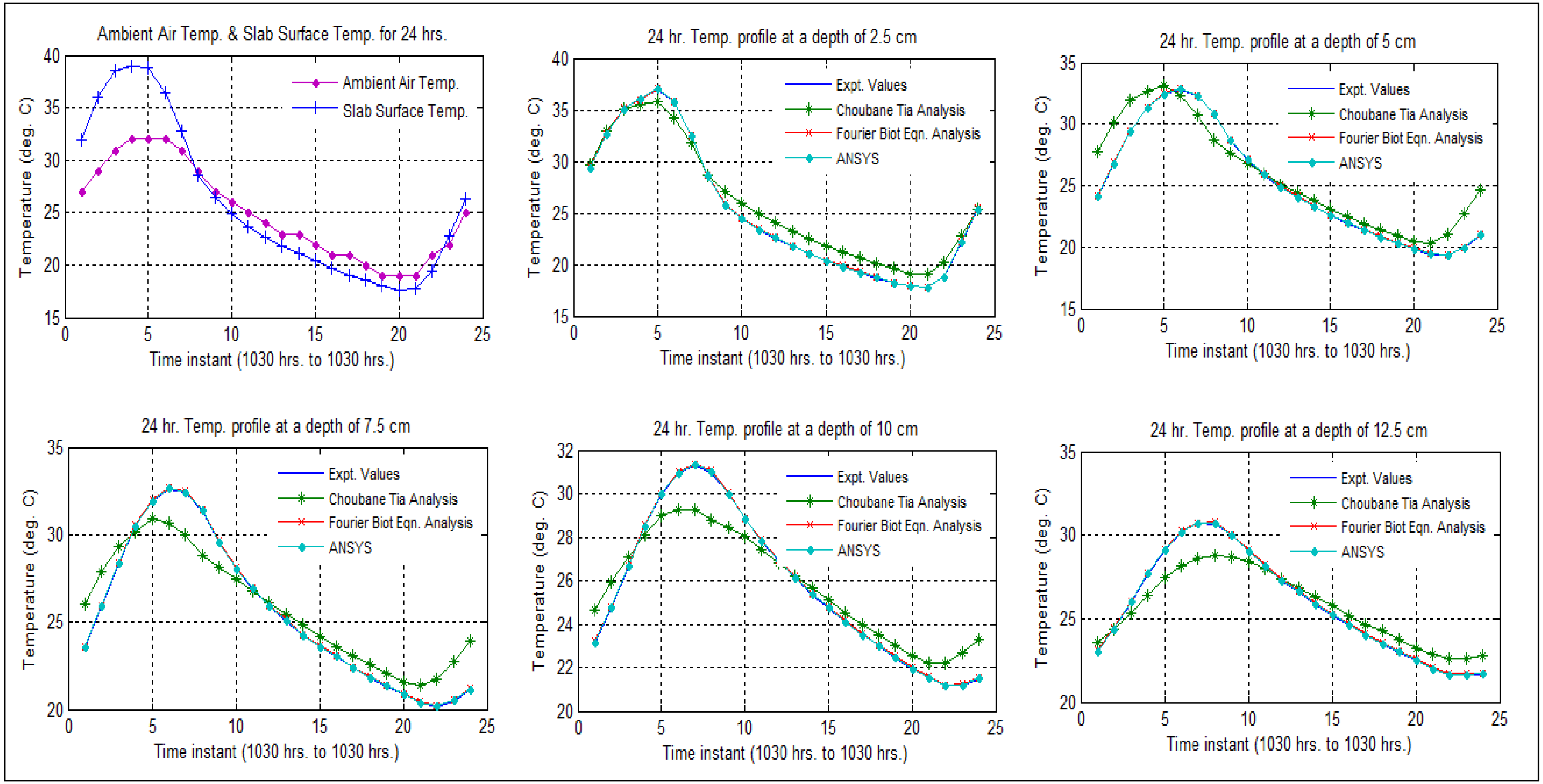


Fig. B-3 (a): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix A for minimum ambient air temperature (surface to 12.5 cm)

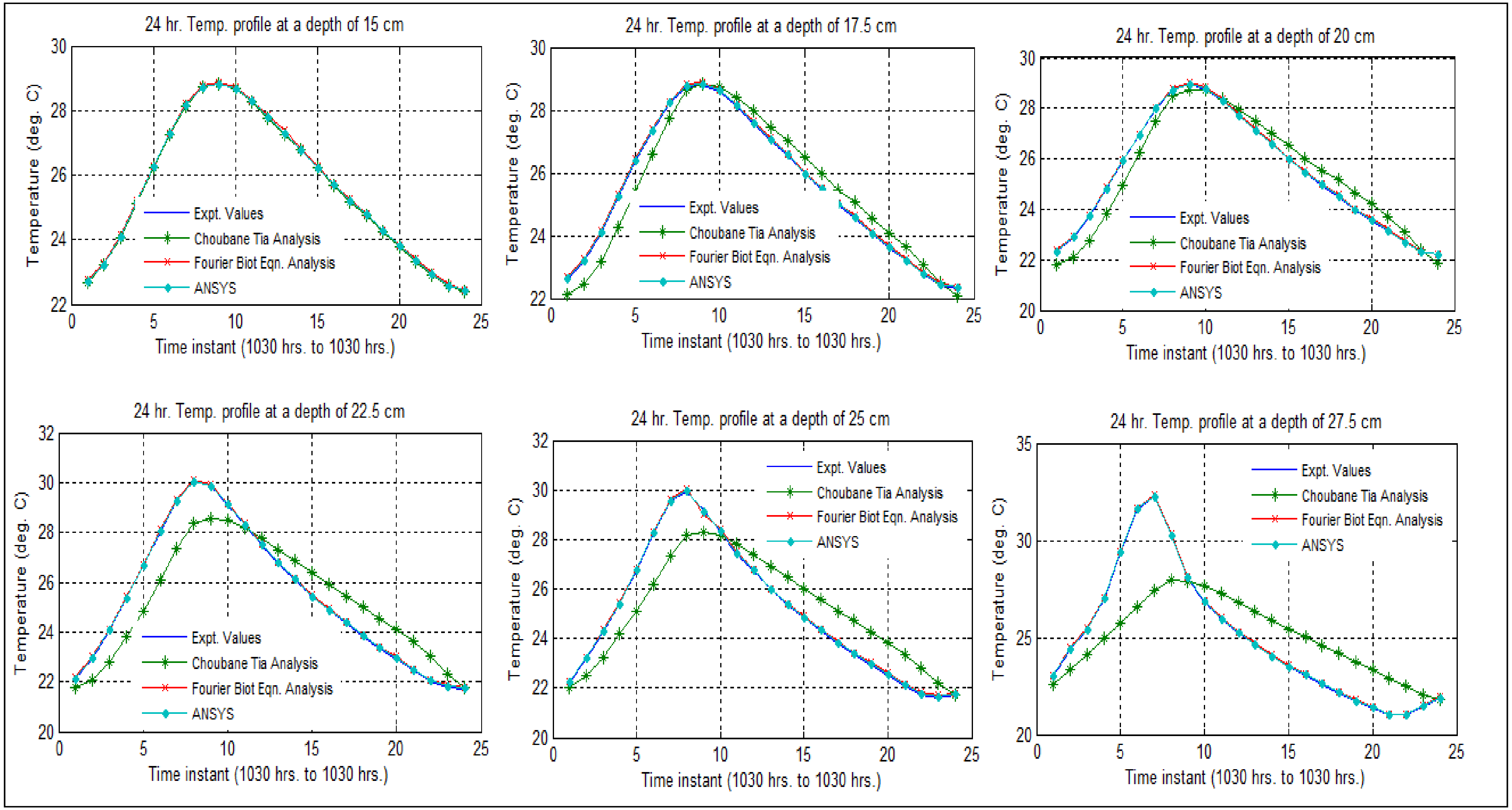


Fig. B-3 (b): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix A for minimum ambient air temperature (15 cm to 27.5 cm)

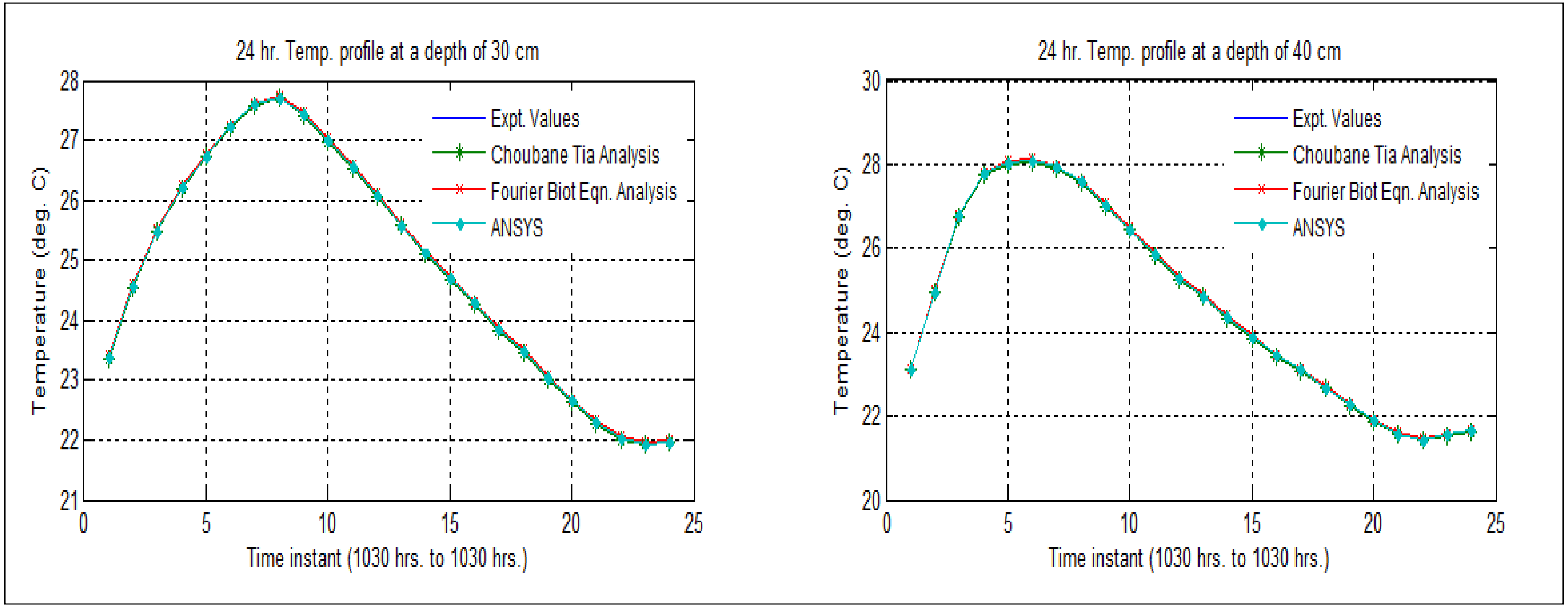


Fig. B-3 (c): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix A for minimum ambient air temperature (30 cm & 40 cm)

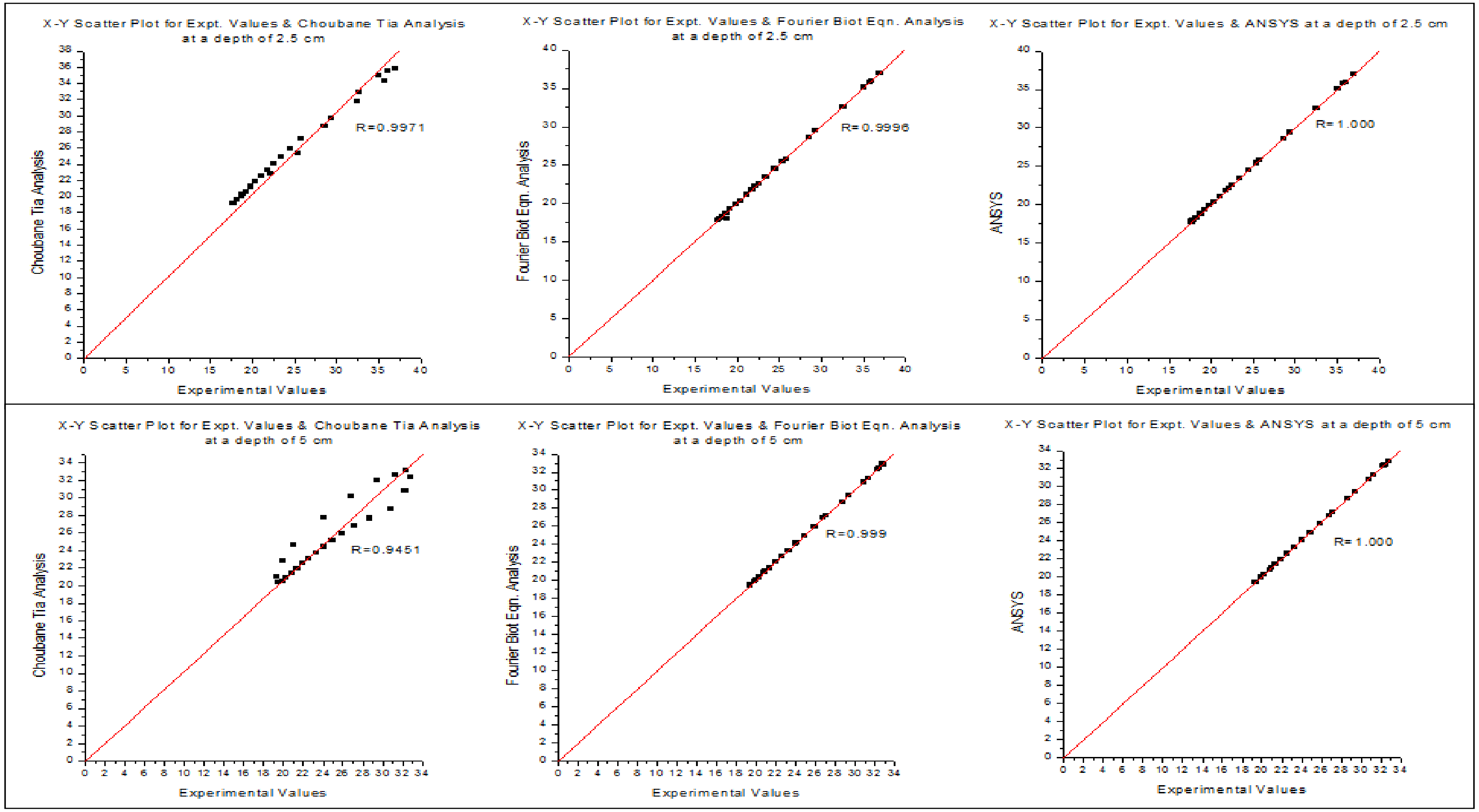


Fig. B-4 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

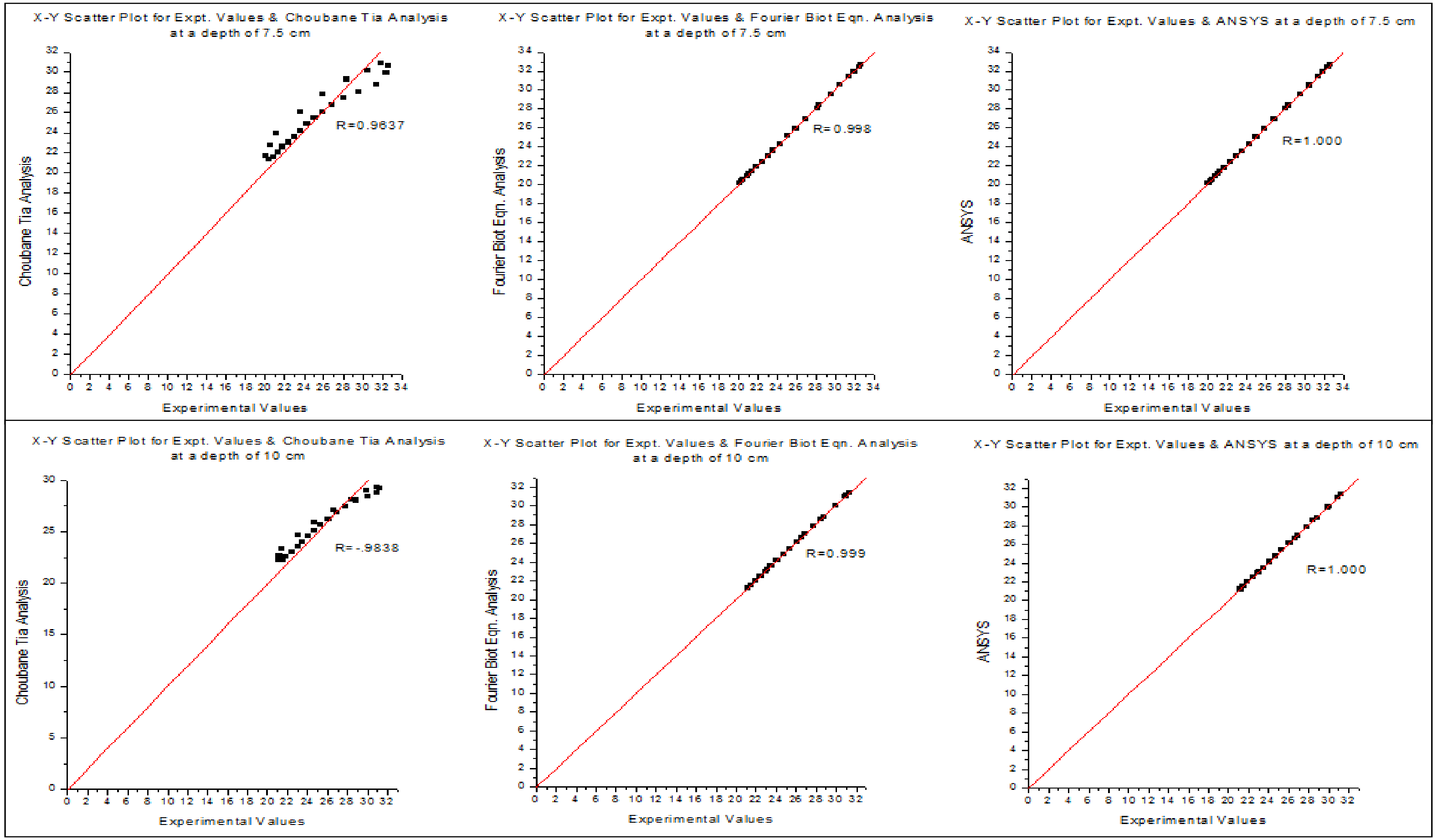


Fig. B-4 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

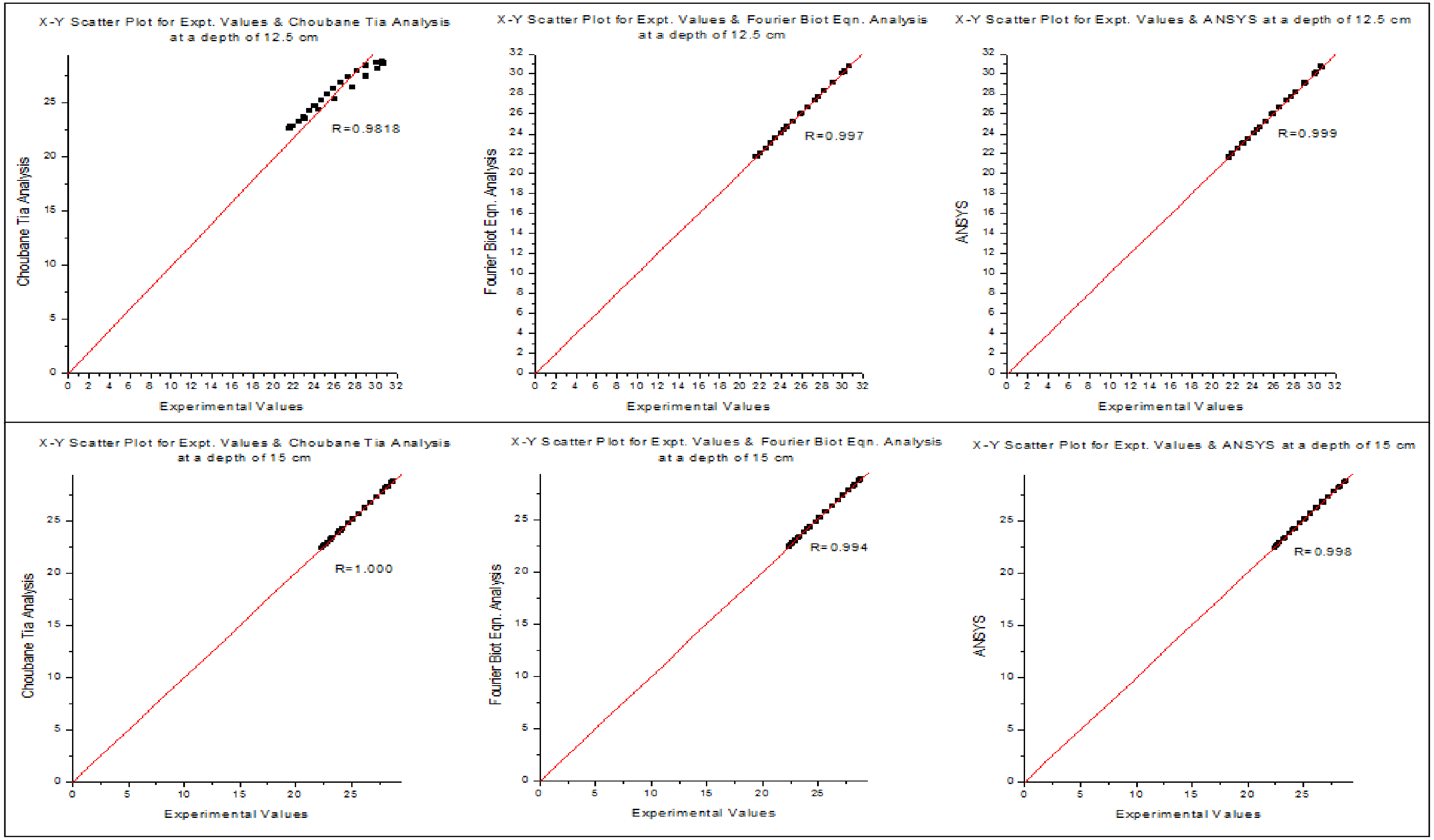


Fig. B-4 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

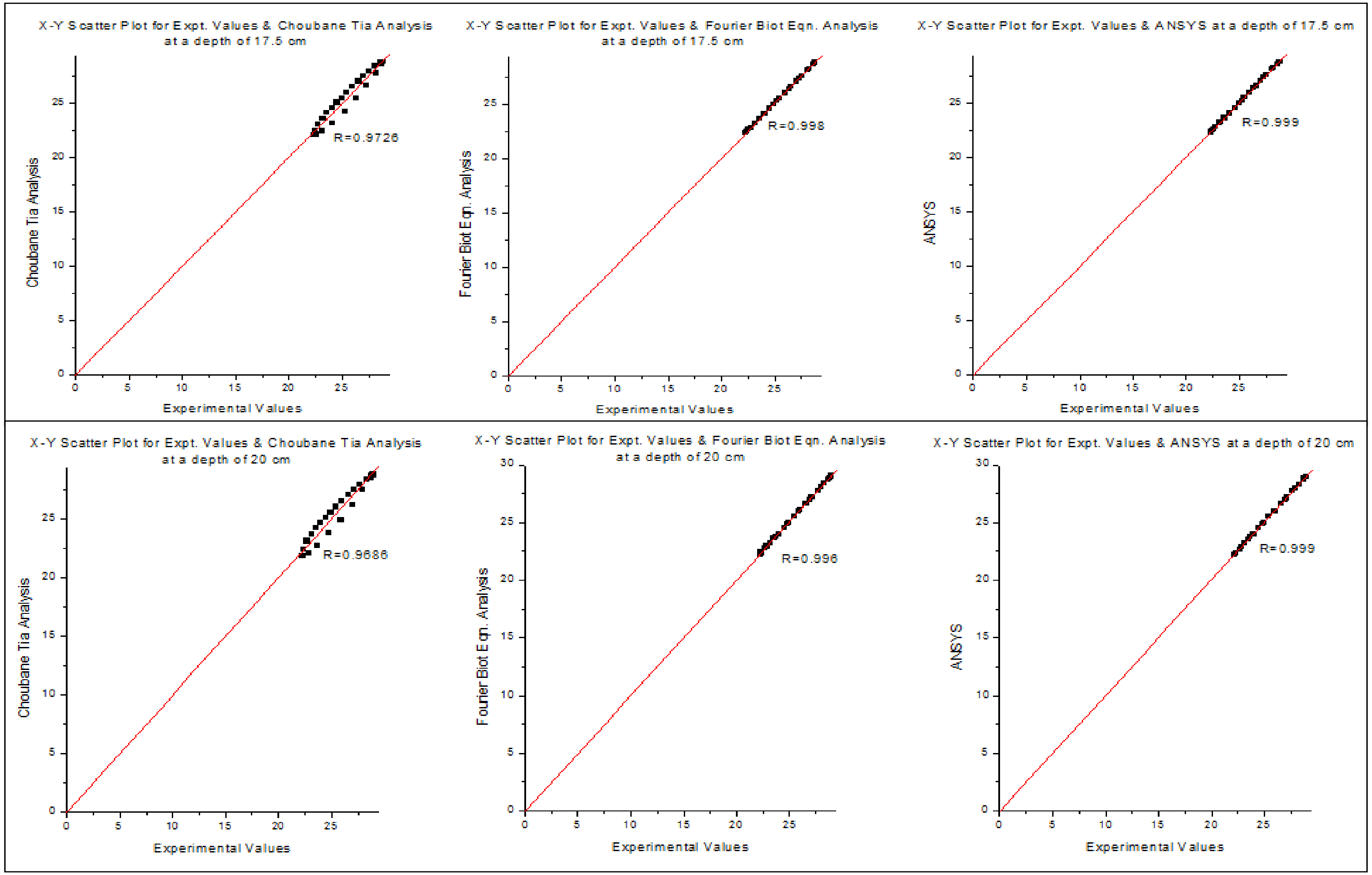


Fig. B-4 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

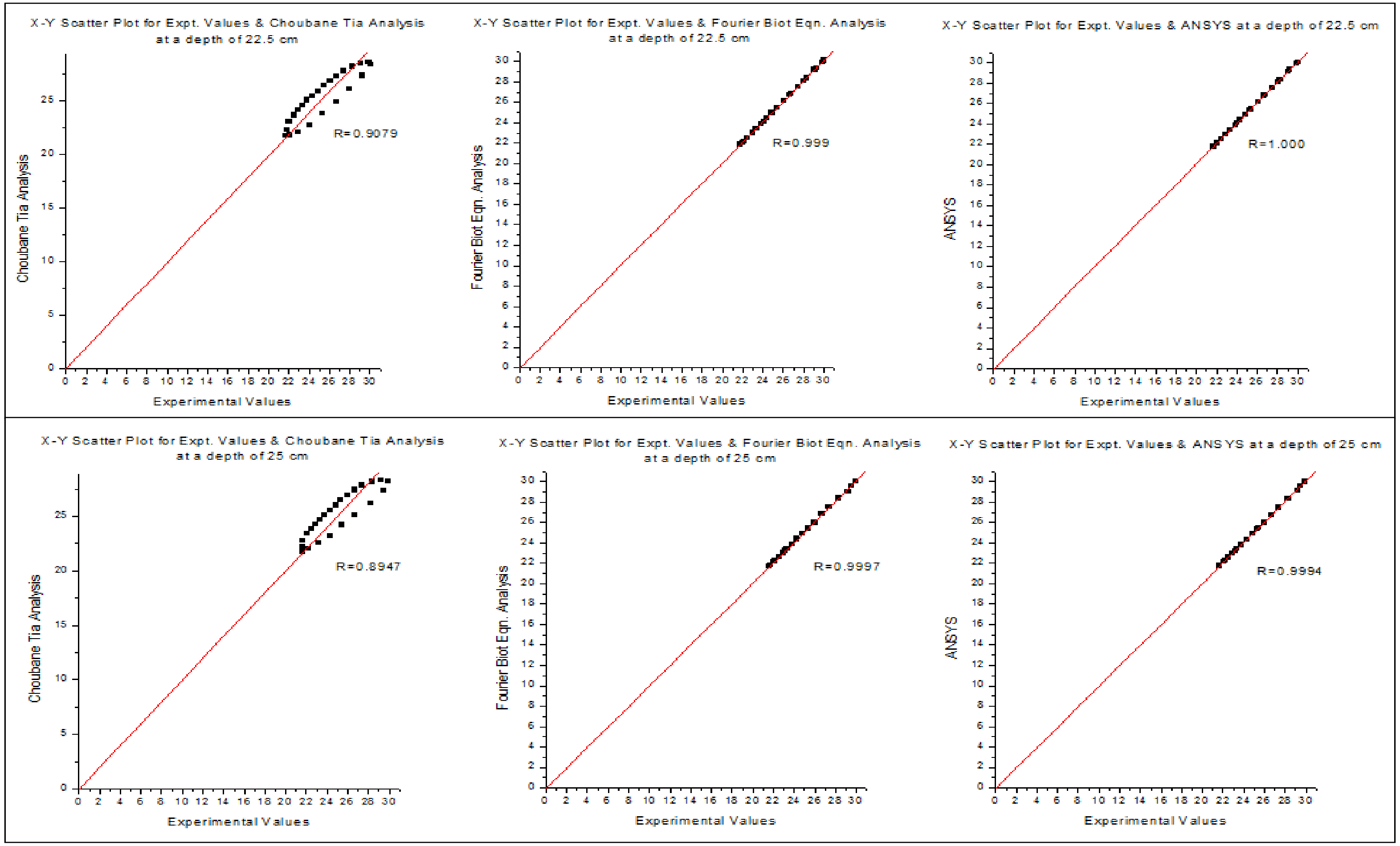


Fig. B-4 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

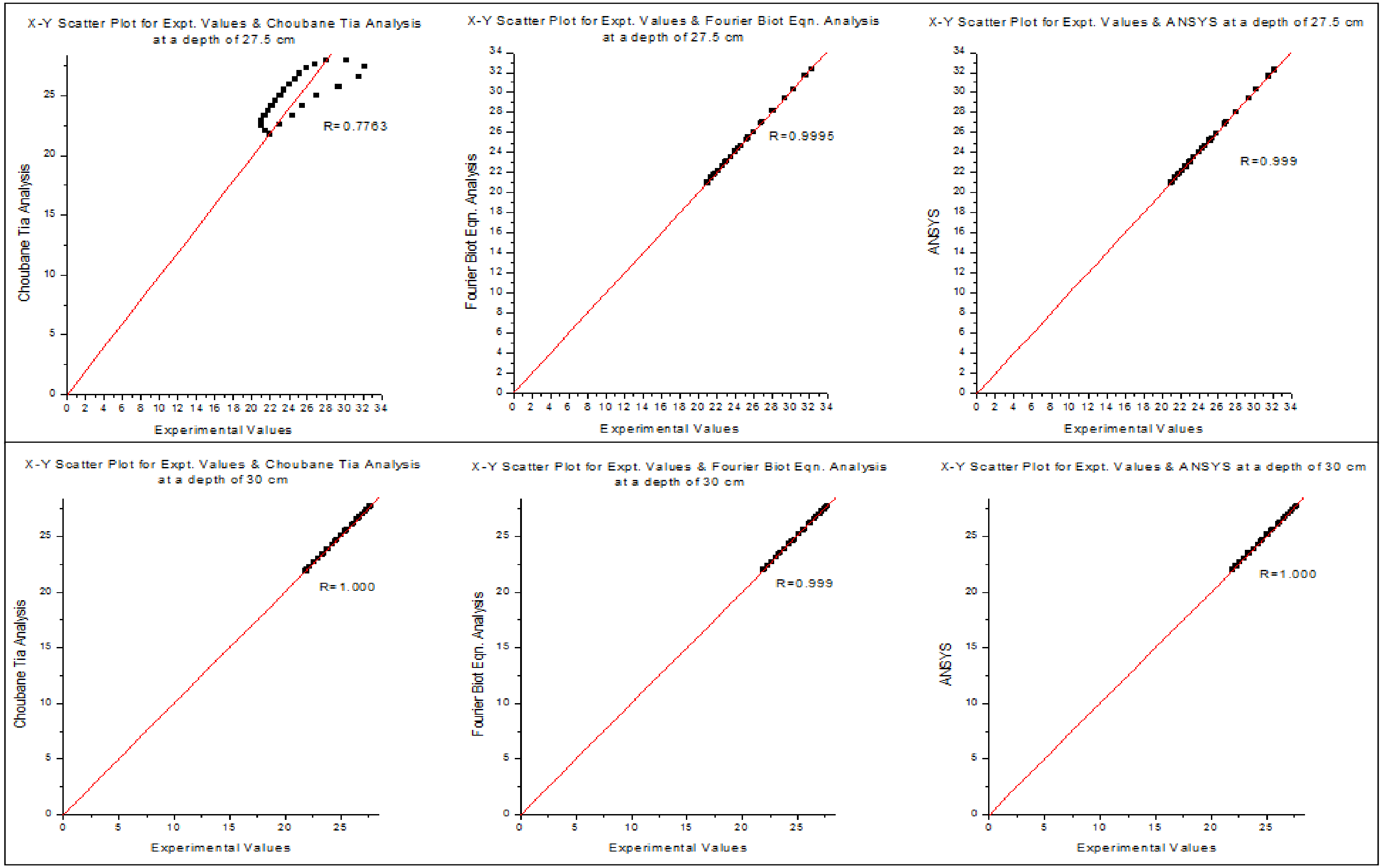


Fig. B-4 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

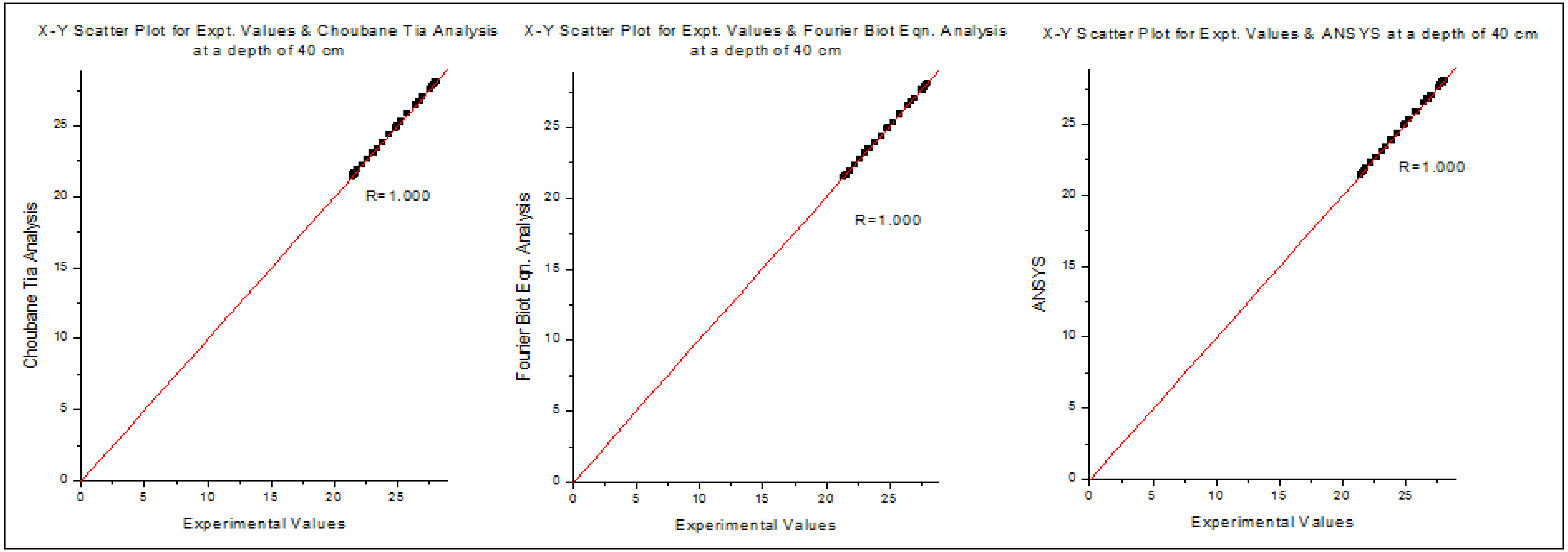


Fig. B-4 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-3 (a): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for part humid and part rainy condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	36	37.52	35.36	36.08	35.36	35.36	34.00	34.82	34.00	34.00	32.86	33.73	32.93	32.89
2	1200 to 1300	37	44.20	40.20	41.72	40.24	40.22	38.46	39.52	38.83	38.64	36.34	37.60	36.61	36.48
3	1300 to 1400	38	44.13	42.35	42.19	42.80	42.58	40.89	40.45	40.54	40.71	38.95	38.91	38.70	38.82
4	1400 to 1500	38	46.54	45.26	44.41	45.50	45.38	43.02	42.50	43.36	43.19	40.82	40.80	40.68	40.75
5	1500 to 1600	38	44.47	45.93	43.11	46.01	45.97	44.07	41.88	44.15	44.11	42.12	40.76	42.29	42.21
6	1600 to 1700	37	41.55	44.30	40.94	44.46	44.38	43.28	40.36	43.46	43.37	42.02	39.82	42.16	42.09
7	1700 to 1800	35	30.97	34.96	32.46	34.68	34.82	37.18	33.74	37.39	37.29	37.42	34.79	37.54	37.48
8	1800 to 1900	33	26.85	25.11	27.87	25.79	25.45	26.94	28.77	27.06	27.00	28.51	29.57	28.65	28.58
9	1900 to 2000	32	27.99	26.00	28.40	26.11	26.06	26.56	28.79	26.64	26.60	27.77	29.17	27.83	27.80
10	2000 to 2100	31	27.82	26.58	28.18	26.44	26.51	26.84	28.53	26.91	26.88	27.76	28.86	27.81	27.78
11	2100 to 2200	29	27.37	26.70	27.74	26.82	26.76	26.79	28.09	26.90	26.84	27.57	28.43	27.69	27.63
12	2200 to 2300	28	27.05	26.74	27.39	26.89	26.81	26.70	27.72	26.81	26.76	27.33	28.04	27.52	27.43
13	2300 to 0000	28	26.76	26.79	27.10	26.88	26.84	26.70	27.43	26.80	26.75	27.18	27.75	27.14	27.16
14	0000 to 0100	27	26.32	26.53	26.68	26.58	26.55	26.47	27.03	26.62	26.55	26.97	27.36	27.07	27.02
15	0100 to 0200	27	26.01	26.14	26.36	26.22	26.18	26.10	26.71	26.15	26.13	26.71	27.03	26.80	26.76
16	0200 to 0300	26	25.62	25.93	26.00	26.02	25.97	25.89	26.36	25.95	25.92	26.45	26.71	26.55	26.50
17	0300 to 0400	26	25.11	25.33	25.52	25.46	25.39	25.38	25.91	25.44	25.41	25.98	26.28	26.07	26.03
18	0400 to 0500	25	24.81	24.95	25.21	25.01	24.98	24.98	25.60	25.03	25.01	25.54	25.97	25.62	25.58
19	0500 to 0600	25	24.83	24.86	25.18	24.93	24.89	24.77	25.51	24.84	24.80	25.24	25.82	25.31	25.28
20	0600 to 0700	26	24.67	24.73	24.99	24.81	24.77	24.63	25.29	24.72	24.68	25.03	25.58	25.11	25.07
21	0700 to 0800	28	25.45	25.09	25.56	25.15	25.12	24.86	25.68	24.93	24.89	25.17	25.82	25.26	25.22
22	0800 to 0900	29	26.70	26.10	26.60	26.17	26.14	25.65	26.54	25.73	25.69	25.85	26.51	25.93	25.89
23	0900 to 1000	31	29.00	27.73	28.52	27.80	27.77	27.03	28.12	27.10	27.07	27.00	27.78	27.06	27.03
24	1000 to 1100	33	31.93	29.90	31.05	30.03	29.97	29.04	30.28	29.12	29.08	28.65	29.62	28.77	28.71

Table B-3 (b): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for part humid and part rainy condition at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	32.30	32.81	32.43	32.36	31.63	32.07	31.72	31.68	31.49	31.49	31.32	31.41
2	1200 to 1300	35.13	35.95	35.39	35.26	33.79	34.59	33.92	33.85	33.51	33.51	33.63	33.57
3	1300 to 1400	37.63	37.56	37.75	37.69	35.99	36.41	36.08	36.04	35.46	35.46	35.53	35.49
4	1400 to 1500	39.31	39.32	39.43	39.37	37.58	38.05	37.60	37.59	37.00	37.00	36.97	36.99
5	1500 to 1600	40.51	39.77	40.62	40.56	38.78	38.91	38.69	38.73	38.16	38.16	38.28	38.22
6	1600 to 1700	40.61	39.32	40.70	40.65	39.16	38.86	39.08	39.12	38.44	38.44	38.58	38.51
7	1700 to 1800	38.07	35.62	38.11	38.09	37.63	36.23	37.68	37.66	36.62	36.62	36.43	36.53
8	1800 to 1900	30.89	30.25	30.54	30.71	32.03	30.82	32.14	32.08	31.28	31.28	31.21	31.24
9	1900 to 2000	29.42	29.53	29.32	29.37	30.38	29.87	30.47	30.42	30.19	30.19	30.11	30.15
10	2000 to 2100	29.07	29.19	29.13	29.10	29.89	29.50	29.95	29.92	29.81	29.81	29.95	29.88
11	2100 to 2200	28.73	28.76	28.80	28.77	29.43	29.08	29.50	29.47	29.39	29.39	29.53	29.46
12	2200 to 2300	28.34	28.35	28.46	28.40	28.95	28.66	29.04	29.00	28.95	28.95	29.02	28.99
13	2300 to 0000	28.02	28.06	28.09	28.05	28.64	28.36	28.75	28.69	28.65	28.65	28.73	28.69
14	0000 to 0100	27.72	27.69	27.85	27.79	28.30	27.99	29.41	28.86	28.29	28.29	28.41	28.35
15	0100 to 0200	27.36	27.35	27.45	27.41	27.94	27.65	28.04	27.99	27.94	27.94	28.04	27.99
16	0200 to 0300	27.11	27.04	27.22	27.16	27.64	27.36	27.75	27.69	27.66	27.66	27.74	27.70
17	0300 to 0400	26.80	26.63	26.85	26.83	27.29	26.96	27.40	27.34	27.27	27.27	27.37	27.32
18	0400 to 0500	26.42	26.32	26.51	26.46	26.96	26.64	27.02	26.99	26.95	26.95	27.03	26.99
19	0500 to 0600	26.08	26.13	26.14	26.11	26.67	26.42	26.74	26.71	26.69	26.69	26.78	26.74
20	0600 to 0700	25.85	25.87	25.93	25.89	26.40	26.14	26.48	26.44	26.40	26.40	26.52	26.46
21	0700 to 0800	25.85	25.97	25.92	25.88	26.31	26.14	26.38	26.35	26.32	26.32	26.42	26.37
22	0800 to 0900	26.33	26.51	26.40	26.36	26.62	26.55	26.64	26.63	26.63	26.63	26.70	26.66
23	0900 to 1000	27.18	27.52	27.24	27.21	27.22	27.34	27.41	27.31	27.22	27.22	27.37	27.30
24	1000 to 1100	28.56	29.07	28.62	28.59	28.32	28.62	28.41	28.36	28.28	28.28	28.21	28.24

Table B-3 (c): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for part humid and part rainy condition at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	31.27	31.09	31.73	31.50	31.26	30.87	31.45	31.35	31.61	30.81	31.70	31.65
2	1200 to 1300	32.73	32.71	32.52	32.62	32.67	32.19	32.22	32.45	33.33	31.94	33.48	33.40
3	1300 to 1400	34.15	34.70	34.32	34.23	33.95	34.14	34.05	34.00	34.72	33.78	34.81	34.76
4	1400 to 1500	35.36	36.17	35.43	35.40	35.03	35.55	35.18	35.10	36.03	35.15	36.07	36.05
5	1500 to 1600	36.35	37.54	36.45	36.40	35.95	37.04	36.01	35.98	36.83	36.66	36.94	36.89
6	1600 to 1700	36.76	38.06	36.89	36.82	36.40	37.72	36.52	36.46	37.19	37.41	37.25	37.22
7	1700 to 1800	35.87	36.79	35.94	35.91	35.48	36.73	35.60	35.54	35.43	36.45	35.57	35.50
8	1800 to 1900	32.20	31.63	32.12	32.16	31.92	31.86	32.03	31.98	31.11	31.98	31.23	31.17
9	1900 to 2000	31.20	30.50	31.15	31.17	31.00	30.79	31.03	31.01	30.42	31.06	30.54	30.48
10	2000 to 2100	30.79	30.10	30.53	30.66	30.74	30.38	30.81	30.78	30.10	30.65	30.21	30.16
11	2100 to 2200	30.40	29.68	30.28	30.34	30.37	29.96	30.44	30.40	29.68	30.23	29.79	29.74
12	2200 to 2300	29.94	29.24	30.01	29.98	29.90	29.51	30.01	29.96	29.27	29.78	29.40	29.33
13	2300 to 0000	29.54	28.93	29.62	29.58	29.49	29.20	29.61	29.55	28.91	29.46	29.02	28.97
14	0000 to 0100	29.15	28.57	29.21	29.18	29.11	28.84	29.22	29.16	28.68	29.09	28.80	28.74
15	0100 to 0200	28.81	28.22	28.92	28.87	28.80	28.48	28.89	28.84	28.35	28.73	28.49	28.42
16	0200 to 0300	28.55	27.94	28.62	28.59	28.55	28.21	28.62	28.59	28.06	28.46	28.18	28.12
17	0300 to 0400	28.19	27.56	28.30	28.24	28.20	27.83	28.31	28.26	27.73	28.08	27.82	27.77
18	0400 to 0500	27.83	27.24	27.91	27.87	27.86	27.50	27.96	27.91	27.40	27.75	27.52	27.46
19	0500 to 0600	27.53	26.95	27.62	27.57	27.60	27.20	27.68	27.64	27.14	27.44	27.25	27.20
20	0600 to 0700	27.24	26.65	27.33	27.28	27.31	26.90	27.42	27.36	26.92	27.13	27.01	26.97
21	0700 to 0800	27.08	26.51	27.16	27.12	27.13	26.72	27.20	27.16	26.90	26.94	27.00	26.95
22	0800 to 0900	27.21	26.73	27.22	27.21	27.27	26.87	27.40	27.33	27.02	27.05	27.06	27.04
23	0900 to 1000	27.63	27.18	27.49	27.56	27.67	27.21	27.81	27.74	27.60	27.32	27.14	27.37
24	1000 to 1100	28.38	28.06	28.52	28.45	28.38	27.94	28.35	28.36	28.48	27.92	28.57	28.52

Table B-3 (d): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for part humid & part rainy condition at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	31.66	30.93	31.73	31.69	32.58	31.22	32.66	32.62	31.69	31.69	31.74	31.71	31.03	31.03	31.09	31.06
2	1200 to 1300	33.49	31.98	33.56	33.53	34.98	32.29	35.03	35.01	32.89	32.89	32.94	32.91	31.90	31.90	31.96	31.93
3	1300 to 1400	35.00	33.61	35.07	35.03	35.93	33.65	36.03	35.98	33.87	33.87	33.94	33.91	32.84	32.84	32.88	32.86
4	1400 to 1500	36.19	34.97	36.25	36.22	36.68	35.00	36.82	36.75	35.25	35.25	35.30	35.28	33.65	33.65	33.70	33.68
5	1500 to 1600	37.00	36.40	37.05	37.03	37.08	36.27	37.12	37.10	36.26	36.26	36.31	36.29	34.55	34.55	34.61	34.58
6	1600 to 1700	37.30	37.15	37.41	37.35	37.10	36.92	37.19	37.14	36.73	36.73	36.80	36.77	35.23	35.23	35.30	35.26
7	1700 to 1800	35.99	35.95	36.07	36.03	34.76	35.23	34.82	34.79	34.29	34.29	34.34	34.31	35.64	35.64	35.70	35.67
8	1800 to 1900	31.35	32.00	32.44	31.89	29.19	31.89	29.27	29.23	31.68	31.68	31.74	31.71	34.04	34.04	34.08	34.06
9	1900 to 2000	29.84	31.32	29.95	29.89	28.58	31.56	28.64	28.61	31.78	31.78	31.83	31.81	32.52	32.52	32.60	32.56
10	2000 to 2100	29.53	30.90	29.61	29.57	28.69	31.15	28.77	28.73	31.38	31.38	31.44	31.41	31.87	31.87	31.90	31.88
11	2100 to 2200	29.23	30.48	29.34	29.28	28.62	30.73	28.71	28.67	30.96	30.96	31.01	30.98	31.35	31.35	31.40	31.37
12	2200 to 2300	28.92	30.04	29.01	28.97	28.42	30.29	28.50	28.46	30.53	30.53	30.60	30.57	30.88	30.88	30.93	30.91
13	2300 to 0000	28.70	29.71	28.82	28.76	28.19	29.95	28.35	28.27	30.18	30.18	30.21	30.20	30.56	30.56	30.62	30.59
14	0000 to 0100	28.41	29.33	28.56	28.48	27.93	29.55	28.00	27.97	29.77	29.77	29.82	29.79	30.20	30.20	30.27	30.24
15	0100 to 0200	28.10	28.97	28.21	28.15	27.63	29.20	27.72	27.67	29.41	29.41	29.47	29.44	29.85	29.85	29.82	29.83
16	0200 to 0300	27.85	28.69	27.97	27.91	27.42	28.91	27.55	27.48	29.11	29.11	29.17	29.14	29.57	29.57	29.62	29.59
17	0300 to 0400	27.53	28.31	27.62	27.57	27.05	28.51	27.17	27.11	28.70	28.70	28.77	28.74	29.27	29.27	29.34	29.31
18	0400 to 0500	27.20	27.98	27.32	27.26	26.83	28.18	26.91	26.87	28.37	28.37	28.44	28.40	28.96	28.96	29.03	28.99
19	0500 to 0600	26.96	27.66	27.05	27.00	26.64	27.86	26.72	26.68	28.06	28.06	28.12	28.09	28.74	28.74	28.80	28.77
20	0600 to 0700	26.81	27.35	26.92	26.86	26.45	27.57	26.54	26.50	27.77	27.77	27.84	27.81	28.46	28.46	28.53	28.49
21	0700 to 0800	26.71	27.18	26.81	26.76	26.47	27.43	26.56	26.52	27.69	27.69	27.75	27.72	28.20	28.20	28.26	28.23
22	0800 to 0900	26.91	27.26	27.04	26.97	26.79	27.50	26.85	26.82	27.77	27.77	27.83	27.80	28.10	28.10	28.16	28.13
23	0900 to 1000	27.42	27.49	27.49	27.46	27.51	27.74	27.62	27.56	28.07	28.07	28.13	28.10	28.14	28.14	28.17	28.16
24	1000 to 1100	28.37	28.02	28.42	28.40	28.67	28.23	28.75	28.71	28.54	28.54	28.60	28.57	28.41	28.41	28.45	28.43

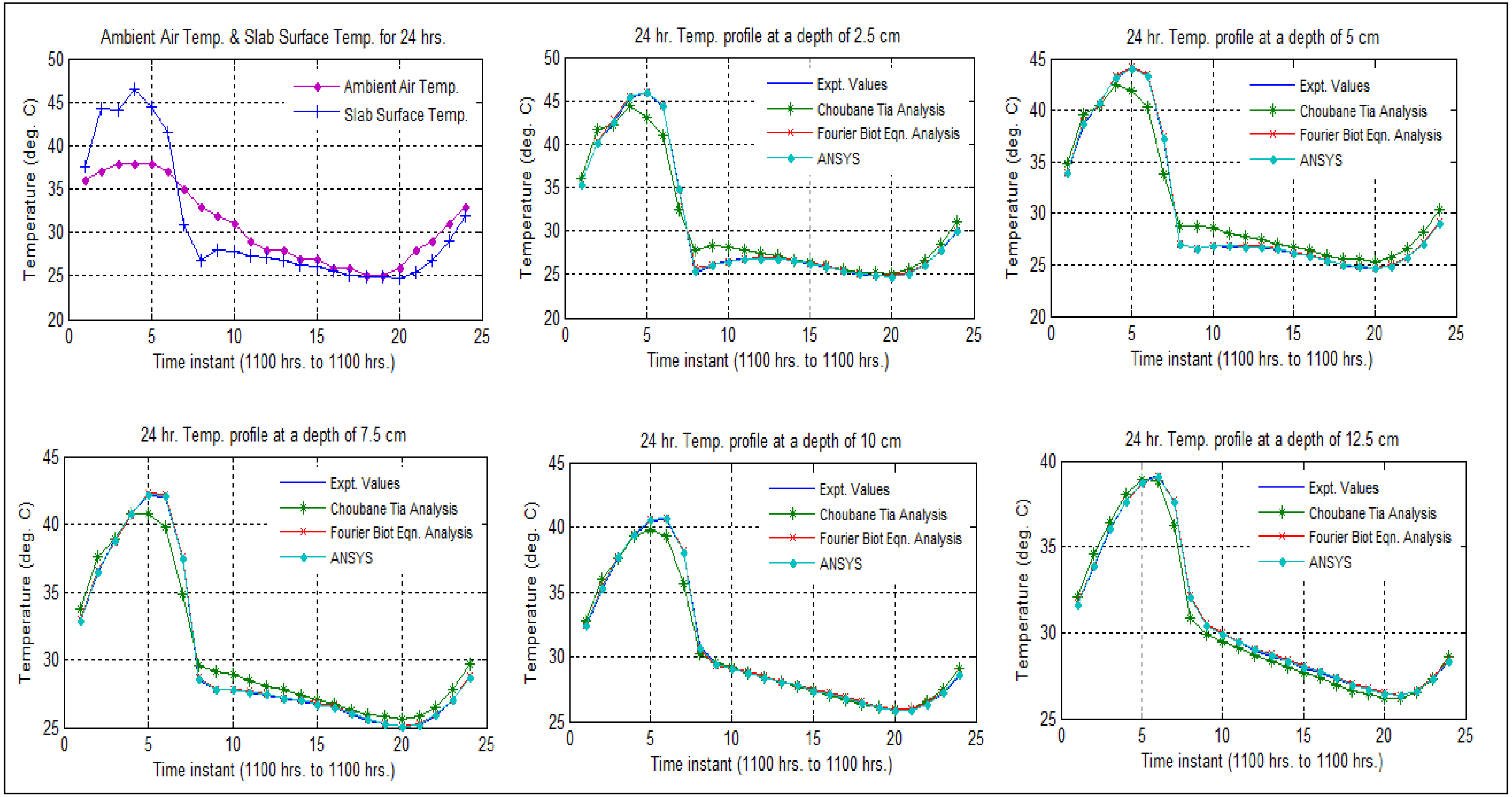


Fig. B-5 (a): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix A for part humid and part rainy condition (surface to 12.5 cm)

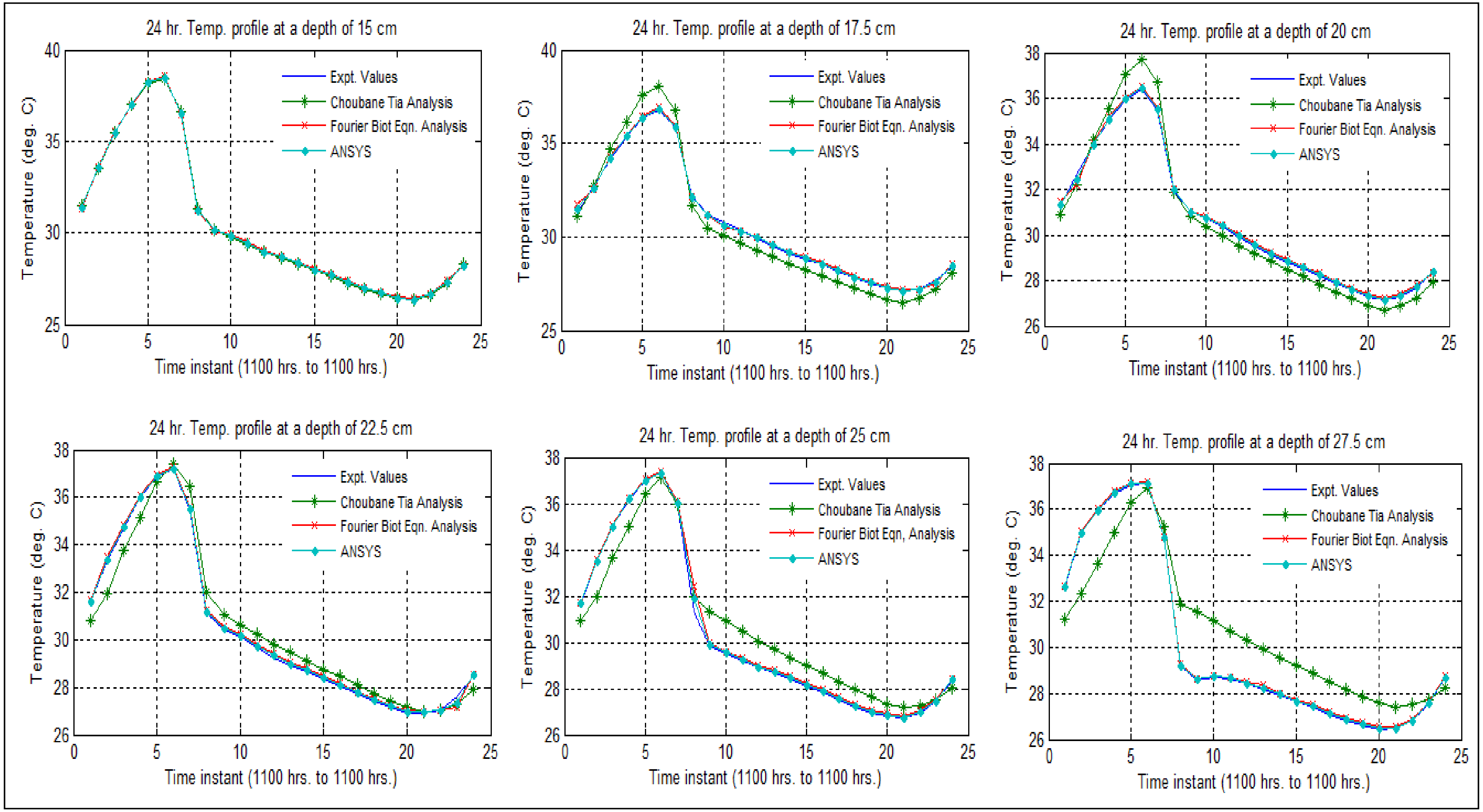


Fig. B-5 (b): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix A for part humid and part rainy condition (15 cm to 27.5 cm)

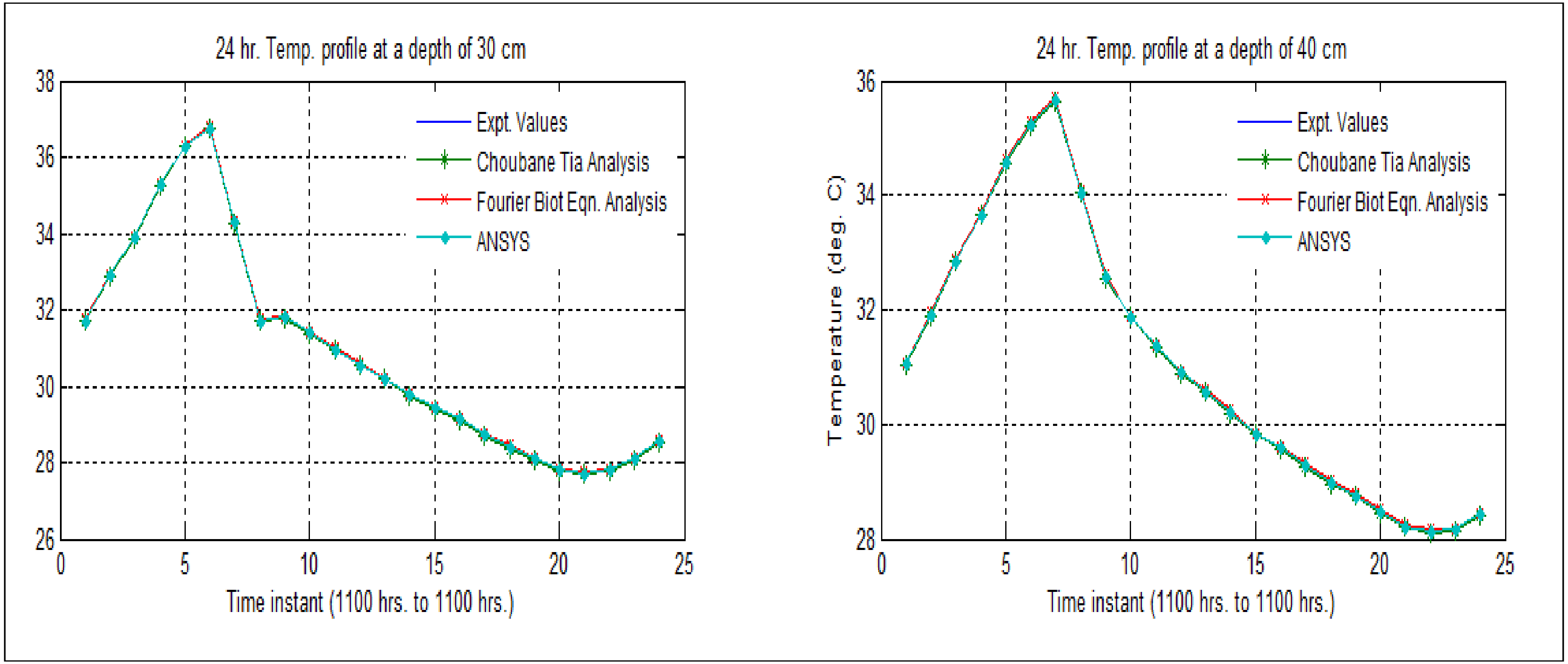


Fig. B-5 (c): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix A for part humid and part rainy condition (30 cm to 40 cm)

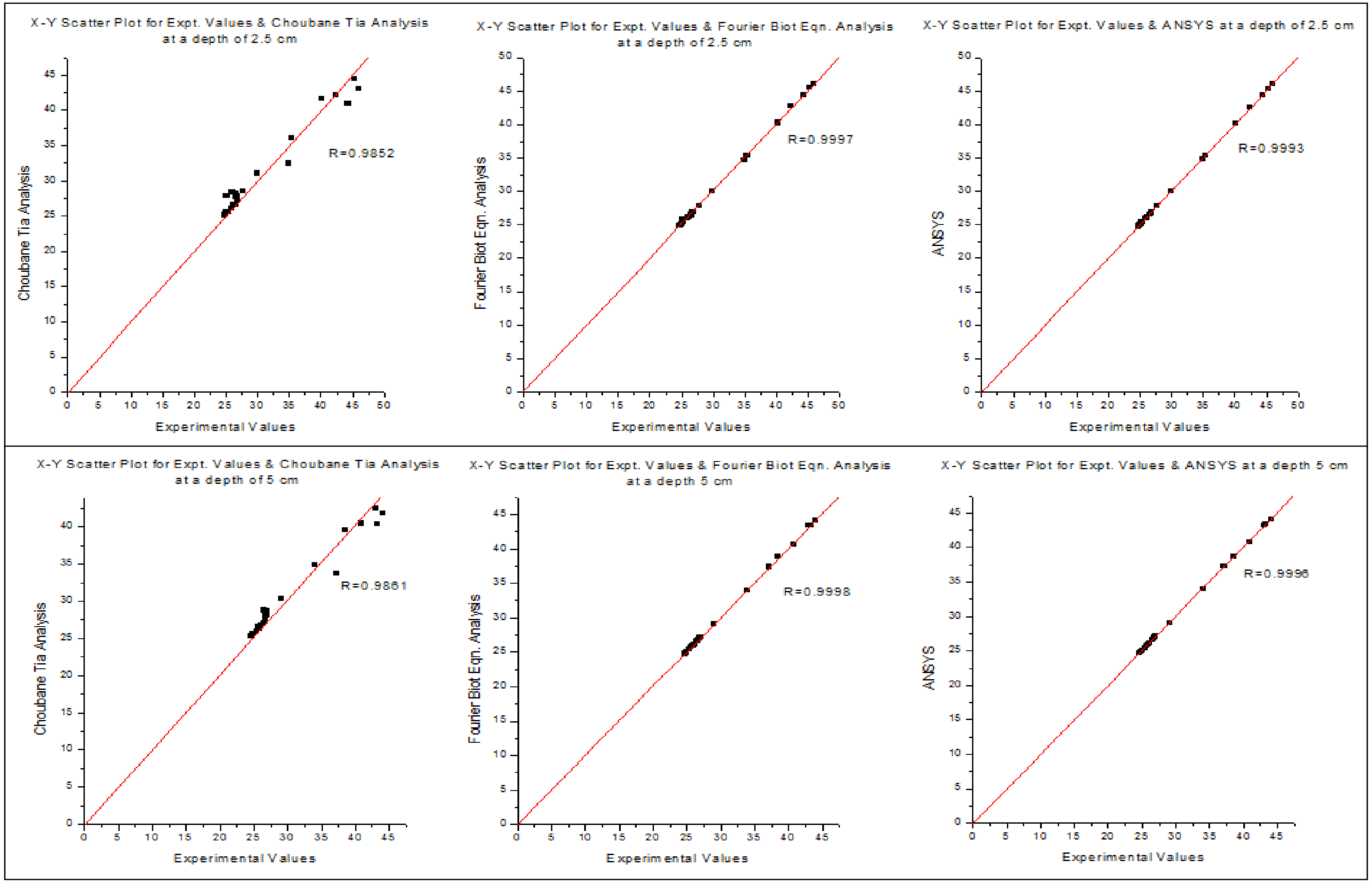


Fig. B-6 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

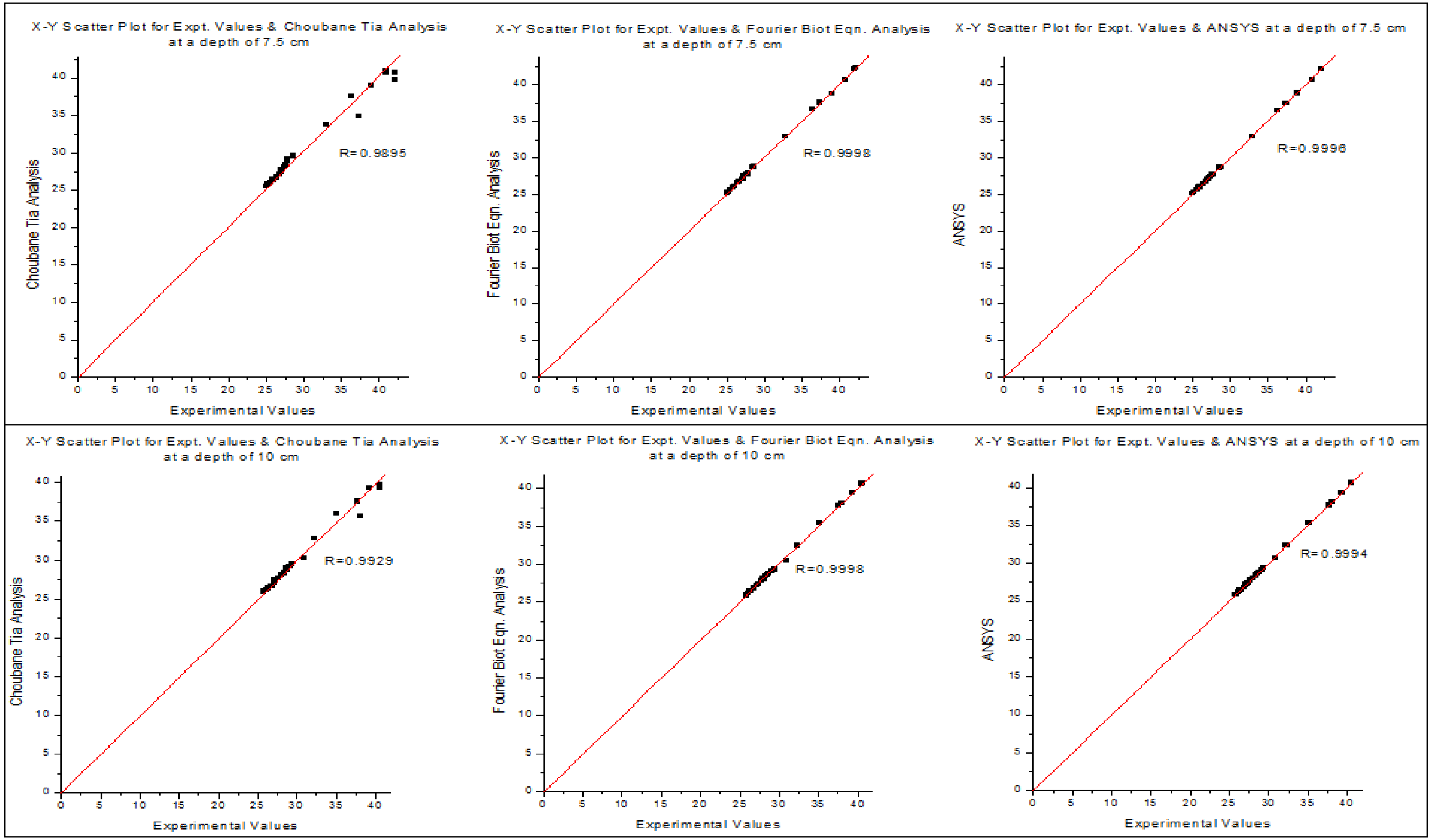


Fig. B-6 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

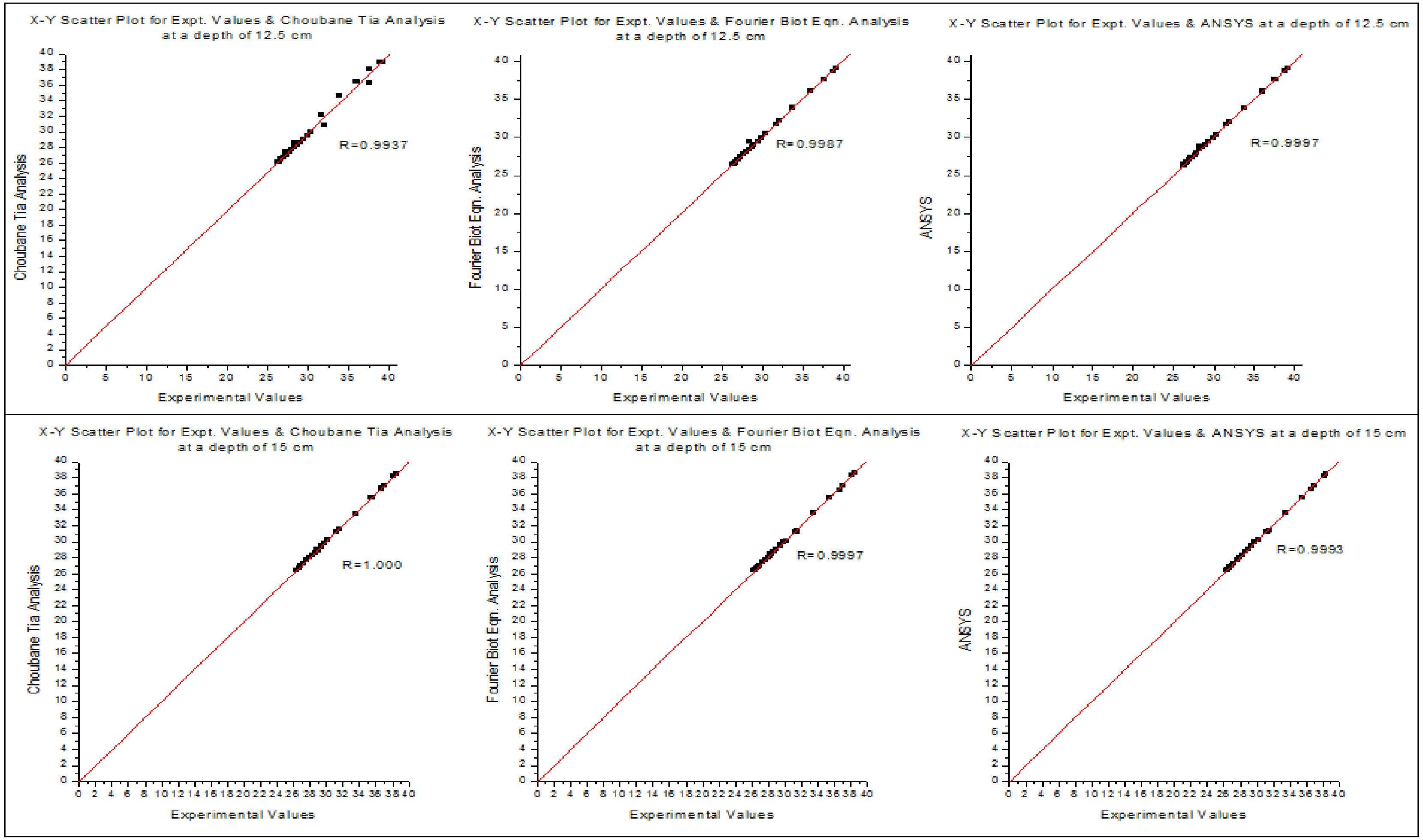


Fig. B-6 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

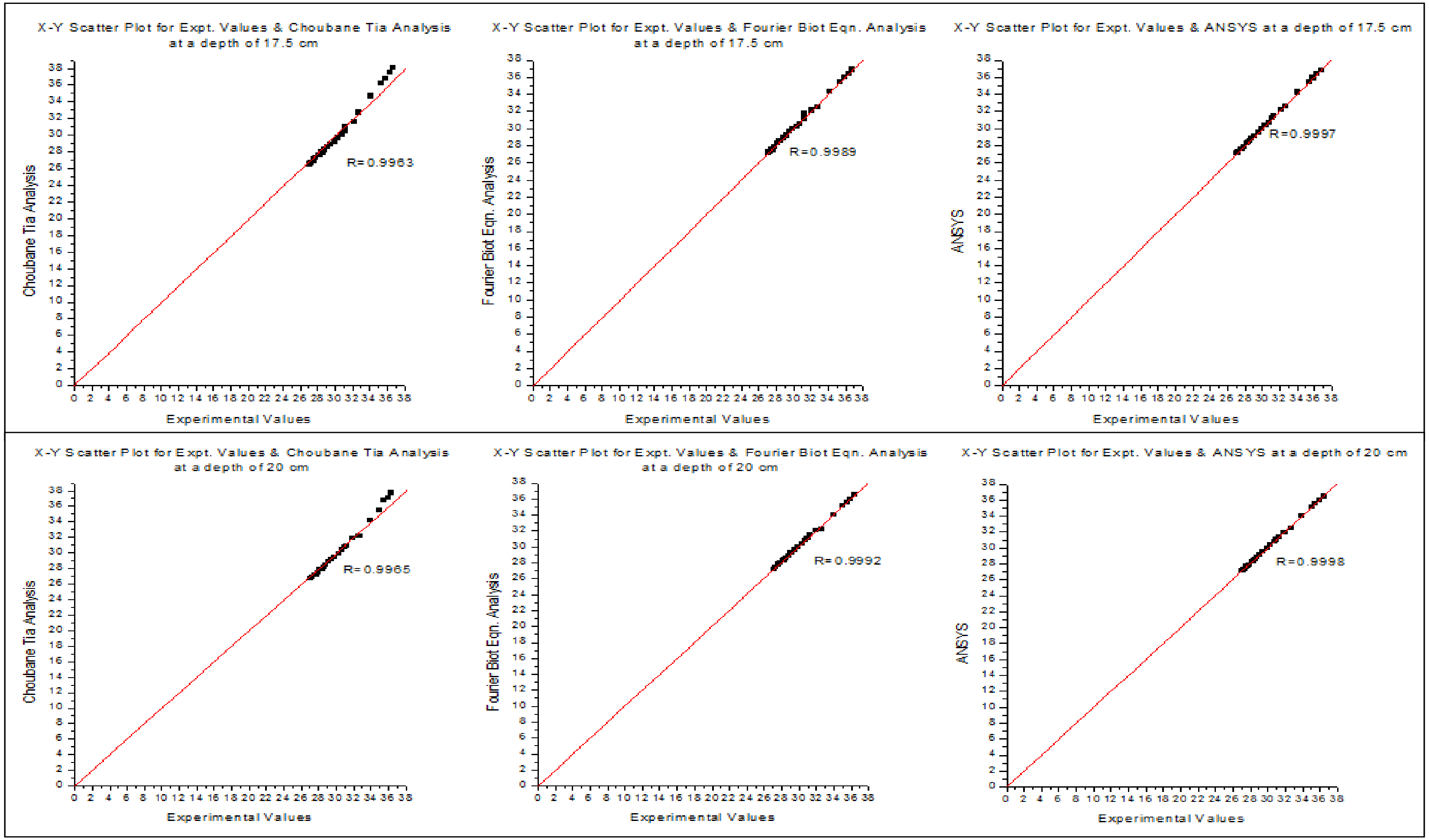


Fig. B-6 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

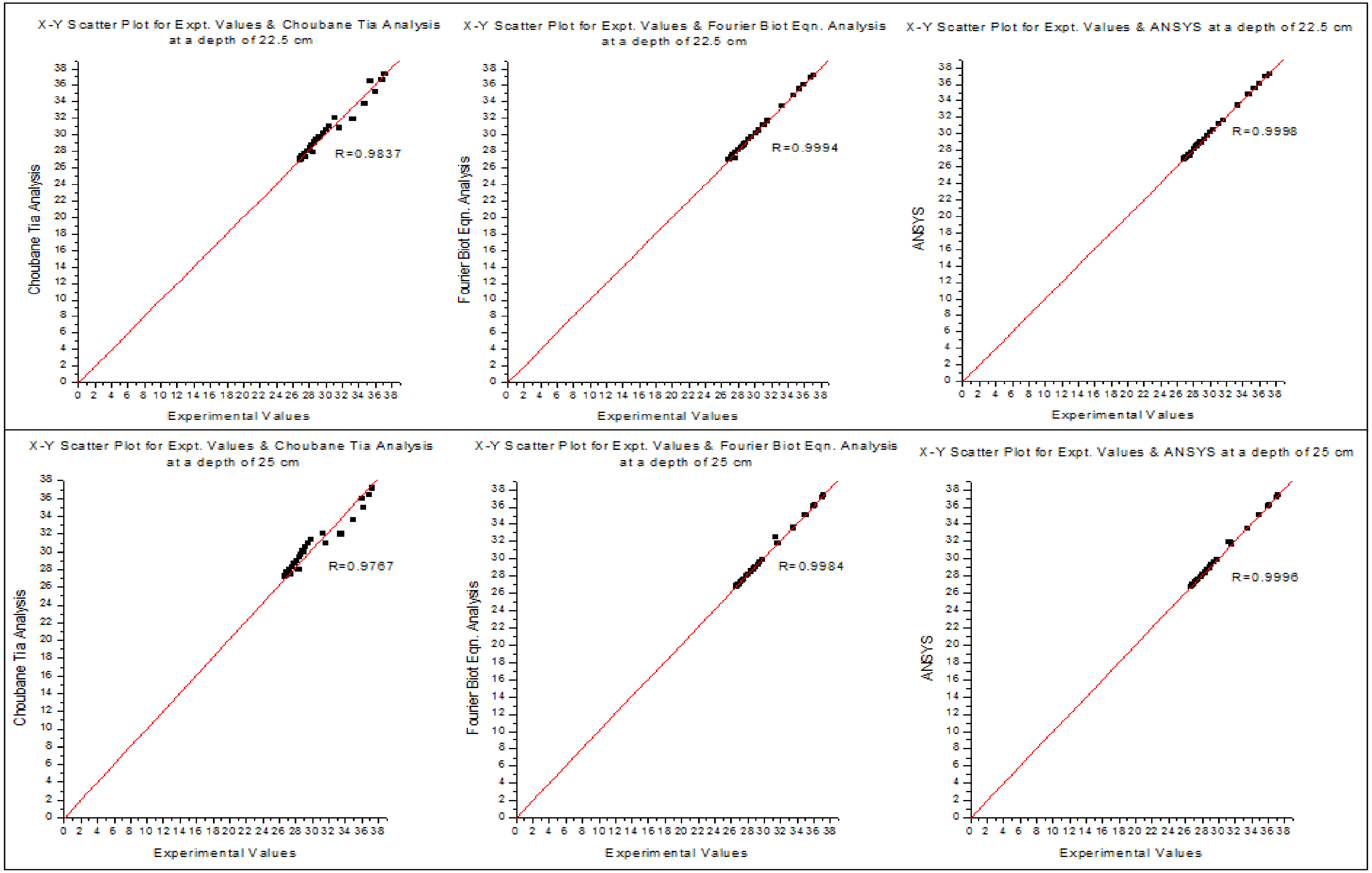


Fig. B-6 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

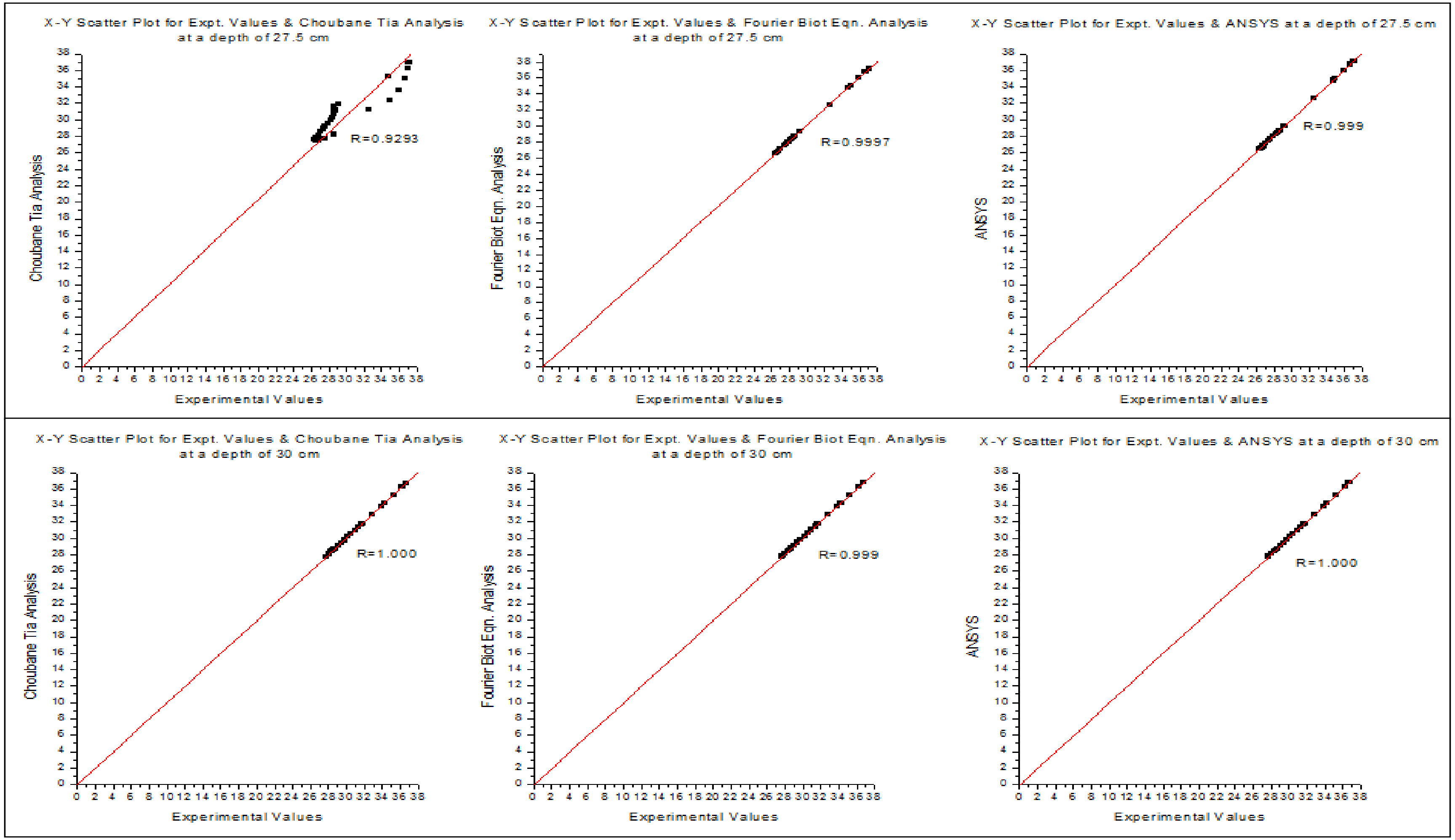


Fig. B-6 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

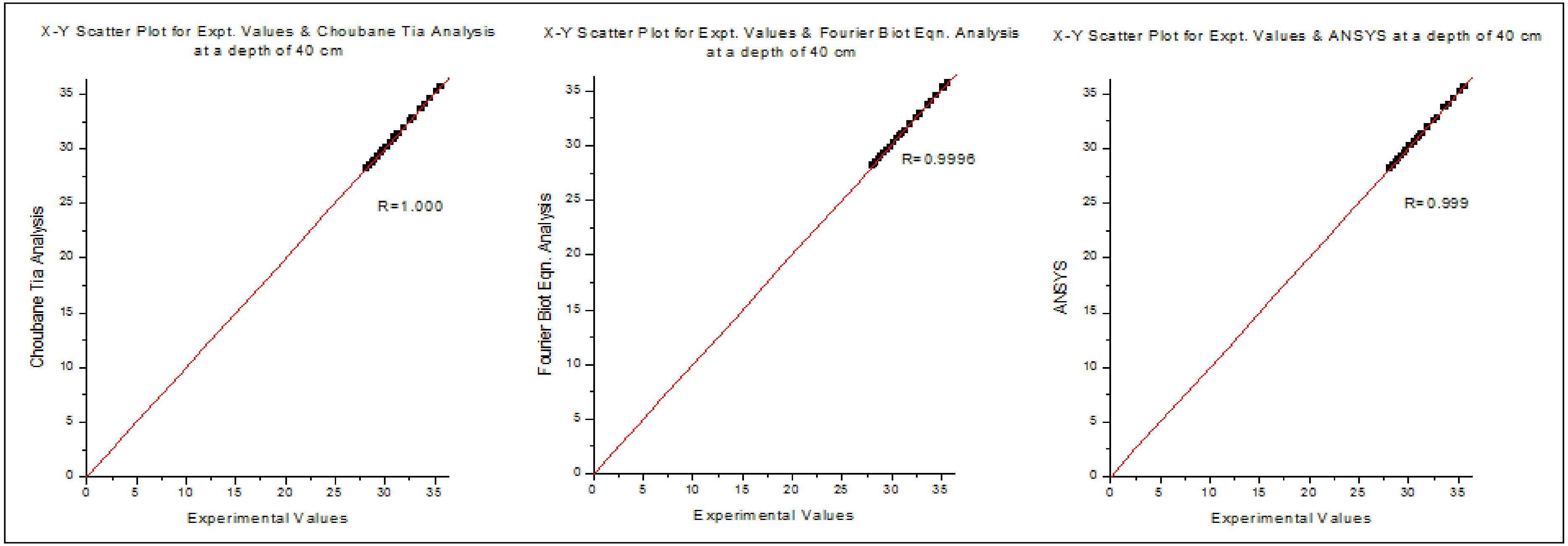


Fig. B-6 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-4 (a): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for part humid and part rainy condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	36	34.88	34.14	33.76	33.99	34.06	30.22	32.78	30.44	30.33	30.22	31.93	30.67	30.45
2	1130 to 1230	37	41.06	38.21	38.48	38.14	38.18	32.19	36.23	32.43	32.31	31.84	34.30	31.99	31.92
3	1230 to 1330	38	42.43	41.13	39.62	41.26	41.19	34.91	37.17	34.85	34.88	34.24	35.08	34.89	34.57
4	1330 to 1430	38	44.84	42.88	41.70	42.42	42.65	36.78	38.95	36.62	36.70	36.12	36.60	36.84	36.48
5	1430 to 1530	38	44.35	43.72	41.56	43.64	43.68	38.55	39.13	38.76	38.66	37.90	37.05	37.93	37.91
6	1530 to 1630	37	42.01	42.49	40.05	42.35	42.42	39.28	38.34	39.90	39.59	38.80	36.88	38.92	38.86
7	1630 to 1730	35	36.63	38.68	36.20	38.54	38.61	39.05	35.83	39.19	39.12	38.93	35.51	39.02	38.97
8	1730 to 1830	33	27.04	27.04	29.21	27.74	27.39	36.07	31.09	36.22	36.15	36.84	32.69	36.82	36.83
9	1830 to 1930	32	26.29	24.98	28.59	24.23	24.60	30.75	30.58	30.87	30.81	32.82	32.23	32.58	32.70
10	1930 to 2030	31	26.30	25.69	28.38	25.65	25.67	29.20	30.16	29.46	29.33	30.99	31.64	30.31	30.65
11	2030 to 2130	29	25.95	25.83	27.87	25.53	25.68	28.61	29.52	28.37	28.49	30.10	30.90	30.25	30.17
12	2130 to 2230	28	25.64	26.02	27.44	26.28	26.15	28.12	28.99	28.34	28.23	29.41	30.29	29.23	29.32
13	2230 to 2330	28	25.83	26.25	27.43	26.50	26.38	27.79	28.80	27.55	27.67	28.90	29.94	28.24	28.57
14	2330 to 0030	27	25.62	26.20	27.10	26.36	26.28	27.55	28.38	27.46	27.51	28.59	29.45	28.71	28.65
15	0030 to 0130	27	25.31	25.72	26.74	25.37	25.55	27.25	27.96	27.26	27.26	28.24	28.99	28.18	28.21
16	0130 to 0230	26	25.14	25.58	26.51	25.16	25.37	26.96	27.69	27.02	26.99	27.89	28.68	28.00	27.94
17	0230 to 0330	26	24.58	25.07	25.97	25.26	25.16	26.77	27.18	26.91	26.84	27.57	28.20	27.72	27.64
18	0330 to 0430	25	24.23	24.59	25.61	24.15	24.37	26.38	26.81	26.50	26.44	27.21	27.81	27.37	27.29
19	0430 to 0530	25	24.19	24.38	25.49	24.14	24.26	26.01	26.61	26.10	26.05	26.90	27.55	27.00	26.95
20	0530 to 0630	26	24.10	24.41	25.33	24.33	24.37	25.80	26.39	25.23	25.52	26.70	27.29	26.85	26.77
21	0630 to 0730	28	24.50	24.65	25.57	24.15	24.40	25.63	26.50	25.81	25.72	26.46	27.28	26.54	26.50
22	0730 to 0830	29	25.61	25.61	26.34	25.79	25.70	25.72	26.96	25.67	25.70	26.44	27.48	26.79	26.62
23	0830 to 0930	31	27.34	27.13	27.59	27.22	27.18	26.17	27.80	26.79	26.48	26.73	27.96	26.89	26.81
24	0930 to 1030	33	29.98	29.55	29.56	29.11	29.33	27.05	29.18	27.20	27.12	27.31	28.84	27.26	27.28

Table B-4 (b): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for part humid and part rainy condition at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	29.94	31.22	29.62	29.78	30.09	30.65	30.21	30.15	30.22	30.22	30.40	30.31
2	1130 to 1230	31.01	32.69	31.62	31.32	30.91	31.40	31.04	30.98	30.44	30.44	30.60	30.52
3	1230 to 1330	32.75	33.35	32.16	32.45	32.39	31.98	32.36	32.38	30.97	30.97	31.06	31.01
4	1330 to 1430	34.41	34.65	34.92	34.67	33.90	33.09	33.66	33.78	31.93	31.93	32.05	31.99
5	1430 to 1530	35.96	35.31	35.98	35.97	35.26	33.93	35.69	35.48	32.90	32.90	32.47	32.69
6	1530 to 1630	37.05	35.66	36.96	37.00	36.39	34.69	36.51	36.45	33.96	33.96	34.03	34.00
7	1630 to 1730	37.79	35.26	37.77	37.78	37.07	35.06	37.20	37.14	34.91	34.91	35.00	34.96
8	1730 to 1830	37.29	34.01	37.52	37.41	36.85	35.05	36.92	36.89	35.81	35.81	35.86	35.83
9	1830 to 1930	34.27	33.57	34.37	34.32	34.74	34.58	34.23	34.48	35.26	35.26	35.33	35.30
10	1930 to 2030	32.48	32.83	32.20	32.34	33.14	33.71	33.12	33.13	34.31	34.31	34.35	34.33
11	2030 to 2130	31.38	32.01	31.16	31.27	32.14	32.84	32.10	32.12	33.40	33.40	33.45	33.43
12	2130 to 2230	30.62	31.33	30.75	30.68	31.28	32.12	31.39	31.34	32.65	32.65	32.70	32.68
13	2230 to 2330	30.00	30.86	30.10	30.05	30.67	31.55	30.79	30.73	32.02	32.02	32.06	32.04
14	2330 to 0030	29.50	30.31	29.71	29.61	30.15	30.97	30.27	30.21	31.41	31.41	31.55	31.48
15	0030 to 0130	29.05	29.82	29.11	29.08	29.66	30.46	29.80	29.73	30.89	30.89	30.94	30.92
16	0130 to 0230	28.71	29.48	28.85	28.78	29.24	30.09	29.35	29.29	30.51	30.51	30.58	30.54
17	0230 to 0330	28.39	29.02	28.48	28.44	28.88	29.65	28.95	28.91	30.10	30.10	30.15	30.12
18	0330 to 0430	28.05	28.63	28.04	28.05	28.58	29.27	28.72	28.65	29.71	29.71	29.77	29.74
19	0430 to 0530	27.67	28.32	27.84	27.75	28.22	28.92	28.33	28.27	29.34	29.34	29.42	29.38
20	0530 to 0630	27.36	28.02	27.51	27.43	27.89	28.59	28.06	27.98	28.99	28.99	29.04	29.01
21	0630 to 0730	27.08	27.91	27.20	27.14	27.58	28.39	27.70	27.64	28.72	28.72	28.78	28.75
22	0730 to 0830	26.92	27.89	27.03	26.97	27.37	28.20	27.41	27.39	28.41	28.41	28.44	28.43
23	0830 to 0930	26.99	28.08	26.85	26.92	27.37	28.16	27.44	27.41	28.20	28.20	28.26	28.23
24	0930 to 1030	27.35	28.55	27.35	27.35	27.60	28.30	27.76	27.68	28.10	28.10	28.16	28.13

Table B-4 (c): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for part humid and part rainy condition at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	30.31	29.93	30.47	30.39	30.21	29.77	30.45	30.33	30.17	29.75	30.21	30.19
2	1130 to 1230	30.58	29.79	30.65	30.62	30.48	29.46	30.64	30.56	30.64	29.46	30.09	30.37
3	1230 to 1330	31.19	30.31	31.29	31.24	31.03	30.02	31.27	31.15	31.65	30.09	30.79	31.22
4	1330 to 1430	32.27	31.17	32.45	32.36	32.09	30.80	32.19	32.14	33.08	30.83	33.07	33.07
5	1430 to 1530	33.33	32.22	33.45	33.39	33.20	31.89	33.19	33.20	34.62	31.92	34.70	34.66
6	1530 to 1630	34.44	33.48	34.59	34.51	34.41	33.25	34.52	34.46	36.14	33.26	36.25	36.19
7	1630 to 1730	32.10	34.83	32.16	32.13	37.89	34.80	37.95	37.92	37.33	34.83	37.45	37.39
8	1730 to 1830	35.35	36.28	35.11	35.23	37.28	36.47	37.40	37.34	37.90	36.38	38.03	37.96
9	1830 to 1930	35.21	35.62	35.08	35.15	36.10	35.65	36.21	36.15	35.83	35.36	35.92	35.88
10	1930 to 2030	33.89	34.60	33.94	33.91	34.60	34.60	34.71	34.66	34.07	34.30	34.11	34.09
11	2030 to 2130	32.56	33.69	32.63	32.59	33.55	33.70	33.67	33.61	32.88	33.45	32.94	32.91
12	2130 to 2230	31.35	32.93	31.44	31.39	32.71	32.96	32.82	32.76	32.05	32.73	32.01	32.03
13	2230 to 2330	30.99	32.26	31.05	31.02	32.04	32.28	32.02	32.03	31.35	32.08	31.44	31.39
14	2330 to 0030	30.63	31.65	30.72	30.67	31.41	31.68	31.55	31.48	30.77	31.50	30.83	30.80
15	0030 to 0130	30.84	31.13	30.92	30.88	30.88	31.17	30.97	30.93	30.33	31.01	30.41	30.37
16	0130 to 0230	30.53	30.74	30.61	30.57	30.50	30.78	30.61	30.56	29.88	30.63	29.95	29.91
17	0230 to 0330	30.14	30.35	30.32	30.23	30.08	30.41	30.15	30.11	29.48	30.27	29.55	29.52
18	0330 to 0430	29.77	29.97	29.91	29.84	29.70	30.04	29.81	29.76	29.12	29.93	29.23	29.18
19	0430 to 0530	29.40	29.58	29.59	29.50	29.33	29.65	29.42	29.38	28.80	29.55	28.92	28.86
20	0530 to 0630	29.05	29.22	29.02	29.03	28.97	29.29	29.01	28.99	28.50	29.19	28.61	28.56
21	0630 to 0730	28.74	28.91	28.87	28.81	28.69	28.95	28.74	28.72	28.14	28.84	28.23	28.18
22	0730 to 0830	28.48	28.52	28.52	28.50	28.39	28.52	28.50	28.44	27.85	28.42	27.97	27.91
23	0830 to 0930	28.25	28.20	28.35	28.30	28.17	28.15	28.28	28.22	27.73	28.06	27.85	27.79
24	0930 to 1030	28.20	27.94	28.28	28.24	28.10	27.82	28.17	28.13	27.82	27.75	27.90	27.86

Table B-4 (d): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for part humid and part rainy condition at 25 cm, 27.5 cm, 30 cm &40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	30.47	29.87	30.54	30.50	31.28	30.12	31.36	31.32	30.52	30.52	30.65	30.58	30.90	30.90	30.93	30.91
2	1130 to 1230	31.13	29.77	31.44	31.29	33.05	30.41	33.03	33.04	31.37	31.37	31.44	31.40	32.38	32.38	32.44	32.41
3	1230 to 1330	32.55	30.52	32.66	32.60	35.64	31.31	35.73	35.69	32.45	32.45	32.57	32.51	34.92	34.92	34.91	34.91
4	1330 to 1430	34.12	31.26	34.25	34.19	37.76	32.08	37.88	37.82	33.30	33.30	33.45	33.38	36.29	36.29	36.34	36.32
5	1430 to 1530	35.87	32.29	35.95	35.91	40.05	33.02	40.02	40.04	34.09	34.09	34.15	34.12	37.09	37.09	37.13	37.11
6	1530 to 1630	37.28	33.52	37.40	37.34	40.75	34.03	40.81	40.78	34.78	34.78	34.84	34.81	36.46	36.46	36.51	36.48
7	1630 to 1730	38.13	34.91	38.30	38.21	39.54	35.06	39.61	39.58	35.26	35.26	35.31	35.28	35.52	35.52	35.58	35.55
8	1730 to 1830	37.11	36.01	37.22	37.16	33.37	35.35	33.51	33.44	34.42	34.42	34.48	34.45	30.05	30.05	30.09	30.07
9	1830 to 1930	34.45	34.75	34.51	34.48	31.21	33.80	31.31	31.26	32.54	32.54	32.61	32.57	27.76	27.76	27.80	27.78
10	1930 to 2030	33.00	33.71	33.10	33.05	30.76	32.81	30.88	30.82	31.63	31.63	31.70	31.66	27.71	27.71	27.77	27.74
11	2030 to 2130	32.15	32.92	32.22	32.19	30.32	32.11	30.45	30.38	31.04	31.04	31.00	31.02	27.49	27.49	27.52	27.51
12	2130 to 2230	31.43	32.24	31.51	31.47	29.87	31.51	29.97	29.92	30.51	30.51	30.60	30.56	27.26	27.26	27.30	27.28
13	2230 to 2330	30.86	31.64	30.95	30.91	29.46	30.99	29.58	29.52	30.10	30.10	30.16	30.13	27.05	27.05	27.11	27.08
14	2330 to 0030	30.43	31.11	30.50	30.47	29.13	30.52	29.21	29.17	29.72	29.72	29.80	29.76	26.90	26.90	27.00	26.95
15	0030 to 0130	29.99	30.65	30.07	30.03	28.84	30.10	28.93	28.89	29.35	29.35	29.41	29.38	26.80	26.80	26.88	26.84
16	0130 to 0230	29.61	30.29	29.72	29.66	28.61	29.76	28.70	28.66	29.04	29.04	29.10	29.07	26.68	26.68	26.73	26.71
17	0230 to 0330	29.25	29.95	29.33	29.29	28.28	29.44	28.37	28.32	28.73	28.73	28.80	28.77	26.48	26.48	26.54	26.51
18	0330 to 0430	28.91	29.62	29.00	28.95	27.96	29.13	28.03	28.00	28.46	28.46	28.52	28.49	26.26	26.26	26.32	26.29
19	0430 to 0530	28.65	29.27	28.77	28.71	27.63	28.81	27.71	27.67	28.18	28.18	28.24	28.21	26.09	26.09	26.14	26.12
20	0530 to 0630	28.29	28.92	28.37	28.33	27.25	28.49	27.33	27.29	27.90	27.90	27.95	27.92	25.95	25.95	26.00	25.98
21	0630 to 0730	27.94	28.59	28.01	27.98	27.00	28.19	27.08	27.04	27.64	27.64	27.70	27.67	25.89	25.89	25.94	25.92
22	0730 to 0830	27.72	28.22	27.83	27.78	27.18	27.91	27.27	27.23	27.50	27.50	27.56	27.53	26.00	26.00	26.04	26.02
23	0830 to 0930	27.71	27.92	27.81	27.76	27.56	27.75	27.64	27.60	27.53	27.53	27.60	27.56	26.36	26.36	26.42	26.39
24	0930 to 1030	27.95	27.72	28.03	27.99	28.37	27.74	28.46	28.41	27.80	27.80	27.84	27.82	26.97	26.97	27.02	27.00

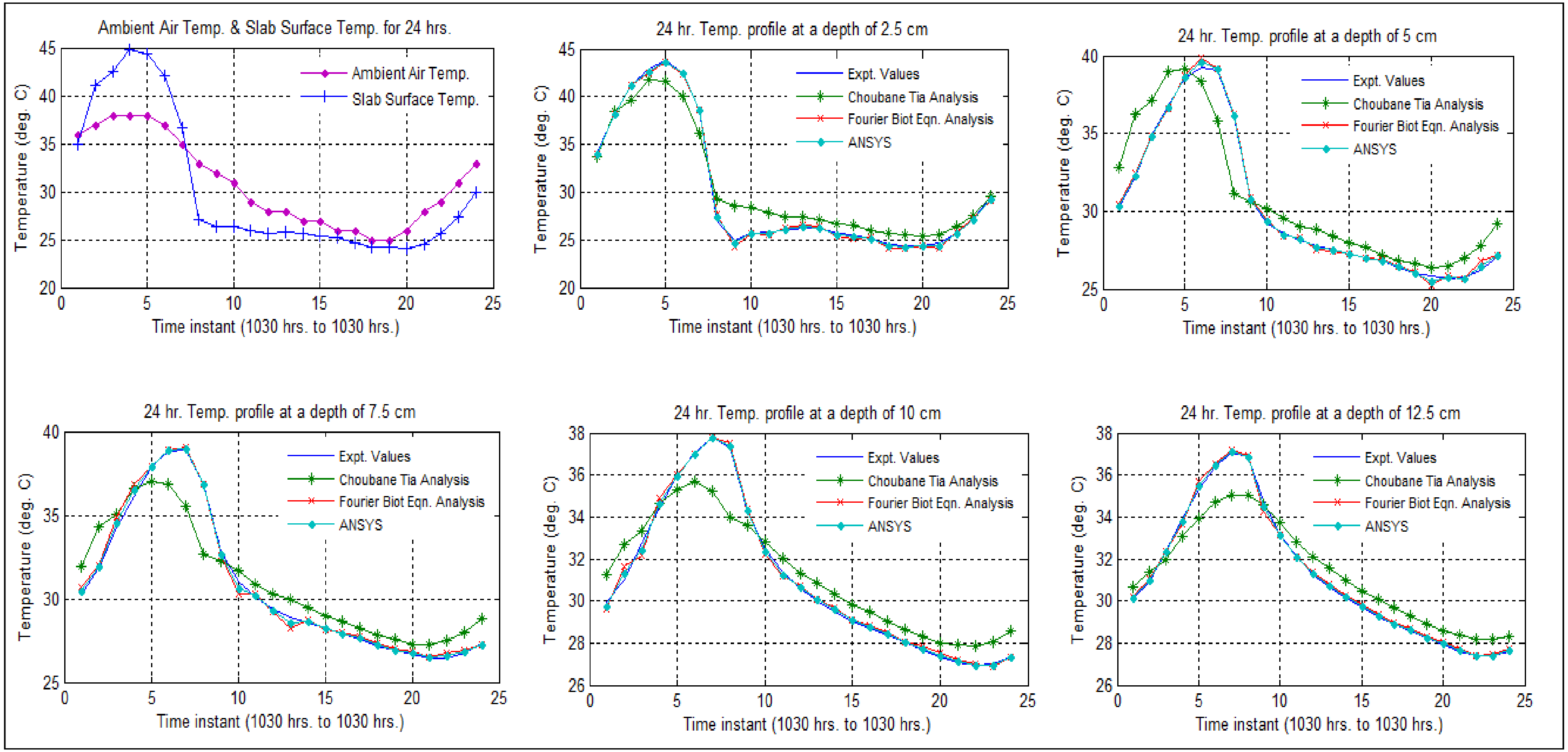


Fig. B-7 (a): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix A for part humid and part rainy condition (surface to 12.5 cm)

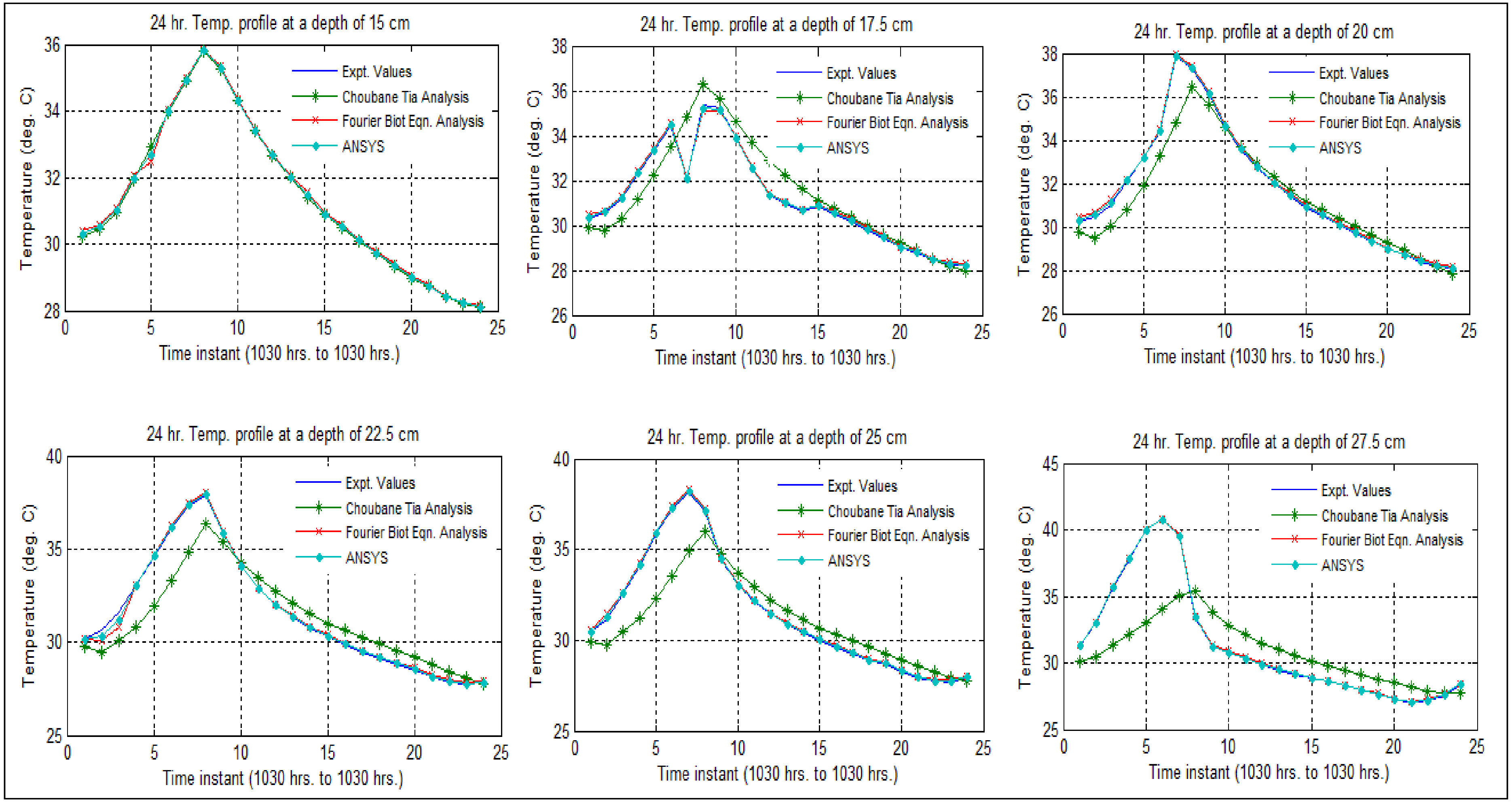


Fig. B-7 (b): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix A for part humid and part rainy condition (15 cm to 27.5 cm)

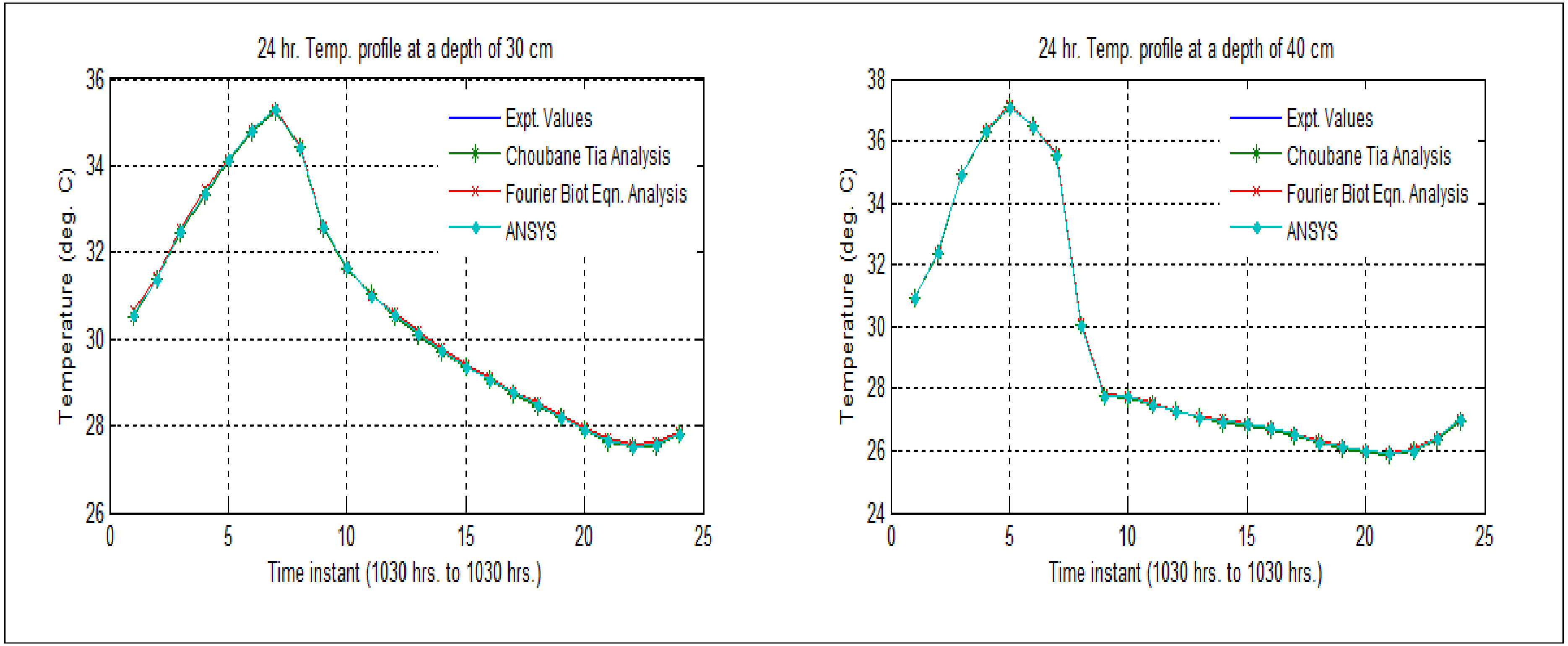


Fig. B-7 (c): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix A for part humid and part rainy condition (30 cm & 40 cm)

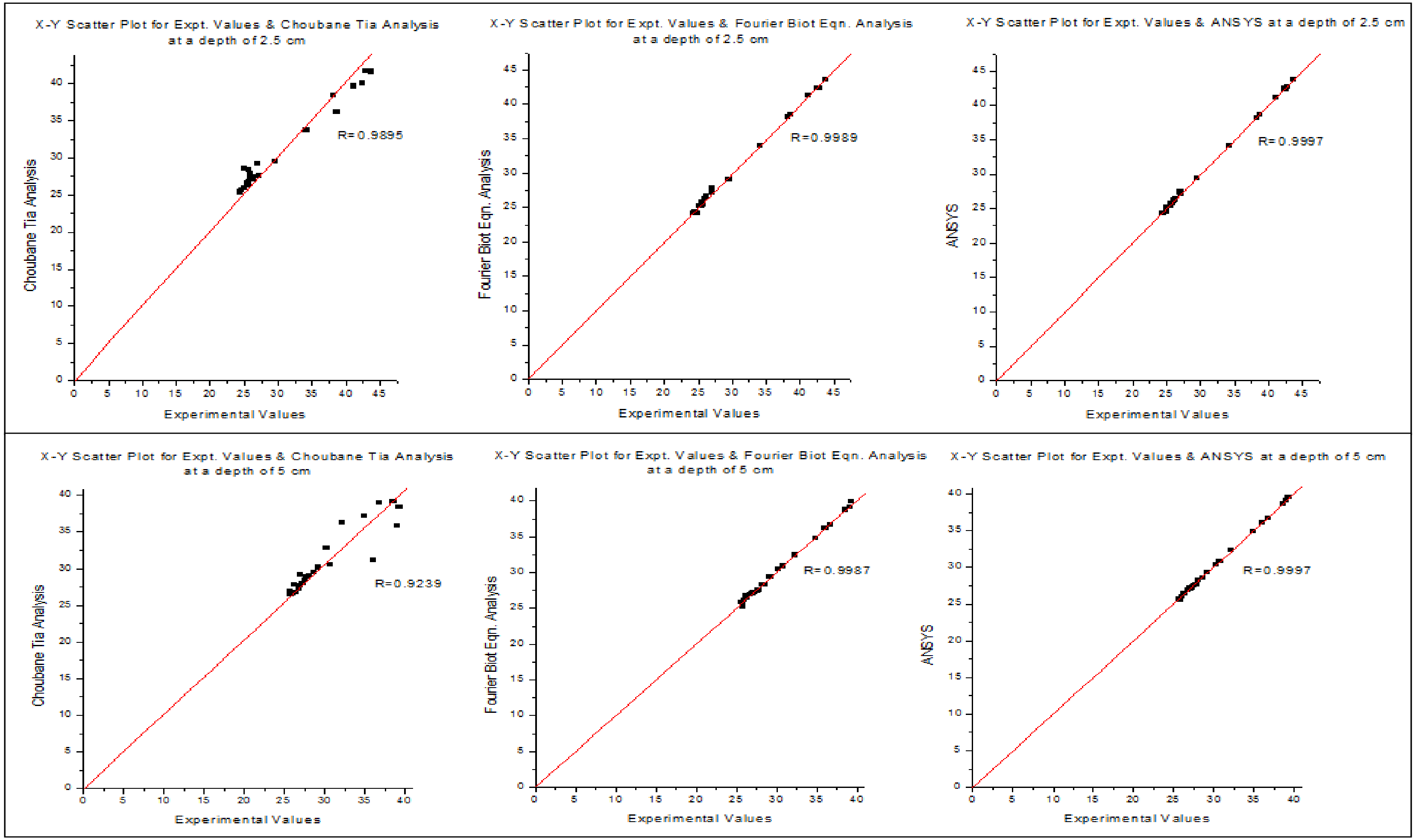


Fig. B-8 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

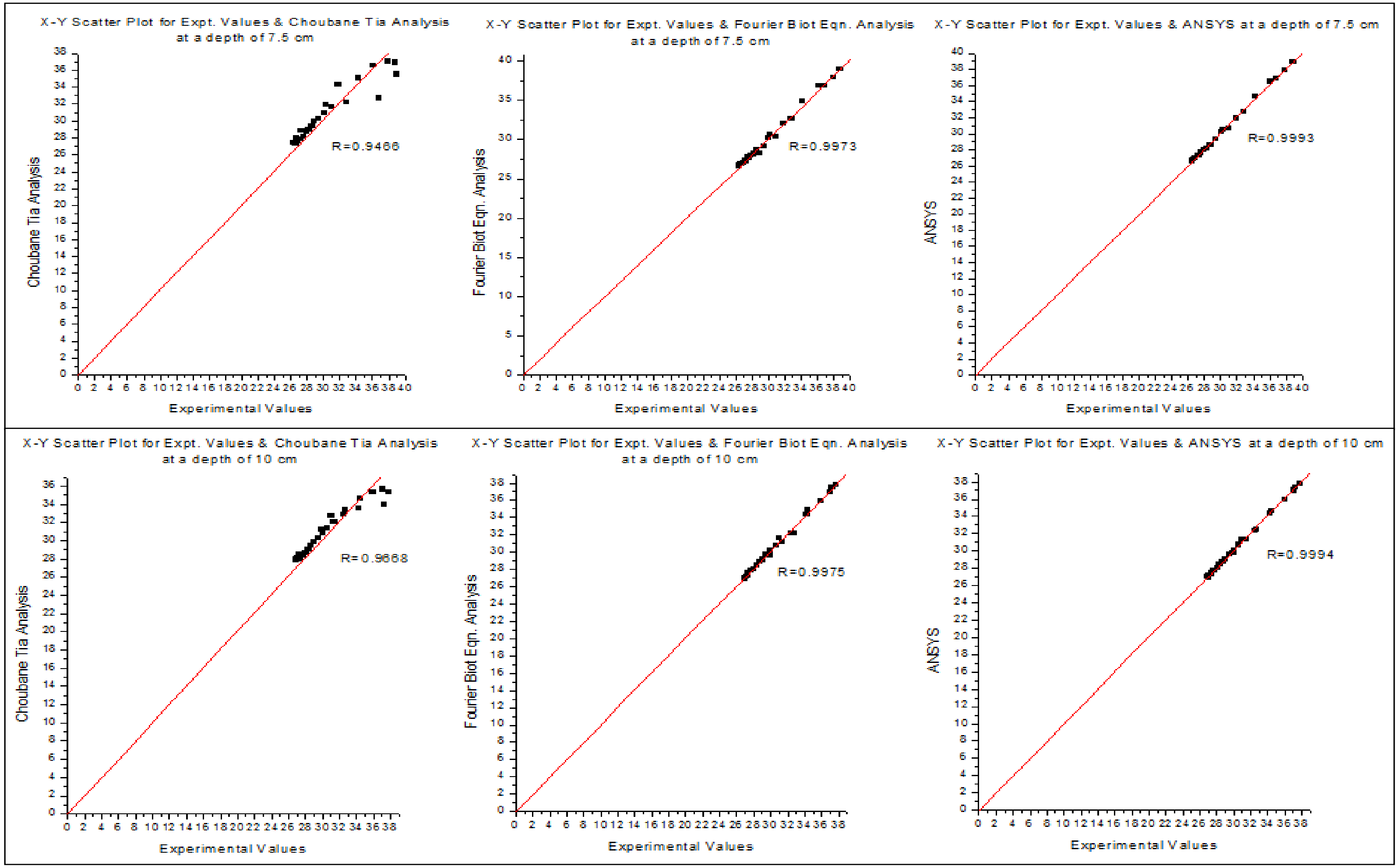


Fig. B-8 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

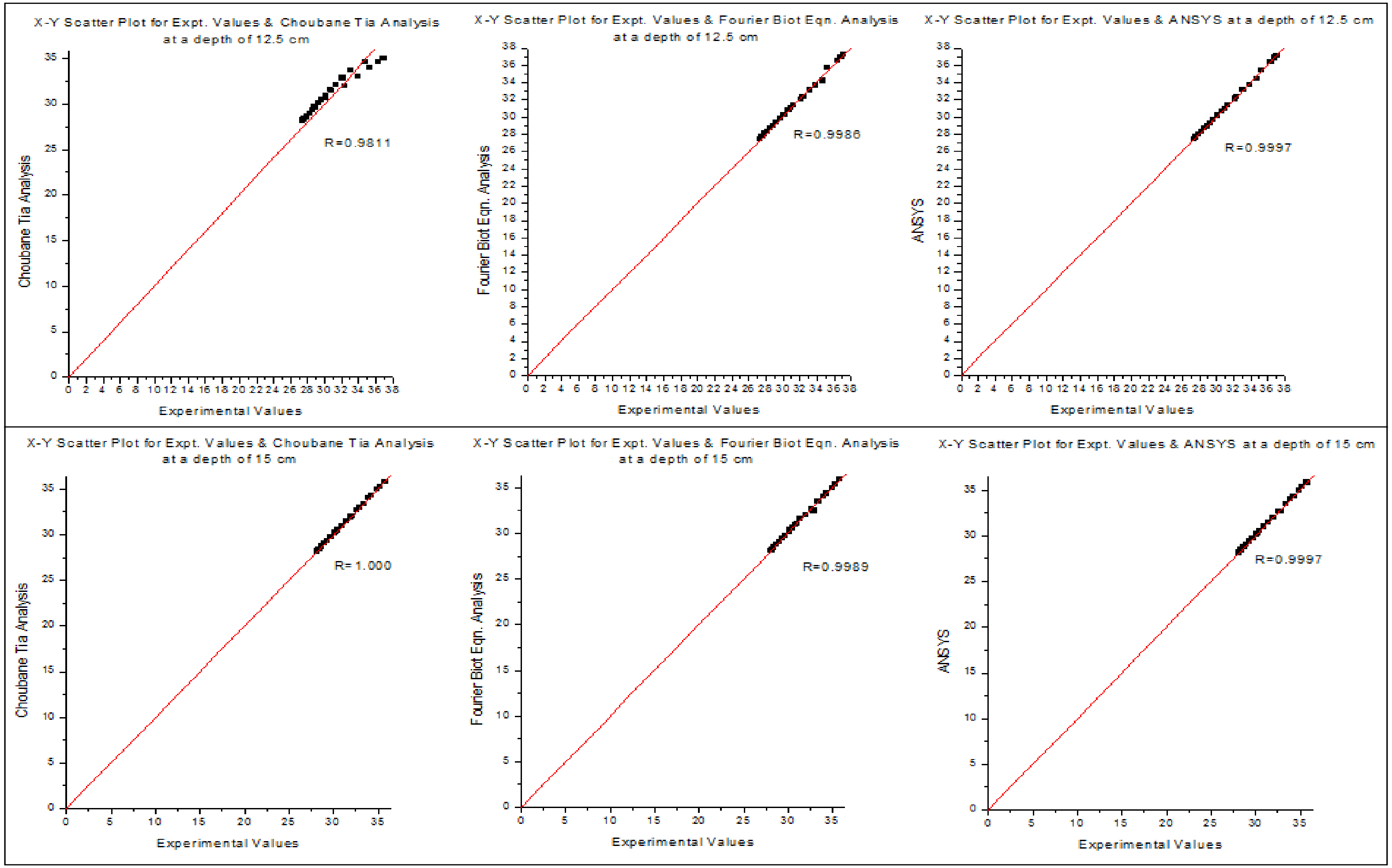


Fig. B-8 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

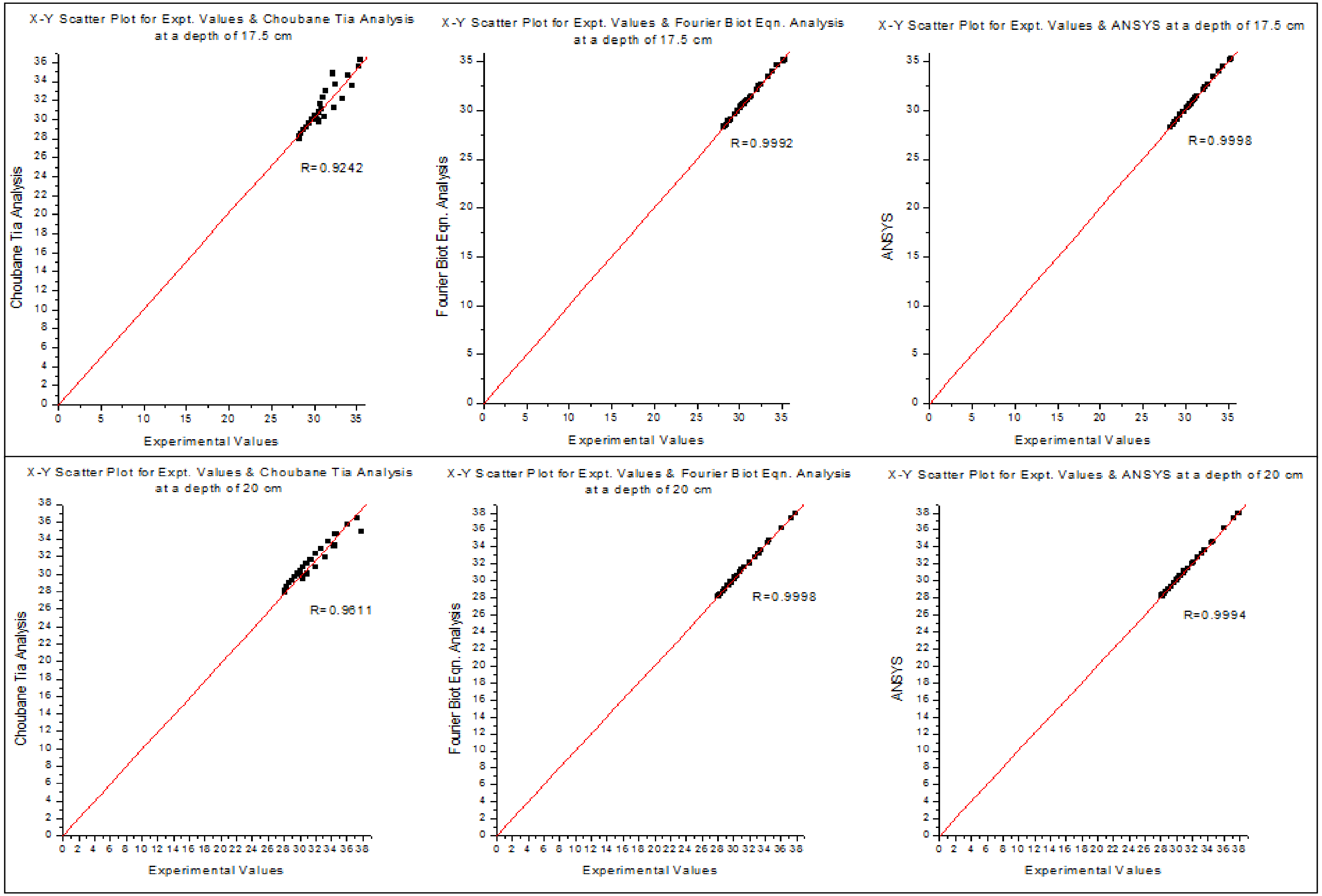


Fig. B-8 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

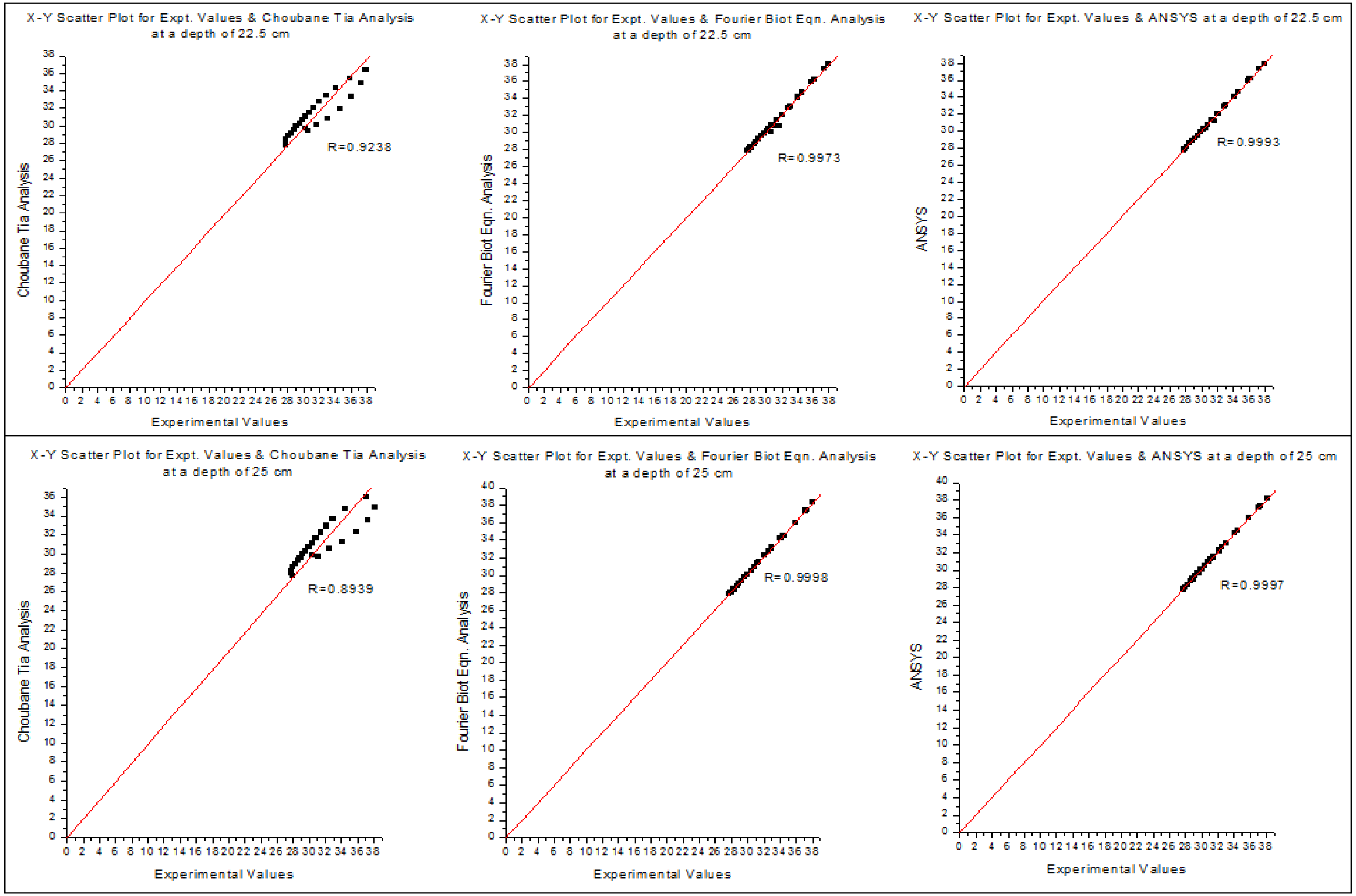


Fig. B-8 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

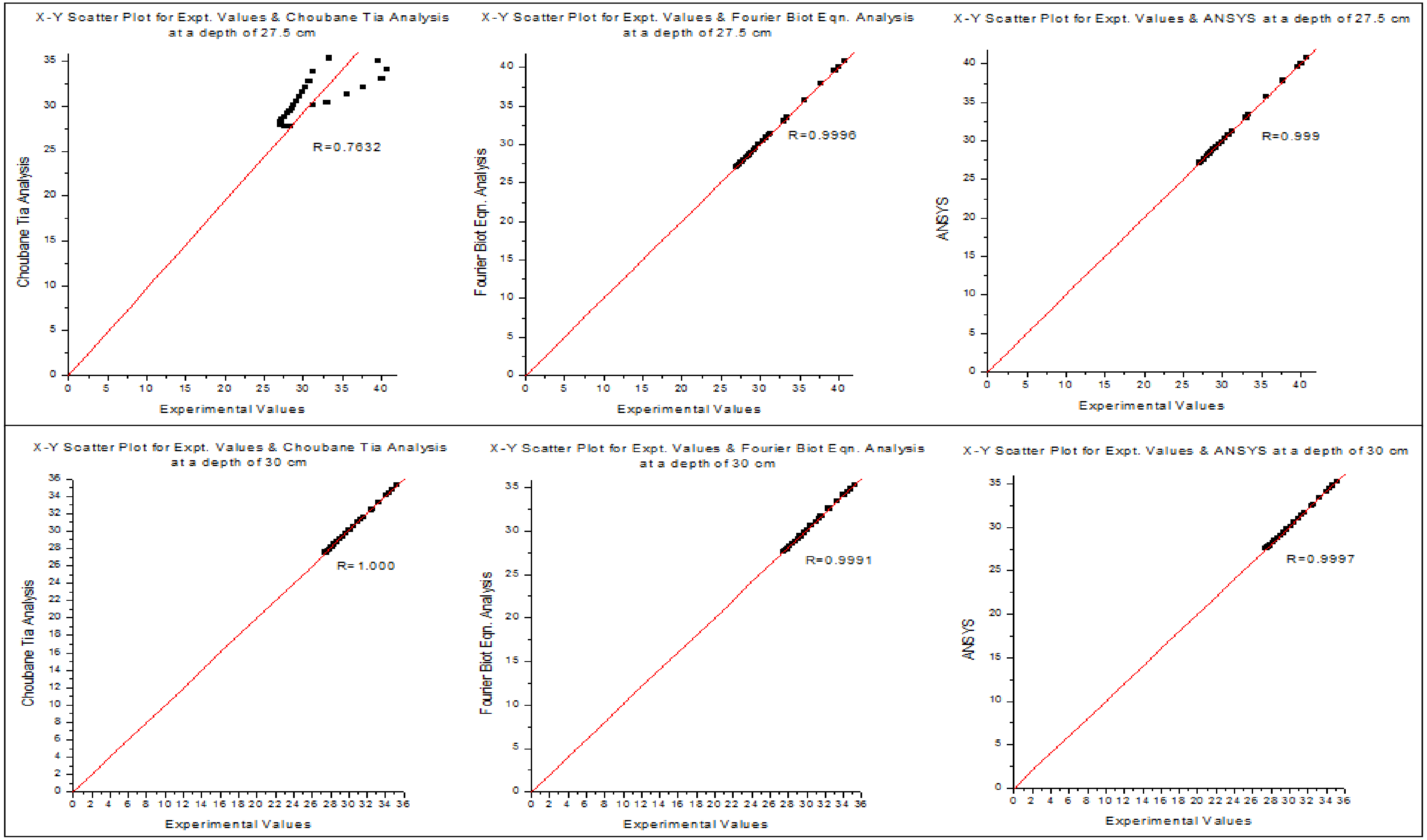


Fig. B-8 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

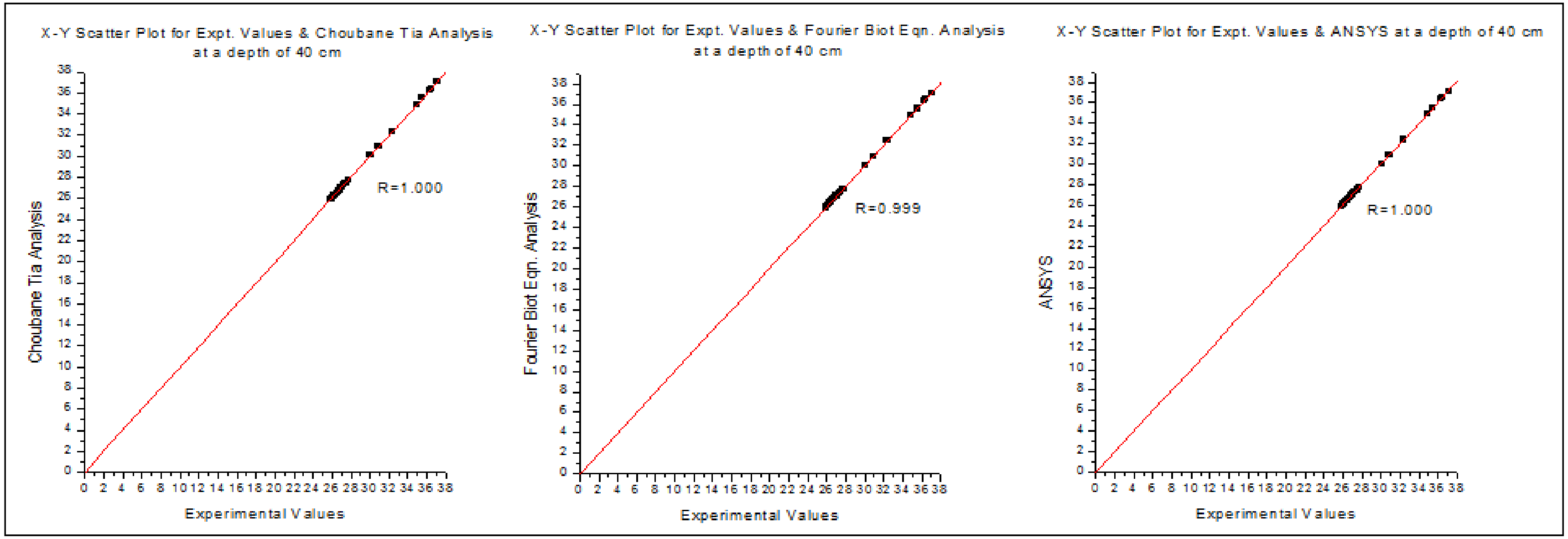


Fig. B-8 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-5 (a): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for 24 hr. cloudy and humid condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	27	32.72	29.82	30.76	29.42	29.62	28.28	29.00	28.64	28.46	26.47	27.45	26.46	26.46
2	1200 to 1300	29	36.81	33.25	34.44	33.40	33.32	31.76	32.30	31.82	31.79	29.61	30.38	29.26	29.43
3	1300 to 1400	30	39.79	35.73	37.26	35.34	35.53	34.48	34.96	34.69	34.58	32.22	32.88	32.84	32.53
4	1400 to 1500	30	41.34	38.41	38.95	38.55	38.48	36.84	36.75	36.05	36.45	34.48	34.73	34.08	34.28
5	1500 to 1600	30	36.87	37.99	35.85	37.60	37.79	37.28	34.85	37.58	37.43	35.43	33.87	35.44	35.43
6	1600 to 1700	29	30.95	32.82	31.16	33.00	32.91	33.40	31.27	33.82	33.61	33.12	31.27	33.89	33.51
7	1700 to 1800	28	28.98	29.73	29.31	29.91	29.82	30.26	29.55	30.64	30.45	30.54	29.71	30.43	30.48
8	1800 to 1900	27	27.67	27.93	27.96	27.32	27.63	28.34	28.19	28.63	28.48	28.68	28.37	28.63	28.65
9	1900 to 2000	26	26.30	26.55	26.63	26.03	26.29	26.89	26.92	26.72	26.80	27.30	27.17	27.01	27.16
10	2000 to 2100	24	25.53	25.45	25.82	25.61	25.53	25.71	26.08	25.72	25.71	26.18	26.31	26.31	26.25
11	2100 to 2200	24	24.88	24.80	25.15	24.79	24.79	24.92	25.40	24.85	24.89	25.32	25.63	25.48	25.40
12	2200 to 2300	23	23.78	24.21	24.16	24.84	24.53	24.31	24.52	24.89	24.60	24.77	24.86	24.93	24.85
13	2300 to 0000	23	22.28	22.59	22.84	22.15	22.37	22.88	23.37	22.11	22.49	23.63	23.86	23.47	23.55
14	0000 to 0100	23	21.58	22.01	22.10	22.36	22.18	22.05	22.58	22.25	22.15	22.72	23.05	22.17	22.44
15	0100 to 0200	23	21.38	21.69	21.75	21.52	21.61	21.64	22.13	21.37	21.50	22.14	22.51	22.25	22.19
16	0200 to 0300	23	21.00	21.38	21.36	21.59	21.49	21.27	21.72	21.42	21.35	21.68	22.09	21.28	21.48
17	0300 to 0400	22	20.69	20.92	21.00	20.32	20.62	20.82	21.33	20.23	20.52	21.28	21.66	21.15	21.22
18	0400 to 0500	22	20.64	20.67	20.86	20.34	20.50	20.53	21.11	20.24	20.38	20.92	21.37	20.16	20.54
19	0500 to 0600	22	20.30	20.40	20.53	20.42	20.41	20.26	20.78	20.30	20.28	20.64	21.05	20.20	20.42
20	0600 to 0700	21	20.12	20.17	20.32	20.17	20.17	20.01	20.54	20.12	20.07	20.34	20.79	20.08	20.21
21	0700 to 0800	22	20.29	20.22	20.43	20.52	20.37	20.00	20.59	20.37	20.18	20.22	20.79	20.25	20.23
22	0800 to 0900	22	21.36	20.99	21.27	20.67	20.83	20.48	21.23	20.47	20.47	20.59	21.24	20.32	20.45
23	0900 to 1000	24	23.60	22.78	23.14	22.91	22.85	21.99	22.76	22.05	22.02	21.77	22.47	21.38	21.57
24	1000 to 1100	26	26.30	24.52	25.39	24.80	24.66	23.44	24.61	23.09	23.26	22.94	23.95	22.75	22.84

Table B-5 (b): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for 24 hr. cloudy and humid condition at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (ºC) at 10 cm				Temperature (ºC) at 12.5 cm				Temperature (ºC) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	25.46	26.11	25.84	25.65	24.30	24.97	24.74	24.52	24.05	24.05	24.10	24.07
2	1200 to 1300	28.12	28.69	28.35	28.24	26.45	27.24	26.05	26.25	26.01	26.01	26.29	26.15
3	1300 to 1400	30.57	31.01	30.72	30.65	28.57	29.37	28.27	28.42	27.94	27.94	27.44	27.69
4	1400 to 1500	32.71	32.89	32.88	32.80	30.52	31.24	30.37	30.44	29.77	29.77	29.50	29.63
5	1500 to 1600	33.99	32.90	33.11	33.55	31.92	31.94	31.51	31.72	31.00	31.00	31.59	31.29
6	1600 to 1700	32.70	31.18	32.81	32.76	31.45	30.97	31.74	31.59	30.67	30.67	30.47	30.57
7	1700 to 1800	30.87	29.78	30.87	30.87	30.30	29.76	30.17	30.23	29.66	29.66	29.11	29.38
8	1800 to 1900	29.30	28.49	29.40	29.35	29.03	28.56	29.24	29.14	28.57	28.57	28.15	28.36
9	1900 to 2000	28.12	27.37	28.22	28.17	28.06	27.54	28.01	28.03	27.66	27.66	27.40	27.53
10	2000 to 2100	27.05	26.53	26.95	27.00	27.14	26.71	27.04	27.09	26.88	26.88	26.95	26.92
11	2100 to 2200	26.28	25.86	26.44	26.36	26.48	26.06	26.26	26.37	26.26	26.26	26.08	26.17
12	2200 to 2300	25.65	25.17	25.49	25.57	25.89	25.46	25.79	25.84	25.74	25.74	25.98	25.86
13	2300 to 0000	24.74	24.31	24.65	24.70	25.19	24.73	25.03	25.11	25.10	25.10	25.02	25.06
14	0000 to 0100	23.78	23.50	23.91	23.84	24.34	23.92	24.17	24.26	24.31	24.31	24.04	24.18
15	0100 to 0200	23.16	22.88	23.16	23.16	23.61	23.25	23.46	23.53	23.62	23.62	23.06	23.34
16	0200 to 0300	22.67	22.45	22.78	22.72	23.17	22.82	23.11	23.14	23.19	23.19	23.07	23.13
17	0300 to 0400	22.17	22.00	22.30	22.24	22.69	22.35	22.56	22.62	22.71	22.71	22.04	22.37
18	0400 to 0500	21.75	21.66	21.90	21.83	22.25	21.97	22.13	22.19	22.30	22.30	22.04	22.17
19	0500 to 0600	21.54	21.34	21.70	21.62	21.95	21.65	22.08	22.02	21.99	21.99	21.75	21.87
20	0600 to 0700	21.28	21.07	21.40	21.34	21.67	21.37	21.81	21.74	21.69	21.69	21.42	21.56
21	0700 to 0800	21.09	21.01	21.16	21.12	21.52	21.27	21.30	21.41	21.55	21.55	21.36	21.46
22	0800 to 0900	21.26	21.30	21.20	21.23	21.55	21.41	21.32	21.43	21.58	21.58	21.38	21.48
23	0900 to 1000	22.03	22.26	22.30	22.16	22.05	22.13	22.20	22.12	22.09	22.09	22.34	22.21
24	1000 to 1100	22.90	23.41	22.75	22.83	22.67	22.99	22.80	22.74	22.69	22.69	22.68	22.68

Table B-5 (c): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for 24 hr. cloudy and humid condition at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (^{o}C) at 17.5 cm				Temperature (^{o}C) at 20 cm				Temperature (^{o}C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	23.36	23.34	23.61	23.48	23.14	22.83	23.33	23.24	23.69	22.53	23.17	23.43
2	1200 to 1300	24.70	25.00	24.72	24.71	24.37	24.23	24.55	24.46	25.25	23.68	25.20	25.22
3	1300 to 1400	26.12	26.74	26.80	26.46	25.65	25.76	25.95	25.80	26.79	24.99	26.22	26.51
4	1400 to 1500	27.52	28.48	27.83	27.68	26.99	27.37	26.94	26.97	28.27	26.45	28.23	28.25
5	1500 to 1600	28.68	30.07	28.88	28.78	28.03	29.16	28.34	28.19	29.17	28.27	29.24	29.20
6	1600 to 1700	28.79	30.25	28.26	28.53	28.23	29.74	28.68	28.45	29.03	29.12	29.07	29.05
7	1700 to 1800	28.51	29.48	28.06	28.29	28.00	29.21	28.03	28.01	28.62	28.85	28.42	28.52
8	1800 to 1900	27.89	28.53	27.09	27.49	27.51	28.43	27.34	27.43	27.88	28.28	27.62	27.75
9	1900 to 2000	27.30	27.73	27.00	27.15	27.02	27.77	27.00	27.01	27.19	27.76	27.00	27.09
10	2000 to 2100	26.80	27.02	26.69	26.74	26.59	27.14	26.89	26.74	26.66	27.23	26.39	26.53
11	2100 to 2200	26.34	26.44	26.20	26.27	26.13	26.61	26.01	26.07	26.13	26.77	26.00	26.06
12	2200 to 2300	25.91	25.98	25.99	25.95	25.72	26.21	25.59	25.66	25.67	26.41	25.40	25.53
13	2300 to 0000	25.39	25.44	25.21	25.30	25.19	25.74	25.01	25.10	25.05	26.01	25.00	25.03
14	0000 to 0100	24.83	24.69	24.42	24.63	24.68	25.04	24.42	24.55	24.41	25.37	24.20	24.30
15	0100 to 0200	24.27	23.99	24.03	24.15	24.14	24.36	24.02	24.08	23.84	24.72	23.52	23.68
16	0200 to 0300	23.79	23.55	23.44	23.62	23.68	23.93	23.42	23.55	23.38	24.30	23.12	23.25
17	0300 to 0400	23.37	23.08	23.02	23.20	23.32	23.46	23.11	23.22	23.01	23.85	23.01	23.01
18	0400 to 0500	23.06	22.65	23.02	23.04	22.99	23.03	23.01	23.00	22.66	23.42	22.41	22.53
19	0500 to 0600	22.74	22.34	22.53	22.64	22.67	22.72	22.46	22.57	22.37	23.12	22.09	22.23
20	0600 to 0700	22.44	22.04	22.11	22.27	22.40	22.42	22.29	22.34	22.07	22.82	22.00	22.04
21	0700 to 0800	22.21	21.87	22.03	22.12	22.14	22.21	22.02	22.08	21.87	22.59	21.60	21.74
22	0800 to 0900	22.15	21.80	22.04	22.10	22.11	22.07	22.02	22.07	21.89	22.39	21.63	21.76
23	0900 to 1000	22.46	22.12	22.19	22.33	22.38	22.24	22.10	22.24	22.32	22.43	22.15	22.23
24	1000 to 1100	22.81	22.51	22.37	22.59	22.65	22.46	22.40	22.52	22.69	22.53	22.10	22.39

Table B-5 (d): 24 hr. slab (edge) temperature values (measured and calculated) for Mix A for 24 hr. cloudy and humid condition at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	24.03	22.44	24.11	24.07	25.64	22.56	25.45	25.54	22.89	22.89	23.04	22.97	22.85	22.85	22.94	22.90
2	1200 to 1300	25.81	23.36	25.13	25.47	27.45	23.27	27.26	27.35	23.41	23.41	23.65	23.53	23.49	23.49	23.51	23.50
3	1300 to 1400	27.41	24.45	27.14	27.27	28.68	24.12	28.25	28.47	24.02	24.02	24.07	24.05	24.31	24.31	24.58	24.45
4	1400 to 1500	28.76	25.71	28.15	28.45	29.41	25.15	29.17	29.29	24.78	24.78	24.88	24.83	25.18	25.18	25.30	25.24
5	1500 to 1600	29.61	27.38	29.16	29.38	29.74	26.52	29.30	29.52	25.66	25.66	25.78	25.72	26.14	26.14	26.34	26.24
6	1600 to 1700	29.36	28.40	29.05	29.20	28.89	27.57	28.42	28.66	26.64	26.64	26.72	26.68	26.74	26.74	26.89	26.81
7	1700 to 1800	28.67	28.41	28.41	28.54	27.85	27.89	27.60	27.72	27.27	27.27	27.00	27.14	26.90	26.90	26.99	26.95
8	1800 to 1900	27.83	28.07	27.62	27.72	27.03	27.80	27.01	27.02	27.48	27.48	27.30	27.39	26.75	26.75	26.89	26.82
9	1900 to 2000	27.08	27.72	27.00	27.04	26.38	27.62	26.00	26.19	27.49	27.49	27.32	27.41	26.55	26.55	26.35	26.45
10	2000 to 2100	26.49	27.30	26.21	26.35	25.77	27.35	25.40	25.59	27.37	27.37	27.25	27.31	26.29	26.29	26.12	26.20
11	2100 to 2200	25.94	26.91	25.70	25.82	25.28	27.04	25.00	25.14	27.15	27.15	27.10	27.13	26.03	26.03	25.91	25.97
12	2200 to 2300	25.46	26.60	25.26	25.36	24.86	26.76	24.70	24.78	26.90	26.90	27.00	26.95	25.79	25.79	25.59	25.69
13	2300 to 0000	24.82	26.23	24.60	24.71	23.68	26.42	24.00	23.84	26.57	26.57	26.69	26.63	25.43	25.43	25.29	25.36
14	0000 to 0100	24.06	25.67	24.00	24.03	23.11	25.96	23.00	23.05	26.22	26.22	26.35	26.28	25.01	25.01	25.00	25.01
15	0100 to 0200	23.50	25.08	23.32	23.41	22.83	25.44	23.00	22.92	25.80	25.80	25.68	25.74	24.65	24.65	24.48	24.57
16	0200 to 0300	23.16	24.67	23.01	23.08	22.50	25.05	22.40	22.45	25.43	25.43	25.34	25.38	24.32	24.32	24.28	24.30
17	0300 to 0400	22.76	24.25	22.68	22.72	22.23	24.65	22.10	22.17	25.07	25.07	24.91	24.99	24.01	24.01	23.92	23.96
18	0400 to 0500	22.41	23.84	22.22	22.32	21.98	24.27	22.00	21.99	24.73	24.73	24.61	24.67	23.70	23.70	23.59	23.65
19	0500 to 0600	22.16	23.54	22.00	22.08	21.75	23.99	22.00	21.88	24.45	24.45	24.29	24.37	23.43	23.43	23.29	23.36
20	0600 to 0700	21.90	23.25	22.00	21.95	21.59	23.70	21.30	21.45	24.18	24.18	24.00	24.09	23.28	23.28	23.16	23.22
21	0700 to 0800	21.66	22.99	21.21	21.43	21.50	23.43	21.30	21.40	23.89	23.89	23.70	23.80	23.08	23.08	23.00	23.04
22	0800 to 0900	21.68	22.76	21.22	21.45	21.59	23.18	21.31	21.45	23.66	23.66	23.50	23.58	22.93	22.93	23.00	22.96
23	0900 to 1000	22.12	22.72	22.03	22.08	22.15	23.08	22.00	22.08	23.52	23.52	23.40	23.46	22.96	22.96	23.00	22.98
24	1000 to 1100	22.61	22.71	22.27	22.44	23.00	23.02	22.88	22.94	23.45	23.45	23.20	23.33	23.07	23.07	23.00	23.03

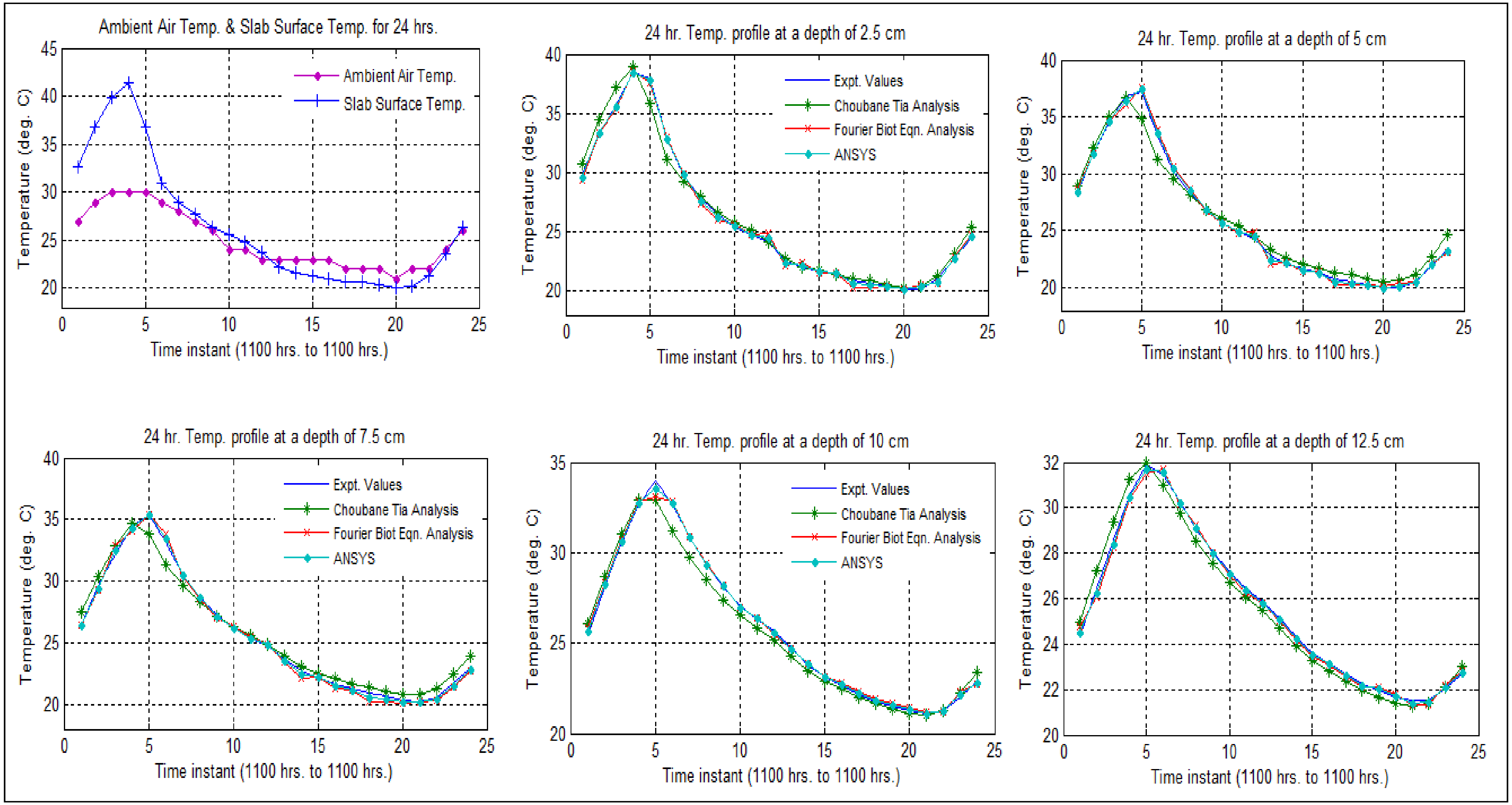


Fig. B-9 (a): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix A for 24 hr. cloudy and humid condition (surface to 12.5 cm)

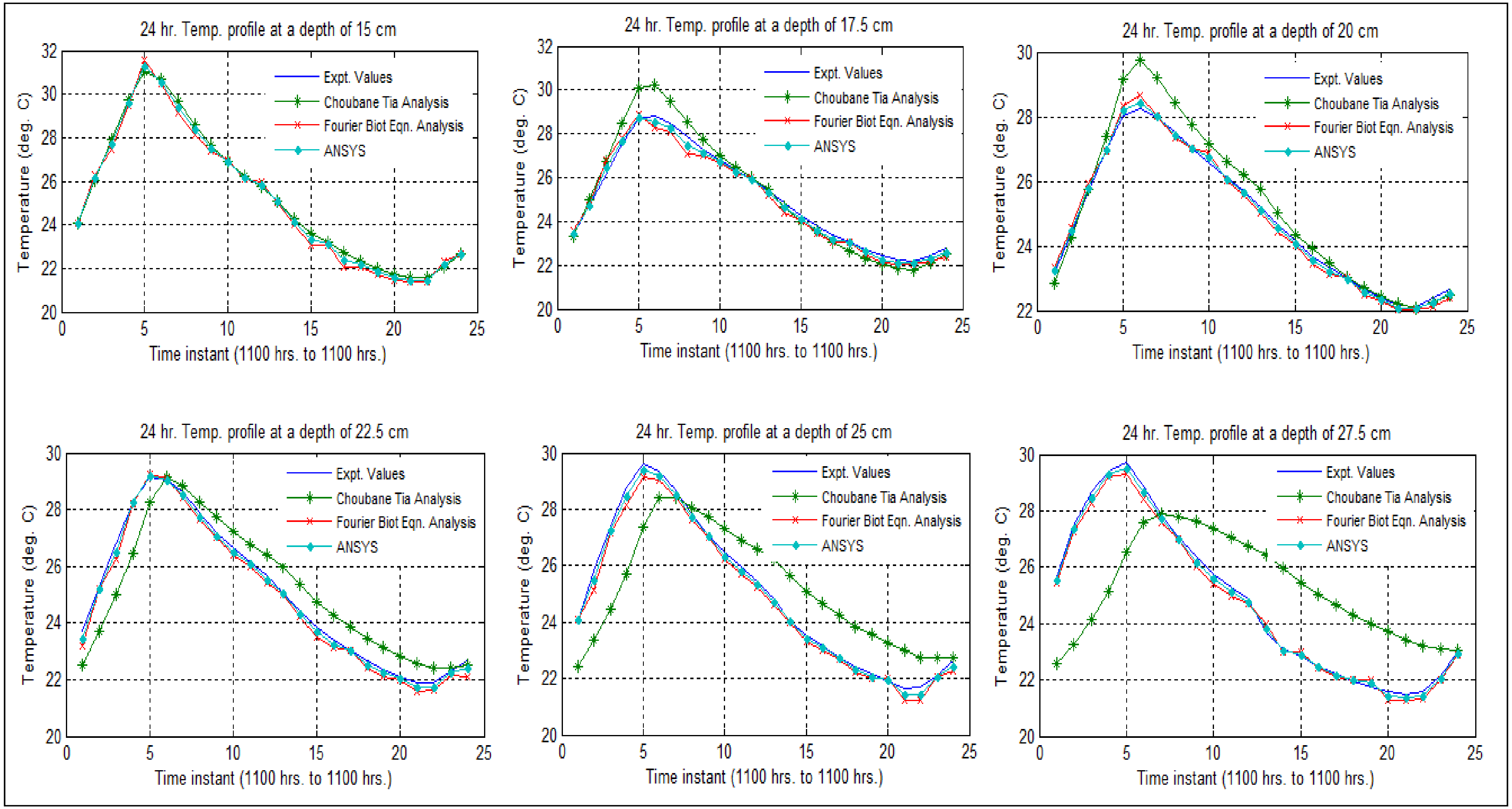


Fig. B-9 (b): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix A for 24 hr. cloudy and humid condition (15 cm to 27.5 cm)

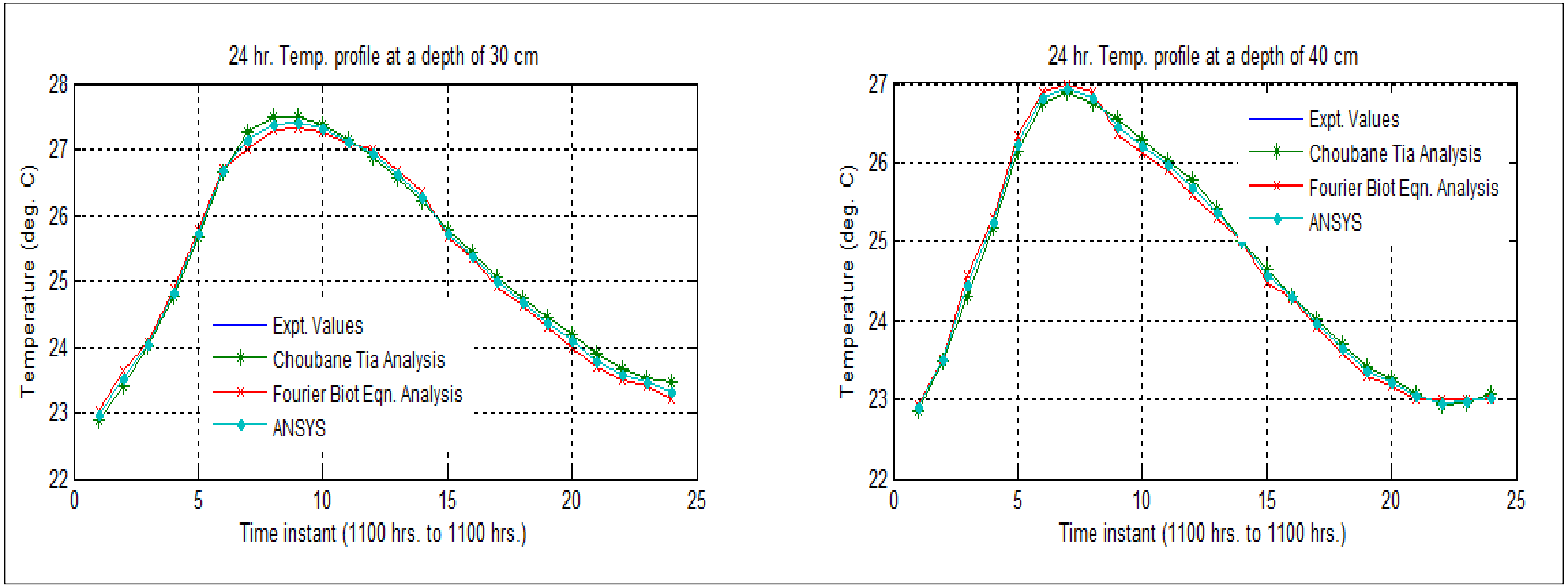


Fig. B-9 (c): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix A for 24 hr. cloudy and humid condition (30 cm & 40 cm)

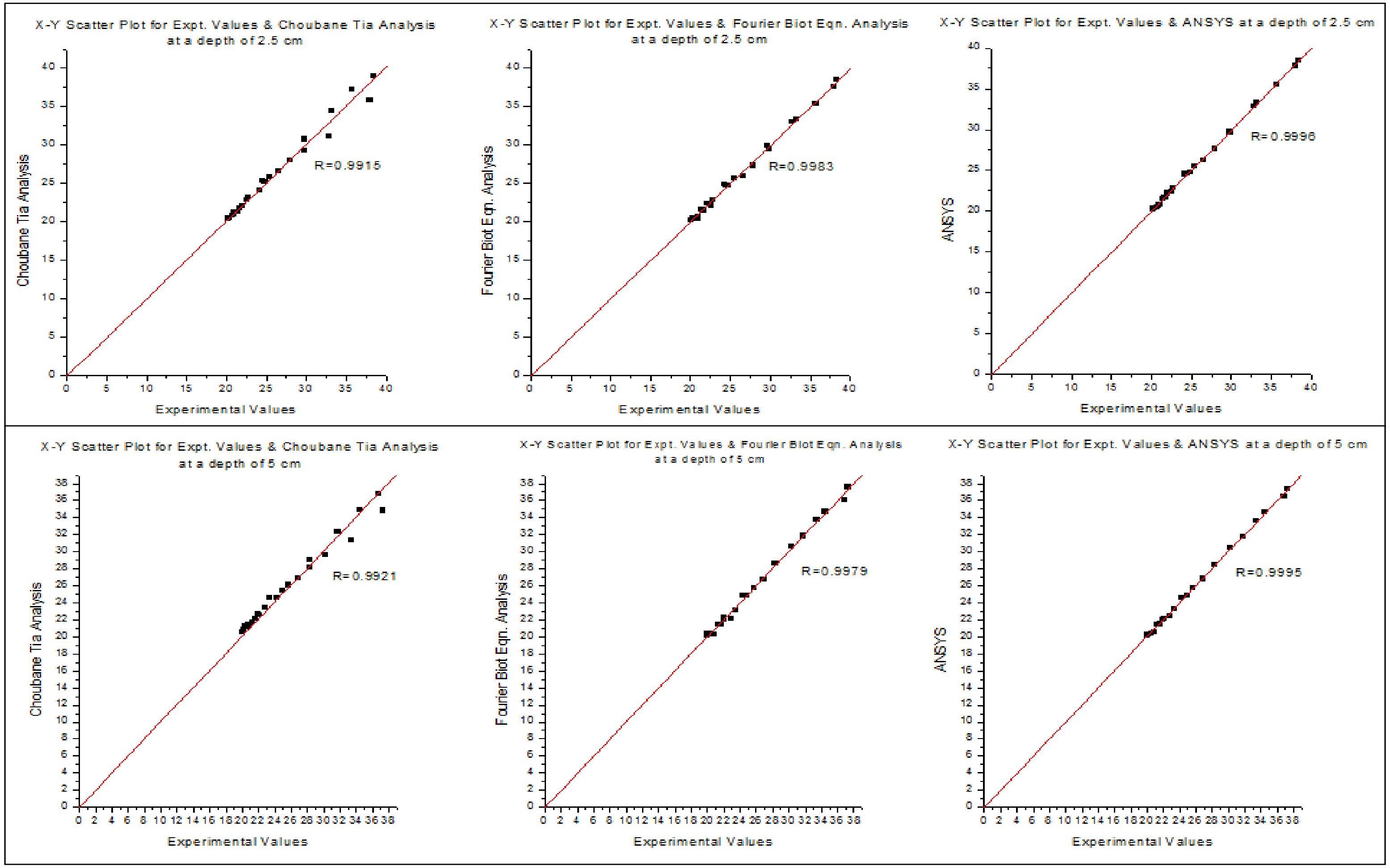


Fig. B-10 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

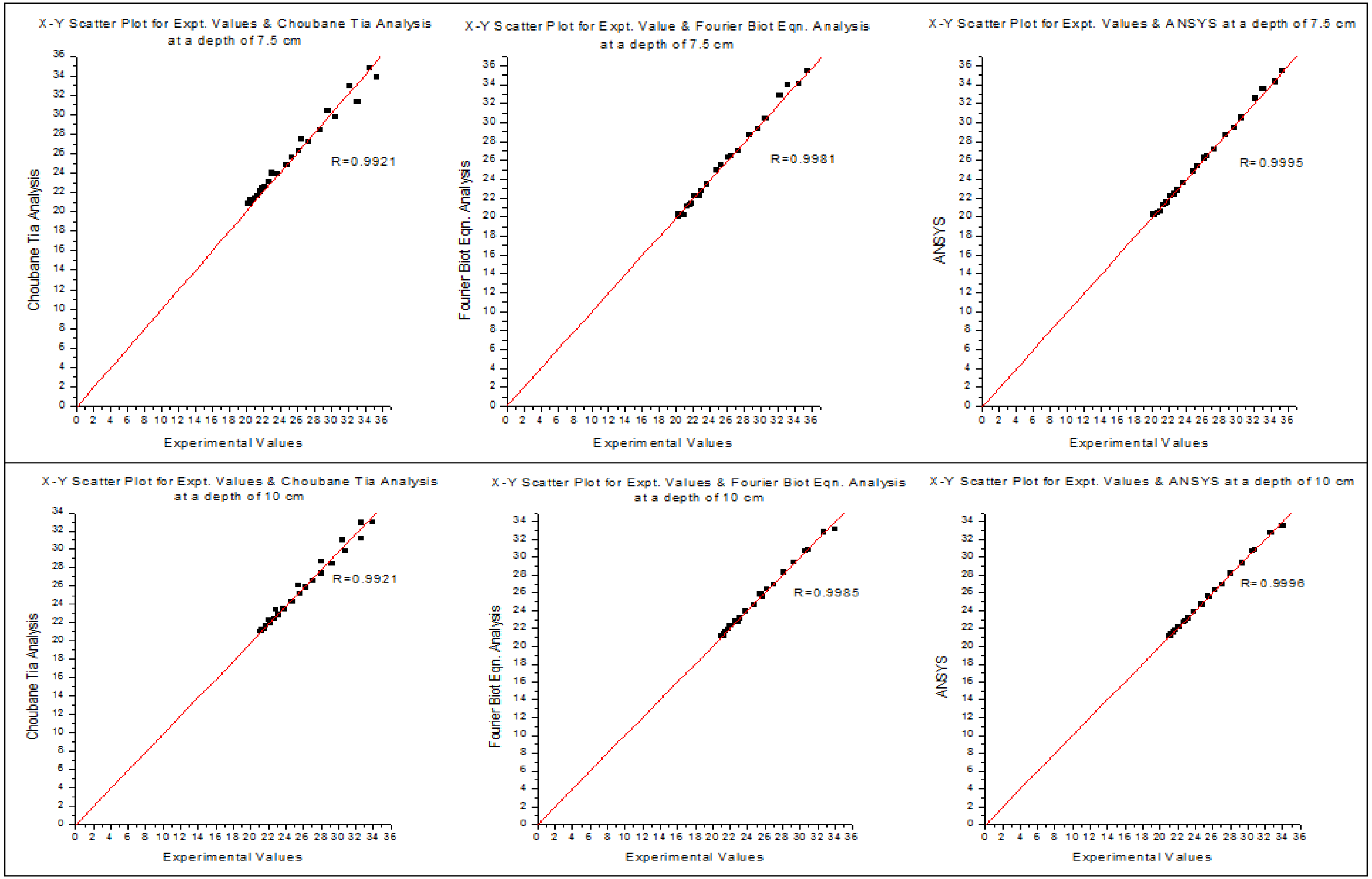


Fig. B-10 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

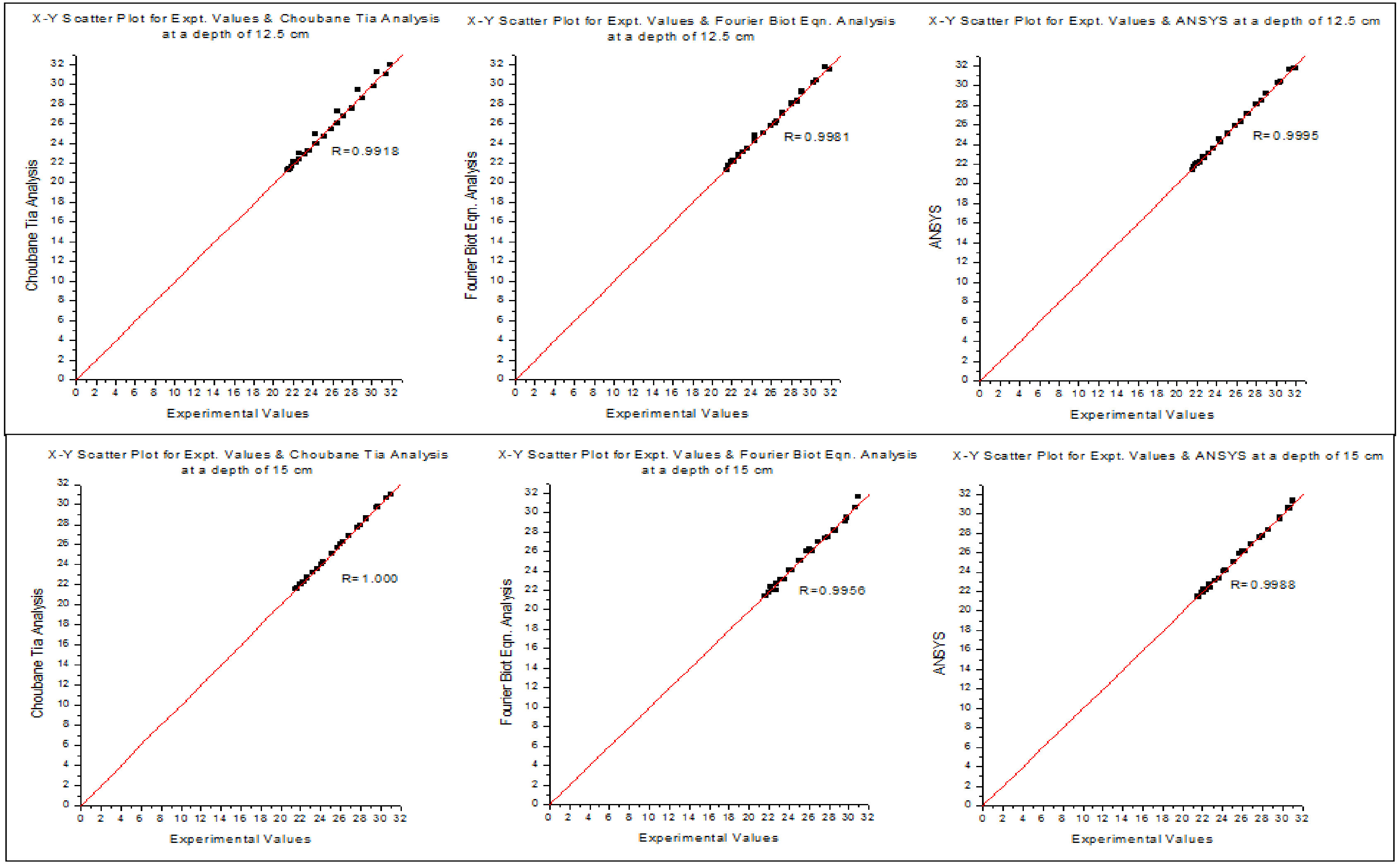


Fig. B-10 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

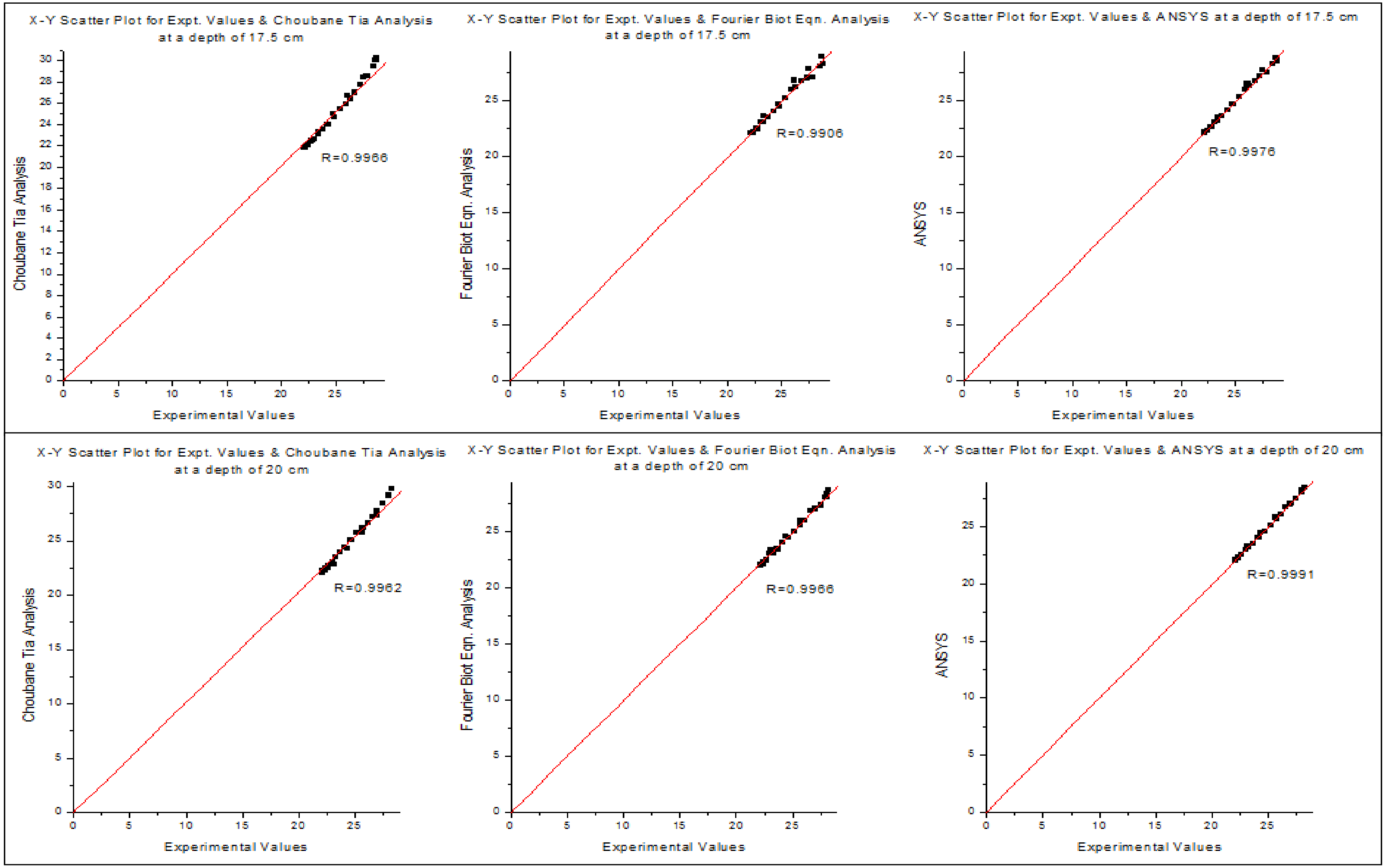


Fig. B-10 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

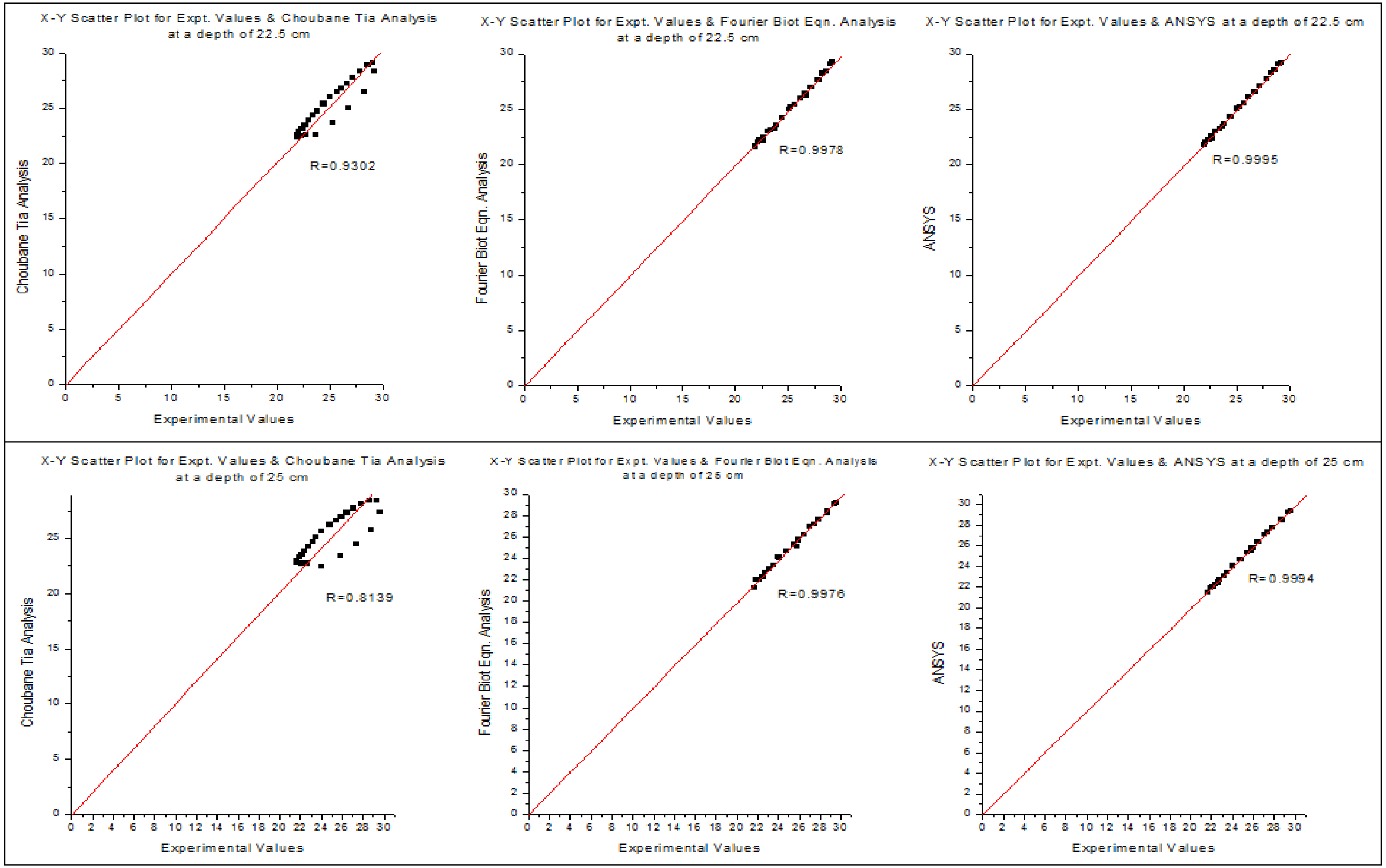


Fig. B-10 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

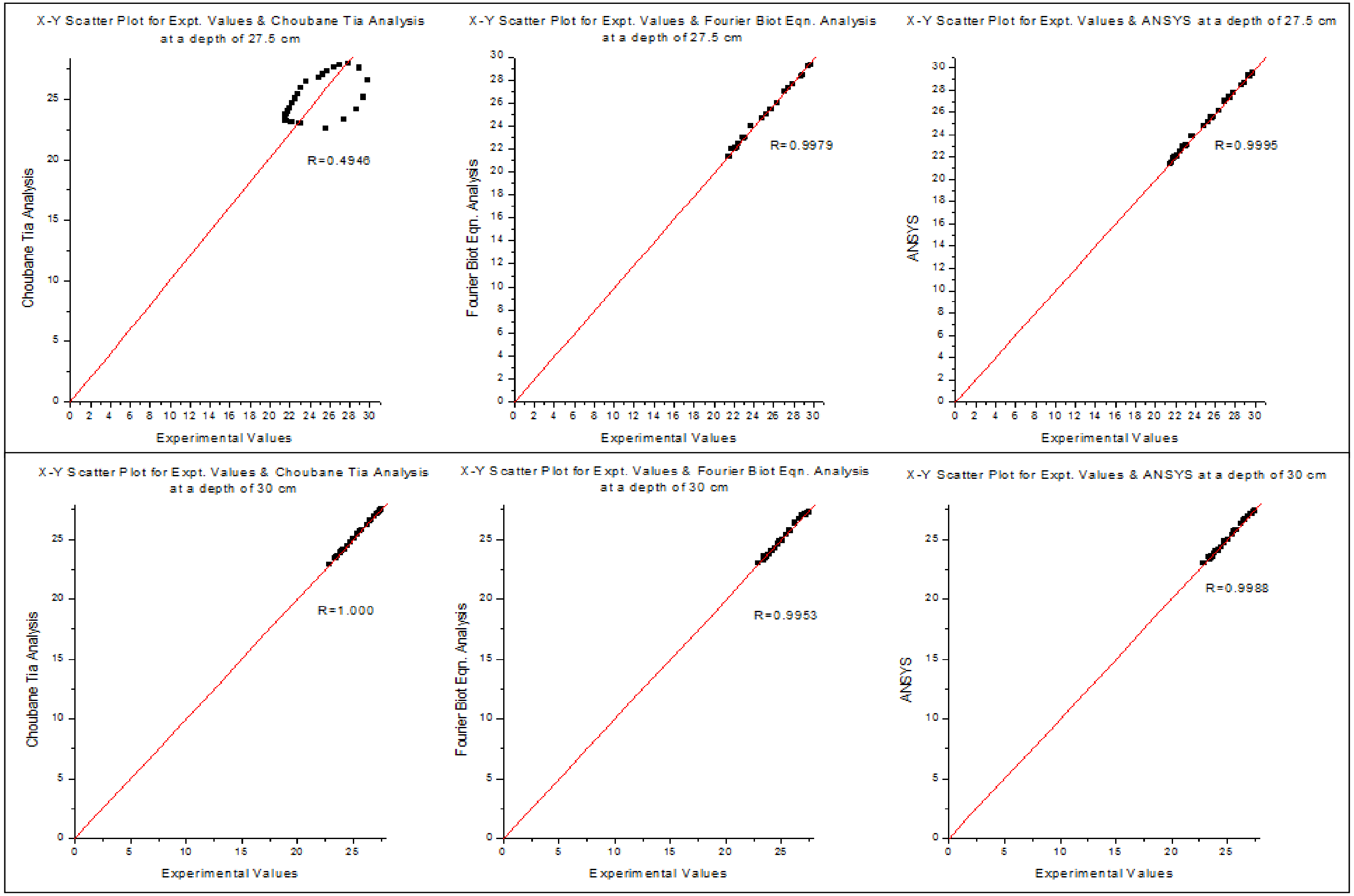


Fig. B-10 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

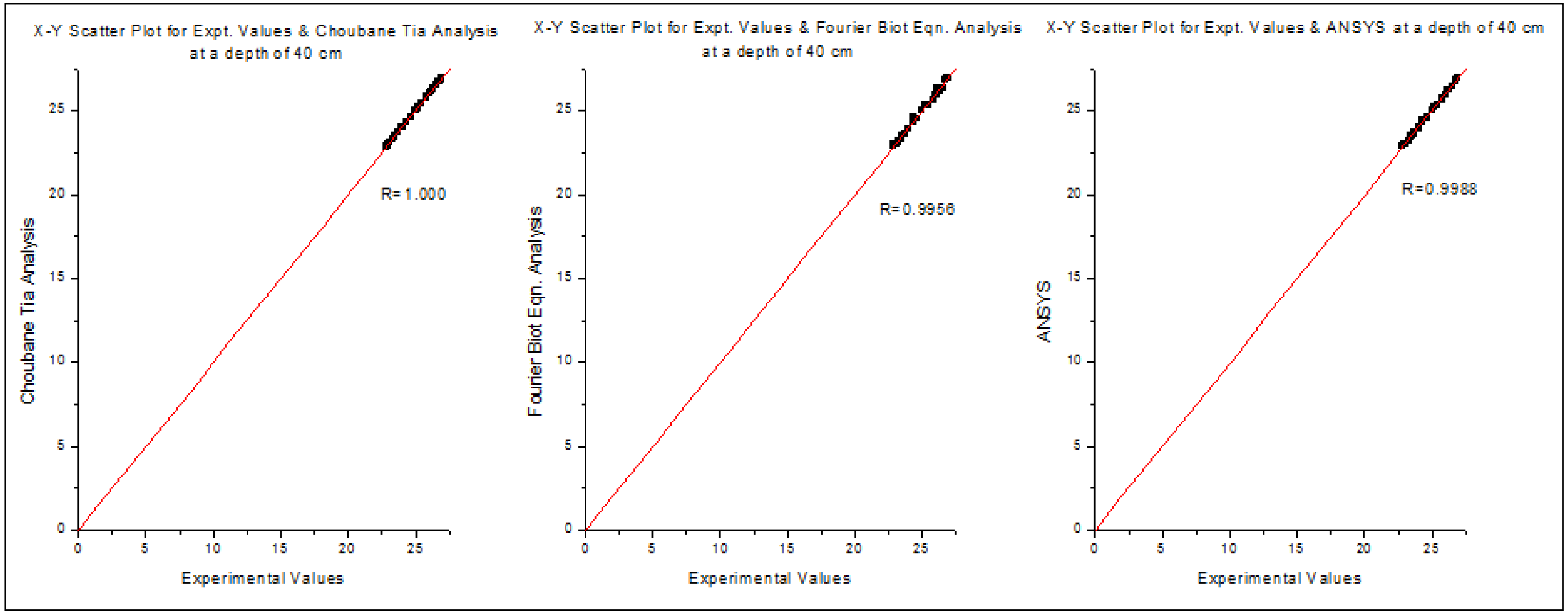


Fig. B-10 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-6 (a): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for 24 hr. cloudy and humid condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	27	30.40	28.76	28.30	28.85	28.81	23.35	26.47	23.49	23.42	22.89	24.89	22.76	22.83
2	1130 to 1230	29	34.79	32.75	31.74	32.60	32.67	25.89	29.07	25.97	25.93	24.98	26.79	25.09	25.03
3	1230 to 1330	30	37.08	35.59	33.67	35.69	35.64	28.56	30.69	28.67	28.61	27.41	28.15	27.54	27.47
4	1330 to 1430	30	39.63	37.77	35.87	37.90	37.83	30.86	32.58	30.97	30.91	29.72	29.77	29.88	29.80
5	1430 to 1530	30	38.08	38.07	35.00	38.14	38.10	32.63	32.30	32.77	32.70	31.70	29.98	31.86	31.78
6	1530 to 1630	29	32.21	33.25	30.87	33.37	33.31	32.62	29.69	32.75	32.68	32.28	28.67	32.41	32.34
7	1630 to 1730	28	28.63	29.57	28.36	29.70	29.63	31.04	28.11	31.17	31.11	31.20	27.89	31.39	31.30
8	1730 to 1830	27	27.41	27.33	27.52	27.44	27.38	29.32	27.62	29.51	29.42	29.86	27.68	29.97	29.91
9	1830 to 1930	26	26.08	26.06	26.52	26.17	26.11	27.98	26.89	28.05	28.02	28.67	27.19	28.80	28.73
10	1930 to 2030	24	25.02	25.03	25.67	25.16	25.09	26.94	26.22	26.82	26.88	27.67	26.68	27.81	27.74
11	2030 to 2130	24	24.31	24.34	25.06	24.48	24.41	26.13	25.71	25.99	26.06	26.88	26.24	26.96	26.92
12	2130 to 2230	23	23.65	23.87	24.49	23.87	23.87	25.43	25.22	25.61	25.52	26.23	25.82	26.40	26.31
13	2230 to 2330	23	21.82	21.96	23.04	22.05	22.01	24.72	24.11	24.81	24.77	25.54	25.00	25.68	25.61
14	2330 to 0030	23	21.22	21.34	22.51	21.45	21.40	23.59	23.62	23.69	23.64	24.58	24.56	24.61	24.60
15	0030 to 0130	23	20.94	21.12	22.16	21.19	21.15	22.88	23.22	22.97	22.93	23.76	24.11	23.81	23.79
16	0130 to 0230	23	20.53	20.80	21.72	20.93	20.86	22.35	22.75	22.47	22.41	23.26	23.62	23.32	23.29
17	0230 to 0330	22	20.32	20.45	21.47	20.41	20.43	21.91	22.46	22.03	21.97	22.82	23.30	22.88	22.85
18	0330 to 0430	22	20.12	20.16	21.21	20.27	20.21	21.58	22.15	21.69	21.63	22.39	22.95	22.50	22.44
19	0430 to 0530	22	19.83	19.95	20.89	20.04	20.00	21.28	21.80	21.38	21.33	22.05	22.57	22.20	22.12
20	0530 to 0630	21	19.58	19.71	20.61	19.82	19.76	20.99	21.49	21.10	21.05	21.73	22.25	21.90	21.81
21	0630 to 0730	22	19.62	19.65	20.56	19.70	19.68	20.75	21.38	20.91	20.83	21.55	22.08	21.69	21.62
22	0730 to 0830	22	20.20	20.03	20.95	20.18	20.10	20.61	21.60	20.74	20.67	21.38	22.14	21.48	21.43
23	0830 to 0930	24	21.99	21.47	22.24	21.61	21.54	20.89	22.46	21.01	20.95	21.50	22.64	21.53	21.51
24	0930 to 1030	26	23.21	22.41	23.15	22.54	22.48	21.29	23.10	21.40	21.35	21.69	23.04	21.72	21.71

Table B-6 (b): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for 24 hr. cloudy and humid condition at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	22.20	23.58	22.31	22.26	22.17	22.53	22.29	22.23	21.75	21.75	21.83	21.79
2	1130 to 1230	23.68	24.89	23.79	23.74	23.39	23.38	23.44	23.42	22.25	22.25	22.37	22.31
3	1230 to 1330	25.54	26.03	25.69	25.61	24.94	24.34	25.02	24.98	23.09	23.09	23.19	23.14
4	1330 to 1430	27.44	27.42	27.59	27.51	26.62	25.53	26.71	26.67	24.12	24.12	24.21	24.17
5	1430 to 1530	29.24	28.05	29.35	29.29	28.30	26.49	28.45	28.38	25.31	25.31	25.45	25.38
6	1530 to 1630	30.41	27.81	30.52	30.46	29.51	27.12	29.68	29.59	26.59	26.59	26.67	26.63
7	1630 to 1730	30.27	27.70	30.30	30.29	29.65	27.53	29.80	29.72	27.38	27.38	27.51	27.45
8	1730 to 1830	29.47	27.71	29.42	29.44	29.20	27.72	29.26	29.23	27.70	27.70	27.81	27.75
9	1830 to 1930	28.68	27.42	28.72	28.70	28.63	27.58	28.71	28.67	27.68	27.68	27.79	27.73
10	1930 to 2030	27.93	27.05	27.92	27.92	28.02	27.31	28.15	28.09	27.49	27.49	27.57	27.53
11	2030 to 2130	27.20	26.67	27.28	27.24	27.39	26.99	27.45	27.42	27.21	27.21	27.32	27.26
12	2130 to 2230	26.69	26.31	26.76	26.73	26.89	26.67	26.98	26.93	26.92	26.92	27.04	26.98
13	2230 to 2330	26.12	25.73	26.28	26.20	26.44	26.28	26.51	26.48	26.68	26.68	26.76	26.72
14	2330 to 0030	25.29	25.32	25.40	25.34	25.69	25.89	25.79	25.74	26.30	26.30	26.42	26.36
15	0030 to 0130	24.57	24.83	24.69	24.63	25.01	25.38	25.12	25.06	25.76	25.76	25.88	25.82
16	0130 to 0230	23.96	24.33	24.09	24.03	24.45	24.87	24.55	24.50	25.26	25.26	25.39	25.32
17	0230 to 0330	23.48	23.98	23.61	23.54	23.97	24.50	24.08	24.02	24.87	24.87	24.96	24.92
18	0330 to 0430	23.12	23.60	23.26	23.19	23.51	24.10	23.63	23.57	24.46	24.46	24.51	24.49
19	0430 to 0530	22.75	23.21	22.86	22.80	23.19	23.70	23.28	23.24	24.06	24.06	24.22	24.14
20	0530 to 0630	22.40	22.87	22.58	22.49	22.88	23.36	22.97	22.92	23.71	23.71	23.82	23.76
21	0630 to 0730	22.12	22.65	22.21	22.17	22.58	23.10	22.66	22.62	23.42	23.42	23.55	23.49
22	0730 to 0830	21.87	22.59	21.95	21.91	22.31	22.95	22.41	22.36	23.20	23.20	23.31	23.25
23	0830 to 0930	21.83	22.78	21.93	21.88	22.21	22.88	22.32	22.27	22.95	22.95	23.08	23.01
24	0930 to 1030	21.90	22.99	21.98	21.94	22.30	22.93	22.43	22.37	22.88	22.88	22.96	22.92

Table B-6 (c): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for 24 hr. cloudy and humid condition at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (^oC) at 17.5 cm				Temperature (^oC) at 20 cm				Temperature (^oC) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	21.96	21.23	22.07	22.02	21.83	20.97	21.96	21.89	21.97	20.98	22.08	22.03
2	1130 to 1230	22.55	21.52	22.75	22.65	22.36	21.16	22.45	22.41	22.80	21.20	22.91	22.86
3	1230 to 1330	23.43	22.27	23.64	23.54	23.22	21.87	23.34	23.28	23.92	21.91	24.03	23.98
4	1330 to 1430	24.59	23.18	24.72	24.65	24.31	22.70	24.38	24.35	25.32	22.69	25.44	25.38
5	1430 to 1530	25.81	24.51	25.94	25.88	25.52	24.10	25.61	25.57	26.86	24.06	26.94	26.90
6	1530 to 1630	27.07	26.22	27.18	27.13	26.85	26.01	26.92	26.89	28.41	25.97	28.52	28.47
7	1630 to 1730	27.90	27.26	28.06	27.98	27.80	27.17	27.88	27.84	29.06	27.10	29.20	29.13
8	1730 to 1830	28.16	27.65	28.29	28.22	28.18	27.57	28.25	28.21	28.99	27.46	29.11	29.05
9	1830 to 1930	28.01	27.70	28.17	28.09	28.07	27.65	28.16	28.11	28.64	27.54	28.71	28.67
10	1930 to 2030	27.74	27.56	27.88	27.81	27.79	27.55	27.87	27.83	28.11	27.43	28.20	28.15
11	2030 to 2130	27.40	27.31	27.45	27.42	27.44	27.31	27.52	27.48	27.56	27.20	27.65	27.61
12	2130 to 2230	27.05	27.05	27.16	27.10	27.06	27.06	27.14	27.10	27.05	26.96	27.14	27.09
13	2230 to 2330	26.81	26.90	26.92	26.86	26.78	26.95	26.84	26.81	26.67	26.84	26.74	26.71
14	2330 to 0030	26.40	26.52	26.48	26.44	26.38	26.56	26.45	26.42	26.16	26.43	26.25	26.20
15	0030 to 0130	25.86	25.97	25.94	25.90	25.84	26.01	25.91	25.88	25.51	25.89	25.60	25.55
16	0130 to 0230	25.33	25.47	25.38	25.36	25.30	25.53	25.40	25.35	24.98	25.43	25.07	25.03
17	0230 to 0330	24.95	25.09	25.00	24.97	24.90	25.15	25.01	24.96	24.54	25.05	24.64	24.59
18	0330 to 0430	24.56	24.67	24.62	24.59	24.51	24.74	24.62	24.56	24.09	24.66	24.17	24.13
19	0430 to 0530	24.17	24.27	24.22	24.20	24.10	24.35	24.21	24.15	23.69	24.29	23.77	23.73
20	0530 to 0630	23.82	23.93	23.87	23.84	23.75	24.01	23.84	23.79	23.37	23.96	23.45	23.41
21	0630 to 0730	23.52	23.62	23.56	23.54	23.45	23.70	23.54	23.49	23.16	23.66	23.25	23.21
22	0730 to 0830	23.26	23.35	23.32	23.29	23.22	23.40	23.31	23.27	22.86	23.35	22.94	22.90
23	0830 to 0930	23.08	22.97	23.14	23.11	22.99	22.97	23.08	23.03	22.65	22.92	22.73	22.69
24	0930 to 1030	23.00	22.83	23.07	23.04	22.90	22.77	23.00	22.95	22.60	22.72	22.69	22.65

Table B-6 (d): 24 hr. slab (D) temperature values (measured and calculated) for Mix A for 24 hr. cloudy and humid condition at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	22.39	21.24	22.44	22.41	23.71	21.78	23.85	23.78	22.57	22.57	22.64	22.61	22.11	22.11	22.16	22.13
2	1130 to 1230	23.39	21.62	23.45	23.42	25.38	22.43	25.46	25.42	23.62	23.62	23.72	23.67	23.25	23.25	23.30	23.28
3	1230 to 1330	24.67	22.38	24.75	24.71	27.15	23.28	27.23	27.19	24.61	24.61	24.70	24.66	24.94	24.94	25.00	24.97
4	1330 to 1430	26.09	23.16	26.15	26.12	29.22	24.08	29.33	29.28	25.48	25.48	25.55	25.52	26.95	26.95	27.00	26.98
5	1430 to 1530	27.70	24.40	27.84	27.77	31.69	25.12	31.77	31.73	26.22	26.22	26.29	26.25	28.43	28.43	28.48	28.46
6	1530 to 1630	28.99	26.09	29.05	29.02	30.83	26.37	30.92	30.87	26.82	26.82	26.88	26.85	27.57	27.57	27.62	27.60
7	1630 to 1730	29.15	27.06	29.24	29.19	29.56	27.04	29.71	29.63	27.05	27.05	27.11	27.08	26.43	26.43	26.48	26.45
8	1730 to 1830	28.81	27.32	28.90	28.85	28.64	27.16	28.80	28.72	26.97	26.97	27.05	27.01	25.50	25.50	25.54	25.52
9	1830 to 1930	28.29	27.35	28.37	28.33	27.80	27.10	27.88	27.84	26.77	26.77	26.82	26.80	24.96	24.96	25.00	24.98
10	1930 to 2030	27.71	27.23	27.80	27.76	27.06	26.92	27.17	27.12	26.53	26.53	26.60	26.56	24.54	24.54	24.59	24.56
11	2030 to 2130	27.16	26.98	27.25	27.20	26.54	26.66	26.67	26.60	26.22	26.22	26.30	26.26	24.17	24.17	24.21	24.19
12	2130 to 2230	26.75	26.73	26.81	26.78	26.05	26.38	26.14	26.09	25.92	25.92	26.00	25.96	23.85	23.85	23.89	23.87
13	2230 to 2330	26.31	26.56	26.40	26.35	25.32	26.12	25.41	25.36	25.50	25.50	25.55	25.53	23.34	23.34	23.39	23.36
14	2330 to 0030	25.73	26.11	25.81	25.77	24.67	25.62	24.75	24.71	24.96	24.96	25.02	24.99	22.63	22.63	22.68	22.65
15	0030 to 0130	25.12	25.60	25.22	25.17	24.07	25.14	24.16	24.11	24.51	24.51	24.58	24.54	22.27	22.27	22.33	22.30
16	0130 to 0230	24.66	25.16	24.73	24.70	23.65	24.73	23.75	23.70	24.14	24.14	24,2	24.14	22.03	22.03	22.06	22.04
17	0230 to 0330	24.22	24.80	24.31	24.27	23.31	24.40	23.38	23.35	23.84	23.84	23.91	23.87	21.78	21.78	21.82	21.80
18	0330 to 0430	23.82	24.43	23.91	23.87	23.03	24.06	23.11	23.07	23.55	23.55	23,61	23.55	21.59	21.59	21.63	21.61
19	0430 to 0530	23.47	24.08	23.59	23.53	22.76	23.74	22.86	22.81	23.26	23.26	23.31	23.28	21.46	21.46	21.51	21.49
20	0530 to 0630	23.25	23.78	23.36	23.30	22.50	23.46	22.61	22.55	23.01	23.01	23.07	23.04	21.30	21.30	21.35	21.33
21	0630 to 0730	22.99	23.49	23.10	23.05	22.28	23.20	22.36	22.32	22.79	22.79	22.85	22.82	21.13	21.13	21.19	21.16
22	0730 to 0830	22.75	23.21	22.85	22.80	22.23	22.96	22.31	22.27	22.62	22.62	22.68	22.65	21.13	21.13	21.17	21.15
23	0830 to 0930	22.64	22.83	22.75	22.70	22.54	22.71	22.62	22.58	22.55	22.55	22.60	22.58	21.41	21.41	21.46	21.43
24	0930 to 1030	22.70	22.66	22.82	22.76	22.83	22.61	22.93	22.88	22.56	22.56	22.62	22.59	21.60	21.60	21.66	21.63

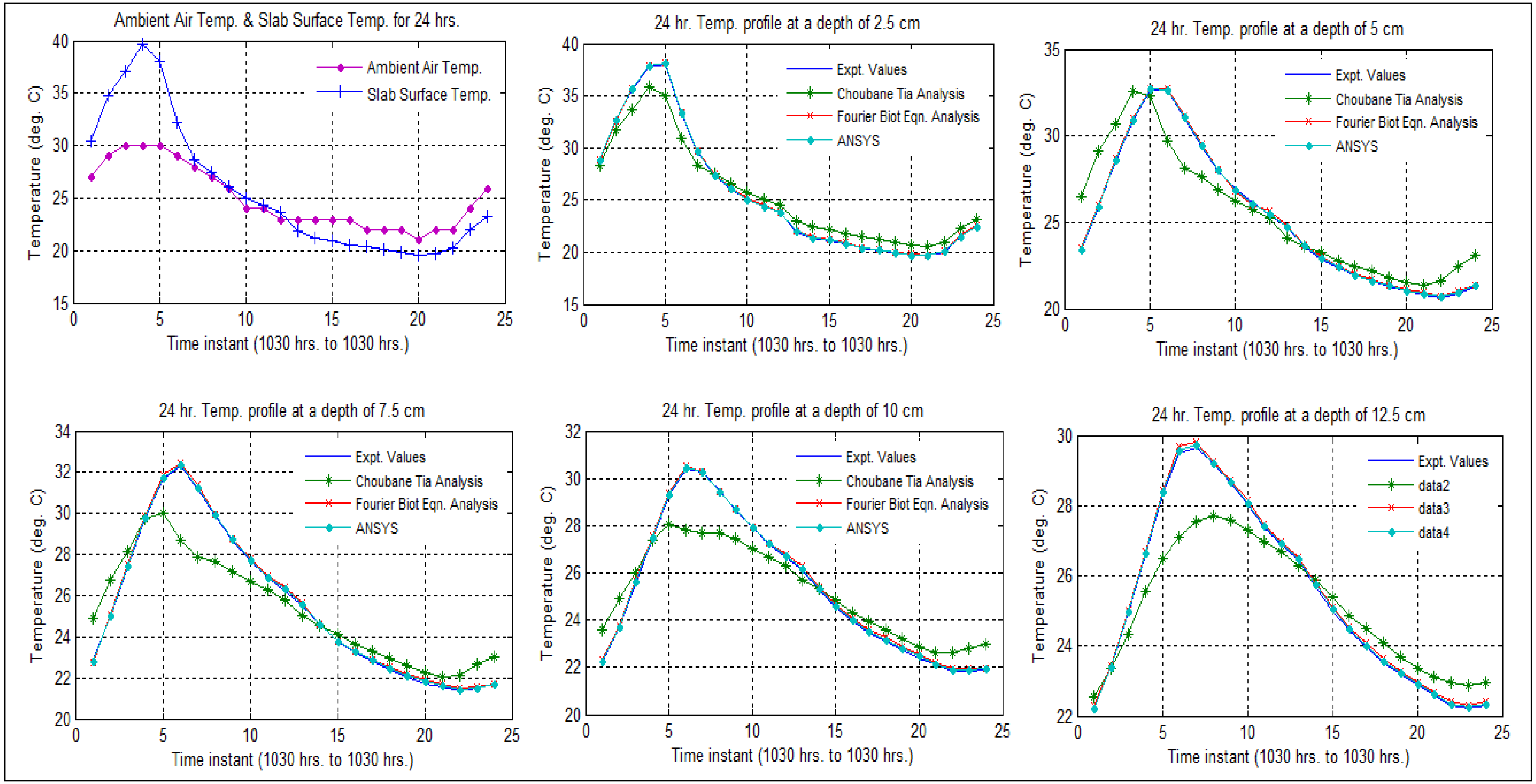


Fig. B-11 (a): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix A for 24 hr. cloudy and humid condition (surface to 12.5 cm)

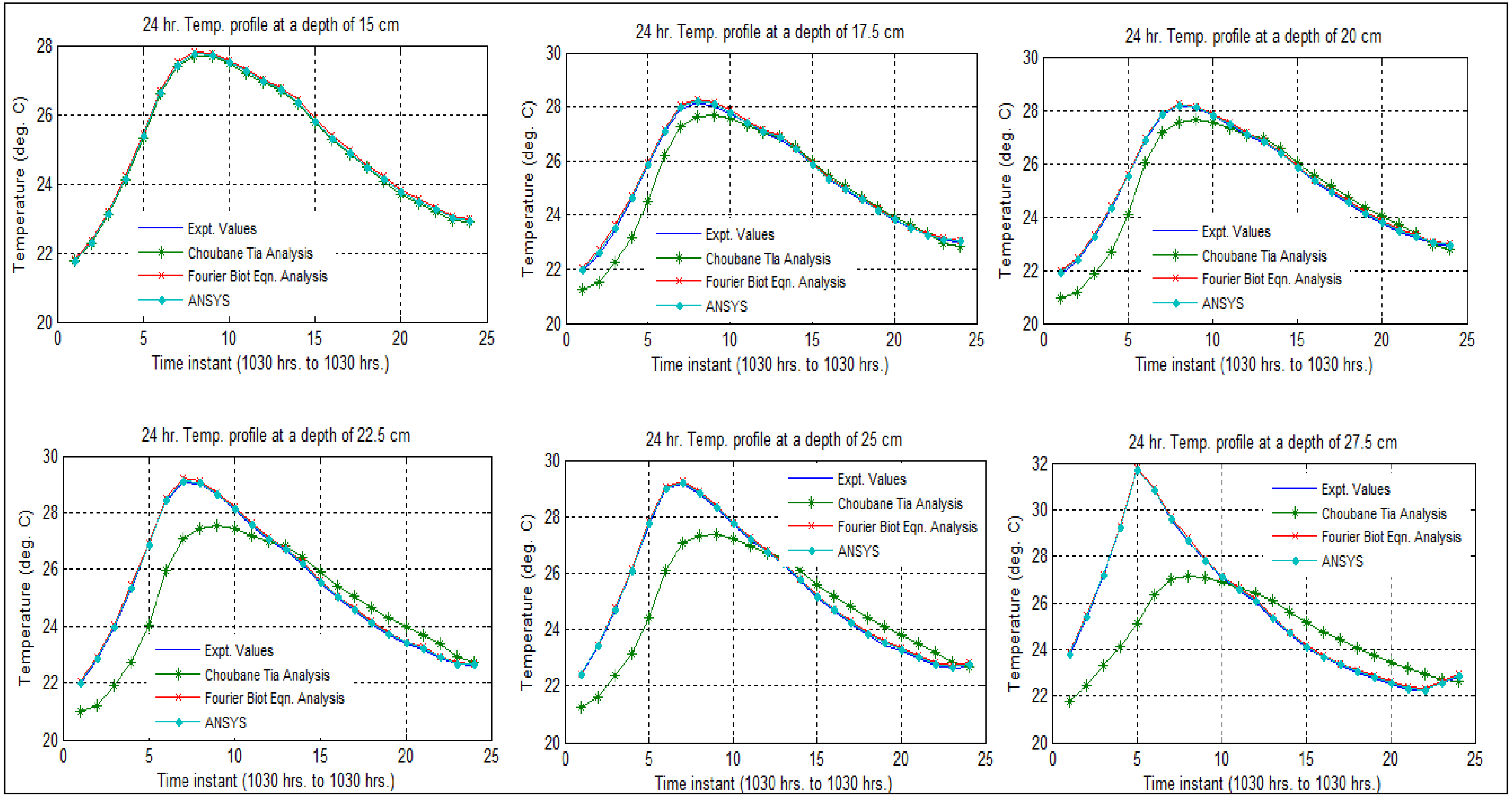


Fig. B-11 (b): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix A for 24 hr. cloudy and humid condition (15 cm to 27.5 cm)

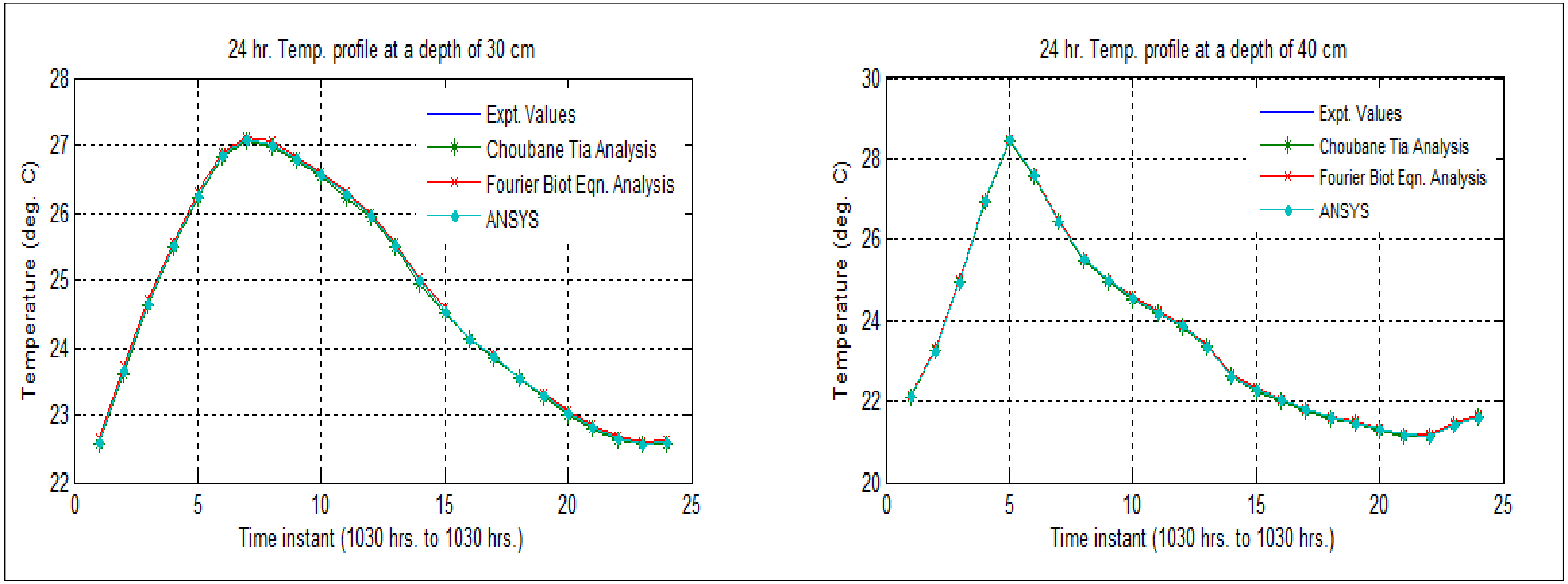


Fig. B-11 (c): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix A for 24 hr. cloudy and humid condition (30 cm & 40 cm)

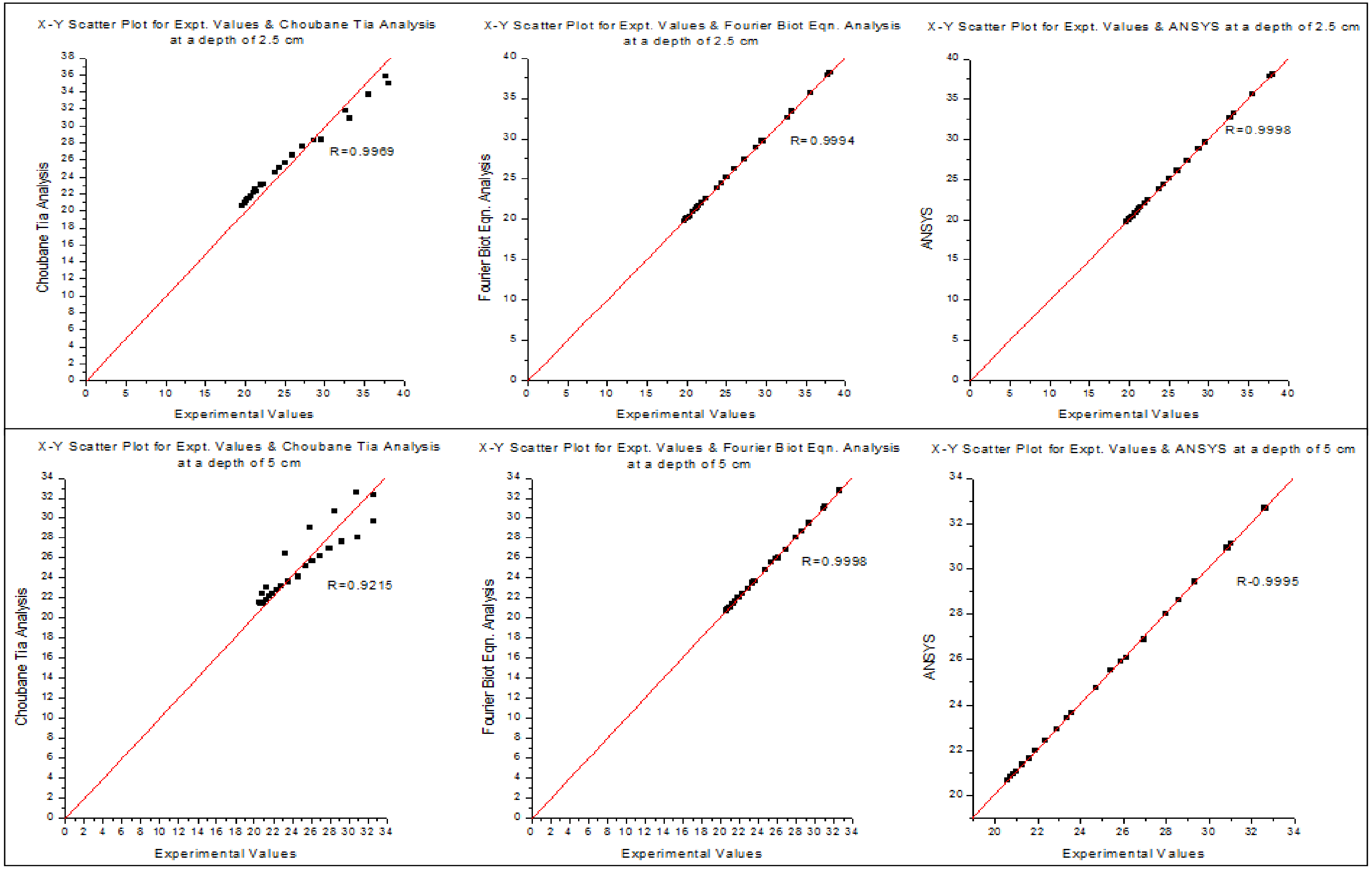


Fig. B-12 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

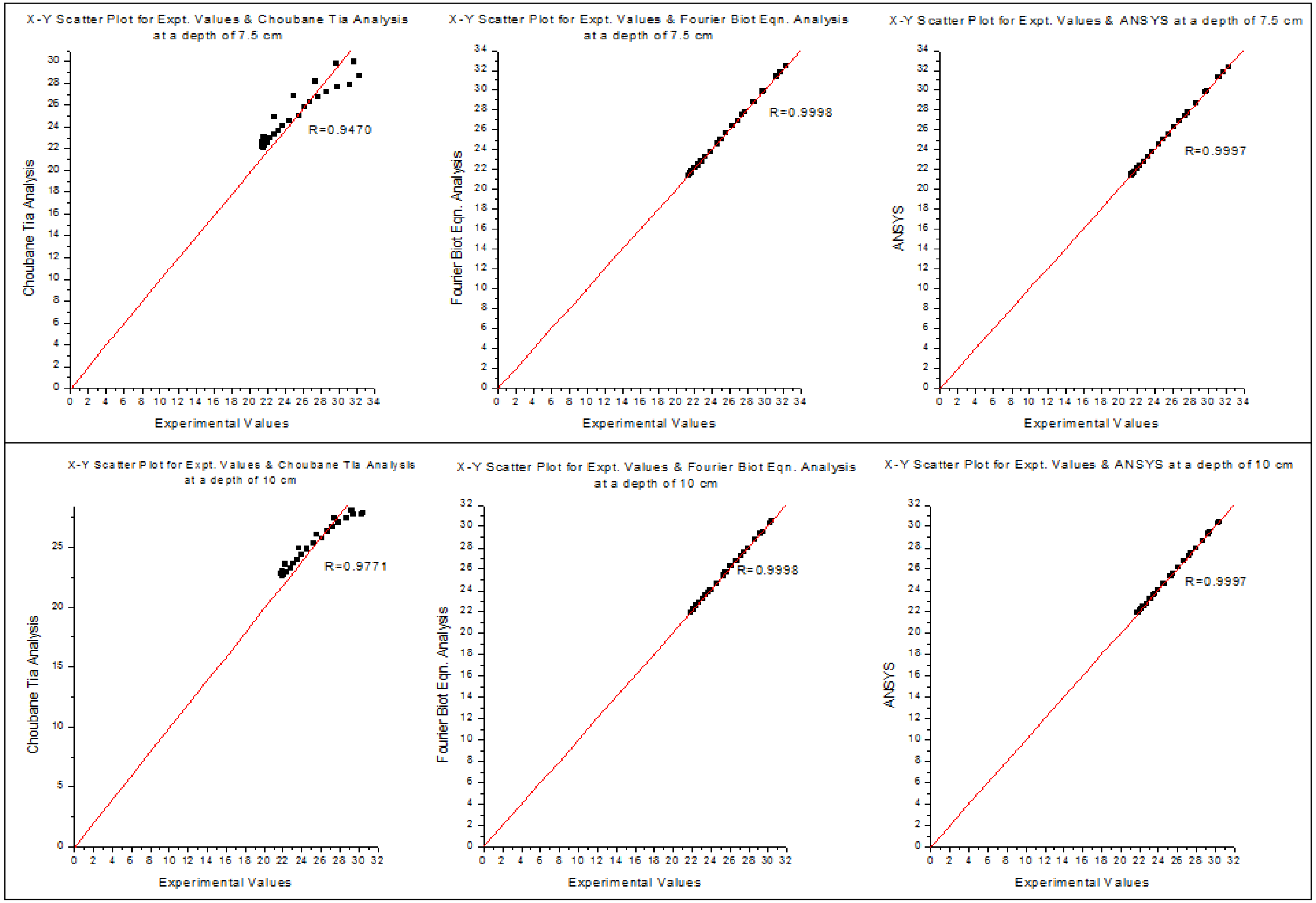


Fig. B-12 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

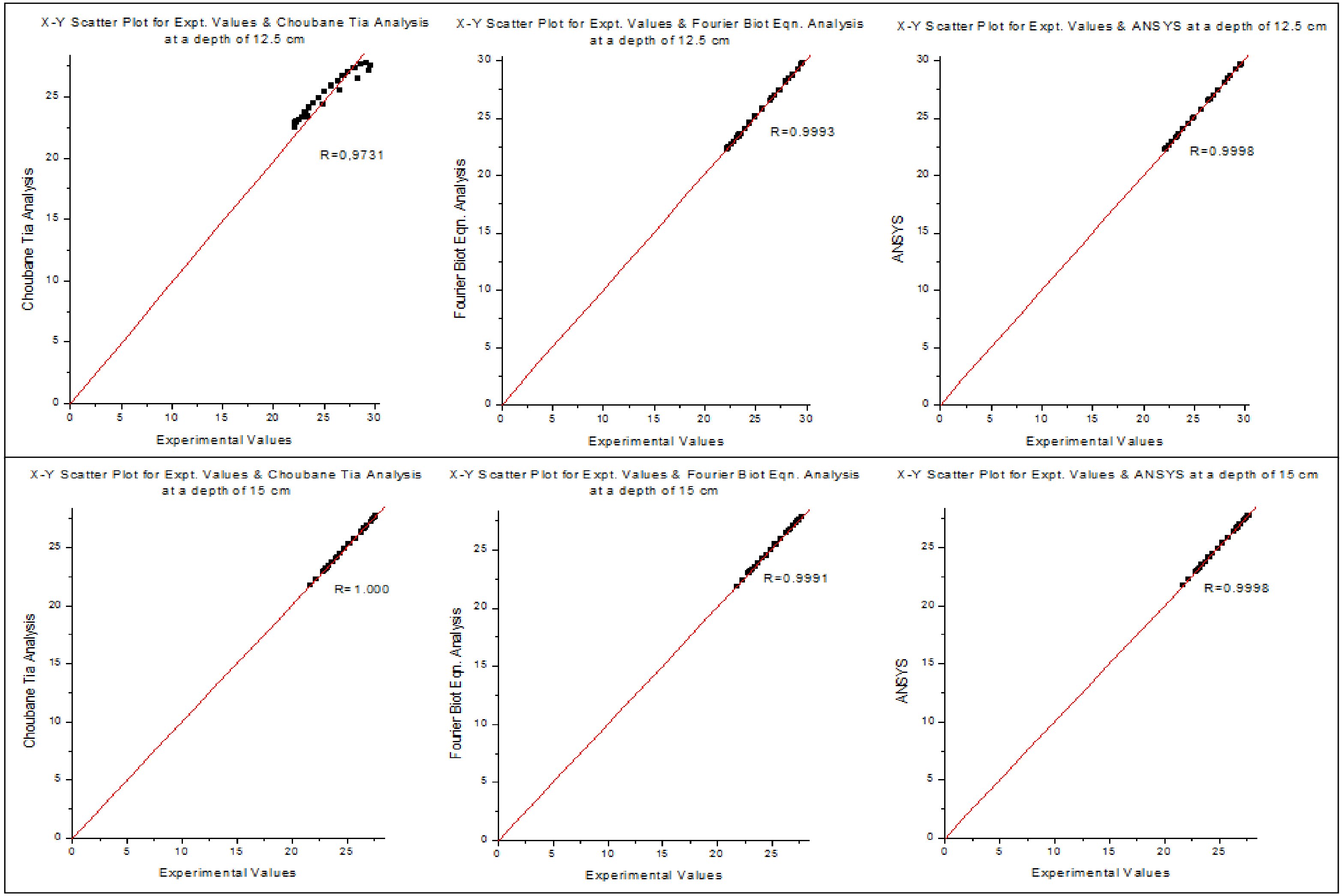


Fig. B-12 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

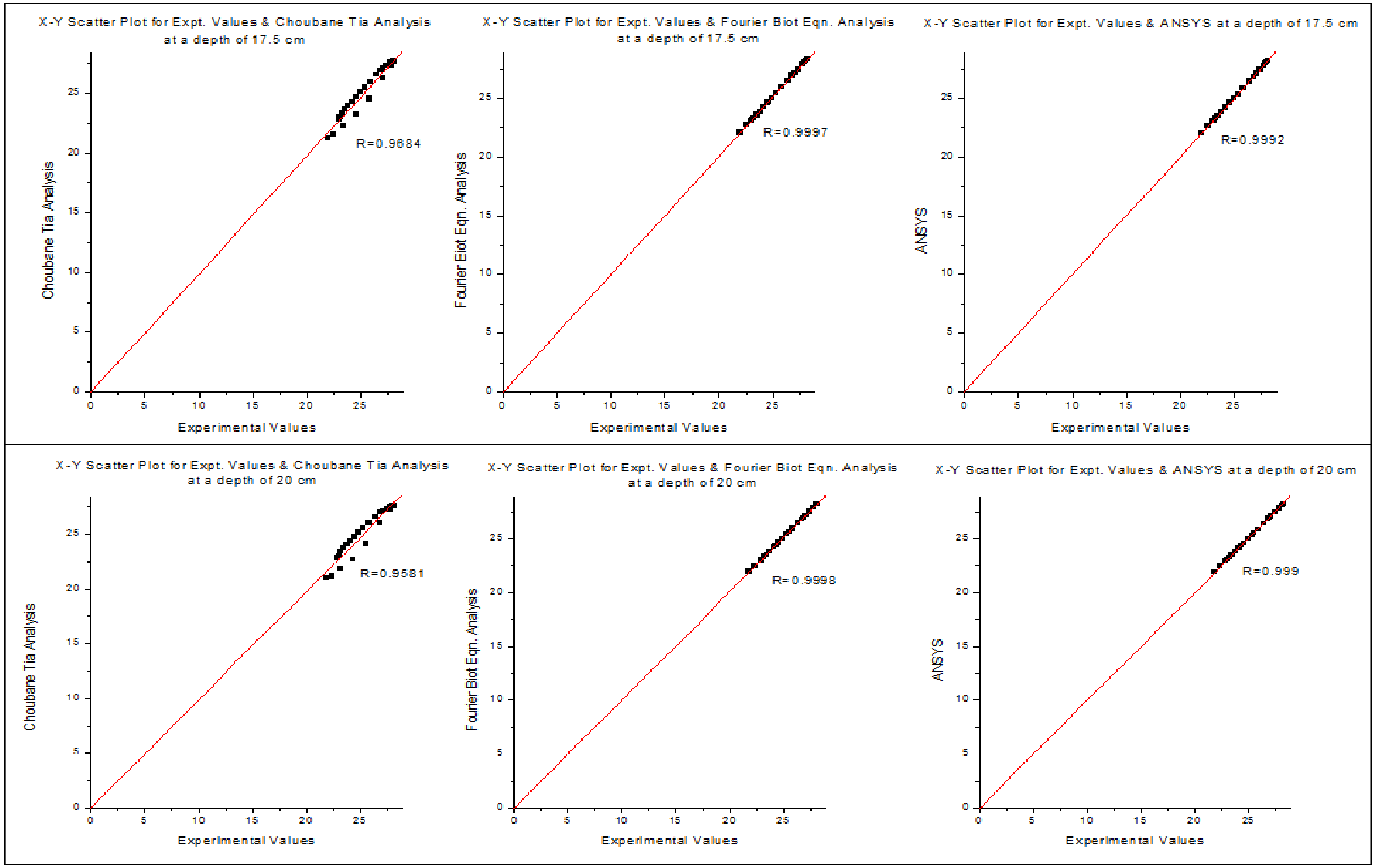


Fig. B-12 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

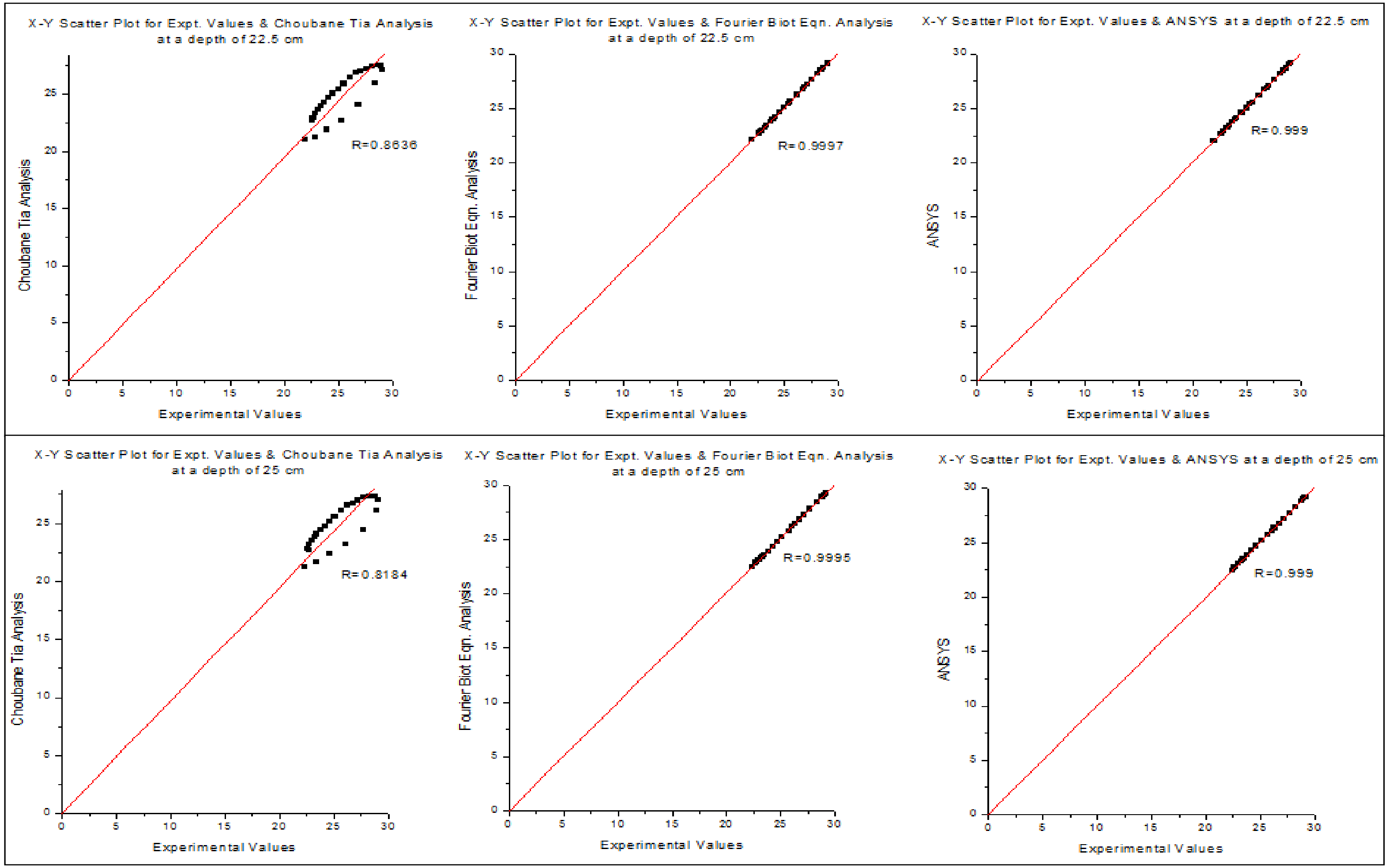


Fig. B-12 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

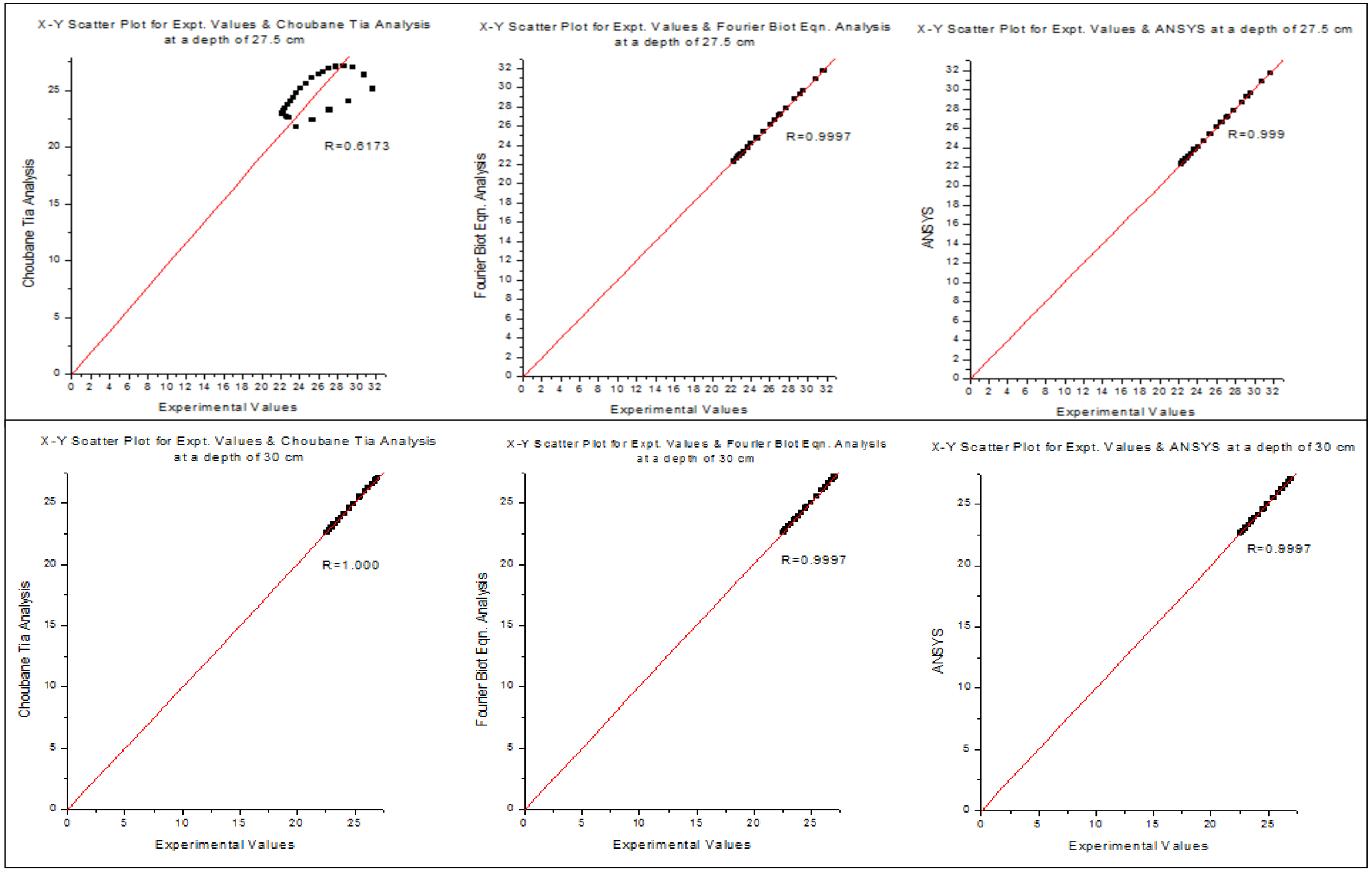


Fig. B-12 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

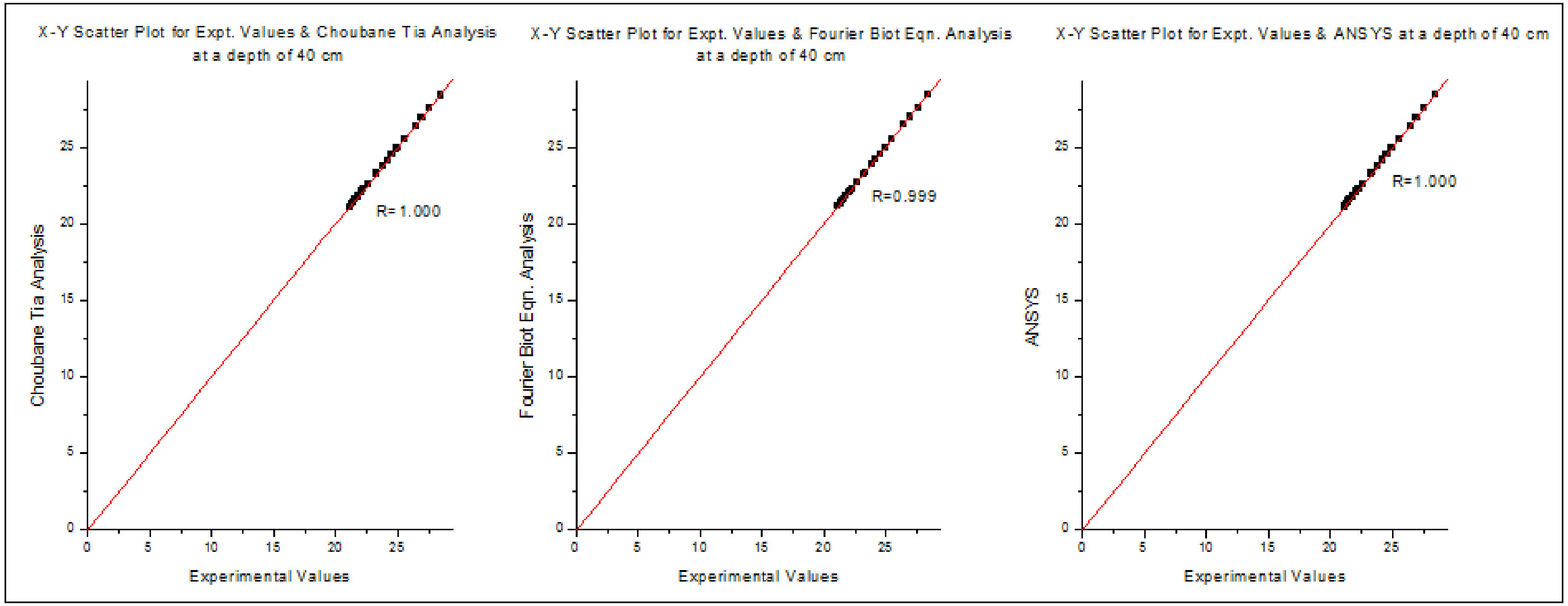


Fig. B-12 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-7 (a): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for maximum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	36	43.16	34.57	40.04	34.73	34.65	32.43	37.31	32.58	32.50	31.27	34.97	31.83	31.55
2	1130 to 1230	37	48.85	38.11	44.70	38.17	38.14	35.54	41.06	35.52	35.53	33.55	37.94	33.40	33.47
3	1230 to 1330	39	51.39	41.00	47.03	40.87	40.93	38.60	43.20	38.66	38.63	36.06	39.90	36.52	36.29
4	1330 to 1430	39	51.00	42.49	47.16	42.50	42.50	40.62	43.77	40.70	40.66	38.13	40.84	38.25	38.19
5	1430 to 1530	39	49.15	42.97	46.10	42.90	42.94	41.61	43.39	41.79	41.70	39.43	41.03	39.51	39.47
6	1530 to 1630	39	44.90	42.27	43.07	42.85	42.56	41.43	41.43	41.41	41.42	39.87	39.99	39.90	39.88
7	1630 to 1730	38	40.77	40.77	39.99	40.98	40.87	40.29	39.27	40.89	40.59	39.34	38.62	39.37	39.35
8	1730 to 1830	37	36.41	38.55	36.60	38.37	38.46	38.52	36.74	38.64	38.58	38.27	36.85	38.33	38.30
9	1830 to 1930	35	33.79	36.21	34.46	36.32	36.26	36.61	35.03	36.72	36.66	36.87	35.51	36.95	36.91
10	1930 to 2030	33	31.79	33.96	32.75	33.30	33.63	34.77	33.60	34.91	34.84	35.46	34.32	35.53	35.50
11	2030 to 2130	32	30.15	32.05	31.28	32.37	32.21	33.05	32.28	33.26	33.15	34.09	33.15	34.17	34.13
12	2130 to 2230	31	28.99	30.91	30.24	30.32	30.62	31.92	31.33	31.22	31.57	33.06	32.29	33.15	33.10
13	2230 to 2330	30	28.41	30.15	29.63	30.22	30.19	31.01	30.71	31.15	31.08	32.32	31.65	32.40	32.36
14	2330 to 0030	29	27.83	29.41	29.01	29.24	29.33	30.25	30.06	30.17	30.21	31.47	30.97	31.61	31.54
15	0030 to 0130	28	27.23	28.88	28.42	28.11	28.50	29.64	29.47	29.78	29.71	30.85	30.40	30.95	30.90
16	0130 to 0230	28	26.36	28.34	27.64	28.25	28.30	29.09	28.77	29.18	29.13	30.42	29.76	30.51	30.46
17	0230 to 0330	27	25.84	27.73	27.13	27.19	27.46	28.56	28.27	28.63	28.60	29.85	29.27	29.91	29.88
18	0330 to 0430	26	25.80	27.20	26.97	27.03	27.11	28.01	28.01	28.02	28.01	29.28	28.93	29.32	29.30
19	0430 to 0530	26	24.91	26.84	26.21	26.20	26.52	27.57	27.38	27.42	27.50	28.87	28.40	28.91	28.89
20	0530 to 0630	26	24.51	26.31	25.80	26.30	26.31	27.04	26.96	27.14	27.09	28.43	27.97	28.51	28.47
21	0630 to 0730	28	24.99	26.00	26.05	26.20	26.10	26.72	27.01	26.83	26.78	27.97	27.86	28.04	28.00
22	0730 to 0830	29	26.11	26.29	26.84	26.92	26.61	26.78	27.50	26.71	26.74	27.84	28.09	27.77	27.80
23	0830 to 0930	31	27.95	27.00	28.17	26.93	26.96	27.08	28.38	27.17	27.13	27.87	28.58	27.92	27.89
24	0930 to 1030	34	32.43	27.86	31.59	27.66	27.76	27.66	30.86	27.76	27.71	28.17	30.25	28.31	28.24

Table B-7 (b): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for maximum ambient air temperature at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	31.22	33.02	31.29	31.26	30.60	31.47	30.87	30.73	30.32	30.32	30.94	30.63
2	1130 to 1230	33.26	35.33	33.61	33.44	32.29	33.23	32.35	32.32	31.65	31.65	31.73	31.69
3	1230 to 1330	35.53	37.13	35.48	35.50	34.16	34.89	34.41	34.28	33.17	33.17	33.13	33.15
4	1330 to 1430	37.47	38.35	37.36	37.41	35.93	36.31	35.83	35.88	34.72	34.72	34.82	34.77
5	1430 to 1530	38.76	39.01	38.88	38.82	37.22	37.33	37.34	37.28	36.00	36.00	36.04	36.02
6	1530 to 1630	39.29	38.74	39.20	39.24	38.01	37.68	38.25	38.13	36.82	36.82	36.93	36.87
7	1630 to 1730	38.98	38.05	38.34	38.66	38.06	37.55	38.31	38.18	37.11	37.11	37.14	37.13
8	1730 to 1830	38.13	36.92	38.68	38.40	37.54	36.95	37.44	37.49	36.94	36.94	37.02	36.98
9	1830 to 1930	36.91	35.91	36.90	36.91	36.66	36.21	36.76	36.71	36.43	36.43	36.47	36.45
10	1930 to 2030	35.69	34.93	35.75	35.72	35.77	35.41	35.86	35.82	35.78	35.78	35.83	35.80
11	2030 to 2130	34.45	33.88	34.51	34.48	34.75	34.48	34.87	34.81	34.94	34.94	35.04	34.99
12	2130 to 2230	33.53	33.10	33.59	33.56	33.94	33.76	34.06	34.00	34.28	34.28	34.30	34.29
13	2230 to 2330	32.78	32.45	32.86	32.82	33.24	33.11	33.31	33.27	33.63	33.63	33.62	33.63
14	2330 to 0030	32.02	31.75	32.07	32.05	32.54	32.40	32.59	32.57	32.92	32.92	33.03	32.98
15	0030 to 0130	31.40	31.19	31.38	31.39	31.94	31.85	32.02	31.98	32.38	32.38	32.41	32.40
16	0130 to 0230	30.91	30.62	31.07	30.99	31.45	31.33	31.50	31.48	31.90	31.90	31.93	31.92
17	0230 to 0330	30.48	30.13	30.52	30.50	30.95	30.85	31.03	30.99	31.43	31.43	31.42	31.43
18	0330 to 0430	29.91	29.72	30.01	29.96	30.53	30.39	30.61	30.57	30.93	30.93	31.00	30.97
19	0430 to 0530	29.50	29.27	29.60	29.55	30.10	30.01	30.14	30.12	30.60	30.60	30.65	30.62
20	0530 to 0630	29.00	28.84	29.06	29.03	29.64	29.58	29.66	29.65	30.17	30.17	30.20	30.18
21	0630 to 0730	28.61	28.59	28.75	28.68	29.18	29.21	29.22	29.20	29.72	29.72	29.74	29.73
22	0730 to 0830	28.45	28.60	28.53	28.49	28.93	29.05	28.97	28.95	29.42	29.42	29.41	29.41
23	0830 to 0930	28.40	28.77	28.56	28.48	28.80	28.95	28.81	28.81	29.12	29.12	29.15	29.13
24	0930 to 1030	28.61	29.75	28.64	28.62	28.80	29.36	28.36	28.58	29.09	29.09	29.12	29.11

Table B-7 (c): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for maximum ambient air temperature at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	30.33	29.55	30.49	30.41	30.27	29.18	30.22	30.24	30.27	29.20	30.33	30.30
2	1130 to 1230	31.33	30.57	31.54	31.43	31.00	30.02	31.04	31.02	31.06	29.97	31.06	31.06
3	1230 to 1330	32.52	31.98	32.55	32.54	31.96	31.32	32.04	32.00	32.06	31.19	32.06	32.06
4	1330 to 1430	33.80	33.58	33.91	33.86	33.00	32.88	33.09	33.04	33.18	32.64	33.25	33.21
5	1430 to 1530	34.91	35.01	35.03	34.97	34.13	34.36	34.19	34.16	34.43	34.06	34.45	34.44
6	1530 to 1630	35.84	36.15	35.93	35.88	35.12	35.68	35.14	35.13	35.56	35.39	35.60	35.58
7	1630 to 1730	36.33	36.75	36.30	36.31	35.80	36.46	35.90	35.85	36.20	36.24	36.22	36.21
8	1730 to 1830	36.41	36.89	36.41	36.41	36.11	36.80	36.16	36.14	36.42	36.67	36.50	36.46
9	1830 to 1930	36.13	36.55	36.20	36.16	36.03	36.59	36.05	36.04	36.21	36.53	36.23	36.22
10	1930 to 2030	35.65	36.02	35.72	35.69	35.74	36.15	35.81	35.78	35.83	36.15	35.88	35.86
11	2030 to 2130	35.01	35.27	35.02	35.02	35.25	35.47	35.31	35.28	35.30	35.53	35.38	35.34
12	2130 to 2230	34.46	34.66	34.52	34.49	34.71	34.89	34.77	34.74	34.70	34.97	34.77	34.74
13	2230 to 2330	33.90	34.02	34.01	33.95	34.25	34.26	34.31	34.28	34.19	34.37	34.22	34.20
14	2330 to 0030	33.22	33.31	33.31	33.27	33.62	33.57	33.71	33.66	33.53	33.69	33.59	33.56
15	0030 to 0130	32.65	32.78	32.71	32.68	33.02	33.05	33.00	33.01	32.89	33.18	32.91	32.90
16	0130 to 0230	32.24	32.33	32.32	32.28	32.57	32.62	32.61	32.59	32.47	32.77	32.51	32.49
17	0230 to 0330	31.78	31.87	31.81	31.79	32.17	32.17	32.15	32.16	32.01	32.33	32.00	32.01
18	0330 to 0430	31.32	31.35	31.36	31.34	31.71	31.64	31.72	31.71	31.56	31.80	31.59	31.57
19	0430 to 0530	30.90	31.05	31.01	30.96	31.29	31.35	31.31	31.30	31.15	31.51	31.20	31.17
20	0530 to 0630	30.57	30.62	30.59	30.58	30.88	30.93	30.91	30.90	30.76	31.10	30.81	30.78
21	0630 to 0730	30.15	30.12	30.17	30.16	30.58	30.40	30.63	30.61	30.45	30.58	30.52	30.48
22	0730 to 0830	29.82	29.72	29.83	29.83	30.24	29.95	30.30	30.27	30.12	30.10	30.15	30.14
23	0830 to 0930	29.47	29.28	29.53	29.50	29.85	29.43	29.93	29.89	29.76	29.56	29.81	29.79
24	0930 to 1030	29.40	28.94	29.55	29.48	29.70	28.90	29.74	29.72	29.60	28.98	29.66	29.63

Table B-7 (d): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for maximum ambient air temperature at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	30.37	29.62	30.43	30.40	30.93	30.43	30.97	30.95	31.63	31.63	31.70	31.67	30.81	30.81	30.88	30.84
2	1130 to 1230	31.39	30.44	31.43	31.41	32.51	31.42	32.57	32.54	32.91	32.91	32.96	32.93	32.70	32.70	32.86	32.78
3	1230 to 1330	32.61	31.58	32.69	32.65	34.68	32.51	34.76	34.72	33.96	33.96	34.04	34.00	34.70	34.70	35.00	34.85
4	1330 to 1430	34.13	32.85	34.20	34.16	37.21	33.50	37.27	37.24	34.61	34.61	34.68	34.64	35.97	35.97	36.00	35.99
5	1430 to 1530	35.66	34.10	35.73	35.70	39.01	34.49	38.98	38.99	35.22	35.22	35.27	35.24	36.21	36.21	36.29	36.25
6	1530 to 1630	36.71	35.31	36.77	36.74	38.57	35.42	38.67	38.62	35.72	35.72	35.79	35.75	36.12	36.12	36.19	36.16
7	1630 to 1730	36.90	36.09	36.97	36.94	37.82	36.01	37.89	37.85	36.01	36.01	36.08	36.04	35.81	35.81	35.89	35.85
8	1730 to 1830	36.79	36.50	36.82	36.80	36.87	36.29	36.88	36.87	36.04	36.04	36.07	36.06	35.43	35.43	35.48	35.46
9	1830 to 1930	36.35	36.39	36.41	36.38	35.87	36.16	35.91	35.89	35.84	35.84	35.90	35.87	34.90	34.90	34.96	34.93
10	1930 to 2030	35.77	36.04	35.81	35.79	34.96	35.80	35.00	34.98	35.45	35.45	35.50	35.47	34.41	34.41	34.48	34.45
11	2030 to 2130	35.07	35.45	35.11	35.09	34.13	35.25	34.20	34.17	34.91	34.91	35.00	34.95	33.76	33.76	33.81	33.78
12	2130 to 2230	34.43	34.91	34.50	34.47	33.32	34.71	33.40	33.36	34.37	34.37	34.41	34.39	33.14	33.14	33.19	33.17
13	2230 to 2330	33.79	34.33	33.82	33.81	32.59	34.16	32.62	32.60	33.85	33.85	33.89	33.87	32.70	32.70	32.75	32.73
14	2330 to 0030	33.05	33.69	33.11	33.08	31.80	33.55	31.84	31.82	33.28	33.28	33.33	33.31	32.34	32.34	32.39	32.37
15	0030 to 0130	32.47	33.19	32.53	32.50	31.22	33.06	31.30	31.26	32.80	32.80	32.85	32.83	31.90	31.90	32.00	31.95
16	0130 to 0230	31.99	32.78	32.00	31.99	30.77	32.65	30.82	30.79	32.38	32.38	32.41	32.40	31.55	31.55	31.61	31.58
17	0230 to 0330	31.50	32.35	31.56	31.53	30.34	32.23	30.40	30.37	31.97	31.97	32.00	31.98	31.20	31.20	31.27	31.23
18	0330 to 0430	31.04	31.84	31.00	31.02	29.93	31.75	30.00	29.97	31.54	31.54	31.60	31.57	30.83	30.83	30.90	30.86
19	0430 to 0530	30.69	31.53	30.72	30.71	29.53	31.40	29.58	29.55	31.13	31.13	31.20	31.17	30.61	30.61	30.68	30.65
20	0530 to 0630	30.33	31.14	30.41	30.37	29.10	31.03	29.14	29.12	30.78	30.78	30.81	30.79	30.29	30.29	30.33	30.31
21	0630 to 0730	29.94	30.64	30.01	29.97	28.82	30.59	28.60	28.71	30.42	30.42	30.48	30.45	29.95	29.95	30.00	29.98
22	0730 to 0830	29.65	30.19	29.72	29.68	28.73	30.20	28.81	28.77	30.14	30.14	30.20	30.17	29.76	29.76	29.81	29.78
23	0830 to 0930	29.35	29.69	29.41	29.38	28.68	29.81	28.74	28.71	29.92	29.92	30.00	29.96	29.56	29.56	29.60	29.58
24	0930 to 1030	29.30	29.17	29.35	29.33	28.82	29.48	28.88	28.85	29.90	29.90	29.97	29.94	29.59	29.59	29.61	29.60

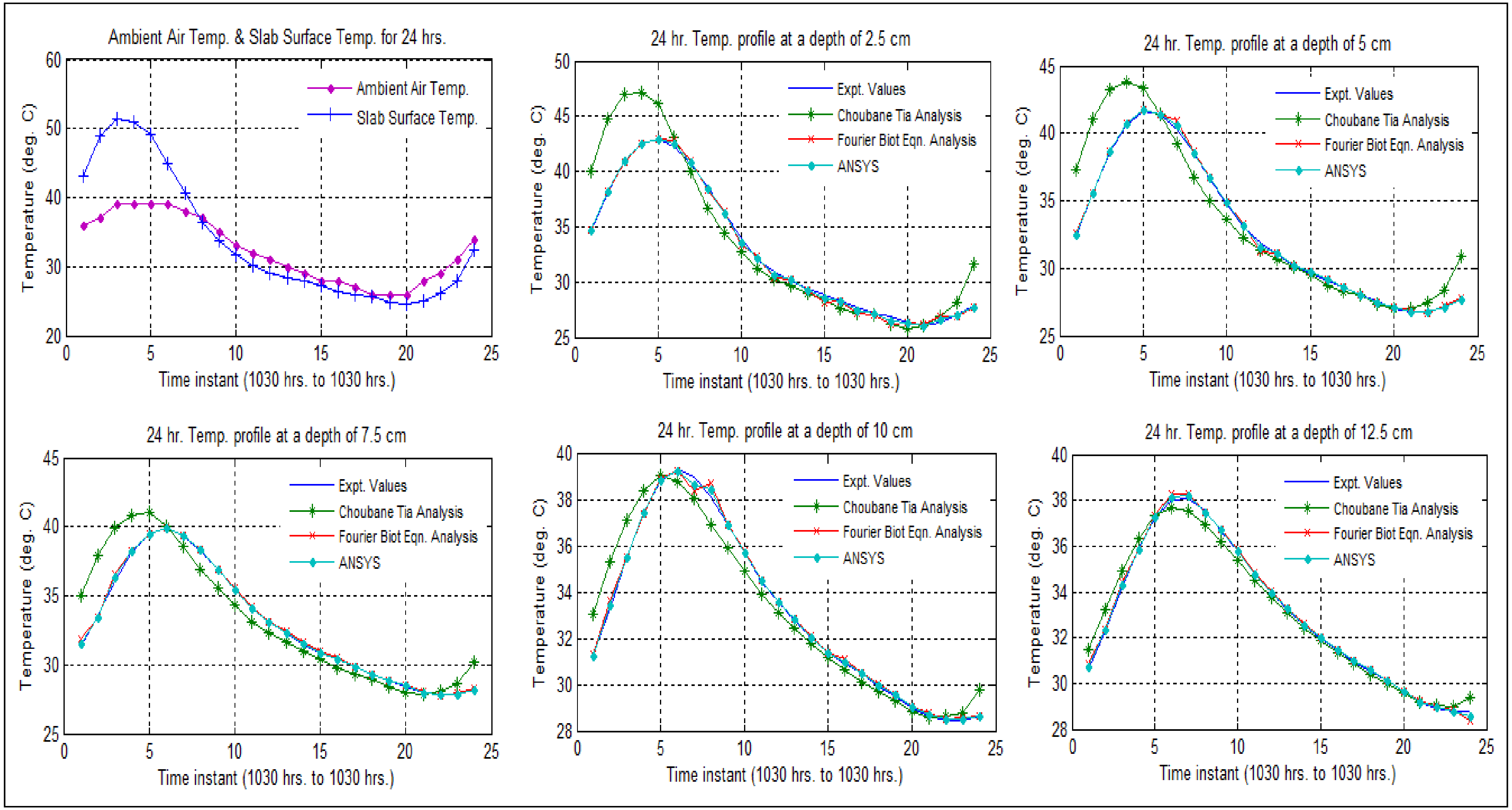


Fig. B-13 (a): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix B for maximum ambient air temperature (surface to 12.5 cm)

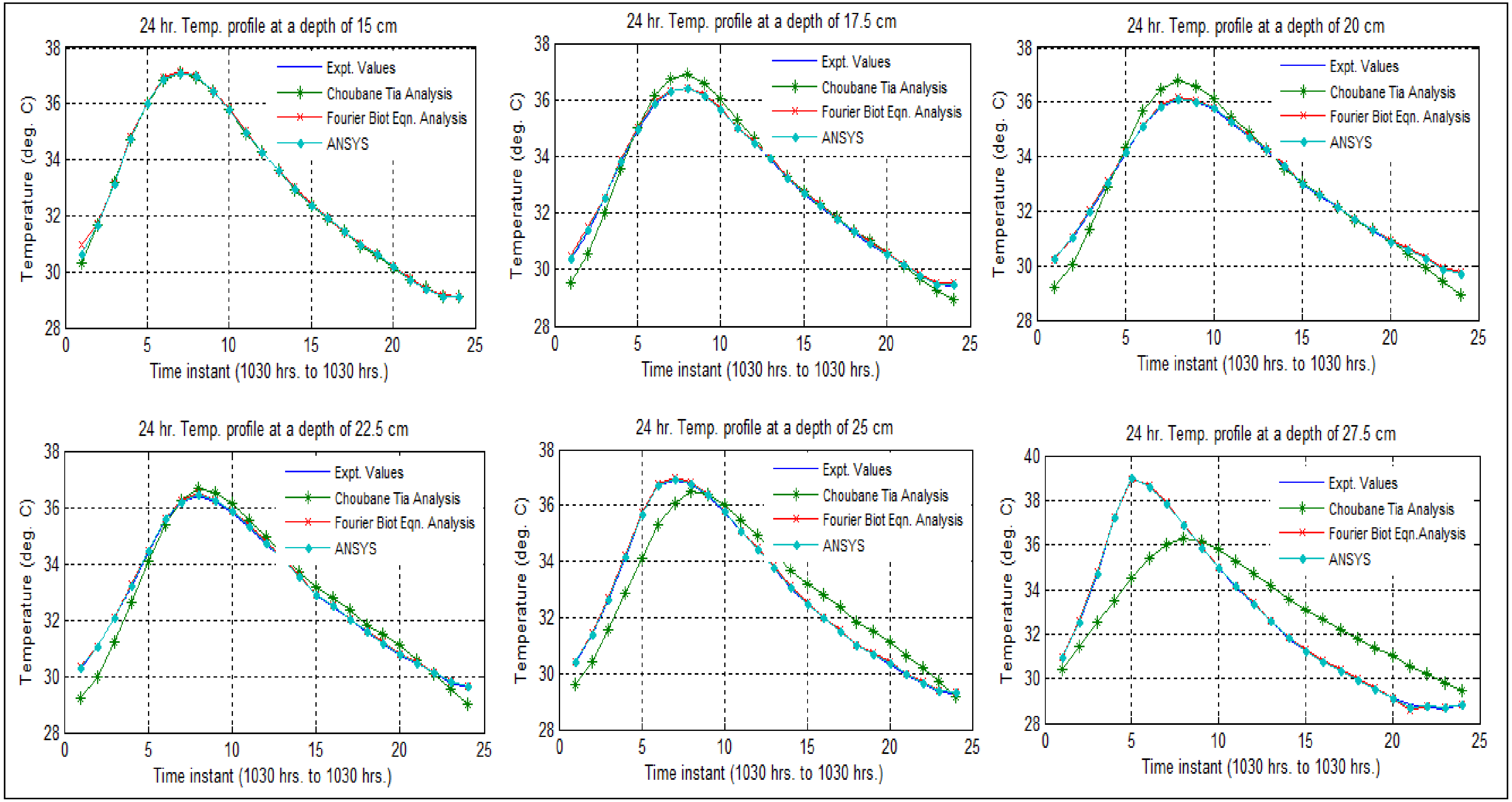


Fig. B-13 (b): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix B for maximum ambient air temperature (15 cm to 27.5 cm)

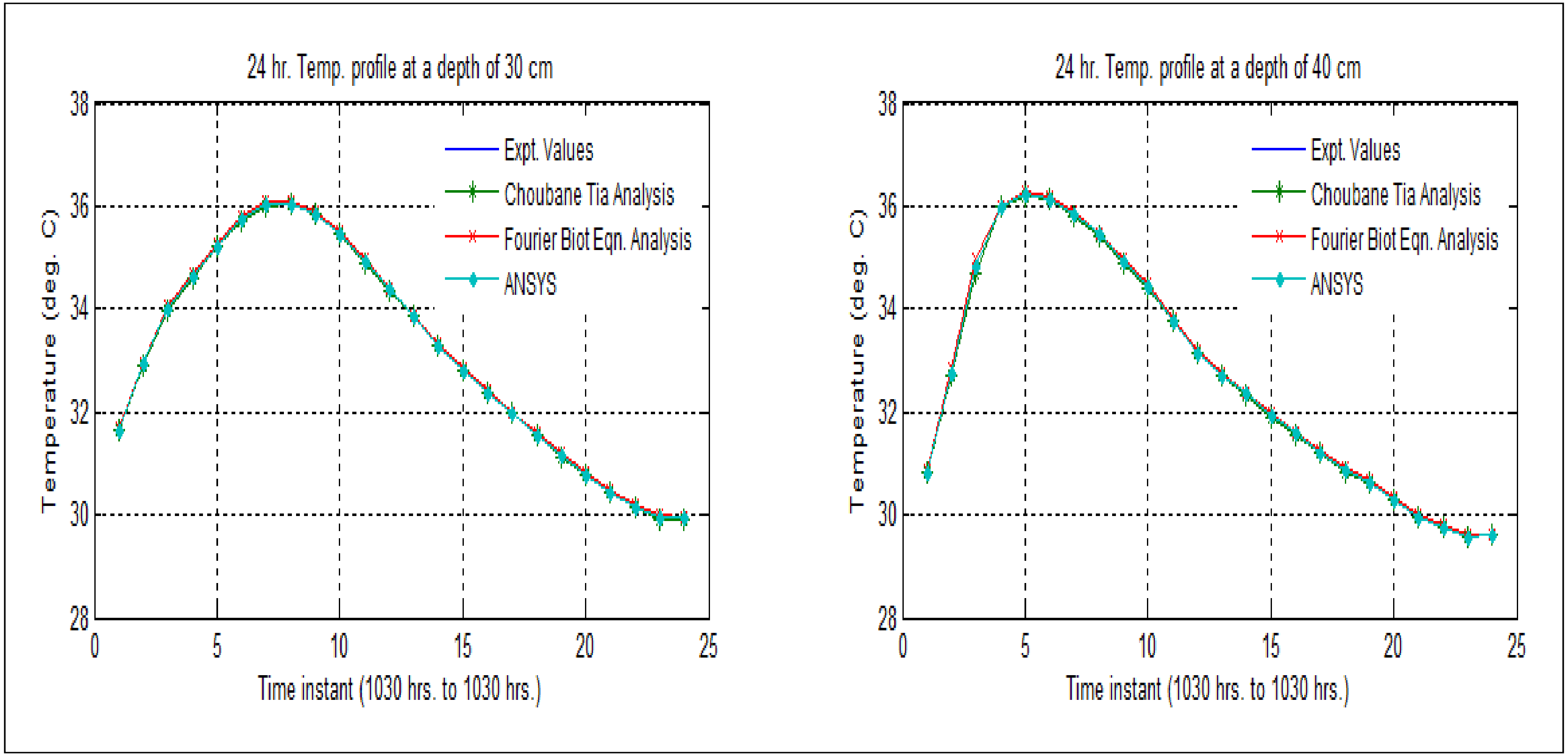


Fig. B-13 (c): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix B for maximum ambient air temperature (30 cm & 40 cm)

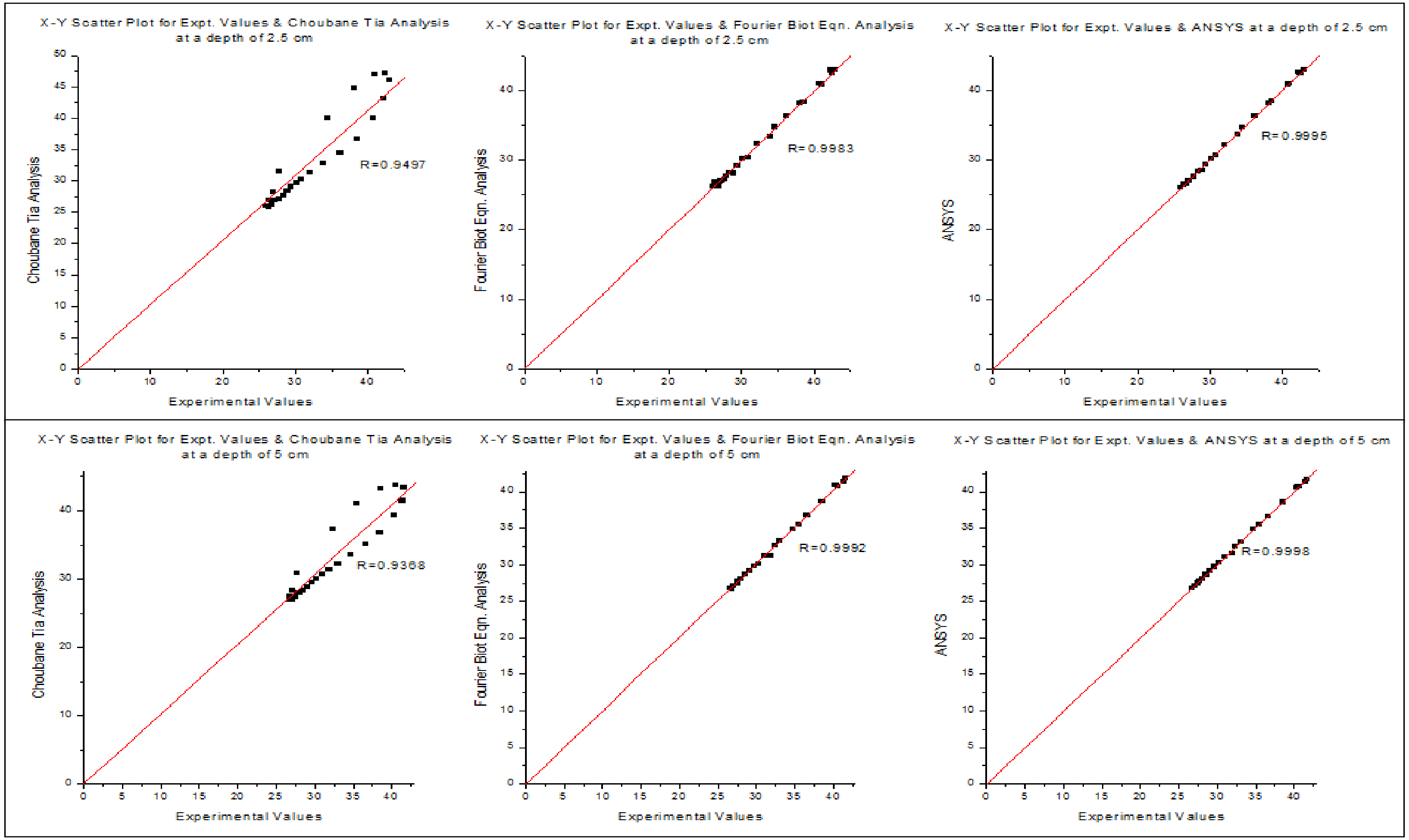


Fig. B-14 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

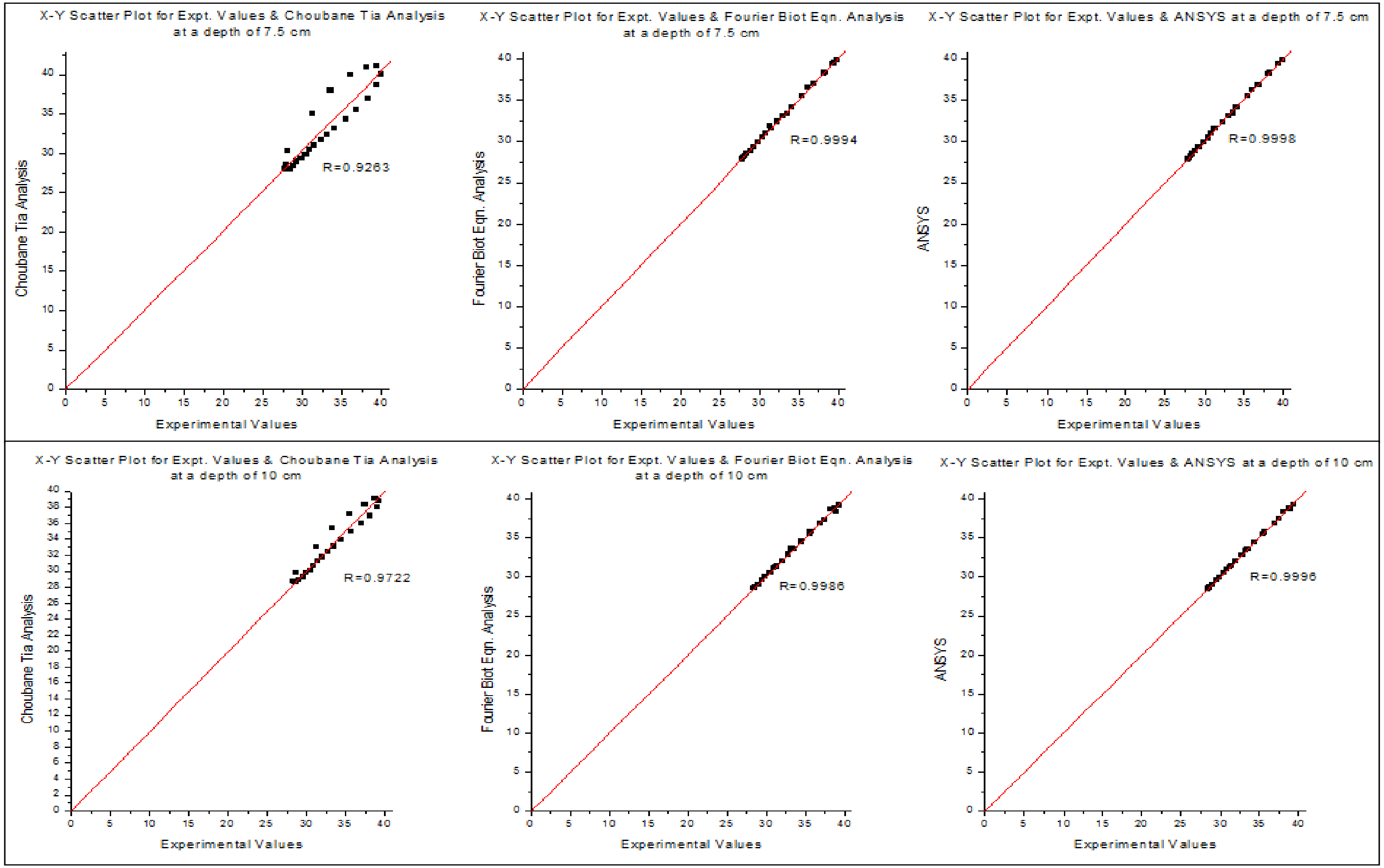


Fig. B-14 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

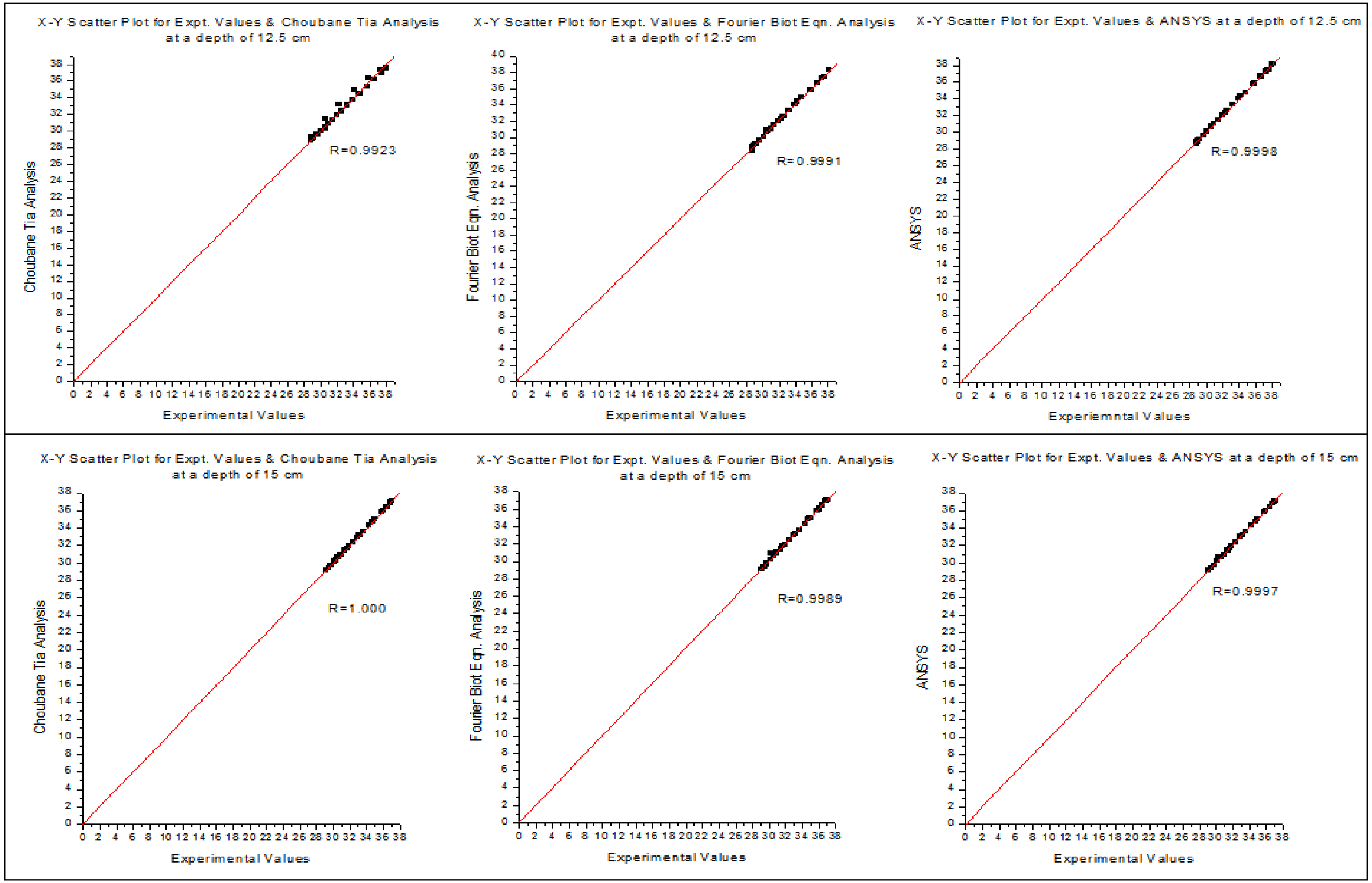


Fig. B-14 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

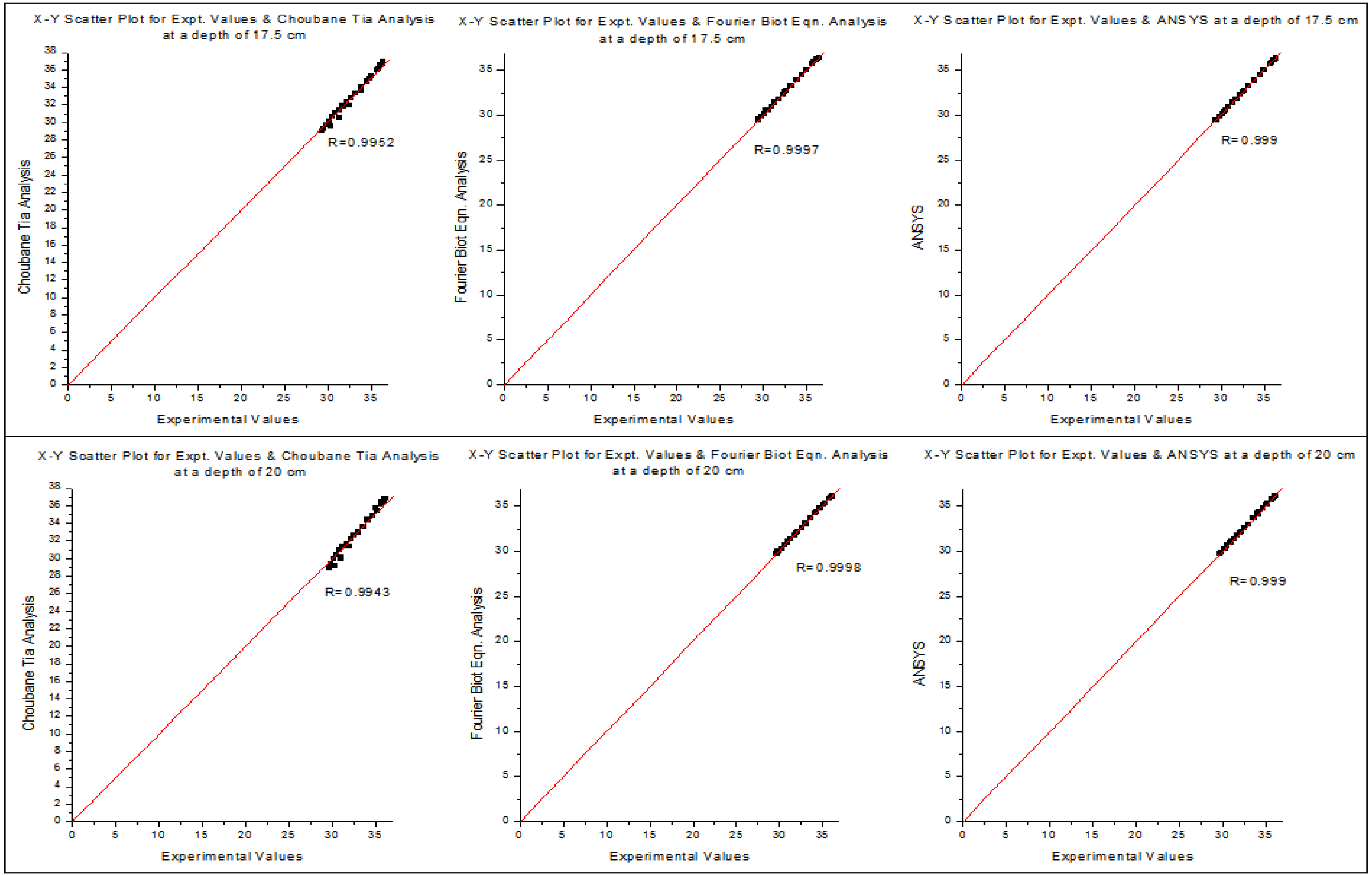


Fig. B-14 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

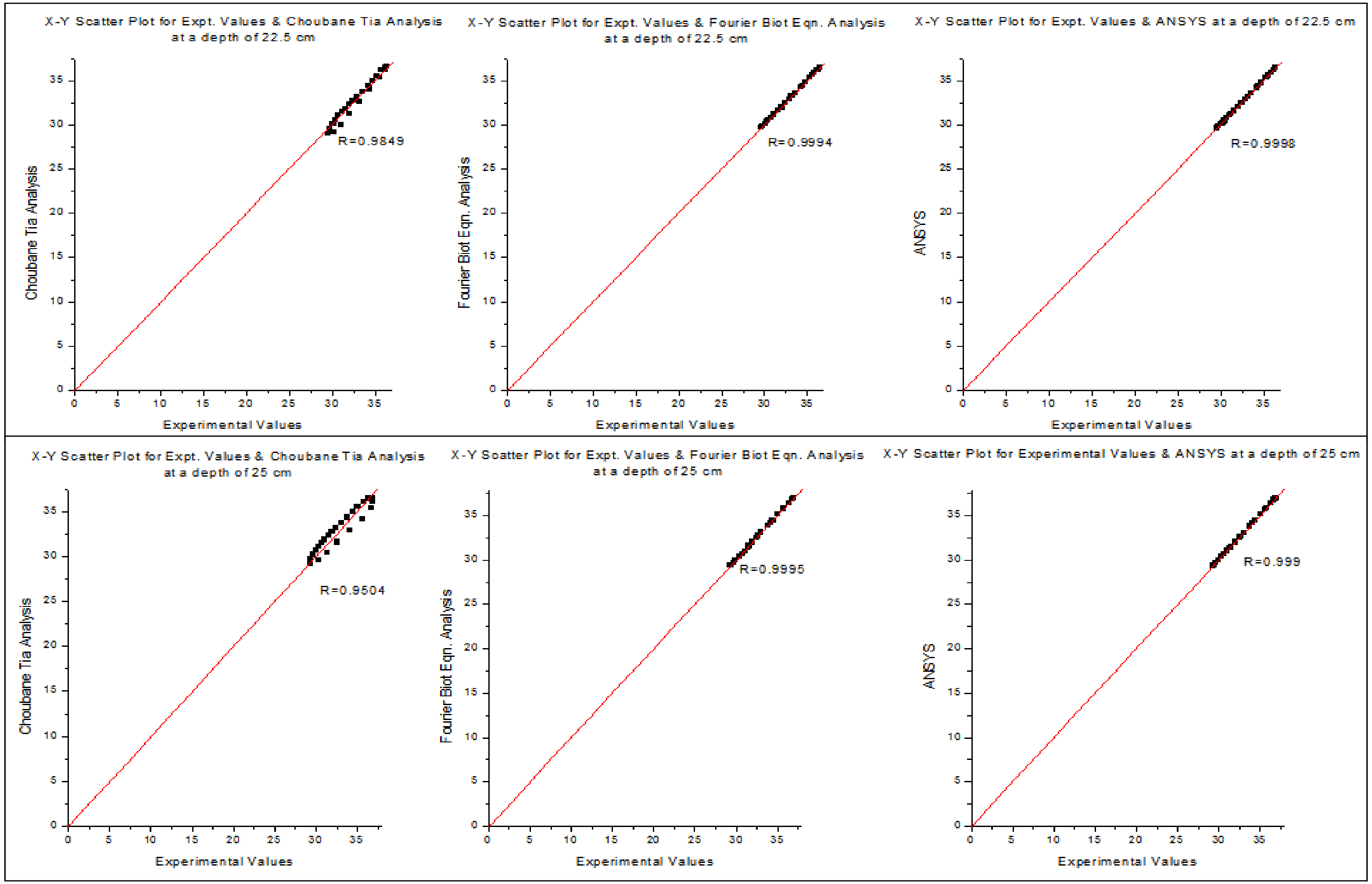


Fig. B-14 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

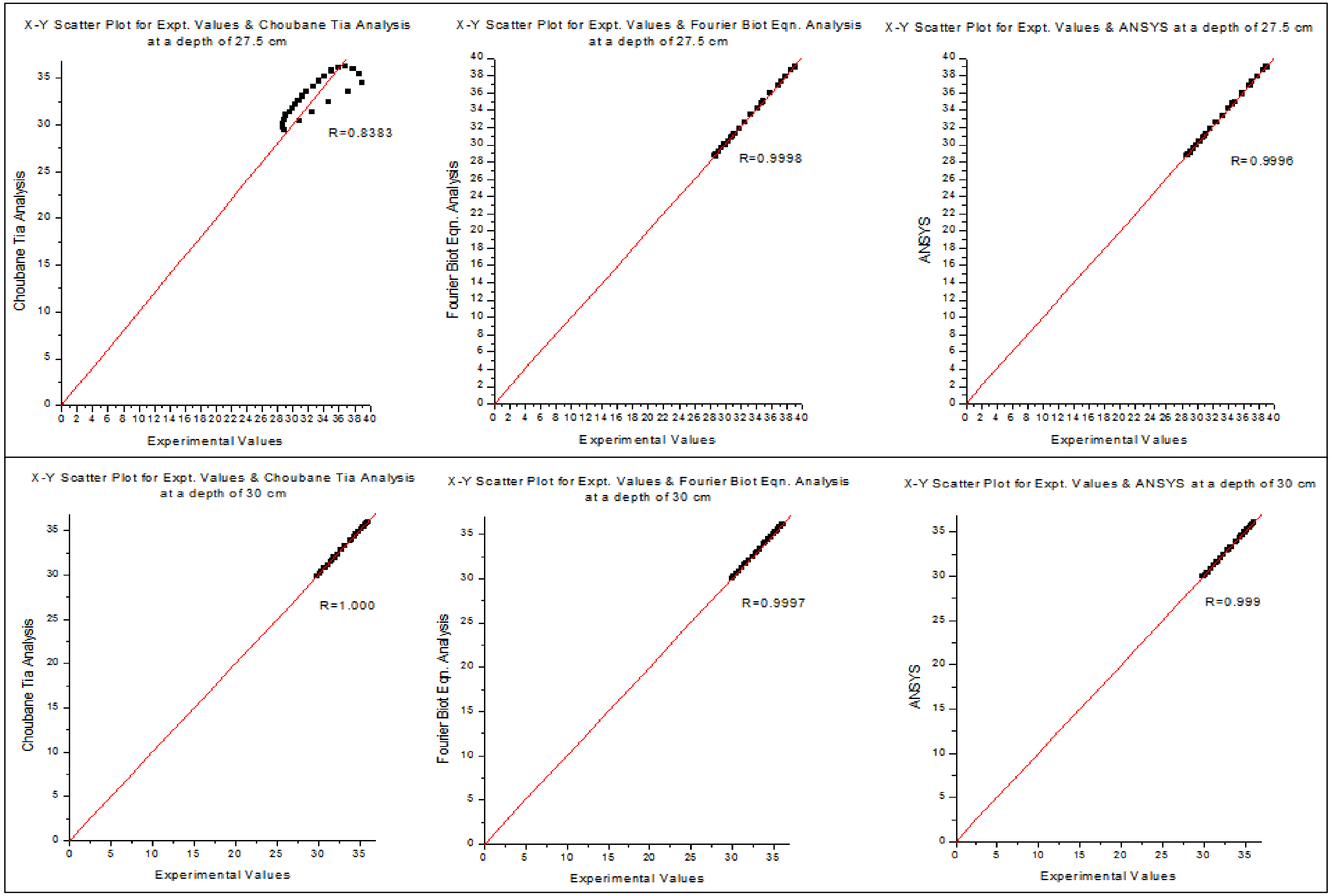


Fig. B-14 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

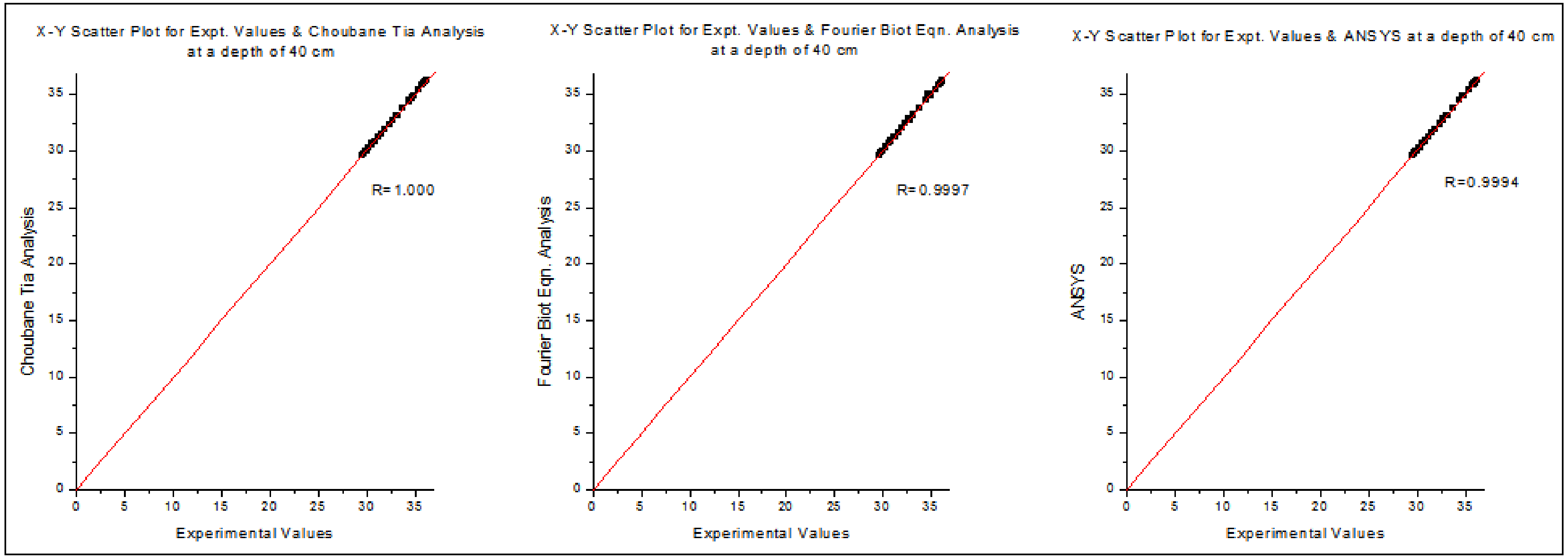


Fig. B-14 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-8 (a): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for maximum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	36	43.06	36.18	39.94	36.75	36.47	32.76	37.21	32.60	32.68	31.39	34.87	31.44	31.41
2	1200 to 1300	37	47.53	39.89	43.47	39.46	39.68	35.86	39.93	35.71	35.78	33.78	36.89	33.82	33.80
3	1300 to 1400	39	48.90	43.10	44.72	43.00	43.05	38.96	41.08	38.06	38.51	36.37	37.99	36.43	36.40
4	1400 to 1500	39	48.46	45.69	44.63	45.69	45.69	41.38	41.31	41.21	41.29	38.57	38.51	38.61	38.59
5	1500 to 1600	39	46.58	46.88	43.51	46.50	46.69	42.94	40.85	42.78	42.86	40.14	38.62	40.20	40.17
6	1600 to 1700	39	42.86	43.72	40.97	43.33	43.52	42.64	39.35	42.72	42.68	40.67	37.99	40.71	40.69
7	1700 to 1800	38	38.54	40.58	37.91	40.45	40.51	41.00	37.38	41.39	41.19	40.19	36.95	40.22	40.20
8	1800 to 1900	37	35.64	37.53	35.83	37.50	37.51	38.78	36.00	38.73	38.76	38.94	36.15	39.01	38.98
9	1900 to 2000	35	33.65	35.32	34.35	35.35	35.33	36.85	34.95	36.24	36.55	37.56	35.47	37.61	37.58
10	2000 to 2100	33	31.93	33.51	33.00	33.26	33.39	35.22	33.93	35.18	35.20	36.26	34.71	36.31	36.28
11	2100 to 2200	32	30.65	31.99	31.92	32.27	32.13	33.78	33.02	33.19	33.48	34.98	33.95	35.04	35.01
12	2200 to 2300	31	29.43	30.52	30.86	30.25	30.39	32.53	32.09	32.18	32.35	33.91	33.14	33.94	33.92
13	2300 to 0000	30	28.73	29.68	30.21	29.18	29.43	31.41	31.49	31.12	31.26	32.87	32.57	32.92	32.90
14	0000 to 0100	29	28.15	28.99	29.64	29.18	29.08	30.57	30.93	30.12	30.34	32.04	32.01	32.08	32.06
15	0100 to 0200	28	27.40	28.34	28.93	28.09	28.21	29.90	30.25	29.06	29.48	31.30	31.36	31.35	31.32
16	0200 to 0300	28	26.74	27.57	28.30	27.20	27.38	29.24	29.65	29.14	29.19	30.71	30.79	30.76	30.74
17	0300 to 0400	27	26.27	27.02	27.84	27.12	27.07	28.64	29.20	28.08	28.36	30.10	30.35	30.05	30.08
18	0400 to 0500	26	26.04	26.87	27.54	25.99	26.43	28.21	28.84	28.00	28.10	29.55	29.94	29.59	29.57
19	0500 to 0600	26	25.23	26.28	26.81	26.14	26.21	27.73	28.18	27.10	27.41	29.09	29.35	29.06	29.08
20	0600 to 0700	26	25.03	25.97	26.55	25.19	25.58	27.23	27.87	27.13	27.18	28.64	28.98	28.59	28.62
21	0700 to 0800	28	25.60	26.09	26.88	26.09	26.09	26.95	27.99	26.75	26.85	28.23	28.93	28.19	28.21
22	0800 to 0900	29	26.69	26.60	27.63	26.81	26.71	27.02	28.43	27.63	27.32	28.07	29.11	28.12	28.09
23	0900 to 1000	31	29.60	27.90	29.74	27.56	27.73	27.45	29.86	27.92	27.69	28.14	29.95	28.18	28.16
24	1000 to 1100	34	36.38	30.28	34.86	30.90	30.59	28.33	33.52	28.23	28.28	28.46	32.35	28.51	28.49

Table B-8 (b): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for maximum ambient air temperature at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	31.41	32.90	31.50	31.45	30.90	31.33	30.87	30.88	30.14	30.14	30.24	30.19
2	1200 to 1300	33.54	34.37	33.68	33.61	32.63	32.35	32.59	32.61	30.85	30.85	30.90	30.88
3	1300 to 1400	35.81	35.43	35.80	35.81	34.51	33.42	34.46	34.49	31.95	31.95	32.03	31.99
4	1400 to 1500	37.82	36.22	37.51	37.66	36.24	34.45	36.29	36.27	33.19	33.19	33.22	33.20
5	1500 to 1600	39.27	36.81	39.32	39.30	37.60	35.41	37.71	37.66	34.44	34.44	34.66	34.55
6	1600 to 1700	39.97	36.89	40.01	39.99	38.38	36.06	38.31	38.35	35.48	35.48	35.66	35.57
7	1700 to 1800	39.75	36.61	39.80	39.77	38.47	36.36	38.38	38.42	36.21	36.21	36.44	36.33
8	1800 to 1900	38.81	36.29	38.72	38.76	38.08	36.40	38.17	38.12	36.50	36.50	36.55	36.53
9	1900 to 2000	37.68	35.90	37.71	37.70	37.25	36.23	37.36	37.30	36.48	36.48	36.54	36.51
10	2000 to 2100	36.54	35.35	36.59	36.56	36.41	35.84	36.48	36.44	36.19	36.19	36.23	36.21
11	2100 to 2200	35.39	34.71	35.38	35.39	35.48	35.29	35.55	35.51	35.70	35.70	35.73	35.72
12	2200 to 2300	34.42	33.99	34.27	34.34	34.63	34.65	34.65	34.64	35.12	35.12	35.19	35.16
13	2300 to 0000	33.50	33.44	33.45	33.48	33.85	34.12	33.93	33.89	34.60	34.60	34.65	34.62
14	0000 to 0100	32.68	32.89	32.55	32.62	33.09	33.57	33.03	33.06	34.04	34.04	34.02	34.03
15	0100 to 0200	32.02	32.27	32.03	32.02	32.48	32.98	32.52	32.50	33.48	33.48	33.51	33.49
16	0200 to 0300	31.39	31.72	31.26	31.32	31.91	32.44	32.04	31.97	32.96	32.96	33.02	32.99
17	0300 to 0400	30.79	31.28	30.83	30.81	31.30	32.01	31.22	31.26	32.52	32.52	32.51	32.51
18	0400 to 0500	30.29	30.84	30.31	30.30	30.78	31.54	30.81	30.79	32.03	32.03	32.00	32.02
19	0500 to 0600	29.83	30.30	29.79	29.81	30.37	31.05	30.43	30.40	31.59	31.59	31.52	31.56
20	0600 to 0700	29.29	29.90	29.26	29.28	29.85	30.61	29.91	29.88	31.13	31.13	31.20	31.17
21	0700 to 0800	28.87	29.70	28.91	28.89	29.39	30.30	29.31	29.35	30.73	30.73	30.70	30.71
22	0800 to 0900	28.74	29.67	28.79	28.76	29.10	30.09	29.09	29.10	30.39	30.39	30.40	30.39
23	0900 to 1000	28.72	30.01	28.76	28.74	28.95	30.04	29.01	28.98	30.04	30.04	30.06	30.05
24	1000 to 1100	28.84	31.35	28.82	28.83	29.03	30.52	29.05	29.04	29.87	29.87	29.84	29.85

Table B-8 (c): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for maximum ambient air temperature at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	30.28	29.34	30.49	30.39	30.28	28.93	30.22	30.25	30.43	28.90	30.45	30.44
2	1200 to 1300	31.01	29.86	31.07	31.04	30.98	29.37	31.02	31.00	31.57	29.40	31.56	31.57
3	1300 to 1400	32.13	31.02	32.17	32.15	32.16	30.63	32.25	32.21	33.08	30.79	33.06	33.07
4	1400 to 1500	33.32	32.44	33.35	33.34	33.49	32.20	33.53	33.51	34.65	32.48	34.66	34.65
5	1500 to 1600	34.51	33.89	34.45	34.48	34.77	33.75	34.80	34.79	36.00	34.04	36.05	36.02
6	1600 to 1700	35.50	35.17	35.35	35.42	35.86	35.12	35.91	35.89	36.92	35.33	36.97	36.94
7	1700 to 1800	36.20	36.16	36.28	36.24	36.53	36.20	36.50	36.51	37.48	36.34	37.52	37.50
8	1800 to 1900	36.49	36.58	36.55	36.52	36.84	36.64	36.91	36.88	37.60	36.68	37.63	37.61
9	1900 to 2000	36.45	36.63	36.52	36.49	36.76	36.69	36.81	36.78	37.31	36.66	37.30	37.30
10	2000 to 2100	36.17	36.39	36.20	36.18	36.47	36.46	36.51	36.49	36.75	36.38	36.80	36.77
11	2100 to 2200	35.70	35.94	35.72	35.71	35.98	36.01	36.01	35.99	36.08	35.90	36.10	36.09
12	2200 to 2300	35.16	35.40	35.20	35.18	35.37	35.48	35.41	35.39	35.29	35.38	35.33	35.31
13	2300 to 0000	34.63	34.87	34.71	34.67	34.76	34.94	34.80	34.78	34.61	34.82	34.65	34.63
14	0000 to 0100	34.11	34.31	34.13	34.12	34.21	34.38	34.25	34.23	33.98	34.24	34.00	33.99
15	0100 to 0200	33.55	33.77	33.61	33.58	33.64	33.85	33.70	33.67	33.35	33.73	33.40	33.38
16	0200 to 0300	33.04	33.26	33.01	33.02	33.12	33.35	33.15	33.13	32.81	33.24	32.87	32.84
17	0300 to 0400	32.58	32.82	32.61	32.60	32.65	32.91	32.70	32.68	32.39	32.79	32.42	32.41
18	0400 to 0500	32.12	32.33	32.10	32.11	32.21	32.42	32.24	32.23	31.87	32.31	31.85	31.86
19	0500 to 0600	31.68	31.92	31.71	31.69	31.75	32.04	31.80	31.77	31.40	31.95	31.42	31.41
20	0600 to 0700	31.20	31.45	31.21	31.21	31.30	31.56	31.31	31.31	30.94	31.48	31.01	30.97
21	0700 to 0800	30.78	30.98	30.80	30.79	30.85	31.07	30.90	30.87	30.57	30.99	30.61	30.59
22	0800 to 0900	30.47	30.56	30.52	30.49	30.55	30.61	30.60	30.58	30.20	30.52	30.25	30.23
23	0900 to 1000	30.12	30.02	30.15	30.13	30.21	29.96	30.22	30.22	29.90	29.88	29.92	29.91
24	1000 to 1100	29.92	29.39	29.87	29.90	29.99	29.08	30.03	30.01	29.73	28.95	29.75	29.74

Table B-8 (d): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for maximum ambient air temperature at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	30.93	29.25	30.95	30.94	32.91	30.00	32.97	32.94	31.13	31.13	31.20	31.16	32.02	32.02	31.88	31.95
2	1200 to 1300	32.38	29.93	32.44	32.41	34.91	30.98	34.97	34.94	32.54	32.54	32.60	32.57	34.75	34.75	34.86	34.81
3	1300 to 1400	33.98	31.48	34.04	34.01	36.47	32.72	36.52	36.49	34.50	34.50	34.52	34.51	37.39	37.39	37.36	37.38
4	1400 to 1500	35.35	33.28	35.39	35.37	37.08	34.58	37.11	37.10	36.40	36.40	36.43	36.42	38.46	38.46	38.48	38.47
5	1500 to 1600	36.34	34.74	36.36	36.35	37.22	35.87	37.27	37.24	37.41	37.41	37.46	37.44	37.91	37.91	37.89	37.90
6	1600 to 1700	36.95	35.80	37.02	36.98	37.21	36.54	37.28	37.25	37.53	37.53	37.57	37.55	37.16	37.16	37.21	37.19
7	1700 to 1800	37.24	36.57	37.27	37.25	37.09	36.90	37.06	37.08	37.32	37.32	37.34	37.33	36.56	36.56	36.66	36.61
8	1800 to 1900	37.19	36.70	37.22	37.21	36.70	36.70	36.77	36.74	36.69	36.69	36.72	36.70	35.90	35.90	35.98	35.94
9	1900 to 2000	36.83	36.54	36.88	36.85	36.19	36.33	36.22	36.21	36.03	36.03	36.00	36.01	35.05	35.05	35.10	35.08
10	2000 to 2100	36.27	36.15	36.33	36.30	35.37	35.78	35.41	35.39	35.27	35.27	35.31	35.29	34.32	34.32	34.42	34.37
11	2100 to 2200	35.49	35.62	35.51	35.50	34.61	35.17	34.66	34.63	34.55	34.55	34.59	34.57	33.51	33.51	33.59	33.55
12	2200 to 2300	34.77	35.08	34.81	34.79	34.00	34.59	34.00	34.00	33.91	33.91	34.00	33.95	32.83	32.83	32.90	32.86
13	2300 to 0000	34.18	34.49	34.21	34.20	33.46	33.96	33.51	33.49	33.23	33.23	33.30	33.26	32.30	32.30	32.40	32.35
14	0000 to 0100	33.55	33.90	33.61	33.58	32.89	33.36	32.92	32.91	32.62	32.62	32.66	32.64	31.75	31.75	31.81	31.78
15	0100 to 0200	32.99	33.41	33.00	33.00	32.50	32.88	32.55	32.53	32.14	32.14	32.17	32.15	31.31	31.31	31.40	31.36
16	0200 to 0300	32.55	32.92	32.63	32.59	32.04	32.39	32.00	32.02	31.65	31.65	31.70	31.67	30.88	30.88	30.94	30.91
17	0300 to 0400	32.09	32.46	32.12	32.10	31.56	31.91	31.61	31.59	31.16	31.16	31.20	31.18	30.54	30.54	30.61	30.57
18	0400 to 0500	31.58	32.00	31.61	31.60	31.11	31.49	31.17	31.14	30.78	30.78	30.81	30.79	30.18	30.18	30.22	30.20
19	0500 to 0600	31.15	31.66	31.19	31.17	30.75	31.15	30.81	30.78	30.44	30.44	30.49	30.46	29.84	29.84	29.91	29.88
20	0600 to 0700	30.76	31.19	30.81	30.78	30.34	30.70	30.40	30.37	30.02	30.02	30.00	30.01	29.47	29.47	29.51	29.49
21	0700 to 0800	30.36	30.73	30.41	30.38	29.98	30.31	30.00	29.99	29.71	29.71	29.75	29.73	29.19	29.19	29.22	29.21
22	0800 to 0900	30.04	30.31	30.02	30.03	29.83	29.97	29.89	29.86	29.51	29.51	29.55	29.53	29.10	29.10	29.15	29.13
23	0900 to 1000	29.81	29.77	29.85	29.83	29.83	29.63	29.90	29.87	29.46	29.46	29.50	29.48	29.18	29.18	29.22	29.20
24	1000 to 1100	29.76	28.99	29.78	29.77	30.23	29.20	30.20	30.22	29.58	29.58	29.62	29.60	29.41	29.41	29.47	29.44

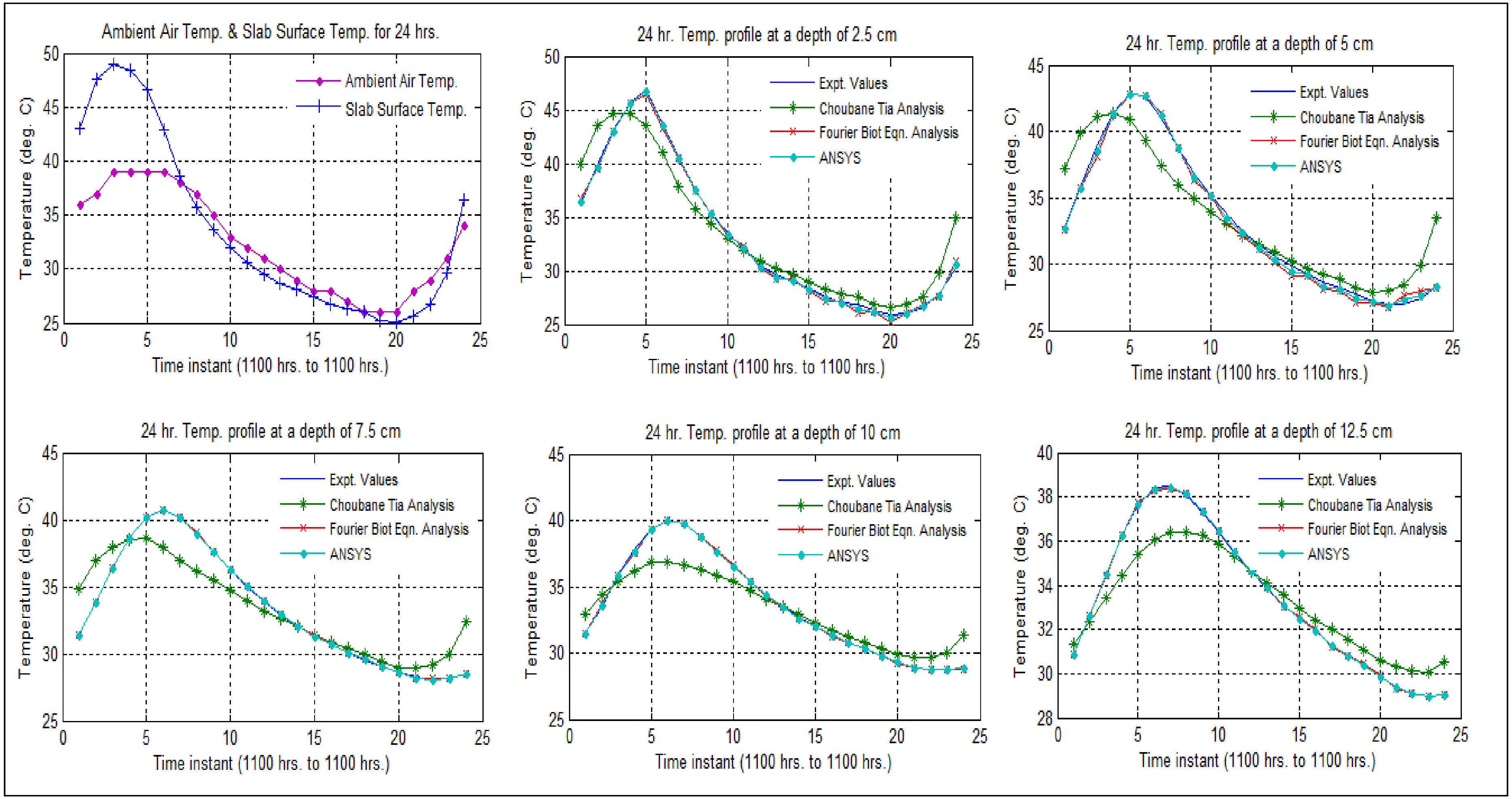


Fig. B-15 (a): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix B for maximum ambient air temperature (surface to 12.5 cm)

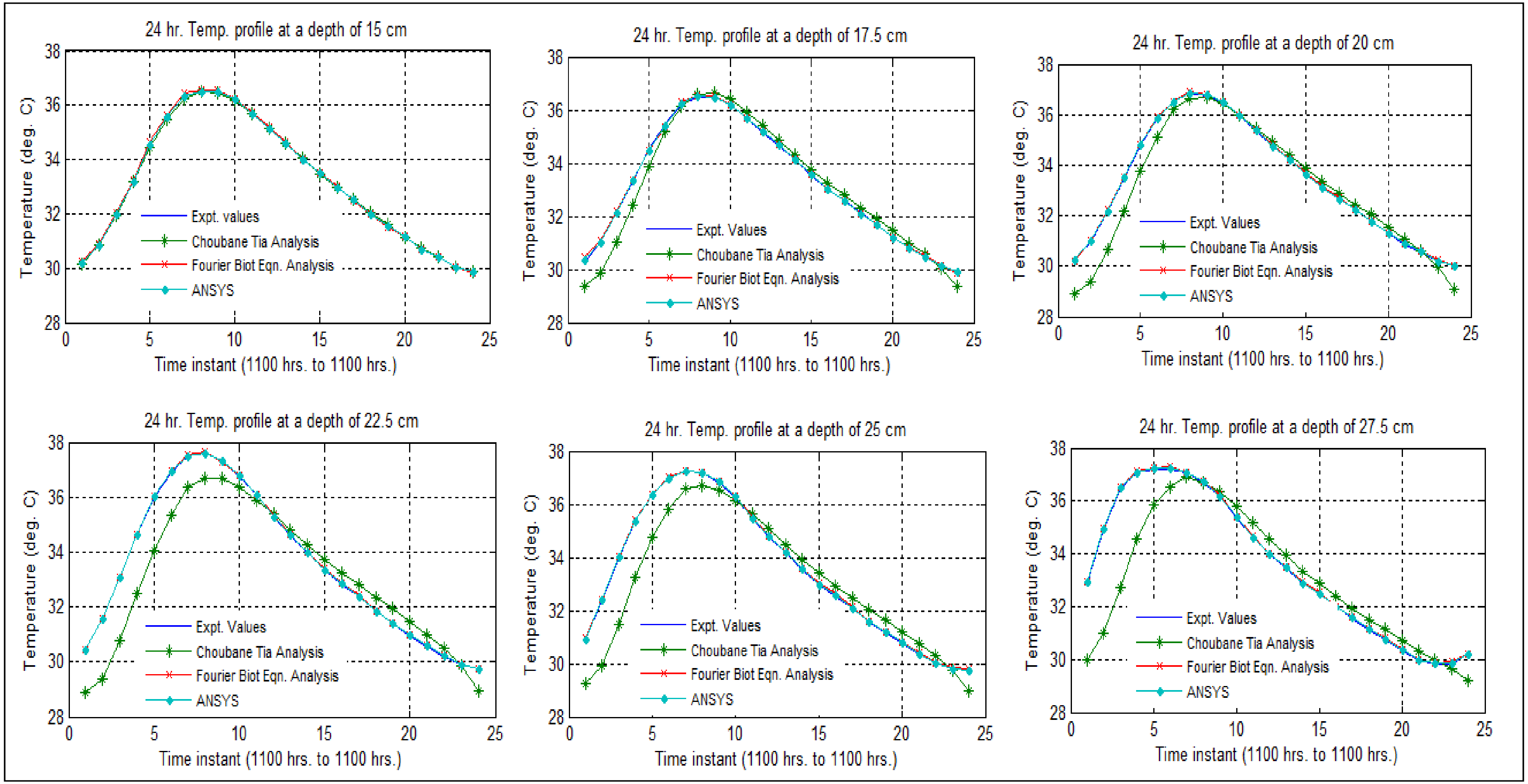


Fig. B-15 (b): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix B for maximum ambient air temperature (15 cm to 27.5 cm)

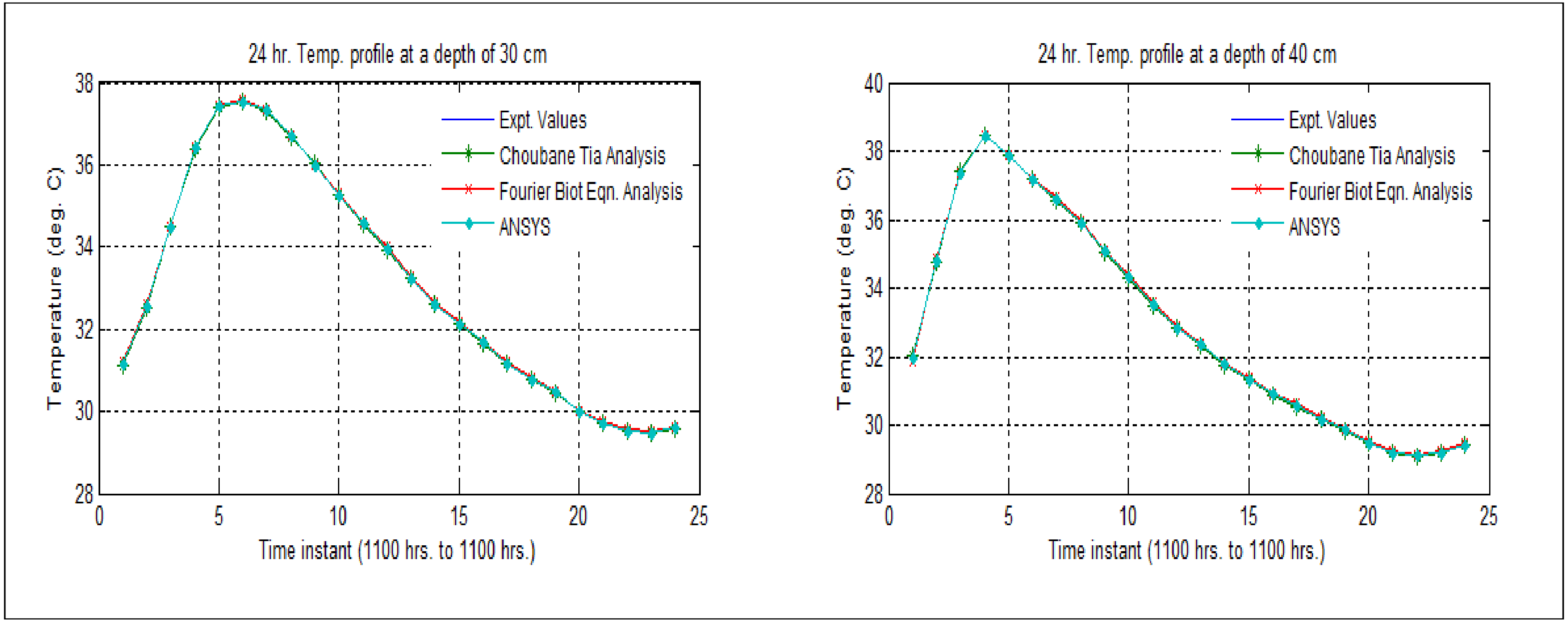


Fig. B-15 (c): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix B for maximum ambient air temperature (30 cm & 40 cm)

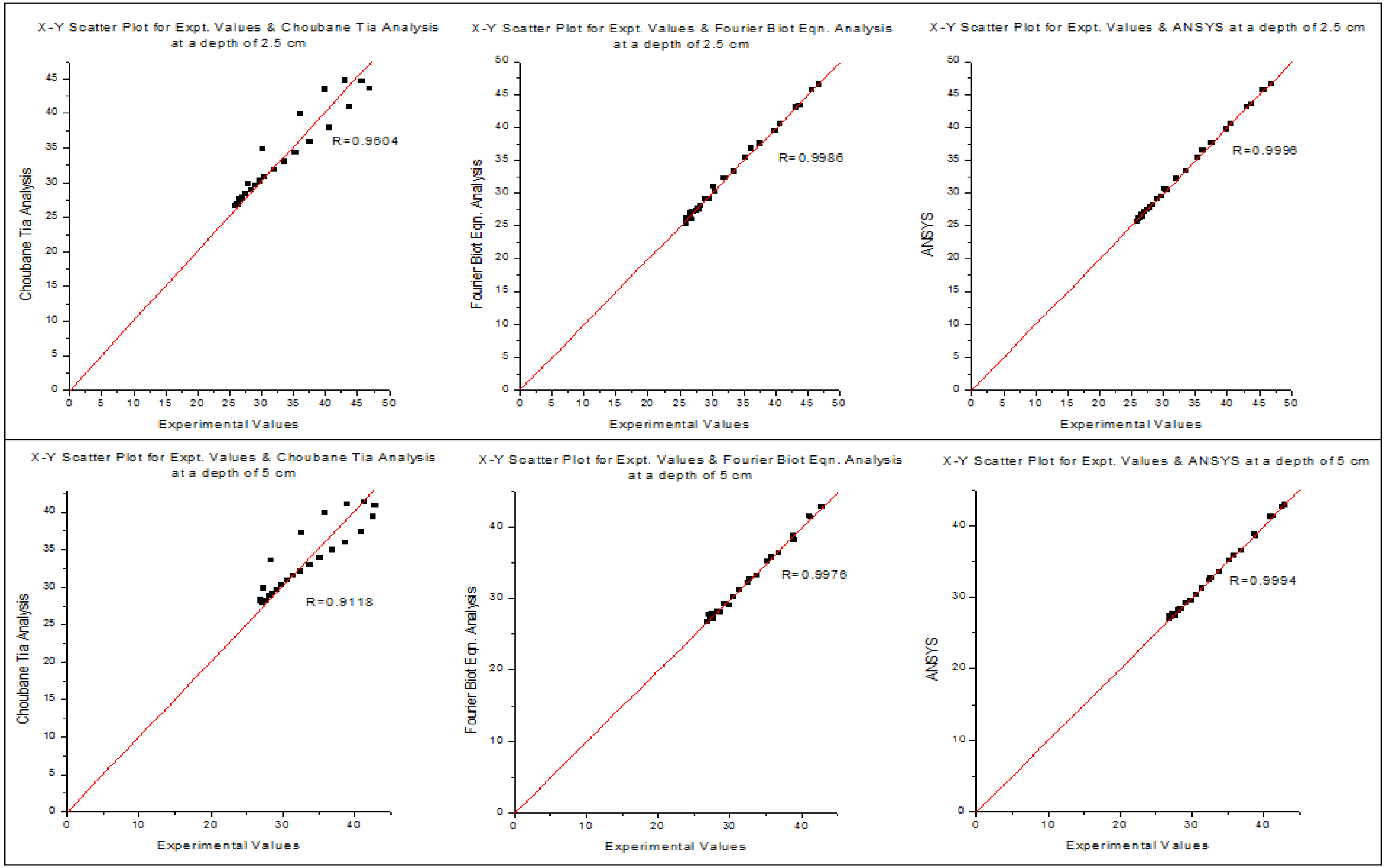


Fig. B-16 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

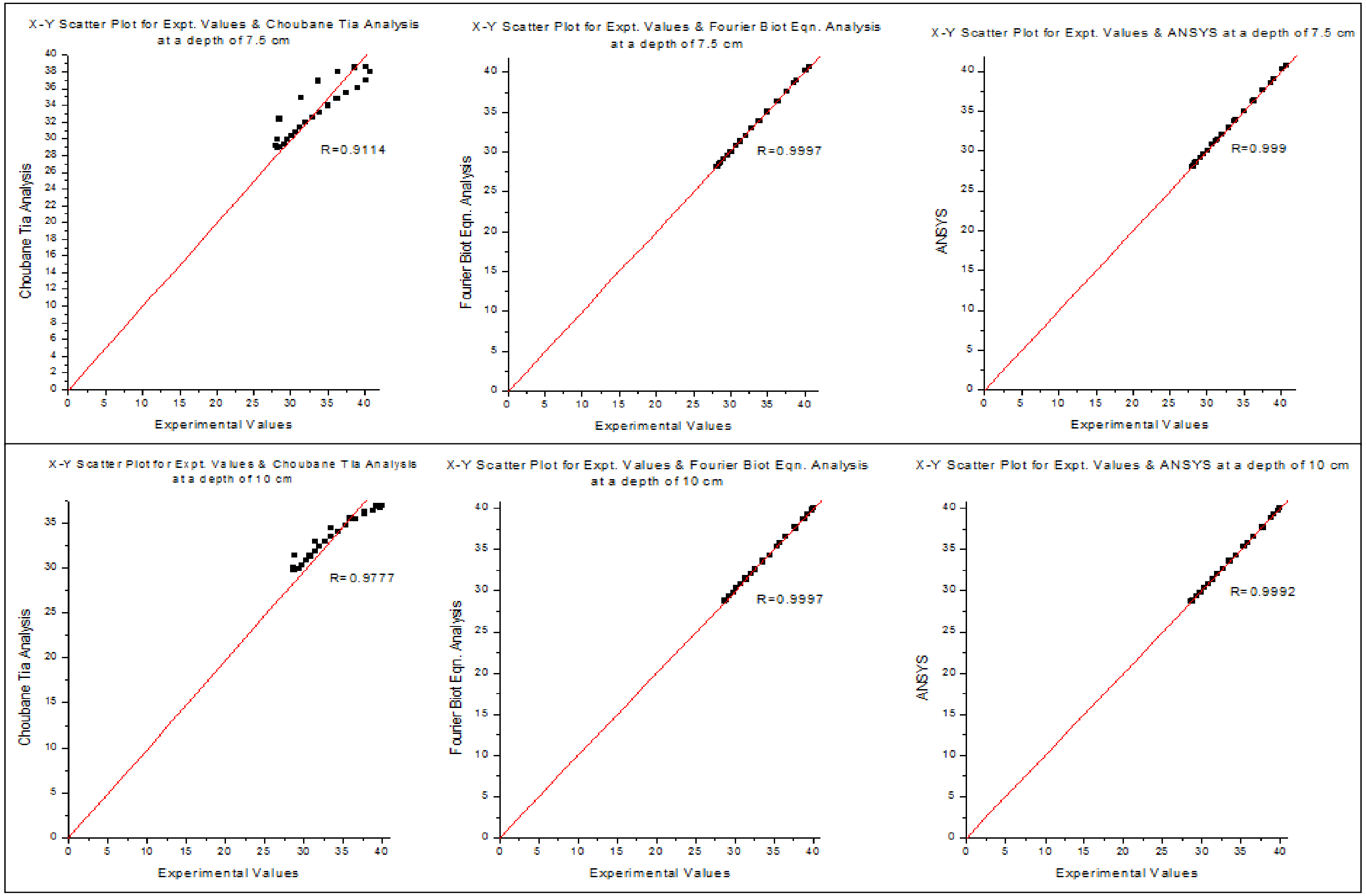


Fig. B-16 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

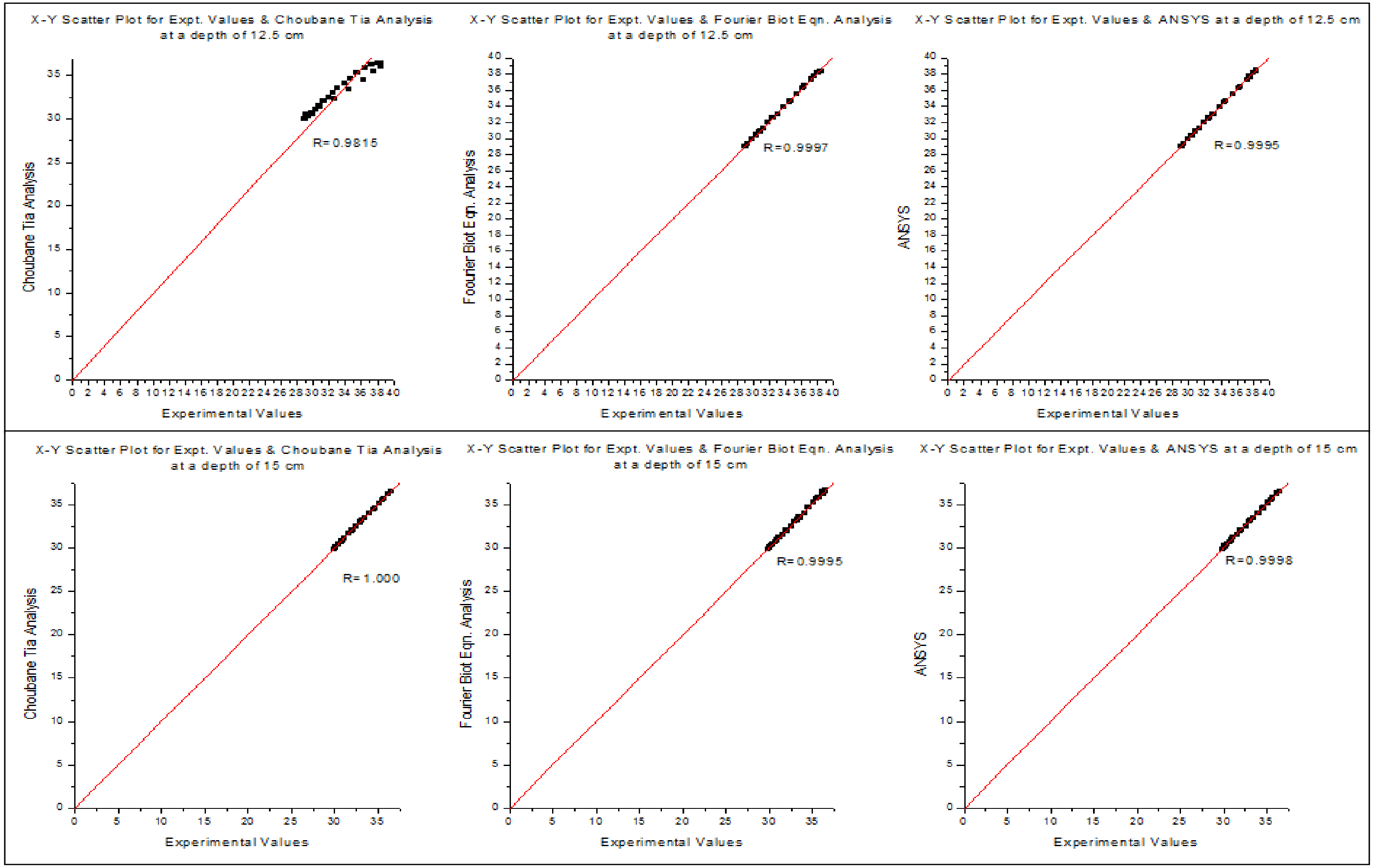


Fig. B-16 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

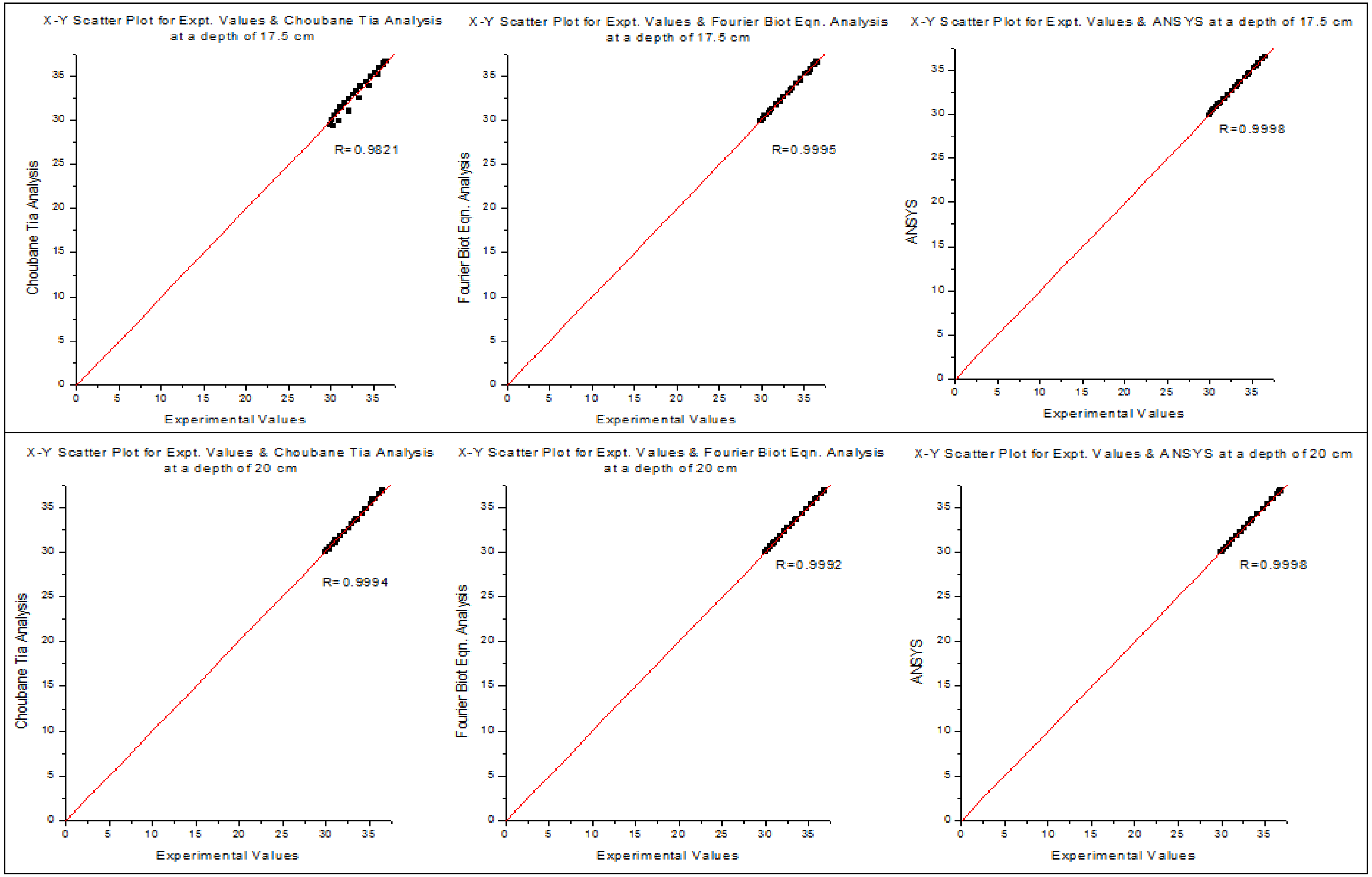


Fig. B-16 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

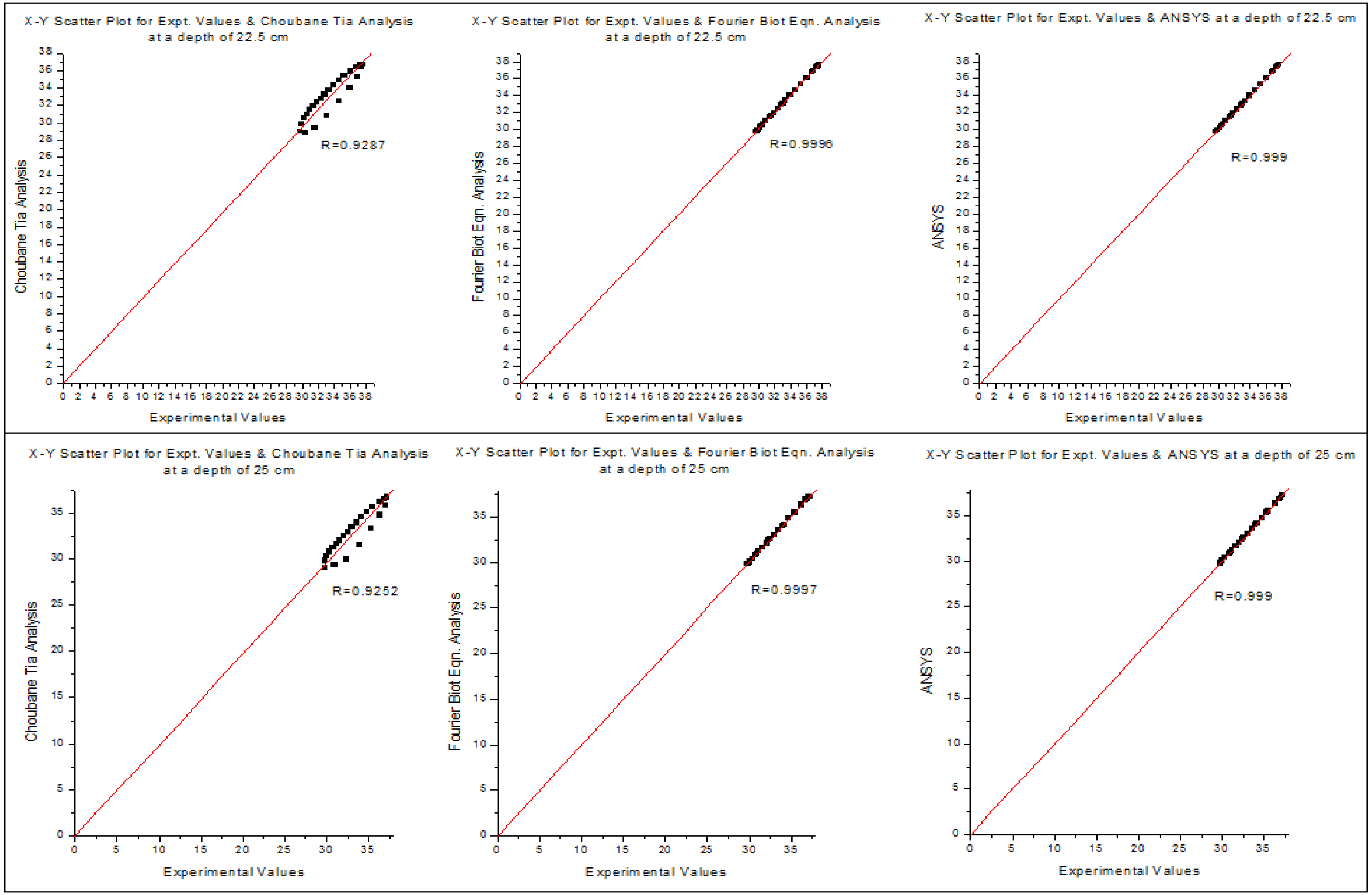


Fig. B-16 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

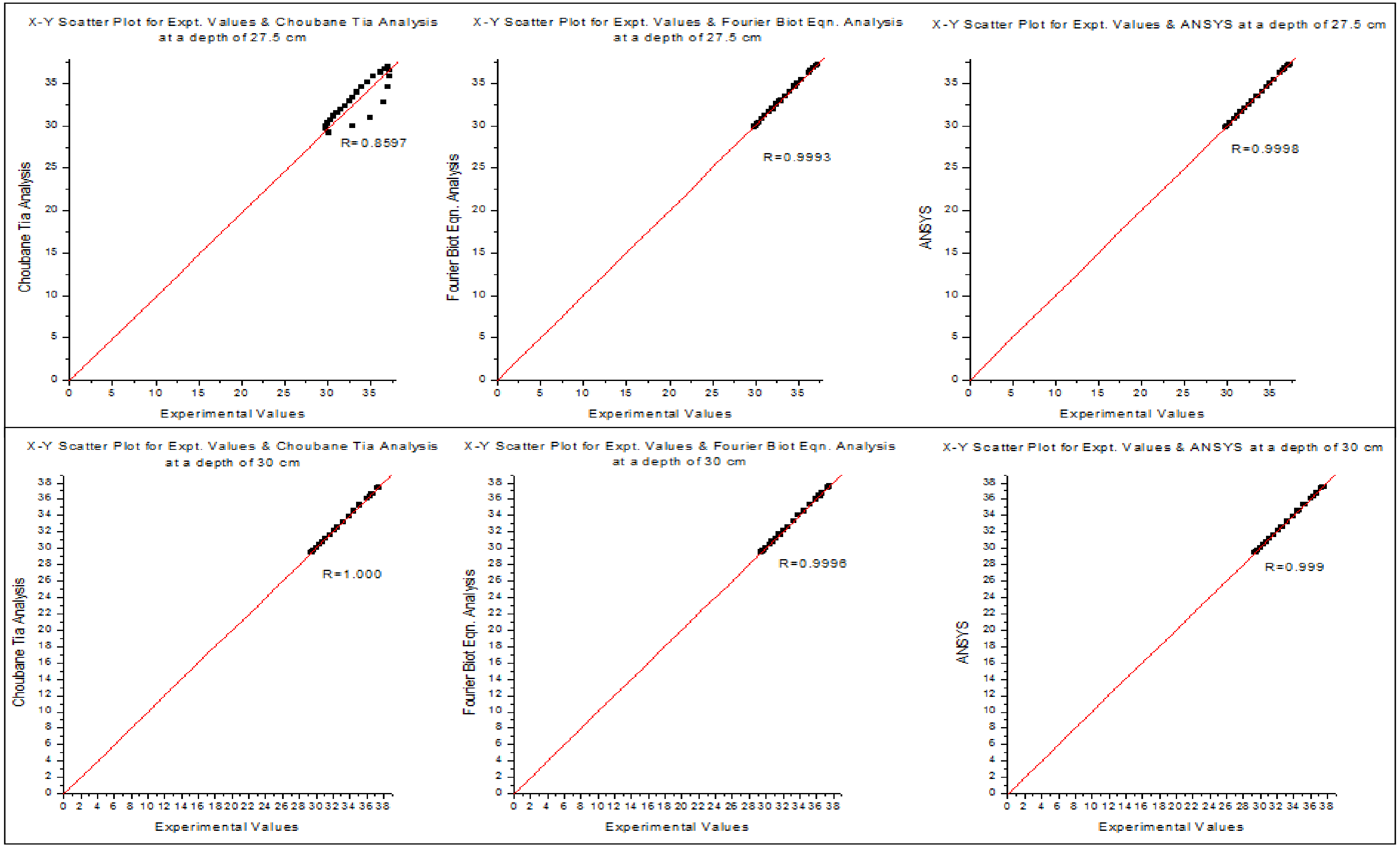


Fig. B-16 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

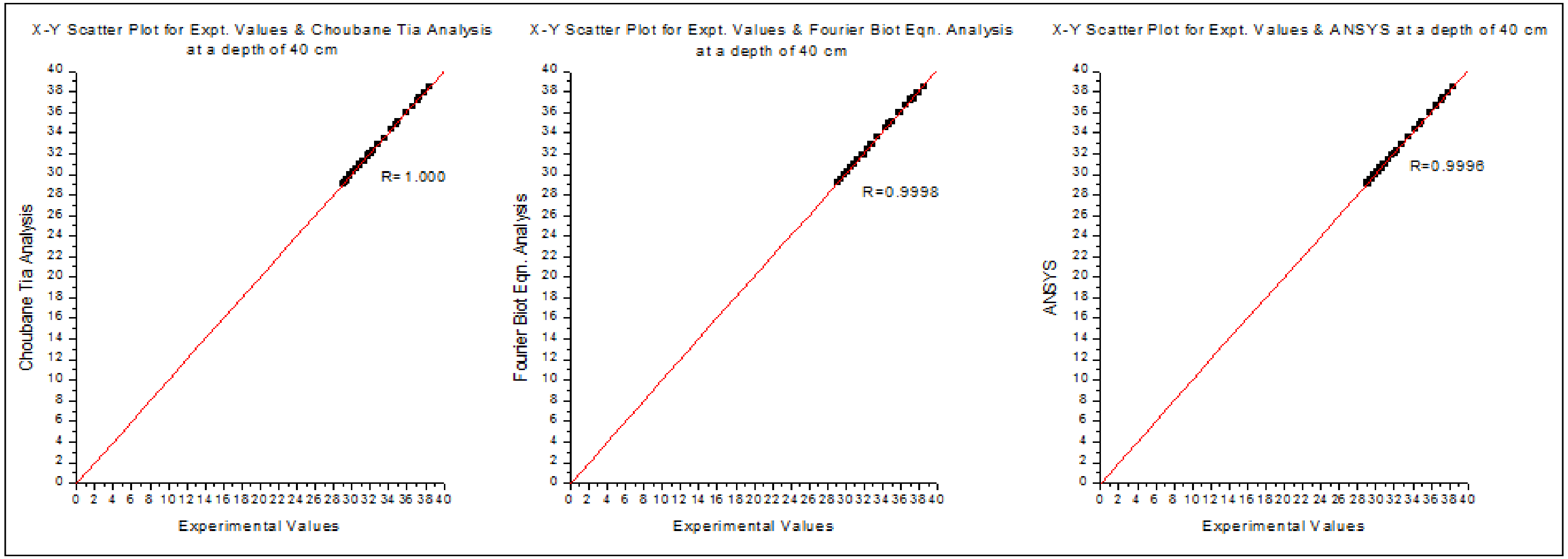


Fig. B-16 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-9 (a): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for minimum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	27	35.18	28.15	32.21	28.19	28.17	25.37	29.60	25.44	25.40	23.91	27.35	23.49	23.70
2	1130 to 1230	29	39.12	31.18	35.53	31.67	31.42	28.49	32.38	28.46	28.47	26.36	29.66	26.16	26.26
3	1230 to 1330	32	41.83	33.14	37.99	33.90	33.52	31.14	34.61	31.34	31.24	28.73	31.68	28.29	28.51
4	1330 to 1430	32	42.45	34.15	38.85	34.52	34.34	32.95	35.68	32.45	32.70	30.65	32.91	30.75	30.70
5	1430 to 1530	32	40.82	34.49	37.95	34.88	34.69	33.81	35.40	33.73	33.77	31.89	33.17	31.70	31.79
6	1530 to 1630	31	38.15	33.87	36.12	33.51	33.69	33.65	34.29	33.10	33.37	32.26	32.68	32.97	32.62
7	1630 to 1730	30	33.53	32.49	32.69	32.79	32.64	32.61	31.92	32.80	32.71	31.89	31.21	31.47	31.68
8	1730 to 1830	28	28.61	30.21	28.94	30.05	30.13	30.74	29.20	30.41	30.58	30.77	29.37	30.92	30.85
9	1830 to 1930	27	25.84	27.72	26.67	27.35	27.54	28.56	27.38	28.24	28.40	29.19	27.95	29.16	29.17
10	1930 to 2030	25	24.16	25.90	25.20	25.19	25.54	26.83	26.10	26.13	26.48	27.78	26.84	27.08	27.43
11	2030 to 2130	24	22.92	24.61	24.05	24.23	24.42	25.50	25.03	25.16	25.33	26.63	25.85	26.11	26.37
12	2130 to 2230	23	21.96	23.52	23.14	23.22	23.37	24.42	24.17	25.15	24.79	25.59	25.05	25.10	25.35
13	2230 to 2330	23	21.07	22.72	22.29	22.44	22.58	23.49	23.36	23.31	23.40	24.76	24.27	24.20	24.48
14	2330 to 0030	22	20.14	21.83	21.41	21.40	21.61	22.67	22.53	22.28	22.47	23.93	23.49	23.18	23.55
15	0030 to 0130	22	19.25	21.02	20.59	21.60	21.31	21.81	21.78	21.42	21.61	23.19	22.80	23.27	23.23
16	0130 to 0230	21	18.54	20.25	19.91	20.52	20.39	21.10	21.11	21.36	21.23	22.47	22.15	22.24	22.35
17	0230 to 0330	20	17.82	19.67	19.20	19.42	19.55	20.41	20.42	20.29	20.35	21.81	21.47	21.19	21.50
18	0330 to 0430	19	17.34	19.07	18.72	19.31	19.19	19.88	19.95	19.21	19.54	21.31	21.01	21.14	21.22
19	0430 to 0530	19	16.95	18.55	18.30	18.42	18.48	19.32	19.49	19.29	19.31	20.73	20.53	20.19	20.46
20	0530 to 0630	19	16.62	18.18	17.92	18.49	18.34	18.82	19.07	18.34	18.58	20.19	20.07	20.22	20.21
21	0630 to 0730	19	16.59	17.85	17.77	17.66	17.76	18.41	18.82	18.46	18.43	19.82	19.74	19.30	19.56
22	0730 to 0830	21	17.46	18.03	18.35	18.38	18.20	18.35	19.15	18.34	18.34	19.54	19.85	19.52	19.53
23	0830 to 0930	23	23.12	20.06	22.62	20.77	20.41	19.39	22.19	19.68	19.54	19.95	21.84	19.05	19.50
24	0930 to 1030	26	27.64	23.35	26.16	23.90	23.63	21.19	24.85	21.23	21.21	21.01	23.73	21.36	21.19

Table B-9 (b): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for minimum ambient air temperature at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	23.66	25.47	23.50	23.58	23.21	23.94	23.27	23.24	22.79	22.79	22.27	22.53
2	1130 to 1230	25.84	27.38	25.92	25.88	24.94	25.53	24.55	24.74	24.12	24.12	24.42	24.27
3	1230 to 1330	27.97	29.21	27.55	27.76	26.78	27.19	26.02	26.40	25.63	25.63	25.52	25.57
4	1330 to 1430	29.79	30.56	29.24	29.52	28.46	28.63	28.84	28.65	27.11	27.11	27.22	27.16
5	1430 to 1530	31.00	31.25	31.65	31.33	29.71	29.64	29.51	29.61	28.35	28.35	28.76	28.55
6	1530 to 1630	31.50	31.27	31.53	31.51	30.46	30.08	30.64	30.55	29.09	29.09	29.06	29.08
7	1630 to 1730	31.33	30.57	31.58	31.45	30.65	29.99	30.02	30.34	29.48	29.48	29.57	29.53
8	1730 to 1830	30.52	29.47	30.59	30.55	30.21	29.49	30.38	30.30	29.43	29.43	29.21	29.32
9	1830 to 1930	29.15	28.40	29.10	29.13	29.24	28.72	29.07	29.15	28.90	28.90	28.75	28.83
10	1930 to 2030	27.90	27.44	27.05	27.48	28.27	27.90	28.03	28.15	28.20	28.20	28.02	28.11
11	2030 to 2130	26.83	26.53	26.07	26.45	27.32	27.05	27.04	27.18	27.43	27.43	27.32	27.37
12	2130 to 2230	25.89	25.77	25.06	25.47	26.55	26.34	26.04	26.30	26.76	26.76	26.52	26.64
13	2230 to 2330	25.07	25.03	25.13	25.10	25.78	25.64	25.08	25.43	26.09	26.09	26.05	26.07
14	2330 to 0030	24.32	24.30	24.12	24.22	25.09	24.95	25.08	25.08	25.44	25.44	25.34	25.39
15	0030 to 0130	23.57	23.65	23.17	23.37	24.45	24.35	24.11	24.28	24.88	24.88	24.66	24.77
16	0130 to 0230	22.96	23.02	23.15	23.05	23.79	23.74	23.10	23.44	24.29	24.29	24.35	24.32
17	0230 to 0330	22.30	22.37	22.12	22.21	23.21	23.11	23.08	23.15	23.69	23.69	23.54	23.61
18	0330 to 0430	21.74	21.91	21.09	21.42	22.71	22.65	22.06	22.38	23.23	23.23	23.33	23.28
19	0430 to 0530	21.25	21.42	21.12	21.19	22.15	22.15	22.08	22.11	22.73	22.73	22.84	22.78
20	0530 to 0630	20.72	20.93	20.14	20.43	21.66	21.65	21.09	21.37	22.21	22.21	22.31	22.26
21	0630 to 0730	20.23	20.53	20.19	20.21	21.21	21.19	21.12	21.17	21.73	21.73	21.57	21.65
22	0730 to 0830	19.98	20.46	19.97	19.97	20.82	20.97	20.63	20.72	21.38	21.38	21.35	21.37
23	0830 to 0930	20.24	21.55	20.94	20.59	20.80	21.33	20.26	20.53	21.17	21.17	21.12	21.15
24	0930 to 1030	21.12	22.79	21.42	21.27	21.33	22.03	21.22	21.27	21.45	21.45	21.24	21.34

Table B-9 (c): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for minimum ambient air temperature at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	22.87	21.99	22.72	22.80	22.67	21.55	22.32	22.49	22.64	21.48	22.46	22.55
2	1130 to 1230	23.82	23.14	23.81	23.81	23.35	22.60	23.36	23.35	23.33	22.49	23.27	23.30
3	1230 to 1330	25.01	24.52	25.53	25.27	24.25	23.87	24.23	24.24	24.23	23.67	24.20	24.21
4	1330 to 1430	26.24	26.00	26.49	26.36	25.22	25.31	25.21	25.21	25.22	25.03	25.35	25.29
5	1430 to 1530	27.26	27.37	27.40	27.33	26.22	26.70	26.17	26.20	26.32	26.35	26.41	26.37
6	1530 to 1630	28.11	28.32	28.52	28.32	27.10	27.75	27.23	27.17	27.28	27.39	27.11	27.20
7	1630 to 1730	28.67	29.03	28.53	28.60	27.82	28.65	27.75	27.79	28.01	28.33	28.07	28.04
8	1730 to 1830	28.80	29.30	28.72	28.76	28.29	29.09	28.12	28.20	28.37	28.80	28.42	28.40
9	1830 to 1930	28.67	28.96	28.60	28.64	28.29	28.89	28.10	28.20	28.31	28.68	28.40	28.36
10	1930 to 2030	28.19	28.36	28.31	28.25	28.01	28.37	28.00	28.01	27.96	28.24	28.00	27.98
11	2030 to 2130	27.60	27.65	27.51	27.56	27.57	27.72	27.61	27.59	27.48	27.64	27.60	27.54
12	2130 to 2230	27.03	27.03	27.23	27.13	27.08	27.14	27.11	27.09	26.98	27.10	27.00	26.99
13	2230 to 2330	26.51	26.39	26.63	26.57	26.65	26.54	26.72	26.69	26.50	26.53	26.61	26.56
14	2330 to 0030	25.93	25.78	26.02	25.98	26.12	25.96	26.20	26.16	25.98	25.99	26.00	25.99
15	0030 to 0130	25.36	25.25	25.51	25.44	25.61	25.45	25.70	25.65	25.44	25.50	25.50	25.47
16	0130 to 0230	24.87	24.68	24.97	24.92	25.11	24.91	25.22	25.17	24.99	24.98	25.00	24.99
17	0230 to 0330	24.34	24.10	24.42	24.38	24.67	24.36	24.80	24.73	24.50	24.45	24.59	24.54
18	0330 to 0430	23.84	23.66	23.92	23.88	24.19	23.92	24.39	24.29	24.01	24.02	24.00	24.01
19	0430 to 0530	23.36	23.15	23.43	23.40	23.71	23.41	23.90	23.81	23.55	23.53	23.59	23.57
20	0530 to 0630	22.95	22.64	23.00	22.97	23.30	22.91	23.41	23.36	23.18	23.04	23.21	23.19
21	0630 to 0730	22.46	22.13	22.54	22.50	22.89	22.40	23.00	22.94	22.72	22.54	22.80	22.76
22	0730 to 0830	22.02	21.70	22.00	22.01	22.45	21.93	22.59	22.52	22.31	22.06	22.40	22.35
23	0830 to 0930	21.77	21.09	21.40	21.59	22.14	21.08	22.18	22.16	21.98	21.13	22.00	21.99
24	0930 to 1030	21.91	21.05	21.71	21.81	22.14	20.84	22.22	22.18	22.03	20.80	22.10	22.07

Table B-9 (d): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for minimum ambient air temperature at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (ºC) at 25 cm				Temperature (ºC) at 27.5 cm				Temperature (ºC) at 30 cm				Temperature (ºC) at 40 cm			
		Expt.	Chouban e Tia Model	Fourier Biot Eqn.	ANSY S	Expt.	Chouban e Tia Model	Fourier Biot Eqn.	ANSY S	Expt.	Chouban e Tia Model	Fourier Biot Eqn.	ANSY S	Expt.	Chouban e Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	22.77	21.77	22.88	22.82	23.24	22.43	23.32	23.28	23.44	23.44	23.39	23.42	22.39	22.39	22.42	22.40
2	1130 to 1230	23.57	22.82	23.69	23.63	24.35	23.59	24.42	24.39	24.79	24.79	24.89	24.84	23.96	23.96	23.91	23.93
3	1230 to 1330	24.59	23.93	24.64	24.61	25.74	24.64	25.87	25.80	25.81	25.81	25.91	25.86	25.68	25.68	25.81	25.74
4	1330 to 1430	25.77	25.16	25.93	25.85	27.89	25.71	28.01	27.95	26.68	26.68	26.96	26.82	27.44	27.44	27.58	27.51
5	1430 to 1530	27.13	26.32	27.30	27.21	29.77	26.59	29.98	29.88	27.19	27.19	27.29	27.24	28.15	28.15	28.30	28.23
6	1530 to 1630	28.20	27.24	28.36	28.28	29.78	27.31	29.91	29.85	27.58	27.58	27.69	27.63	27.99	27.99	28.04	28.01
7	1630 to 1730	28.61	28.07	28.75	28.68	29.15	27.88	29.21	29.18	27.75	27.75	28.00	27.88	27.63	27.63	27.70	27.67
8	1730 to 1830	28.66	28.43	28.80	28.73	28.56	27.99	28.62	28.59	27.47	27.47	27.52	27.50	26.86	26.86	26.99	26.92
9	1830 to 1930	28.33	28.35	28.41	28.37	27.73	27.89	27.80	27.76	27.30	27.30	27.22	27.26	26.27	26.27	26.41	26.34
10	1930 to 2030	27.79	27.95	27.90	27.84	26.96	27.52	27.00	26.98	26.95	26.95	27.00	26.97	25.71	25.71	25.90	25.81
11	2030 to 2130	27.20	27.41	27.31	27.25	26.30	27.02	26.40	26.35	26.49	26.49	26.54	26.52	25.23	25.23	25.39	25.31
12	2130 to 2230	26.70	26.91	26.82	26.76	25.61	26.56	25.72	25.66	26.06	26.06	26.12	26.09	24.89	24.89	25.00	24.95
13	2230 to 2330	26.12	26.37	26.00	26.06	25.03	26.06	25.00	25.01	25.59	25.59	25.70	25.65	24.53	24.53	24.62	24.57
14	2330 to 0030	25.56	25.86	25.62	25.59	24.47	25.57	24.59	24.53	25.13	25.13	25.20	25.16	24.15	24.15	24.10	24.13
15	0030 to 0130	25.04	25.37	25.00	25.02	23.87	25.09	23.92	23.89	24.64	24.64	24.81	24.73	23.77	23.77	23.88	23.82
16	0130 to 0230	24.54	24.88	24.48	24.51	23.34	24.62	23.40	23.37	24.20	24.20	24.31	24.26	23.39	23.39	23.45	23.42
17	0230 to 0330	24.02	24.39	24.00	24.01	22.86	24.16	23.00	22.93	23.78	23.78	24.01	23.89	23.15	23.15	23.36	23.26
18	0330 to 0430	23.54	23.96	23.60	23.57	22.38	23.74	22.50	22.44	23.37	23.37	23.51	23.44	22.81	22.81	23.00	22.91
19	0430 to 0530	23.15	23.48	23.22	23.18	21.90	23.29	22.00	21.95	22.93	22.93	23.00	22.97	22.47	22.47	22.61	22.54
20	0530 to 0630	22.71	23.03	22.80	22.76	21.52	22.87	21.61	21.57	22.56	22.56	22.72	22.64	22.15	22.15	22.28	22.21
21	0630 to 0730	22.25	22.55	22.30	22.28	21.12	22.43	21.20	21.16	22.18	22.18	22.32	22.25	21.80	21.80	21.95	21.88
22	0730 to 0830	21.86	22.09	22.02	21.94	20.86	22.03	21.00	20.93	21.87	21.87	22.00	21.94	21.61	21.61	21.72	21.66
23	0830 to 0930	21.63	21.26	21.72	21.68	21.11	21.45	21.09	21.10	21.71	21.71	21.91	21.81	21.62	21.62	21.70	21.66
24	0930 to 1030	21.85	20.95	21.98	21.92	21.69	21.27	21.72	21.71	21.78	21.78	21.99	21.89	21.79	21.79	21,92	21.79

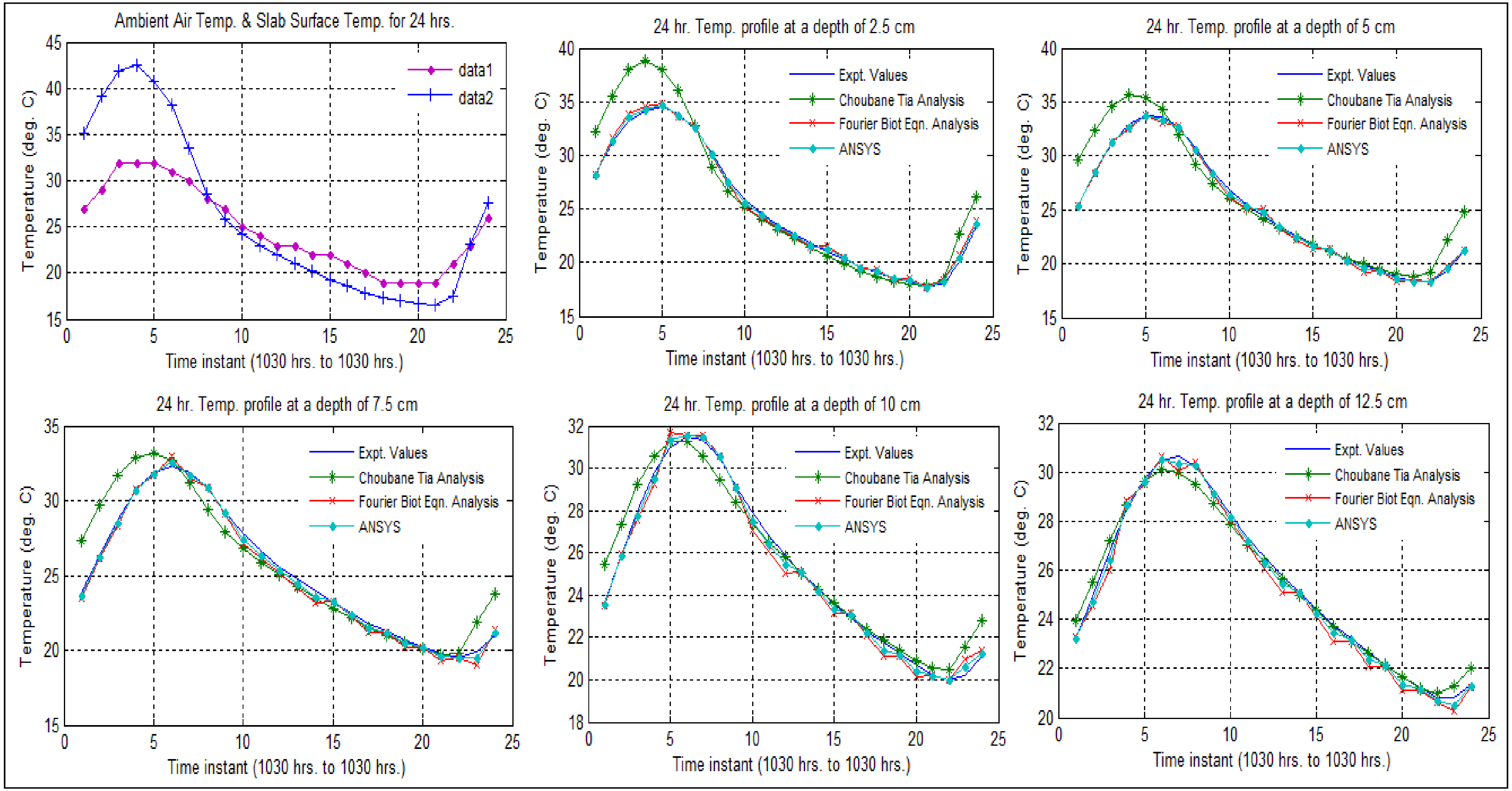


Fig. B-17 (a): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix B for minimum ambient air temperature (surface to 12.5 cm)

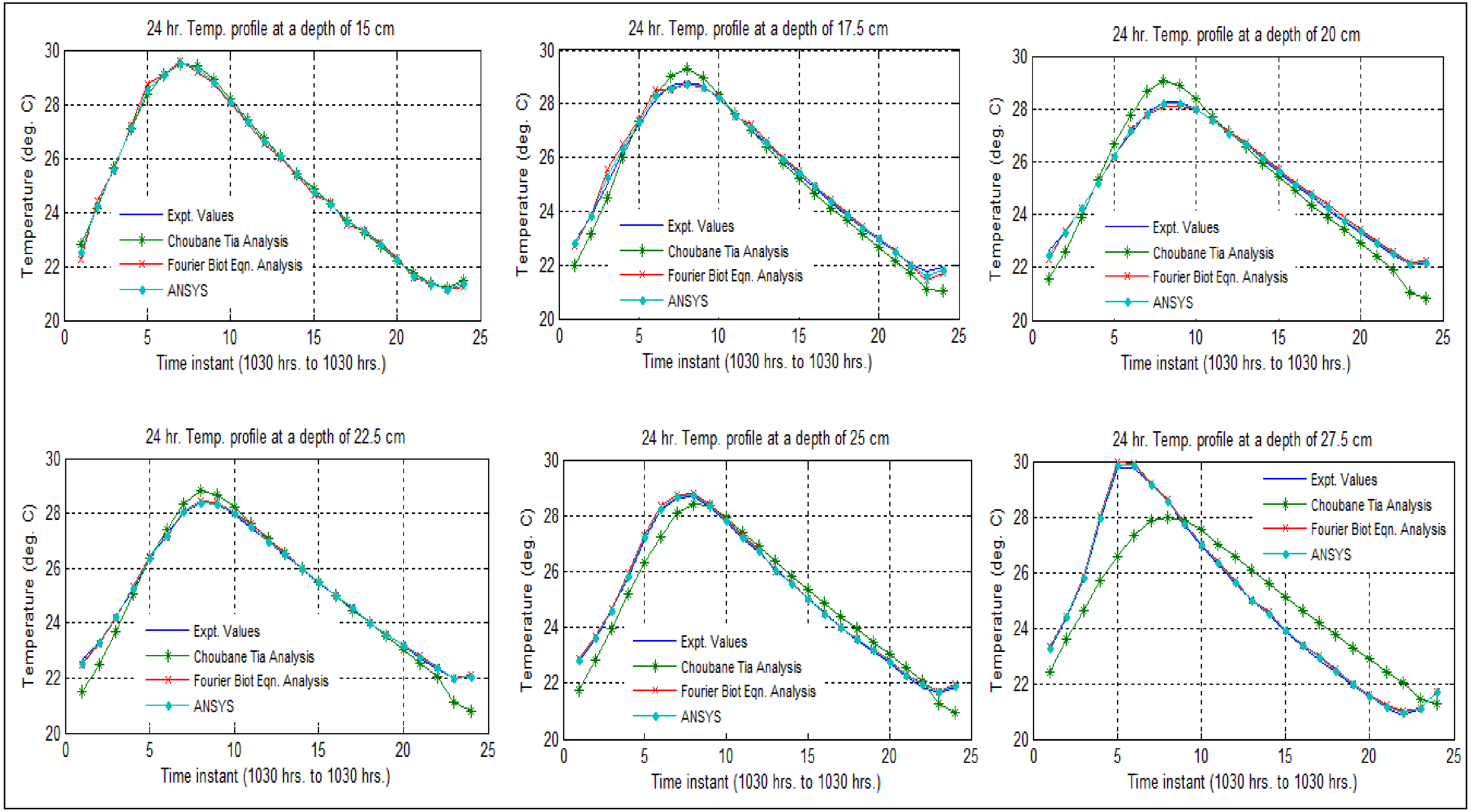


Fig. B-17 (b): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix B for minimum ambient air temperature (15 cm to 27.5 cm)

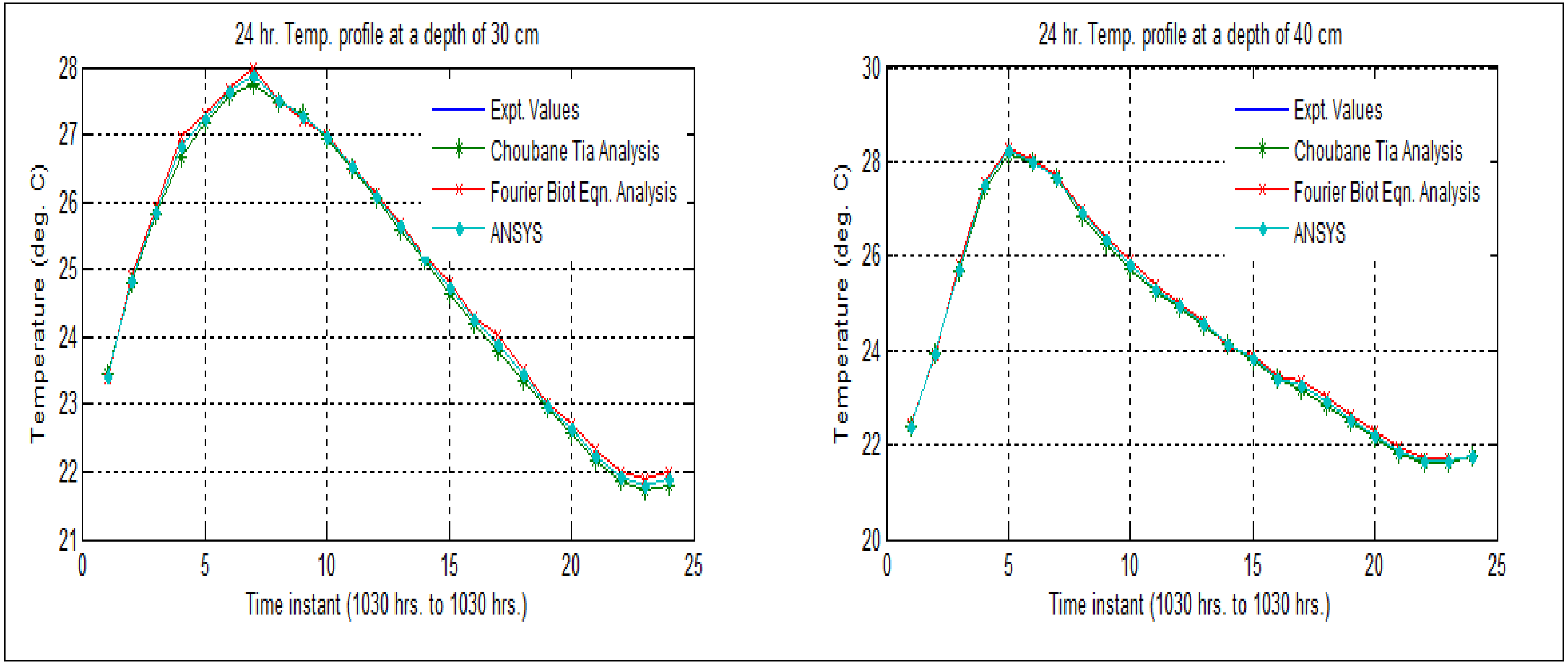


Fig. B-17 (c): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix B for minimum ambient air temperature (30 cm & 40 cm)

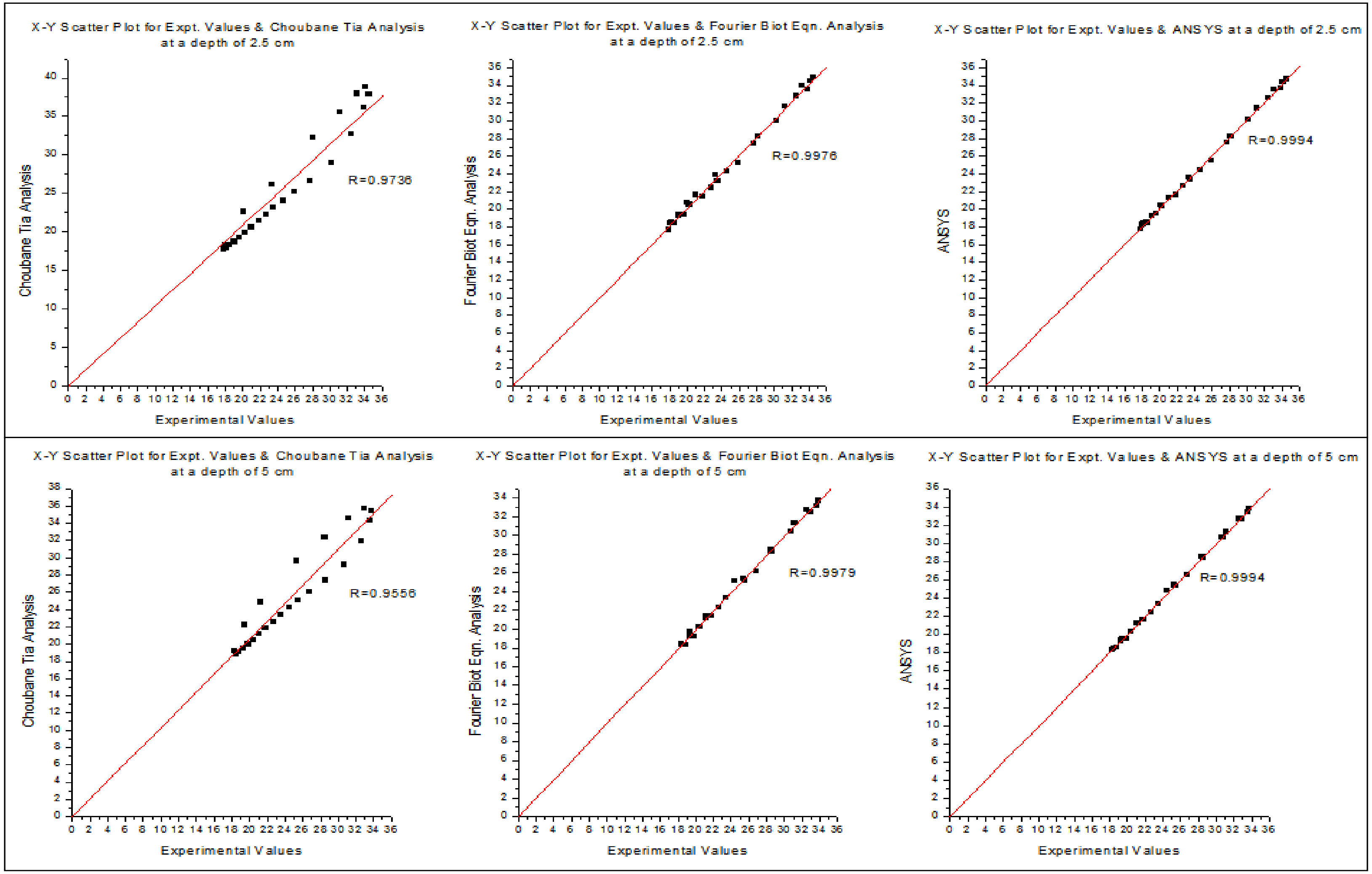


Fig. B-18 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

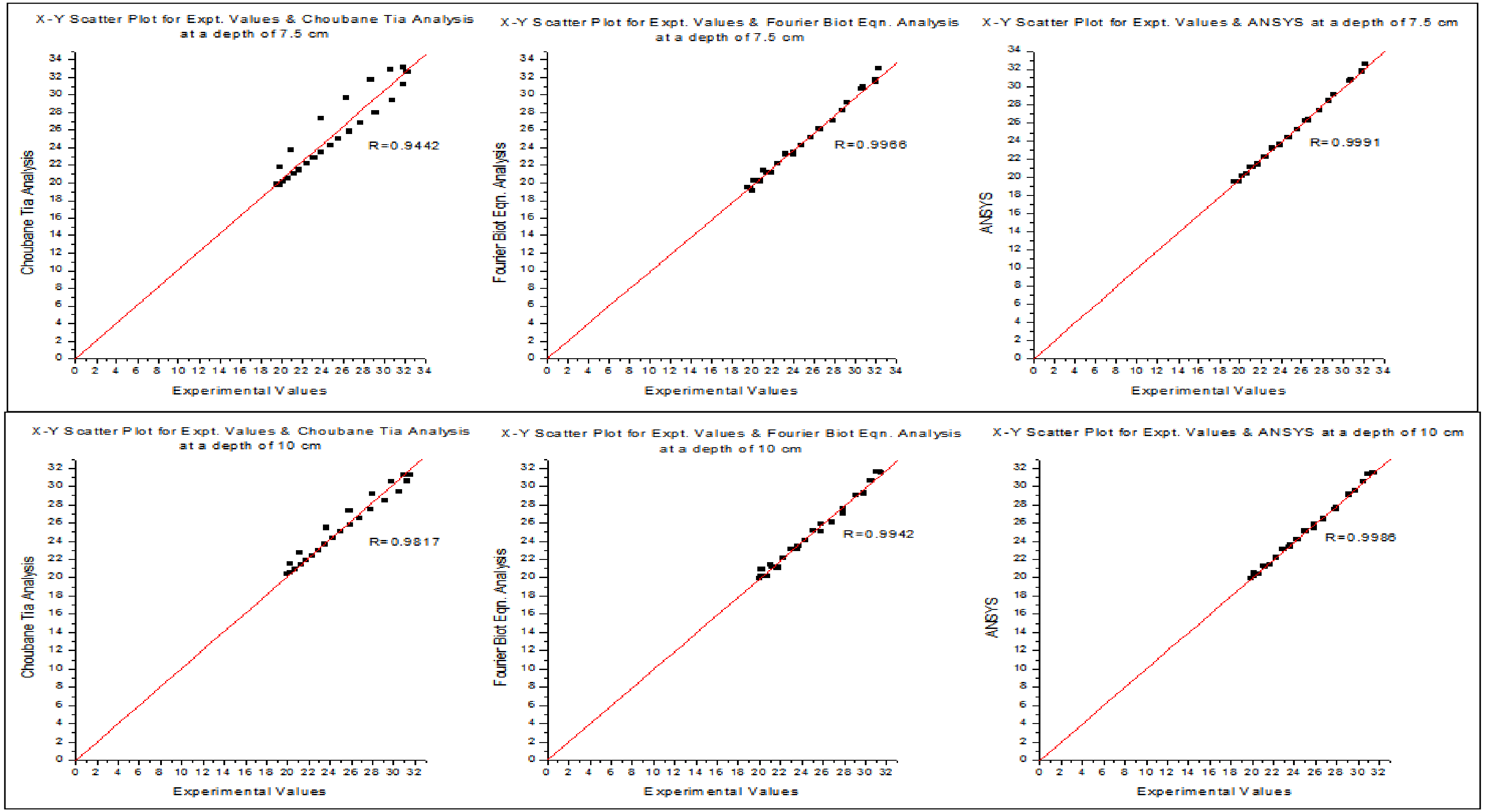


Fig. B-18 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

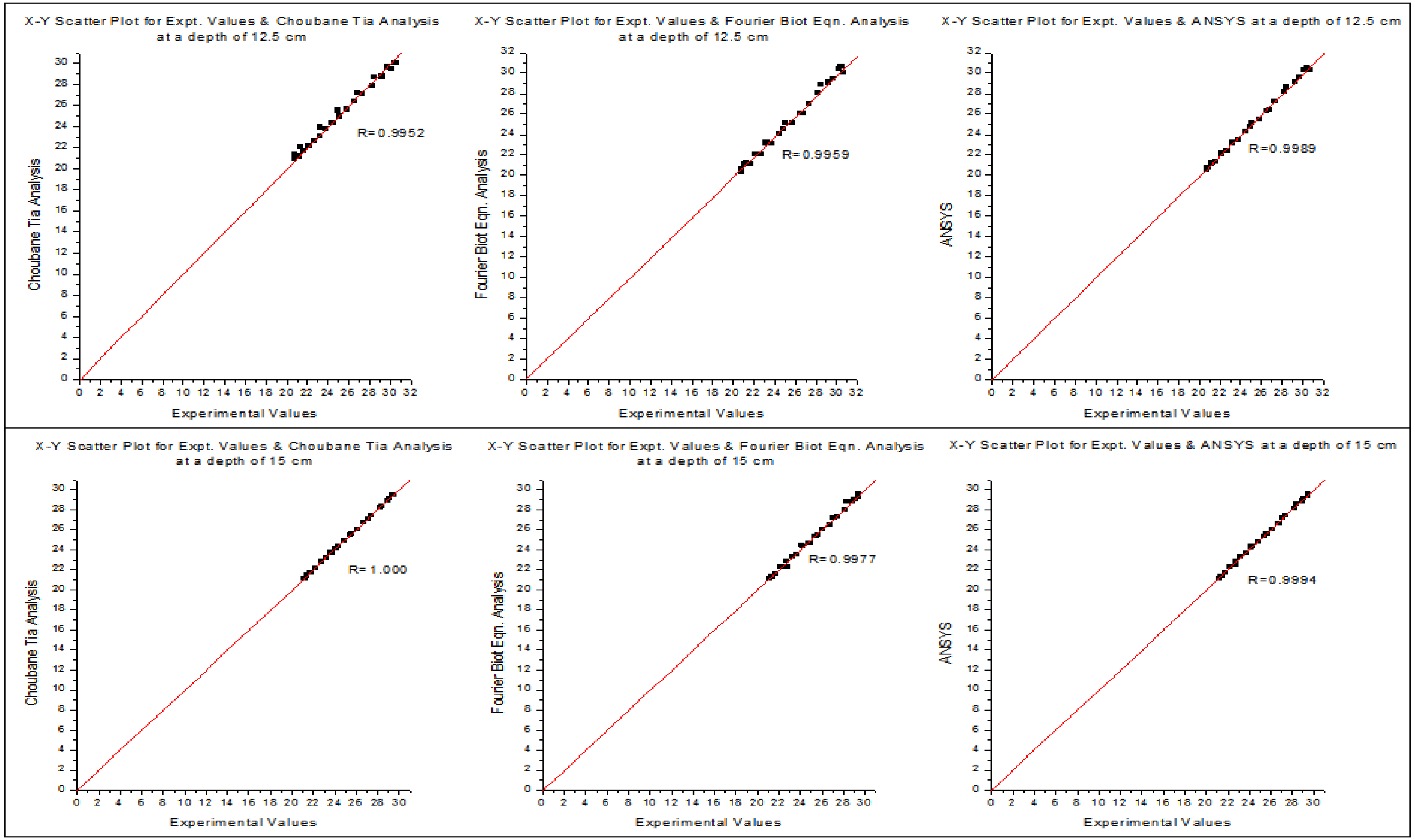


Fig. B-18 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

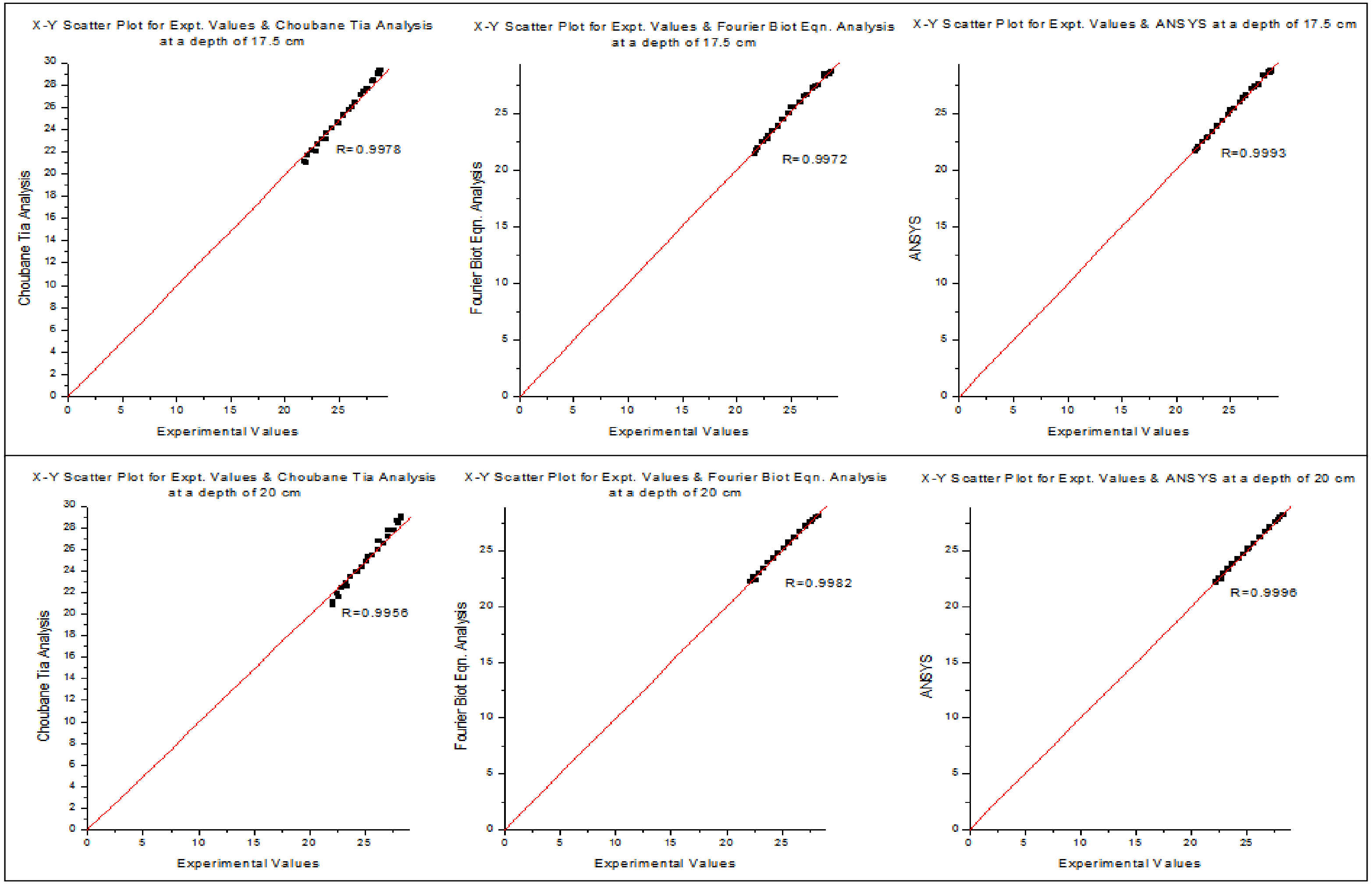


Fig. B-18 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

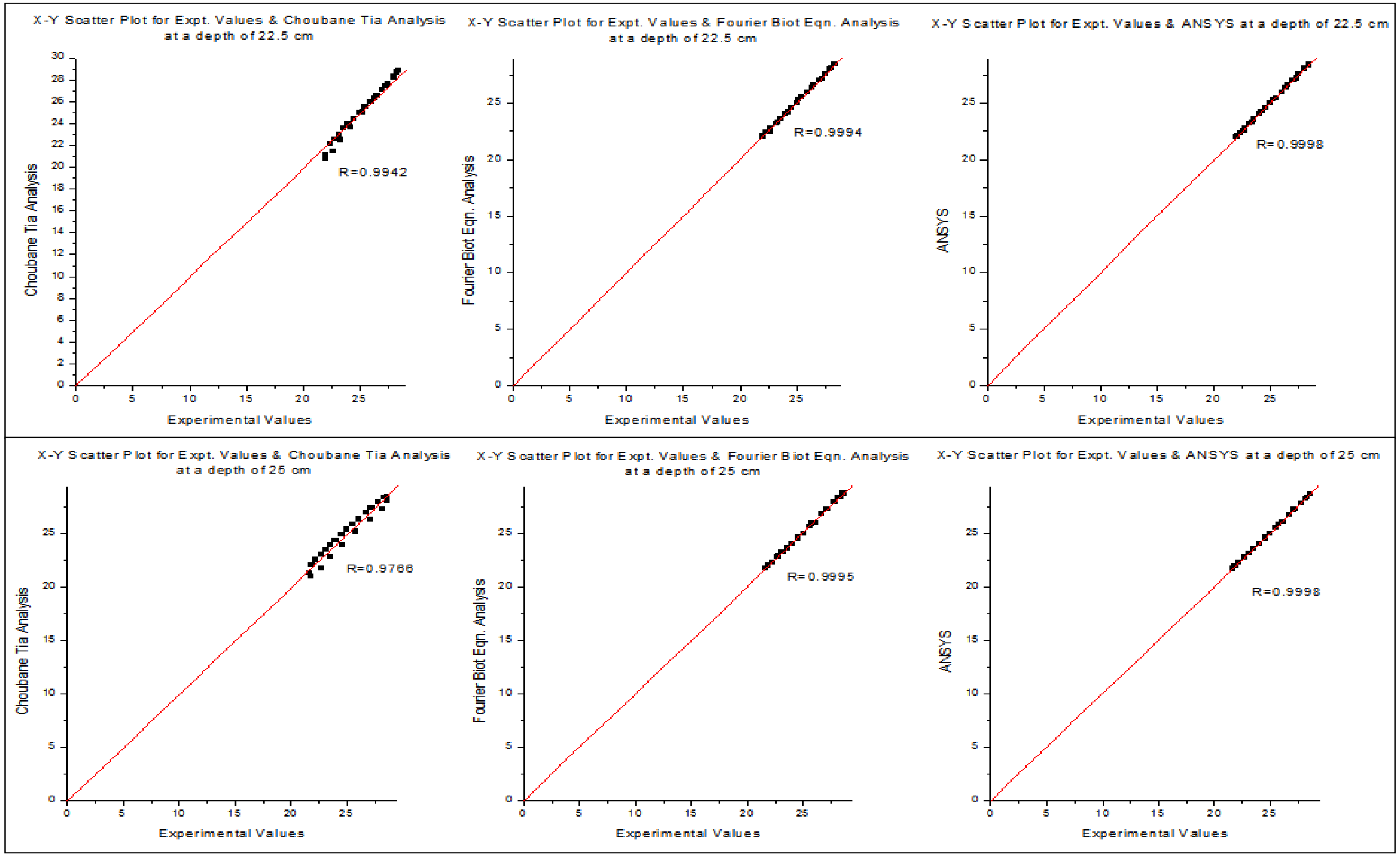


Fig. B-18 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

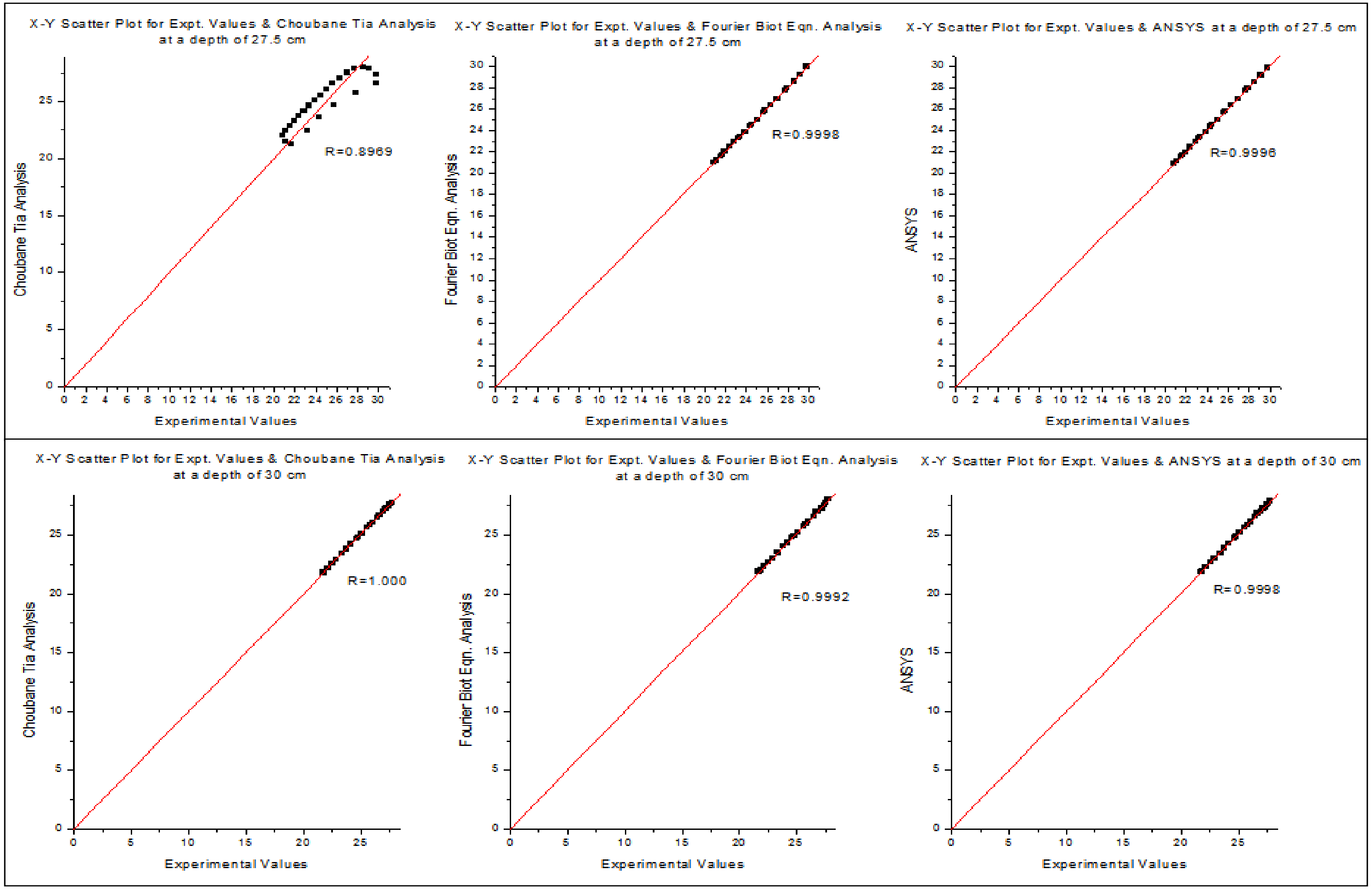


Fig. B-18 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

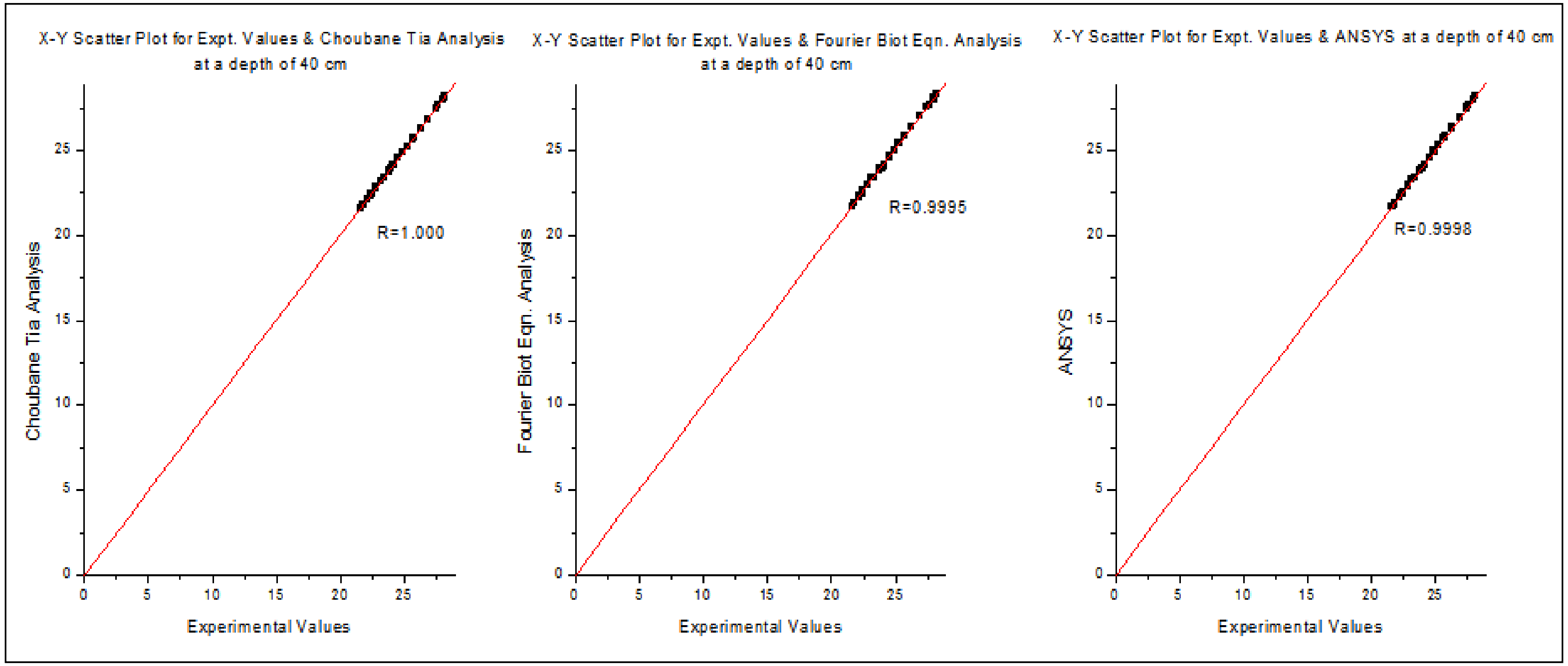


Fig. B-18 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-10 (a): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for minimum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (ºC) at 2.5 cm				Temperature (ºC) at 5 cm				Temperature (ºC) at 7.5 cm			
		(ºC)	(ºC)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	27	34.15	27.89	31.31	27.51	27.70	24.73	28.81	24.66	24.69	23.38	26.65	23.64	23.51
2	1200 to 1300	29	37.67	30.80	34.19	30.13	30.46	27.60	31.14	27.77	27.68	25.76	28.51	25.36	25.56
3	1300 to 1400	32	39.73	34.63	36.03	34.29	34.46	30.79	32.79	30.58	30.68	28.24	29.99	28.89	28.56
4	1400 to 1500	32	40.34	37.27	36.76	37.07	37.17	33.14	33.62	33.74	33.44	30.34	30.92	30.34	30.34
5	1500 to 1600	32	39.01	38.80	36.00	38.49	38.64	34.37	33.38	34.95	34.66	31.67	31.14	31.18	31.42
6	1600 to 1700	31	36.86	39.52	34.60	39.18	39.35	34.79	32.62	34.35	34.57	32.32	30.95	32.14	32.23
7	1700 to 1800	30	32.90	35.85	31.80	35.67	35.76	33.74	30.84	33.92	33.83	32.12	30.02	32.55	32.34
8	1800 to 1900	28	29.17	30.64	29.12	30.88	30.76	31.39	29.06	31.30	31.35	30.95	28.99	30.85	30.90
9	1900 to 2000	27	26.80	27.60	27.32	27.12	27.36	28.99	27.74	28.08	28.54	29.42	28.09	29.05	29.24
10	2000 to 2100	25	25.17	25.71	25.97	25.96	25.83	27.16	26.66	26.97	27.07	27.99	27.22	27.98	27.99
11	2100 to 2200	24	23.85	24.38	24.85	24.03	24.21	25.75	25.69	25.02	25.39	26.76	26.39	26.01	26.39
12	2200 to 2300	23	22.87	23.33	23.96	23.03	23.18	24.64	24.89	24.02	24.33	25.69	25.66	25.01	25.35
13	2300 to 0000	23	21.87	22.46	23.08	22.26	22.36	23.67	24.11	23.18	23.43	24.81	24.97	24.12	24.46
14	0000 to 0100	22	20.97	21.61	22.24	21.22	21.42	22.87	23.34	22.15	22.51	23.97	24.26	24.10	24.04
15	0100 to 0200	22	20.12	20.85	21.46	20.41	20.63	22.07	22.61	22.28	22.17	23.25	23.57	23.18	23.21
16	0200 to 0300	21	19.42	20.16	20.80	20.34	20.25	21.40	22.00	21.23	21.31	22.55	23.01	22.15	22.35
17	0300 to 0400	20	18.72	19.58	20.14	19.25	19.41	20.73	21.37	20.17	20.45	21.87	22.40	21.11	21.49
18	0400 to 0500	19	18.20	19.03	19.61	19.15	19.09	20.16	20.83	20.10	20.13	21.36	21.87	21.07	21.21
19	0500 to 0600	19	17.71	18.57	19.12	18.27	18.42	19.69	20.35	19.18	19.44	20.80	21.39	20.12	20.46
20	0600 to 0700	19	17.29	18.23	18.70	18.35	18.29	19.20	19.93	19.25	19.22	20.27	20.97	20.16	20.22
21	0700 to 0800	19	17.35	18.05	18.62	18.48	18.27	18.82	19.73	18.34	18.58	19.91	20.67	19.22	19.56
22	0800 to 0900	21	18.67	18.53	19.52	18.03	18.28	18.76	20.26	18.10	18.43	19.63	20.88	19.37	19.50
23	0900 to 1000	23	24.69	20.95	24.00	20.30	20.62	19.68	23.38	19.36	19.52	19.94	22.85	19.84	19.89
24	1000 to 1100	26	28.64	23.28	26.97	23.54	23.41	21.14	25.50	21.98	21.56	20.81	24.23	20.20	20.51

Table B-10 (b): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for minimum ambient air temperature at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	23.56	24.85	23.59	23.58	23.13	23.40	23.33	23.23	22.29	22.29	22.30	22.30
2	1200 to 1300	25.71	26.31	25.76	25.73	24.88	24.52	24.64	24.76	23.15	23.15	23.27	23.21
3	1300 to 1400	27.94	27.64	27.89	27.91	26.75	25.74	26.85	26.80	24.28	24.28	24.59	24.44
4	1400 to 1500	29.92	28.67	30.02	29.97	28.50	26.87	28.63	28.56	25.51	25.51	25.46	25.49
5	1500 to 1600	31.24	29.28	31.30	31.27	29.81	27.82	29.14	29.48	26.74	26.74	26.69	26.71
6	1600 to 1700	31.90	29.57	31.64	31.77	30.59	28.49	30.71	30.65	27.71	27.71	27.95	27.83
7	1700 to 1800	31.82	29.35	31.63	31.73	30.71	28.82	30.96	30.84	28.44	28.44	28.59	28.51
8	1800 to 1900	30.91	28.93	30.54	30.72	30.32	28.85	30.35	30.33	28.78	28.78	28.82	28.80
9	1900 to 2000	29.64	28.35	29.73	29.69	29.33	28.52	29.41	29.37	28.61	28.61	28.70	28.66
10	2000 to 2100	28.42	27.66	28.59	28.50	28.38	27.98	28.29	28.33	28.17	28.17	28.20	28.18
11	2100 to 2200	27.28	26.95	27.21	27.25	27.40	27.36	27.44	27.42	27.62	27.62	27.66	27.64
12	2200 to 2300	26.35	26.28	26.41	26.38	26.60	26.74	26.63	26.61	27.05	27.05	27.10	27.07
13	2300 to 0000	25.46	25.66	25.57	25.51	25.80	26.18	25.85	25.82	26.53	26.53	26.58	26.56
14	0000 to 0100	24.71	25.00	24.66	24.68	25.07	25.56	25.04	25.05	25.95	25.95	26.02	25.99
15	0100 to 0200	23.95	24.36	24.01	23.98	24.40	24.96	24.48	24.44	25.38	25.38	25.44	25.41
16	0200 to 0300	23.27	23.82	23.35	23.31	23.71	24.45	23.76	23.73	24.89	24.89	24.93	24.91
17	0300 to 0400	22.65	23.25	22.70	22.68	23.14	23.90	23.20	23.17	24.36	24.36	24.43	24.40
18	0400 to 0500	22.04	22.71	22.04	22.04	22.56	23.37	22.63	22.60	23.84	23.84	23.82	23.83
19	0500 to 0600	21.53	22.24	21.48	21.51	22.01	22.90	22.05	22.03	23.37	23.37	23.41	23.39
20	0600 to 0700	21.05	21.82	21.10	21.07	21.55	22.48	21.47	21.51	22.96	22.96	23.01	22.98
21	0700 to 0800	20.56	21.45	20.64	20.60	21.08	22.05	21.09	21.08	22.48	22.48	22.55	22.52
22	0800 to 0900	20.24	21.39	20.37	20.31	20.71	21.78	20.57	20.64	22.06	22.06	22.12	22.09
23	0900 to 1000	20.46	22.38	20.55	20.50	20.73	22.00	20.71	20.72	21.69	21.69	21.65	21.67
24	1000 to 1100	21.28	23.17	21.31	21.29	21.27	22.30	21.15	21.21	21.64	21.64	21.60	21.62

Table B-10 (c): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for minimum ambient air temperature at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	22.48	21.53	22.60	22.54	22.22	21.13	22.33	22.27	22.26	21.07	22.16	22.21
2	1200 to 1300	23.35	22.21	23.44	23.40	23.15	21.69	23.37	23.26	23.56	21.58	23.18	23.37
3	1300 to 1400	24.49	23.28	24.59	24.54	24.32	22.72	24.40	24.36	25.00	22.61	25.20	25.10
4	1400 to 1500	25.67	24.60	25.84	25.75	25.58	24.14	25.37	25.47	26.41	24.12	26.18	26.29
5	1500 to 1600	26.85	26.04	26.68	26.77	26.82	25.73	26.30	26.56	27.55	25.81	27.15	27.35
6	1600 to 1700	27.80	27.22	27.54	27.67	27.79	27.03	27.24	27.51	28.47	27.14	28.12	28.29
7	1700 to 1800	28.51	28.19	28.34	28.42	28.51	28.10	28.44	28.48	28.90	28.14	29.01	28.95
8	1800 to 1900	28.80	28.69	28.72	28.76	28.80	28.61	28.85	28.82	28.91	28.52	29.02	28.96
9	1900 to 2000	28.72	28.62	28.91	28.82	28.60	28.55	28.66	28.63	28.57	28.39	28.71	28.64
10	2000 to 2100	28.32	28.24	28.34	28.33	28.12	28.19	28.08	28.10	27.89	28.01	27.95	27.92
11	2100 to 2200	27.78	27.74	27.82	27.80	27.54	27.71	27.61	27.57	27.18	27.54	27.26	27.22
12	2200 to 2300	27.22	27.20	27.23	27.23	26.97	27.18	27.00	26.99	26.57	27.02	26.65	26.61
13	2300 to 0000	26.72	26.71	26.79	26.76	26.44	26.72	26.51	26.47	25.91	26.55	26.00	25.95
14	0000 to 0100	26.15	26.16	26.21	26.18	25.85	26.19	25.91	25.88	25.27	26.04	25.39	25.33
15	0100 to 0200	25.57	25.61	25.62	25.60	25.28	25.66	25.31	25.30	24.77	25.53	24.88	24.83
16	0200 to 0300	25.05	25.14	25.02	25.04	24.83	25.21	24.91	24.87	24.21	25.08	24.32	24.27
17	0300 to 0400	24.54	24.63	24.47	24.51	24.29	24.71	24.31	24.30	23.65	24.60	23.71	23.68
18	0400 to 0500	24.03	24.12	24.01	24.02	23.77	24.22	23.86	23.82	23.20	24.12	23.27	23.24
19	0500 to 0600	23.50	23.66	23.54	23.52	23.34	23.75	23.41	23.37	22.75	23.66	22.81	22.78
20	0600 to 0700	23.11	23.25	23.08	23.10	22.92	23.35	23.01	22.97	22.29	23.27	22.40	22.34
21	0700 to 0800	22.62	22.74	22.66	22.64	22.46	22.84	22.51	22.49	21.82	22.76	21.91	21.87
22	0800 to 0900	22.18	22.22	22.18	22.18	22.03	22.26	22.08	22.05	21.51	22.20	21.54	21.52
23	0900 to 1000	21.83	21.46	21.73	21.78	21.67	21.30	21.76	21.71	21.23	21.22	21.28	21.25
24	1000 to 1100	21.80	21.17	21.68	21.74	21.60	20.90	21.63	21.62	21.26	20.84	21.33	21.30

Table B-10 (d): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for minimum ambient air temperature at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (ºC) at 25 cm				Temperature (ºC) at 27.5 cm				Temperature (ºC) at 30 cm				Temperature (ºC) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	22.81	21.35	22.88	22.84	24.24	21.99	24.32	24.28	22.98	22.98	22.99	22.98	22.74	22.74	22.82	22.78
2	1200 to 1300	24.28	21.90	24.31	24.30	25.73	22.64	25.82	25.78	23.80	23.80	23.88	23.84	24.29	24.29	24.41	24.35
3	1300 to 1400	25.60	22.95	25,66	25.60	26.78	23.73	26.88	26.83	24.97	24.97	24.98	24.97	26.34	26.34	26.42	26.38
4	1400 to 1500	26.75	24.54	26.81	26.78	27.41	25.42	27.52	27.46	26.74	26.74	26.98	26.86	28.10	28.10	28.15	28.12
5	1500 to 1600	27.60	26.28	27.67	27.64	27.81	27.13	27.92	27.86	28.36	28.36	28.49	28.43	28.18	28.18	28.24	28.21
6	1600 to 1700	28.24	27.55	28.32	28.28	28.00	28.25	28.01	28.00	29.25	29.25	29.33	29.29	27.72	27.72	27.94	27.83
7	1700 to 1800	28.50	28.33	28.58	28.54	27.56	28.66	27.61	27.59	29.13	29.13	29.21	29.17	27.34	27.34	27.46	27.40
8	1800 to 1900	28.23	28.42	28.31	28.27	26.82	28.32	26.90	26.86	28.21	28.21	28.30	28.26	26.81	26.81	26.92	26.87
9	1900 to 2000	27.73	28.14	27.81	27.77	26.31	27.82	26.40	26.35	27.40	27.40	27.46	27.43	26.11	26.11	26.21	26.16
10	2000 to 2100	27.11	27.71	27.22	27.17	25.77	27.29	25.82	25.79	26.74	26.74	26.81	26.78	25.46	25.46	25.52	25.49
11	2100 to 2200	26.58	27.22	26.71	26.64	25.27	26.75	25.32	25.30	26.14	26.14	26.22	26.18	24.96	24.96	25.00	24.98
12	2200 to 2300	25.96	26.69	26.00	25.98	24.85	26.21	24.91	24.88	25.57	25.57	25.62	25.60	24.52	24.52	24.61	24.56
13	2300 to 0000	25.37	26.22	25.42	25.39	24.37	25.72	24.42	24.39	25.04	25.04	25.00	25.02	24.07	24.07	24.15	24.11
14	0000 to 0100	24.89	25.71	25.00	24.95	23.90	25.21	23.95	23.92	24.53	24.53	24.61	24.57	23.61	23.61	23.72	23.67
15	0100 to 0200	24.37	25.21	24.42	24.39	23.43	24.71	23.48	23.45	24.03	24.03	24.00	24.01	23.26	23.26	23.37	23.31
16	0200 to 0300	23.86	24.77	23.92	23.89	23.04	24.26	23.11	23.08	23.57	23.57	23.61	23.59	22.87	22.87	22.92	22.89
17	0300 to 0400	23.38	24.30	23.40	23.39	22.62	23.80	22.73	22.67	23.11	23.11	23.20	23.16	22.46	22.46	22.52	22.49
18	0400 to 0500	23.00	23.84	23.00	23.00	22.22	23.37	22.24	22.23	22.72	22.72	22.81	22.76	22.10	22.10	22.18	22.14
19	0500 to 0600	22.54	23.38	22.60	22.57	21.81	22.92	21.97	21.89	22.27	22.27	22.34	22.30	21.75	21.75	21.82	21.78
20	0600 to 0700	22.12	22.99	22.20	22.16	21.52	22.53	21.60	21.56	21.89	21.89	22.00	21.94	21.49	21.49	21.52	21.51
21	0700 to 0800	21.71	22.52	21.80	21.76	21.16	22.11	21.22	21.19	21.53	21.53	21.60	21.56	21.17	21.17	21.25	21.21
22	0800 to 0900	21.44	22.01	21.53	21.48	20.99	21.72	21.00	20.99	21.30	21.30	21.40	21.35	21.00	21.00	21.05	21.03
23	0900 to 1000	21.29	21.22	21.34	21.31	21.19	21.30	21.26	21.23	21.45	21.45	21.50	21.47	21.16	21.16	21.22	21.19
24	1000 to 1100	21.50	20.97	21.47	21.49	21.81	21.31	21.92	21.86	21.85	21.85	21.90	21.87	21.52	21.52	21.66	21.59

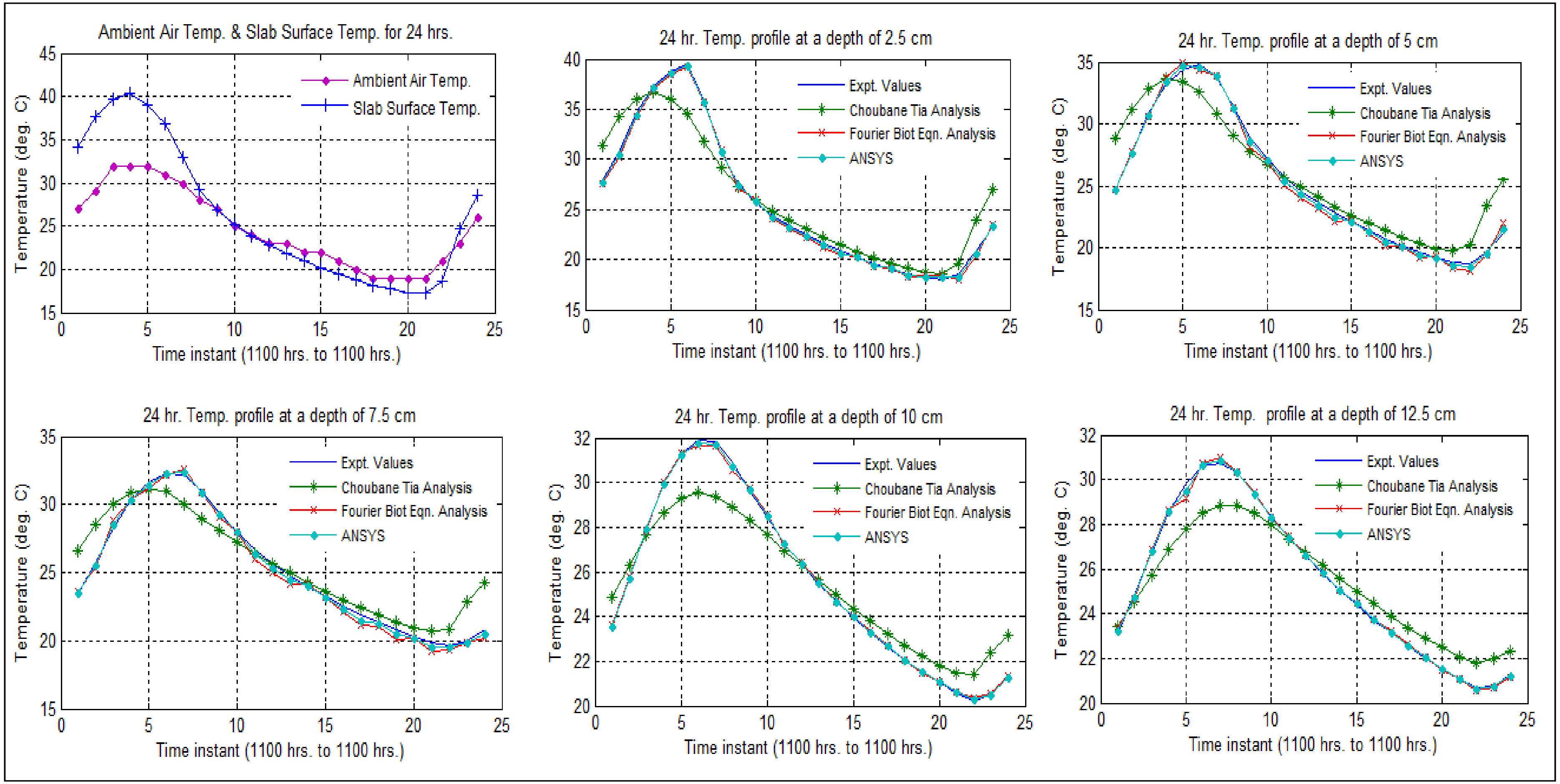


Fig. B-19 (a): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix B for minimum ambient air temperature (surface to 12.5 cm)

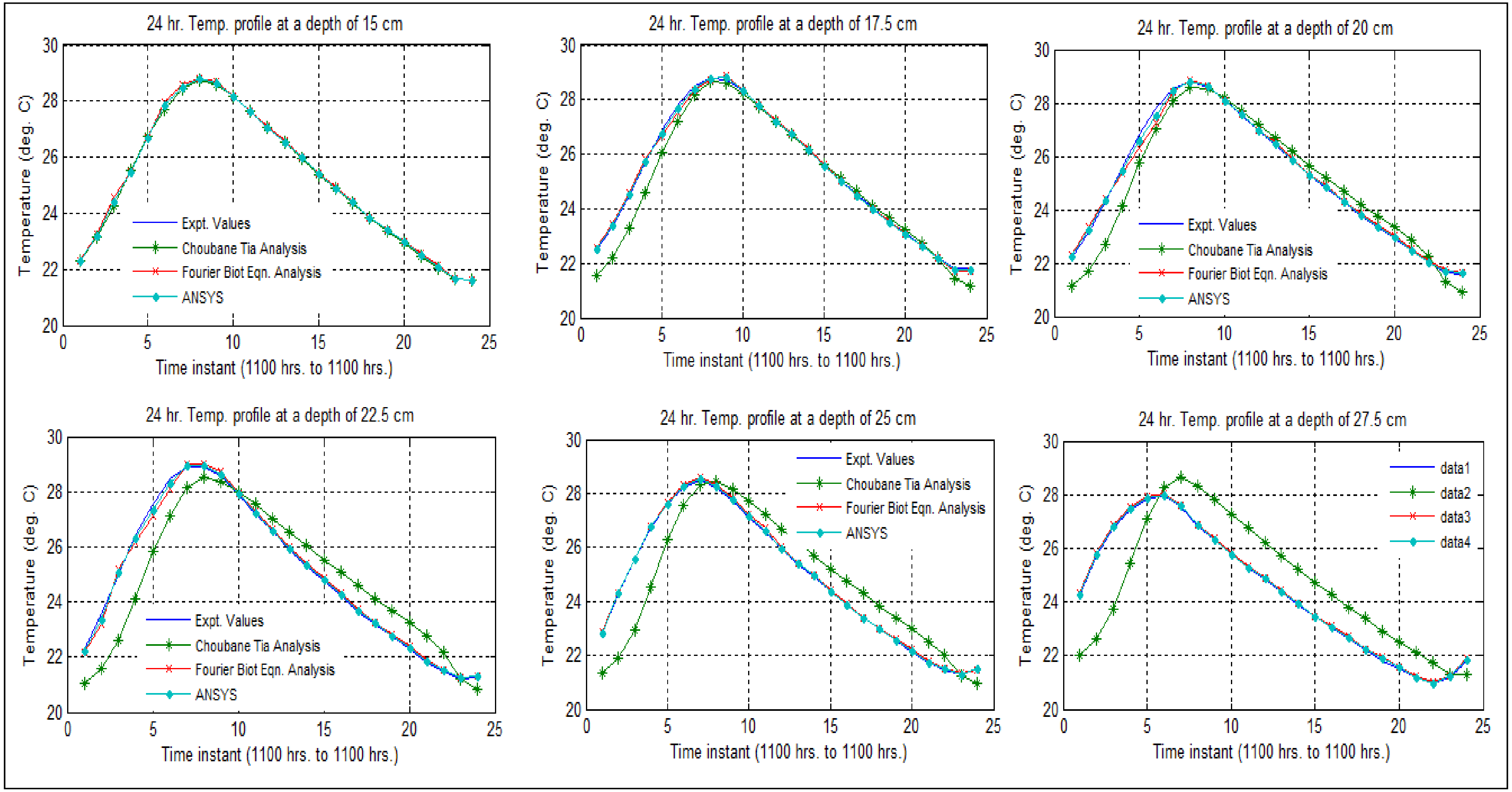


Fig. B-19 (b): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix B for minimum ambient air temperature (15 cm to 27.5 cm)

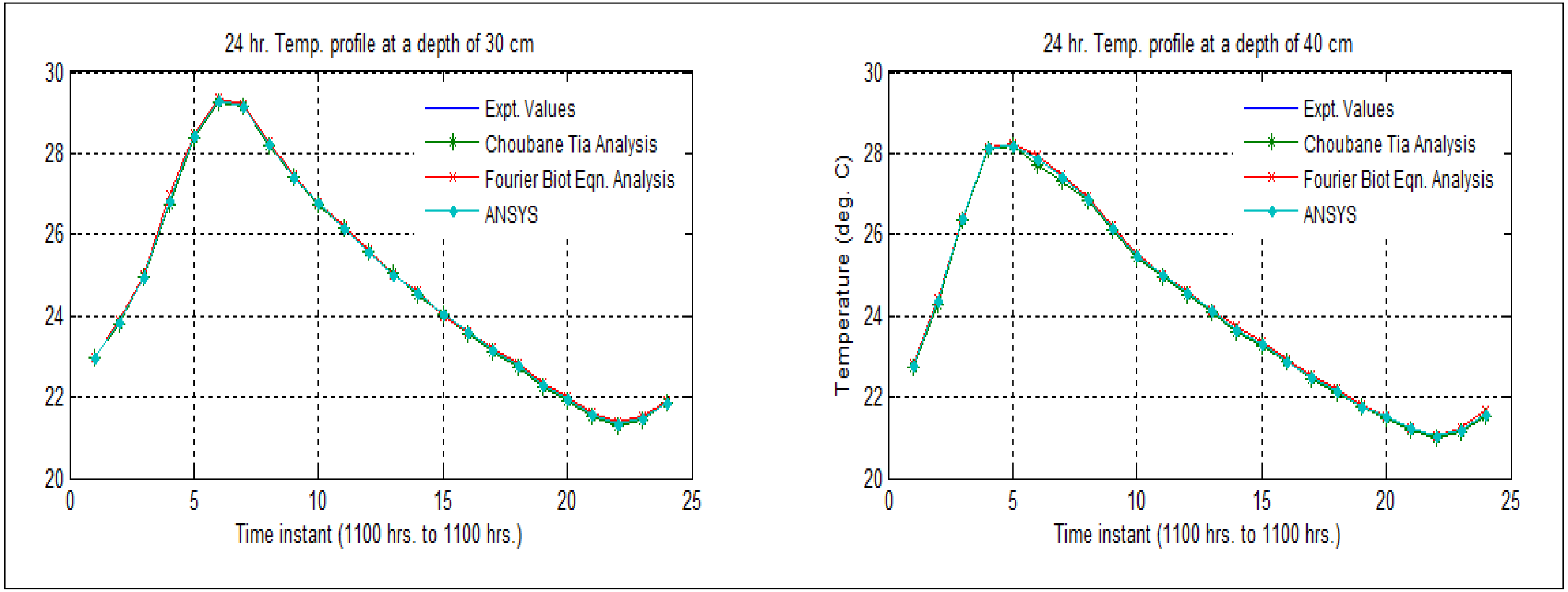


Fig. B-19 (c): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix B for minimum ambient air temperature (30 cm & 40 cm)

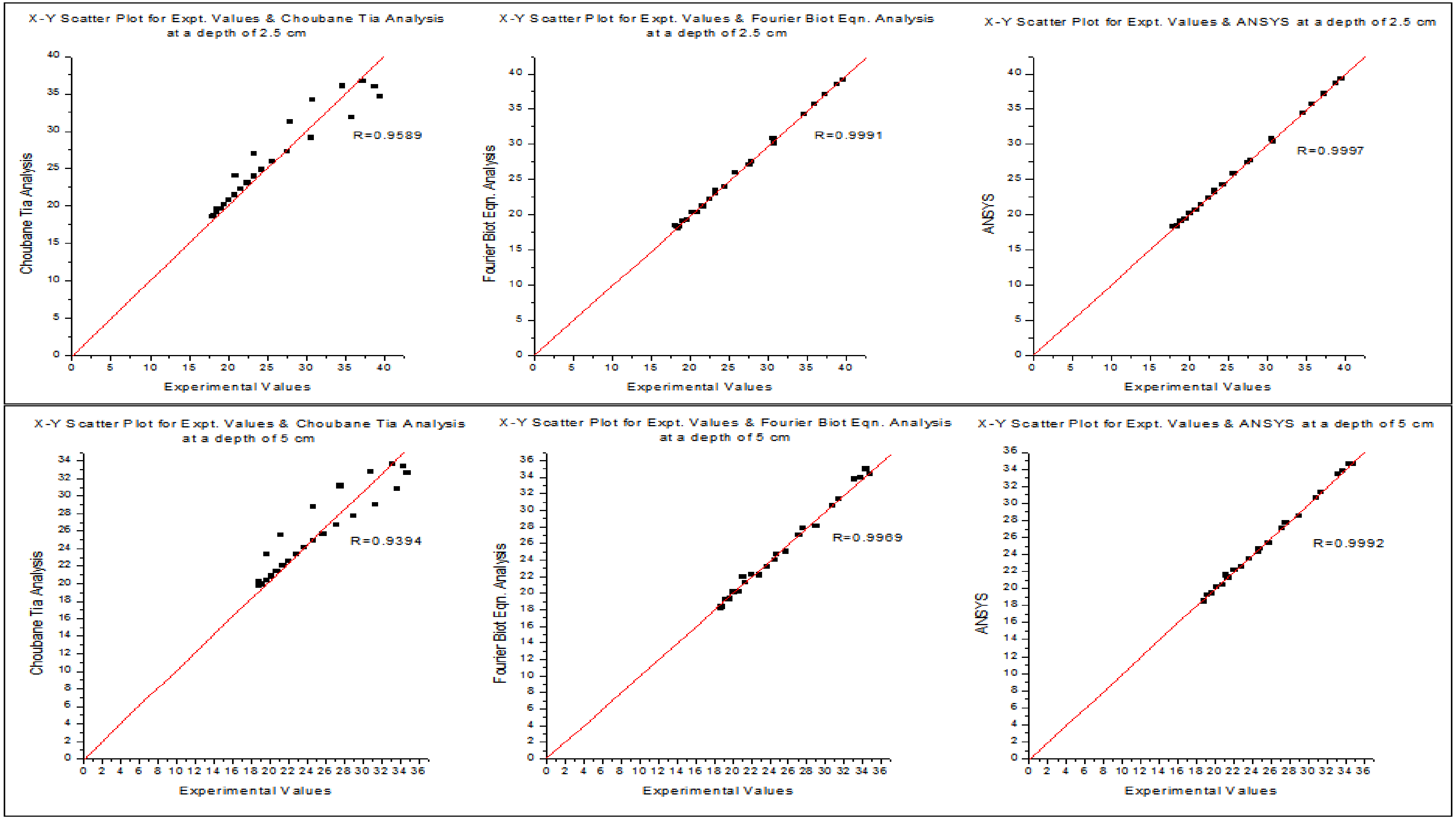


Fig. B-20 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

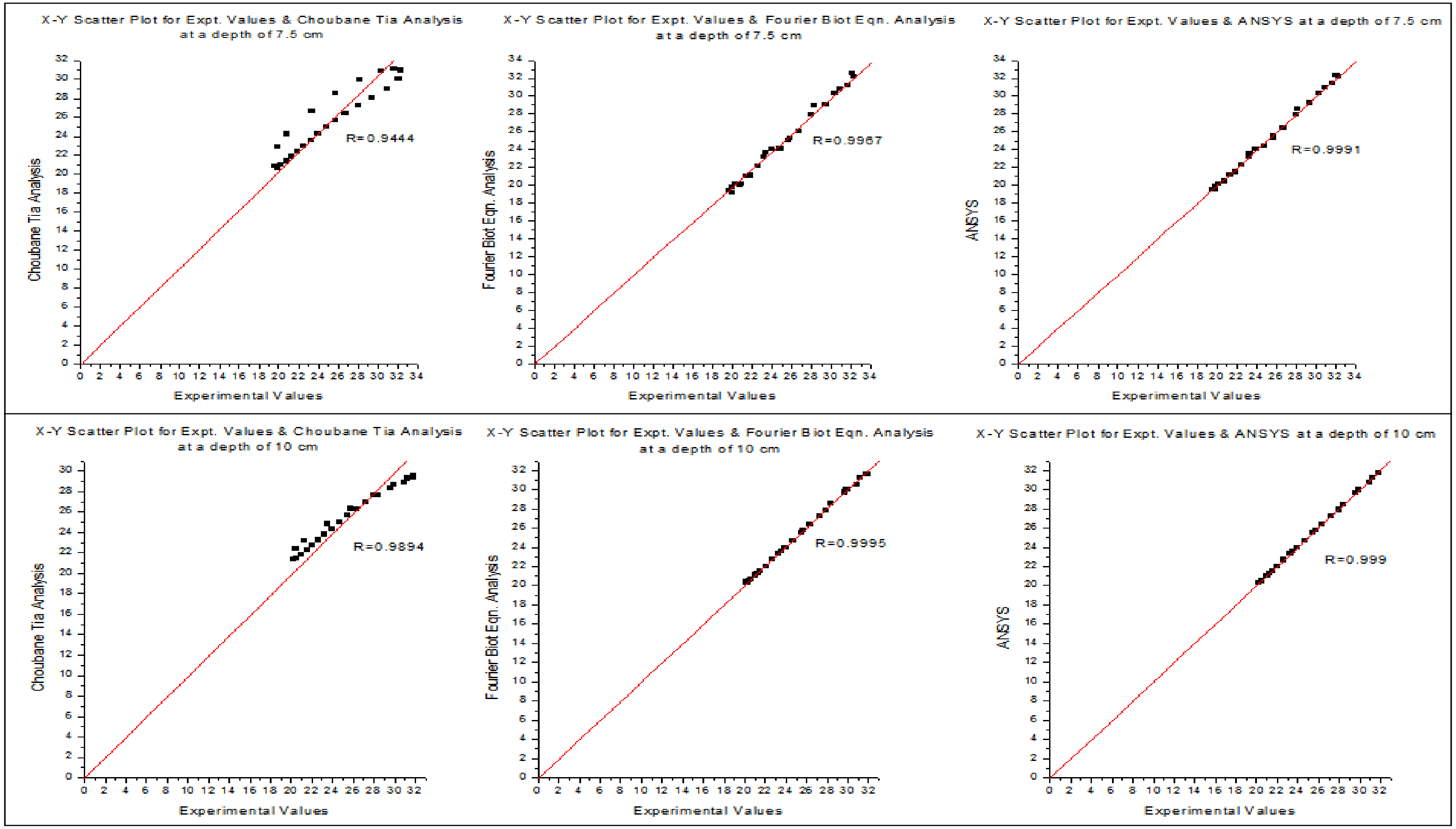


Fig. B-20 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

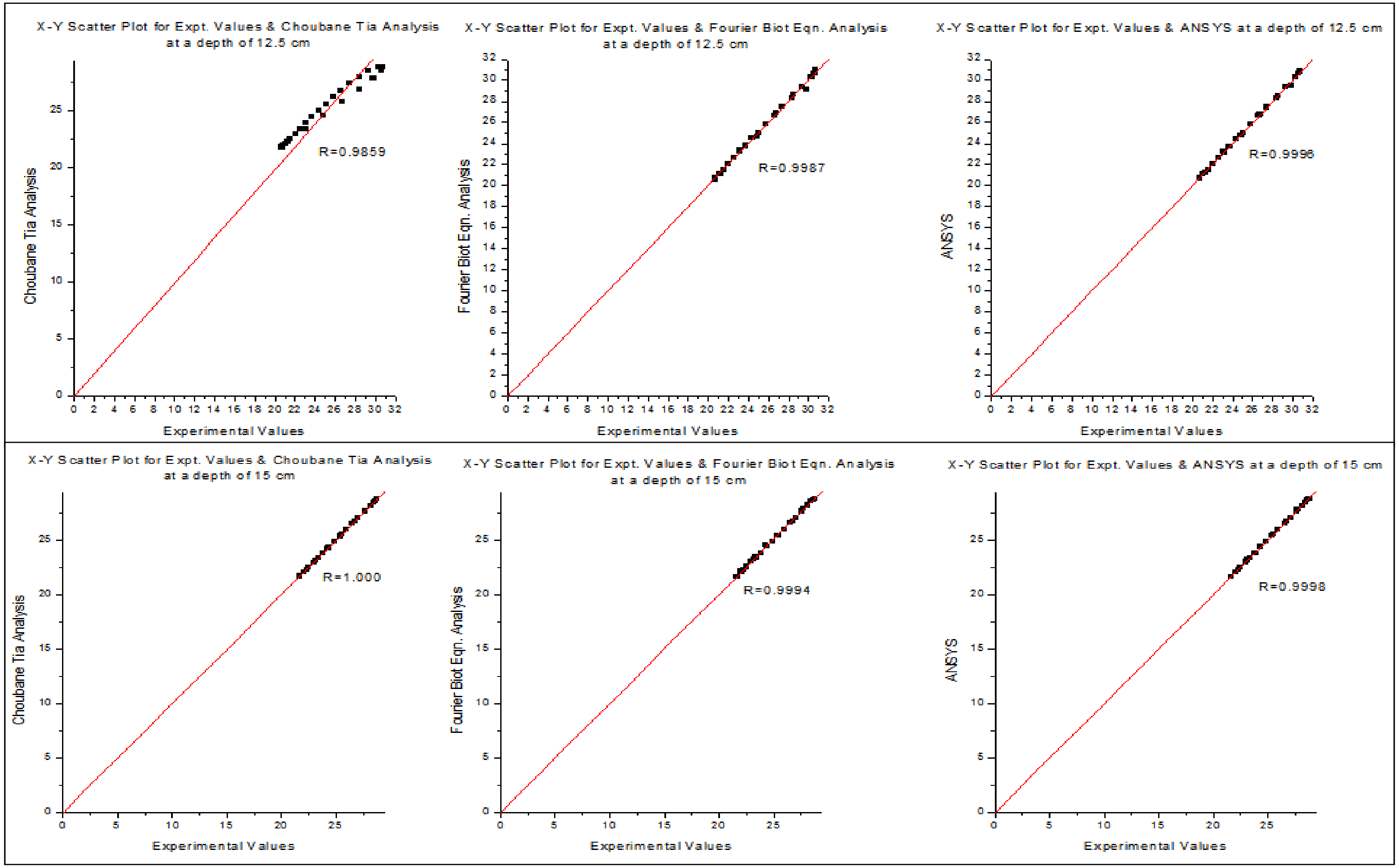


Fig. B-20 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

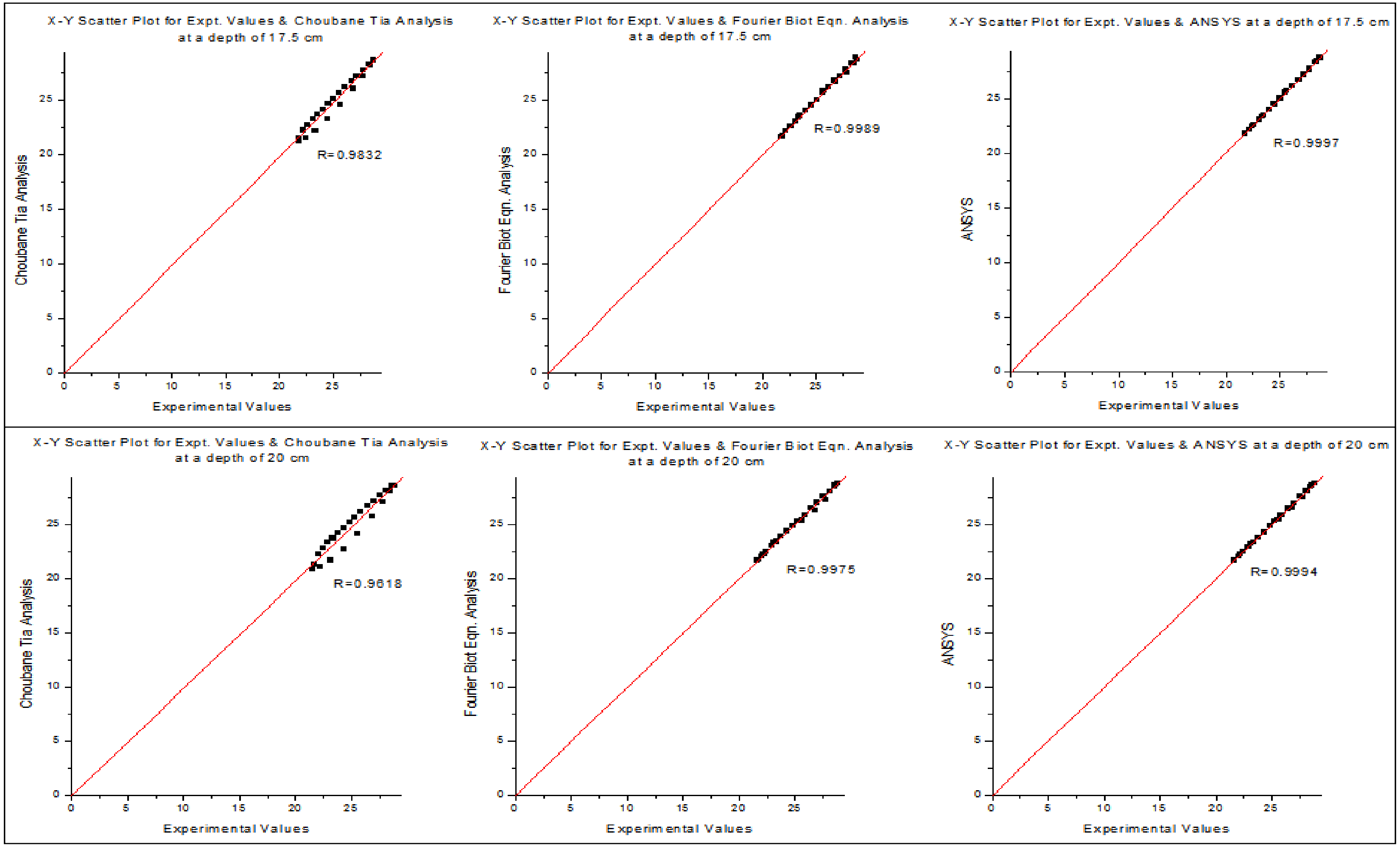


Fig. B-20 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

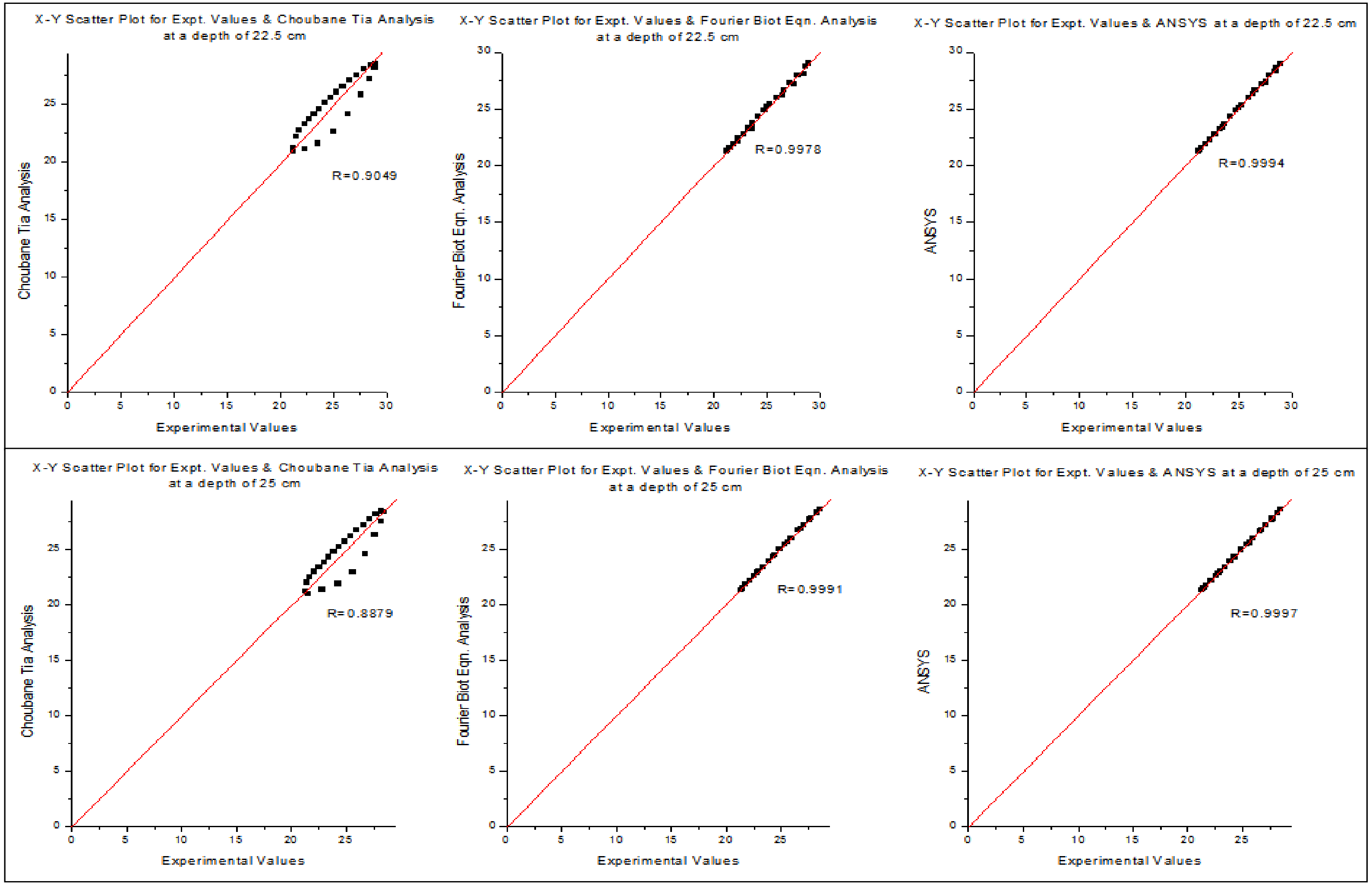


Fig. B-20 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

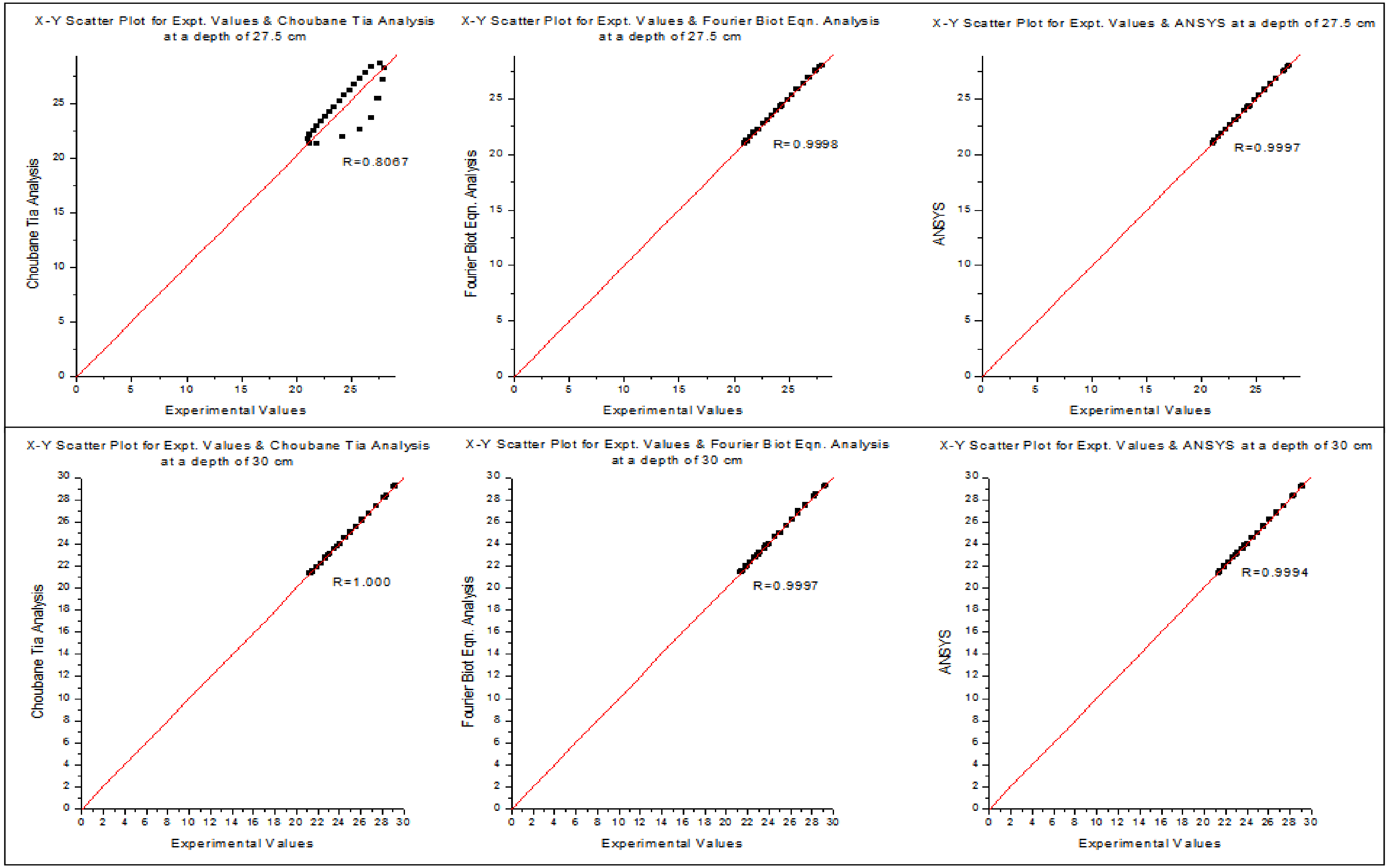


Fig. B-20 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

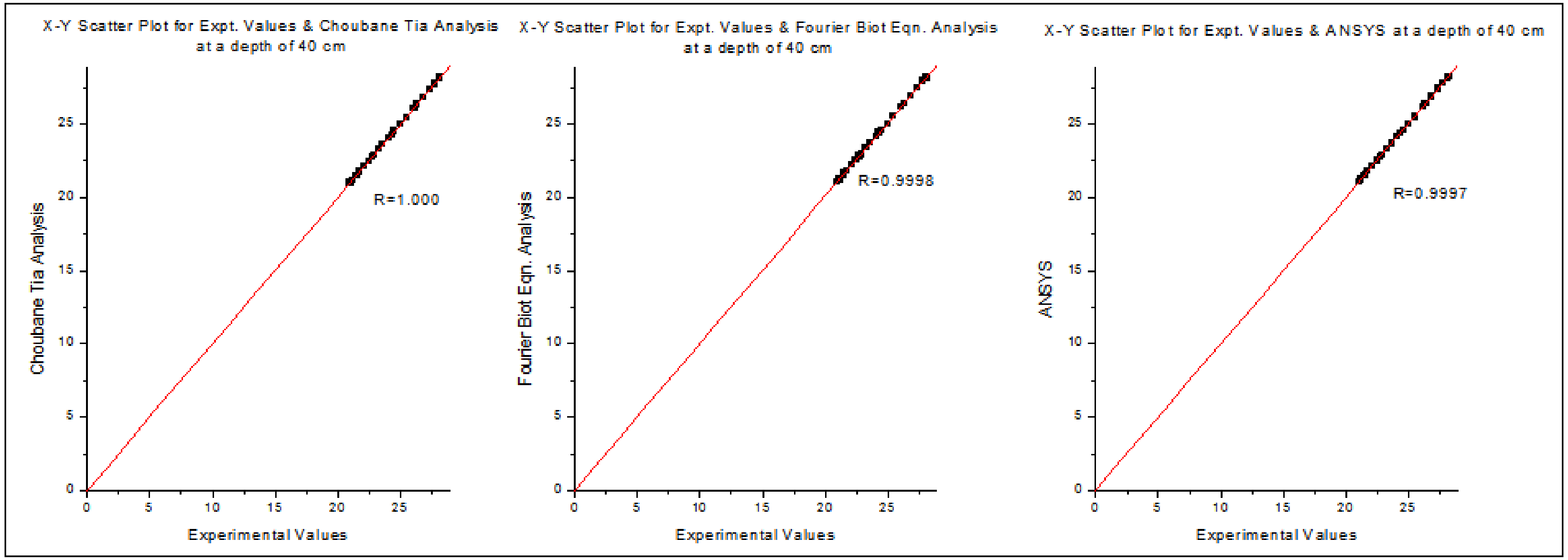


Fig. B-20 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-11 (a): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for part humid and part rainy condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	27	34.78	26.63	32.20	26.86	26.75	25.16	29.93	25.82	25.49	24.42	27.98	24.44	24.43
2	1130 to 1230	28	39.97	30.65	36.39	30.78	30.71	28.32	33.25	28.61	28.47	26.65	30.55	26.85	26.75
3	1230 to 1330	29	43.50	33.92	39.45	33.87	33.90	31.61	35.89	31.32	31.47	29.24	32.83	29.28	29.26
4	1330 to 1430	29	42.41	35.11	39.03	35.28	35.19	33.46	36.04	33.99	33.73	31.16	33.46	31.55	31.36
5	1430 to 1530	29	31.53	33.95	31.03	33.88	33.91	33.14	30.56	33.23	33.18	31.79	30.14	31.73	31.76
6	1530 to 1630	28	27.99	27.79	28.16	27.63	27.71	28.28	28.30	28.75	28.51	28.66	28.40	28.54	28.60
7	1630 to 1730	28	25.99	26.05	26.33	26.26	26.15	26.79	26.62	26.25	26.52	27.19	26.88	27.47	27.33
8	1730 to 1830	27	23.76	24.88	24.46	24.63	24.76	25.60	25.08	25.13	25.37	26.25	25.62	26.34	26.29
9	1830 to 1930	26	22.51	23.59	23.35	23.89	23.74	24.38	24.11	24.62	24.50	25.23	24.76	25.40	25.31
10	1930 to 2030	24	21.80	22.88	22.67	22.89	22.88	23.50	23.44	23.47	23.49	24.52	24.12	24.67	24.60
11	2030 to 2130	23	21.26	22.38	22.14	22.39	22.38	23.00	22.93	23.07	23.04	23.94	23.62	24.02	23.98
12	2130 to 2230	22	20.67	21.85	21.60	21.73	21.79	22.42	22.42	22.36	22.39	23.41	23.15	23.52	23.47
13	2230 to 2330	21	20.05	21.37	21.00	21.17	21.27	21.84	21.84	21.92	21.88	22.92	22.59	23.00	22.96
14	2330 to 0030	21	19.77	20.95	20.67	20.26	20.60	21.48	21.47	21.52	21.50	22.45	22.18	22.52	22.48
15	0030 to 0130	20	20.18	20.86	20.90	20.96	20.91	21.30	21.55	21.42	21.36	22.21	22.13	22.31	22.26
16	0130 to 0230	20	20.37	20.98	21.02	20.90	20.94	21.30	21.60	21.40	21.35	22.11	22.12	22.17	22.14
17	0230 to 0330	20	20.25	21.00	20.90	20.92	20.96	21.30	21.48	21.40	21.35	22.04	22.00	22.06	22.05
18	0330 to 0430	19	20.04	20.90	20.71	20.70	20.80	21.20	21.31	21.18	21.19	21.93	21.85	21.86	21.89
19	0430 to 0530	19	20.27	20.80	20.84	20.58	20.69	21.10	21.36	21.13	21.12	21.80	21.82	21.81	21.81
20	0530 to 0630	19	20.08	20.88	20.67	20.72	20.80	21.09	21.19	21.11	21.10	21.72	21.66	21.81	21.76
21	0630 to 0730	20	20.14	20.68	20.68	20.07	20.37	20.93	21.17	20.94	20.94	21.61	21.60	21.71	21.66
22	0730 to 0830	21	21.34	21.07	21.57	21.92	21.49	21.20	21.78	21.29	21.24	21.66	21.98	21.71	21.68
23	0830 to 0930	23	23.85	21.96	23.50	21.65	21.80	21.82	23.21	21.83	21.83	22.05	22.97	22.19	22.12
24	0930 to 1030	25	27.72	23.89	26.55	23.64	23.76	23.18	25.53	23.59	23.39	22.96	24.65	22.99	22.98

Table B-11 (b): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for part humid and part rainy condition at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	24.38	26.35	24.53	24.45	24.19	25.04	24.39	24.29	24.04	24.04	24.03	24.03
2	1130 to 1230	26.29	28.29	26.30	26.29	25.64	26.48	25.88	25.76	25.10	25.10	25.21	25.16
3	1230 to 1330	28.55	30.25	28.55	28.55	27.50	28.16	27.61	27.56	26.57	26.57	26.61	26.59
4	1330 to 1430	30.39	31.27	30.54	30.47	29.19	29.47	29.56	29.37	28.07	28.07	28.15	28.11
5	1430 to 1530	31.07	29.76	31.16	31.11	29.50	29.41	29.54	29.52	29.11	29.11	29.16	29.13
6	1530 to 1630	28.45	28.46	28.63	28.54	26.39	28.48	26.47	26.43	28.46	28.46	28.50	28.48
7	1630 to 1730	26.90	27.09	26.94	26.92	26.17	27.26	26.61	26.39	27.39	27.39	27.34	27.37
8	1730 to 1830	26.04	26.08	26.11	26.07	26.02	26.46	26.30	26.16	26.75	26.75	26.81	26.78
9	1830 to 1930	25.26	25.32	25.32	25.29	25.60	25.79	25.77	25.69	26.16	26.16	26.19	26.18
10	1930 to 2030	24.67	24.70	24.71	24.69	25.13	25.19	25.17	25.15	25.58	25.58	25.64	25.61
11	2030 to 2130	24.18	24.22	24.22	24.20	24.81	24.72	24.87	24.84	25.12	25.12	25.14	25.13
12	2130 to 2230	23.63	23.78	23.70	23.67	24.32	24.30	24.40	24.36	24.73	24.73	24.82	24.77
13	2230 to 2330	23.16	23.23	23.20	23.18	23.81	23.77	23.88	23.84	24.21	24.21	24.27	24.24
14	2330 to 0030	22.74	22.80	22.76	22.75	23.37	23.32	23.45	23.41	23.76	23.76	23.83	23.79
15	0030 to 0130	22.48	22.64	22.57	22.52	23.14	23.07	23.21	23.17	23.44	23.44	23.50	23.47
16	0130 to 0230	22.36	22.58	22.42	22.39	22.97	22.97	22.98	22.98	23.30	23.30	23.33	23.31
17	0230 to 0330	22.30	22.45	22.28	22.29	22.88	22.84	22.91	22.90	23.16	23.16	23.21	23.18
18	0330 to 0430	22.15	22.31	22.21	22.18	22.73	22.70	22.81	22.77	23.03	23.03	23.07	23.05
19	0430 to 0530	22.01	22.22	22.08	22.05	22.57	22.57	22.62	22.60	22.86	22.86	22.92	22.89
20	0530 to 0630	21.91	22.07	21.92	21.91	22.48	22.42	22.55	22.51	22.71	22.71	22.76	22.74
21	0630 to 0730	21.80	21.99	21.77	21.78	22.34	22.32	22.42	22.38	22.60	22.60	22.65	22.62
22	0730 to 0830	21.83	22.17	21.88	21.85	22.30	22.34	22.37	22.34	22.50	22.50	22.54	22.52
23	0830 to 0930	22.13	22.78	22.26	22.19	22.44	22.64	22.49	22.47	22.56	22.56	22.58	22.57
24	0930 to 1030	22.92	23.92	22.91	22.91	22.98	23.35	23.04	23.01	22.92	22.92	22.96	22.94

Table B-11 (c): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for part humid and part rainy condition at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	24.18	23.36	24.22	24.20	24.29	23.00	24.26	24.27	24.35	22.95	24.33	24.34
2	1130 to 1230	24.93	24.17	25.00	24.96	24.80	23.68	24.88	24.84	24.89	23.63	24.95	24.92
3	1230 to 1330	26.04	25.46	26.11	26.08	25.56	24.84	25.63	25.59	25.66	24.72	25.69	25.67
4	1330 to 1430	27.23	27.06	27.41	27.32	26.56	26.45	26.58	26.57	26.68	26.24	26.74	26.71
5	1430 to 1530	28.26	28.84	28.49	28.38	27.50	28.61	27.55	27.53	27.70	28.42	27.75	27.72
6	1530 to 1630	27.90	28.41	28.01	27.95	27.73	28.32	27.77	27.75	27.87	28.19	27.93	27.90
7	1630 to 1730	27.30	27.48	27.29	27.30	27.34	27.53	27.39	27.36	27.34	27.54	27.40	27.37
8	1730 to 1830	26.93	26.97	27.00	26.97	27.00	27.11	27.04	27.02	26.96	27.17	27.02	26.99
9	1830 to 1930	26.49	26.44	26.52	26.50	26.71	26.62	26.79	26.75	26.61	26.71	26.63	26.62
10	1930 to 2030	25.98	25.88	26.00	25.99	26.25	26.08	26.31	26.28	26.17	26.19	26.20	26.18
11	2030 to 2130	25.52	25.43	25.52	25.52	25.84	25.64	25.91	25.87	25.72	25.75	25.79	25.76
12	2130 to 2230	25.07	25.05	25.12	25.09	25.40	25.27	25.51	25.45	25.26	25.39	25.30	25.28
13	2230 to 2330	24.64	24.55	24.71	24.67	24.97	24.79	25.00	24.99	24.87	24.93	24.91	24.89
14	2330 to 0030	24.22	24.10	24.29	24.25	24.60	24.34	24.68	24.64	24.44	24.50	24.49	24.46
15	0030 to 0130	23.89	23.73	24.00	23.94	24.25	23.95	24.29	24.27	24.09	24.10	24.13	24.11
16	0130 to 0230	23.64	23.56	23.73	23.69	23.98	23.75	24.00	23.99	23.83	23.88	23.90	23.87
17	0230 to 0330	23.46	23.41	23.55	23.51	23.76	23.60	23.81	23.79	23.66	23.72	23.71	23.68
18	0330 to 0430	23.31	23.28	23.38	23.35	23.58	23.47	23.61	23.60	23.49	23.58	23.52	23.50
19	0430 to 0530	23.24	23.09	23.28	23.26	23.44	23.27	23.48	23.46	23.34	23.38	23.38	23.36
20	0530 to 0630	23.10	22.95	23.08	23.09	23.31	23.12	23.35	23.33	23.25	23.24	23.22	23.24
21	0630 to 0730	22.96	22.82	23.00	22.98	23.26	23.00	23.30	23.28	23.15	23.13	23.19	23.17
22	0730 to 0830	22.90	22.64	22.95	22.92	23.12	22.77	23.15	23.14	23.02	22.89	23.01	23.02
23	0830 to 0930	22.90	22.53	22.92	22.91	23.10	22.55	23.07	23.08	23.00	22.62	23.03	23.02
24	0930 to 1030	23.11	22.63	23.14	23.12	23.20	22.50	23.17	23.19	23.17	22.52	23.21	23.19

Table B-11 (d): 24 hr. slab (edge) temperature values (measured & calculated) for Mix B for part humid and part rainy condition at 25cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourie r Biot Eqn.	ANSYS
1	1030 to 1130	24.62	23.22	24.66	24.64	25.21	23.81	25.27	25.24	24.72	24.72	24.99	24.85	24.67	24.67	24.73	24.70
2	1130 to 1230	25.21	24.02	25.25	25.23	26.13	24.85	26.16	26.14	26.13	26.13	26.17	26.15	26.17	26.17	26.22	26.19
3	1230 to 1330	26.18	25.08	26.23	26.20	27.66	25.94	27.72	27.69	27.28	27.28	27.36	27.32	28.13	28.13	28.20	28.16
4	1330 to 1430	27.35	26.42	27.43	27.39	29.27	27.00	29.32	29.30	27.97	27.97	28.00	27.98	29.31	29.31	29.34	29.33
5	1430 to 1530	28.47	28.26	28.51	28.49	29.52	28.15	29.61	29.56	28.07	28.07	28.14	28.11	28.52	28.52	28.55	28.54
6	1530 to 1630	27.95	28.02	27.99	27.97	26.89	27.81	26.94	26.91	27.57	27.57	27.61	27.59	27.59	27.59	27.63	27.61
7	1630 to 1730	27.11	27.51	27.15	27.13	26.10	27.44	26.14	26.12	27.33	27.33	27.35	27.34	26.92	26.92	27.01	26.97
8	1730 to 1830	26.74	27.14	26.81	26.77	25.72	27.04	25.79	25.75	26.86	26.86	26.90	26.88	26.11	26.11	26.17	26.14
9	1830 to 1930	26.29	26.70	26.32	26.31	25.19	26.60	25.26	25.22	26.40	26.40	26.44	26.42	25.37	25.37	25.43	25.40
10	1930 to 2030	25.78	26.21	25.81	25.80	24.87	26.13	24.91	24.89	25.95	25.95	26.00	25.98	24.94	24.94	25.01	24.97
11	2030 to 2130	25.36	25.77	25.40	25.38	24.40	25.69	24.48	24.44	25.52	25.52	25.57	25.54	24.62	24.62	24.67	24.65
12	2130 to 2230	24.92	25.41	25.00	24.96	23.82	25.32	23.88	23.85	25.14	25.14	25.20	25.17	24.32	24.32	24.40	24.36
13	2230 to 2330	24.44	24.97	24.51	24.47	23.34	24.90	23.40	23.37	24.74	24.74	24.81	24.77	24.00	24.00	24.00	24.00
14	2330 to 0030	24.01	24.56	24.00	24.01	23.04	24.54	23.00	23.02	24.42	24.42	24.48	24.45	23.70	23.70	23.74	23.72
15	0030 to 0130	23.70	24.18	23.75	23.73	22.89	24.18	22.93	22.91	24.12	24.12	24.18	24.15	23.52	23.52	23.55	23.53
16	0130 to 0230	23.50	23.95	23.55	23.52	22.80	23.95	22,84	22.80	23.88	23.88	23.94	23.91	23.42	23.42	23.46	23.44
17	0230 to 0330	23.35	23.77	23.40	23.37	22.74	23.76	22.76	22.75	23.68	23.68	23.72	23.70	23.32	23.32	23.41	23.37
18	0330 to 0430	23.30	23.63	23.37	23.33	22.60	23.60	22.66	22.63	23.51	23.51	23.55	23.53	23.30	23.30	23.33	23.32
19	0430 to 0530	23.15	23.45	23.20	23.17	22.47	23.45	22.51	22.49	23.40	23.40	23.44	23.42	23.29	23.29	23.32	23.30
20	0530 to 0630	23.02	23.30	23.00	23.01	22.39	23.31	22.43	22.41	23.25	23.25	23.31	23.28	23.20	23.20	23.23	23.21
21	0630 to 0730	22.90	23.20	22.92	22.91	22.30	23.22	22.34	22.32	23.19	23.19	23.22	23.21	23.10	23.10	23.13	23.12
22	0730 to 0830	22.84	22.99	22.91	22.87	22.40	23.07	22.46	22.43	23.15	23.15	23.20	23.17	23.10	23.10	23.12	23.11
23	0830 to 0930	22.91	22.75	22.94	22.93	22.74	22.93	22.79	22.76	23.16	23.16	23.19	23.17	23.22	23.22	23.27	23.24
24	0930 to 1030	23.18	22.68	23.22	23.20	23.37	22.99	23.41	23.39	23.45	23.45	23.51	23.48	23.49	23.49	23.53	23.51

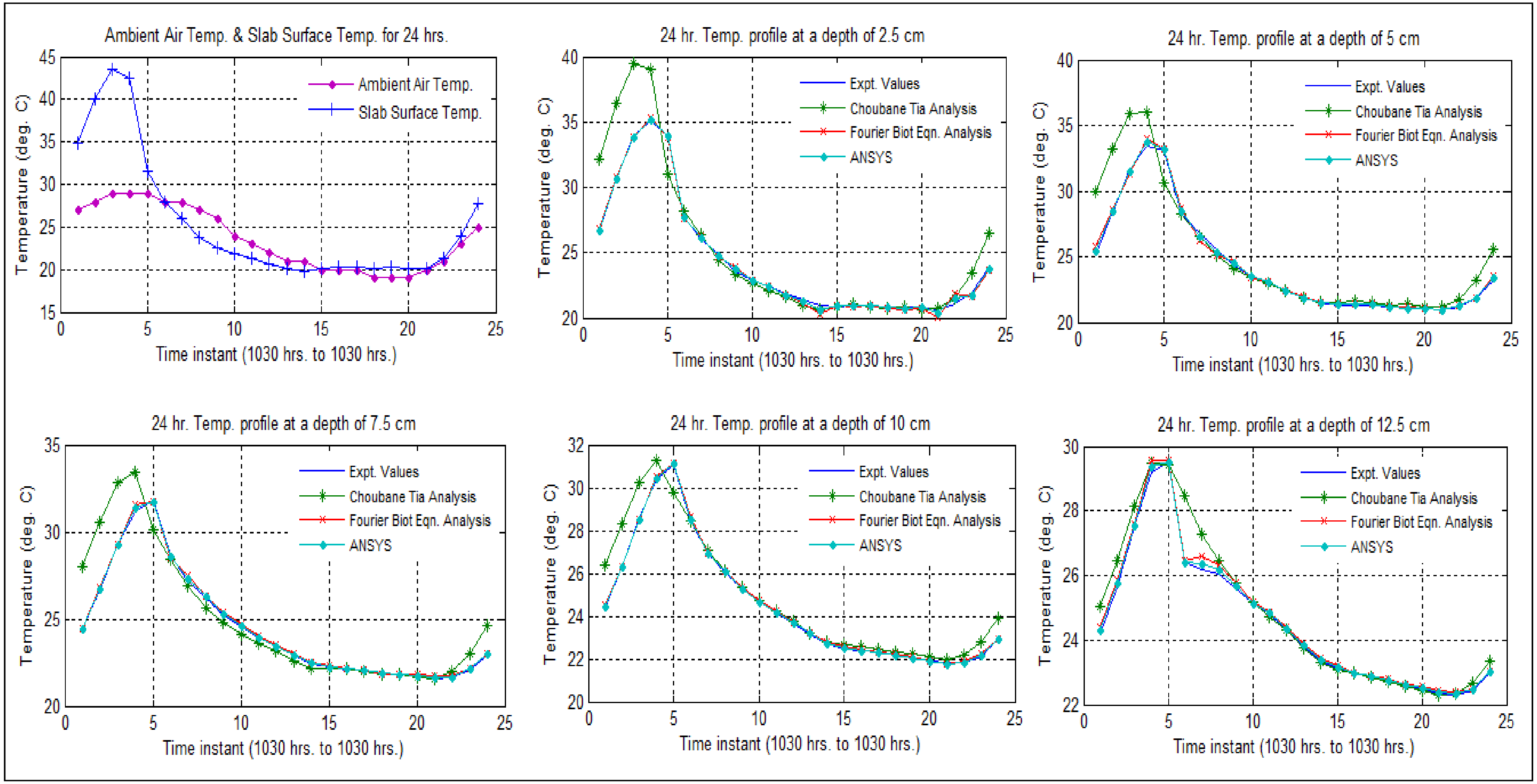


Fig. B-21 (a): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix B for part humid and part rainy condition (surface to 12.5 cm)

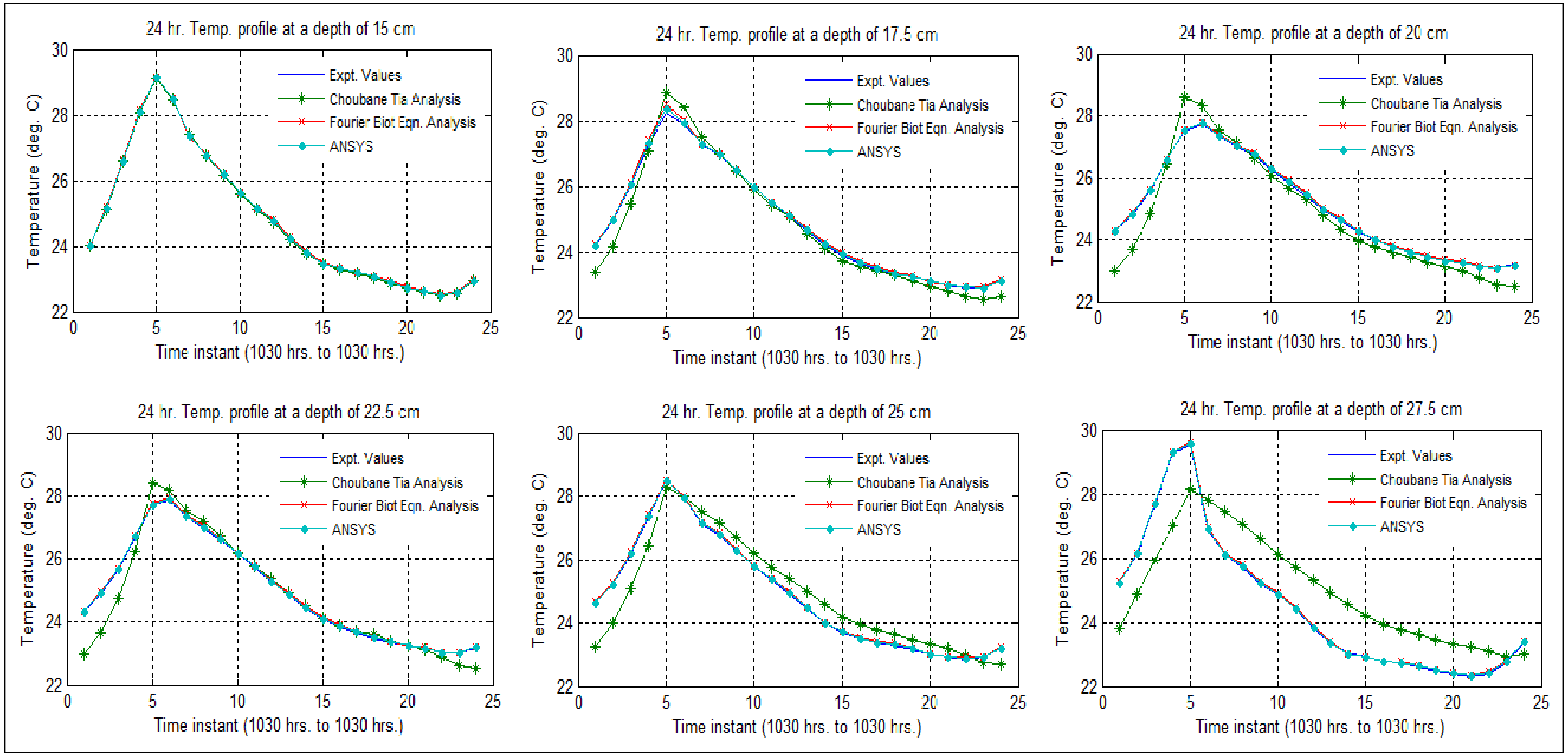


Fig. B-21 (b): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix B for part humid and part rainy condition (15 cm to 27.5 cm)

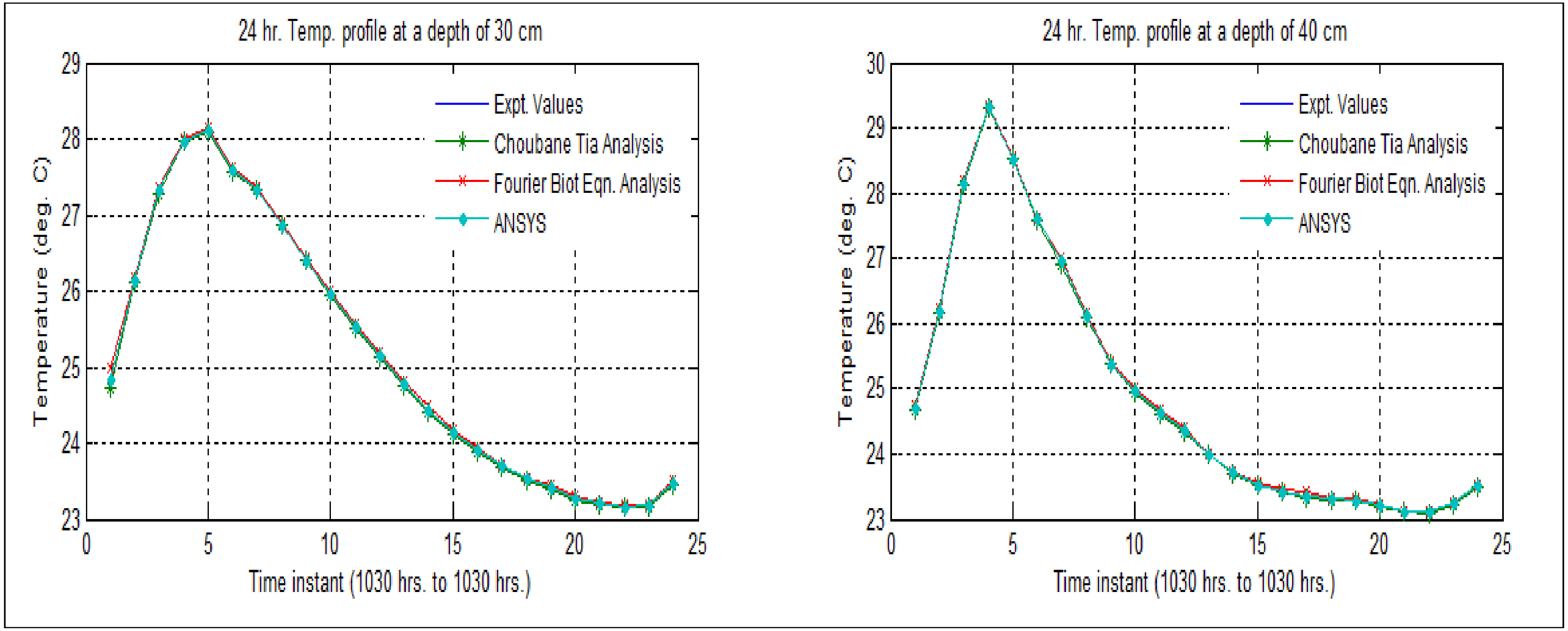


Fig. B-21 (c): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix B for part humid and part rainy condition (30 cm & 40 cm)

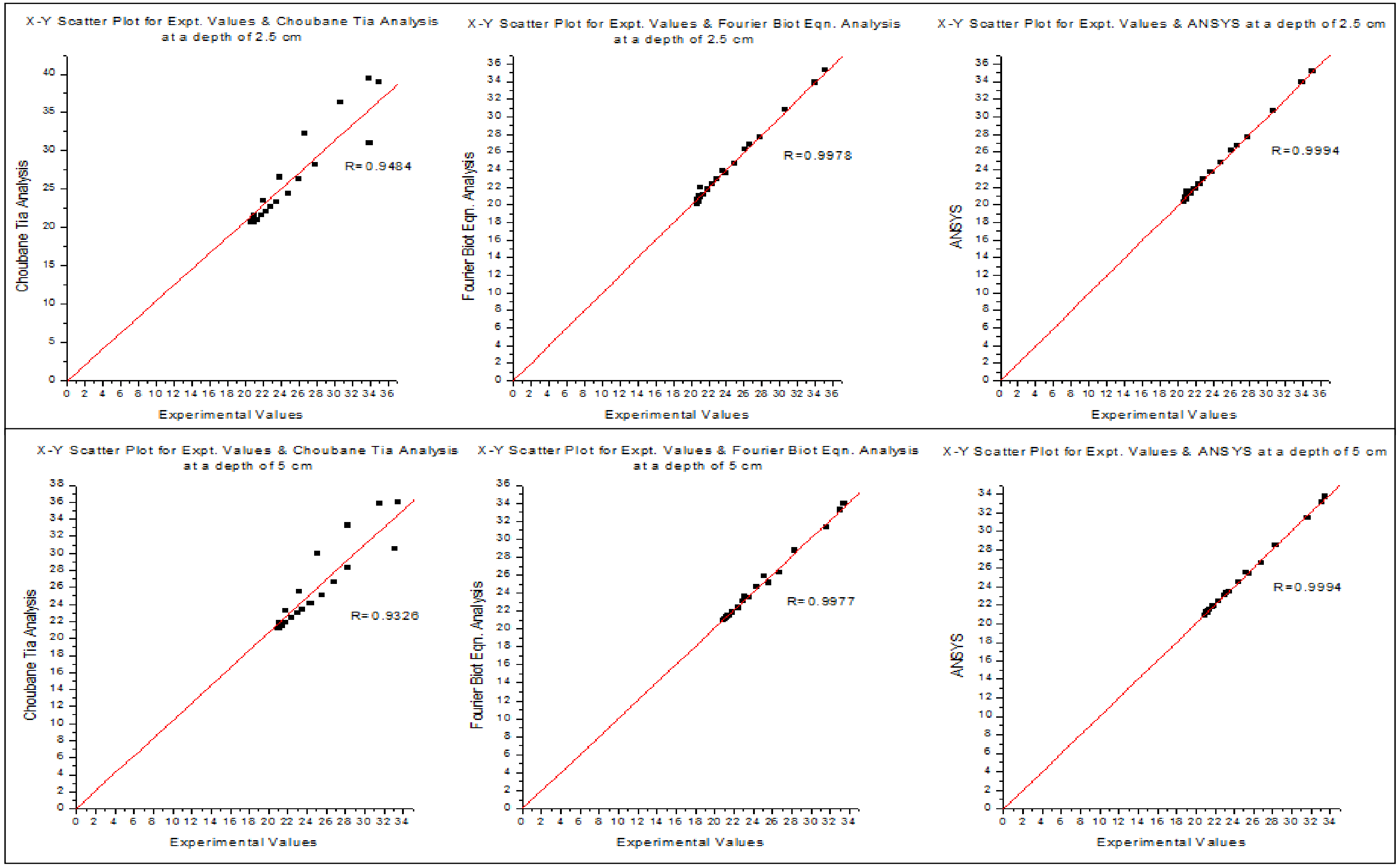


Fig. B-22 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

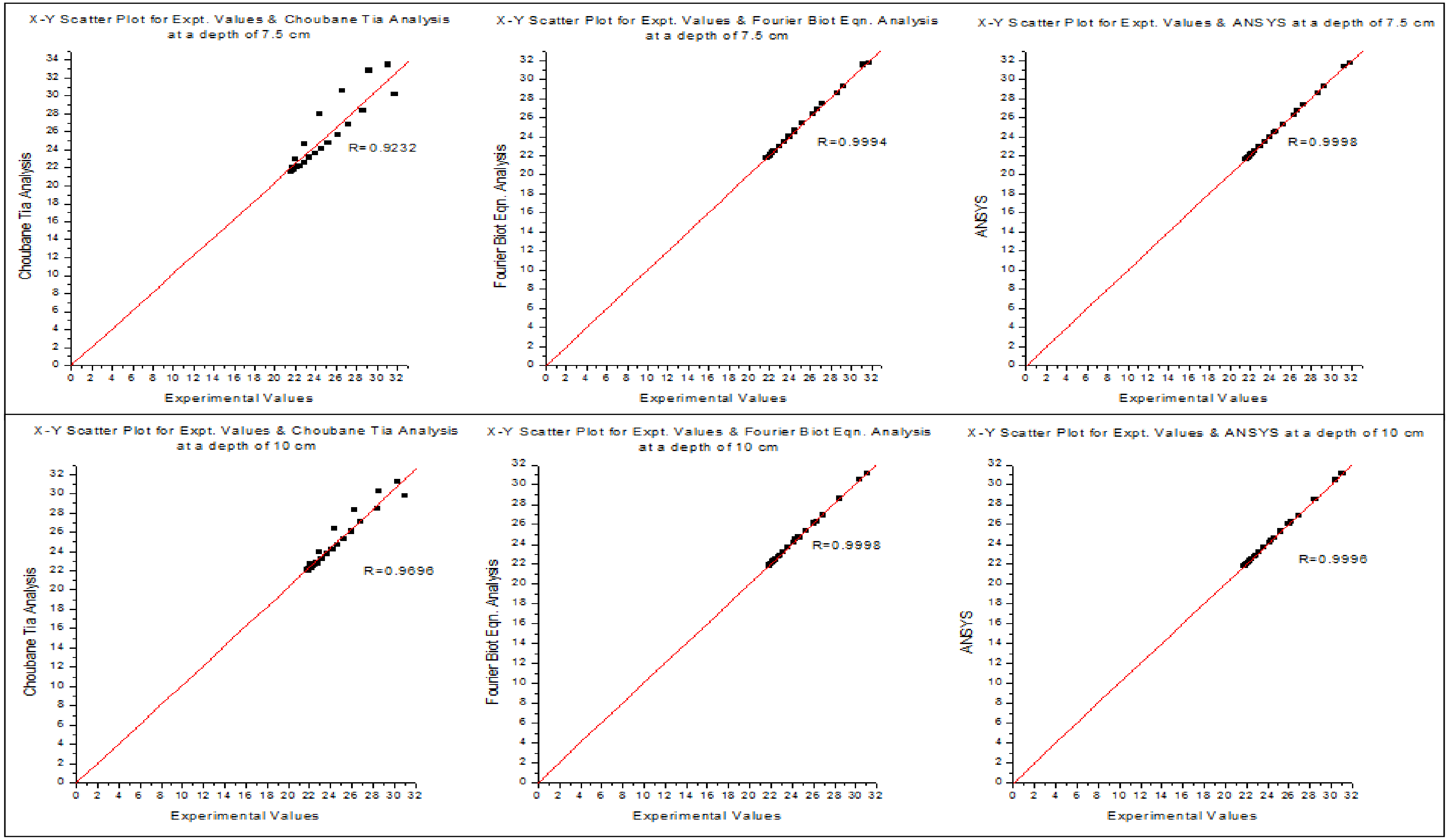


Fig. B-22 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

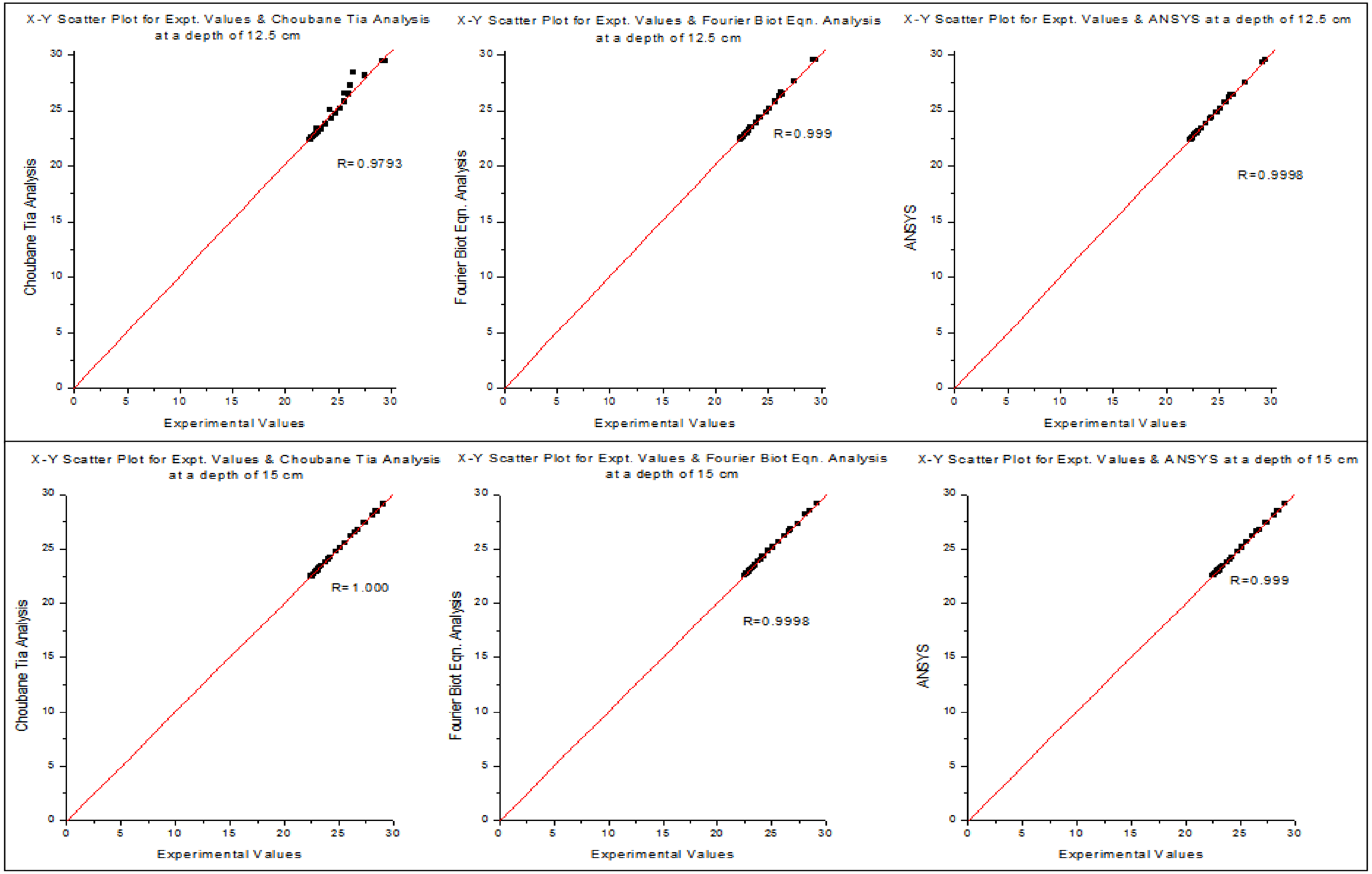


Fig. B-22 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

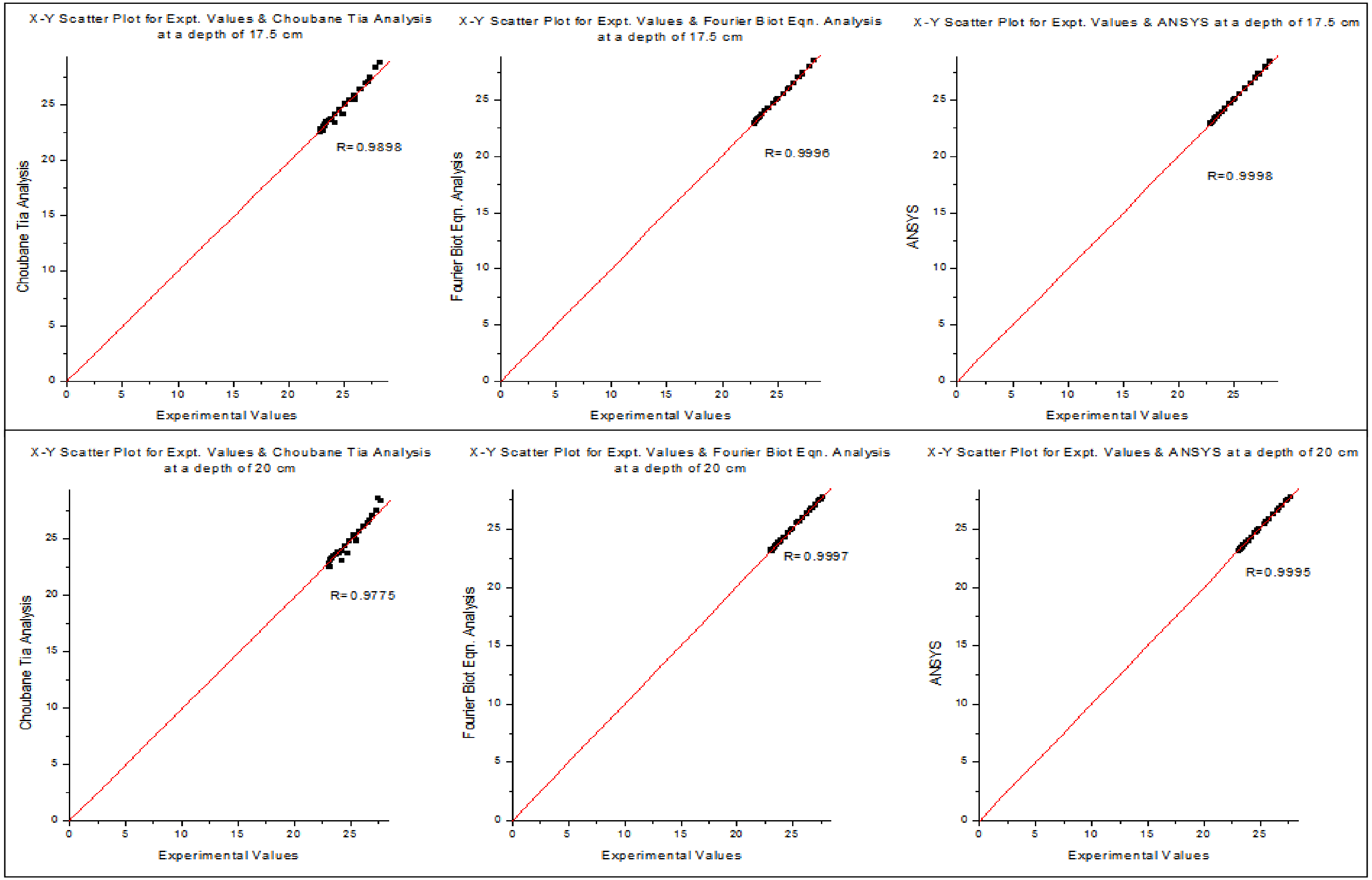


Fig. B-22 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

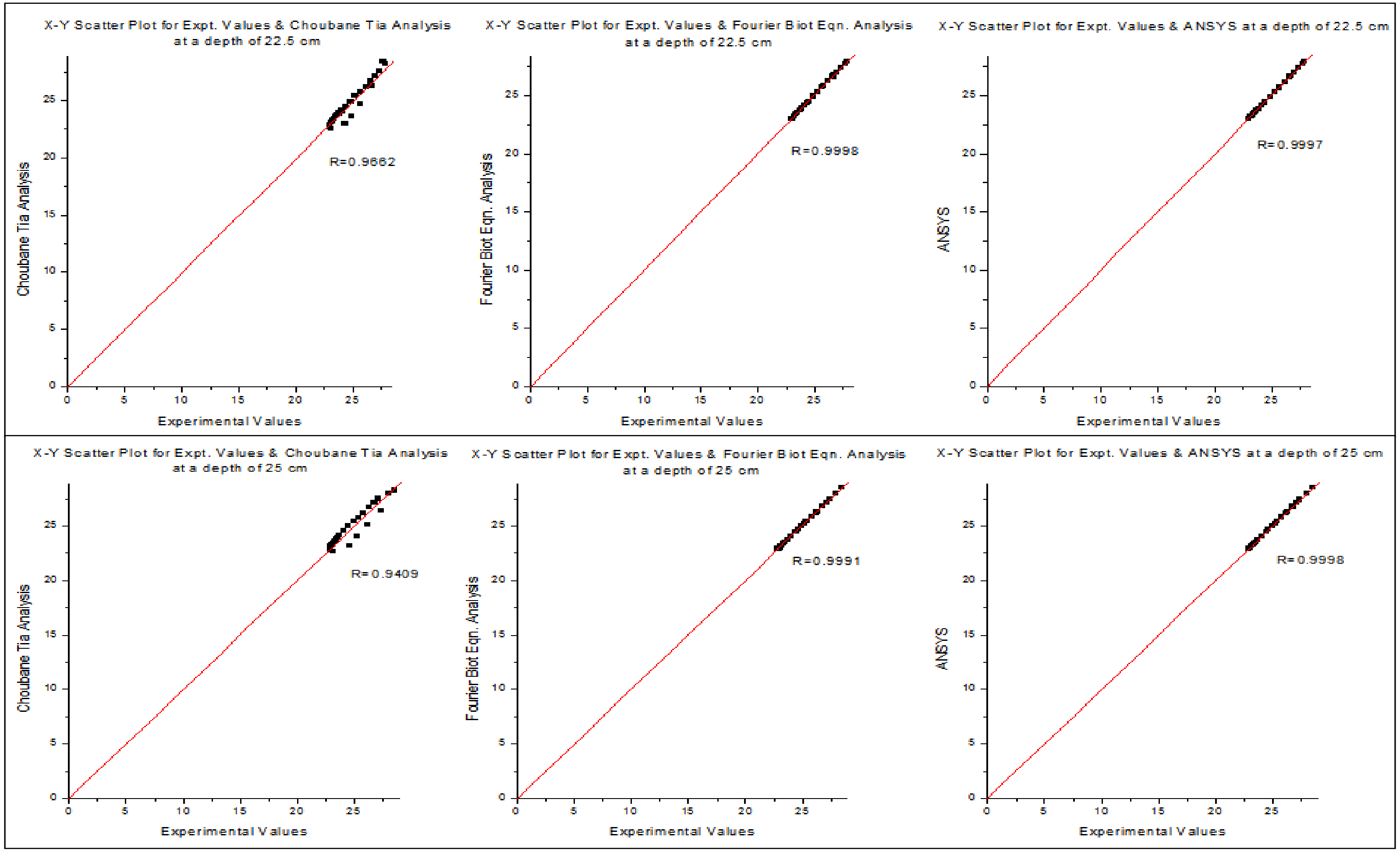


Fig. B-22 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

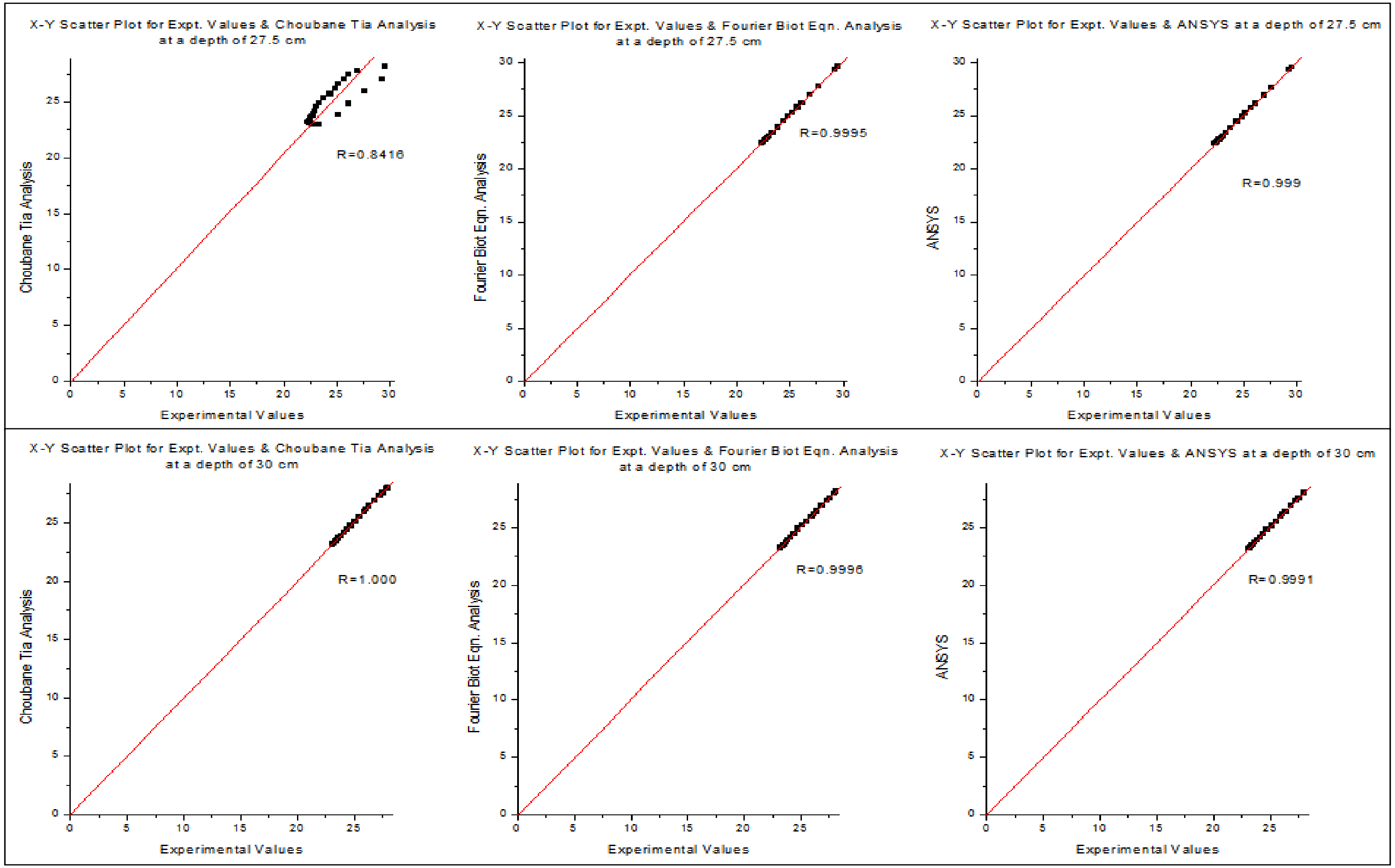


Fig. B-22 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

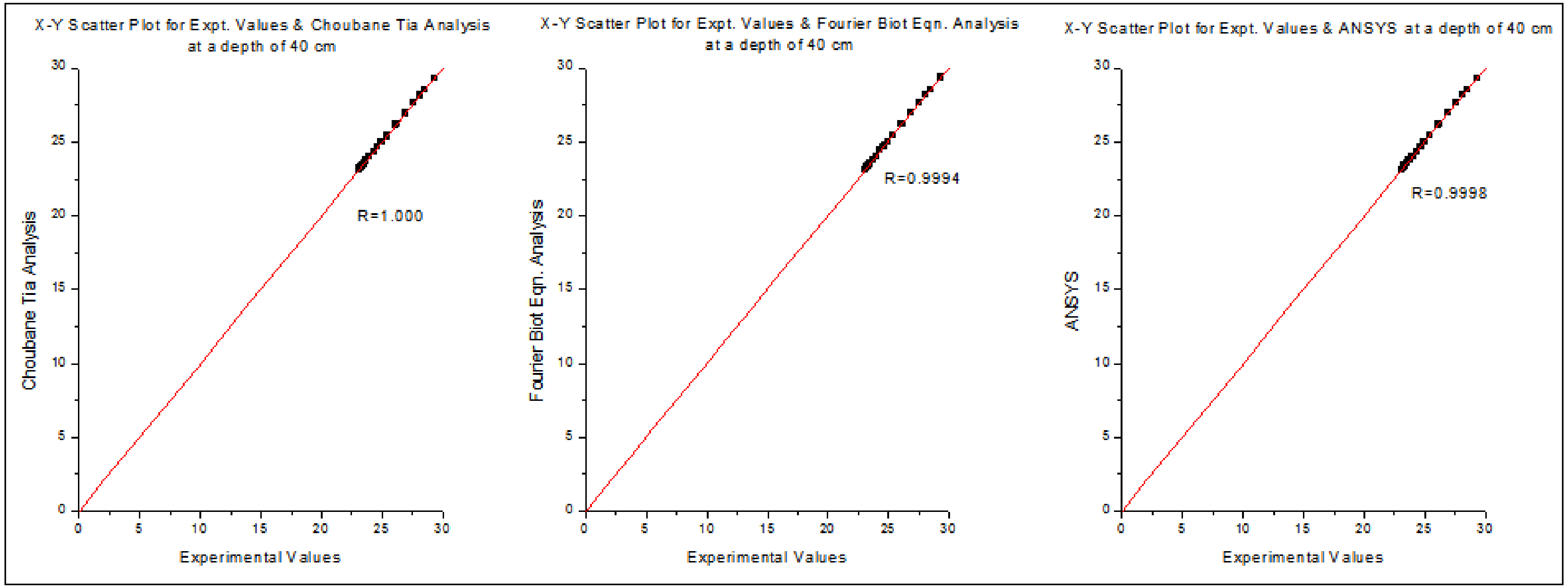


Fig. B-22 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-12 (a): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for part humid and part rainy condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (ºC) at 2.5 cm				Temperature (ºC) at 5 cm				Temperature (ºC) at 7.5 cm			
		(ºC)	(ºC)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	27	35.46	29.75	32.66	29.70	29.72	26.38	30.21	26.71	26.55	24.96	28.12	24.89	24.93
2	1200 to 1300	28	39.76	33.98	36.06	33.69	33.83	29.80	32.83	29.47	29.63	27.45	30.07	27.51	27.48
3	1300 to 1400	29	40.91	37.76	37.14	37.25	37.50	33.23	33.85	33.55	33.39	30.17	31.05	30.22	30.20
4	1400 to 1500	29	39.81	38.98	36.58	38.97	38.98	35.01	33.78	35.08	35.04	32.14	31.40	32.22	32.18
5	1500 to 1600	29	28.22	33.35	28.08	33.33	33.34	34.08	27.98	34.15	34.12	32.64	27.92	32.70	32.67
6	1600 to 1700	28	27.26	27.56	27.63	27.67	27.62	29.75	27.94	29.85	29.80	30.38	28.19	30.42	30.40
7	1700 to 1800	28	25.37	25.84	26.19	25.90	25.87	27.57	26.88	27.35	27.46	28.60	27.45	28.53	28.56
8	1800 to 1900	27	23.65	24.91	24.79	24.96	24.94	26.27	25.76	26.15	26.21	27.29	26.56	27.35	27.32
9	1900 to 2000	26	22.88	23.72	24.07	23.81	23.77	25.06	25.08	25.11	25.08	26.18	25.93	26.27	26.22
10	2000 to 2100	24	22.33	23.08	23.51	23.13	23.11	24.21	24.53	24.20	24.21	25.25	25.38	25.32	25.29
11	2100 to 2200	23	21.67	22.50	22.89	22.54	22.52	23.53	23.94	23.21	23.37	24.62	24.82	24.67	24.64
12	2200 to 2300	22	21.12	21.84	22.36	21.91	21.88	22.90	23.42	22.10	22.50	23.93	24.32	24.01	23.97
13	2300 to 0000	21	20.50	21.33	21.77	21.39	21.36	22.25	22.86	22.06	22.16	23.32	23.77	23.39	23.35
14	0000 to 0100	21	20.40	21.01	21.58	21.06	21.04	21.75	22.60	21.09	21.42	22.80	23.45	22.86	22.83
15	0100 to 0200	20	20.66	21.14	21.67	21.20	21.17	21.60	22.55	21.89	21.74	22.49	23.28	22.53	22.51
16	0200 to 0300	20	20.83	21.32	21.71	21.37	21.34	21.60	22.46	21.84	21.72	22.35	23.10	22.40	22.38
17	0300 to 0400	20	20.68	21.29	21.52	21.34	21.31	21.60	22.25	21.86	21.73	22.24	22.86	22.30	22.27
18	0400 to 0500	19	20.49	21.12	21.31	21.16	21.14	21.52	22.03	21.70	21.61	22.12	22.63	22.18	22.15
19	0500 to 0600	19	20.71	21.16	21.43	21.22	21.19	21.40	22.05	21.61	21.51	21.97	22.58	22.05	22.01
20	0600 to 0700	19	20.39	21.11	21.14	21.14	21.13	21.38	21.79	21.75	21.56	21.88	22.34	21.84	21.86
21	0700 to 0800	20	20.86	21.09	21.47	21.13	21.11	21.27	21.99	21.91	21.59	21.75	22.44	21.79	21.77
22	0800 to 0900	21	21.97	21.71	22.29	21.77	21.74	21.48	22.56	21.54	21.51	21.80	22.79	21.85	21.83
23	0900 to 1000	23	24.56	23.19	24.24	23.22	23.20	22.15	23.96	22.73	22.44	22.19	23.72	22.13	22.16
24	1000 to 1100	25	28.07	25.44	26.91	25.54	25.49	23.53	25.89	23.53	23.53	23.05	25.02	22.97	23.01

Table B-12 (b): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for part humid and part rainy condition at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	25.08	26.39	25.18	25.13	24.62	25.01	24.81	24.71	23.99	23.99	24.01	24.00
2	1200 to 1300	27.16	27.77	27.23	27.19	26.18	25.95	26.55	26.37	24.59	24.59	24.42	24.51
3	1300 to 1400	29.57	28.73	29.68	29.63	28.09	26.90	28.15	28.12	25.55	25.55	25.59	25.57
4	1400 to 1500	31.41	29.44	31.44	31.42	29.76	27.90	29.83	29.80	26.79	26.79	26.85	26.82
5	1500 to 1600	32.17	27.90	32.23	32.20	30.71	27.92	30.74	30.72	27.98	27.98	27.97	27.98
6	1600 to 1700	30.51	28.38	30.77	30.64	29.88	28.50	29.91	29.90	28.57	28.57	28.62	28.60
7	1700 to 1800	29.02	27.90	28.98	29.00	28.80	28.21	28.84	28.82	28.41	28.41	28.07	28.24
8	1800 to 1900	27.87	27.21	27.94	27.91	27.85	27.68	27.91	27.88	28.00	28.00	28.00	28.00
9	1900 to 2000	26.81	26.60	26.86	26.84	26.94	27.11	27.00	26.97	27.45	27.45	27.52	27.48
10	2000 to 2100	25.92	26.06	25.98	25.95	26.16	26.57	26.21	26.19	26.91	26.91	26.93	26.92
11	2100 to 2200	25.23	25.52	25.29	25.26	25.51	26.06	25.58	25.55	26.43	26.43	26.47	26.45
12	2200 to 2300	24.64	25.03	24.70	24.67	24.96	25.58	25.00	24.98	25.95	25.95	26.01	25.98
13	2300 to 0000	24.00	24.51	24.03	24.01	24.40	25.07	24.48	24.44	25.46	25.46	25.52	25.49
14	0000 to 0100	23.44	24.14	23.40	23.42	23.82	24.66	23.90	23.86	25.02	25.02	25.01	25.02
15	0100 to 0200	23.17	23.87	23.22	23.20	23.43	24.32	23.51	23.47	24.63	24.63	24.98	24.81
16	0200 to 0300	23.01	23.62	23.07	23.04	23.27	24.01	23.32	23.30	24.29	24.29	24.38	24.33
17	0300 to 0400	22.86	23.36	22.94	22.90	23.13	23.75	23.21	23.17	24.03	24.03	24.12	24.07
18	0400 to 0500	22.72	23.13	22.80	22.76	22.95	23.52	22.92	22.93	23.81	23.81	23.88	23.84
19	0500 to 0600	22.55	23.01	22.62	22.58	22.76	23.35	22.82	22.79	23.60	23.60	23.64	23.62
20	0600 to 0700	22.45	22.80	22.50	22.48	22.64	23.16	22.73	22.68	23.42	23.42	23.45	23.44
21	0700 to 0800	22.33	22.81	22.38	22.35	22.50	23.09	22.58	22.54	23.30	23.30	23.36	23.33
22	0800 to 0900	22.34	22.98	22.42	22.38	22.43	23.12	22.48	22.45	23.22	23.22	23.38	23.30
23	0900 to 1000	22.63	23.51	22.72	22.67	22.64	23.34	22.71	22.68	23.20	23.20	23.26	23.23
24	1000 to 1100	23.33	24.29	23.38	23.35	23.16	23.70	23.22	23.19	23.25	23.25	23.28	23.27

Table B-12 (c): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for part humid and part rainy condition at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	24.22	23.32	24.28	24.25	23.92	23.01	24.01	23.97	23.67	23.06	23.72	23.69
2	1200 to 1300	24.84	23.71	24.81	24.83	24.57	23.29	24.63	24.60	24.67	23.34	24.78	24.73
3	1300 to 1400	25.82	24.68	25.91	25.86	25.60	24.29	25.68	25.64	26.11	24.39	26.20	26.15
4	1400 to 1500	27.00	26.10	27.06	27.03	26.91	25.84	27.00	26.95	27.60	26.00	27.71	27.65
5	1500 to 1600	28.15	28.08	28.22	28.19	28.17	28.22	28.24	28.20	28.86	28.40	28.92	28.89
6	1600 to 1700	28.62	28.58	28.66	28.64	28.79	28.52	28.90	28.84	29.22	28.40	29.30	29.26
7	1700 to 1800	28.41	28.48	28.45	28.43	28.65	28.42	28.72	28.69	28.72	28.24	28.78	28.75
8	1800 to 1900	27.97	28.15	28.01	27.99	28.19	28.13	28.24	28.22	28.05	27.95	28.02	28.03
9	1900 to 2000	27.42	27.61	27.49	27.45	27.61	27.60	27.68	27.64	27.30	27.43	27.39	27.34
10	2000 to 2100	26.89	27.08	26.92	26.90	27.02	27.09	27.07	27.05	26.68	26.92	26.72	26.70
11	2100 to 2200	26.44	26.62	26.50	26.47	26.55	26.64	26.61	26.58	26.09	26.49	26.14	26.11
12	2200 to 2300	25.97	26.15	26.02	26.00	26.05	26.17	26.12	26.08	25.56	26.03	25.62	25.59
13	2300 to 0000	25.48	25.67	25.52	25.50	25.55	25.70	25.61	25.58	25.08	25.56	25.14	25.11
14	0000 to 0100	25.05	25.22	25.01	25.03	25.10	25.25	25.18	25.14	24.65	25.11	24.71	24.68
15	0100 to 0200	24.67	24.80	24.72	24.70	24.74	24.83	24.80	24.77	24.22	24.72	24.28	24.25
16	0200 to 0300	24.34	24.44	24.40	24.37	24.39	24.47	24.44	24.41	23.89	24.38	23.92	23.91
17	0300 to 0400	24.09	24.19	24.14	24.11	24.12	24.24	24.20	24.16	23.65	24.17	23.70	23.68
18	0400 to 0500	23.87	23.98	23.94	23.91	23.91	24.04	24.00	23.95	23.47	24.00	23.52	23.49
19	0500 to 0600	23.66	23.75	23.72	23.69	23.71	23.81	23.82	23.76	23.31	23.77	23.39	23.35
20	0600 to 0700	23.48	23.59	23.55	23.52	23.53	23.66	23.64	23.58	23.21	23.64	23,27	23.21
21	0700 to 0800	23.33	23.43	23.40	23.37	23.39	23.48	23.45	23.42	23.08	23.44	23.14	23.11
22	0800 to 0900	23.30	23.27	23.40	23.35	23.30	23.28	23.38	23.34	22.94	23.25	23.01	22.98
23	0900 to 1000	23.24	23.10	23.32	23.28	23.30	23.03	23.37	23.34	22.90	23.00	23.00	22.95
24	1000 to 1100	23.30	22.94	23.37	23.34	23.31	22.78	23.36	23.33	23.07	22.75	23.08	23.08

Table B-12 (d): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for part humid and part rainy condition at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	24.14	23.46	24.06	24.10	25.50	24.22	25.61	25.56	25.33	25.33	25.39	25.36	26.46	26.46	26.54	26.50
2	1200 to 1300	25.47	23.86	25.53	25.50	27.53	24.85	27.62	27.57	26.31	26.31	26.38	26.34	28.43	28.43	28.53	28.48
3	1300 to 1400	27.01	24.98	27.10	27.05	28.86	26.04	28.92	28.89	27.59	27.59	27.98	27.79	30.53	30.53	30.90	30.72
4	1400 to 1500	28.29	26.58	28.36	28.33	29.42	27.59	29..5	29.42	29.02	29.02	28.99	29.00	30.86	30.86	30.92	30.89
5	1500 to 1600	29.16	28.61	29.20	29.18	29.41	28.87	29.48	29.45	29.17	29.17	29.29	29.23	30.12	30.12	30.20	30.16
6	1600 to 1700	29.02	28.23	29.02	29.02	28.08	27.99	28.16	28.12	27.69	27.69	27.78	27.74	27.91	27.91	27.98	27.95
7	1700 to 1800	28.32	27.93	28.36	28.34	27.22	27.49	27.28	27.25	26.94	26.94	27.00	26.97	26.78	26.78	26.88	26.83
8	1800 to 1900	27.64	27.61	27.71	27.67	26.64	27.10	26.70	26.67	26.43	26.43	26.55	26.49	25.95	25.95	25.99	25.97
9	1900 to 2000	26.97	27.08	27.01	26.99	25.99	26.57	26.05	26.02	25.88	25.88	25.97	25.93	25.16	25.16	25.26	25.21
10	2000 to 2100	26.38	26.59	26.42	26.40	25.53	26.09	25.60	25.56	25.42	25.42	25.51	25.46	24.73	24.73	24.84	24.79
11	2100 to 2200	25.88	26.17	25.92	25.90	25.16	25.68	25.22	25.19	25.02	25.02	25.00	25.01	24.34	24.34	24.41	24.37
12	2200 to 2300	25.40	25.70	25.37	25.38	24.83	25.21	24.91	24.87	24.54	24.54	24.62	24.58	23.87	23.87	23.93	23.90
13	2300 to 0000	24.98	25.25	25.00	24.99	24.41	24.75	24.50	24.46	24.08	24.08	24.15	24.12	23.42	23.42	23.49	23.45
14	0000 to 0100	24.58	24.82	24.62	24.60	24.08	24.35	24.16	24.12	23.73	23.73	23.81	23.77	23.17	23.17	23.22	23.20
15	0100 to 0200	24.21	24.46	24.28	24.24	23.83	24.07	23.90	23.87	23.53	23.53	23.65	23.59	23.02	23.02	23.00	23.01
16	0200 to 0300	23.94	24.17	24.00	23.97	23.65	23.84	23.70	23.67	23.38	23.38	23.42	23.40	23.00	23.00	23.00	23.00
17	0300 to 0400	23.74	24.00	23.81	23.77	23.51	23.70	23.58	23.55	23.30	23.30	23.35	23.33	23.00	23.00	23.00	23.00
18	0400 to 0500	23.56	23.85	23.61	23.58	23.36	23.59	23.42	23.39	23.22	23.22	23.27	23.24	22.94	22.94	23.00	22.97
19	0500 to 0600	23.39	23.63	23.42	23.40	23.30	23.41	23.36	23.33	23.09	23.09	23.16	23.12	22.80	22.80	22.92	22.86
20	0600 to 0700	23.30	23.51	23.36	23.33	23.22	23.30	23.30	23.26	22.99	22.99	23.00	22.99	22.80	22.80	22.91	22.86
21	0700 to 0800	23.23	23.33	23.38	23.30	23.10	23.14	23.16	23.13	22.87	22.87	22.97	22.92	22.71	22.71	22.80	22.75
22	0800 to 0900	23.11	23.17	23.17	23.14	23.10	23.05	23.15	23.13	22.88	22.88	22.98	22.93	22.87	22.87	22.99	22.93
23	0900 to 1000	23.12	23.01	23.15	23.14	23.22	23.05	23.28	23.25	23.12	23.12	23.17	23.15	23.25	23.25	23.28	23.27
24	1000 to 1100	23.32	22.87	23.40	23.36	23.80	23.13	23.88	23.84	23.53	23.53	23.60	23.57	23.96	23.96	23.96	23.96

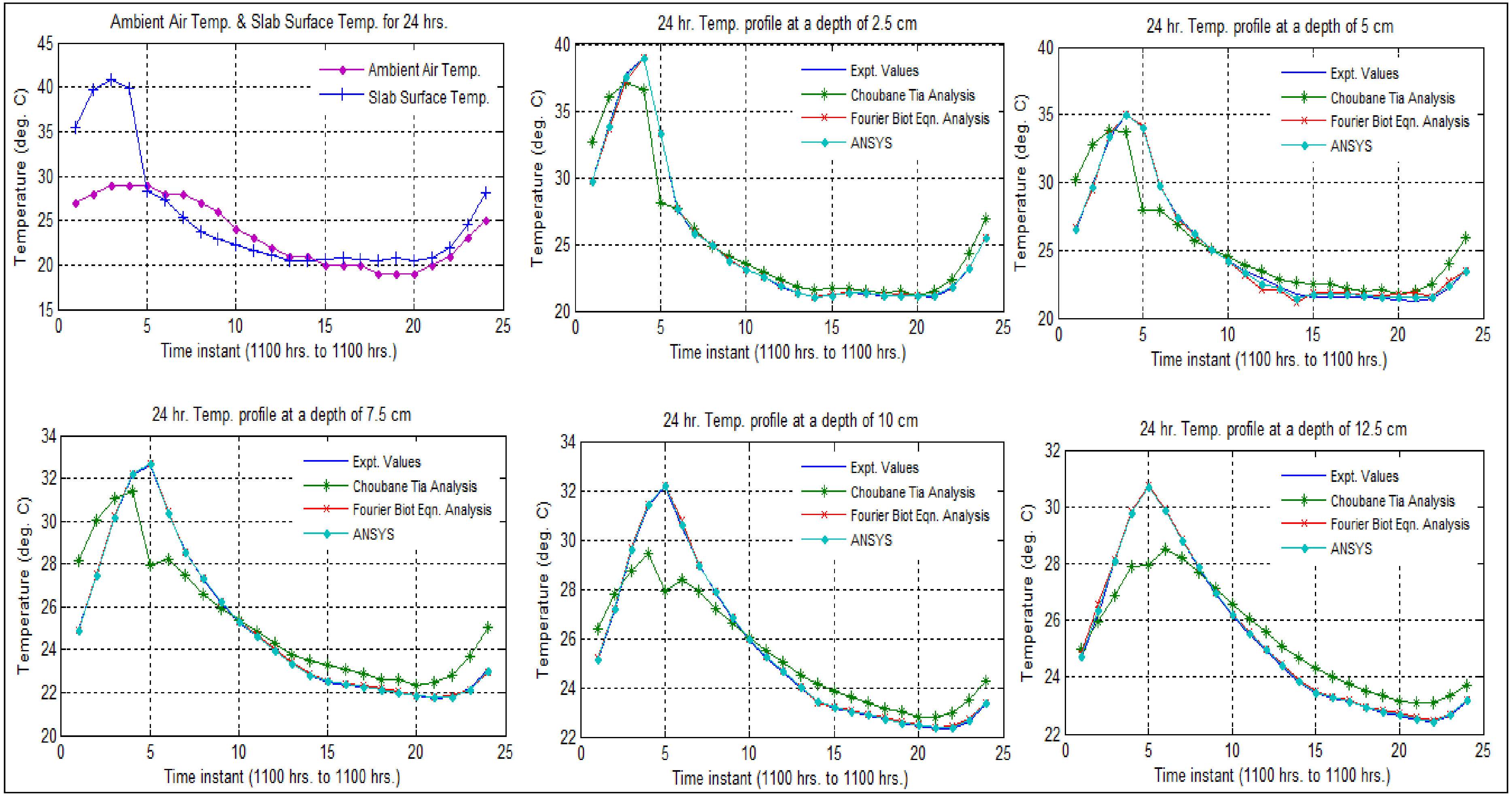


Fig. B-23 (a): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix B for part humid and part rainy condition (surface to 12.5 cm)

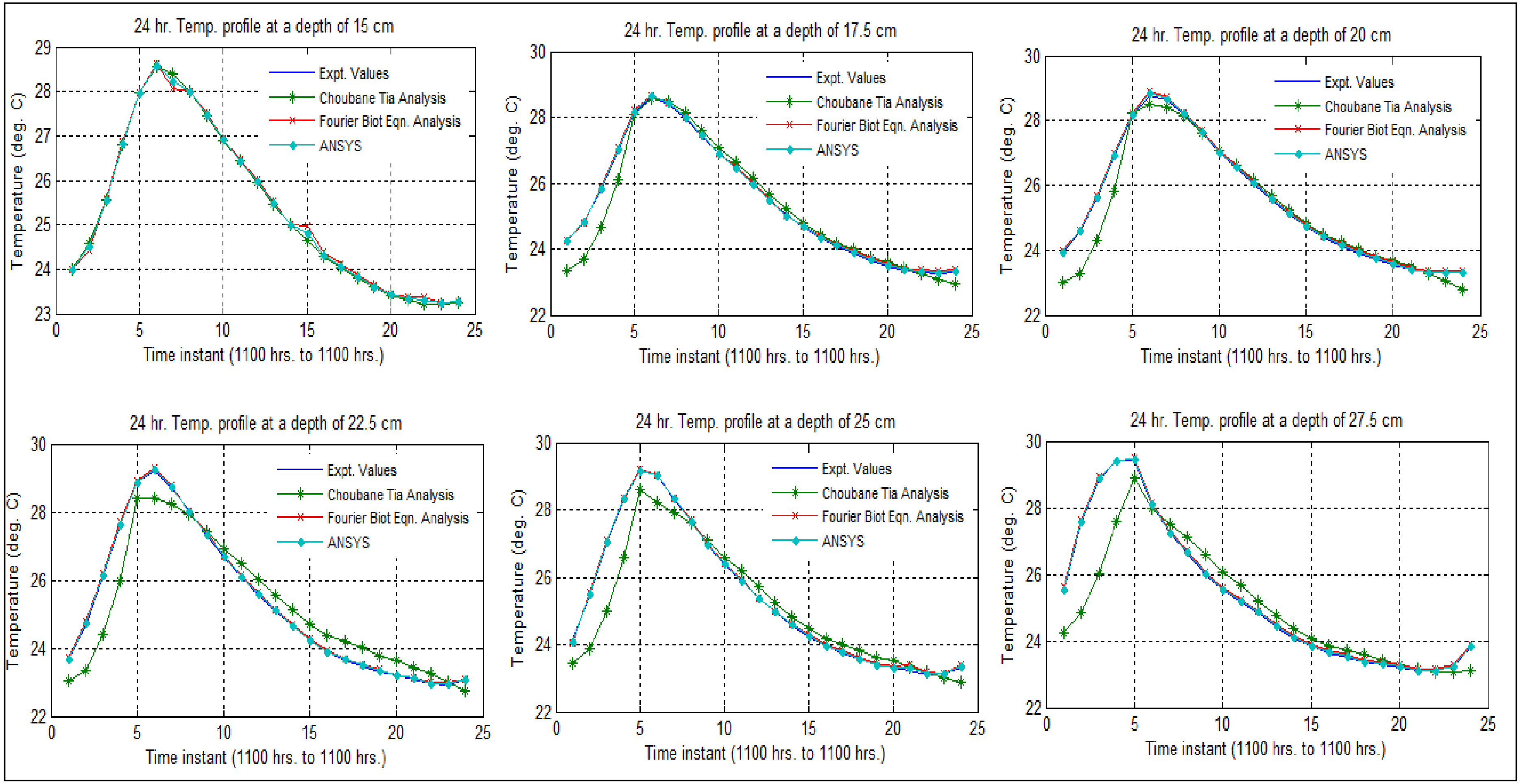


Fig. B-23 (b): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix B for part humid and part rainy condition (15 cm to 12.5 cm)

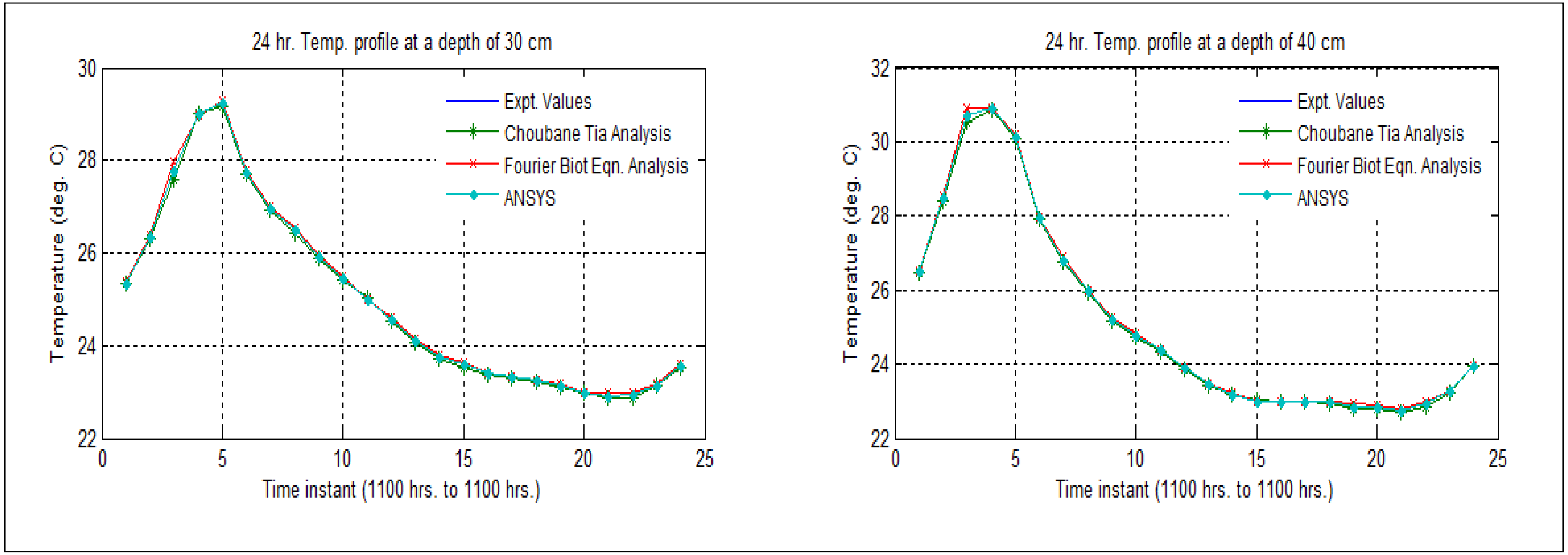


Fig. B-23 (c): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix B for part humid and part rainy condition (30 cm & 40 cm)

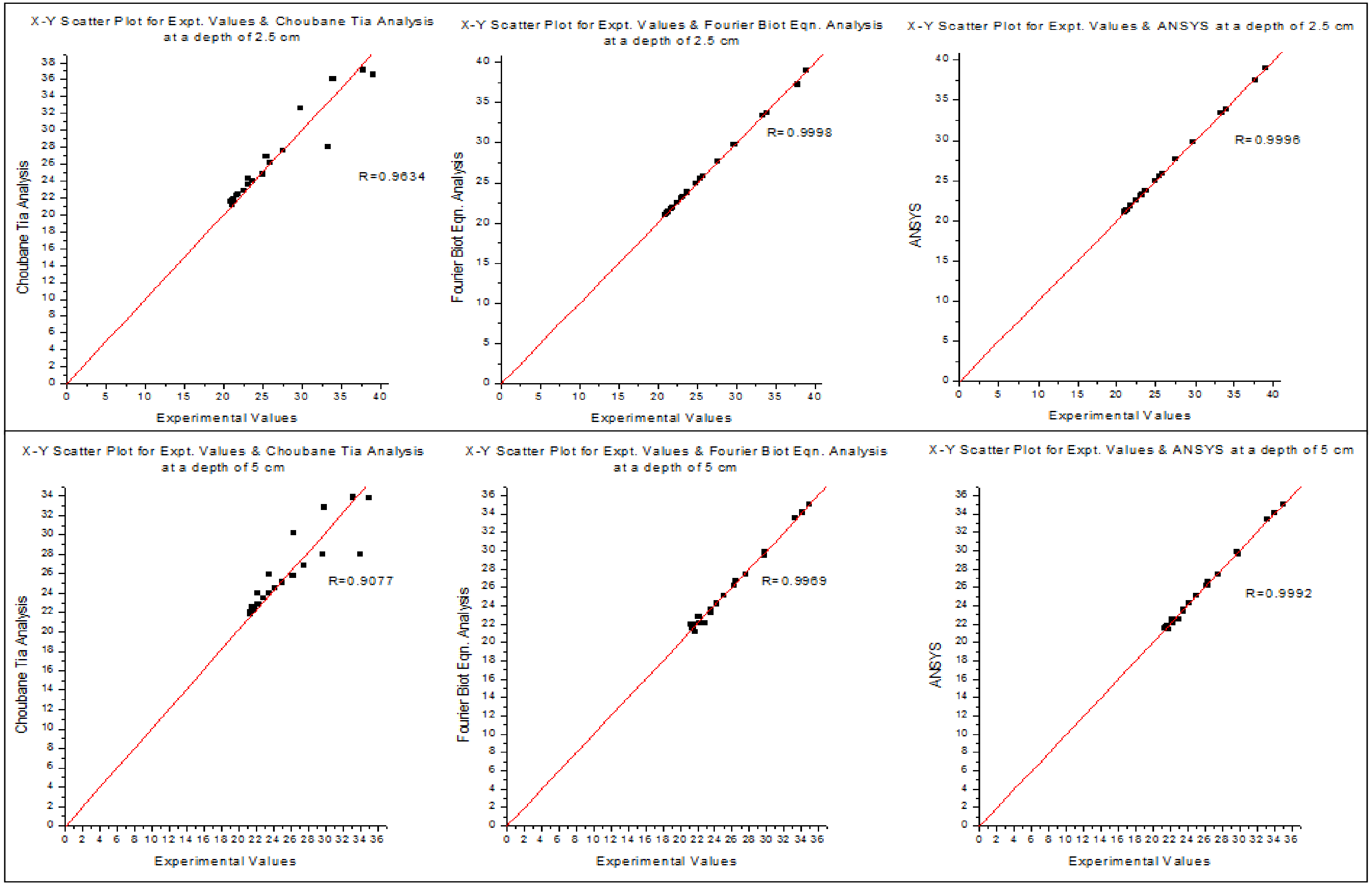


Fig. B-24 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

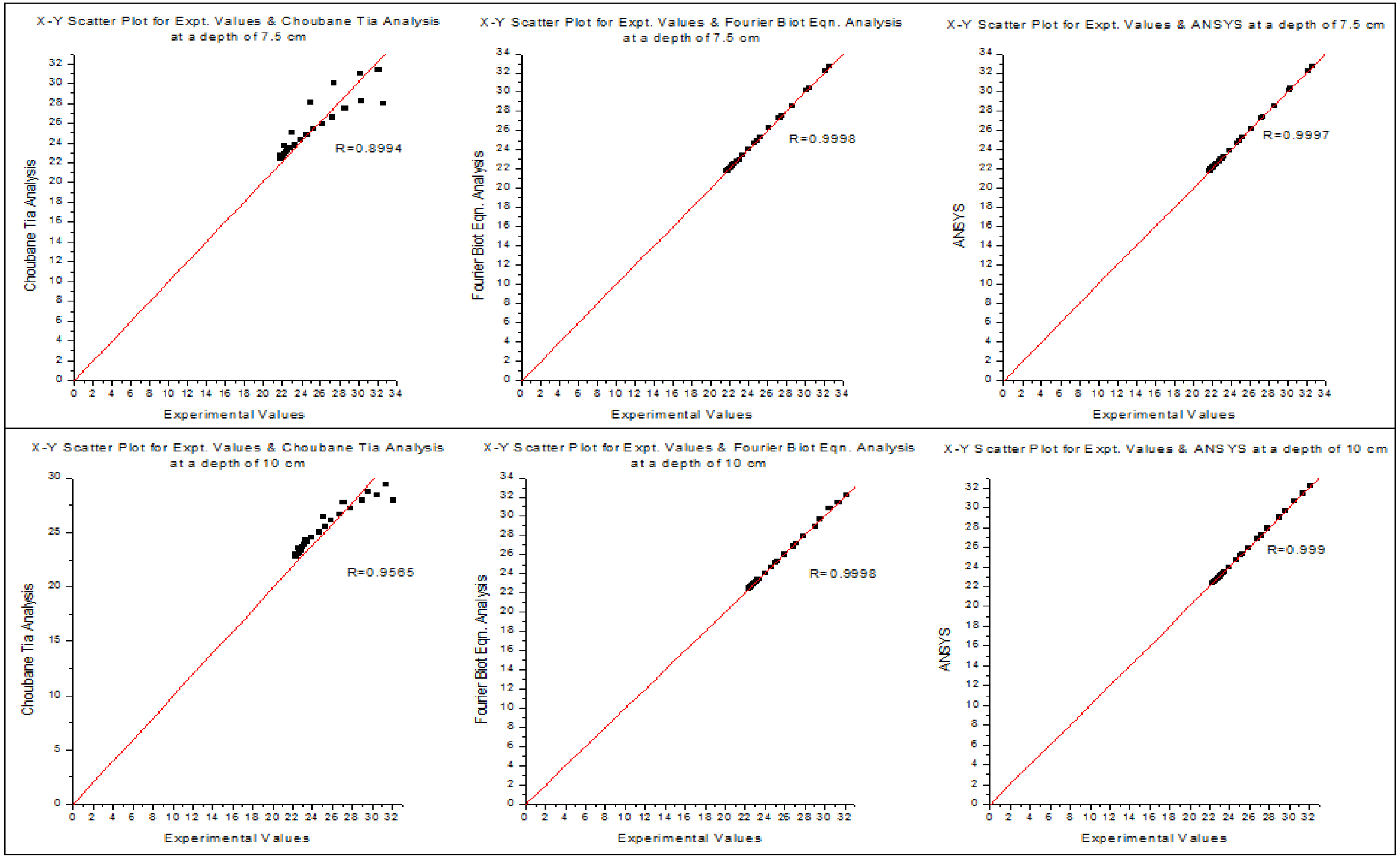


Fig. B-24 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

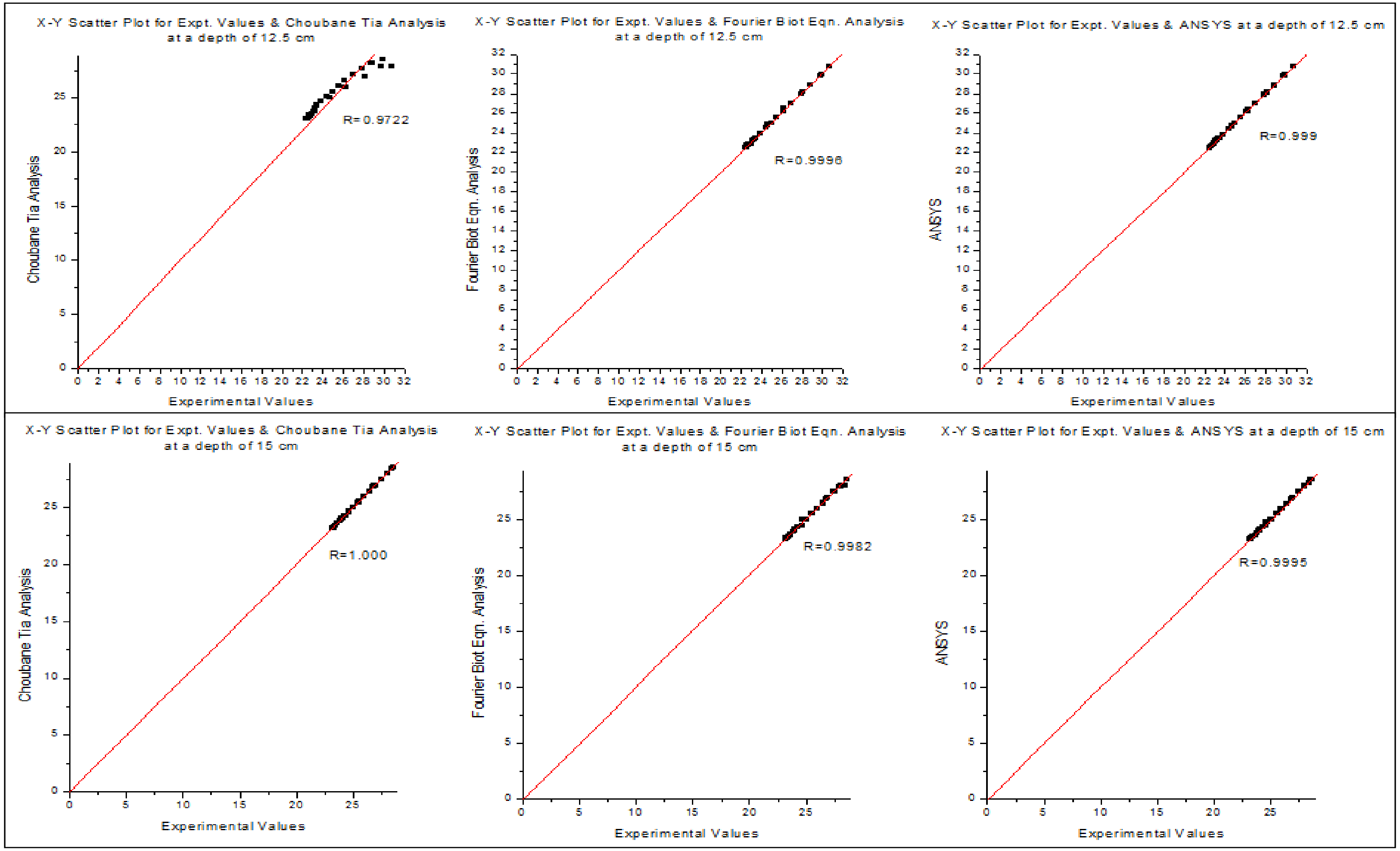


Fig. B-24 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

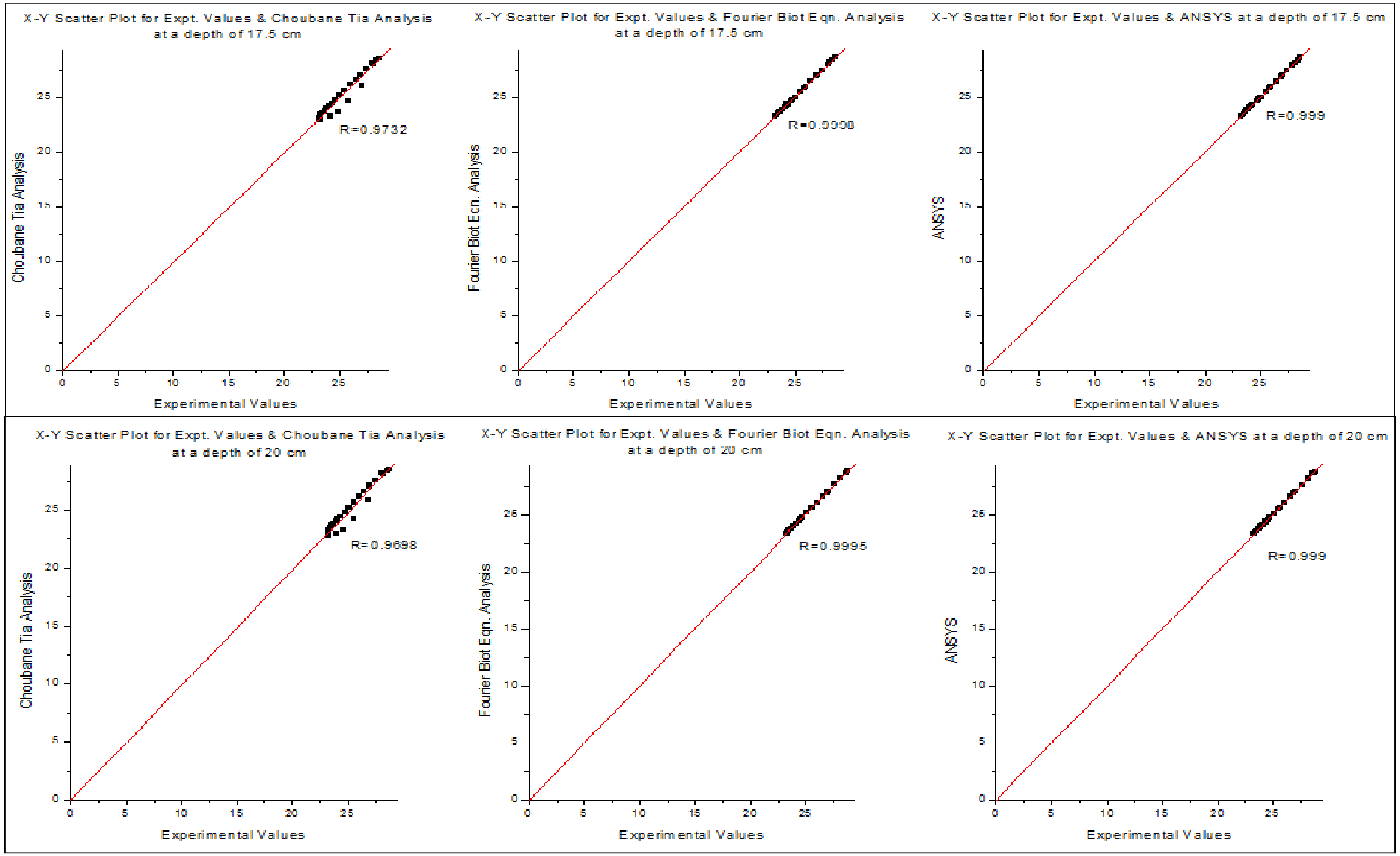


Fig. B-24 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

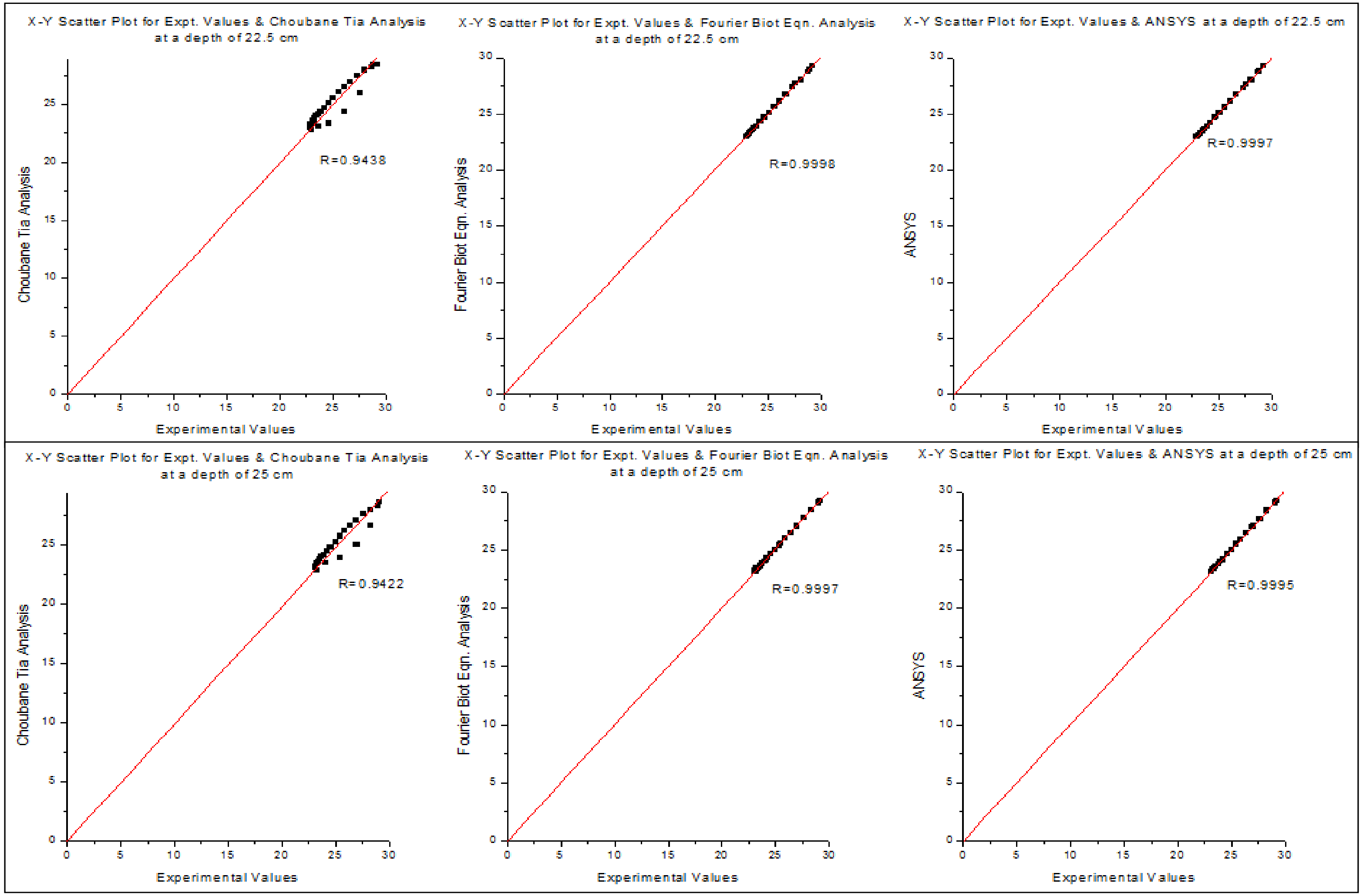


Fig. B-24 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

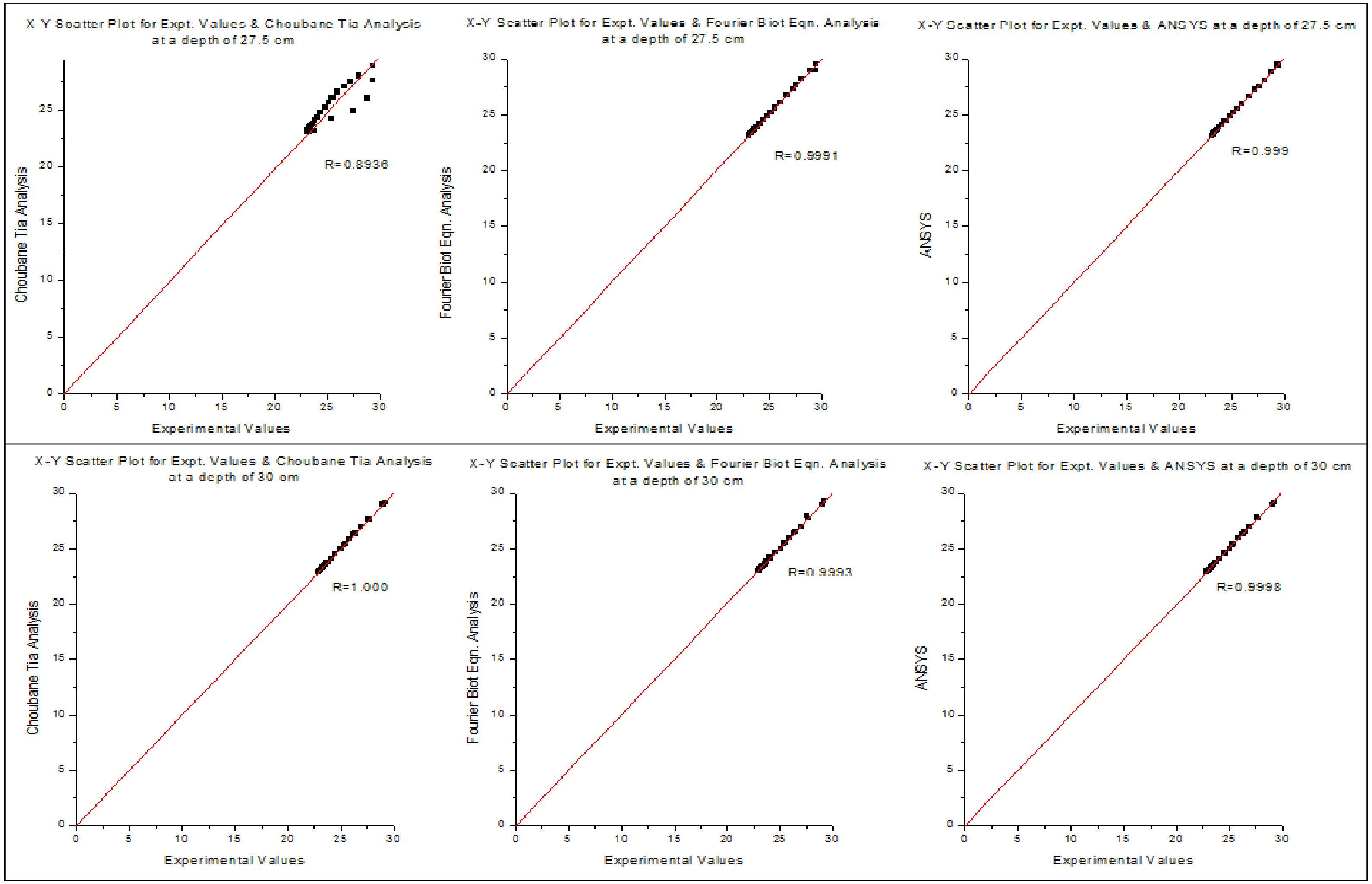


Fig. B-24 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

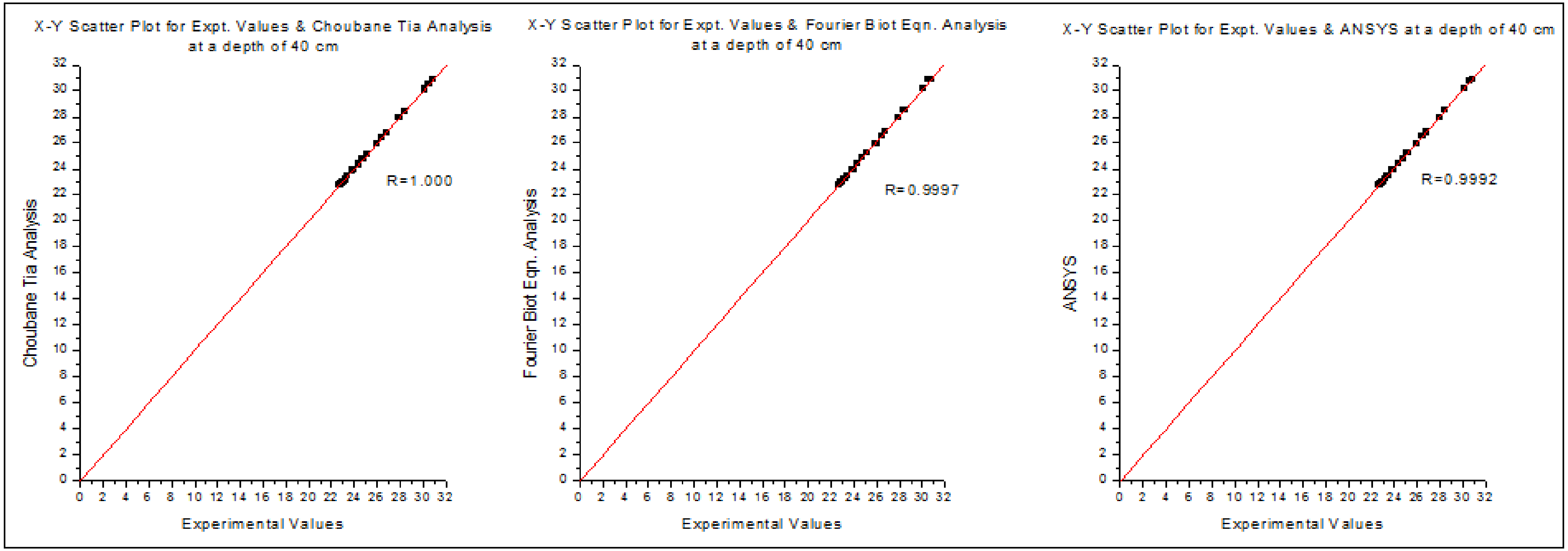


Fig. B-24 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-13 (a): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for 24 hr. cloudy and humid condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	27	31.19	26.77	29.40	26.52	26.64	25.54	27.84	25.58	25.56	24.64	26.49	24.29	24.46
2	1130 to 1230	29	37.15	28.72	34.17	28.25	28.48	27.45	31.55	27.78	27.61	26.11	29.28	26.07	26.09
3	1230 to 1330	31	39.82	31.09	36.48	31.17	31.13	29.87	33.54	29.35	29.61	28.07	30.99	28.14	28.10
4	1330 to 1430	31	38.50	31.77	35.81	31.65	31.71	31.13	33.43	31.75	31.44	29.54	31.36	29.70	29.62
5	1430 to 1530	31	39.81	32.44	37.05	32.61	32.53	31.94	34.61	32.02	31.98	30.43	32.47	30.36	30.40
6	1530 to 1630	31	37.16	32.46	35.24	32.38	32.42	32.21	33.51	32.49	32.35	30.94	31.99	31.02	30.98
7	1630 to 1730	29	32.82	31.57	32.01	31.69	31.63	31.55	31.26	31.64	31.59	30.83	30.60	30.90	30.86
8	1730 to 1830	28	28.04	29.45	28.35	29.78	29.62	29.85	28.60	29.93	29.89	29.90	28.78	29.80	29.85
9	1830 to 1930	27	25.67	27.33	26.42	27.47	27.40	28.00	27.06	28.09	28.04	28.56	27.60	28.61	28.58
10	1930 to 2030	26	24.69	25.90	25.49	25.97	25.94	26.64	26.18	26.78	26.71	27.38	26.77	27.42	27.40
11	2030 to 2130	25	23.78	25.04	24.63	25.13	25.09	25.69	25.38	25.76	25.72	26.60	26.02	26.71	26.66
12	2130 to 2230	24	22.93	24.22	23.86	24.23	24.22	24.87	24.67	24.96	24.91	25.82	25.38	25.90	25.86
13	2230 to 2330	24	22.24	23.51	23.20	23.40	23.45	24.13	24.05	24.27	24.20	25.12	24.78	25.18	25.15
14	2330 to 0030	24	21.52	22.97	22.53	23.02	23.00	23.48	23.41	23.37	23.43	24.58	24.19	24.24	24.41
15	0030 to 0130	24	21.17	22.41	22.15	22.62	22.51	23.02	23.01	23.08	23.05	24.03	23.76	24.18	24.11
16	0130 to 0230	23	20.92	22.04	21.86	22.47	22.25	22.61	22.70	22.32	22.46	23.59	23.43	23.65	23.62
17	0230 to 0330	20	21.23	21.88	22.02	21.80	21.84	22.36	22.73	22.44	22.40	23.33	23.34	23.41	23.37
18	0330 to 0430	20	20.77	21.75	21.60	21.88	21.81	22.19	22.34	22.15	22.17	23.18	22.98	23.24	23.21
19	0430 to 0530	20	19.76	21.38	20.75	21.45	21.41	21.78	21.64	21.83	21.80	22.83	22.41	22.91	22.87
20	0530 to 0630	20	19.53	20.84	20.48	20.93	20.88	21.35	21.34	21.48	21.41	22.35	22.09	22.46	22.41
21	0630 to 0730	21	20.60	20.84	21.23	20.92	20.88	21.25	21.79	21.34	21.29	22.13	22.28	22.11	22.12
22	0730 to 0830	21	22.34	21.26	22.54	21.34	21.30	21.50	22.72	21.46	21.48	22.17	22.88	22.28	22.23
23	0830 to 0930	22	25.00	22.42	24.57	22.43	22.43	22.26	24.19	22.38	22.32	22.62	23.88	22.55	22.58
24	0930 to 1030	24	28.11	23.50	26.94	23.63	23.57	23.08	25.93	23.00	23.04	23.12	25.06	23.22	23.17

Table B-13 (b): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for 24 hr. cloudy and humid condition at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (ºC) at 10 cm				Temperature (ºC) at 12.5 cm				Temperature (ºC) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	24.43	25.36	24.73	24.58	24.11	24.44	24.78	24.44	23.75	23.75	23.99	23.87
2	1130 to 1230	25.72	27.38	25.23	25.47	25.15	25.83	25.10	25.13	24.64	24.64	24.77	24.71
3	1230 to 1330	27.50	28.85	27.30	27.40	26.59	27.10	26.79	26.69	25.76	25.76	25.86	25.81
4	1330 to 1430	28.93	29.60	28.63	28.78	27.99	28.15	28.06	28.02	27.01	27.01	27.12	27.06
5	1430 to 1530	29.84	30.64	29.92	29.88	28.87	29.12	28.95	28.91	27.91	27.91	28.00	27.96
6	1530 to 1630	30.49	30.67	30.69	30.59	29.56	29.56	29.75	29.66	28.65	28.65	28.98	28.81
7	1630 to 1730	30.48	30.00	30.72	30.60	29.80	29.47	29.92	29.86	29.01	29.01	29.06	29.04
8	1730 to 1830	29.72	28.92	29.51	29.61	29.50	28.99	29.65	29.58	29.00	29.00	29.10	29.05
9	1830 to 1930	28.57	28.03	28.63	28.60	28.72	28.36	28.69	28.70	28.58	28.58	28.65	28.61
10	1930 to 2030	27.53	27.25	27.48	27.51	27.88	27.63	27.95	27.91	27.91	27.91	28.00	27.95
11	2030 to 2130	26.79	26.55	26.87	26.83	27.16	26.99	27.24	27.20	27.31	27.31	27.38	27.35
12	2130 to 2230	26.07	25.98	26.07	26.07	26.62	26.46	26.74	26.68	26.83	26.83	26.92	26.88
13	2230 to 2330	25.39	25.41	25.11	25.25	26.00	25.91	26.07	26.04	26.31	26.31	26.40	26.36
14	2330 to 0030	24.89	24.84	24.76	24.82	25.46	25.38	25.51	25.49	25.81	25.81	25.86	25.83
15	0030 to 0130	24.38	24.41	24.45	24.42	25.02	24.94	25.10	25.06	25.36	25.36	25.46	25.41
16	0130 to 0230	23.96	24.06	24.03	23.99	24.63	24.58	24.72	24.68	24.99	24.99	25.05	25.02
17	0230 to 0330	23.63	23.87	23.94	23.78	24.29	24.32	24.36	24.32	24.67	24.67	24.74	24.71
18	0330 to 0430	23.39	23.54	23.46	23.43	24.02	24.00	23.98	24.00	24.38	24.38	24.43	24.40
19	0430 to 0530	23.16	23.08	23.22	23.19	23.74	23.63	23.81	23.77	24.08	24.08	24.11	24.10
20	0530 to 0630	22.73	22.74	22.44	22.59	23.35	23.29	23.42	23.39	23.73	23.73	23,81	23.73
21	0630 to 0730	22.45	22.72	22.07	22.26	23.10	23.09	23.15	23.12	23.40	23.40	23.51	23.46
22	0730 to 0830	22.43	23.03	22.19	22.31	23.00	23.17	23.12	23.06	23.30	23.30	23.37	23.33
23	0830 to 0930	22.80	23.63	22.69	22.74	23.12	23.43	23.22	23.17	23.30	23.30	23.36	23.33
24	0930 to 1030	23.19	24.34	23.08	23.13	23.30	23.76	23.35	23.32	23.33	23.33	23.40	23.36

Table B-13 (c): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for 24 hr. cloudy and humid condition at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	23.71	23.27	23.76	23.74	23.58	23.01	23.65	23.61	23.57	22.97	23.62	23.60
2	1130 to 1230	24.43	23.81	24.47	24.45	24.14	23.34	24.19	24.16	24.17	23.23	24.14	24.16
3	1230 to 1330	25.32	24.81	25.39	25.35	24.85	24.27	24.89	24.87	24.92	24.12	25.01	24.96
4	1330 to 1430	26.37	26.18	26.45	26.41	25.68	25.66	25.73	25.71	25.80	25.45	25.86	25.83
5	1430 to 1530	27.14	27.01	27.21	27.18	26.52	26.41	26.61	26.57	26.68	26.13	26.75	26.71
6	1530 to 1630	27.85	27.95	27.91	27.88	27.17	27.44	27.25	27.21	27.37	27.14	27.42	27.40
7	1630 to 1730	28.36	28.63	28.36	28.36	27.77	28.31	27.86	27.81	27.91	28.07	27.98	27.94
8	1730 to 1830	28.60	28.96	28.66	28.63	28.14	28.85	28.22	28.18	28.18	28.69	28.22	28.20
9	1830 to 1930	28.35	28.69	28.43	28.39	28.11	28.70	28.17	28.14	28.10	28.61	28.16	28.13
10	1930 to 2030	27.90	28.08	27.96	27.93	27.85	28.15	27.91	27.88	27.80	28.11	27.86	27.83
11	2030 to 2130	27.43	27.53	27.48	27.46	27.48	27.64	27.51	27.50	27.43	27.65	27.48	27.45
12	2130 to 2230	27.01	27.09	27.01	27.01	27.11	27.24	27.19	27.15	27.04	27.28	27.00	27.02
13	2230 to 2330	26.61	26.60	26.66	26.63	26.79	26.77	26.82	26.81	26.72	26.83	26.78	26.75
14	2330 to 0030	26.15	26.12	26.18	26.17	26.40	26.31	26.45	26.42	26.31	26.39	26.35	26.33
15	0030 to 0130	25.75	25.67	25.81	25.78	26.03	25.87	26.02	26.02	25.93	25.96	26.01	25.97
16	0130 to 0230	25.34	25.30	25.43	25.39	25.65	25.50	25.71	25.68	25.54	25.60	25.57	25.55
17	0230 to 0330	25.03	24.94	24.99	25.01	25.29	25.12	25.32	25.30	25.19	25.21	25.20	25.20
18	0330 to 0430	24.76	24.66	24.81	24.78	25.02	24.85	25.00	25.01	24.94	24.95	25.00	24.97
19	0430 to 0530	24.49	24.42	24.52	24.51	24.78	24.65	24.83	24.80	24.69	24.77	24.72	24.70
20	0530 to 0630	24.15	24.06	24.20	24.18	24.47	24.30	24.51	24.49	24.35	24.43	24.41	24.38
21	0630 to 0730	23.83	23.65	23.91	23.87	24.16	23.84	24.21	24.19	24.05	23.96	24.00	24.03
22	0730 to 0830	23.58	23.41	23.64	23.61	23.89	23.51	23.95	23.92	23.79	23.59	23.81	23.80
23	0830 to 0930	23.50	23.22	23.55	23.53	23.73	23.21	23.79	23.76	23.70	23.25	23.74	23.72
24	0930 to 1030	23.51	23.05	23.57	23.54	23.70	22.91	23.77	23.74	23.70	22.92	23.72	23.71

Table B-13 (d): 24 hr. slab (edge) temperature values (measured and calculated) for Mix B for 24 hr. cloudy and humid condition at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	23.78	23.15	23.86	23.82	24.50	23.54	24.54	24.52	24.16	24.16	24.23	24.19	24.89	24.89	24.80	24.85
2	1130 to 1230	24.53	23.48	24.57	24.55	25.54	24.08	25.62	25.58	25.05	25.05	24.99	25.02	26.70	26.70	26.77	26.73
3	1230 to 1330	25.38	24.37	25.44	25.41	26.88	25.03	26.92	26.90	26.08	26.08	26.15	26.12	29.00	29.00	28.96	28.98
4	1330 to 1430	26.50	25.55	26.58	26.54	28.46	25.97	28.52	28.49	26.69	26.69	26.74	26.72	29.75	29.75	29.74	29.74
5	1430 to 1530	27.39	26.15	27.44	27.42	29.27	26.48	29.32	29.30	27.12	27.12	27.15	27.13	29.15	29.15	29.20	29.17
6	1530 to 1630	28.05	27.05	28.06	28.06	28.92	27.15	29.01	28.97	27.47	27.47	27.52	27.49	28.79	28.79	28.81	28.80
7	1630 to 1730	28.33	27.90	28.40	28.37	28.69	27.80	28.76	28.73	27.77	27.77	27.83	27.80	28.61	28.61	28.68	28.65
8	1730 to 1830	28.37	28.47	28.41	28.39	28.24	28.19	28.30	28.27	27.86	27.86	27.91	27.88	28.00	28.00	27.96	27.98
9	1830 to 1930	28.10	28.41	28.17	28.14	27.58	28.10	27.63	27.61	27.69	27.69	27.73	27.71	27.15	27.15	27.19	27.17
10	1930 to 2030	27.66	27.97	27.70	27.68	27.01	27.73	27.00	27.01	27.38	27.38	27.42	27.40	26.50	26.50	26.54	26.52
11	2030 to 2130	27.22	27.55	27.30	27.26	26.60	27.35	26.66	26.63	27.04	27.04	27.07	27.06	25.95	25.95	26.00	25.98
12	2130 to 2230	26.87	27.20	26.92	26.89	26.09	27.01	26.14	26.12	26.71	26.71	26.78	26.75	25.44	25.44	25.48	25.46
13	2230 to 2330	26.46	26.77	26.51	26.48	25.59	26.60	25.65	25.62	26.32	26.32	26.40	26.36	25.01	25.01	25.00	25.01
14	2330 to 0030	26.01	26.35	26.00	26.00	25.15	26.20	25.20	25.17	25.93	25.93	26.00	25.96	24.64	24.64	24.59	24.61
15	0030 to 0130	25.61	25.94	25.65	25.63	24.84	25.81	24.90	24.87	25.56	25.56	25.61	25.59	24.27	24.27	24.32	24.29
16	0130 to 0230	25.25	25.59	25.32	25.28	24.50	25.47	24.58	24.54	25.26	25.26	25.30	25.28	23.99	23.99	23.99	23.99
17	0230 to 0330	24.96	25.21	25.00	24.98	24.19	25.13	24.22	24.21	24.95	24.95	25.00	24.98	23.80	23.80	23.80	23.80
18	0330 to 0430	24.65	24.96	24.71	24.68	23.85	24.88	23.91	23.88	24.70	24.70	24.76	24.73	23.62	23.62	23.66	23.64
19	0430 to 0530	24.36	24.78	24.40	24.38	23.48	24.68	23.52	23.50	24.48	24.48	24.52	24.50	23.32	23.32	23.34	23.33
20	0530 to 0630	24.02	24.46	24.00	24.01	23.21	24.38	23.26	23.24	24.20	24.20	24.24	24.22	23.02	23.02	23.00	23.01
21	0630 to 0730	23.73	24.02	23.80	23.76	23.04	24.02	23.00	23.02	23.96	23.96	24.00	23.98	22.94	22.94	22.99	22.97
22	0730 to 0830	23.54	23.66	23.60	23.57	23.07	23.72	23.06	23.07	23.77	23.77	23.80	23.78	23.09	23.09	23.24	23.17
23	0830 to 0930	23.51	23.35	23.57	23.54	23.35	23.52	23.38	23.36	23.74	23.74	23.78	23.76	23.49	23.49	23.53	23.51
24	0930 to 1030	23.60	23.07	23.65	23.63	23.58	23.38	23.61	23.60	23.83	23.83	23.86	23.84	23.93	23.93	23.95	23.94

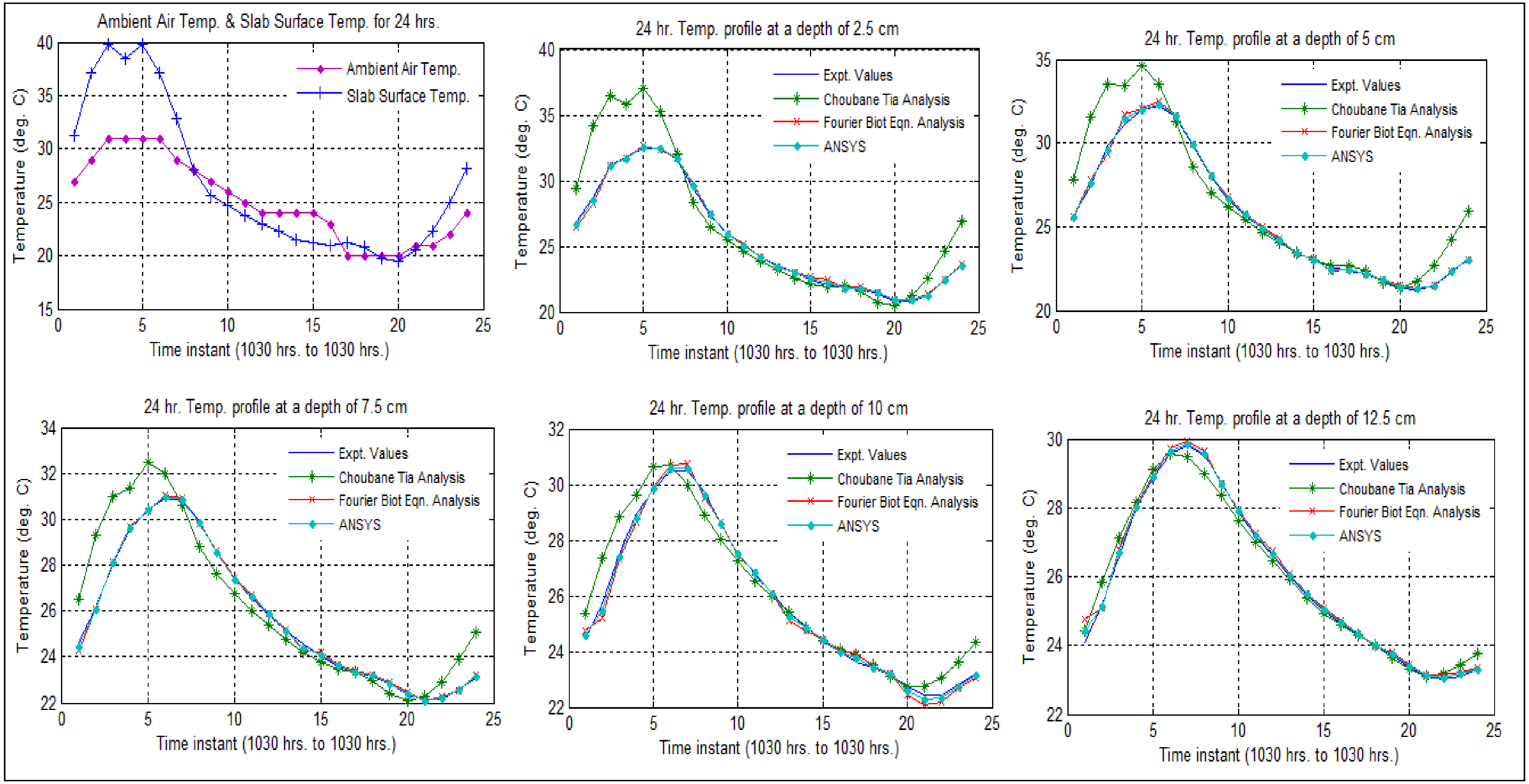


Fig. B-25 (a): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix B for 24 hr. cloudy and humid condition (surface to 12.5 cm)

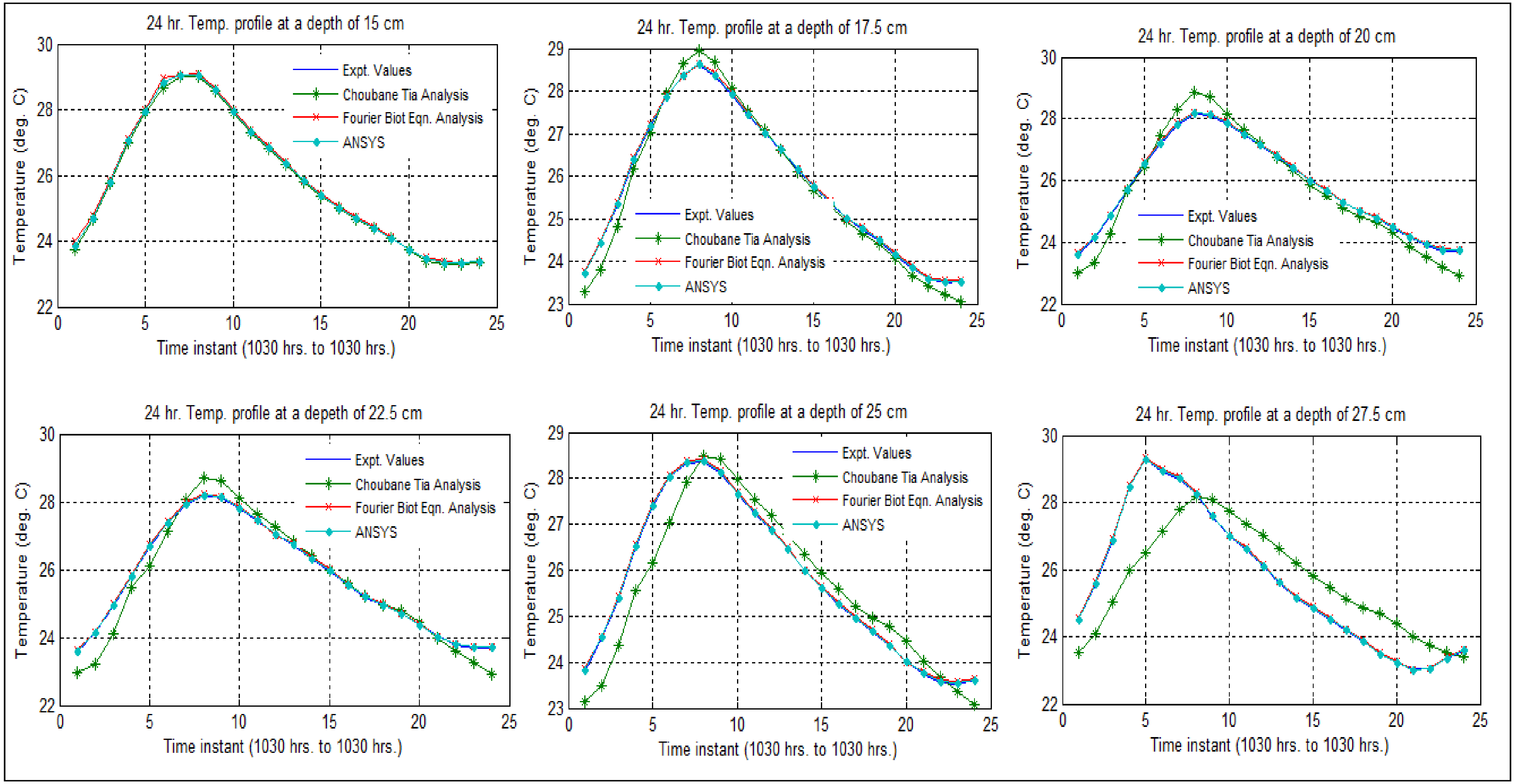


Fig. B-25 (b): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix B for 24 hr. cloudy and humid condition (15 cm to 27.5 cm)

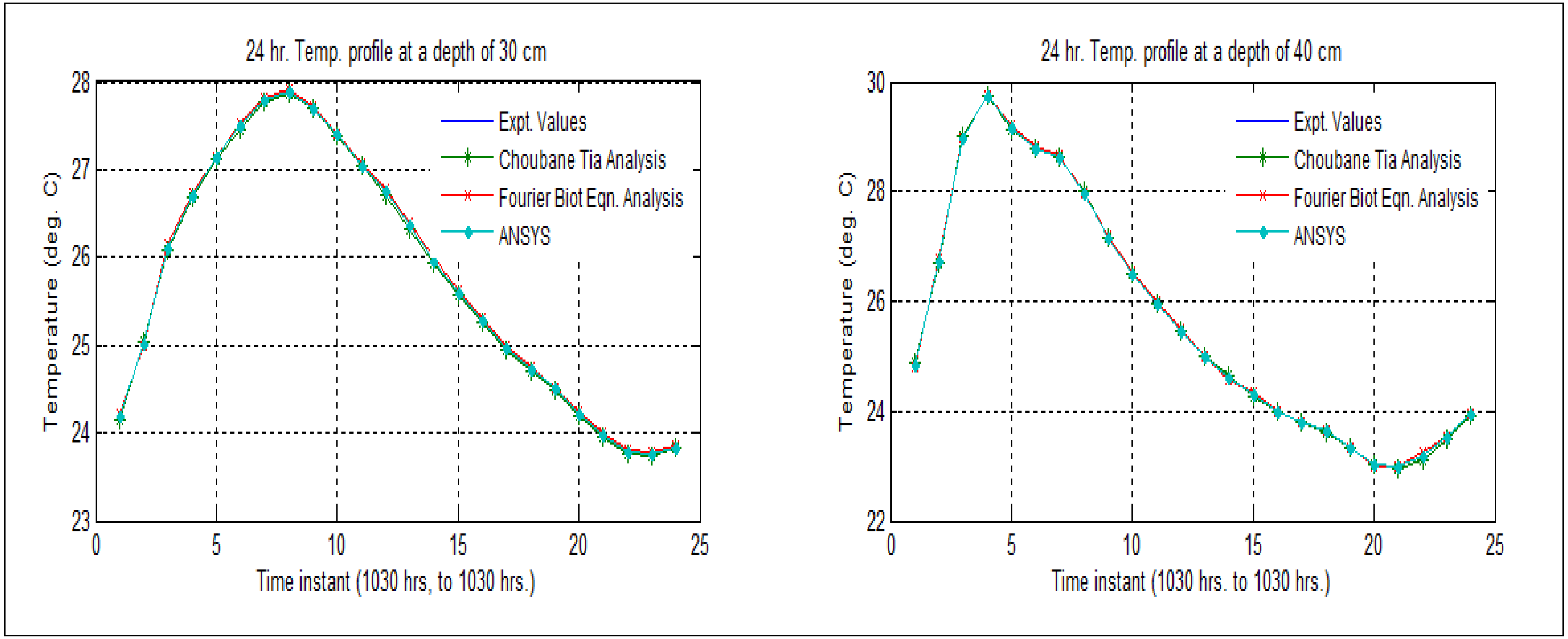


Fig. B-25 (c): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix B for 24 hr. cloudy and humid condition (30 cm to 40 cm)

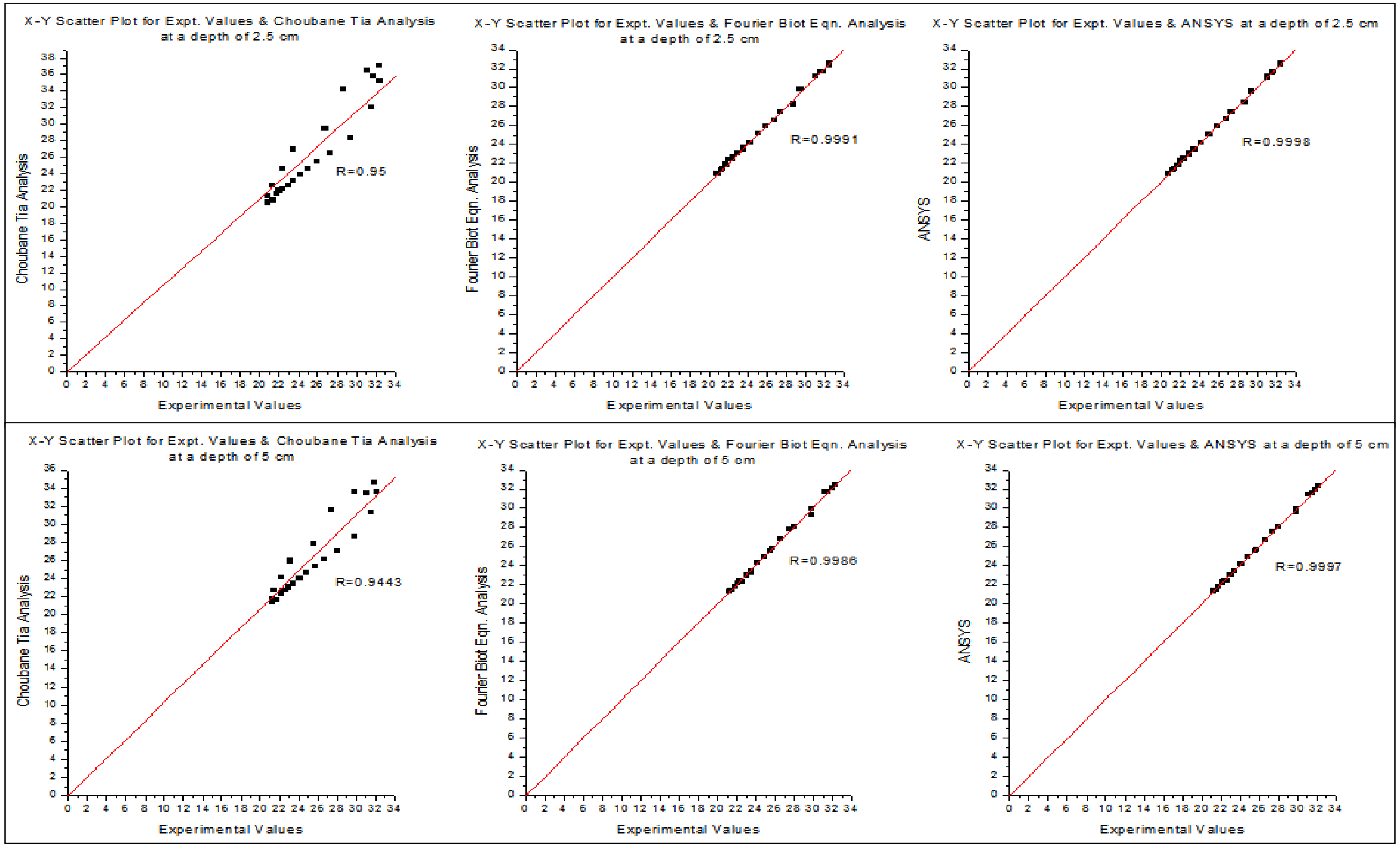


Fig. B-26 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

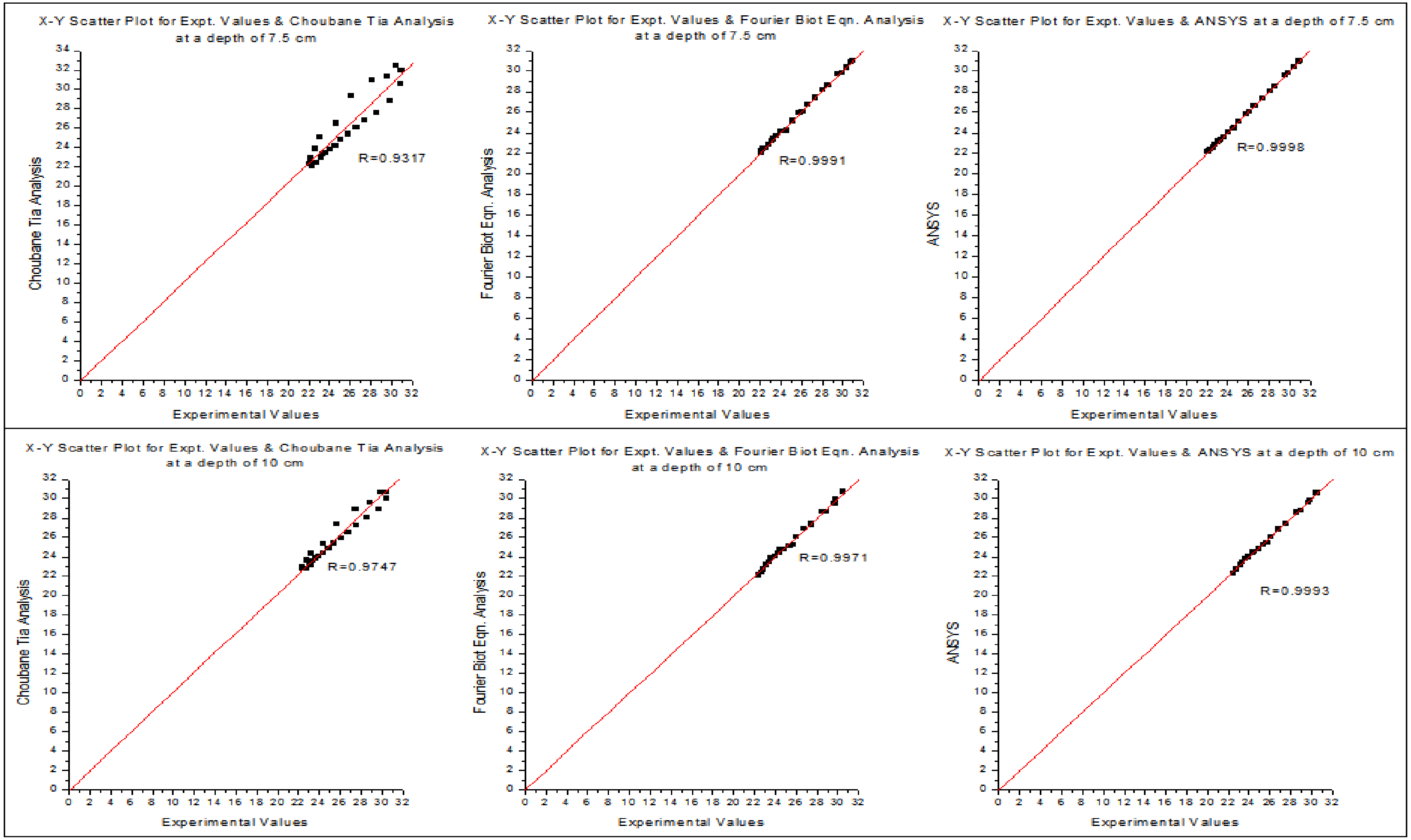


Fig. B-26 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

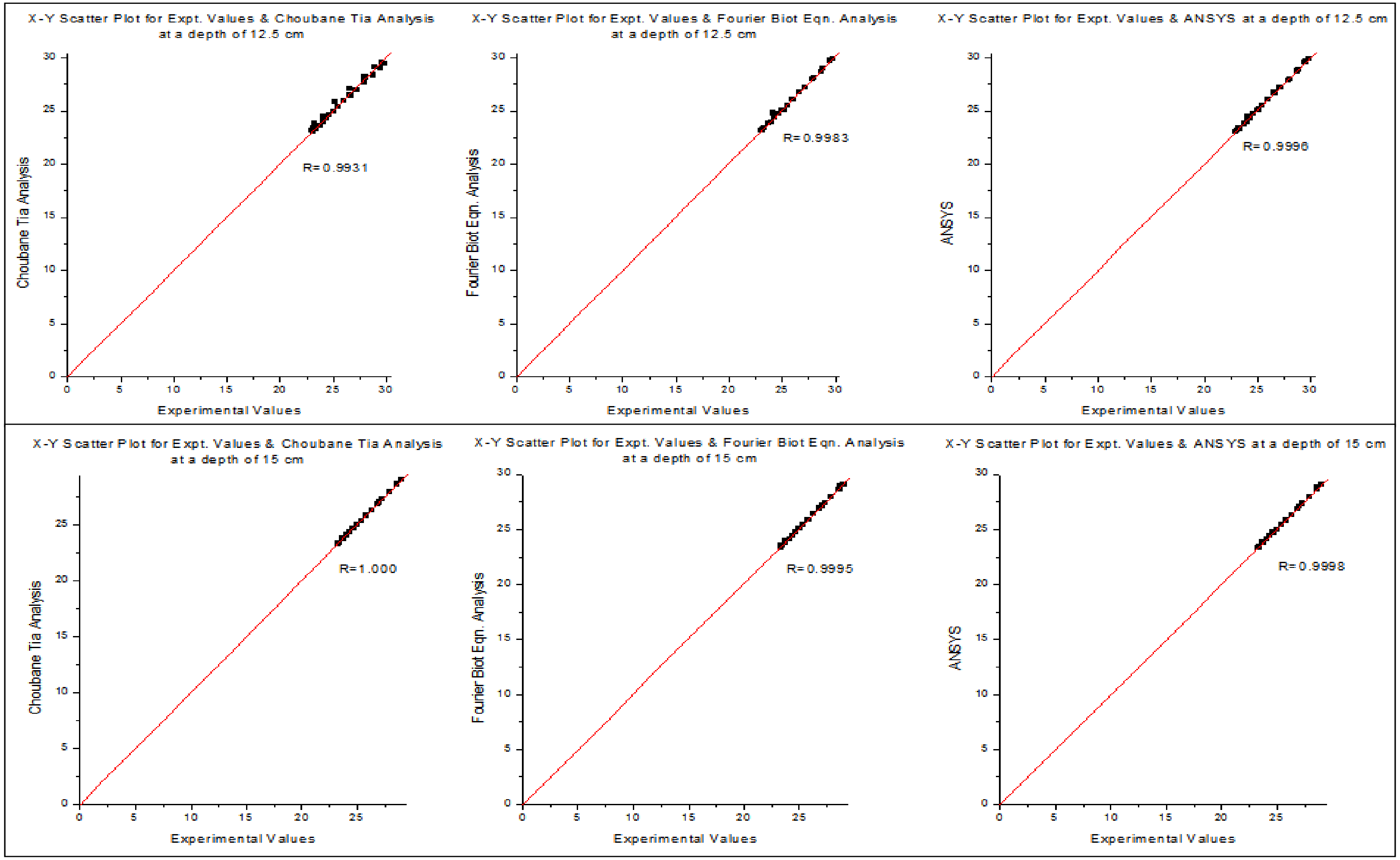


Fig. B-26 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

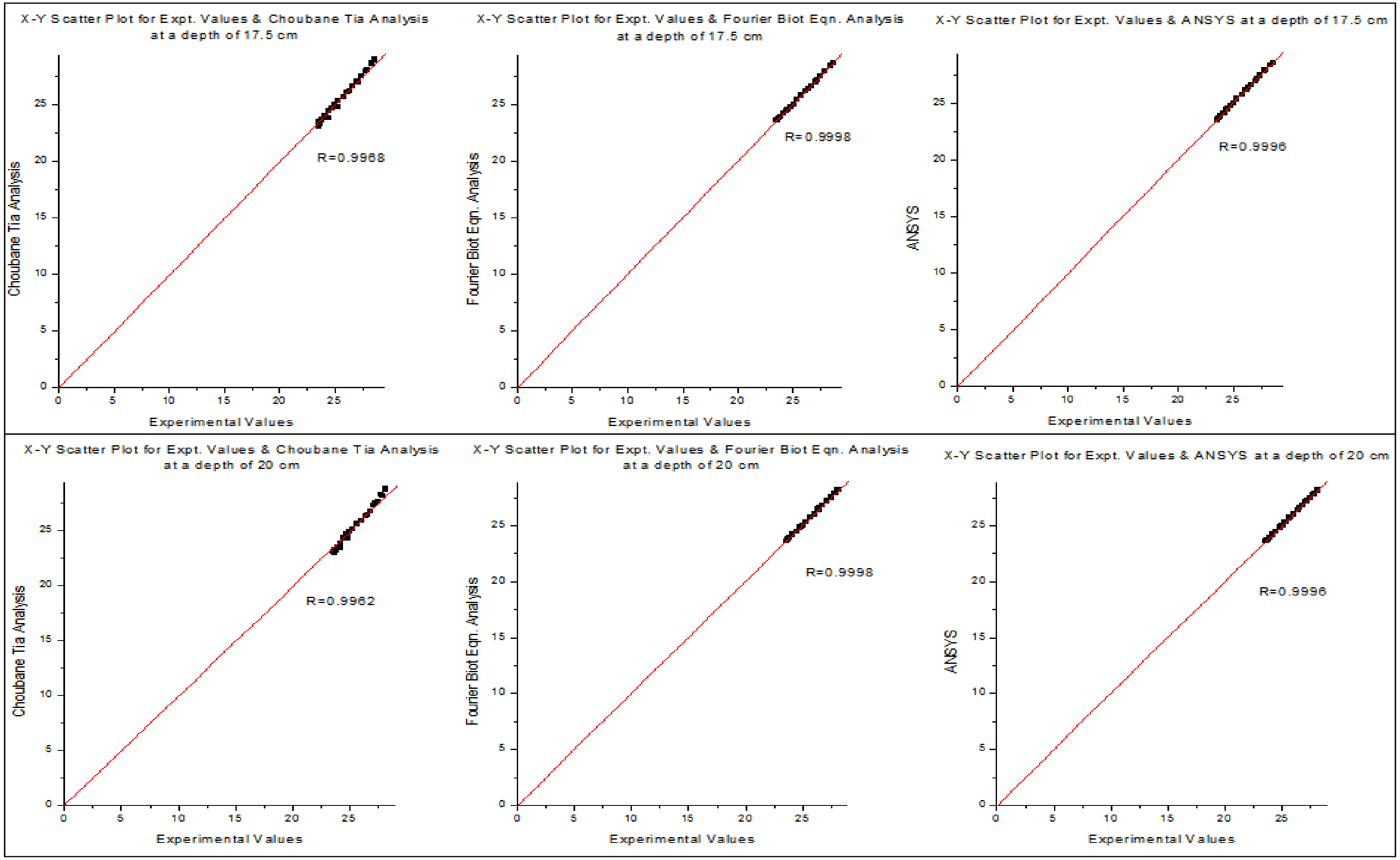


Fig. B-26 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

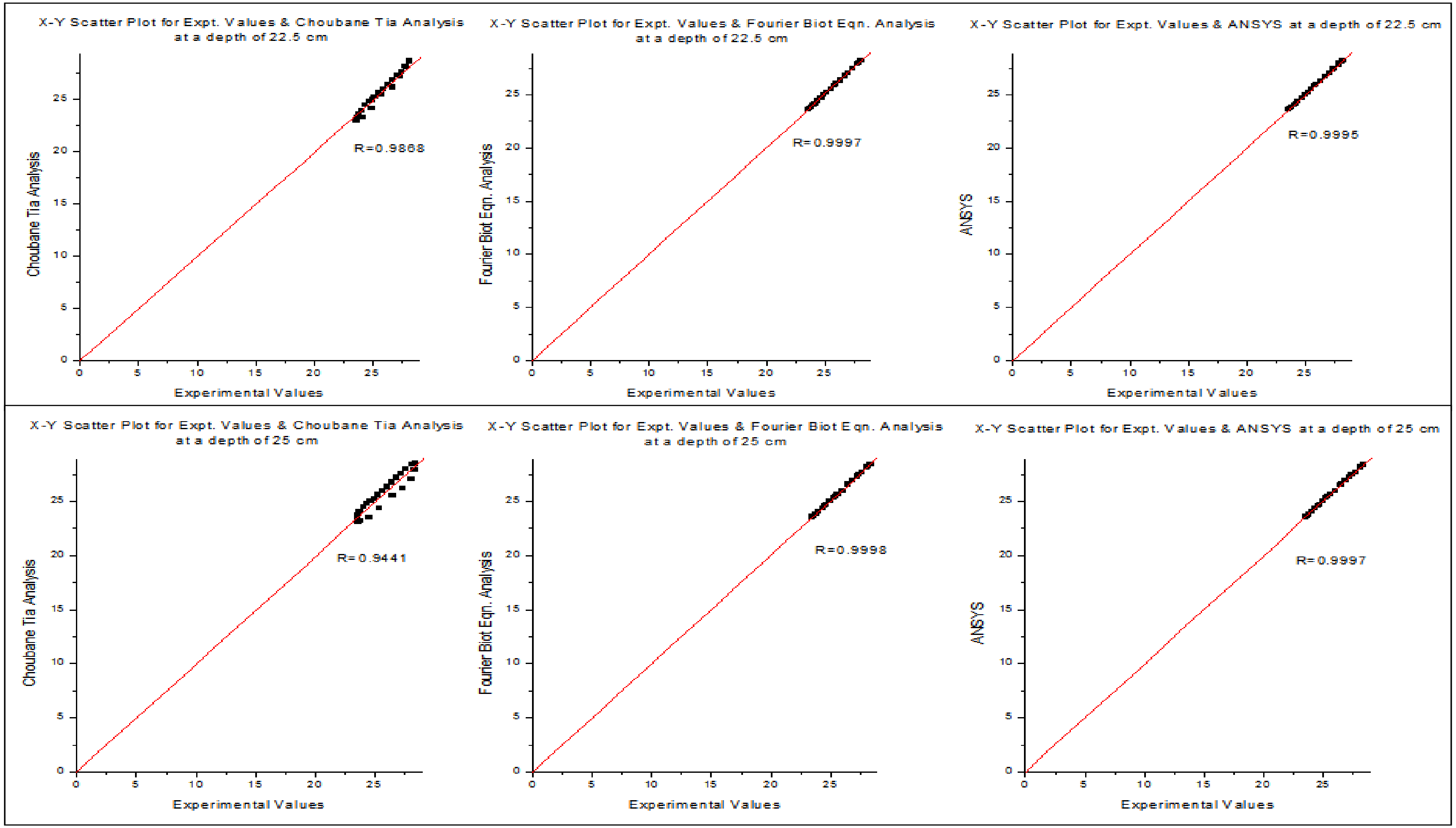


Fig. B-26 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

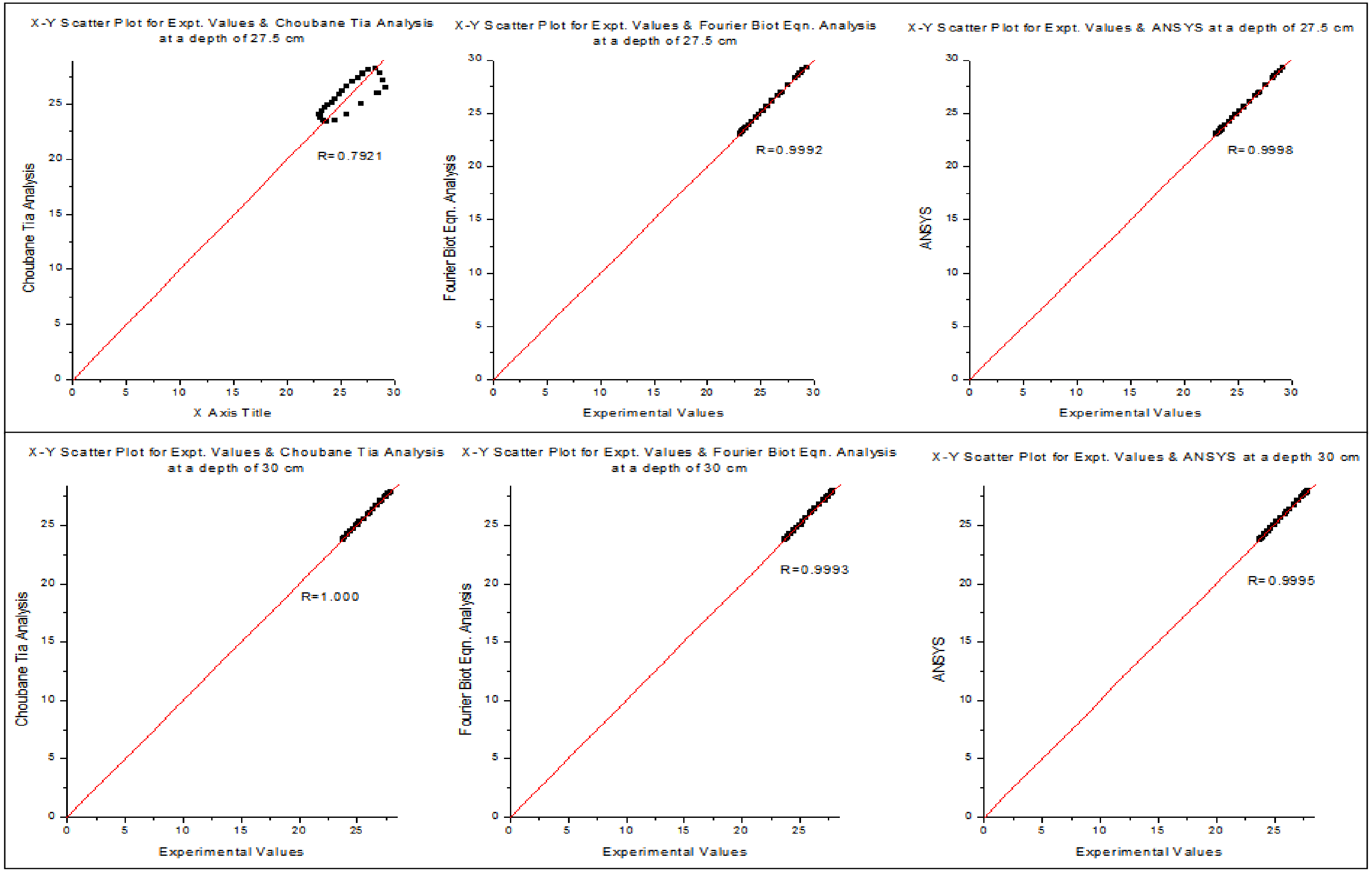


Fig. B-26 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

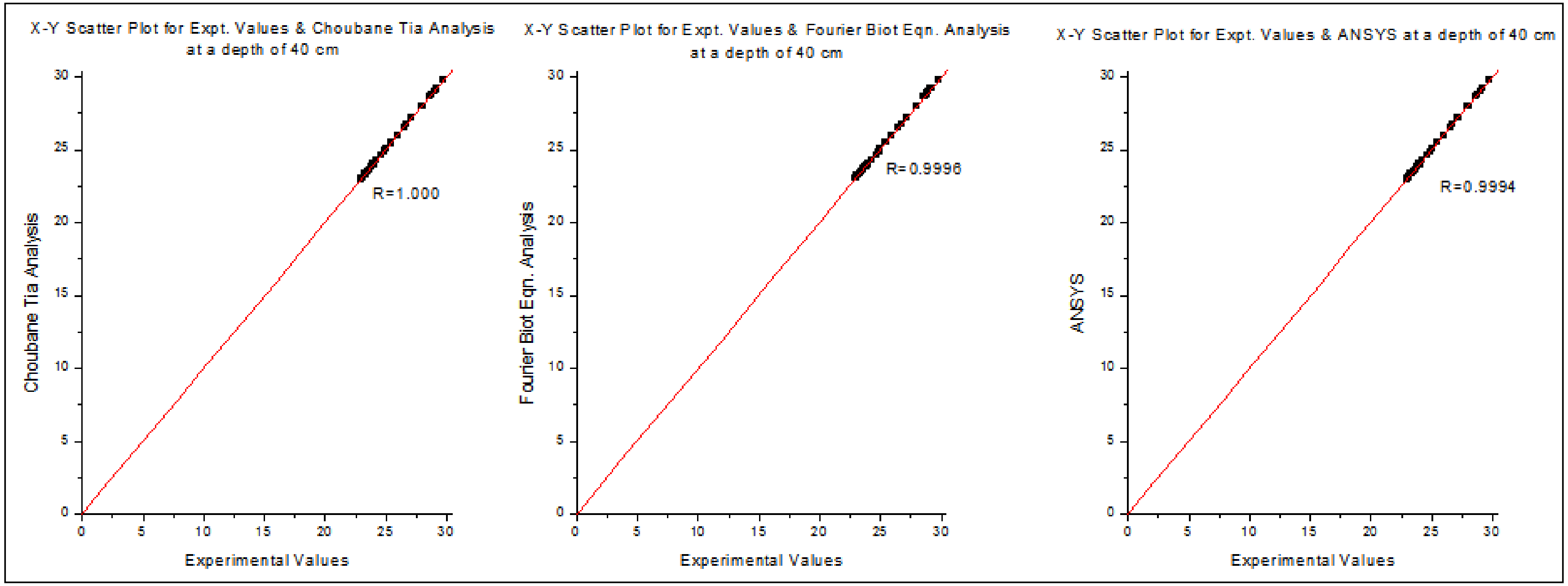


Fig. B-26 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-14 (a): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for 24 hr. cloudy and humid condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	27	31.64	28.17	29.71	28.26	28.22	25.78	28.02	25.48	25.63	24.61	26.58	24.63	24.62
2	1200 to 1300	29	36.64	31.31	33.64	31.43	31.37	28.04	31.01	28.11	28.08	26.24	28.76	26.28	26.26
3	1300 to 1400	31	38.53	34.52	35.23	34.48	34.50	31.04	32.36	31.14	31.09	28.52	29.90	28.59	28.55
4	1400 to 1500	31	37.98	35.86	35.04	35.84	35.85	32.82	32.48	32.88	32.85	30.38	30.30	30.42	30.40
5	1500 to 1600	31	38.64	38.49	35.75	38.52	38.50	34.35	33.24	34.47	34.41	31.59	31.10	31.61	31.60
6	1600 to 1700	31	36.34	38.46	34.20	38.50	38.48	34.95	32.35	35.02	34.98	32.46	30.78	32.52	32.49
7	1700 to 1800	29	31.50	36.95	30.70	36.93	36.94	34.38	30.02	34.42	34.40	32.42	29.45	32.48	32.45
8	1800 to 1900	28	28.83	31.66	28.81	31.56	31.61	32.21	28.80	32.28	32.25	31.43	28.79	31.50	31.47
9	1900 to 2000	27	26.86	28.67	27.34	28.72	28.70	29.87	27.76	29.93	29.90	30.03	28.11	30.08	30.06
10	2000 to 2100	26	25.89	27.09	26.54	27.12	27.11	28.24	27.10	28.32	28.28	28.73	27.57	28.81	28.77
11	2100 to 2200	25	24.82	26.02	25.63	26.03	26.03	27.08	26.33	27.02	27.05	27.73	26.91	27.80	27.76
12	2200 to 2300	24	23.93	25.06	24.85	25.09	25.07	26.12	25.65	26.20	26.16	26.85	26.32	26.91	26.88
13	2300 to 0000	24	23.19	24.26	24.17	24.18	24.22	25.24	25.03	25.33	25.29	26.07	25.75	26.08	26.07
14	0000 to 0100	24	22.51	23.52	23.57	23.59	23.55	24.54	24.49	24.62	24.58	25.33	25.27	25.35	25.34
15	0100 to 0200	24	22.10	23.06	23.15	23.11	23.09	23.92	24.06	24.01	23.96	24.78	24.83	24.82	24.80
16	0200 to 0300	23	21.89	22.67	22.89	22.62	22.64	23.43	23.75	23.47	23.45	24.27	24.48	24.31	24.29
17	0300 to 0400	20	21.85	22.59	22.75	22.66	22.62	23.22	23.53	23.29	23.25	23.91	24.20	23.87	23.89
18	0400 to 0500	20	21.32	22.26	22.28	22.31	22.28	22.94	23.10	22.85	22.89	23.61	23.81	23.66	23.64
19	0500 to 0600	20	20.47	21.63	21.58	21.90	21.76	22.45	22.55	22.48	22.46	23.26	23.37	23.30	23.28
20	0600 to 0700	20	20.48	21.29	21.52	21.35	21.32	21.95	22.42	22.01	21.98	22.81	23.19	22.85	22.83
21	0700 to 0800	21	21.25	21.47	22.02	21.57	21.52	21.80	22.69	21.90	21.85	22.56	23.26	22.60	22.58
22	0800 to 0900	21	22.78	22.11	23.13	22.19	22.15	22.01	23.42	22.05	22.03	22.54	23.66	22.57	22.56
23	0900 to 1000	22	25.00	23.50	24.78	23.43	23.46	22.75	24.58	22.83	22.79	22.89	24.40	22.95	22.92
24	1000 to 1100	24	28.14	24.94	27.16	25.01	24.98	23.45	26.29	23.51	23.48	23.30	25.53	23.34	23.32

Table B-14 (b): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for 24 hr. cloudy and humid condition at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	24.76	25.37	24.69	24.72	24.24	24.41	24.34	24.29	23.69	23.69	23.76	23.72
2	1200 to 1300	26.18	26.88	26.22	26.20	25.33	25.37	25.38	25.36	24.24	24.24	24.29	24.27
3	1300 to 1400	28.16	27.86	28.21	28.19	26.93	26.23	27.01	26.97	25.03	25.03	25.06	25.04
4	1400 to 1500	29.89	28.49	29.92	29.91	28.43	27.07	28.48	28.45	26.03	26.03	26.04	26.04
5	1500 to 1600	31.05	29.34	31.11	31.08	29.49	27.96	29.52	29.51	26.95	26.95	27.00	26.97
6	1600 to 1700	31.90	29.50	31.88	31.89	30.37	28.49	30.41	30.39	27.78	27.78	27.82	27.80
7	1700 to 1800	32.01	29.00	32.08	32.05	30.70	28.66	30.76	30.73	28.44	28.44	28.46	28.45
8	1800 to 1900	31.26	28.78	31.32	31.29	30.37	28.78	30.41	30.39	28.79	28.79	28.81	28.80
9	1900 to 2000	30.17	28.38	30.25	30.21	29.56	28.60	29.62	29.59	28.74	28.74	28.80	28.77
10	2000 to 2100	29.06	27.94	29.11	29.08	28.75	28.22	28.78	28.76	28.42	28.42	28.47	28.44
11	2100 to 2200	28.22	27.39	28.28	28.25	28.04	27.75	28.01	28.02	28.00	28.00	28.00	28.00
12	2200 to 2300	27.38	26.86	27.42	27.40	27.33	27.28	27.30	27.32	27.57	27.57	27.61	27.59
13	2300 to 0000	26.70	26.33	26.76	26.73	26.74	26.79	26.73	26.74	27.11	27.11	27.17	27.14
14	0000 to 0100	26.01	25.90	26.06	26.03	26.13	26.39	26.09	26.11	26.74	26.74	26.80	26.77
15	0100 to 0200	25.40	25.46	25.44	25.42	25.56	25.94	25.59	25.58	26.29	26.29	26.40	26.34
16	0200 to 0300	24.95	25.08	25.01	24.98	25.09	25.54	25.05	25.07	25.87	25.87	25.91	25.89
17	0300 to 0400	24.60	24.75	24.67	24.64	24.78	25.17	24.84	24.81	25.49	25.49	25.52	25.50
18	0400 to 0500	24.32	24.39	24.37	24.35	24.50	24.85	24.56	24.53	25.18	25.18	25.23	25.21
19	0500 to 0600	23.92	24.05	23.97	23.95	24.13	24.58	24.18	24.16	24.97	24.97	24.99	24.98
20	0600 to 0700	23.45	23.82	23.51	23.48	23.69	24.31	23.72	23.70	24.66	24.66	24.69	24.68
21	0700 to 0800	23.27	23.72	23.30	23.28	23.39	24.08	23.42	23.40	24.34	24.34	24.40	24.37
22	0800 to 0900	23.22	23.86	23.26	23.24	23.30	24.00	23.33	23.32	24.10	24.10	24.12	24.11
23	0900 to 1000	23.41	24.24	23.45	23.43	23.42	24.11	23.46	23.44	23.99	23.99	24.02	24.01
24	1000 to 1100	23.76	24.89	23.80	23.78	23.65	24.37	23.68	23.66	23.97	23.97	24.00	23.98

Table B-14 (c): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for 24 hr. cloudy and humid condition at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	23.80	23.20	23.86	23.83	23.76	22.97	23.84	23.80	23.92	22.97	24.01	23.97
2	1200 to 1300	24.36	23.49	24.41	24.38	24.36	23.11	24.40	24.38	24.68	23.10	24.75	24.72
3	1300 to 1400	25.15	24.24	25.19	25.17	25.15	23.87	25.20	25.17	25.68	23.91	25.72	25.70
4	1400 to 1500	26.17	25.37	26.21	26.19	26.19	25.09	26.22	26.20	26.85	25.19	26.91	26.88
5	1500 to 1600	27.04	26.31	27.11	27.07	27.10	26.05	27.15	27.12	27.78	26.17	27.86	27.82
6	1600 to 1700	27.86	27.34	27.91	27.89	27.93	27.19	28.00	27.97	28.57	27.32	28.62	28.60
7	1700 to 1800	28.53	28.34	28.60	28.56	28.59	28.35	28.65	28.62	29.01	28.48	29.05	29.03
8	1800 to 1900	28.80	28.79	28.84	28.82	28.87	28.80	28.94	28.90	29.24	28.82	29.30	29.27
9	1900 to 2000	28.77	28.82	28.81	28.79	28.82	28.83	28.90	28.86	28.97	28.77	29.02	29.00
10	2000 to 2100	28.47	28.51	28.52	28.49	28.54	28.52	28.61	28.58	28.57	28.43	28.62	28.59
11	2100 to 2200	28.07	28.14	28.11	28.09	28.10	28.16	28.15	28.13	28.01	28.08	28.04	28.02
12	2200 to 2300	27.65	27.74	27.68	27.67	27.64	27.78	27.70	27.67	27.46	27.70	27.51	27.49
13	2300 to 0000	27.21	27.30	27.26	27.23	27.18	27.35	27.22	27.20	26.95	27.27	27.00	26.98
14	0000 to 0100	26.81	26.94	26.88	26.85	26.79	27.00	26.82	26.81	26.51	26.92	26.55	26.53
15	0100 to 0200	26.40	26.49	26.47	26.44	26.35	26.56	26.41	26.38	26.02	26.48	26.01	26.01
16	0200 to 0300	25.98	26.07	26.01	26.00	25.93	26.14	26.01	25.97	25.59	26.08	25.62	25.60
17	0300 to 0400	25.59	25.68	25.63	25.61	25.54	25.75	25.59	25.56	25.19	25.70	25.23	25.21
18	0400 to 0500	25.29	25.39	25.32	25.30	25.23	25.48	25.30	25.27	24.97	25.44	25.00	24.99
19	0500 to 0600	25.04	25.21	25.09	25.06	25.01	25.30	25.05	25.03	24.74	25.26	24.80	24.77
20	0600 to 0700	24.76	24.88	24.80	24.78	24.76	24.96	24.80	24.78	24.43	24.91	24.48	24.46
21	0700 to 0800	24.43	24.49	24.48	24.45	24.43	24.54	24.48	24.45	24.11	24.49	24.16	24.13
22	0800 to 0900	24.19	24.15	24.22	24.20	24.17	24.15	24.20	24.19	23.86	24.10	23.91	23.88
23	0900 to 1000	24.09	23.90	24.14	24.12	24.02	23.84	24.06	24.04	23.71	23.79	23.76	23.74
24	1000 to 1100	24.09	23.68	24.12	24.10	24.00	23.51	24.04	24.02	23.80	23.45	23.86	23.83

Table B-14 (d): 24 hr. slab (D) temperature values (measured and calculated) for Mix B for 24 hr. cloudy and humid condition at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (^{o}C) at 25 cm				Temperature (^{o}C) at 27.5 cm				Temperature (^{o}C) at 30 cm				Temperature (^{o}C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	24.26	23.21	24.30	24.28	25.13	23.70	25.19	25.16	24.43	24.43	24.49	24.46	24.89	24.89	24.81	24.85
2	1200 to 1300	25.08	23.47	25.07	25.07	26.44	24.21	26.51	26.47	25.33	25.33	25.36	25.34	26.70	26.70	26.76	26.73
3	1300 to 1400	26.26	24.38	26.30	26.28	27.77	25.26	27.82	27.80	26.56	26.56	26.58	26.57	29.00	29.00	29.68	29.34
4	1400 to 1500	27.22	25.67	27.28	27.25	28.26	26.53	28.32	28.29	27.78	27.78	27.82	27.80	29.75	29.75	29.73	29.74
5	1500 to 1600	27.94	26.66	28.01	27.97	28.52	27.53	28.58	28.55	28.78	28.78	28.81	28.79	29.15	29.15	29.20	29.17
6	1600 to 1700	28.48	27.74	28.56	28.52	28.62	28.44	28.68	28.65	29.43	29.43	29.47	29.45	28.79	28.79	28.80	28.80
7	1700 to 1800	28.80	28.73	28.86	28.83	28.61	29.09	28.68	28.64	29.57	29.57	29.61	29.59	28.61	28.61	28.67	28.64
8	1800 to 1900	28.84	28.84	28.91	28.88	28.35	28.86	28.42	28.38	28.89	28.89	28.94	28.92	28.00	28.00	27.97	27.98
9	1900 to 2000	28.58	28.65	28.62	28.60	27.84	28.45	27.90	27.87	28.19	28.19	28.20	28.20	27.15	27.15	27.20	27.17
10	2000 to 2100	28.08	28.25	28.14	28.11	27.35	27.98	27.41	27.38	27.62	27.62	27.67	27.65	26.50	26.50	26.54	26.52
11	2100 to 2200	27.57	27.88	27.64	27.60	26.93	27.57	27.00	26.97	27.15	27.15	27.20	27.18	25.95	25.95	26.00	25.97
12	2200 to 2300	27.07	27.49	27.12	27.10	26.49	27.15	26.60	26.54	26.69	26.69	26.70	26.70	25.44	25.44	25.50	25.47
13	2300 to 0000	26.65	27.06	26.71	26.68	26.01	26.72	26.00	26.00	26.24	26.24	26.30	26.27	25.01	25.01	25.00	25.00
14	0000 to 0100	26.17	26.69	26.22	26.19	25.61	26.32	25.68	25.65	25.81	25.81	25.90	25.85	24.64	24.64	24.70	24.67
15	0100 to 0200	25.74	26.27	25.81	25.78	25.25	25.91	25.31	25.28	25.41	25.41	25.50	25.46	24.27	24.27	24.29	24.28
16	0200 to 0300	25.35	25.88	25.41	25.38	24.98	25.56	25.05	25.02	25.10	25.10	25.12	25.11	23.99	23.99	23.99	23.99
17	0300 to 0400	25.05	25.54	25.11	25.08	24.78	25.26	24.85	24.81	24.86	24.86	24.90	24.88	23.80	23.80	23.82	23.81
18	0400 to 0500	24.86	25.28	24.92	24.89	24.58	25.00	24.66	24.62	24.59	24.59	24.64	24.62	23.62	23.62	23.65	23.63
19	0500 to 0600	24.61	25.06	24.66	24.63	24.31	24.73	24.39	24.35	24.24	24.24	24.31	24.28	23.32	23.32	23.32	23.32
20	0600 to 0700	24.30	24.72	24.36	24.33	24.01	24.39	24.00	24.01	23.92	23.92	23.95	23.94	23.02	23.02	23.00	23.01
21	0700 to 0800	24.01	24.34	24.06	24.04	23.79	24.08	23.84	23.81	23.72	23.72	23.80	23.76	22.94	22.94	22.95	22.94
22	0800 to 0900	23.79	24.00	23.85	23.82	23.72	23.86	23.80	23.76	23.66	23.66	23.69	23.67	23.09	23.09	23.01	23.05
23	0900 to 1000	23.74	23.77	23.80	23.77	23.92	23.77	24.00	23.96	23.79	23.79	24.00	23.89	23.49	23.49	23.43	23.46
24	1000 to 1100	23.87	23.51	23.92	23.89	24.27	23.69	24.31	24.29	23.98	23.98	23.99	23.98	23.96	23.96	23.85	23.91

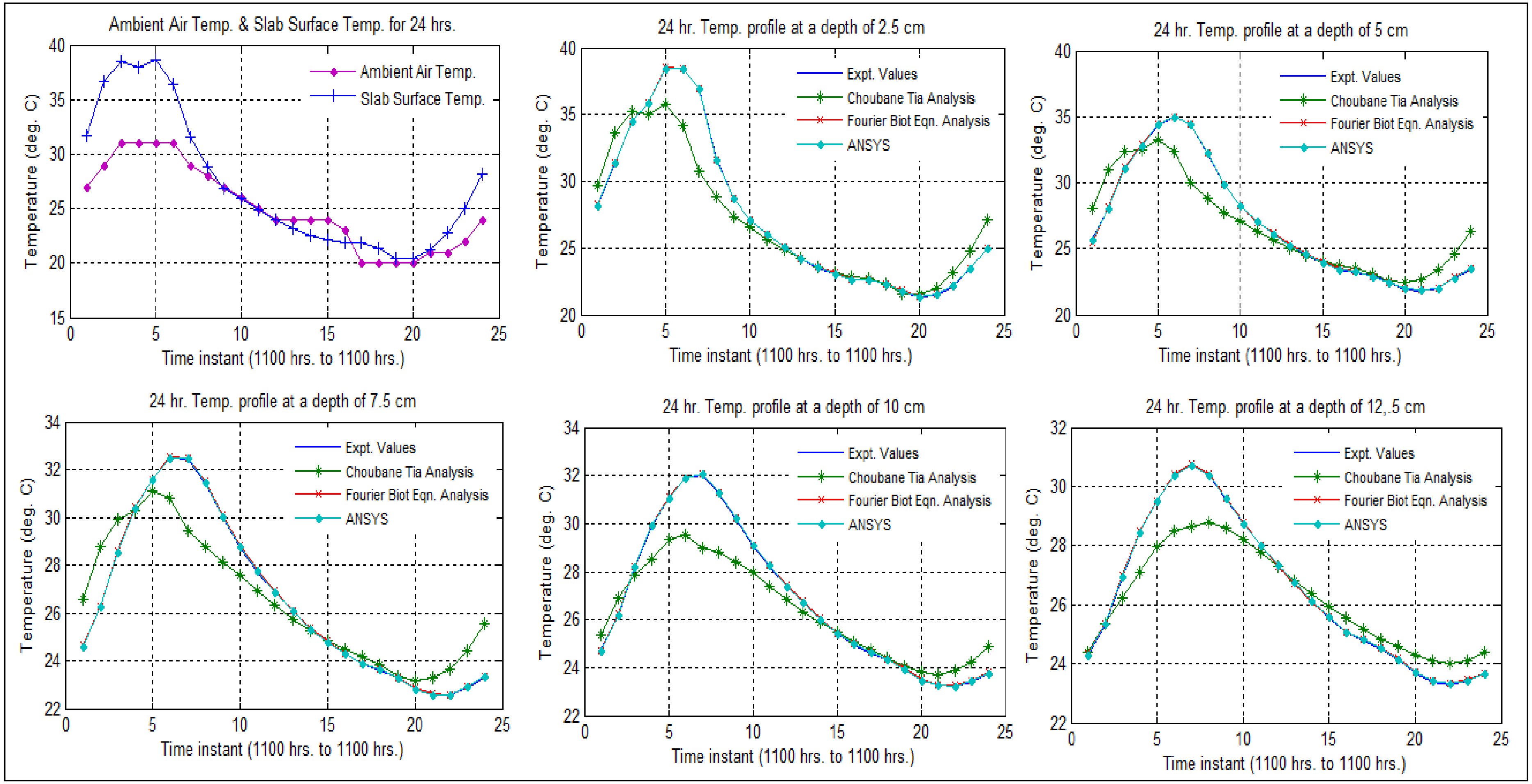


Fig. B-27 (a): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix B for 24 hr. cloudy and humid condition (surface to 12.5 cm)

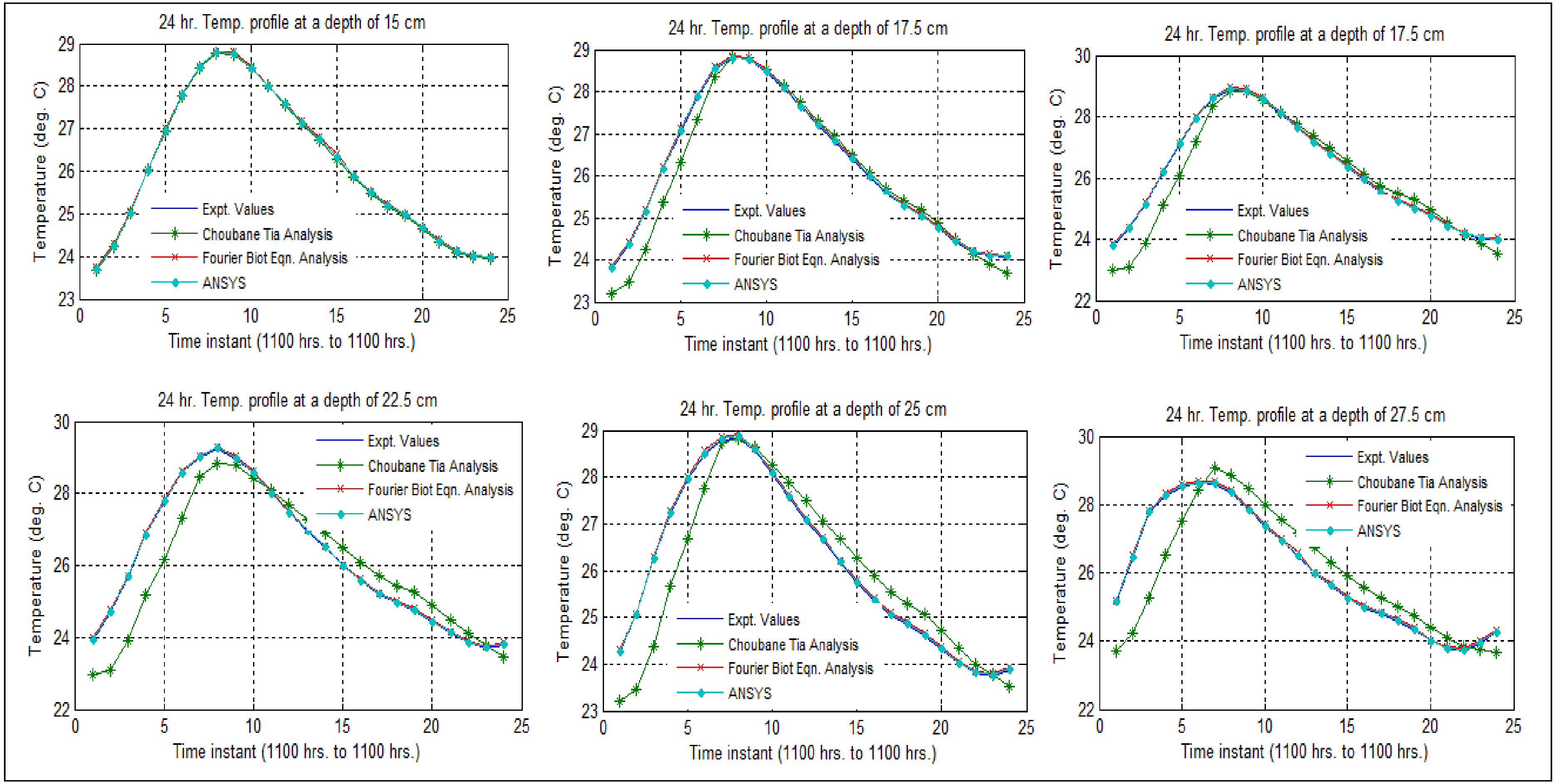


Fig. B-27 (b): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix B for 24 hr. cloudy and humid condition (15 cm to 27.5 cm)

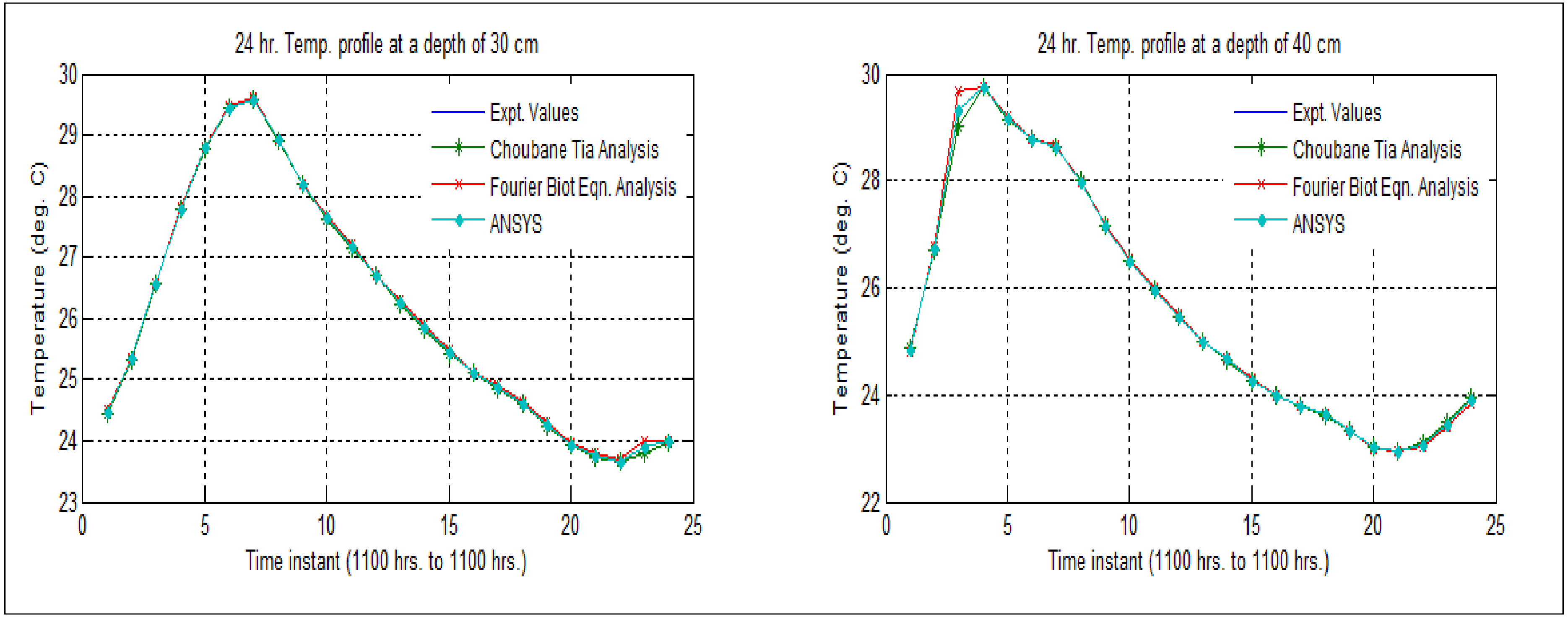


Fig. B-27 (c): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix B for 24 hr. cloudy and humid condition (30 cm & 40 cm)

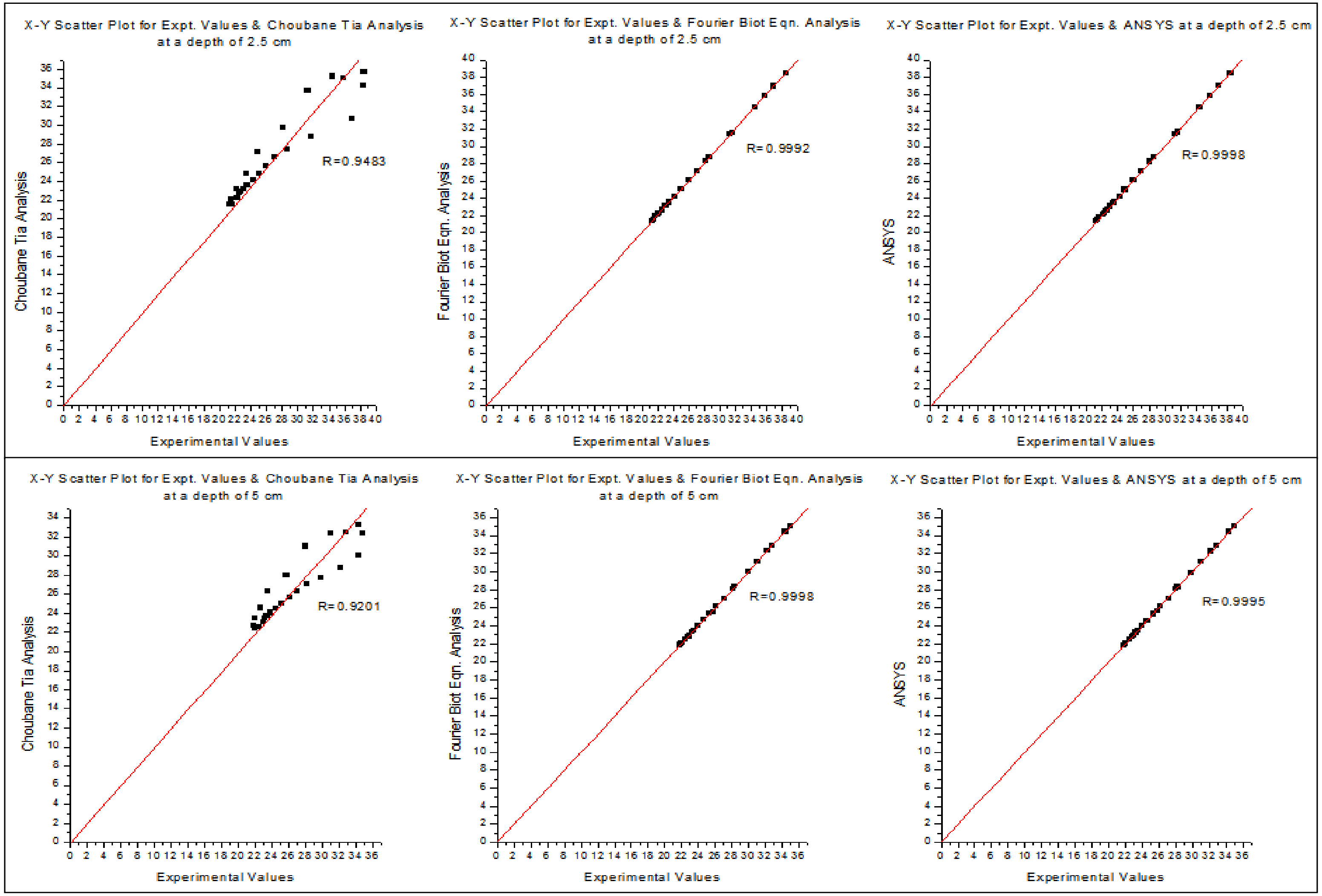


Fig. B-28 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

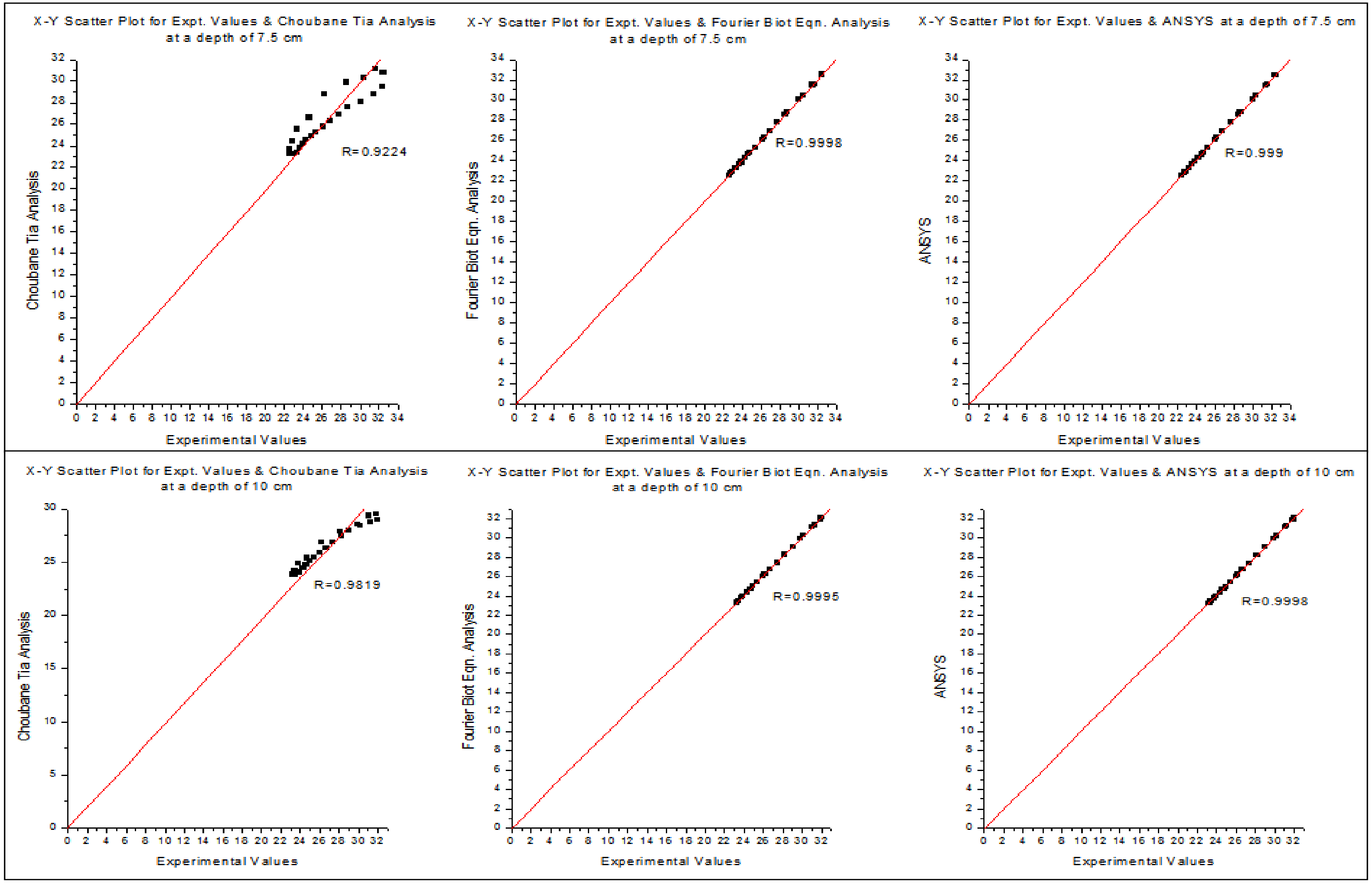


Fig. B-28 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

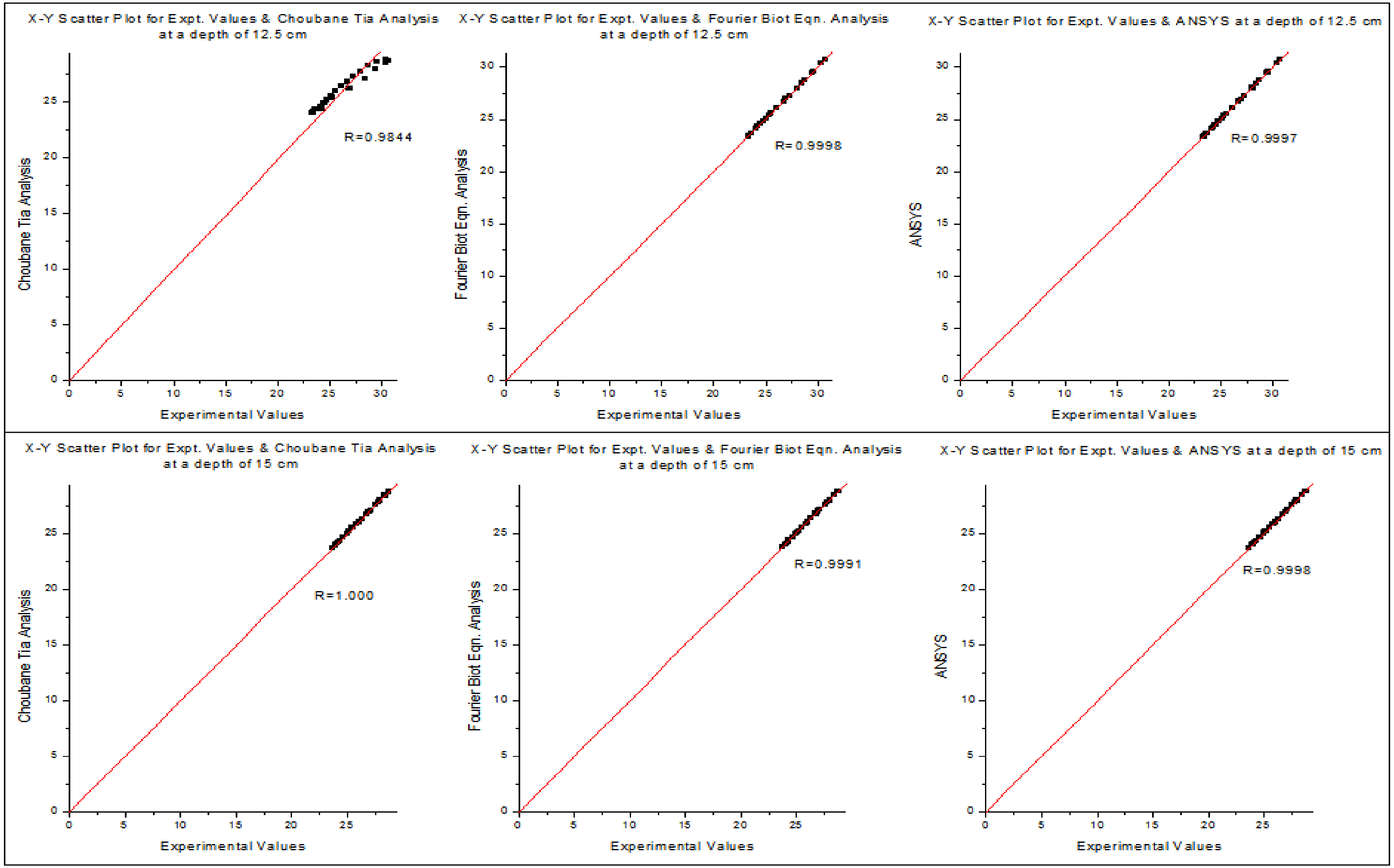


Fig. B-28 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

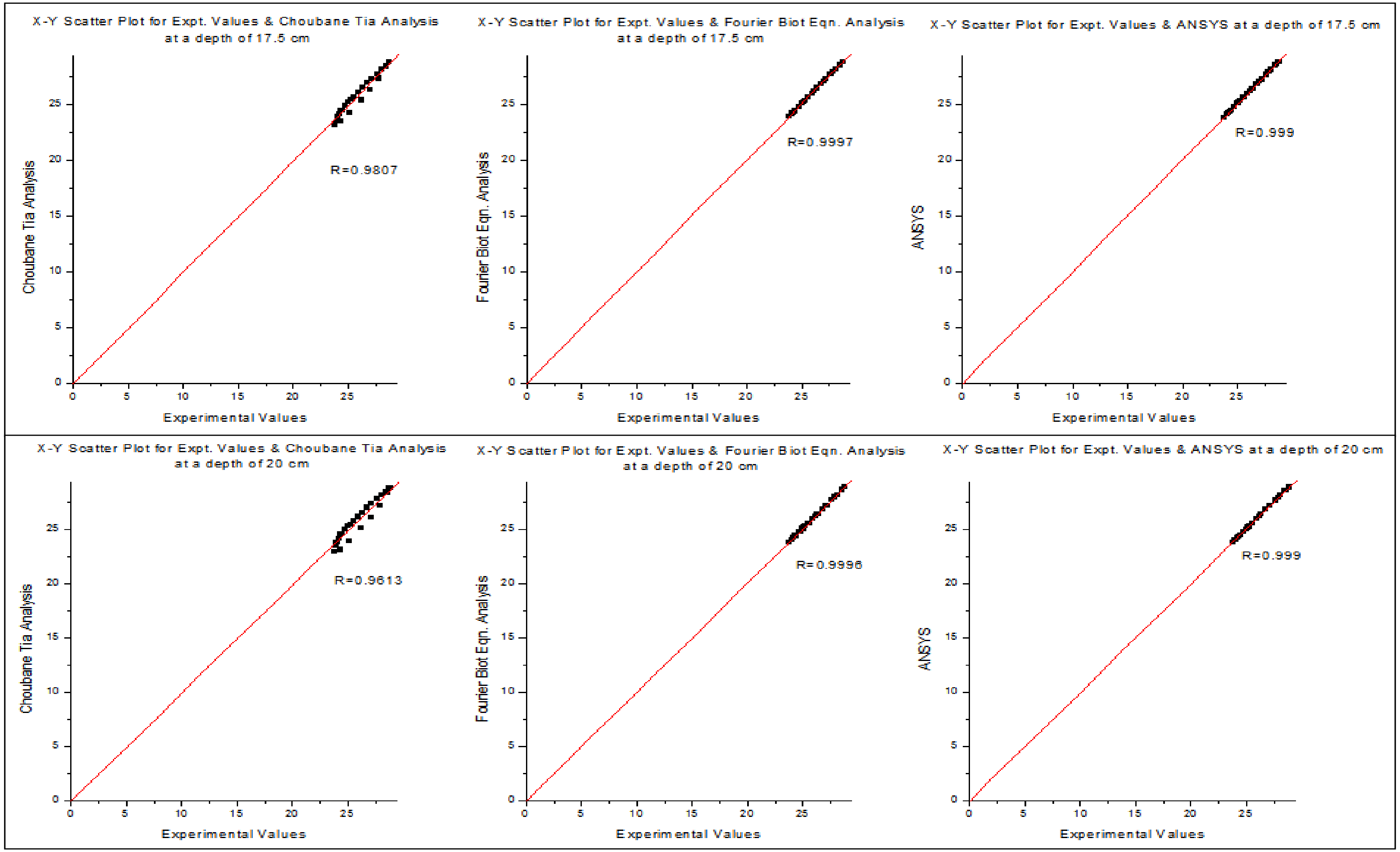


Fig. B-28 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

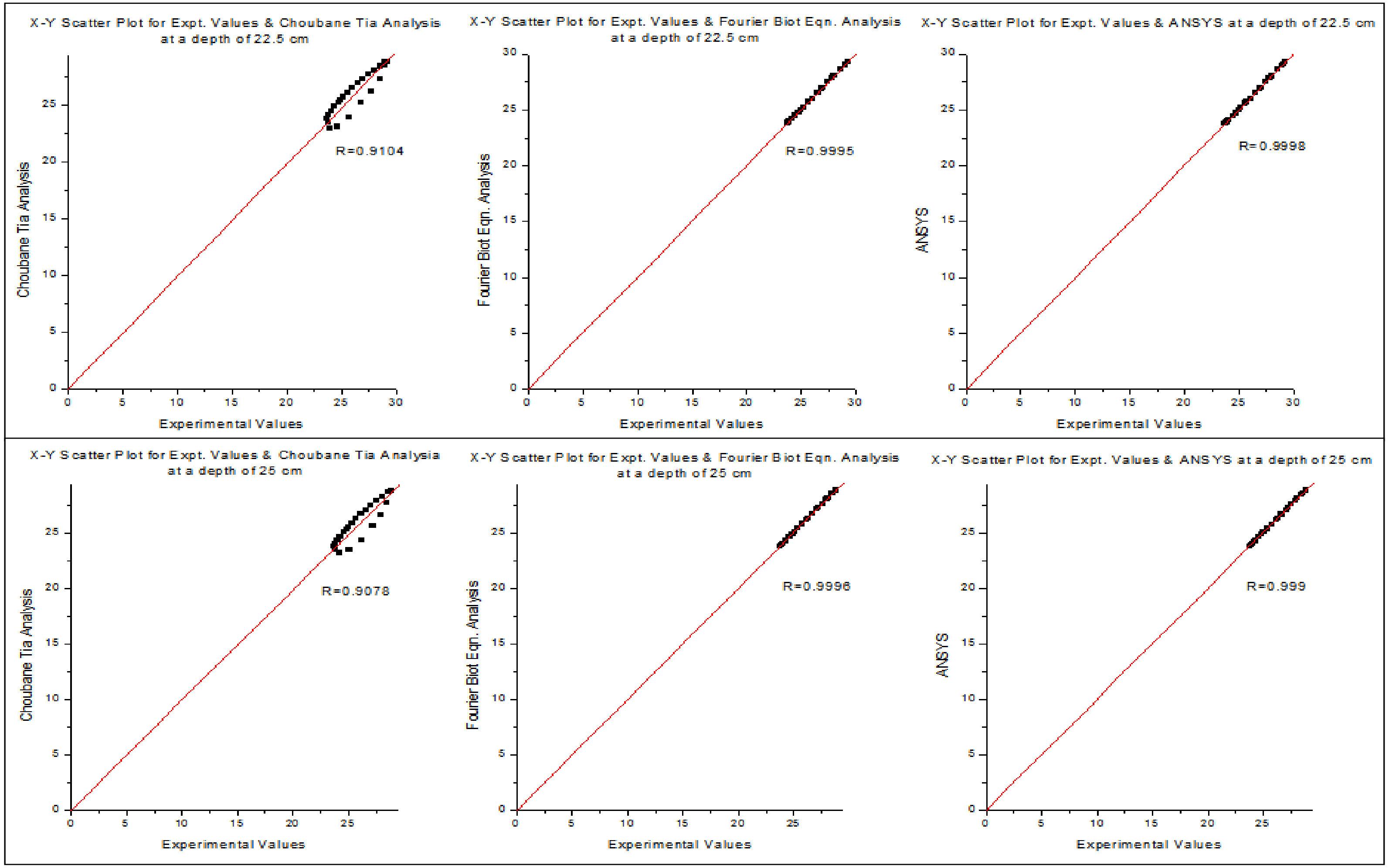


Fig. B-28 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

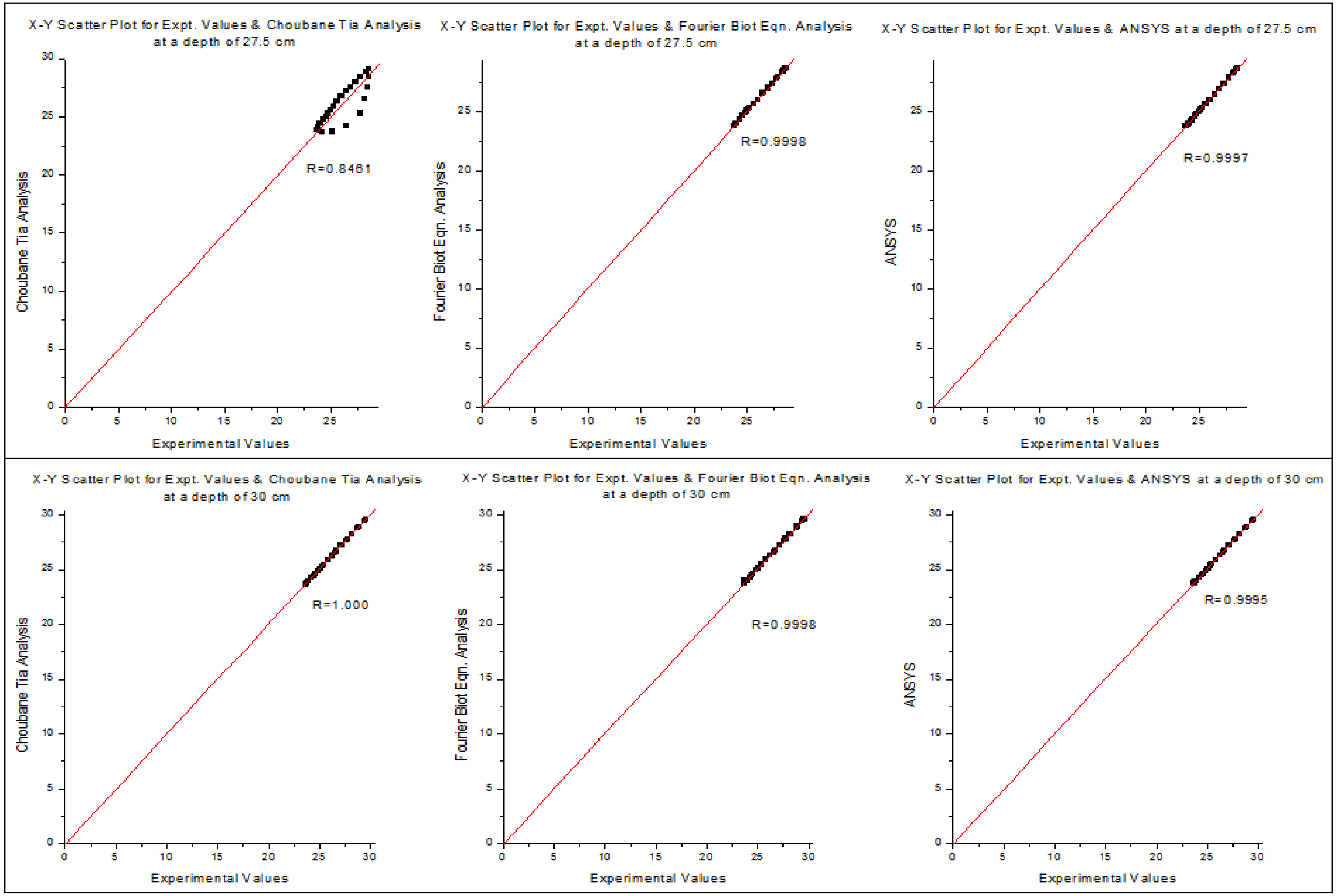


Fig. B-28 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

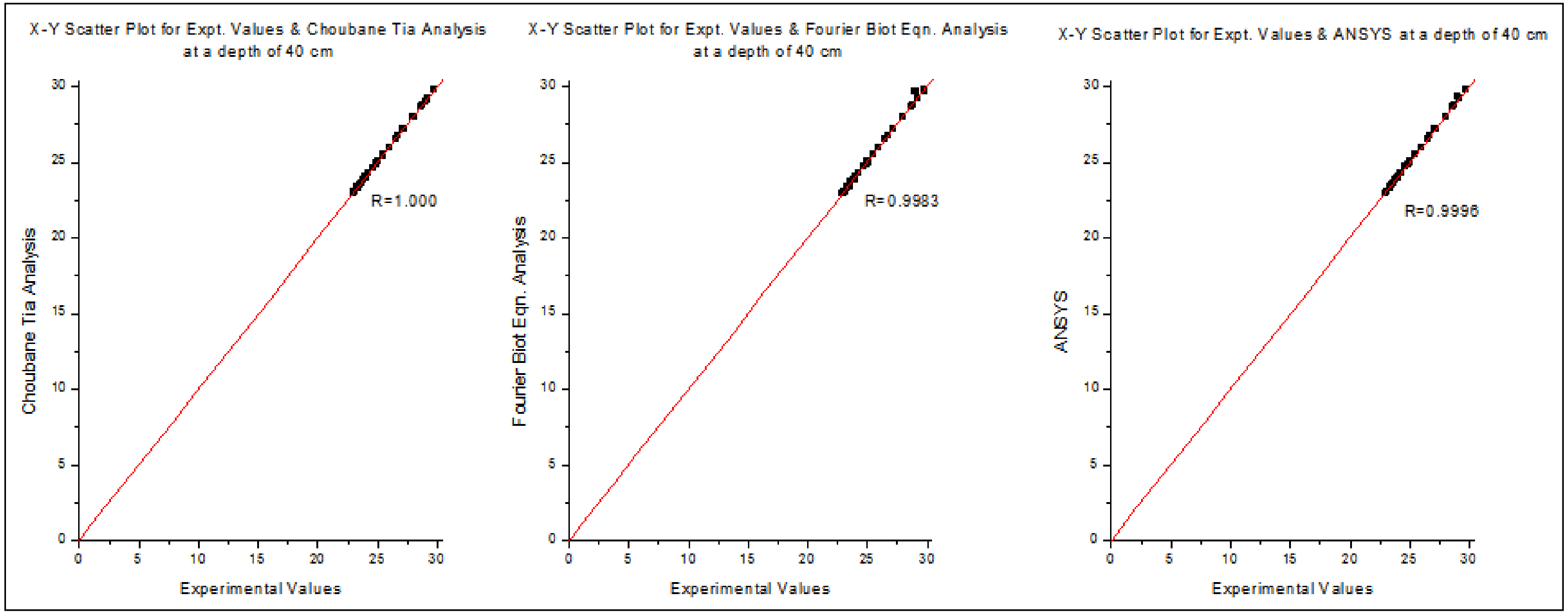


Fig. B-28 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-15 (a): 24 hr. slab (edge) temperature values (measured and calculated) for Mix C for maximum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (^oC) at 2.5 cm				Temperature (^oC) at 5 cm				Temperature (^oC) at 7.5 cm			
		(^oC)	(^oC)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	35	44.40	36.15	40.89	36.63	36.39	32.10	37.80	32.39	32.24	29.29	35.12	29.21	29.25
2	1130 to 1230	36	49.34	41.11	44.97	41.74	41.42	36.79	41.13	36.08	36.44	31.79	37.80	31.62	31.70
3	1230 to 1330	37	51.74	43.39	47.16	43.42	43.40	39.86	43.11	39.62	39.74	34.22	39.61	34.78	34.50
4	1330 to 1430	37	52.51	45.02	48.10	45.37	45.19	42.02	44.21	42.02	42.02	36.39	40.83	36.45	36.42
5	1430 to 1530	37	51.78	45.72	47.83	45.31	45.51	43.29	44.35	43.25	43.27	38.11	41.33	38.49	38.30
6	1530 to 1630	36	48.81	45.22	45.79	45.45	45.33	43.52	43.12	43.28	43.40	39.17	40.80	39.15	39.16
7	1630 to 1730	36	42.29	42.07	40.92	42.12	42.09	42.03	39.70	42.95	42.49	39.52	38.65	39.46	39.49
8	1730 to 1830	34	37.92	39.01	37.57	39.84	39.42	39.75	37.26	39.55	39.65	38.92	37.00	38.35	38.63
9	1830 to 1930	33	34.73	36.04	35.06	36.77	36.40	37.36	35.35	37.85	37.60	37.92	35.61	37.90	37.91
10	1930 to 2030	31	32.84	34.08	33.48	34.63	34.36	35.41	34.06	35.76	35.59	36.71	34.57	36.85	36.78
11	2030 to 2130	29	31.49	32.73	32.32	32.25	32.49	34.03	33.06	34.51	34.27	35.67	33.71	35.69	35.68
12	2130 to 2230	28	30.29	31.69	31.28	31.51	31.60	32.89	32.17	32.68	32.79	34.75	32.95	34.80	34.77
13	2230 to 2330	27	29.32	30.75	30.44	30.58	30.67	31.99	31.44	31.73	31.86	33.98	32.31	33.83	33.90
14	2330 to 0030	26	28.60	29.98	29.78	29.48	29.73	31.10	30.83	31.66	31.38	33.20	31.74	33.79	33.49
15	0030 to 0130	25	27.86	29.24	29.11	29.46	29.35	30.41	30.22	30.64	30.53	32.56	31.18	32.77	32.67
16	0130 to 0230	24	27.37	28.72	28.63	28.32	28.52	29.75	29.75	29.55	29.65	31.97	30.73	31.72	31.84
17	0230 to 0330	23	26.86	28.20	28.18	28.19	28.20	29.17	29.35	29.47	29.32	31.39	30.36	31.66	31.53
18	0330 to 0430	23	26.23	27.62	27.61	27.34	27.48	28.66	28.82	28.57	28.61	30.86	29.87	30.73	30.79
19	0430 to 0530	23	25.60	27.04	27.03	27.48	27.26	28.12	28.30	28.66	28.39	30.43	29.39	30.78	30.61
20	0530 to 0630	24	25.22	26.54	26.64	26.72	26.63	27.55	27.89	27.81	27.68	29.90	28.97	29.88	29.89
21	0630 to 0730	26	25.71	26.36	26.91	26.33	26.34	27.13	27.98	27.87	27.50	29.36	28.89	29.55	29.46
22	0730 to 0830	28	27.17	27.02	27.97	27.30	27.16	27.28	28.67	27.82	27.55	29.03	29.28	28.97	29.00
23	0830 to 0930	31	29.20	28.41	29.47	28.73	28.57	28.07	29.71	28.05	28.06	29.06	29.92	29.46	29.26
24	0930 to 1030	33	31.31	29.81	31.09	29.91	29.86	28.95	30.90	28.79	28.87	29.31	30.73	29.20	29.25

Table B-15 (b): 24 hr. slab (edge) temperature values (measured and calculated) for Mix C for maximum ambient air temperature at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	29.54	32.85	29.34	29.44	29.59	30.99	29.82	29.71	29.55	29.55	29.81	29.68
2	1130 to 1230	31.99	34.99	31.56	31.78	31.31	32.69	31.94	31.63	30.91	30.91	30.86	30.89
3	1230 to 1330	34.24	36.66	34.72	34.48	33.02	34.24	33.28	33.15	32.37	32.37	32.45	32.41
4	1330 to 1430	36.31	37.97	36.57	36.44	34.73	35.64	34.21	34.47	33.82	33.82	33.42	33.62
5	1430 to 1530	37.98	38.76	37.12	37.55	36.18	36.66	36.99	36.58	35.02	35.02	35.15	35.09
6	1530 to 1630	38.96	38.83	38.70	38.83	37.17	37.21	37.92	37.55	35.95	35.95	35.81	35.88
7	1630 to 1730	39.17	37.76	39.63	39.40	37.64	37.03	37.34	37.49	36.47	36.47	36.35	36.41
8	1730 to 1830	38.49	36.79	38.20	38.35	37.44	36.62	37.12	37.28	36.50	36.50	36.66	36.58
9	1830 to 1930	37.45	35.84	37.94	37.70	36.85	36.05	36.97	36.91	36.22	36.22	36.18	36.20
10	1930 to 2030	36.35	35.02	36.91	36.63	36.17	35.39	36.95	36.56	35.71	35.71	35.97	35.84
11	2030 to 2130	35.35	34.28	35.82	35.59	35.42	34.75	35.90	35.66	35.15	35.15	35.35	35.25
12	2130 to 2230	34.54	33.62	34.88	34.71	34.77	34.18	34.93	34.85	34.64	34.64	34.97	34.80
13	2230 to 2330	33.80	33.06	33.90	33.85	34.21	33.68	34.94	34.58	34.18	34.18	34.37	34.28
14	2330 to 0030	33.08	32.52	33.88	33.48	33.60	33.17	33.93	33.77	33.69	33.69	33.96	33.83
15	0030 to 0130	32.49	32.01	32.87	32.68	33.07	32.69	33.92	33.50	33.22	33.22	33.36	33.29
16	0130 to 0230	31.94	31.56	31.84	31.89	32.60	32.24	32.91	32.75	32.78	32.78	32.95	32.86
17	0230 to 0330	31.38	31.21	31.81	31.59	32.17	31.91	32.89	32.53	32.46	32.46	32.64	32.55
18	0330 to 0430	30.87	30.76	30.84	30.86	31.70	31.49	31.91	31.80	32.06	32.06	32.15	32.10
19	0430 to 0530	30.46	30.31	30.87	30.66	31.25	31.06	31.93	31.59	31.65	31.65	31.96	31.81
20	0530 to 0630	29.93	29.88	29.93	29.93	30.79	30.63	30.96	30.88	31.21	31.21	31.38	31.29
21	0630 to 0730	29.42	29.67	29.32	29.37	30.38	30.30	30.18	30.28	30.79	30.79	30.90	30.84
22	0730 to 0830	29.14	29.79	29.04	29.09	30.04	30.20	30.60	30.32	30.51	30.51	30.30	30.41
23	0830 to 0930	29.19	30.09	29.59	29.39	29.91	30.22	29.48	29.70	30.32	30.32	30.24	30.28
24	0930 to 1030	29.47	30.58	29.60	29.53	30.05	30.45	30.06	30.06	30.34	30.34	30.03	30.19

Table B-15 (c): 24 hr. slab (edge) temperature values (measured and calculated) for Mix C for maximum ambient air temperature at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	29.91	28.52	29.37	29.64	30.08	27.90	30.14	30.11	30.36	27.70	30.57	30.47
2	1130 to 1230	30.96	29.65	30.39	30.67	31.12	28.90	31.15	31.13	31.52	28.67	31.67	31.60
3	1230 to 1330	32.06	31.04	32.19	32.13	32.11	30.26	32.21	32.16	32.53	30.02	33.00	32.76
4	1330 to 1430	33.04	32.51	33.18	33.11	32.97	31.73	33.01	32.99	33.52	31.46	33.99	33.76
5	1430 to 1530	33.98	33.84	34.05	34.02	33.81	33.12	34.00	33.90	34.42	32.86	34.79	34.60
6	1530 to 1630	34.63	35.04	34.79	34.71	34.42	34.48	34.57	34.50	34.98	34.27	35.06	35.02
7	1630 to 1730	35.11	36.06	35.07	35.09	34.84	35.82	35.00	34.92	35.39	35.74	35.51	35.45
8	1730 to 1830	35.35	36.42	35.23	35.29	35.11	36.39	35.32	35.22	35.58	36.41	36.00	35.79
9	1830 to 1930	35.36	36.36	35.49	35.42	35.17	36.47	35.40	35.29	35.50	36.55	36.00	35.75
10	1930 to 2030	35.14	35.95	35.24	35.19	35.01	36.13	34.99	35.00	35.23	36.24	35.79	35.51
11	2030 to 2130	34.84	35.45	34.97	34.90	34.73	35.66	34.98	34.85	34.82	35.79	35.00	34.91
12	2130 to 2230	34.54	34.99	34.68	34.61	34.47	35.24	34.59	34.53	34.44	35.37	34.73	34.59
13	2230 to 2330	34.16	34.56	34.29	34.22	34.10	34.81	34.19	34.14	33.98	34.93	34.00	33.99
14	2330 to 0030	33.79	34.07	33.88	33.83	33.72	34.32	33.99	33.86	33.55	34.43	33.70	33.62
15	0030 to 0130	33.42	33.61	33.58	33.50	33.36	33.87	33.49	33.43	33.11	33.97	33.29	33.20
16	0130 to 0230	33.05	33.17	33.18	33.12	33.01	33.41	32.99	33.00	32.74	33.51	32.89	32.82
17	0230 to 0330	32.70	32.85	32.97	32.84	32.68	33.08	32.88	32.78	32.46	33.16	32.69	32.58
18	0330 to 0430	32.45	32.46	32.68	32.56	32.41	32.69	32.59	32.50	32.08	32.77	32.21	32.14
19	0430 to 0530	32.08	32.06	32.18	32.13	32.05	32.30	32.19	32.12	31.68	32.38	31.98	31.83
20	0530 to 0630	31.71	31.61	31.99	31.85	31.69	31.85	31.99	31.84	31.33	31.92	31.45	31.39
21	0630 to 0730	31.31	31.13	31.45	31.38	31.31	31.33	31.40	31.36	30.96	31.39	31.00	30.98
22	0730 to 0830	30.98	30.73	31.00	30.99	30.99	30.86	31.00	31.00	30.70	30.88	30.92	30.81
23	0830 to 0930	30.77	30.39	30.68	30.72	30.81	30.42	30.71	30.76	30.60	30.41	30.51	30.56
24	0930 to 1030	30.70	30.26	30.52	30.61	30.78	30.20	30.59	30.68	30.60	30.16	30.61	30.61

Table B-15(d): 24 hr. slab (edge) temperature values (measured and calculated) for Mix C for maximum ambient air temperature at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	30.09	27.91	30.00	30.05	29.64	28.53	29.99	29.81	29.56	29.56	29.92	29.74	29.63	29.63	29.85	29.74
2	1130 to 1230	31.33	28.96	31.45	31.39	31.10	29.76	31.49	31.30	31.08	31.08	31.01	31.05	32.04	32.04	31.84	31.94
3	1230 to 1330	32.51	30.32	32.74	32.62	32.62	31.16	32.88	32.75	32.55	32.55	32.85	32.70	35.17	35.17	35.40	35.28
4	1330 to 1430	33.76	31.71	33.95	33.86	34.28	32.48	34.49	34.39	33.77	33.77	33.86	33.82	37.55	37.55	37.81	37.68
5	1430 to 1530	34.84	33.06	35.00	34.92	35.38	33.72	35.62	35.50	34.84	34.84	34.88	34.86	38.65	38.65	38.84	38.74
6	1530 to 1630	35.48	34.42	35.73	35.61	35.81	34.91	36.02	35.91	35.76	35.76	35.96	35.86	38.98	38.98	38.92	38.95
7	1630 to 1730	35.92	35.82	36.01	35.96	36.21	36.06	36.41	36.31	36.47	36.47	36.48	36.48	38.73	38.73	38.77	38.75
8	1730 to 1830	36.08	36.47	36.20	36.14	36.17	36.58	36.30	36.24	36.74	36.74	36.80	36.77	37.81	37.81	37.79	37.80
9	1830 to 1930	35.85	36.60	36.00	35.92	35.77	36.62	35.95	35.86	36.61	36.61	36.70	36.65	36.63	36.63	36.60	36.62
10	1930 to 2030	35.44	36.29	35.81	35.62	35.23	36.27	35.39	35.31	36.19	36.19	36.30	36.24	35.50	35.50	35.50	35.50
11	2030 to 2130	34.92	35.84	35.00	34.96	34.68	35.79	34.81	34.75	35.66	35.66	35.71	35.68	34.55	34.55	34.61	34.58
12	2130 to 2230	34.44	35.40	34.61	34.53	34.16	35.33	34.30	34.23	35.14	35.14	35.20	35.17	33.72	33.72	33.80	33.76
13	2230 to 2330	33.91	34.93	34.00	33.96	33.60	34.81	33.80	33.70	34.56	34.56	34.60	34.58	32.96	32.96	33.00	32.98
14	2330 to 0030	33.42	34.41	33.59	33.50	33.08	34.26	33.19	33.13	33.98	33.98	34.00	33.99	32.37	32.37	32.30	32.33
15	0030 to 0130	32.95	33.94	33.02	32.98	32.64	33.76	32.81	32.73	33.44	33.44	33.50	33.47	31.81	31.81	32.00	31.91
16	0130 to 0230	32.57	33.46	32.75	32.66	32.27	33.27	32.40	32.33	32.93	32.93	33.00	32.96	31.30	31.30	32.01	31.65
17	0230 to 0330	32.23	33.09	32.41	32.32	31.86	32.86	32.00	31.93	32.47	32.47	32.50	32.48	30.87	30.87	31.01	30.94
18	0330 to 0430	31.83	32.68	32.00	31.92	31.47	32.43	31.73	31.60	32.02	32.02	32.10	32.06	30.57	30.57	30.81	30.69
19	0430 to 0530	31.42	32.28	31.81	31.61	31.07	32.02	31.20	31.13	31.59	31.59	31.60	31.59	30.19	30.19	30.60	30.40
20	0530 to 0630	31.06	31.83	31.15	31.10	30.73	31.56	30.96	30.85	31.13	31.13	31.20	31.16	29.79	29.79	29.70	29.75
21	0630 to 0730	30.72	31.30	31.00	30.86	30.41	31.07	30.55	30.48	30.70	30.70	30.71	30.71	29.41	29.41	29.49	29.45
22	0730 to 0830	30.48	30.81	30.70	30.59	30.15	30.64	30.20	30.17	30.38	30.38	30.50	30.44	29.26	29.26	29.27	29.26
23	0830 to 0930	30.38	30.37	30.55	30.46	30.10	30.30	30.11	30.11	30.19	30.19	30.25	30.22	29.39	29.39	29.41	29.40
24	0930 to 1030	30.40	30.15	30.63	30.52	30.15	30.16	30.36	30.26	30.19	30.19	30.24	30.21	29.71	29.71	29.88	29.80

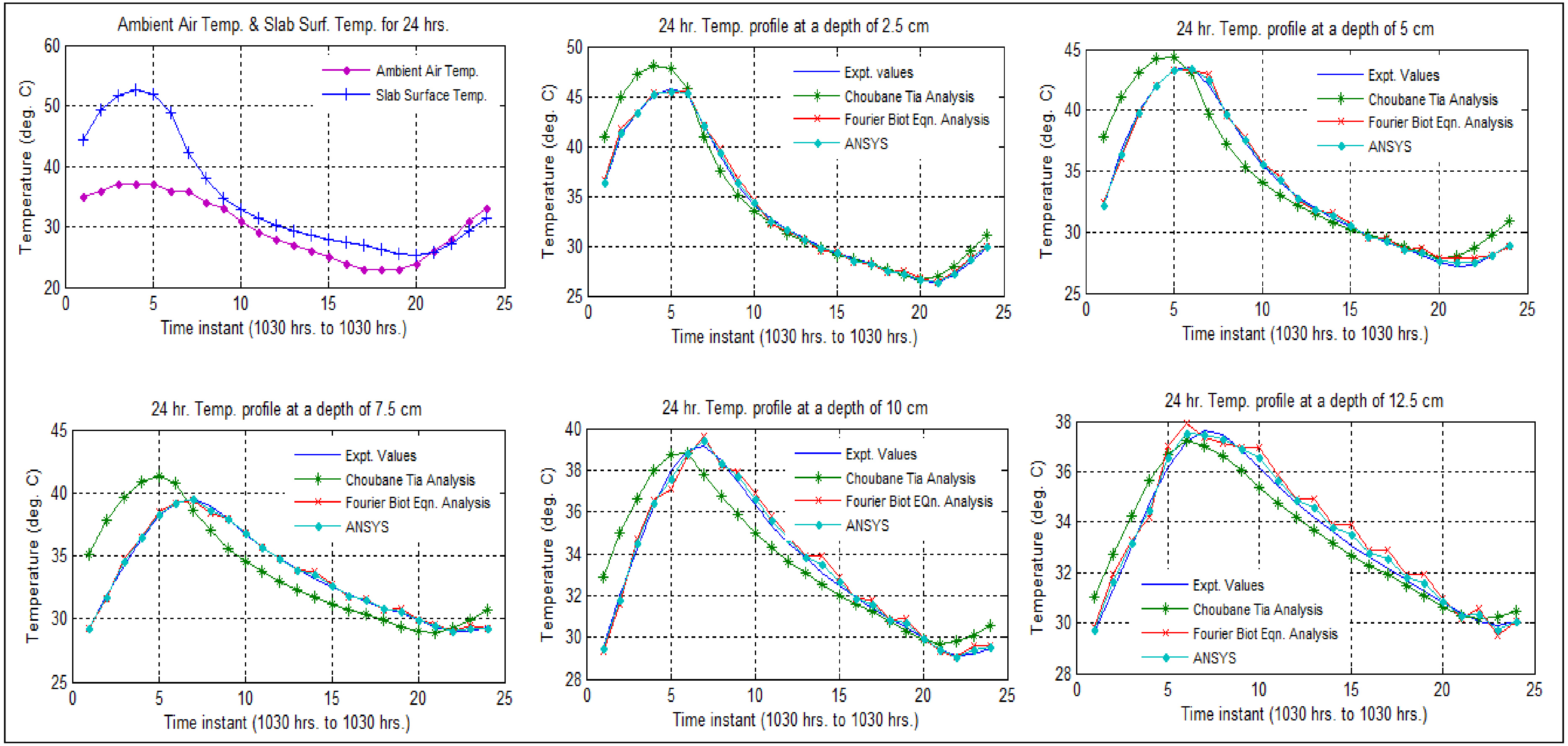


Fig. B-29 (a): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix C for maximum ambient air temperature (surface to 12.5 cm)

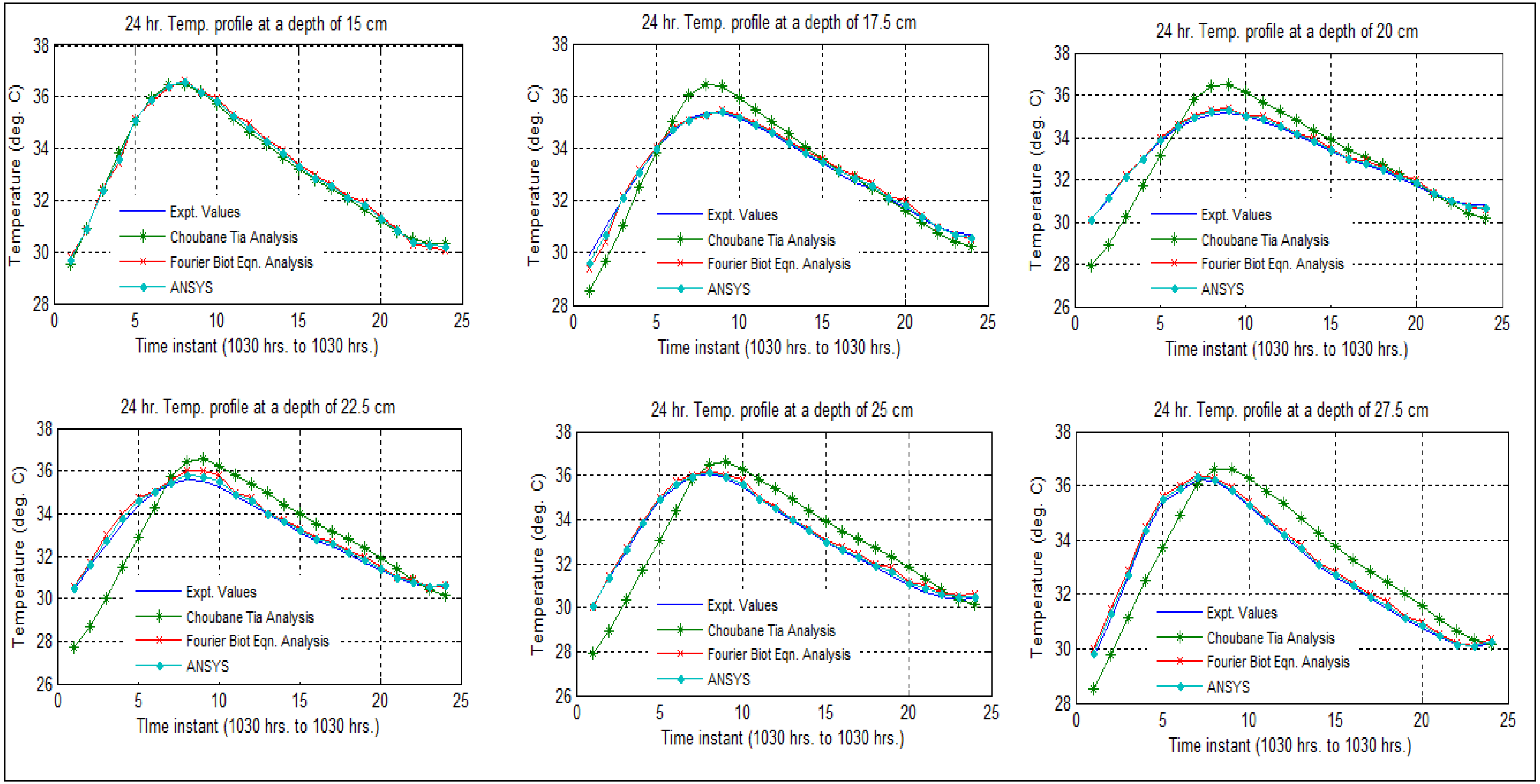


Fig. B-29 (b): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix C for maximum ambient air temperature (15 cm to 27.5 cm)

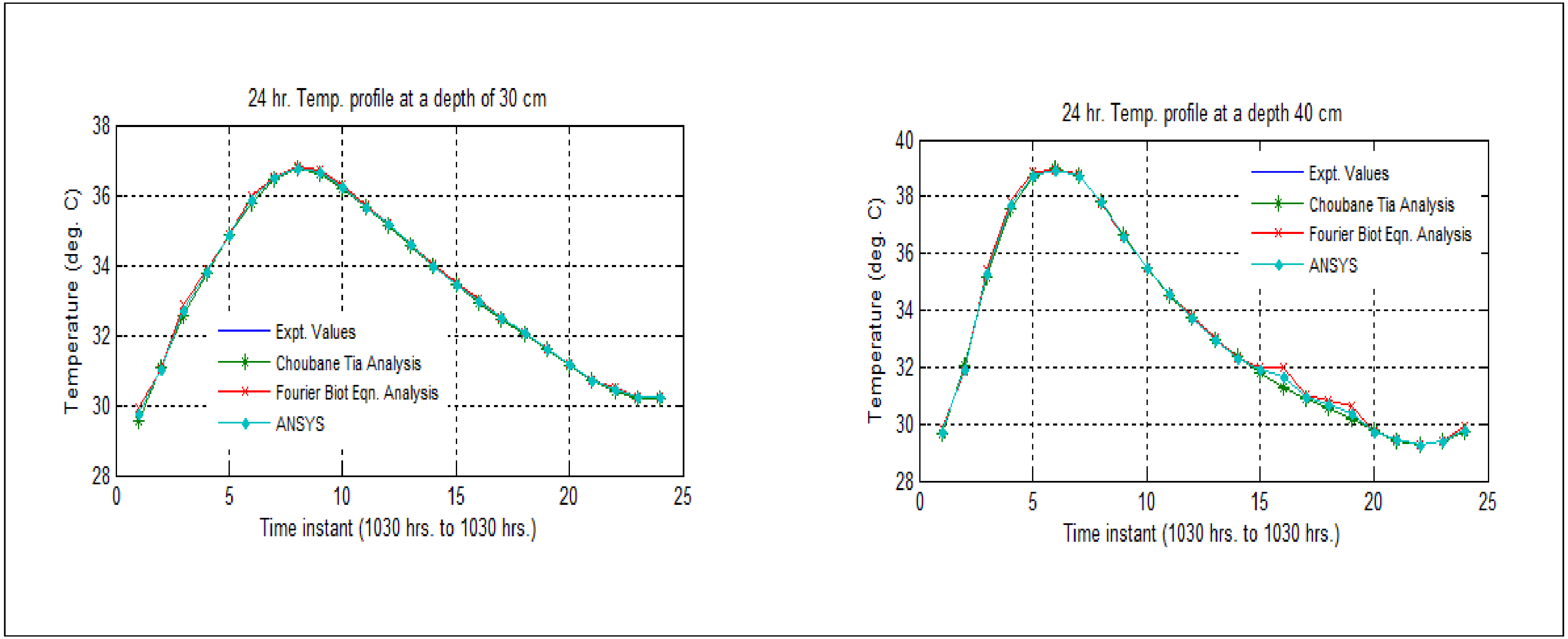


Fig. B-29 (c): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix C for maximum ambient air temperature (30 cm & 40 cm)

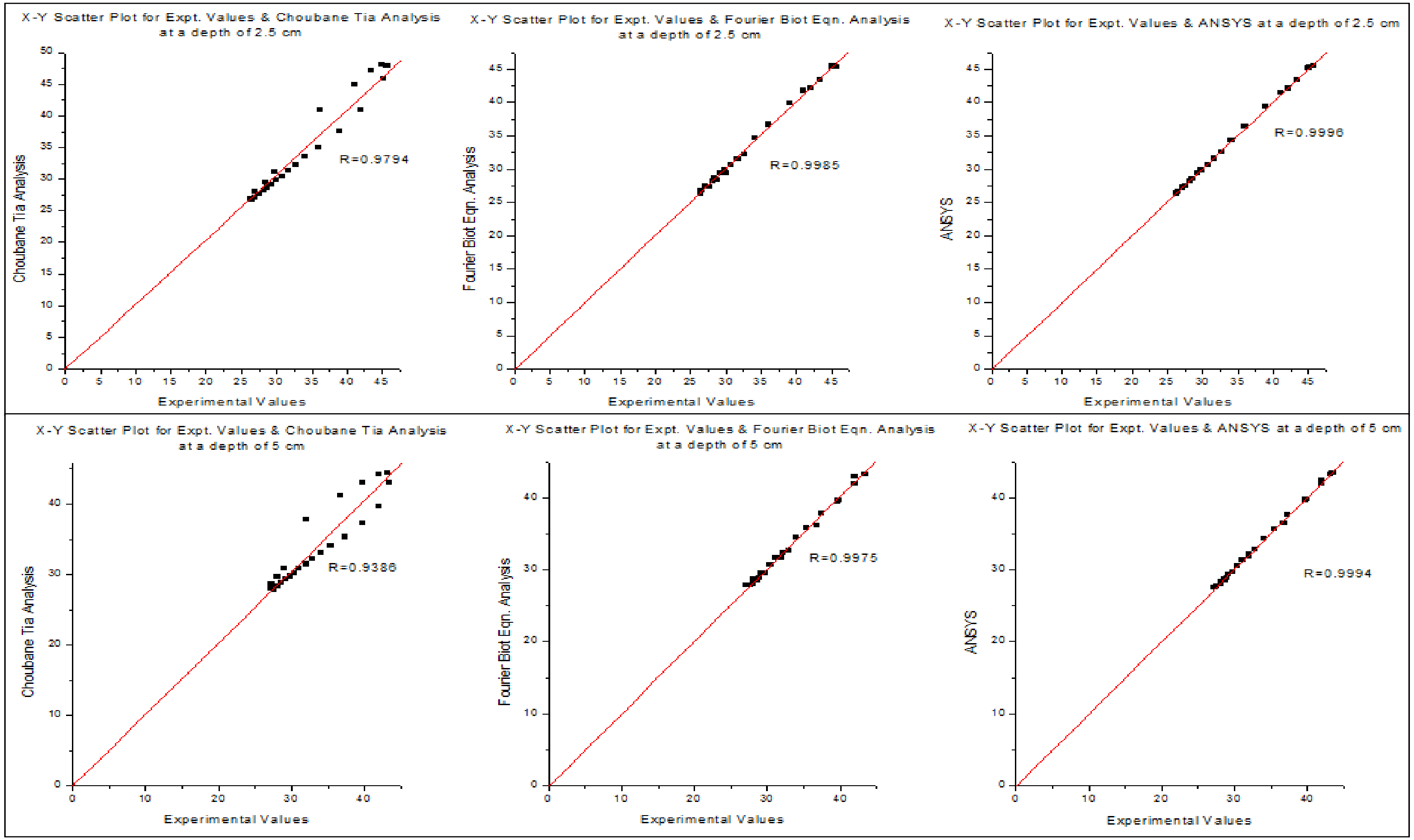


Fig. B-30 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

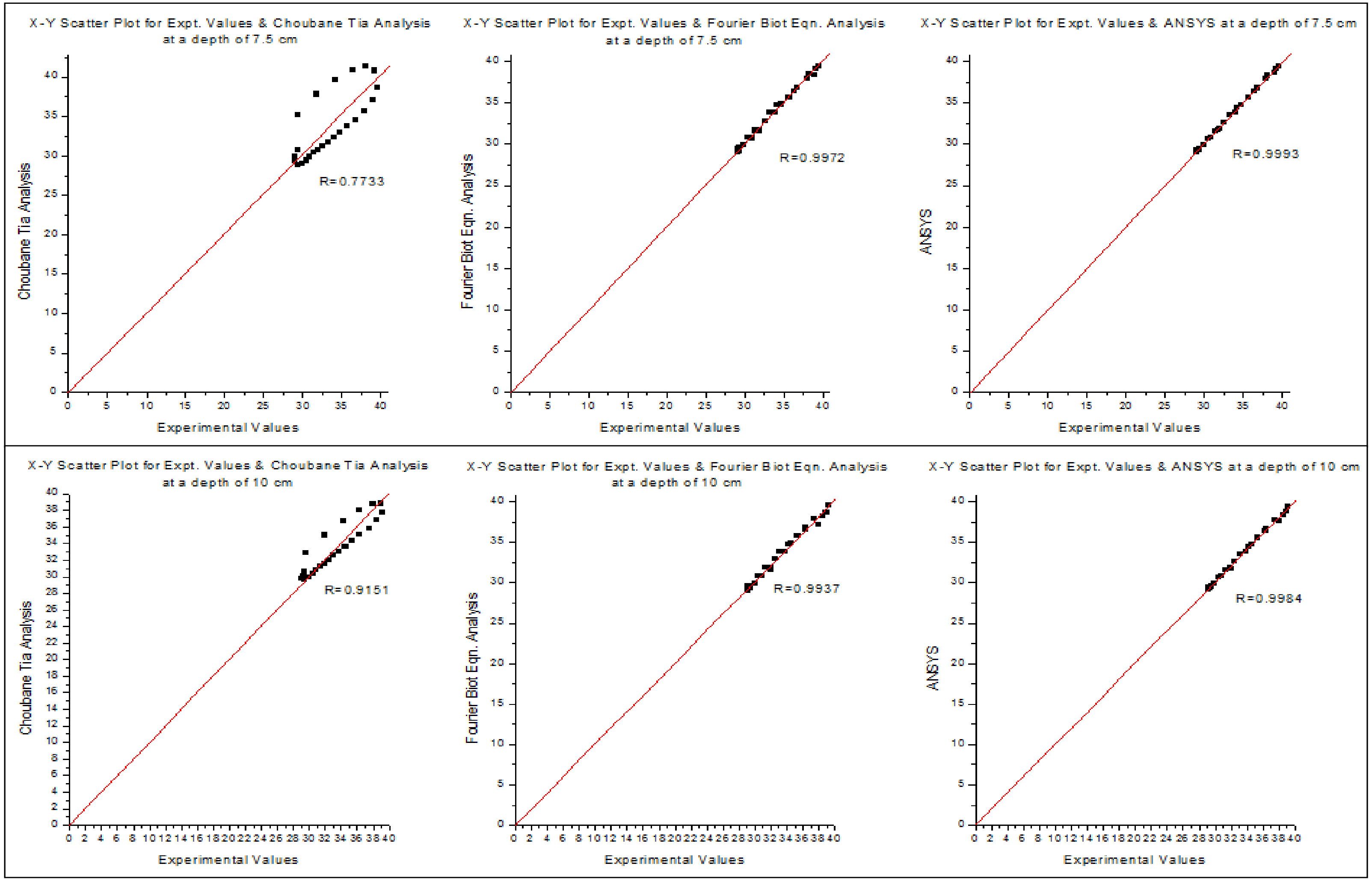


Fig. B-30 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

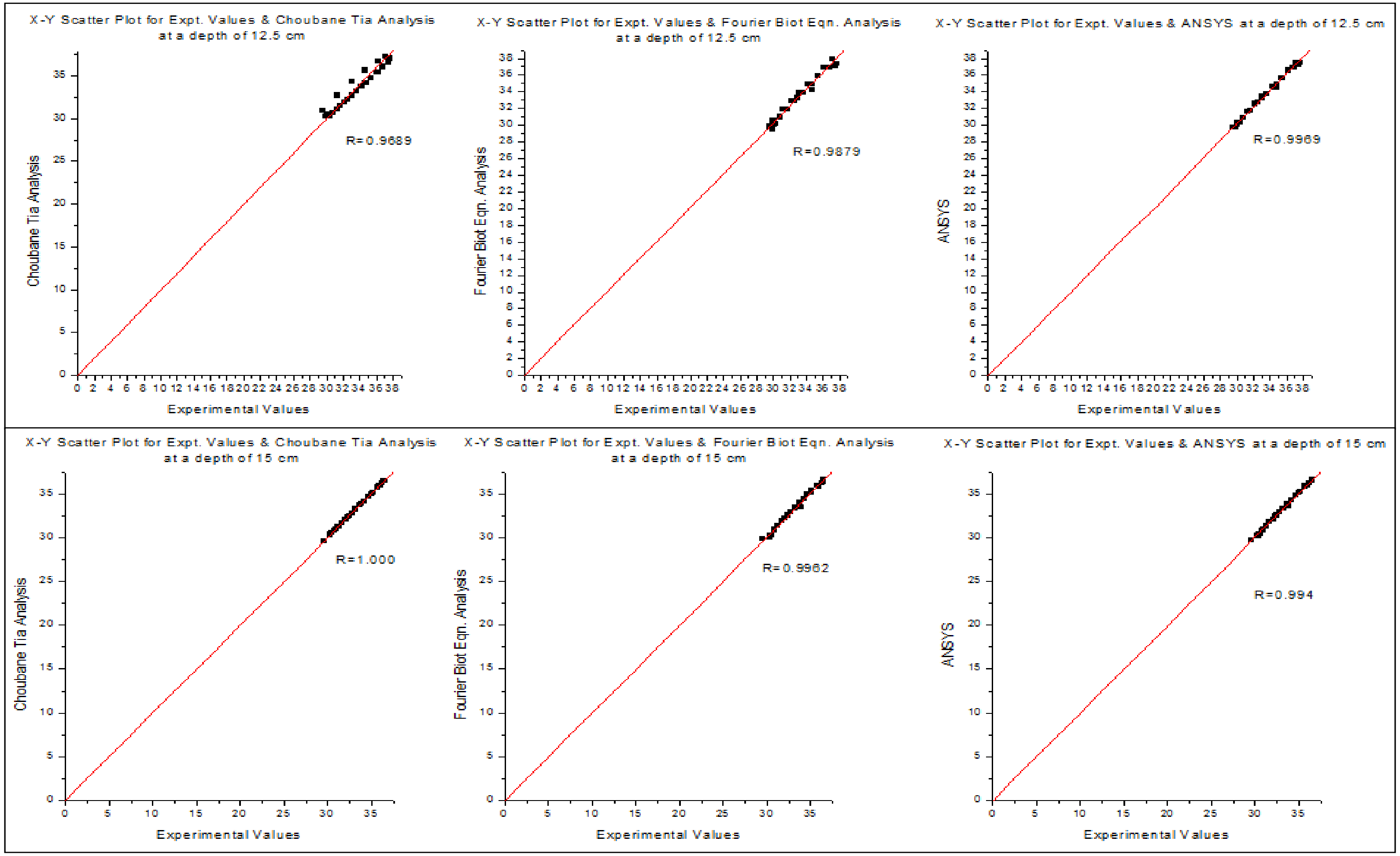


Fig. B-30 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

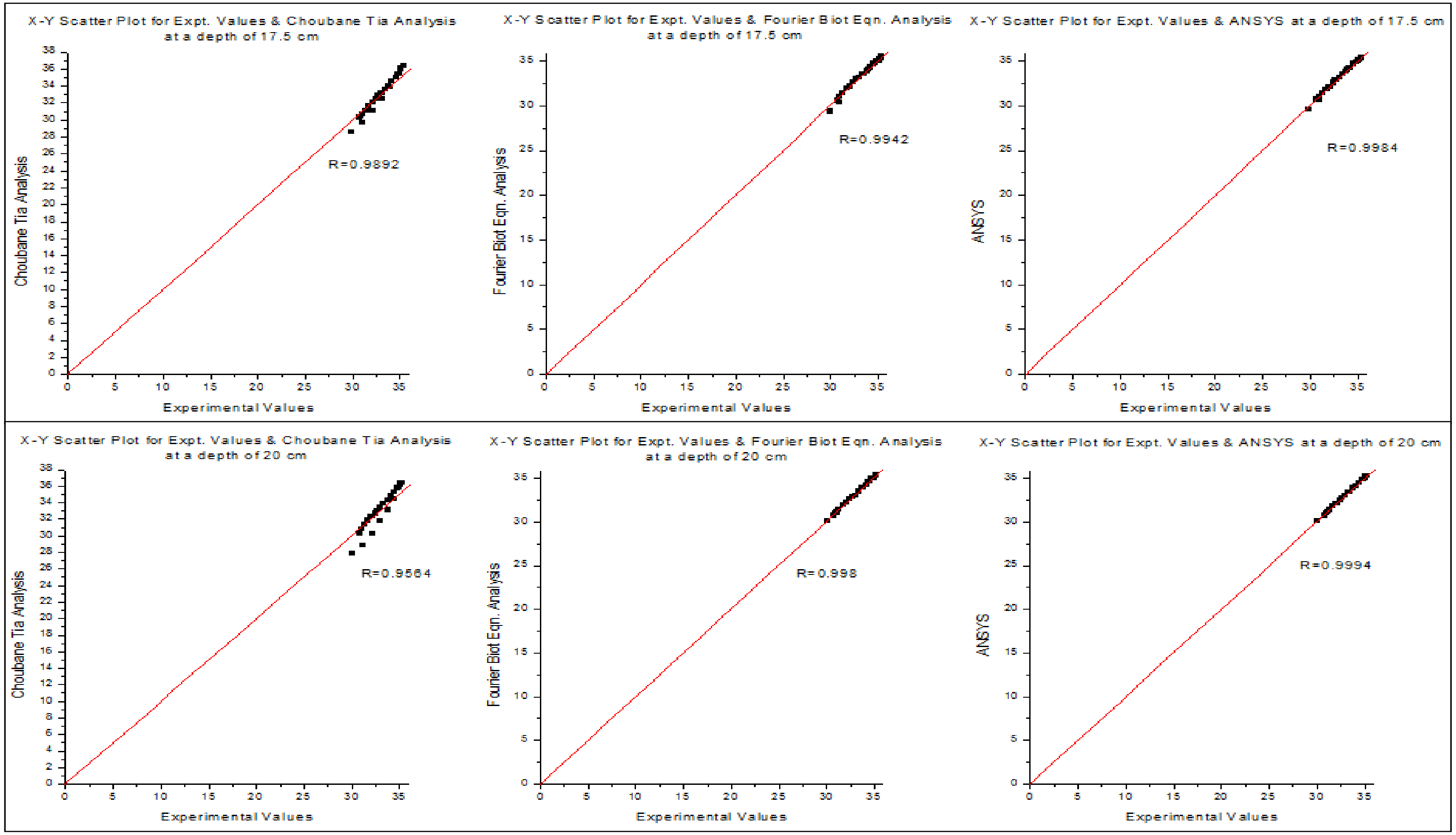


Fig. B-30 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

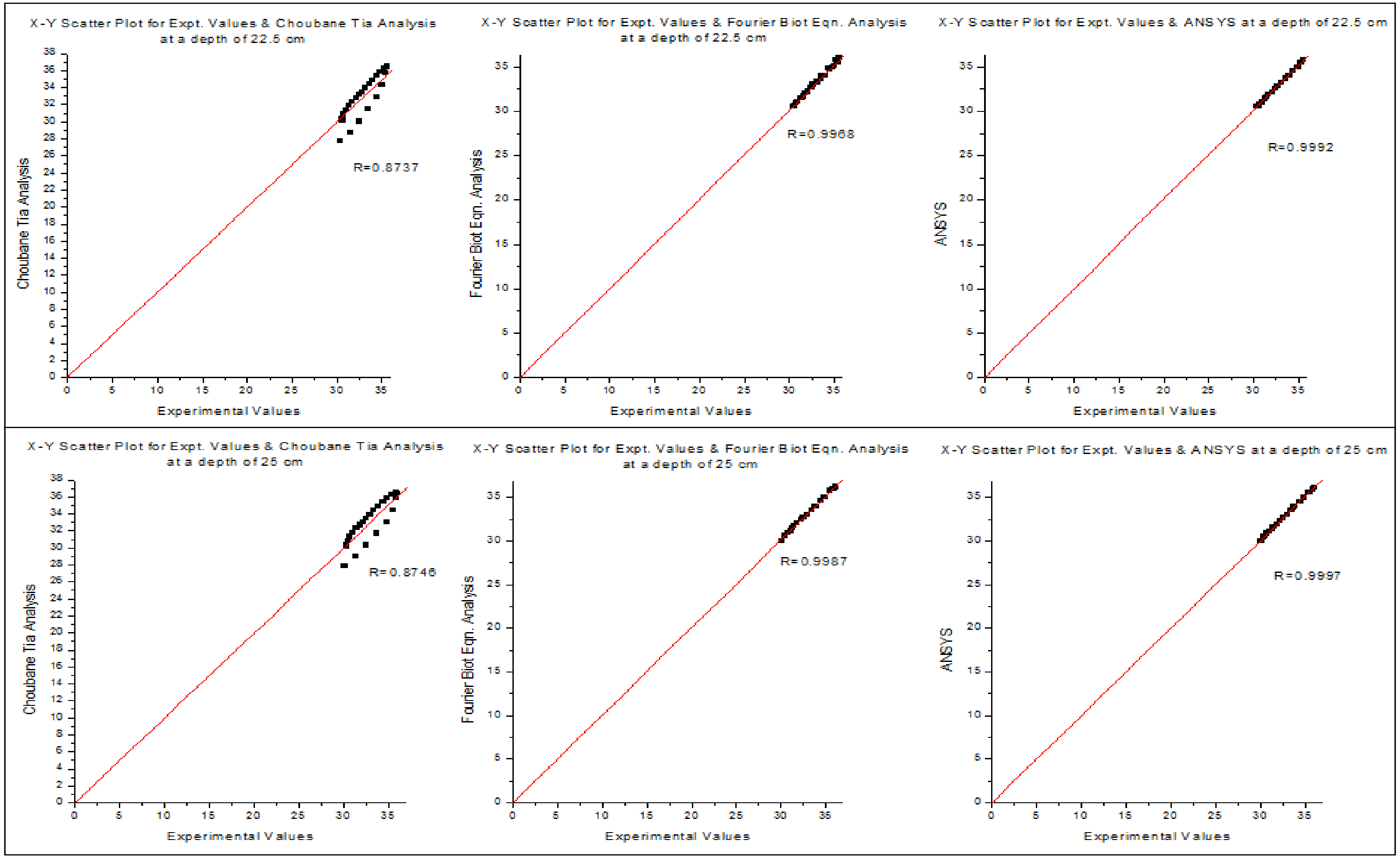


Fig. B-30 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

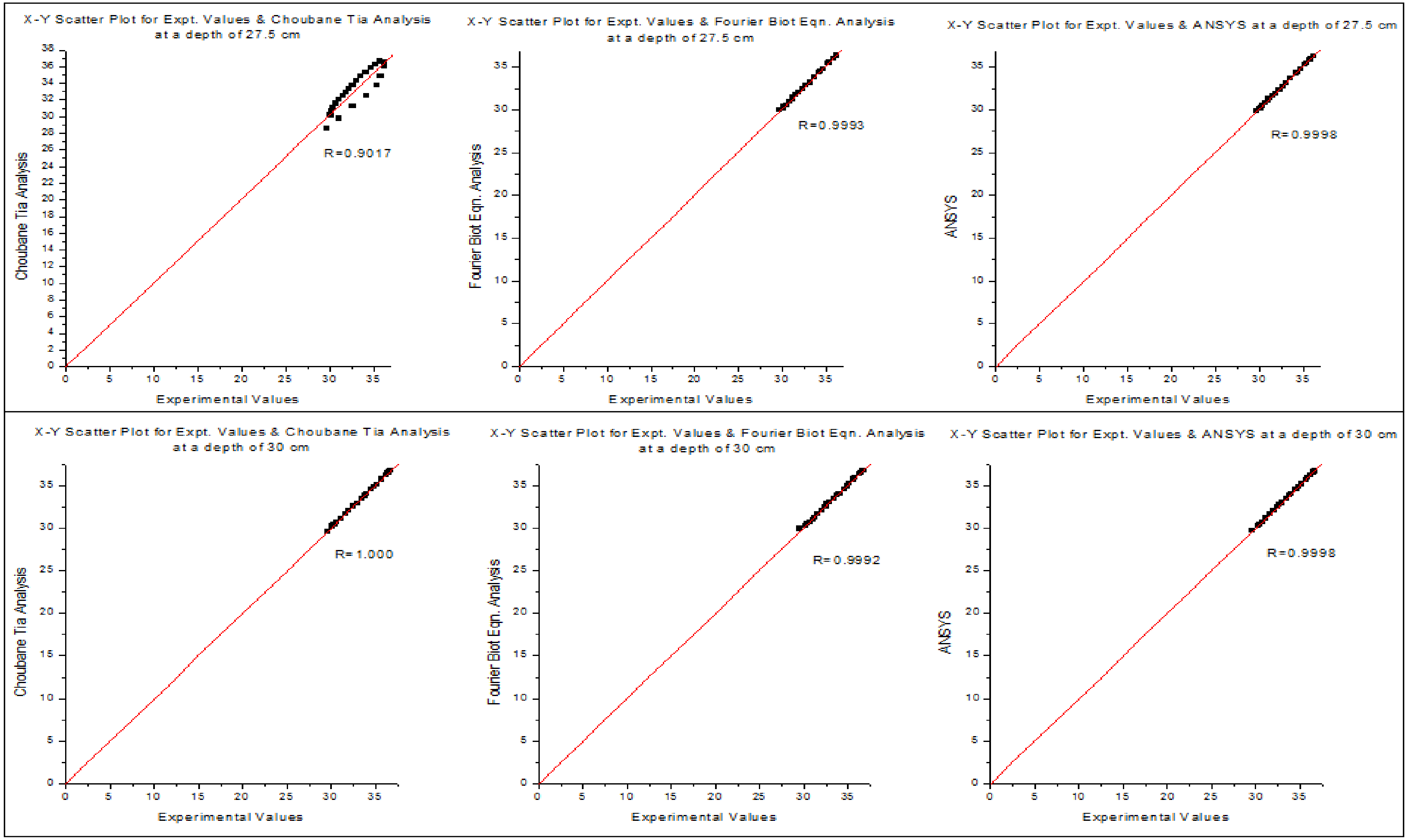


Fig. B-30 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

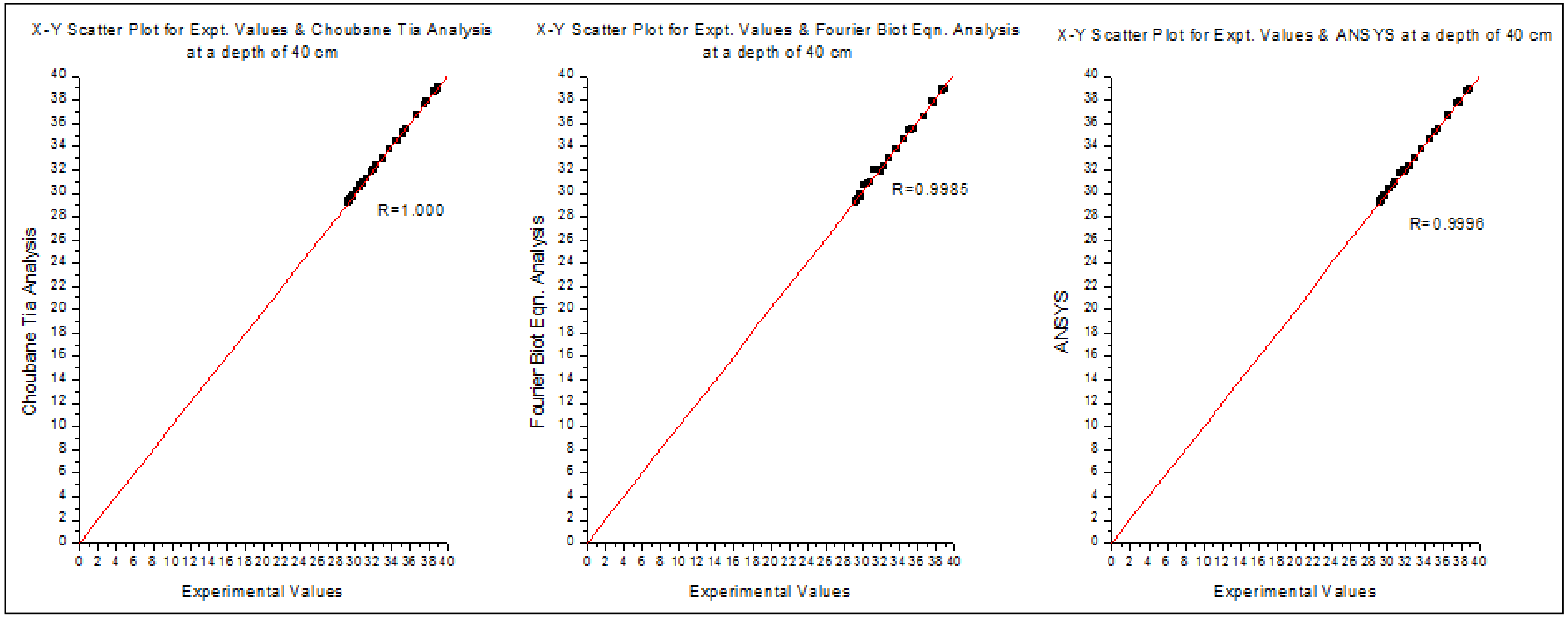


Fig. B-30 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-16 (a): 24 hr. slab (D) temperature values (measured and calculated) for Mix C for maximum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (ºC) at 2.5 cm				Temperature (ºC) at 5 cm				Temperature (ºC) at 7.5 cm			
		(ºC)	(ºC)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	35	43.47	37.08	39.99	37.87	37.48	34.84	36.93	34.54	34.69	32.25	34.31	32.30	32.27
2	1200 to 1300	36	47.25	41.60	42.83	41.24	41.42	39.30	38.97	39.39	39.35	36.16	35.68	36.81	36.48
3	1300 to 1400	37	49.43	44.97	44.54	44.80	44.89	42.84	40.30	42.12	42.48	39.55	36.72	39.64	39.60
4	1400 to 1500	37	50.16	47.39	45.26	47.87	47.63	45.40	41.03	45.53	45.46	42.31	37.47	42.29	42.30
5	1500 to 1600	37	49.19	48.61	44.82	48.87	48.74	46.78	41.05	46.79	46.78	44.17	37.88	44.25	44.21
6	1600 to 1700	36	45.49	47.57	42.30	47.48	47.52	46.68	39.56	46.92	46.80	44.90	37.27	44.54	44.72
7	1700 to 1800	36	40.59	43.30	38.92	43.62	43.46	43.65	37.50	43.26	43.45	43.52	36.34	43.35	43.43
8	1800 to 1900	34	37.31	39.88	36.71	40.00	39.94	40.55	36.22	40.65	40.60	41.29	35.82	41.41	41.35
9	1900 to 2000	33	35.22	37.01	35.33	37.66	37.33	37.79	35.44	37.78	37.78	38.96	35.54	38.86	38.91
10	2000 to 2100	31	33.74	34.96	34.31	34.45	34.71	35.74	34.80	35.64	35.69	37.05	35.22	37.77	37.41
11	2100 to 2200	29	32.53	33.35	33.39	33.94	33.64	34.12	34.14	34.30	34.21	35.50	34.77	35.56	35.53
12	2200 to 2300	28	31.46	32.03	32.55	32.26	32.15	32.75	33.49	32.52	32.63	34.21	34.28	34.69	34.45
13	2300 to 0000	27	30.58	30.87	31.81	30.36	30.61	31.58	32.87	31.58	31.58	33.05	33.76	33.73	33.39
14	0000 to 0100	26	29.84	30.01	31.15	30.24	30.12	30.64	32.28	30.50	30.57	32.12	33.23	32.68	32.40
15	0100 to 0200	25	29.18	29.20	30.57	29.20	29.20	29.81	31.77	29.48	29.65	31.22	32.77	31.67	31.44
16	0200 to 0300	24	28.62	28.64	30.04	28.94	28.79	29.10	31.27	29.39	29.24	30.54	32.29	30.61	30.57
17	0300 to 0400	23	28.06	28.08	29.51	28.44	28.26	28.56	30.76	28.30	28.43	29.88	31.80	29.56	29.72
18	0400 to 0500	23	27.41	27.48	28.90	27.70	27.59	27.94	30.19	28.00	27.97	29.25	31.27	29.63	29.44
19	0500 to 0600	23	26.86	26.91	28.38	27.00	26.95	27.32	29.69	27.49	27.41	28.70	30.79	28.68	28.69
20	0600 to 0700	24	26.54	26.49	28.06	26.41	26.45	26.85	29.37	26.61	26.73	28.15	30.47	28.76	28.45
21	0700 to 0800	26	27.10	26.50	28.37	26.66	26.58	26.73	29.46	26.59	26.66	27.82	30.37	27.44	27.63
22	0800 to 0900	28	28.34	27.22	29.20	27.33	27.28	27.16	29.93	27.45	27.30	27.94	30.53	27.68	27.81
23	0900 to 1000	31	29.97	28.60	30.31	28.53	28.56	28.21	30.60	28.71	28.46	28.52	30.82	28.37	28.45
24	1000 to 1100	33	33.97	30.76	33.28	30.23	30.49	29.79	32.66	29.34	29.57	29.39	32.11	29.91	29.65

Table B-16 (b): 24 hr. slab (D) temperature values (measured and calculated) for Mix C for maximum ambient air temperature at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (ºC) at 10 cm				Temperature (ºC) at 12.5 cm				Temperature (ºC) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	30.24	32.11	30.39	30.32	29.19	30.34	29.85	29.52	29.01	29.01	29.82	29.41
2	1200 to 1300	33.17	32.96	33.66	33.42	31.25	30.80	32.00	31.62	29.20	29.20	29.39	29.30
3	1300 to 1400	35.96	33.79	35.58	35.77	33.50	31.51	33.95	33.72	29.88	29.88	29.86	29.87
4	1400 to 1500	38.47	34.58	38.39	38.43	35.64	32.36	35.85	35.74	30.82	30.82	30.82	30.82
5	1500 to 1600	40.44	35.31	40.83	40.63	37.48	33.35	37.54	37.51	31.98	31.98	32.00	31.99
6	1600 to 1700	41.71	35.44	41.90	41.81	38.82	34.06	38.04	38.43	33.14	33.14	33.46	33.30
7	1700 to 1800	41.81	35.43	41.73	41.77	39.53	34.77	39.40	39.46	34.36	34.36	34.58	34.47
8	1800 to 1900	40.84	35.53	40.24	40.54	39.34	35.35	39.14	39.24	35.26	35.26	35.37	35.31
9	1900 to 2000	39.42	35.64	39.92	39.67	38.61	35.74	38.95	38.78	35.84	35.84	35.98	35.91
10	2000 to 2100	38.00	35.57	38.87	38.43	37.71	35.85	37.92	37.82	36.05	36.05	36.26	36.16
11	2100 to 2200	36.71	35.28	36.74	36.73	36.75	35.68	36.85	36.80	35.96	35.96	36.00	35.98
12	2200 to 2300	35.59	34.92	35.82	35.71	35.89	35.41	35.90	35.89	35.75	35.75	35.95	35.85
13	2300 to 0000	34.57	34.48	34.85	34.71	35.00	35.03	35.91	35.45	35.41	35.41	35.66	35.53
14	0000 to 0100	33.66	33.99	33.82	33.74	34.25	34.57	34.89	34.57	34.97	34.97	34.95	34.96
15	0100 to 0200	32.83	33.57	32.81	32.82	33.49	34.18	33.89	33.69	34.59	34.59	34.95	34.77
16	0200 to 0300	32.15	33.12	32.77	32.46	32.79	33.75	32.87	32.83	34.17	34.17	34.47	34.32
17	0300 to 0400	31.46	32.64	31.74	31.60	32.23	33.28	32.85	32.54	33.72	33.72	33.93	33.82
18	0400 to 0500	30.85	32.15	30.78	30.82	31.62	32.81	31.88	31.75	33.27	33.27	33.74	33.50
19	0500 to 0600	30.32	31.68	30.81	30.57	31.05	32.36	31.89	31.47	32.82	32.82	32.95	32.88
20	0600 to 0700	29.75	31.35	29.86	29.80	30.57	32.02	30.92	30.74	32.48	32.48	32.66	32.57
21	0700 to 0800	29.23	31.10	29.25	29.24	30.04	31.65	30.15	30.09	32.02	32.02	32.07	32.05
22	0800 to 0900	29.01	31.01	29.97	29.49	29.69	31.36	29.56	29.62	31.58	31.58	31.73	31.66
23	0900 to 1000	29.15	31.00	29.54	29.35	29.59	31.11	29.46	29.52	31.17	31.17	31.28	31.22
24	1000 to 1100	29.54	31.64	29.43	29.48	29.68	31.24	29.97	29.82	30.91	30.91	30.98	30.95

Table B-16 (c): 24 hr. slab (D) temperature values (measured and calculated) for Mix C for maximum ambient air temperature at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (ºC) at 17.5 cm				Temperature (ºC) at 20 cm				Temperature (ºC) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	28.83	28.10	28.37	28.60	28.90	27.62	28.14	28.52	28.99	27.57	29.07	29.03
2	1200 to 1300	29.31	28.17	29.40	29.36	29.54	27.70	29.75	29.64	29.86	27.80	29.92	29.89
3	1300 to 1400	30.32	28.90	30.39	30.36	30.61	28.58	30.95	30.78	31.20	28.91	31.47	31.34
4	1400 to 1500	31.61	29.95	31.77	31.69	31.90	29.75	32.00	31.95	32.82	30.22	33.02	32.92
5	1500 to 1600	33.04	31.22	33.31	33.18	33.20	31.05	33.42	33.31	34.46	31.49	34.78	34.62
6	1600 to 1700	34.46	32.67	34.61	34.53	34.45	32.65	34.68	34.57	35.95	33.08	36.04	35.99
7	1700 to 1800	35.73	34.20	35.88	35.81	35.54	34.30	35.73	35.64	37.08	34.65	37.19	37.14
8	1800 to 1900	36.54	35.27	36.74	36.64	36.26	35.39	36.43	36.35	37.69	35.61	37.88	37.78
9	1900 to 2000	36.86	35.92	36.99	36.92	36.50	36.01	36.99	36.75	37.72	36.09	38.00	37.86
10	2000 to 2100	36.80	36.18	36.95	36.87	36.48	36.24	36.99	36.74	37.35	36.23	37.65	37.50
11	2100 to 2200	36.52	36.12	36.71	36.62	36.26	36.17	36.68	36.47	36.81	36.11	36.99	36.90
12	2200 to 2300	36.14	35.94	36.37	36.26	35.87	35.98	35.99	35.93	36.28	35.87	36.41	36.35
13	2300 to 0000	35.61	35.61	35.98	35.80	35.42	35.64	35.59	35.51	35.62	35.50	35.81	35.72
14	0000 to 0100	35.06	35.19	35.22	35.14	34.92	35.22	34.98	34.95	34.95	35.06	35.00	34.97
15	0100 to 0200	34.55	34.81	34.67	34.61	34.48	34.84	35.54	35.01	34.41	34.67	34.64	34.52
16	0200 to 0300	34.03	34.40	34.17	34.10	33.99	34.42	33.98	33.99	33.82	34.25	33.99	33.91
17	0300 to 0400	33.50	33.95	33.66	33.58	33.49	33.98	33.60	33.55	33.25	33.81	33.69	33.47
18	0400 to 0500	32.99	33.51	33.07	33.03	33.00	33.55	33.08	33.04	32.73	33.38	32.99	32.86
19	0500 to 0600	32.57	33.07	32.97	32.77	32.58	33.12	32.71	32.64	32.32	32.95	32.52	32.42
20	0600 to 0700	32.15	32.72	32.38	32.26	32.17	32.75	32.33	32.25	31.82	32.57	32.00	31.91
21	0700 to 0800	31.66	32.21	31.84	31.75	31.68	32.22	31.82	31.75	31.32	32.04	31.61	31.46
22	0800 to 0900	31.18	31.68	31.34	31.26	31.22	31.65	31.38	31.30	30.87	31.50	31.00	30.93
23	0900 to 1000	30.81	31.17	30.37	30.59	30.84	31.11	31.21	31.03	30.66	31.00	30.87	30.76
24	1000 to 1100	30.65	30.66	30.80	30.73	30.70	30.48	30.92	30.81	30.51	30.38	30.79	30.65

Table B-16 (d): 24 hr. slab (D) temperature values (measured and calculated) for Mix C for maximum ambient air temperature at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	29.10	27.95	29.38	29.24	31.40	28.76	31.99	31.69	30.01	30.01	30.92	30.46	29.88	29.88	29.85	29.86
2	1200 to 1300	30.39	28.46	30.50	30.45	34.15	29.69	34.98	34.56	31.48	31.48	31.91	31.69	31.55	31.55	31.83	31.69
3	1300 to 1400	32.09	29.90	32.20	32.14	36.72	31.54	36.99	36.85	33.83	33.83	33.91	33.87	33.71	33.71	33.84	33.77
4	1400 to 1500	33.86	31.37	34.00	33.93	38.77	33.18	38.99	38.88	35.67	35.67	35.92	35.79	34.74	34.74	34.85	34.79
5	1500 to 1600	35.51	32.53	35.71	35.61	40.28	34.17	40.99	40.63	36.41	36.41	36.93	36.67	34.62	34.62	34.87	34.75
6	1600 to 1700	36.90	33.97	37.00	36.95	41.01	35.32	41.39	41.20	37.11	37.11	37.15	37.13	34.63	34.63	34.71	34.67
7	1700 to 1800	37.88	35.25	38.00	37.94	40.32	36.11	40.61	40.46	37.21	37.21	37.28	37.25	34.79	34.79	34.87	34.83
8	1800 to 1900	38.13	35.93	38.31	38.22	39.11	36.35	39.58	39.35	36.88	36.88	36.90	36.89	34.80	34.80	34.99	34.90
9	1900 to 2000	37.87	36.17	38.02	37.95	37.75	36.25	37.92	37.84	36.32	36.32	36.35	36.34	34.64	34.64	34.70	34.67
10	2000 to 2100	37.27	36.15	37.80	37.54	36.55	35.99	36.64	36.59	35.76	35.76	35.80	35.78	34.44	34.44	34.50	34.47
11	2100 to 2200	36.58	35.93	36.81	36.70	35.49	35.63	35.71	35.60	35.21	35.21	35.30	35.26	34.12	34.12	34.21	34.16
12	2200 to 2300	35.90	35.61	36.00	35.95	34.55	35.19	34.71	34.63	34.63	34.63	34.65	34.64	33.76	33.76	33.81	33.78
13	2300 to 0000	35.15	35.19	35.30	35.22	33.69	34.71	33.85	33.77	34.06	34.06	34.10	34.08	33.39	33.39	33.42	33.40
14	0000 to 0100	34.50	34.73	34.81	34.65	32.91	34.21	33.07	32.99	33.51	33.51	33.55	33.53	32.99	32.99	33.01	33.00
15	0100 to 0200	33.86	34.30	34.00	33.93	32.31	33.74	32.67	32.49	32.98	32.98	33.00	32.99	32.64	32.64	32.71	32.67
16	0200 to 0300	33.23	33.87	33.47	33.35	31.69	33.30	31.85	31.77	32.52	32.52	32.60	32.56	32.33	32.33	32.41	32.37
17	0300 to 0400	32.69	33.43	32.91	32.80	31.16	32.86	31.35	31.26	32.08	32.08	32.00	32.04	31.98	31.98	32.01	32.00
18	0400 to 0500	32.22	33.01	32.41	32.32	30.69	32.42	30.91	30.80	31.63	31.63	31.70	31.66	31.63	31.63	31.71	31.67
19	0500 to 0600	31.73	32.56	32.00	31.86	30.22	31.97	30.40	30.31	31.17	31.17	31.30	31.23	31.27	31.27	31.31	31.29
20	0600 to 0700	31.23	32.17	31.40	31.31	29.73	31.56	30.02	29.87	30.74	30.74	30.80	30.77	30.90	30.90	31.00	30.95
21	0700 to 0800	30.77	31.69	31.01	30.89	29.36	31.16	29.71	29.54	30.44	30.44	30.50	30.47	30.62	30.62	30.64	30.63
22	0800 to 0900	30.42	31.22	30.60	30.51	29.29	30.81	29.49	29.39	30.28	30.28	30.30	30.29	30.42	30.42	30.47	30.44
23	0900 to 1000	30.18	30.83	30.31	30.24	29.56	30.60	29.81	29.68	30.32	30.32	30.30	30.31	30.40	30.40	30.32	30.36
24	1000 to 1100	30.11	30.34	30.19	30.15	30.12	30.39	30.96	30.54	30.50	30.50	31.00	30.75	30.52	30.52	30.49	30.50

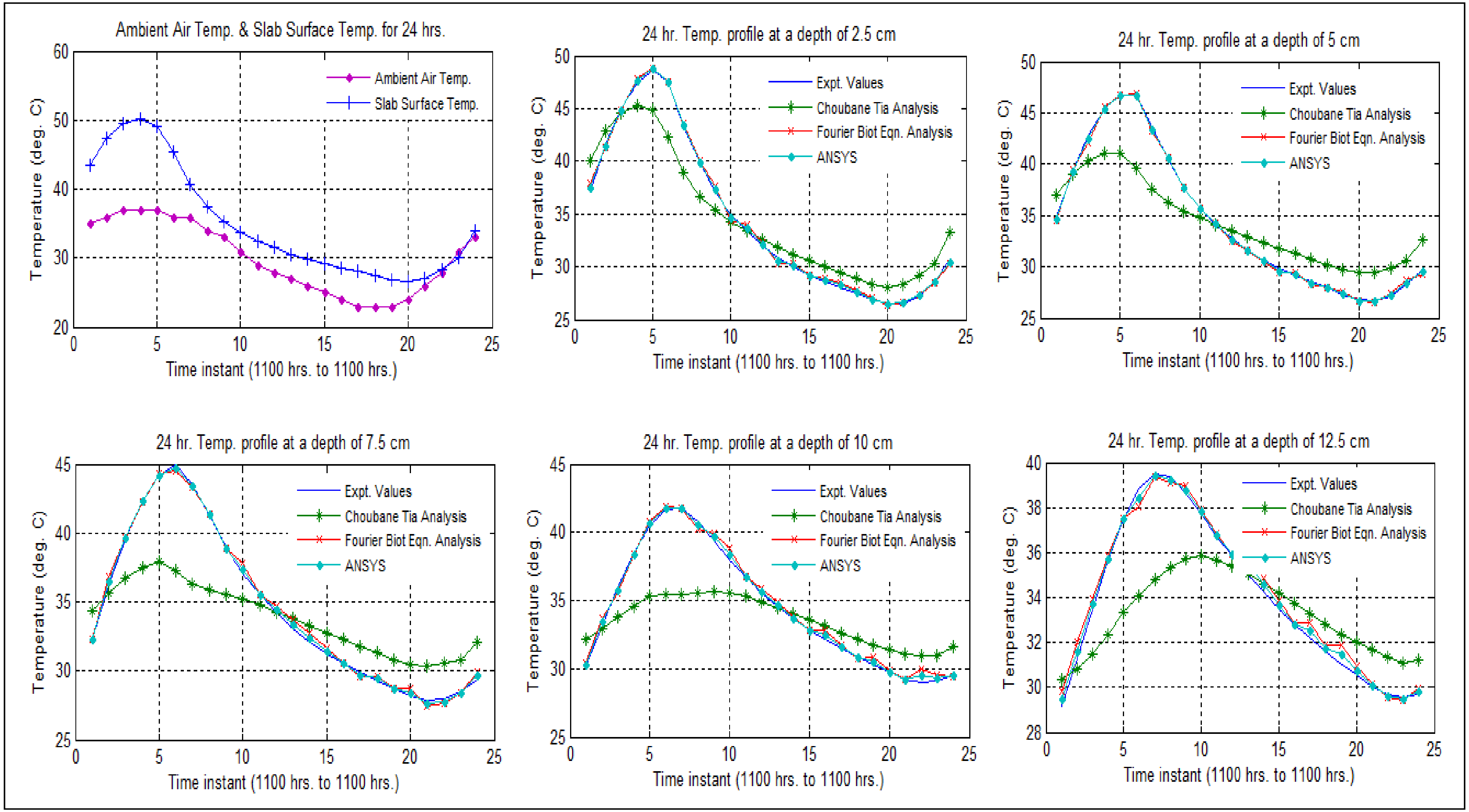


Fig. B-31 (a): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix C for maximum ambient air temperature (surface to 12.5 cm)

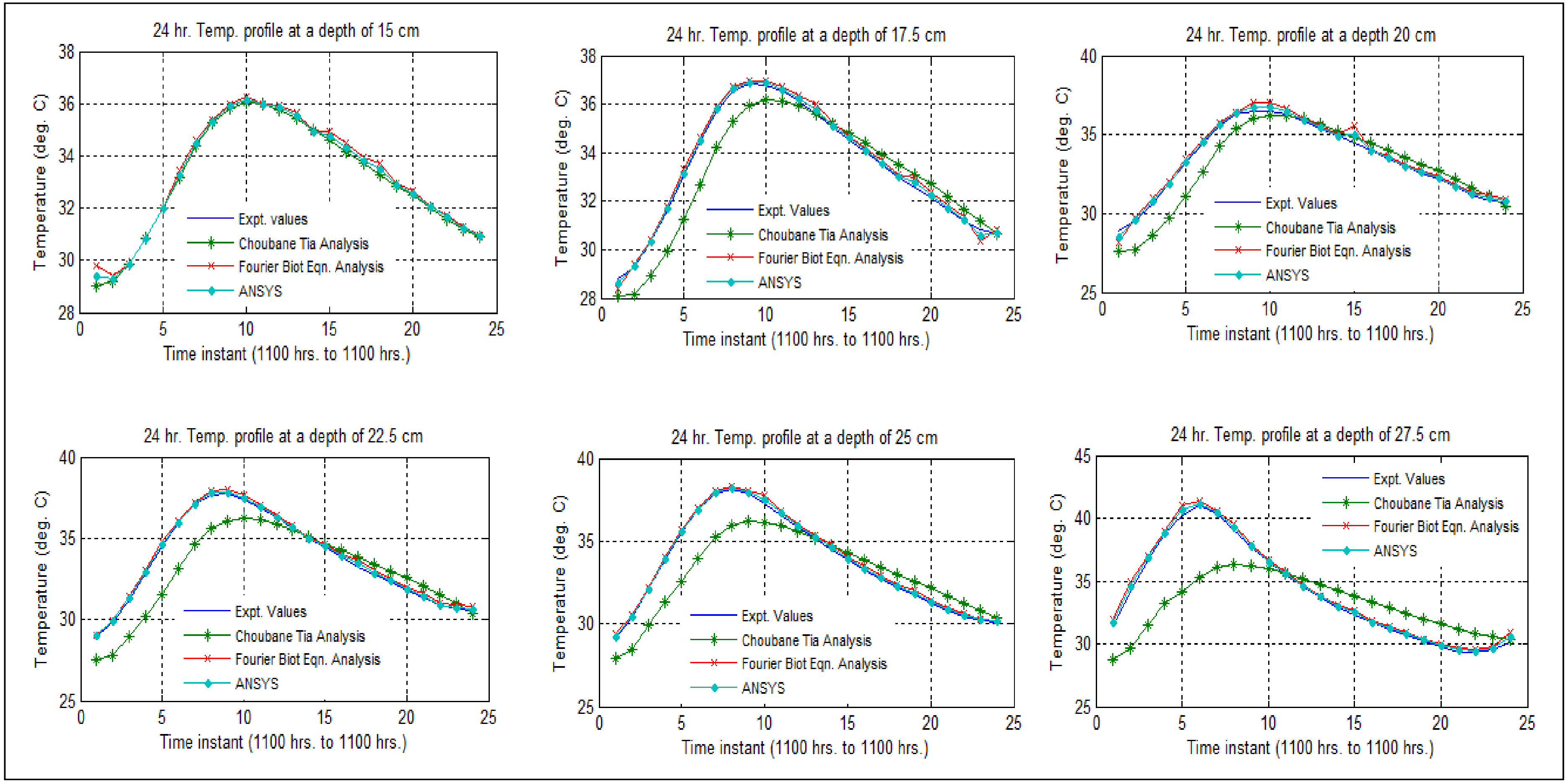


Fig. B-31 (b): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix C for maximum ambient air temperature (15 cm to 27.5 cm)

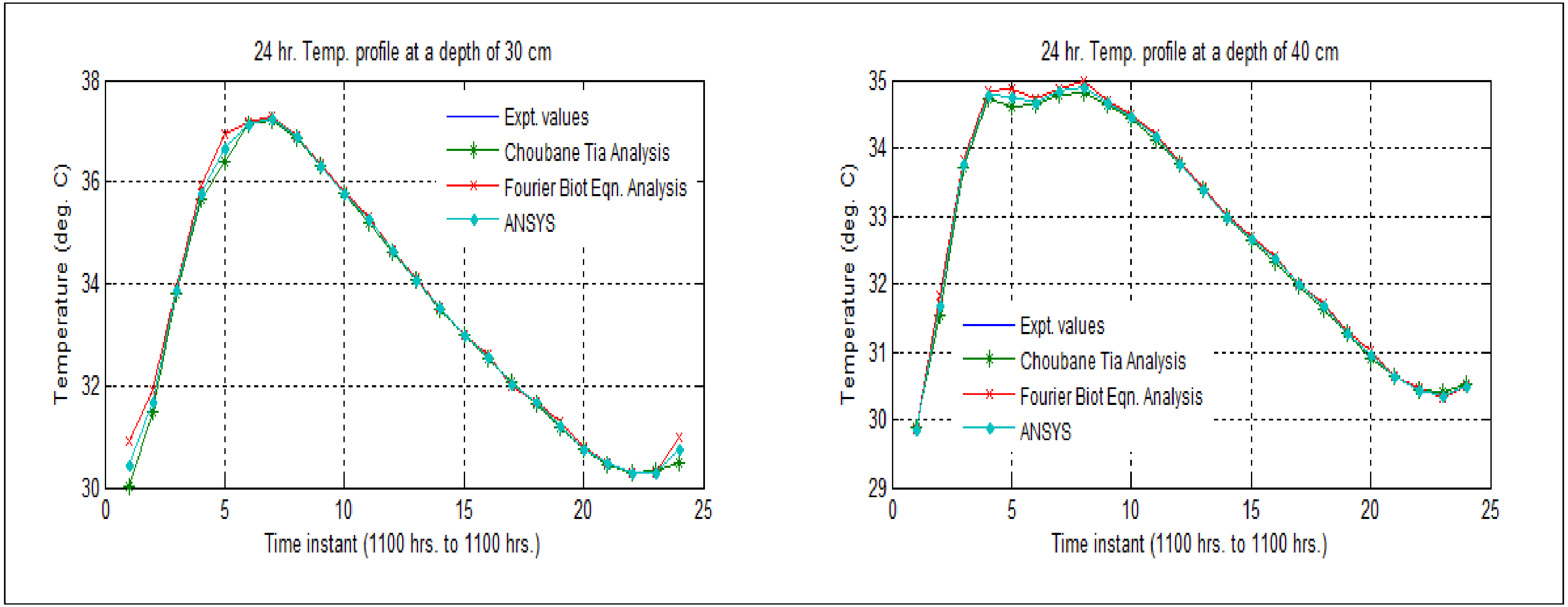


Fig. B-31 (c): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix C for maximum ambient air temperature (30 cm & 40 cm)

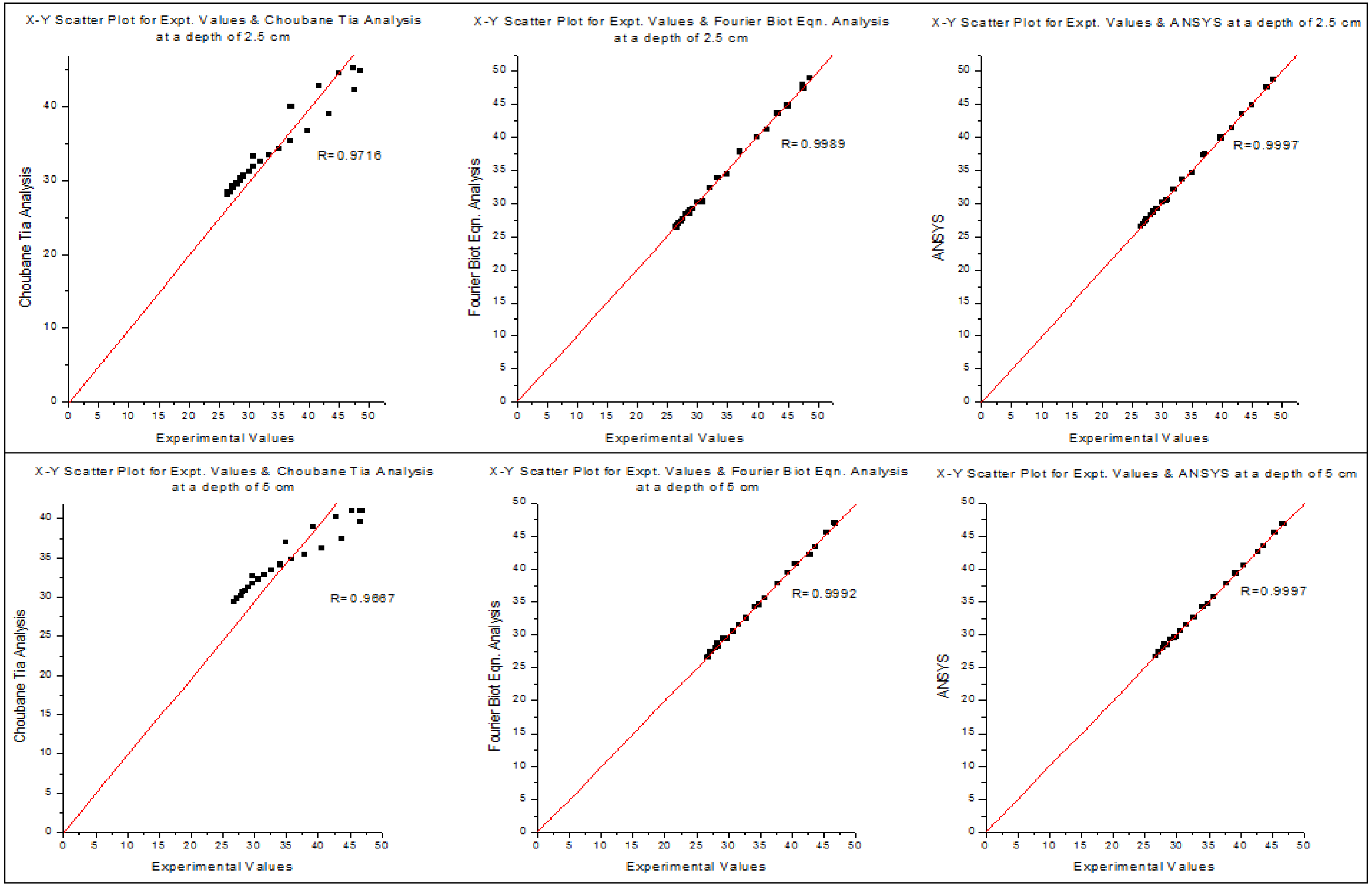


Fig. B-32 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

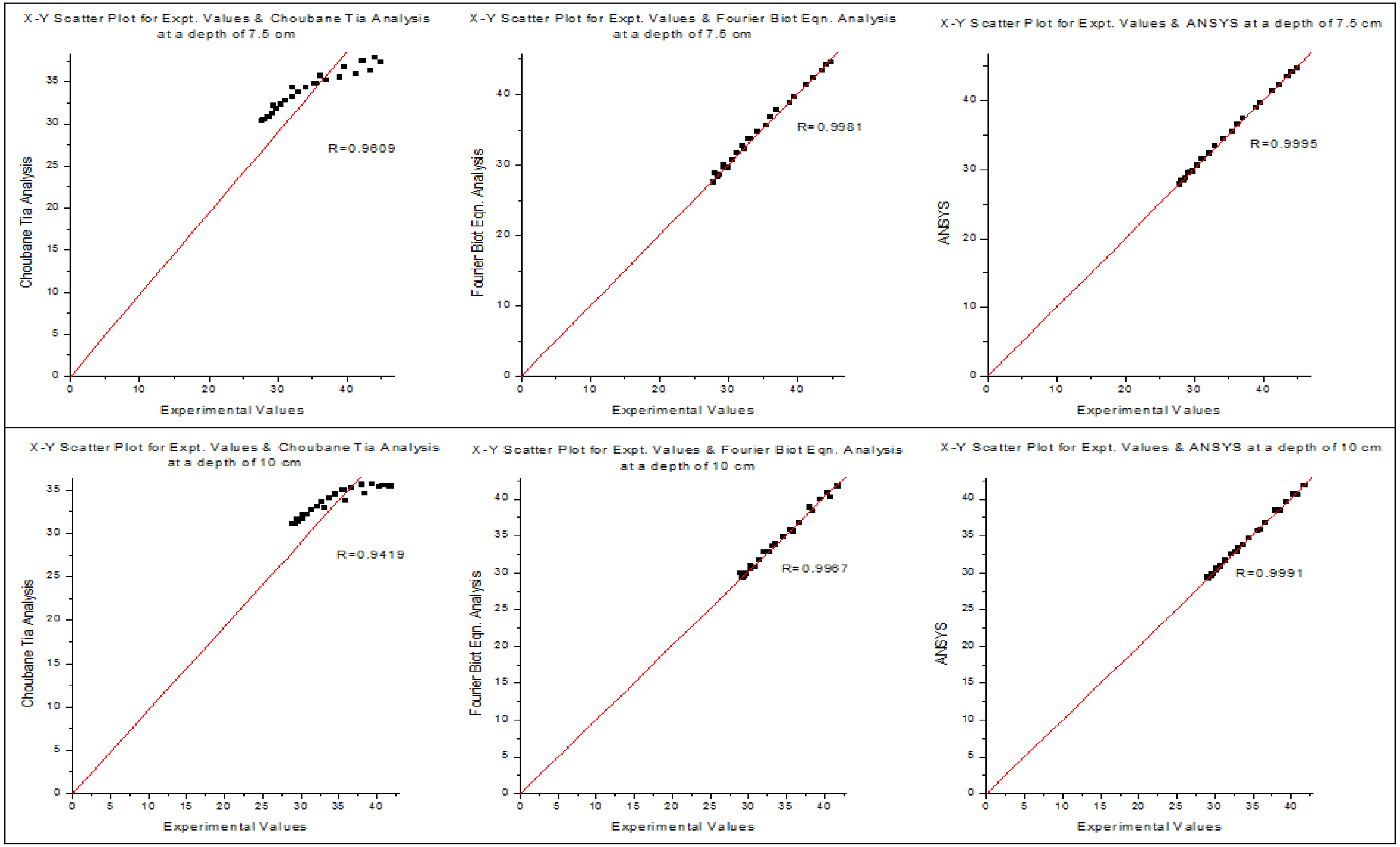


Fig. B-32 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

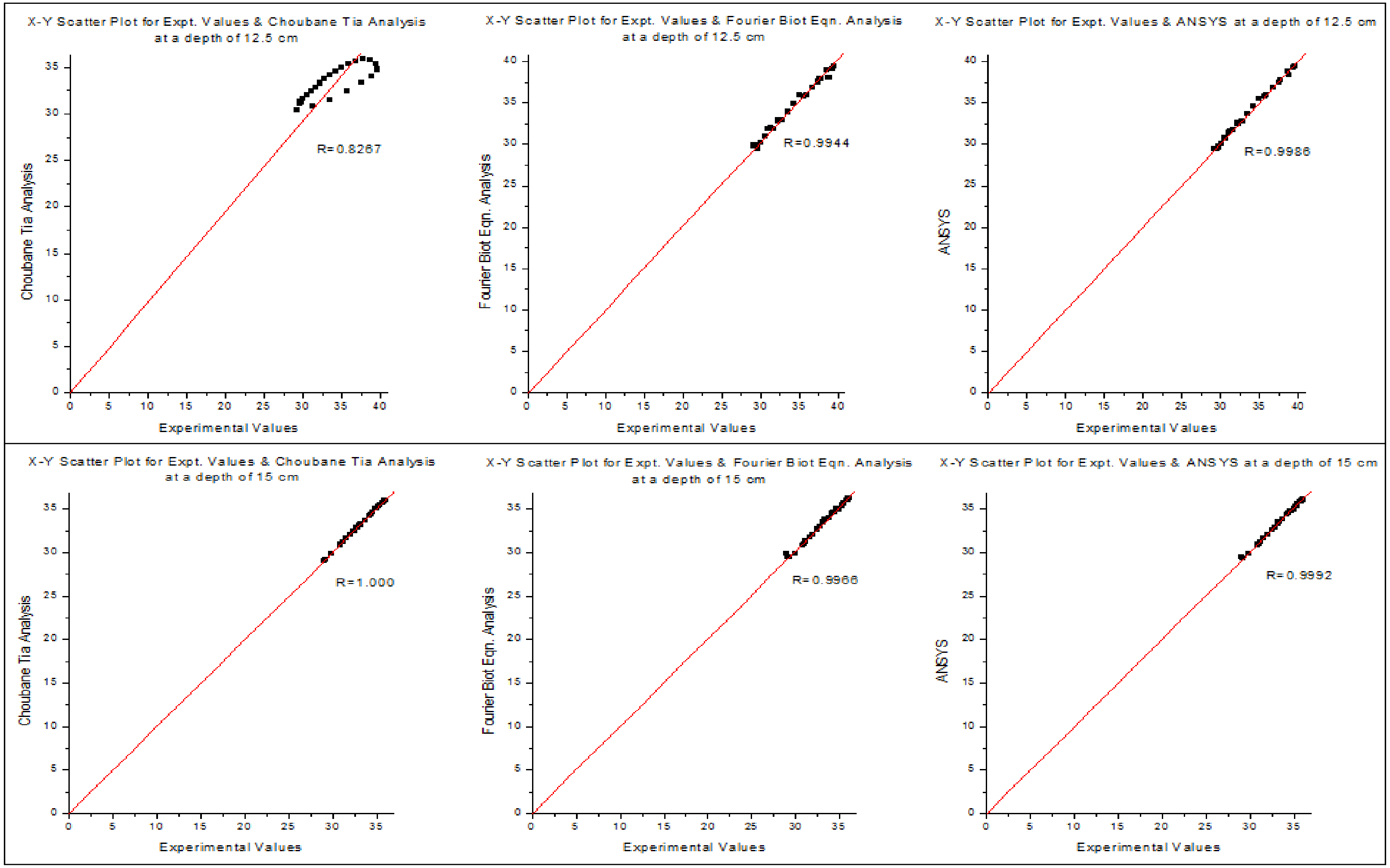


Fig. B-32 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

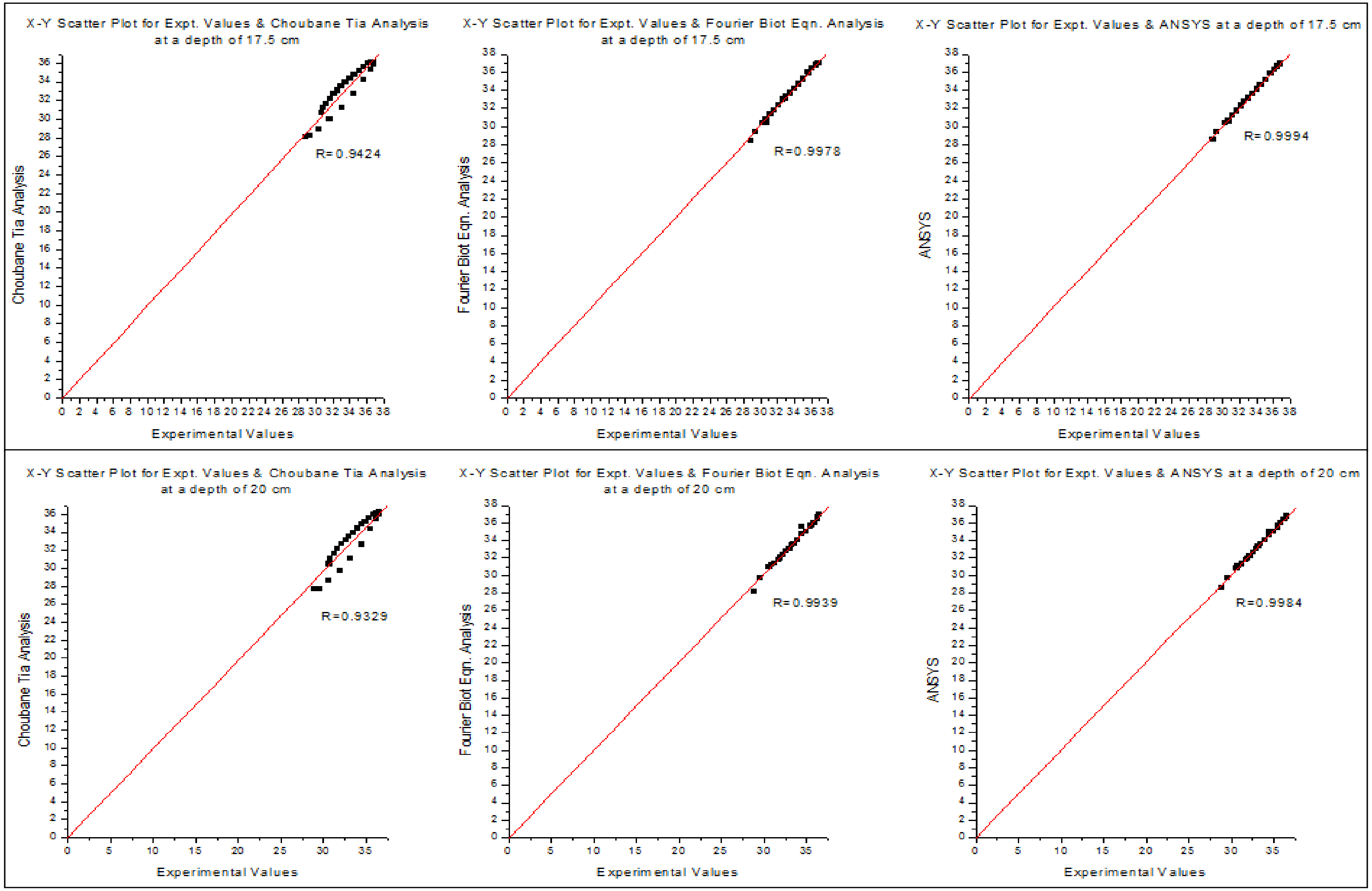


Fig. B-32 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

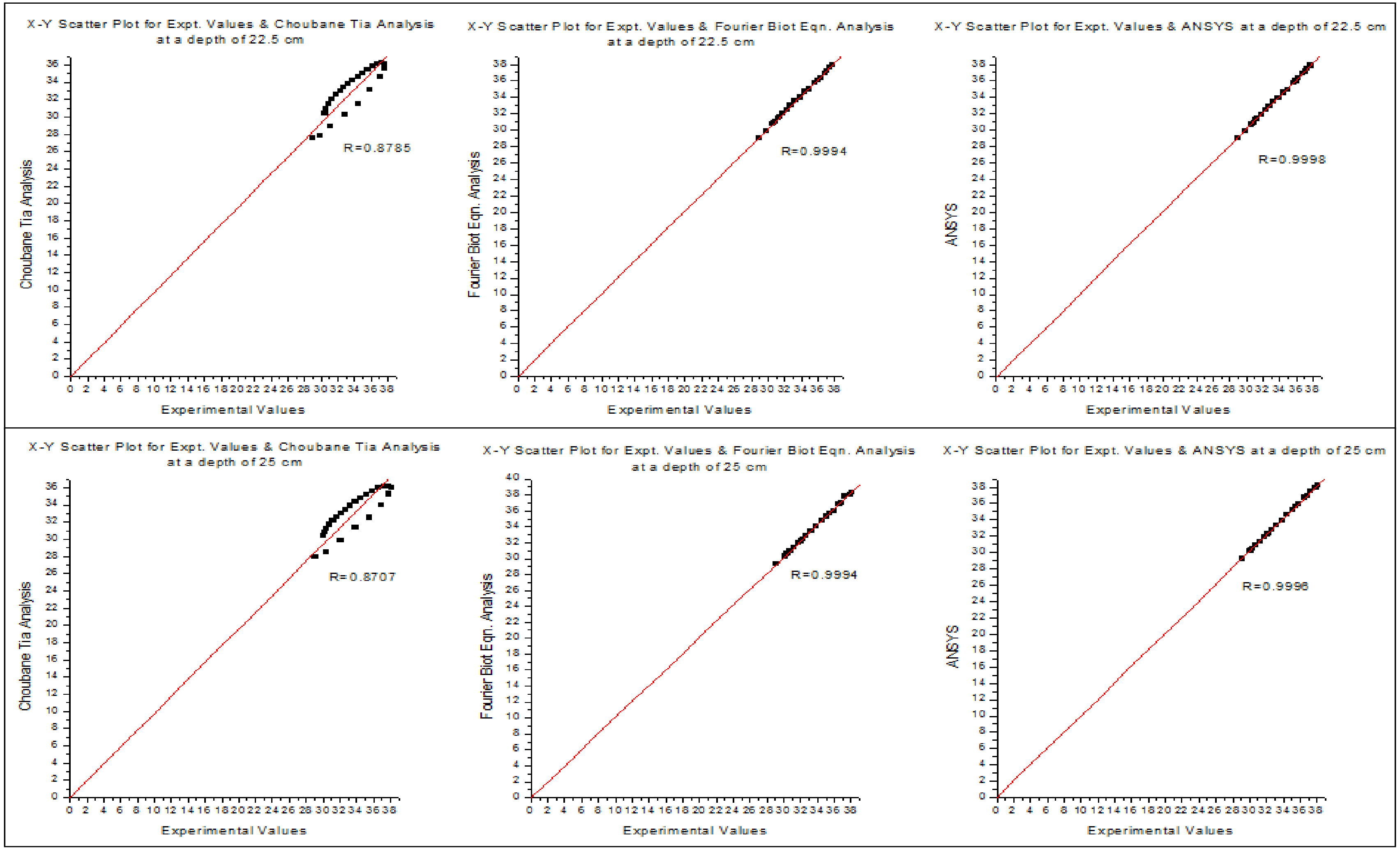


Fig. B-32 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

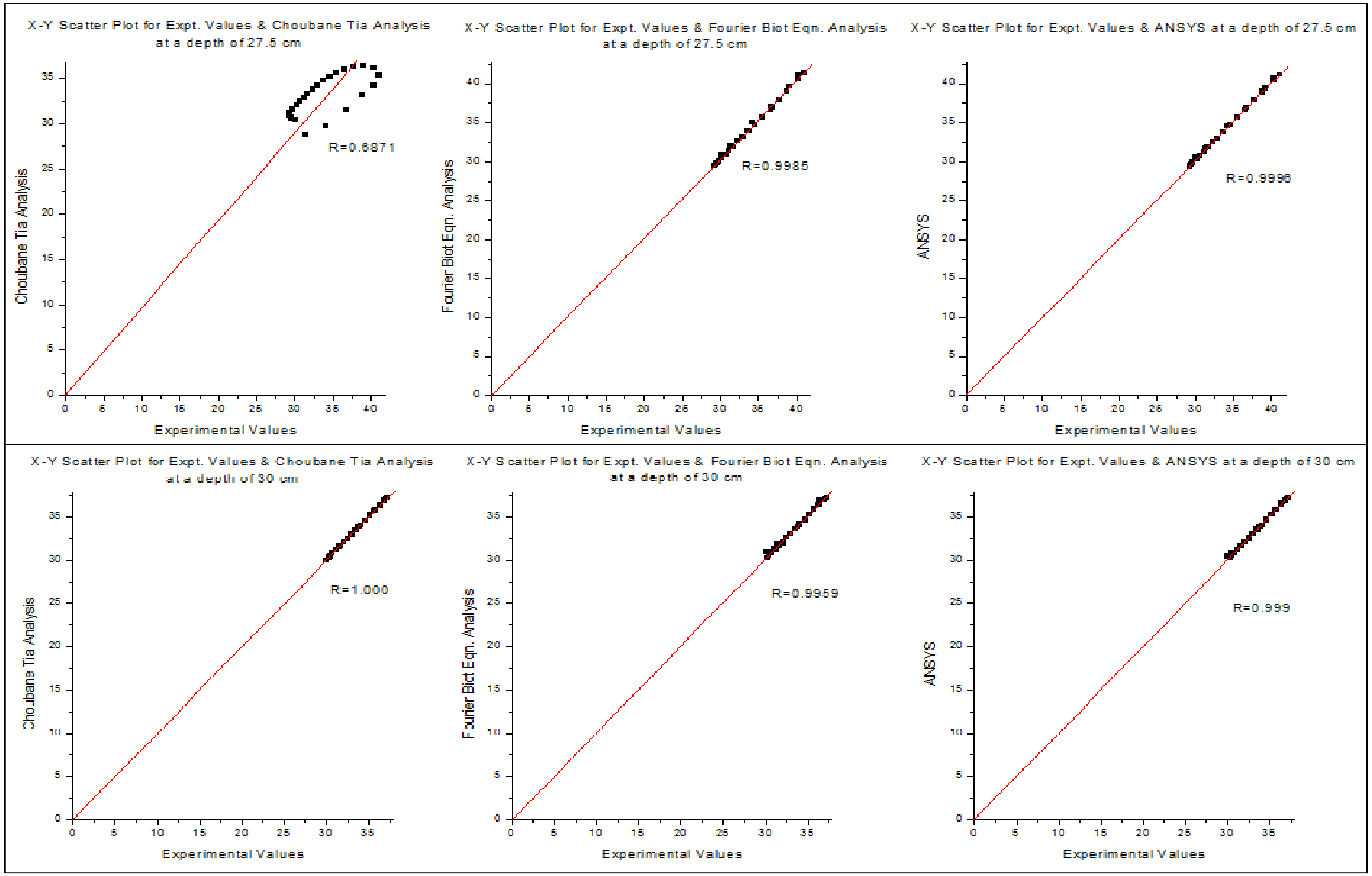


Fig. B-32 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

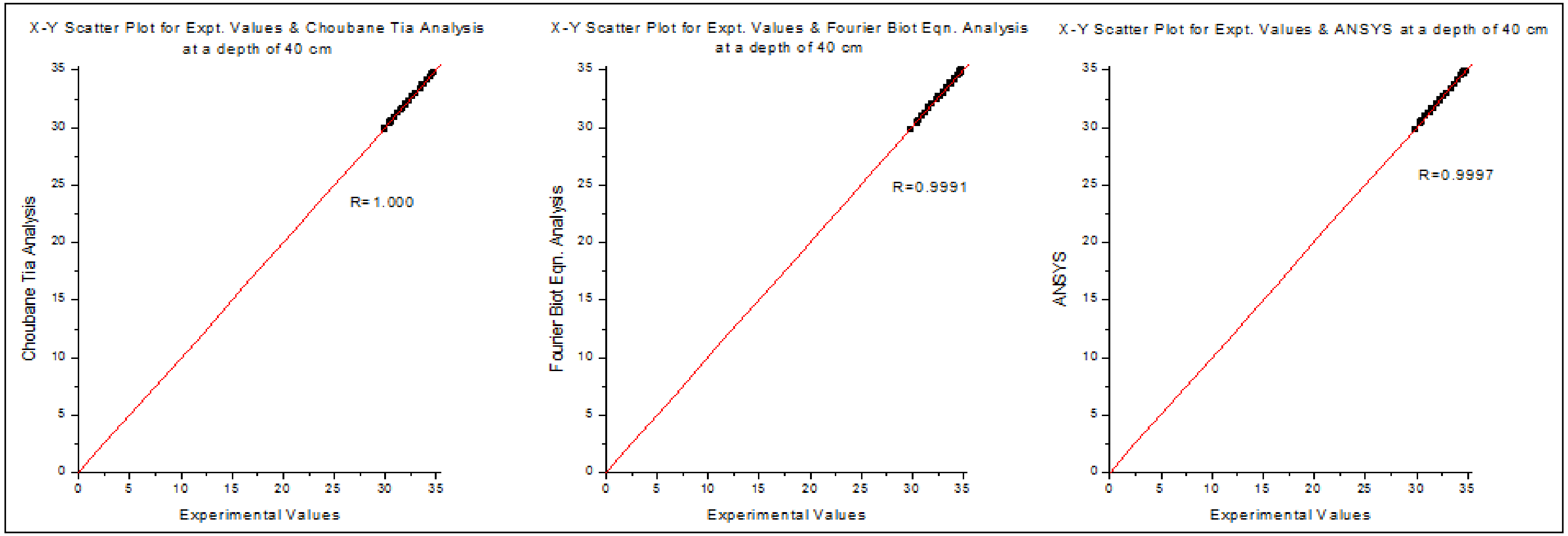


Fig. B-32 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-17 (a): 24 hr. slab (edge) temperature values (measured and calculated) for Mix C for minimum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	26	24.58	23.35	24.24	23.63	23.49	22.95	23.93	22.04	22.49	22.76	23.67	22.93	22.84
2	1130 to 1230	28	27.40	24.86	26.44	24.17	24.51	23.97	25.59	23.36	23.66	23.21	24.85	23.39	23.30
3	1230 to 1330	29	28.87	25.82	27.64	25.23	25.52	24.94	26.54	24.09	24.51	23.83	25.60	23.59	23.71
4	1330 to 1430	29	30.55	27.87	29.03	27.05	27.46	26.52	27.70	26.26	26.39	24.67	26.54	24.59	24.63
5	1430 to 1530	30	24.32	25.63	24.39	25.53	25.58	25.99	24.45	25.32	25.65	25.28	24.50	25.47	25.37
6	1530 to 1630	29	20.73	21.03	21.44	21.63	21.33	22.59	22.08	22.72	22.66	24.27	22.64	24.09	24.18
7	1630 to 1730	29	20.75	20.50	21.25	20.08	20.29	21.37	21.70	21.68	21.52	22.96	22.11	22.70	22.83
8	1730 to 1830	27	19.85	19.79	20.44	19.44	19.61	20.58	20.97	20.26	20.42	22.20	21.45	22.43	22.31
9	1830 to 1930	26	18.87	19.06	19.61	19.01	19.03	19.92	20.27	19.32	19.62	21.65	20.86	21.83	21.74
10	1930 to 2030	24	18.09	18.47	18.96	18.75	18.61	19.35	19.74	19.15	19.25	21.21	20.43	21.73	21.47
11	2030 to 2130	23	17.87	18.24	18.75	18.47	18.35	18.92	19.53	18.96	18.94	20.80	20.22	20.61	20.70
12	2130 to 2230	21	17.58	18.13	18.49	18.67	18.40	18.74	19.30	18.44	18.59	20.49	20.01	20.28	20.38
13	2230 to 2330	20	16.92	17.71	17.93	17.69	17.70	18.40	18.82	18.45	18.42	20.17	19.61	20.29	20.23
14	2330 to 0030	19	16.58	17.36	17.62	17.62	17.49	18.11	18.53	18.41	18.26	19.94	19.33	19.26	19.60
15	0030 to 0130	18	16.62	17.28	17.59	17.36	17.32	17.90	18.46	17.24	17.57	19.69	19.21	19.15	19.42
16	0130 to 0230	18	17.27	17.53	18.04	17.19	17.36	17.92	18.72	17.13	17.52	19.47	19.31	19.08	19.27
17	0230 to 0330	17	17.80	18.03	18.39	18.79	18.41	18.21	18.92	18.86	18.54	19.40	19.38	19.91	19.66
18	0330 to 0430	17	17.72	18.14	18.32	18.81	18.48	18.30	18.85	18.88	18.59	19.40	19.31	19.92	19.66
19	0430 to 0530	17	17.36	17.75	17.99	17.90	17.82	18.14	18.55	18.93	18.54	19.27	19.04	19.96	19.62
20	0530 to 0630	17	17.35	17.55	17.95	17.93	17.74	17.90	18.48	17.96	17.93	19.04	18.95	19.97	19.50
21	0630 to 0730	18	17.42	17.52	17.96	17.21	17.37	17.78	18.43	17.14	17.46	18.84	18.85	18.09	18.46
22	0730 to 0830	20	18.12	17.95	18.44	17.06	17.51	17.96	18.73	17.35	17.65	18.73	18.99	18.86	18.79
23	0830 to 0930	22	18.97	18.52	19.11	18.84	18.68	18.37	19.23	18.86	18.62	18.87	19.35	18.18	18.53
24	0930 to 1030	24	20.43	19.47	20.26	19.12	19.29	19.09	20.12	19.36	19.23	19.21	20.00	19.13	19.17

Table B-17 (b): 24 hr. slab (edge) temperature values (measured and calculated) for Mix C for minimum ambient air temperature at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (ºC) at 10 cm				Temperature (ºC) at 12.5 cm				Temperature (ºC) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	22.88	23.44	22.12	22.50	23.07	23.26	23.64	23.36	23.12	23.12	23.32	23.22
2	1130 to 1230	23.31	24.22	23.97	23.64	23.34	23.71	23.13	23.24	23.31	23.31	23.56	23.44
3	1230 to 1330	23.95	24.80	23.50	23.72	23.80	24.14	23.86	23.83	23.63	23.63	23.43	23.53
4	1330 to 1430	24.78	25.56	24.67	24.72	24.44	24.76	24.53	24.48	24.14	24.14	24.76	24.45
5	1430 to 1530	25.25	24.54	25.85	25.55	24.97	24.58	24.49	24.73	24.62	24.62	24.24	24.43
6	1530 to 1630	23.95	23.13	23.63	23.79	24.01	23.55	24.36	24.19	23.89	23.89	23.18	23.53
7	1630 to 1730	22.73	22.48	22.98	22.86	23.04	22.80	23.56	23.30	23.07	23.07	23.28	23.18
8	1730 to 1830	22.05	21.87	22.83	22.44	22.47	22.24	22.48	22.47	22.55	22.55	22.24	22.39
9	1830 to 1930	21.58	21.38	21.48	21.53	22.04	21.82	22.28	22.16	22.19	22.19	22.14	22.16
10	1930 to 2030	21.18	21.02	21.42	21.30	21.70	21.52	21.24	21.47	21.93	21.93	21.12	21.52
11	2030 to 2130	20.80	20.81	20.35	20.58	21.54	21.31	21.20	21.37	21.71	21.71	21.10	21.40
12	2130 to 2230	20.51	20.61	20.16	20.33	21.27	21.12	21.09	21.18	21.52	21.52	21.05	21.28
13	2230 to 2330	20.22	20.27	20.17	20.19	21.00	20.83	21.10	21.05	21.27	21.27	21.05	21.16
14	2330 to 0030	19.96	20.01	19.15	19.55	20.72	20.58	20.09	20.40	21.03	21.03	21.04	21.04
15	0030 to 0130	19.74	19.85	19.09	19.41	20.49	20.39	20.05	20.27	20.81	20.81	20.02	20.42
16	0130 to 0230	19.53	19.82	19.05	19.29	20.25	20.24	20.03	20.14	20.58	20.58	20.01	20.30
17	0230 to 0330	19.48	19.78	19.95	19.72	20.11	20.11	20.97	20.54	20.38	20.38	20.99	20.68
18	0330 to 0430	19.50	19.71	19.96	19.73	20.04	20.04	20.97	20.51	20.30	20.30	20.99	20.64
19	0430 to 0530	19.29	19.46	19.98	19.63	19.90	19.81	19.99	19.94	20.09	20.09	20.99	20.54
20	0530 to 0630	19.06	19.35	19.98	19.52	19.67	19.68	19.99	19.83	19.95	19.95	20.00	19.97
21	0630 to 0730	18.88	19.20	18.05	18.46	19.45	19.50	19.03	19.24	19.74	19.74	19.01	19.38
22	0730 to 0830	18.80	19.22	18.50	18.65	19.30	19.41	19.28	19.29	19.57	19.57	19.14	19.35
23	0830 to 0930	18.94	19.45	18.68	18.81	19.38	19.54	19.39	19.39	19.61	19.61	19.20	19.40
24	0930 to 1030	19.29	19.91	19.23	19.26	19.63	19.83	19.71	19.67	19.78	19.78	19.35	19.57

Table B-17 (c): 24 hr. slab (edge) temperature values (measured and calculated) for Mix C for minimum ambient air temperature at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (ºC) at 17.5 cm				Temperature (ºC) at 20 cm				Temperature (ºC) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	23.32	23.02	23.16	23.24	23.31	22.96	23.49	23.40	23.30	22.95	23.60	23.45
2	1130 to 1230	23.47	23.03	23.29	23.38	23.44	22.85	23.76	23.60	23.44	22.79	23.75	23.60
3	1230 to 1330	23.74	23.27	23.22	23.48	23.67	23.05	23.93	23.80	23.75	22.98	23.95	23.85
4	1330 to 1430	24.13	23.70	24.39	24.26	24.07	23.44	24.22	24.15	24.22	23.36	24.47	24.35
5	1430 to 1530	24.46	24.64	24.12	24.29	24.30	24.66	24.57	24.44	24.33	24.67	24.67	24.50
6	1530 to 1630	23.75	24.15	23.09	23.42	23.51	24.35	23.75	23.63	23.17	24.47	23.32	23.24
7	1630 to 1730	23.18	23.30	23.14	23.16	23.04	23.49	23.08	23.06	22.63	23.63	22.85	22.74
8	1730 to 1830	22.82	22.80	23.01	22.91	22.71	23.00	22.87	22.79	22.33	23.14	22.52	22.43
9	1830 to 1930	22.54	22.48	22.77	22.66	22.44	22.69	22,64	22.44	22.09	22.83	22.26	22.18
10	1930 to 2030	22.35	22.24	22.56	22.46	22.27	22.47	22.44	22.36	21.93	22.60	22.02	21.98
11	2030 to 2130	22.19	22.01	22.39	22.29	22.12	22.22	22.32	22.22	21.78	22.34	21.97	21.87
12	2130 to 2230	21.91	21.83	22.02	21.96	21.82	22.03	22.01	21.91	21.51	22.13	21.78	21.65
13	2230 to 2330	21.69	21.60	21.91	21.80	21.60	21.81	21.91	21.76	21.38	21.91	21.49	21.44
14	2330 to 0030	21.58	21.36	21.71	21.64	21.55	21.57	21.71	21.63	21.26	21.67	21.38	21.32
15	0030 to 0130	21.42	21.12	21.68	21.55	21.37	21.33	21.50	21.43	21.08	21.42	21.19	21.14
16	0130 to 0230	21.19	20.83	21.31	21.25	21.16	20.99	21.41	21.29	20.89	21.07	21.00	20.94
17	0230 to 0330	21.01	20.58	21.19	21.10	21.00	20.71	21.12	21.06	20.74	20.78	20.96	20.85
18	0330 to 0430	20.89	20.50	20.99	20.94	20.88	20.63	21.00	20.94	20.64	20.69	20.89	20.77
19	0430 to 0530	20.63	20.30	20.81	20.72	20.61	20.45	21.00	20.80	20.32	20.52	20.61	20.46
20	0530 to 0630	20.44	20.15	20.70	20.57	20.44	20.28	20.88	20.66	20.20	20.35	20.41	20.30
21	0630 to 0730	20.23	19.92	20.31	20.27	20.24	20.05	20.41	20.33	20.04	20.11	20.29	20.16
22	0730 to 0830	20.03	19.69	20.07	20.05	20.05	19.78	20.11	20.08	20.00	19.83	20.20	20.10
23	0830 to 0930	20.03	19.68	20.10	20.06	20.04	19.73	20.06	20.05	20.00	19.76	20.17	20.09
24	0930 to 1030	20.16	19.75	20.18	20.17	20.16	19.74	20.24	20.20	20.06	19.75	20.31	20.19

Table B-17(d): 24 hr. slab (edge) temperature values (measured and calculated) for Mix C for minimum ambient air temperature at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (^{o}C) at 25 cm				Temperature (^{o}C) at 27.5 cm				Temperature (^{o}C) at 30 cm				Temperature (^{o}C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	23.29	22.97	23.41	23.35	23.29	23.03	23.79	23.54	23.14	23.14	23.20	23.17	23.70	23.70	23.89	23.80
2	1130 to 1230	23.45	22.85	23,71	23.45	23.49	23.01	23.98	23.73	23.29	23.29	23.30	23.30	24.02	24.02	24.20	24.11
3	1230 to 1330	23.82	23.05	24.01	23.91	23.87	23.27	24.01	23.94	23.63	23.63	23.70	23.66	24.64	24.64	24.65	24.65
4	1330 to 1430	24.32	23.45	24.51	24.41	24.45	23.73	23.79	24.12	24.19	24.19	24.20	24.19	25.52	25.52	25.64	25.58
5	1430 to 1530	24.52	24.68	24.80	24.66	24.70	24.68	24.99	24.84	24.68	24.68	24.70	24.69	25.96	25.96	25.92	25.94
6	1530 to 1630	23.37	24.51	24.69	24.03	23.50	24.48	23.89	23.70	24.38	24.38	24.30	24.34	24.72	24.72	24.84	24.78
7	1630 to 1730	22.63	23.73	22.91	22.77	22.57	23.79	22.99	22.78	23.80	23.80	23.90	23.85	23.51	23.51	23.60	23.55
8	1730 to 1830	22.22	23.23	22.41	22.31	22.06	23.26	22.29	22.18	23.23	23.23	23.40	23.32	22.90	22.90	22.92	22.91
9	1830 to 1930	21.89	22.89	22.00	21.94	21.70	22.88	22.01	21.85	22.80	22.80	22.89	22.84	22.35	22.35	22.35	22.35
10	1930 to 2030	21.70	22.63	21.97	21.83	21.50	22.58	21.78	21.64	22.43	22.43	22.50	22.47	21.84	21.84	21.86	21.85
11	2030 to 2130	21.57	22.36	21.80	21.69	21.33	22.28	21.46	21.39	22.11	22.11	22.16	22.13	21.55	21.55	21.66	21.61
12	2130 to 2230	21.30	22.13	21.55	21.43	21.02	22.03	21.30	21.16	21.83	21.83	21.85	21.84	21.29	21.29	21.38	21.34
13	2230 to 2330	21.13	21.89	21.41	21.27	20.80	21.76	21.00	20.90	21.52	21.52	21.53	21.53	21.01	21.01	20.98	20.99
14	2330 to 0030	21.01	21.65	21.20	21.11	20.74	21.52	20.98	20.86	21.26	21.26	21.25	21.26	20.80	20.80	20.89	20.84
15	0030 to 0130	20.85	21.41	21.00	20.93	20.61	21.29	20.88	20.74	21.05	21.05	21.06	21.06	20.64	20.64	20.69	20.67
16	0130 to 0230	20.67	21.06	20.96	20.82	20.46	20.97	20.71	20.59	20.79	20.79	20.80	20.79	20.50	20.50	20.60	20.55
17	0230 to 0330	20.55	20.79	20.74	20.65	20.34	20.72	20.68	20.51	20.60	20.60	20.68	20.64	20.50	20.50	20.51	20.51
18	0330 to 0430	20.47	20.69	20.64	20.56	20.30	20.62	20.41	20.35	20.48	20.48	20.50	20.49	20.53	20.53	20.52	20.53
19	0430 to 0530	20.22	20.52	20.50	20.36	20.10	20.45	20.24	20.17	20.31	20.31	20.36	20.34	20.45	20.45	20.50	20.48
20	0530 to 0630	20.10	20.35	20.39	20.24	20.00	20.28	20.45	20.23	20.15	20.15	20.20	20.17	20.30	20.30	20.40	20.35
21	0630 to 0730	20.00	20.11	20.11	20.06	19.92	20.06	20.21	20.07	19.95	19.95	19.95	19.95	20.19	20.19	20.19	20.19
22	0730 to 0830	19.92	19.86	20.00	19.96	19.80	19.85	20.11	19.96	19.80	19.80	19.89	19.85	20.10	20.10	20.15	20.13
23	0830 to 0930	19.94	19.79	20.07	20.00	19.80	19.80	20.12	19.96	19.79	19.79	19.80	19.80	20.19	20.19	20.23	20.21
24	0930 to 1030	20.00	19.78	20.12	20.06	19.95	19.84	20.19	20.07	19.92	19.92	20.00	19.96	20.48	20.48	20.38	20.43

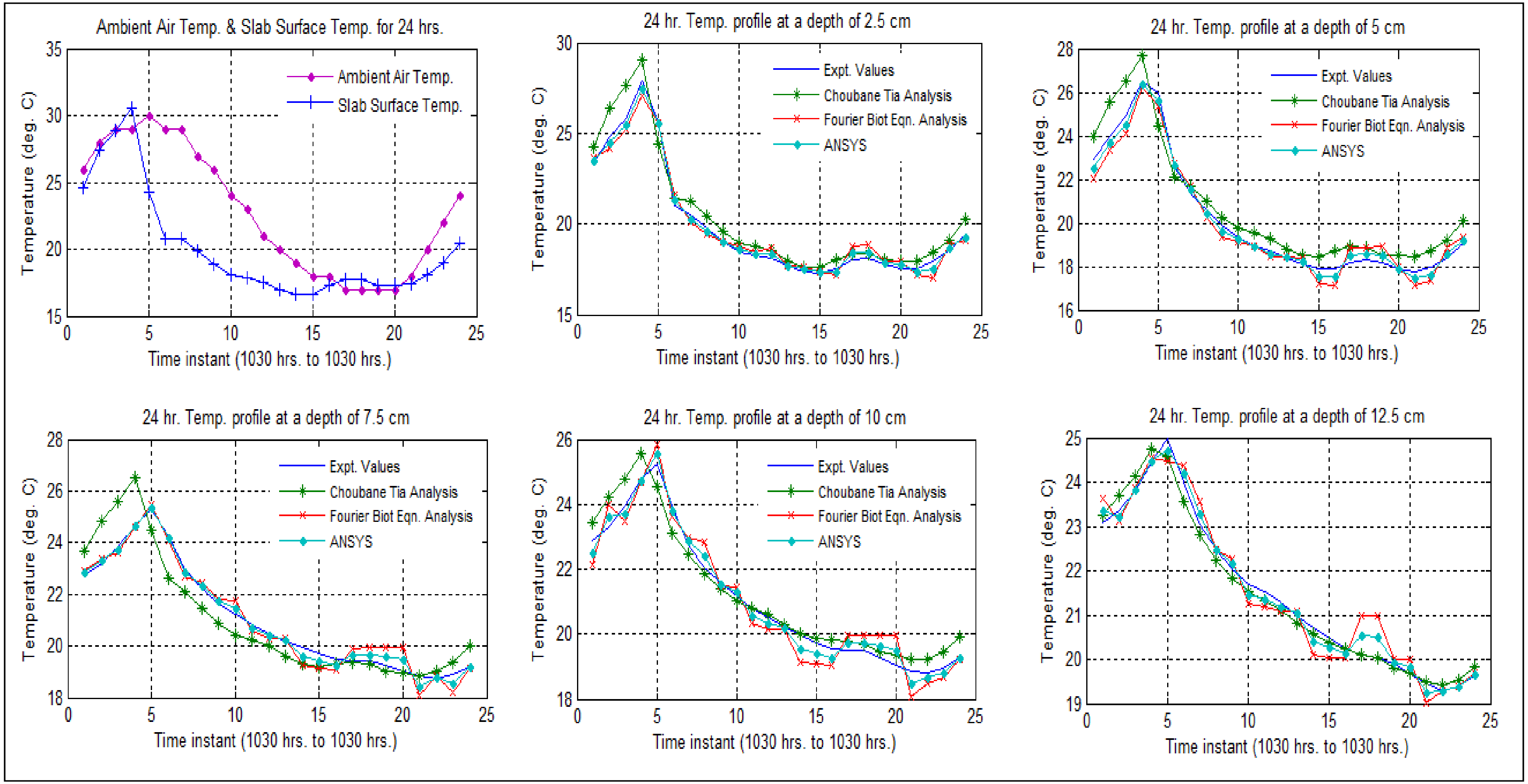


Fig. B-33 (a): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix C for minimum ambient air temperature (surface to 12.5 cm)

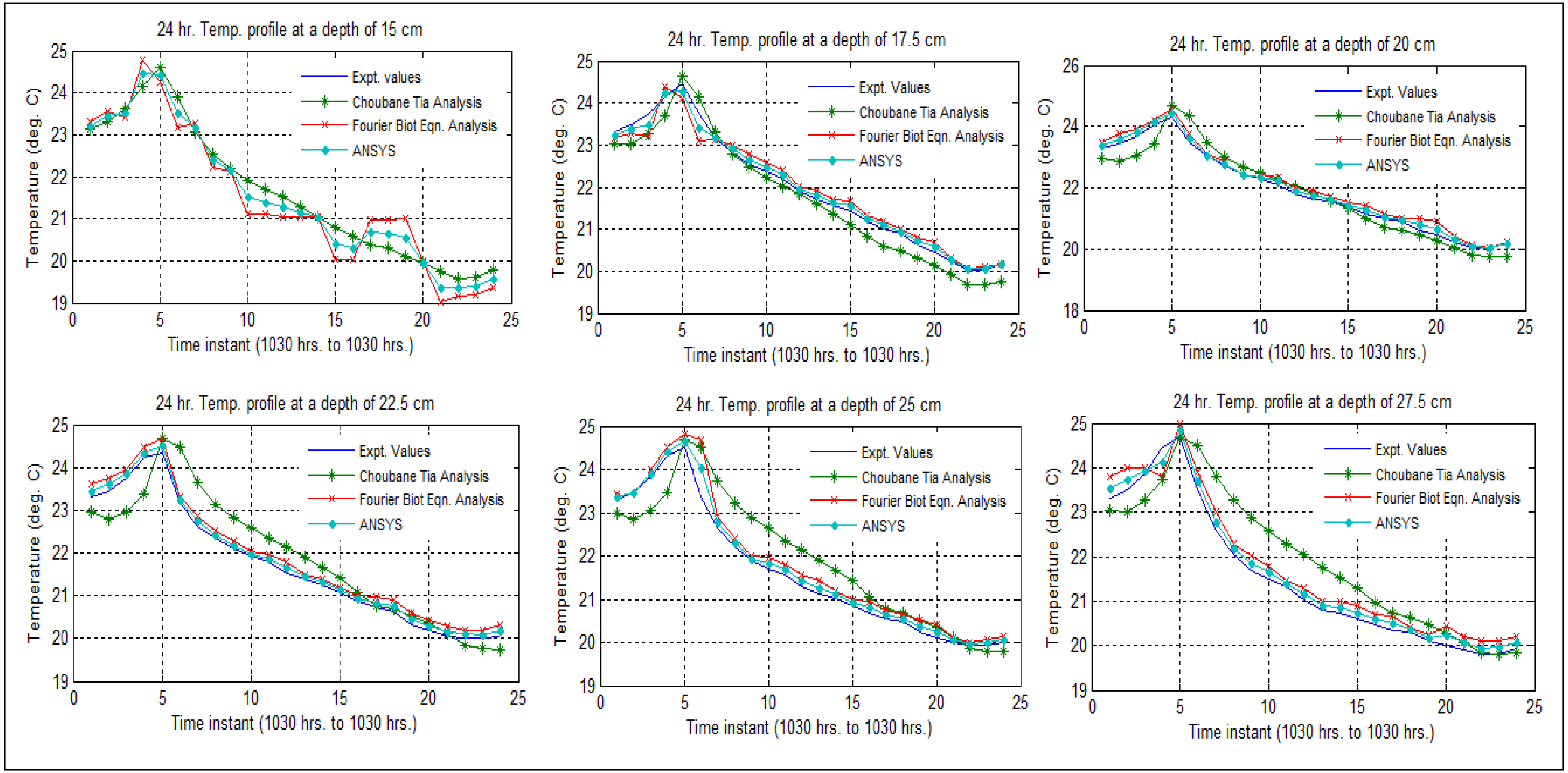


Fig. B-33 (b): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix C for minimum ambient air temperature (15 cm to 27.5 cm)

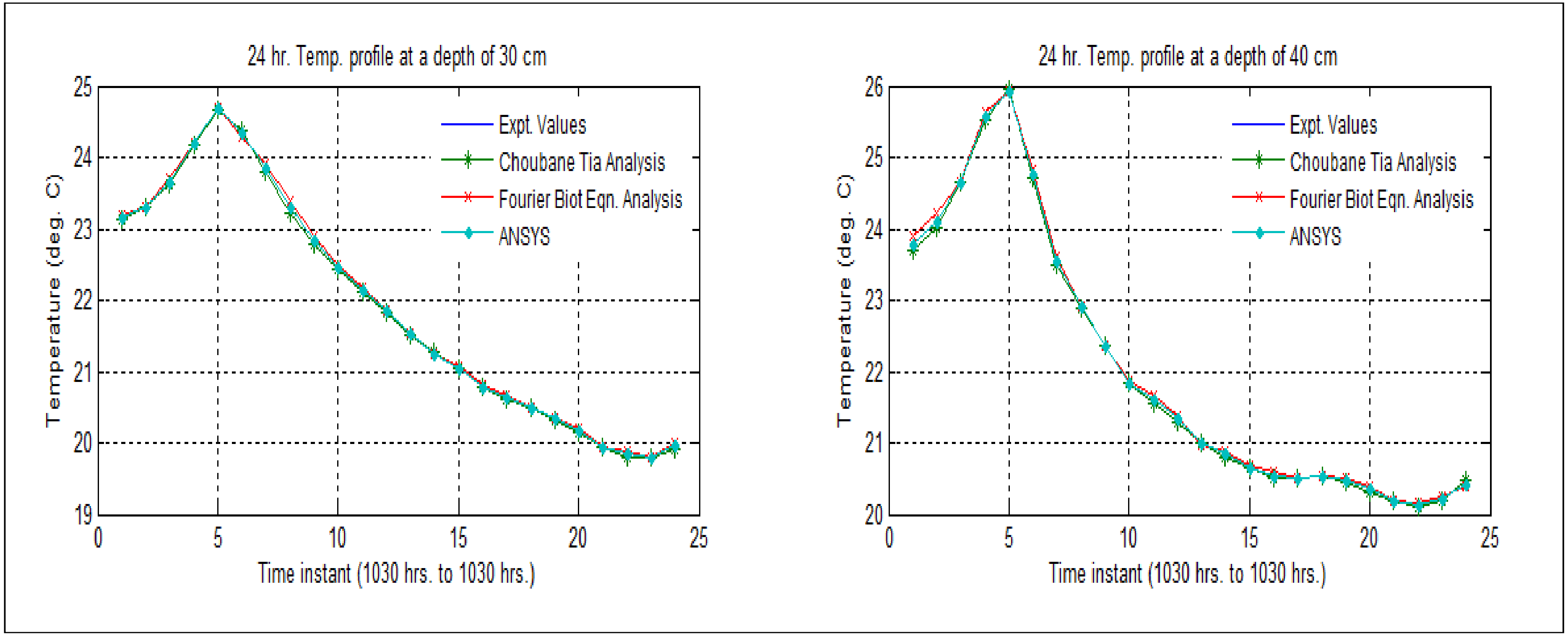


Fig. B-33 (c): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix C for minimum ambient air temperature (30 cm & 40 cm)

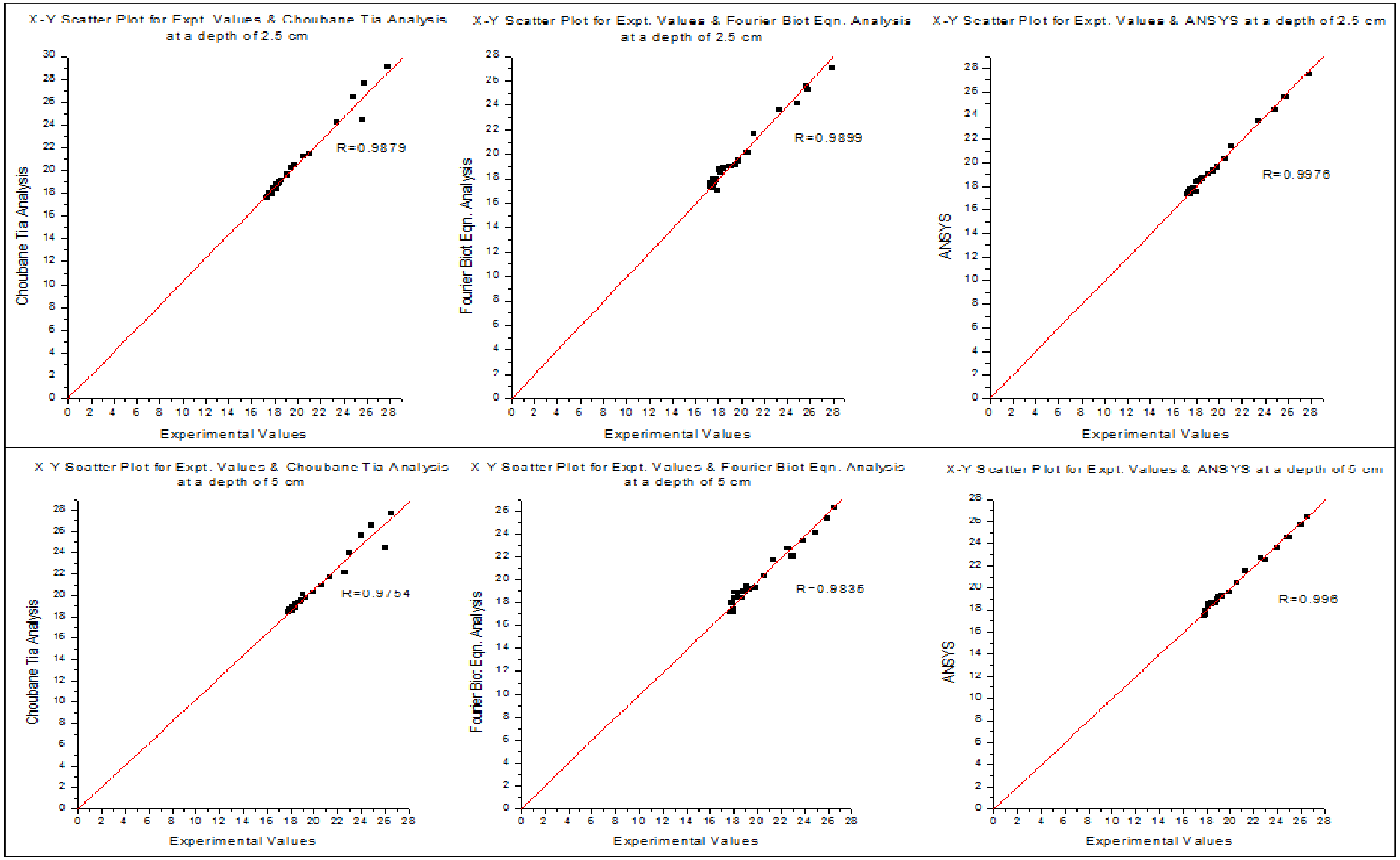


Fig. B-34 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

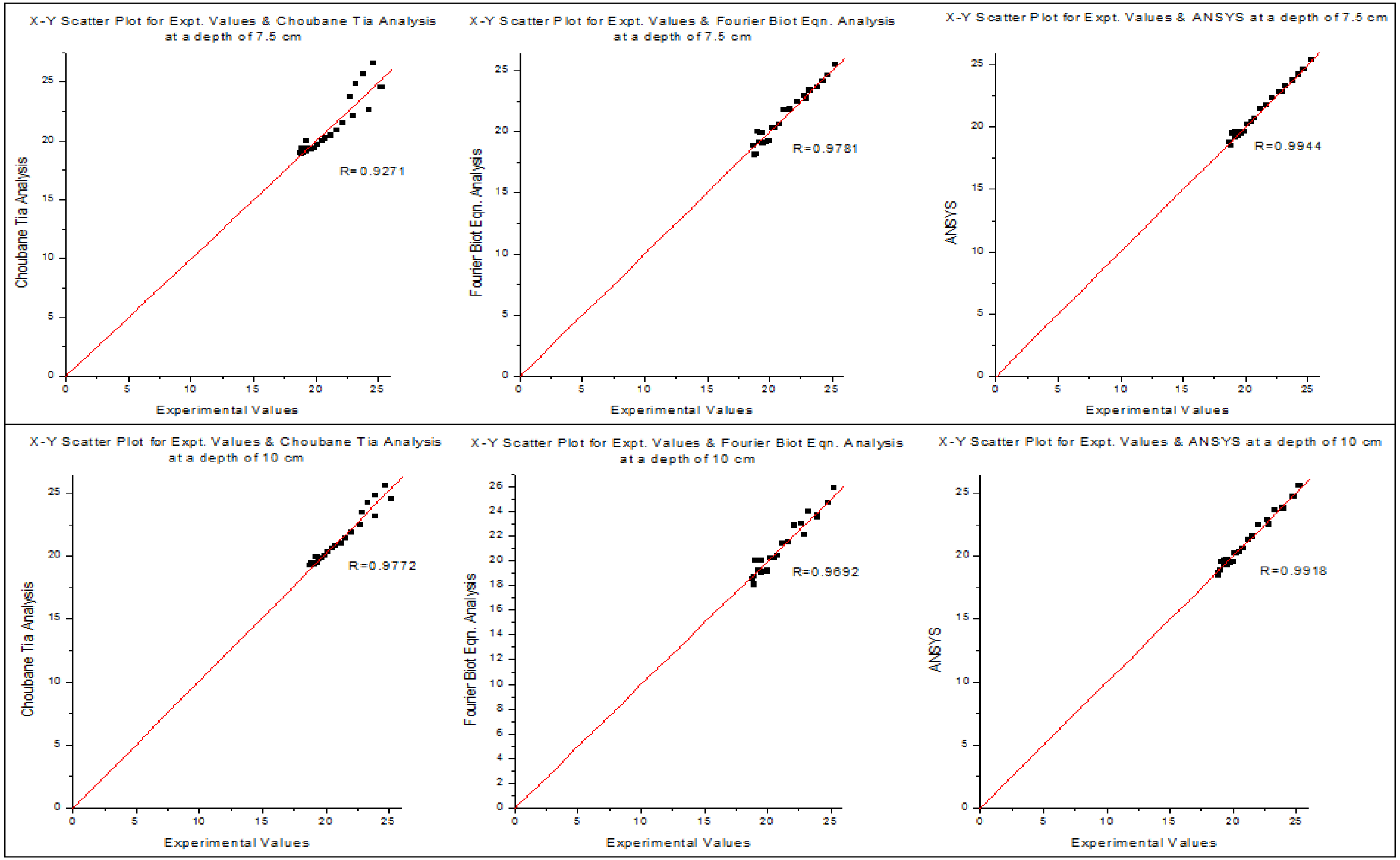


Fig. B-34 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

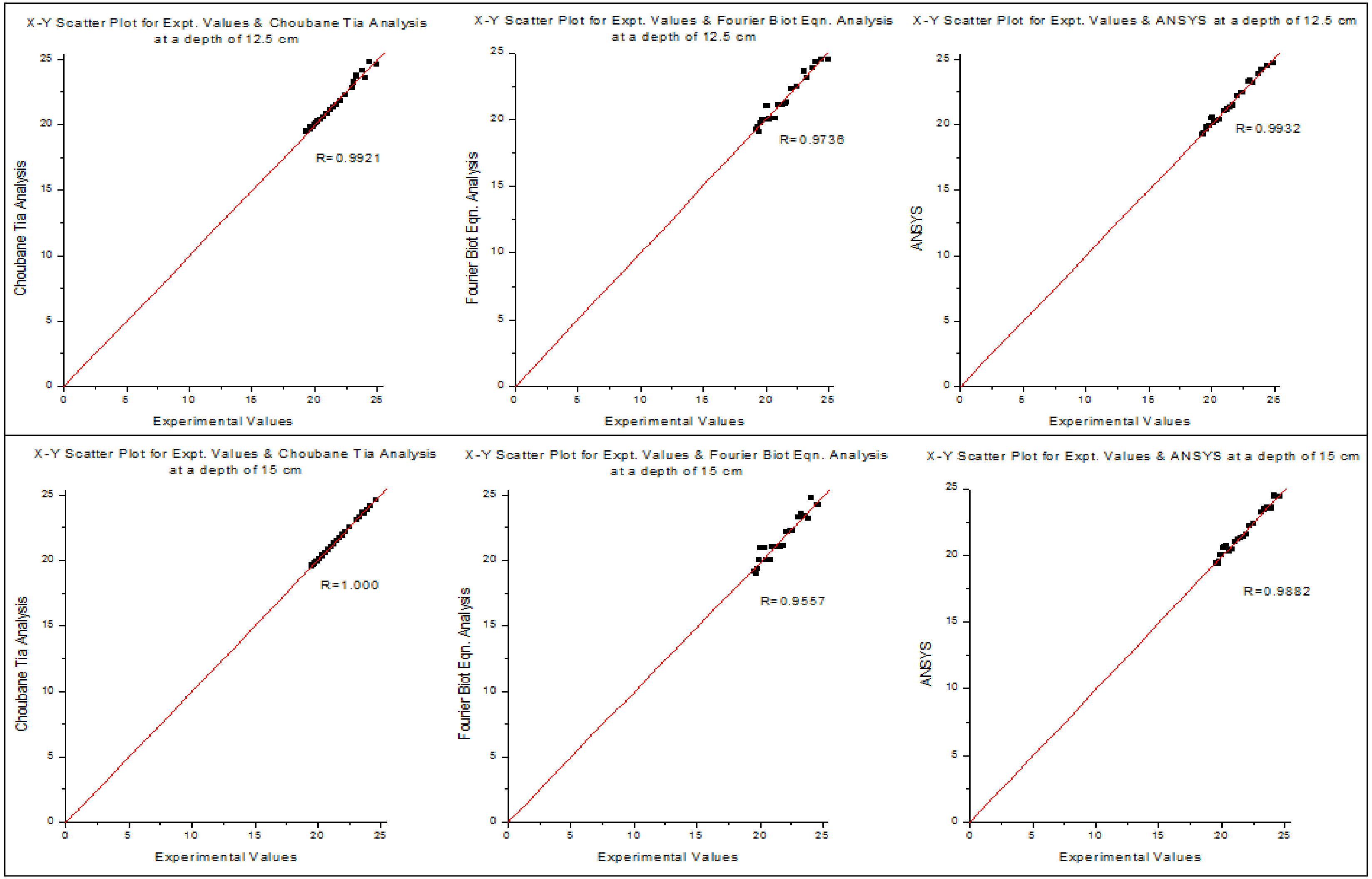


Fig. B-34 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

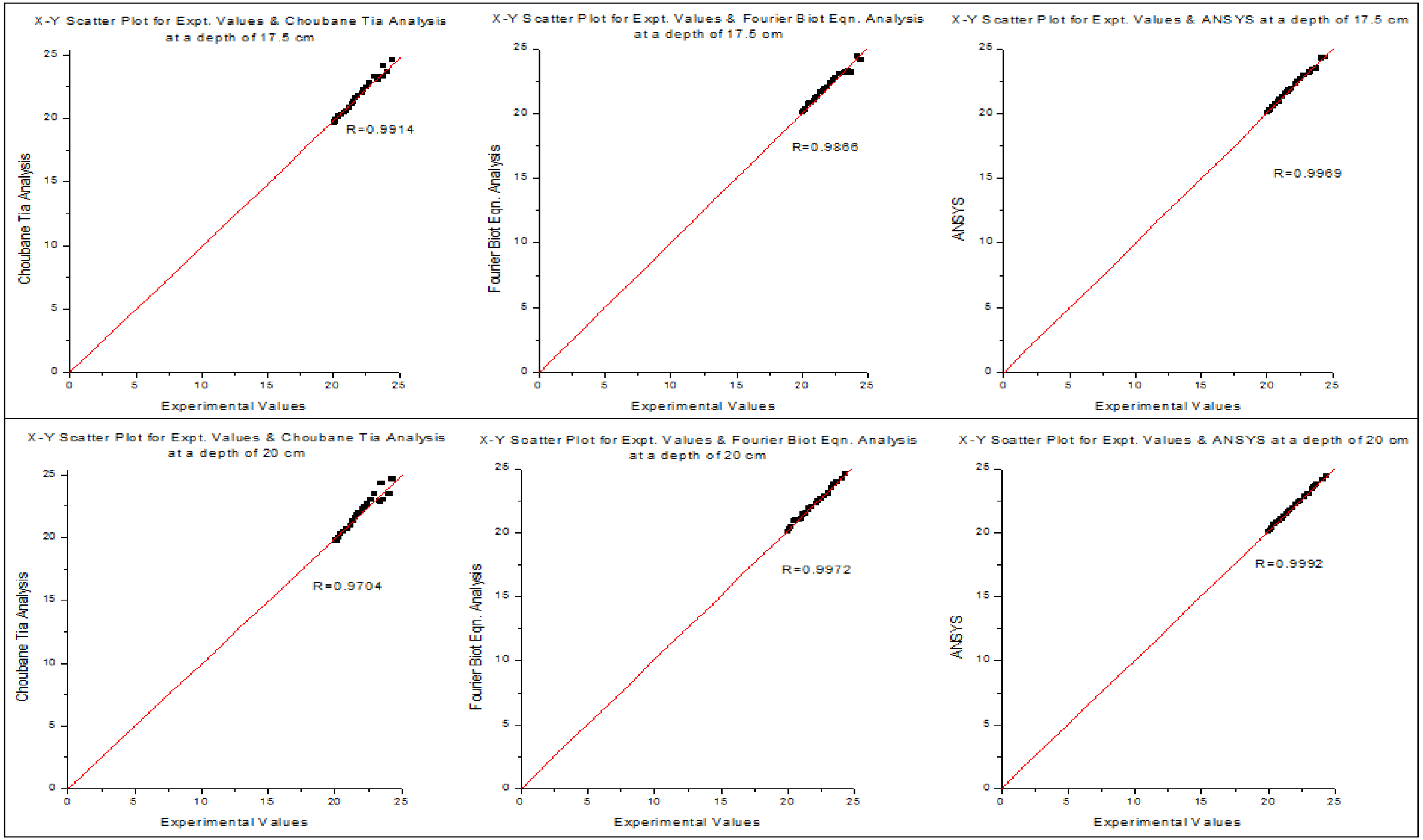


Fig. B-34 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

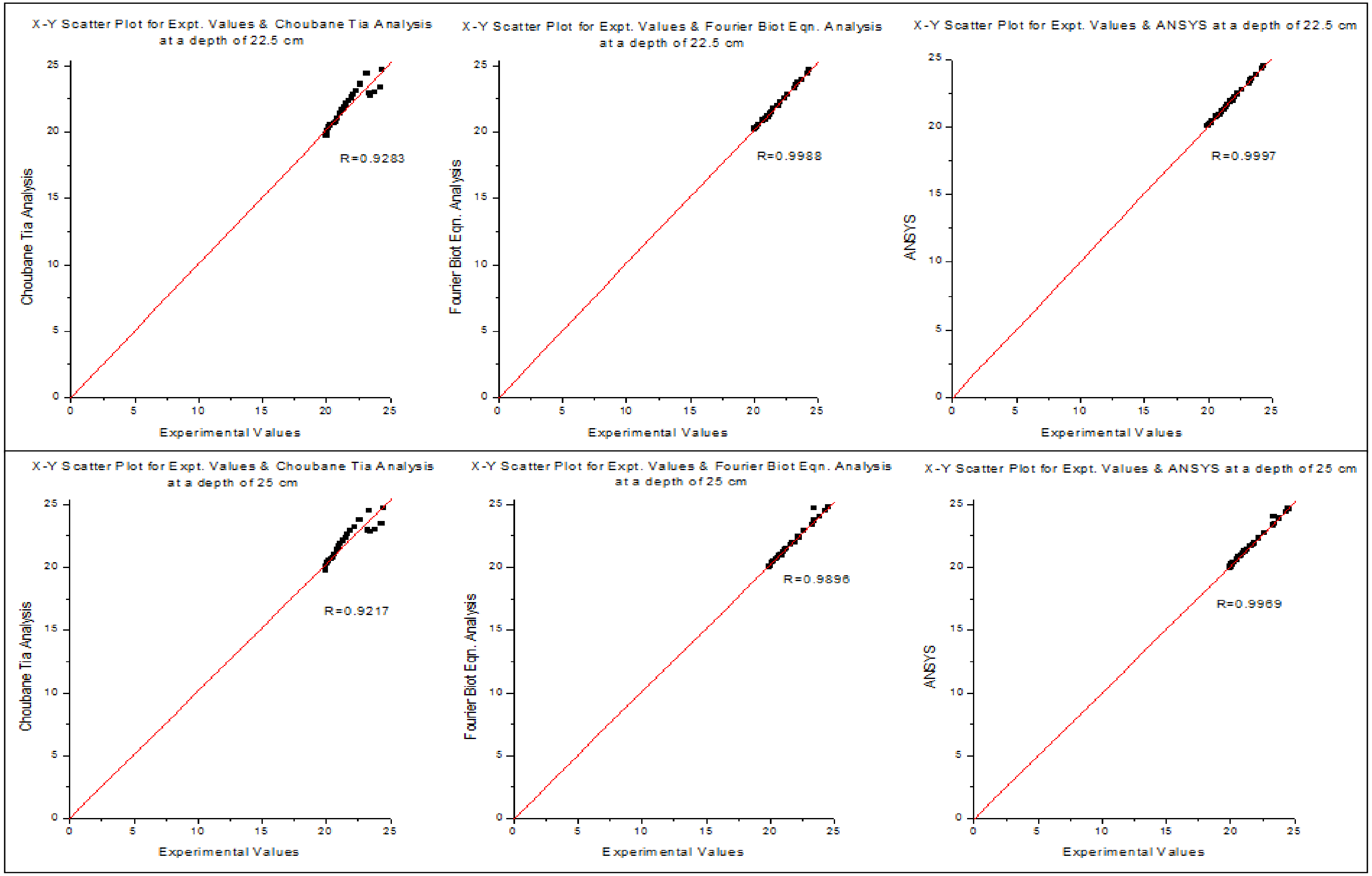


Fig. B-34 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

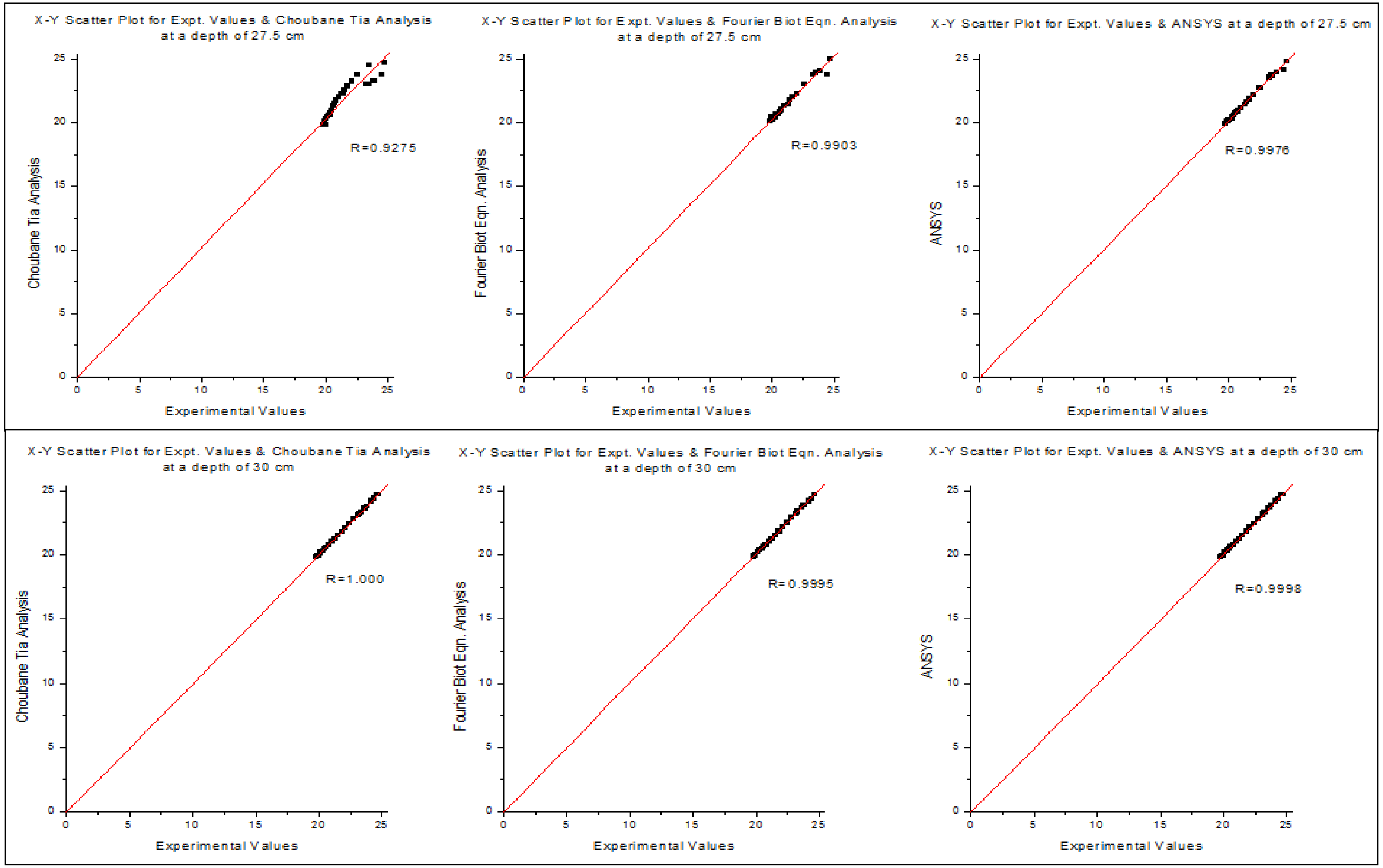


Fig. B-34 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

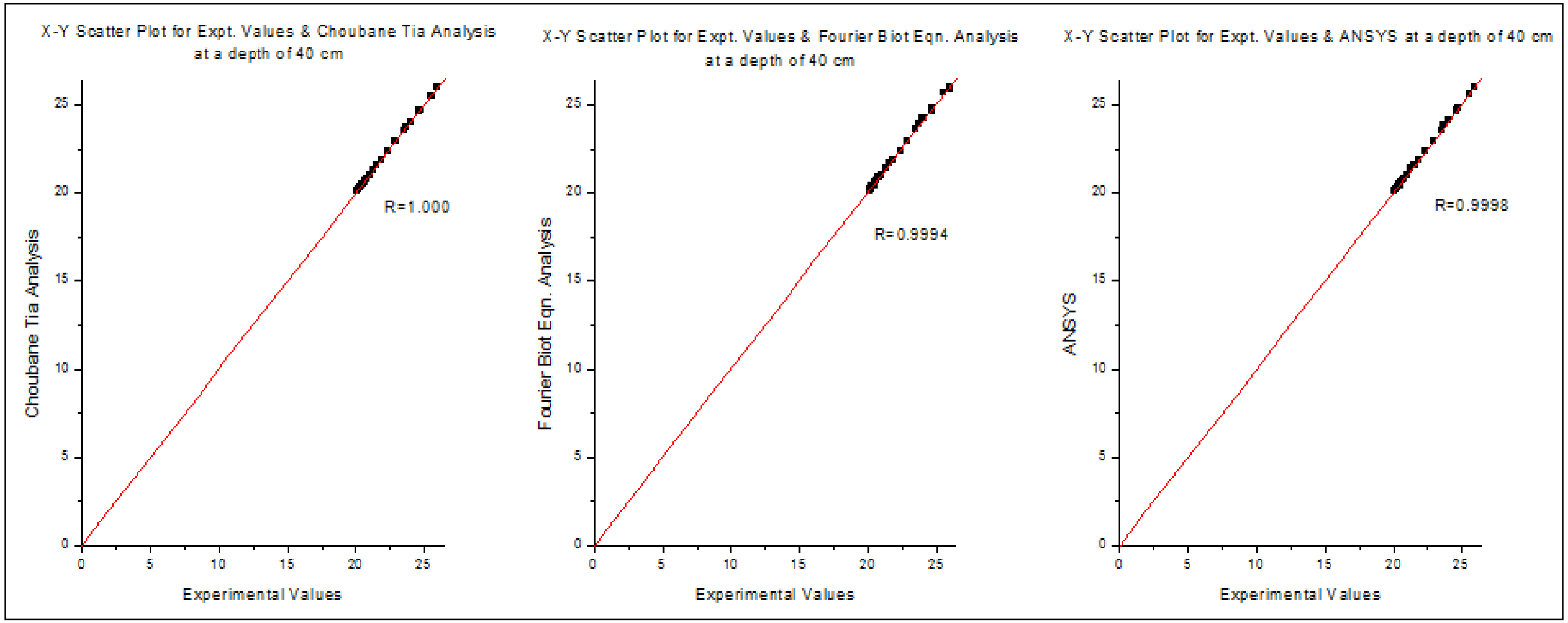


Fig. B-34 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-18 (a): 24 hr. slab (D) temperature values (measured and calculated) for Mix C for minimum ambient air temperature at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (ºC) at 2.5 cm				Temperature (ºC) at 5 cm				Temperature (ºC) at 7.5 cm			
		(ºC)	(ºC)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	26	25.09	24.65	24.69	24.49	24.57	23.89	24.33	23.95	23.92	23.23	24.03	23.87	23.55
2	1200 to 1300	28	27.13	26.17	26.22	26.24	26.20	25.28	25.44	25.41	25.34	24.41	24.76	24.43	24.42
3	1300 to 1400	29	29.63	27.65	28.15	28.00	27.83	26.63	26.86	26.94	26.78	25.47	25.77	25.49	25.48
4	1400 to 1500	29	28.19	29.22	27.09	29.75	29.49	28.36	26.15	28.71	28.54	27.13	25.35	27.88	27.51
5	1500 to 1600	30	22.65	25.67	23.02	26.00	25.83	25.89	23.36	25.62	25.76	26.28	23.67	26.66	26.47
6	1600 to 1700	29	21.22	22.00	22.12	22.51	22.25	22.55	22.89	22.65	22.60	23.66	23.54	23.04	23.35
7	1700 to 1800	29	20.91	21.13	21.92	21.04	21.08	21.46	22.79	21.65	21.56	22.43	23.51	22.68	22.55
8	1800 to 1900	27	20.01	20.34	21.21	20.38	20.36	20.65	22.23	20.22	20.43	21.58	23.07	21.40	21.49
9	1900 to 2000	26	19.24	19.71	20.55	19.91	19.81	19.92	21.68	19.25	19.59	20.87	22.61	20.79	20.83
10	2000 to 2100	24	18.68	19.04	20.04	19.58	19.31	19.27	21.21	19.03	19.15	20.19	22.18	20.65	20.42
11	2100 to 2200	23	18.44	18.76	19.76	18.31	18.53	18.88	20.89	18.86	18.87	19.81	21.84	20.54	20.18
12	2200 to 2300	21	18.02	18.46	19.38	18.58	18.52	18.54	20.54	18.38	18.46	19.43	21.51	19.24	19.33
13	2300 to 0000	20	17.63	18.08	18.99	18.53	18.30	18.16	20.16	18.35	18.25	18.97	21.14	19.22	19.10
14	0000 to 0100	19	17.41	17.74	18.74	17.41	17.58	17.80	19.88	17.27	17.53	18.59	20.83	18.17	18.38
15	0100 to 0200	18	17.37	17.66	18.63	17.17	17.41	17.63	19.71	17.11	17.37	18.35	20.62	18.07	18.21
16	0200 to 0300	18	17.89	17.97	18.94	17.03	17.50	17.80	19.84	17.02	17.41	18.30	20.60	18.01	18.16
17	0300 to 0400	17	18.14	18.28	19.06	18.70	18.49	18.10	19.84	18.80	18.45	18.45	20.49	18.88	18.66
18	0400 to 0500	17	18.00	18.33	18.92	18.74	18.54	18.19	19.71	18.83	18.51	18.50	20.37	18.89	18.70
19	0500 to 0600	17	17.82	18.19	18.74	18.77	18.48	17.98	19.53	17.85	17.91	18.36	20.19	18.90	18.63
20	0600 to 0700	17	17.82	18.15	18.71	18.82	18.48	17.91	19.48	17.88	17.89	18.30	20.11	18.93	18.61
21	0700 to 0800	18	18.11	18.23	18.89	18.04	18.13	17.99	19.56	17.02	17.50	18.30	20.12	18.01	18.16
22	0800 to 0900	20	18.73	18.74	19.32	18.85	18.79	18.36	19.82	18.22	18.29	18.47	20.23	18.77	18.62
23	0900 to 1000	22	19.70	19.47	20.01	19.60	19.53	18.95	20.26	18.71	18.83	18.89	20.46	18.08	18.48
24	1000 to 1100	24	21.52	20.64	21.36	20.74	20.69	20.04	21.21	20.11	20.07	19.66	21.06	19.97	19.82

Table B-18 (b): 24 hr. slab (D) temperature values (measured and calculated) for Mix C for minimum ambient air temperature at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	23.36	23.77	23.08	23.22	23.15	23.56	23.62	23.38	23.41	23.41	23.31	23.36
2	1200 to 1300	24.08	24.20	24.99	24.53	23.53	23.76	23.14	23.33	23.44	23.44	23.57	23.50
3	1300 to 1400	24.90	24.86	24.45	24.67	24.17	24.14	24.83	24.50	23.62	23.62	23.71	23.66
4	1400 to 1500	26.10	24.71	26.83	26.47	25.02	24.22	25.63	25.32	23.89	23.89	24.01	23.95
5	1500 to 1600	26.38	23.93	26.96	26.67	25.60	24.16	25.55	25.58	24.35	24.35	24.58	24.46
6	1600 to 1700	25.02	24.06	25.60	25.31	25.06	24.46	25.35	25.20	24.74	24.74	24.97	24.85
7	1700 to 1800	23.87	24.07	23.98	23.92	24.26	24.49	24.56	24.41	24.75	24.75	24.98	24.87
8	1800 to 1900	23.10	23.74	23.81	23.46	23.54	24.23	23.47	23.50	24.55	24.55	24.73	24.64
9	1900 to 2000	22.39	23.36	22.46	22.43	23.02	23.91	23.26	23.14	24.27	24.27	24.63	24.45
10	2000 to 2100	21.74	22.95	21.38	21.56	22.39	23.53	22.22	22.30	23.92	23.92	24.11	24.01
11	2100 to 2200	21.27	22.59	21.31	21.29	21.85	23.16	21.18	21.52	23.54	23.54	23.89	23.72
12	2200 to 2300	20.83	22.29	20.14	20.48	21.49	22.87	21.08	21.28	23.26	23.26	23.54	23.40
13	2300 to 0000	20.38	21.93	20.13	20.26	21.04	22.53	21.07	21.06	22.93	22.93	23.04	22.99
14	0000 to 0100	20.03	21.61	20.10	20.06	20.65	22.19	20.06	20.35	22.59	22.59	22.83	22.71
15	0100 to 0200	19.75	21.35	19.04	19.39	20.30	21.91	20.02	20.16	22.29	22.29	22.51	22.40
16	0200 to 0300	19.54	21.21	19.01	19.27	20.03	21.66	20.00	20.02	21.97	21.97	22.12	22.05
17	0300 to 0400	19.51	21.02	19.93	19.72	19.99	21.42	19.96	19.97	21.68	21.68	21.98	21.83
18	0400 to 0500	19.52	20.90	19.94	19.73	19.90	21.29	19.96	19.93	21.56	21.56	21.92	21.74
19	0500 to 0600	19.43	20.71	19.94	19.69	19.81	21.11	19.97	19.89	21.37	21.37	21.78	21.58
20	0600 to 0700	19.30	20.62	19.96	19.63	19.66	21.00	19.98	19.82	21.25	21.25	21.64	21.44
21	0700 to 0800	19.20	20.55	19.01	19.10	19.59	20.88	19.00	19.30	21.08	21.08	21.21	21.15
22	0800 to 0900	19.26	20.55	19.45	19.35	19.51	20.78	19.26	19.38	20.93	20.93	21.04	20.98
23	0900 to 1000	19.48	20.62	19.63	19.55	19.62	20.72	19.36	19.49	20.77	20.77	20.95	20.86
24	1000 to 1100	19.90	20.93	19.14	19.52	19.86	20.81	19.66	19.76	20.70	20.70	20.88	20.79

Table B-18 (c): 24 hr. slab (D) temperature values (measured and calculated) for Mix C for minimum ambient air temperature at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	23.30	23.30	23.66	23.48	23.30	23.24	23.49	23.40	23.37	23.23	23.47	23.42
2	1200 to 1300	23.47	23.23	23.79	23.63	23.36	23.13	23.67	23.52	23.62	23.15	23.85	23.74
3	1300 to 1400	23.75	23.28	23.91	23.83	23.60	23.13	23.82	23.71	24.01	23.17	24.04	24.02
4	1400 to 1500	24.12	23.71	24.41	24.27	23.99	23.68	24.14	24.06	24.54	23.80	24.77	24.66
5	1500 to 1600	24.72	24.50	24.94	24.83	24.54	24.61	24.78	24.66	25.12	24.69	25.32	25.22
6	1600 to 1700	25.00	24.89	25.29	25.15	24.80	24.91	25.05	24.92	25.25	24.82	25.42	25.33
7	1700 to 1800	24.92	24.87	25.14	25.03	24.61	24.83	24.98	24.80	24.91	24.65	25.03	24.97
8	1800 to 1900	24.54	24.69	24.72	24.63	24.27	24.65	24.47	24.37	24.41	24.44	24.63	24.52
9	1900 to 2000	24.16	24.43	24.37	24.26	23.91	24.41	24.06	23.98	23.92	24.20	24.08	24.00
10	2000 to 2100	23.71	24.11	23.98	23.85	23.49	24.10	23.73	23.61	23.44	23.90	23.61	23.53
11	2100 to 2200	23.34	23.73	23.65	23.49	23.16	23.74	23.33	23.25	23.09	23.55	23.21	23.15
12	2200 to 2300	23.01	23.46	23.16	23.08	22.76	23.46	23.01	22.88	22.71	23.27	23.03	22.87
13	2300 to 0000	22.63	23.15	22.82	22.73	22.37	23.16	22.51	22.44	22.34	22.99	22.45	22.40
14	0000 to 0100	22.29	22.81	22.57	22.43	22.01	22.84	22.33	22.17	22.00	22.68	22.00	22.00
15	0100 to 0200	21.97	22.49	22.11	22.04	21.68	22.52	21.80	21.74	21.70	22.37	22.00	21.85
16	0200 to 0300	21.68	22.13	21.95	21.81	21.46	22.14	21.65	21.55	21.49	22.00	21.71	21.60
17	0300 to 0400	21.48	21.82	21.71	21.60	21.19	21.83	21.49	21.34	21.25	21.71	21.49	21.37
18	0400 to 0500	21.29	21.70	21.52	21.40	21.02	21.71	21.18	21.10	21.09	21.58	21.22	21.16
19	0500 to 0600	21.13	21.51	21.39	21.26	20.86	21.51	21.00	20.93	20.96	21.39	21.00	20.98
20	0600 to 0700	20.99	21.37	21.09	21.04	20.71	21.37	20.92	20.81	20.80	21.23	21.00	20.90
21	0700 to 0800	20.85	21.17	21.00	20.93	20.57	21.15	20.70	20.63	20.68	21.01	20.92	20.80
22	0800 to 0900	20.69	20.98	20.98	20.83	20.44	20.94	20.69	20.56	20.52	20.81	20.81	20.67
23	0900 to 1000	20.58	20.76	20.81	20.69	20.30	20.71	20.55	20.43	20.46	20.60	20.72	20.59
24	1000 to 1100	20.50	20.60	20.72	20.61	20.30	20.51	20.52	20.41	20.49	20.43	20.63	20.56

Table B-18 (d): 24 hr. slab (D) temperature values (measured and calculated) for Mix C for minimum ambient air temperature at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	23.32	23.27	23.51	23.41	23.72	23.36	23.99	23.85	23.50	23.50	23.80	23.65	23.96	23.96	23.96	23.96
2	1200 to 1300	23.62	23.29	23.81	23.71	24.45	23.55	24.98	24.71	23.92	23.92	24.00	23.96	24.33	24.33	24.53	24.43
3	1300 to 1400	24.08	23.40	24.20	24.14	25.18	23.83	25.98	25.58	24.44	24.44	25.00	24.72	24.82	24.82	24.95	24.89
4	1400 to 1500	24.72	24.08	25.01	24.87	26.36	24.51	26.97	26.66	25.09	25.09	25.20	25.14	25.51	25.51	25.41	25.46
5	1500 to 1600	25.27	24.73	25.41	25.34	25.79	24.73	25.99	25.89	24.69	24.69	24.80	24.75	25.14	25.14	25.07	25.11
6	1600 to 1700	25.14	24.60	25.29	25.22	23.98	24.25	23.99	23.99	23.78	23.78	24.00	23.89	23.68	23.68	23.98	23.83
7	1700 to 1800	24.52	24.32	24.71	24.61	23.13	23.83	23.99	23.56	23.20	23.20	23.20	23.20	22.98	22.98	22.97	22.97
8	1800 to 1900	23.90	24.06	24.00	23.95	22.50	23.49	22.99	22.75	22.76	22.76	23.00	22.88	22.41	22.41	22.57	22.49
9	1900 to 2000	23.40	23.79	23.61	23.50	21.96	23.19	22.00	21.98	22.40	22.40	22.45	22.43	21.94	21.94	21.98	21.96
10	2000 to 2100	23.00	23.50	23.07	23.03	21.57	22.91	21.81	21.69	22.13	22.13	22.20	22.16	21.63	21.63	21.79	21.71
11	2100 to 2200	22.56	23.18	22.78	22.67	21.27	22.62	21.60	21.43	21.87	21.87	21.90	21.89	21.43	21.43	21.49	21.46
12	2200 to 2300	22.19	22.89	22.30	22.24	20.94	22.32	21.00	20.97	21.55	21.55	21.60	21.58	21.20	21.20	21.20	21.20
13	2300 to 0000	21.84	22.63	22.00	21.92	20.64	22.07	20.91	20.77	21.32	21.32	21.40	21.36	20.98	20.98	21.00	20.99
14	0000 to 0100	21.57	22.34	21.81	21.69	20.38	21.82	20.61	20.49	21.11	21.11	21.20	21.16	20.82	20.82	20.89	20.86
15	0100 to 0200	21.31	22.05	21.50	21.41	20.17	21.55	20.42	20.29	20.88	20.88	20.90	20.89	20.74	20.74	20.75	20.74
16	0200 to 0300	21.07	21.71	21.21	21.14	20.03	21.27	20.29	20.16	20.68	20.68	20.70	20.69	20.66	20.66	20.70	20.68
17	0300 to 0400	20.85	21.47	21.00	20.93	20.02	21.09	20.26	20.14	20.59	20.59	20.60	20.59	20.70	20.70	20.70	20.70
18	0400 to 0500	20.77	21.33	20.91	20.84	20.05	20.94	20.30	20.17	20.43	20.43	20.50	20.46	20.65	20.65	20.65	20.65
19	0500 to 0600	20.61	21.13	20.80	20.70	19.86	20.74	20.03	19.94	20.23	20.23	20.30	20.26	20.44	20.44	20.45	20.44
20	0600 to 0700	20.44	20.97	20.61	20.53	19.75	20.58	19.91	19.83	20.06	20.06	20.00	20.03	20.26	20.26	20.30	20.28
21	0700 to 0800	20.32	20.75	20.49	20.41	19.60	20.37	19.87	19.74	19.89	19.89	19.90	19.89	20.09	20.09	20.00	20.04
22	0800 to 0900	20.18	20.58	20.31	20.25	19.62	20.27	19.95	19.79	19.87	19.87	19.90	19.89	20.05	20.05	20.09	20.07
23	0900 to 1000	20.12	20.45	20.22	20.17	19.85	20.24	20.09	19.97	19.98	19.98	20.00	19.99	20.18	20.18	20.48	20.33
24	1000 to 1100	20.23	20.36	20.39	20.31	20.24	20.30	20.39	20.32	20.25	20.25	20.80	20.52	20.52	20.52	20.96	20.74

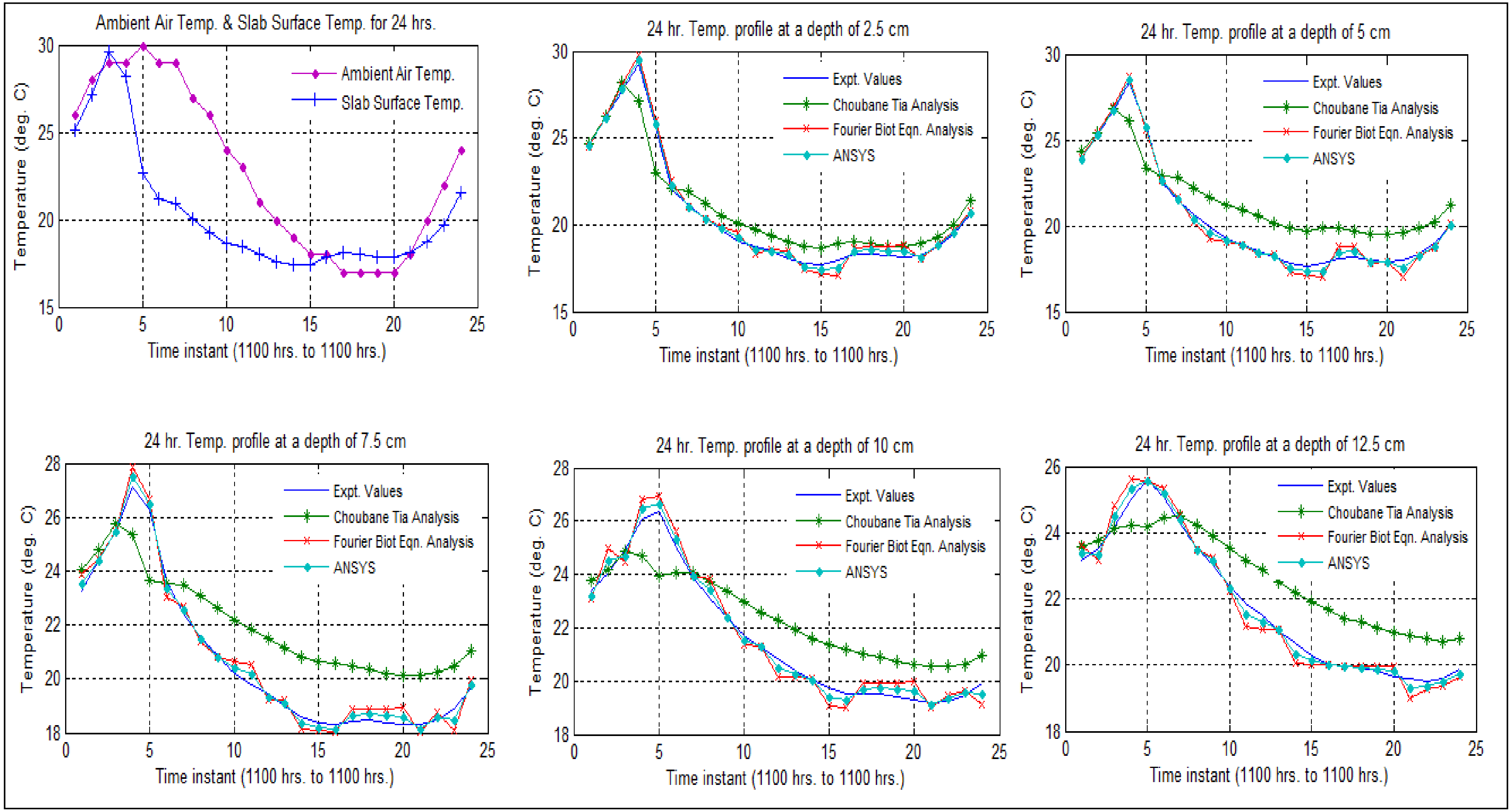


Fig. B-35 (a): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix C for minimum ambient air temperature (surface to 12.5 cm)

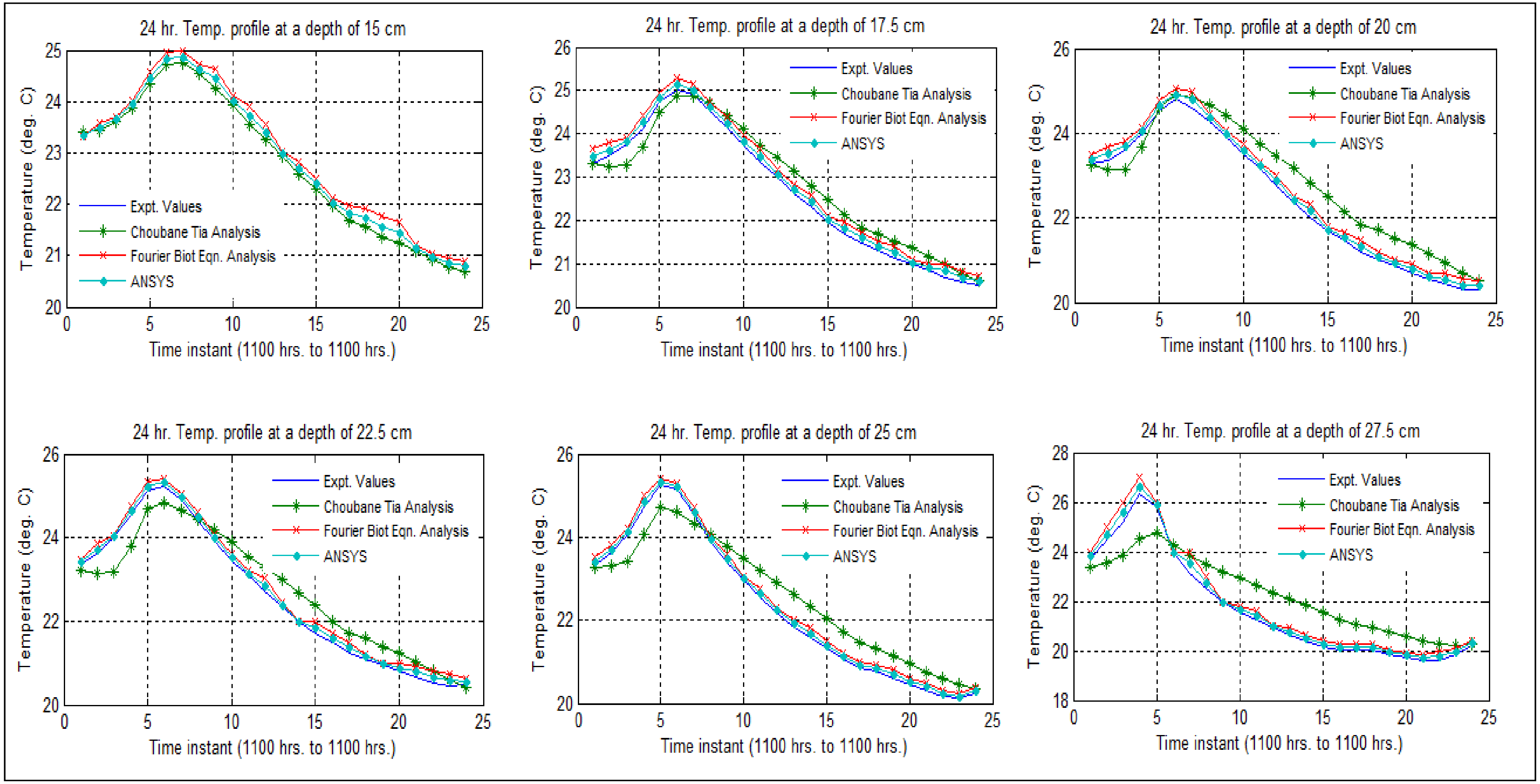


Fig. B-35 (b): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix C for minimum ambient air temperature (15 cm to 27.5 cm)

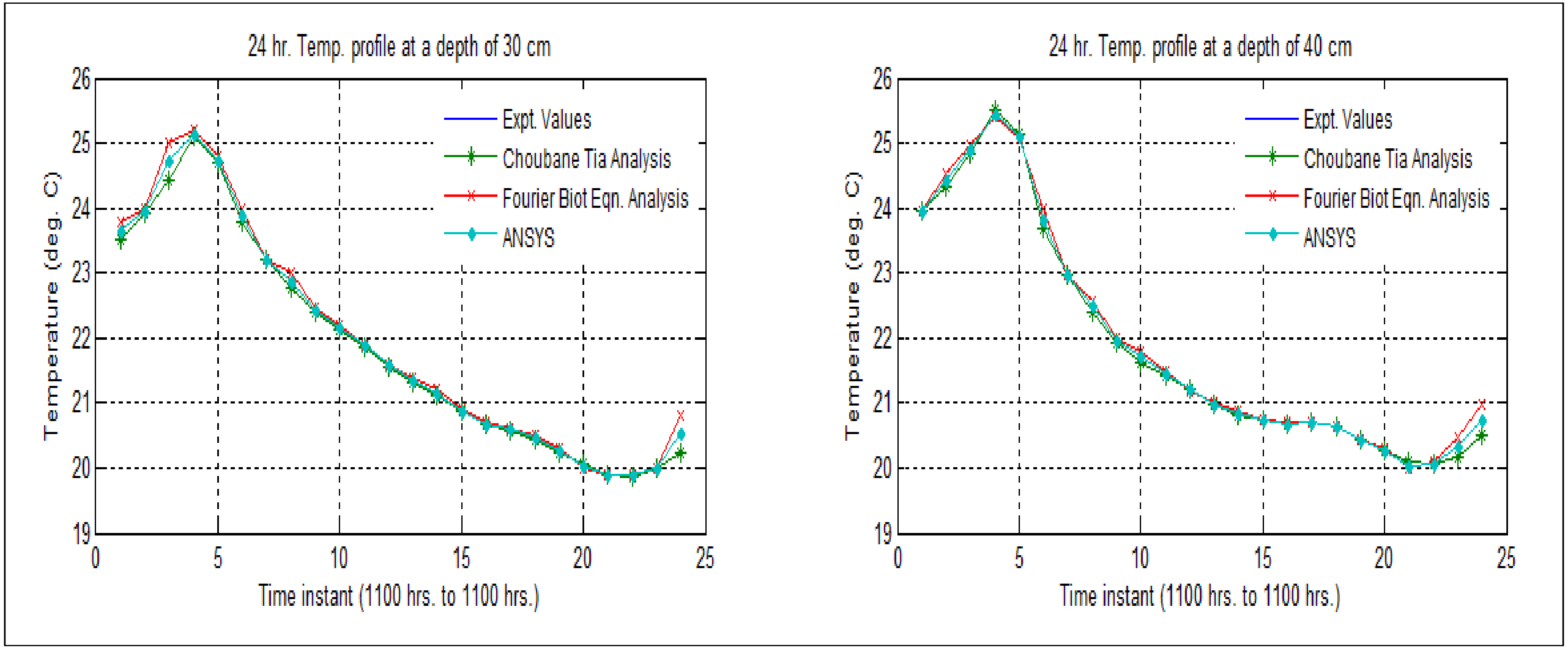


Fig. B-35 (c): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix C for minimum ambient air temperature (30 cm & 40 cm)

The case for part humid and part rainy condition occurred on the same day as the case for minimum ambient air temperature i.e. 4th to 5th March 2014. Hence the observation table and graphs are same as that for the case of minimum ambient air temperature.

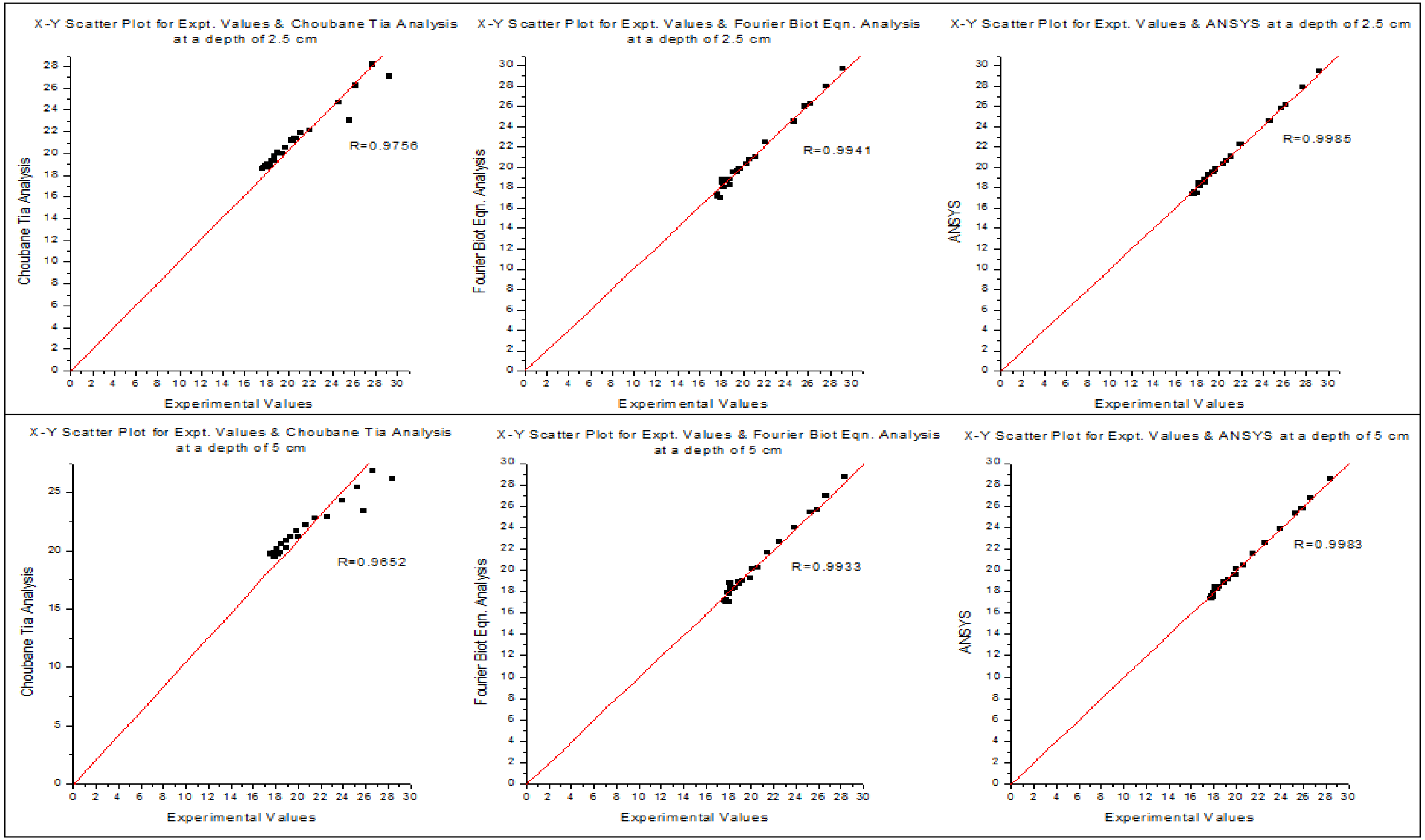


Fig. B-36 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

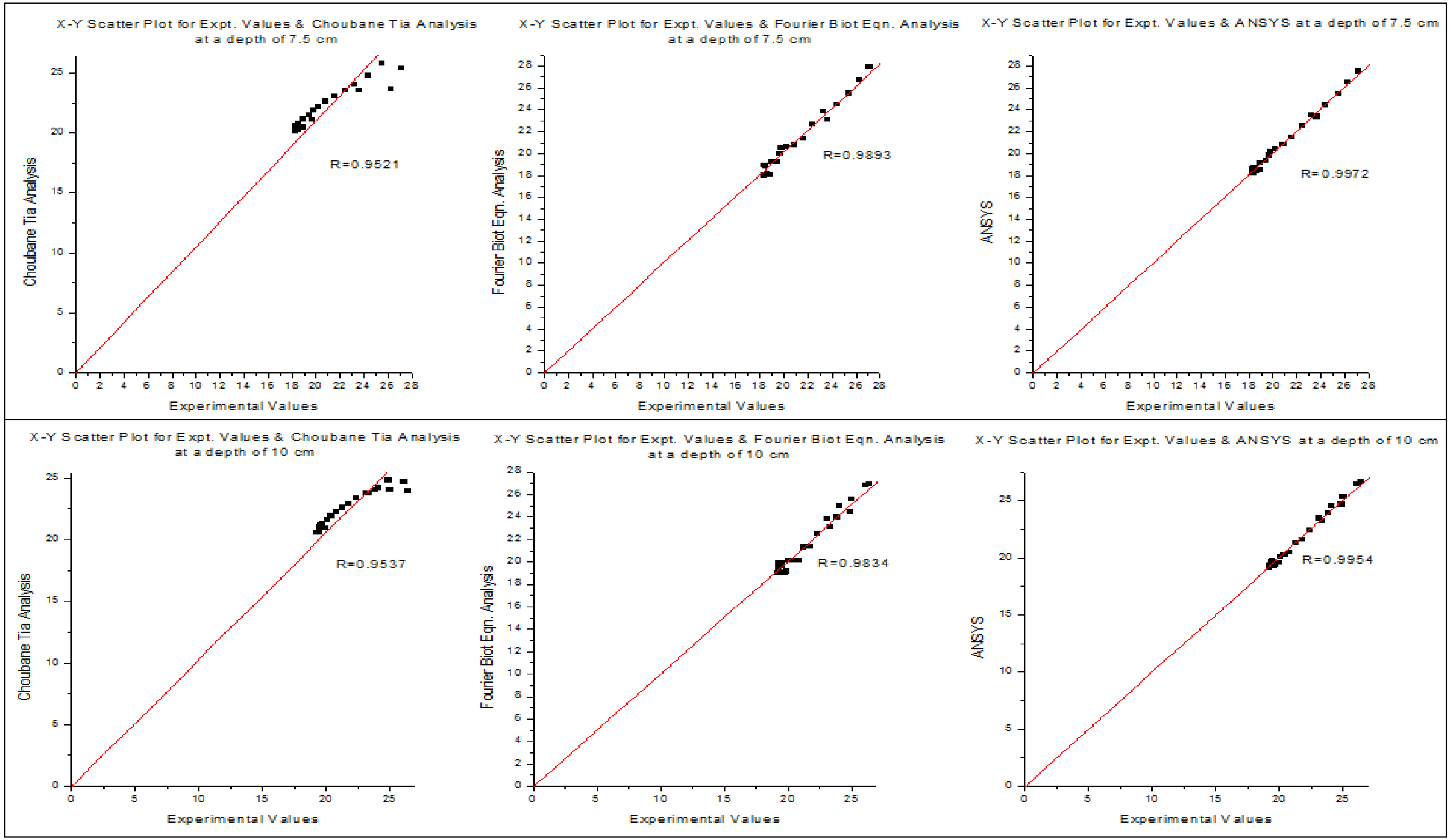


Fig. B-36 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

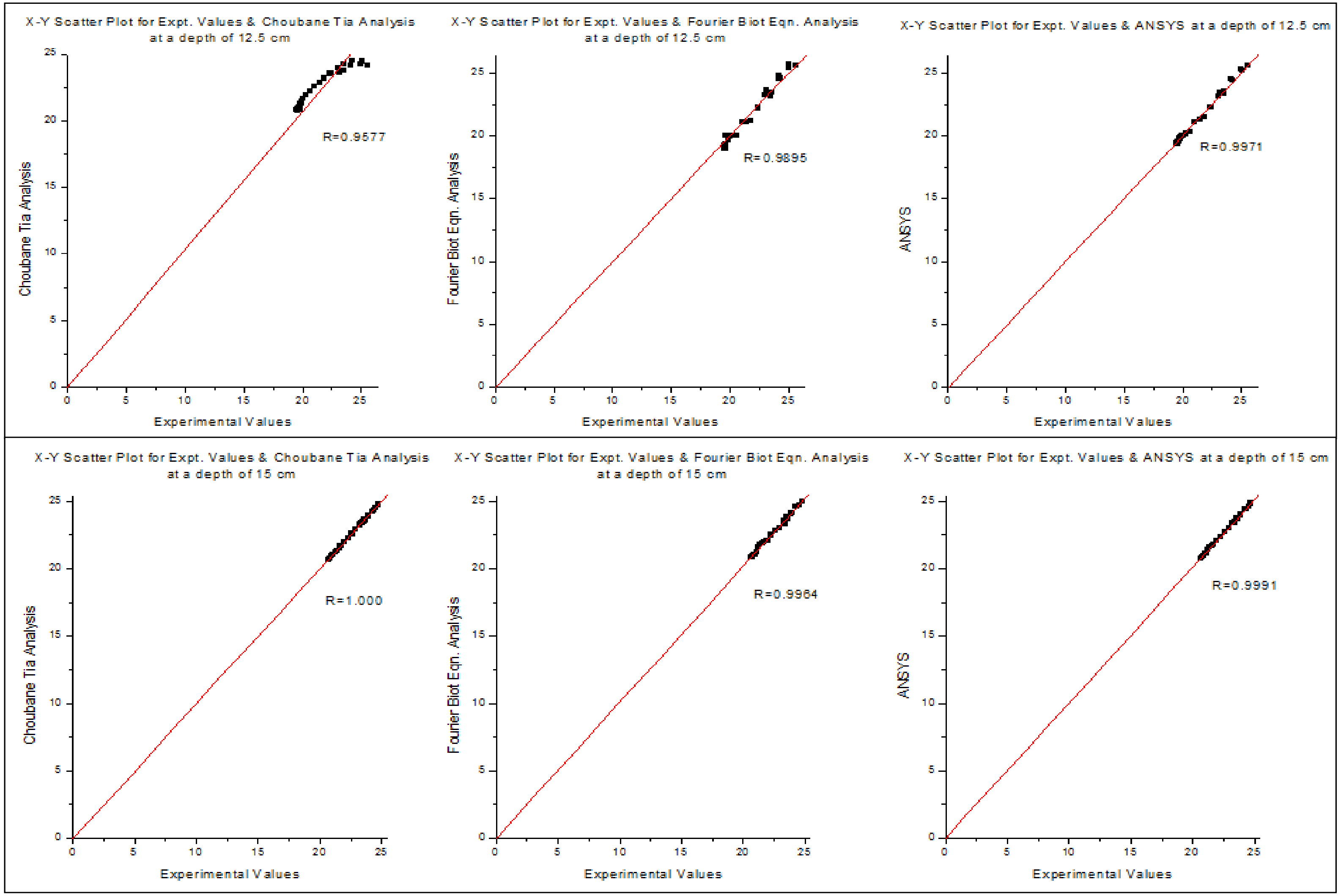


Fig. B-36 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

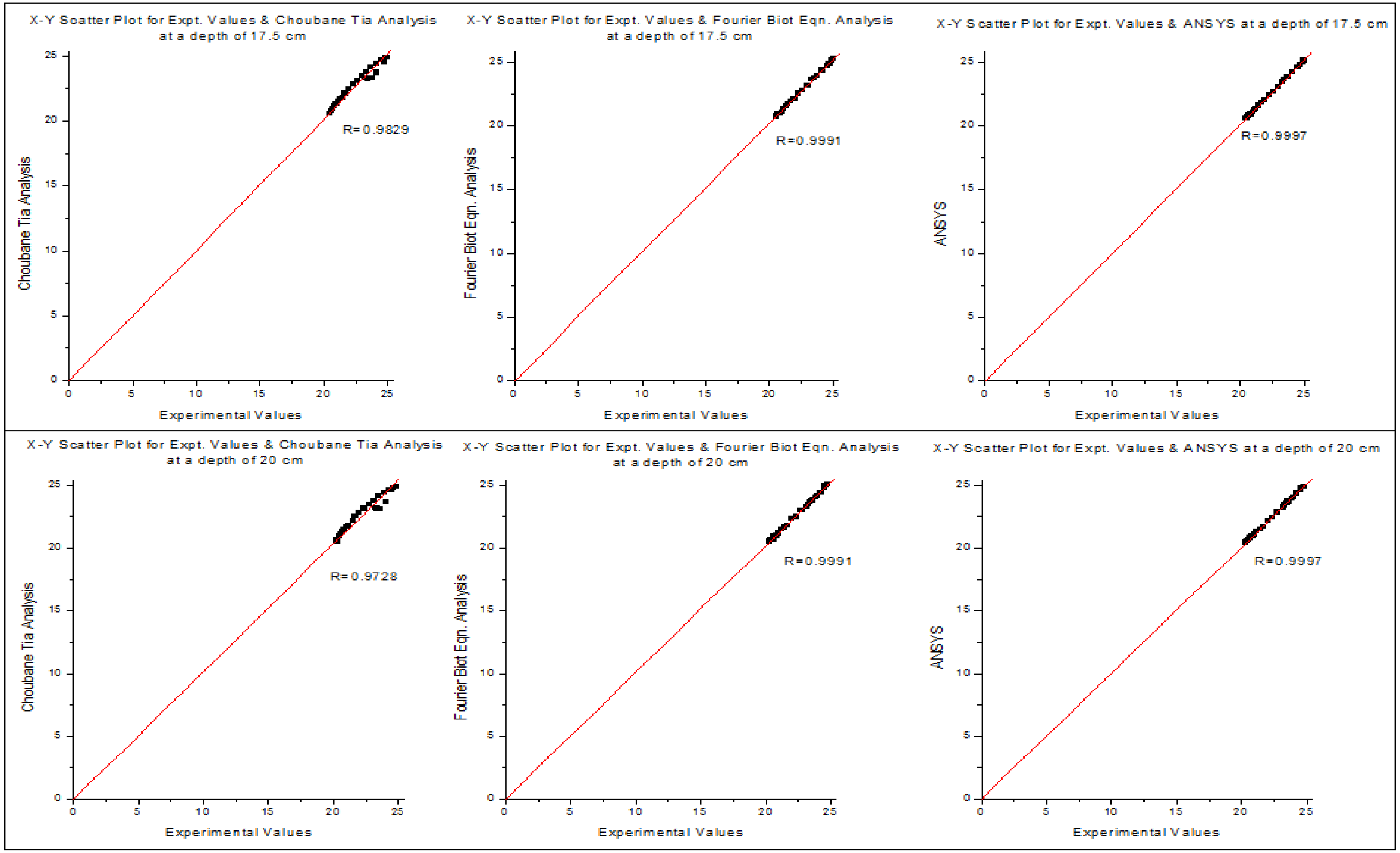


Fig. B-36 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

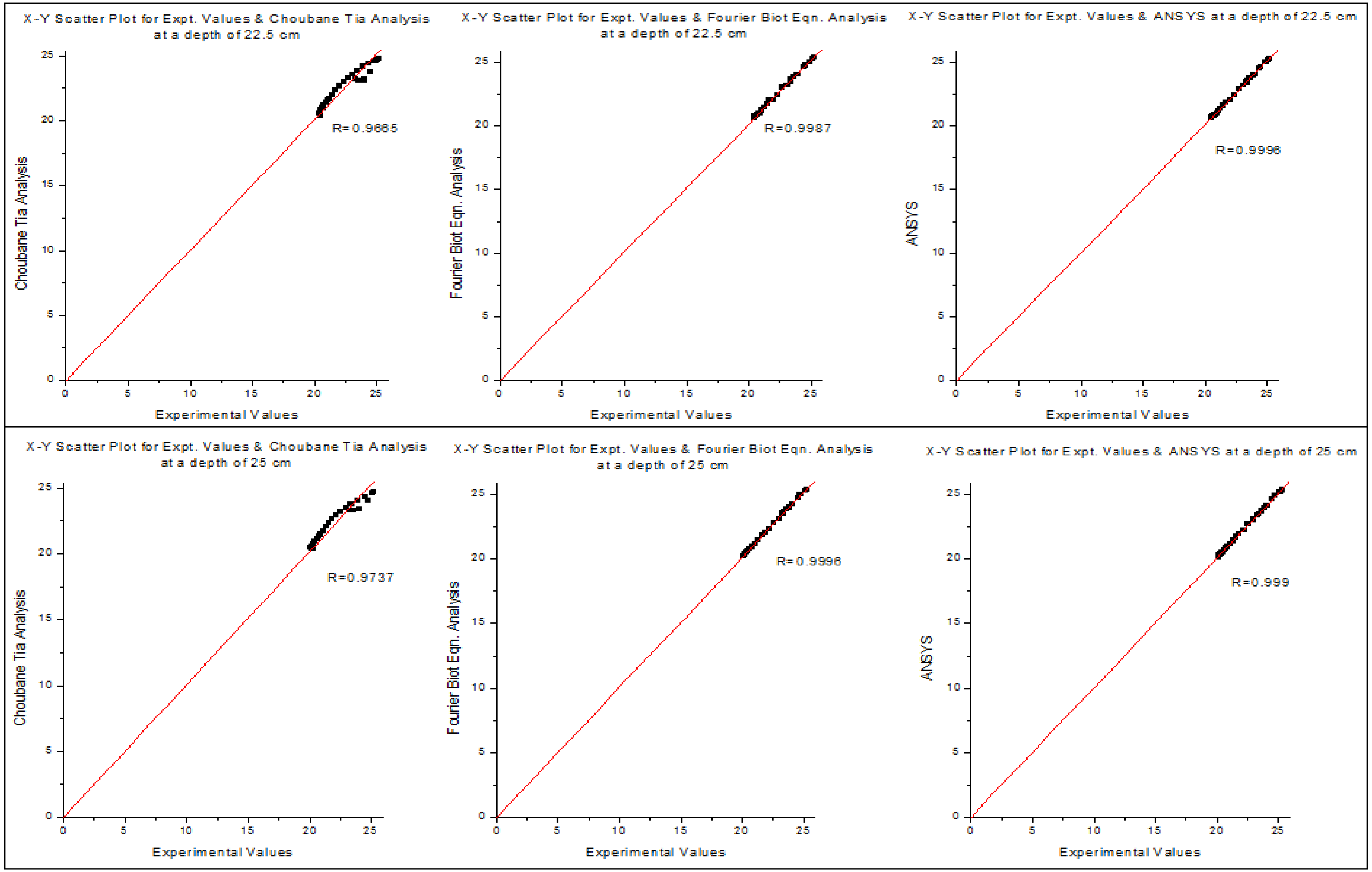


Fig. B-36 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

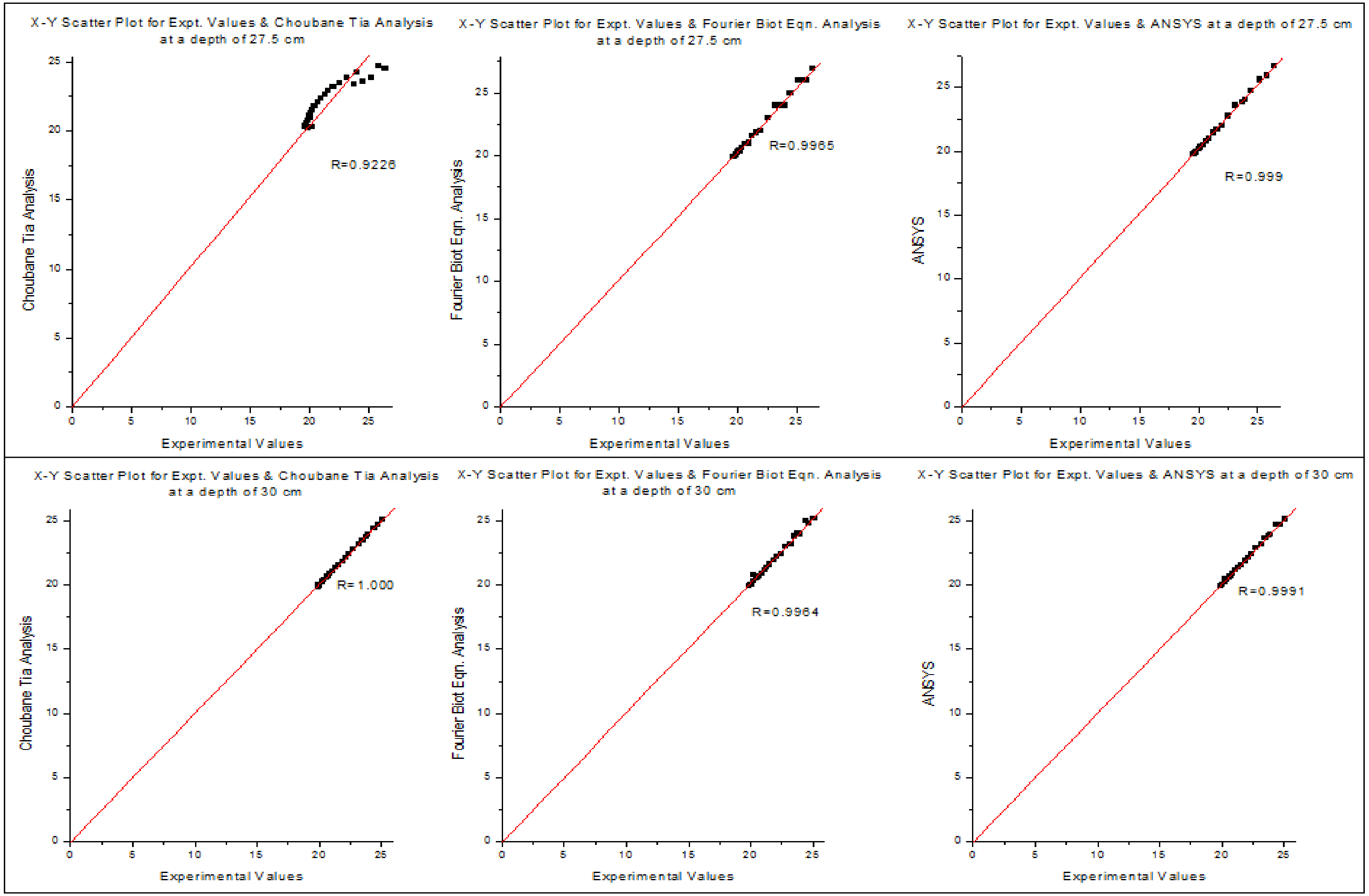


Fig. B-36 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

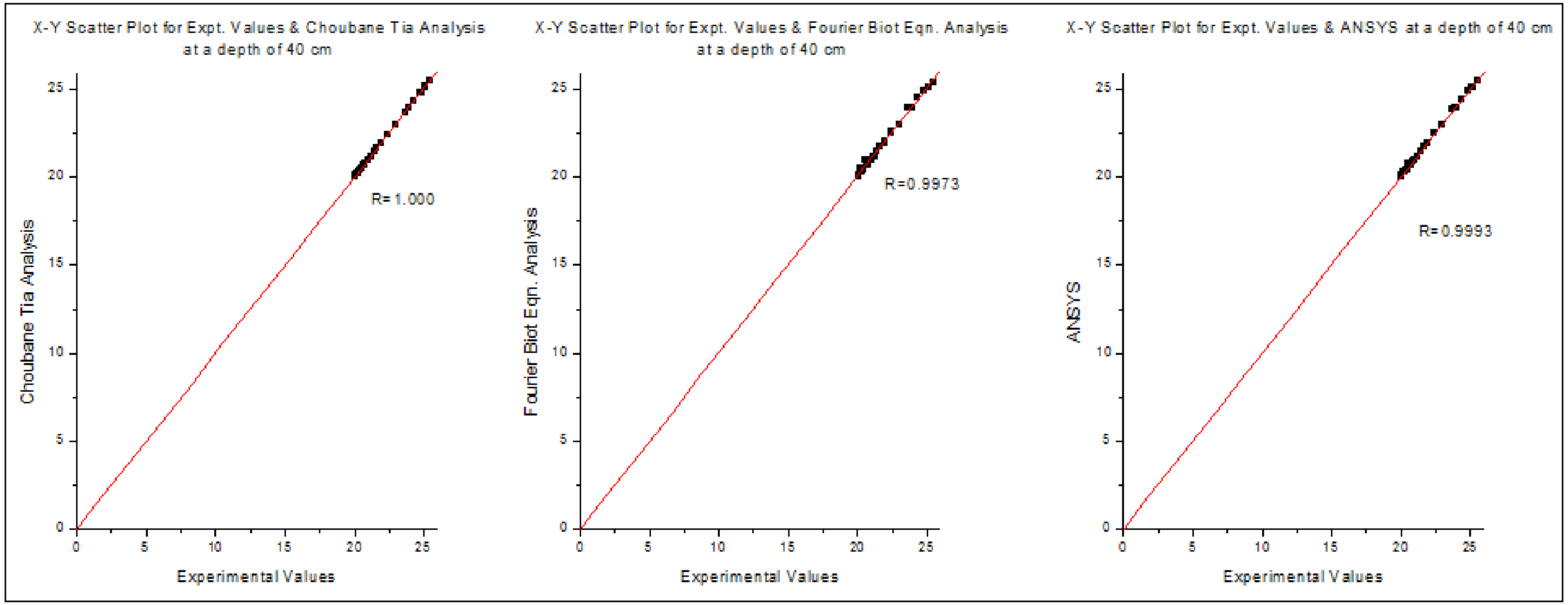


Fig. B-36 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-19 (a): 24 hr. slab (edge) temperature values (measured and calculated) for Mix C for 24 hr. cloudy and humid condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	26	24.58	21.60	23.50	21.68	21.64	20.50	22.54	20.39	20.44	19.80	21.72	19.78	19.79
2	1130 to 1230	28	29.60	24.42	27.46	24.48	24.45	22.67	25.58	22.88	22.77	20.81	23.95	20.66	20.74
3	1230 to 1330	29	30.43	26.69	28.30	26.55	26.62	25.00	26.43	25.24	25.12	22.26	24.81	22.21	22.24
4	1330 to 1430	29	30.81	27.07	28.76	27.80	27.44	25.85	26.96	25.77	25.81	23.42	25.40	23.66	23.54
5	1430 to 1530	30	31.02	27.65	29.08	27.37	27.51	26.60	27.36	26.49	26.54	24.27	25.88	24.48	24.37
6	1530 to 1630	29	31.62	28.48	29.64	28.76	28.62	27.23	27.89	27.09	27.16	24.90	26.39	25.03	24.97
7	1630 to 1730	29	28.56	27.74	27.39	27.10	27.42	27.19	26.36	27.00	27.10	25.39	25.48	25.53	25.46
8	1730 to 1830	27	25.27	25.67	24.93	25.61	25.64	25.98	24.64	25.06	25.52	25.36	24.39	25.67	25.51
9	1830 to 1930	26	23.38	24.06	23.45	24.70	24.38	24.64	23.53	24.46	24.55	24.88	23.61	24.29	24.59
10	1930 to 2030	24	21.23	22.64	21.76	22.64	22.64	23.38	22.24	23.42	23.40	24.25	22.67	24.27	24.26
11	2030 to 2130	23	20.93	21.76	21.47	21.48	21.62	22.46	21.95	22.32	22.39	23.59	22.39	23.20	23.39
12	2130 to 2230	21	20.27	21.16	20.92	21.17	21.16	21.76	21.50	21.11	21.43	23.09	22.02	23.07	23.08
13	2230 to 2330	20	19.83	20.63	20.51	20.04	20.33	21.22	21.11	21.03	21.12	22.53	21.65	22.22	22.38
14	2330 to 0030	19	19.49	20.33	20.19	20.85	20.59	20.81	20.81	20.90	20.86	22.12	21.36	22.34	22.23
15	0030 to 0130	18	18.98	19.96	19.73	19.73	19.84	20.41	20.41	20.82	20.62	21.76	21.01	21.89	21.83
16	0130 to 0230	18	19.13	19.80	19.79	19.74	19.77	20.14	20.39	20.83	20.49	21.52	20.92	21.65	21.59
17	0230 to 0330	17	18.60	19.50	19.35	19.60	19.55	19.95	20.01	19.74	19.85	21.27	20.60	21.43	21.35
18	0330 to 0430	17	18.68	19.23	19.36	19.58	19.41	19.66	19.97	19.72	19.69	20.98	20.50	20.82	20.90
19	0430 to 0530	17	19.02	19.38	19.59	19.51	19.44	19.68	20.11	19.68	19.68	20.78	20.56	20.79	20.78
20	0530 to 0630	17	18.88	19.33	19.46	19.48	19.41	19.63	19.98	19.66	19.64	20.64	20.44	20.70	20.67
21	0630 to 0730	18	19.14	19.35	19.64	19.80	19.58	19.58	20.08	19.87	19.72	20.55	20.47	20.66	20.60
22	0730 to 0830	20	20.10	19.87	20.37	19.00	19.44	19.85	20.61	19.66	19.76	20.55	20.82	20.62	20.59
23	0830 to 0930	22	20.11	20.01	20.37	20.73	20.37	20.03	20.61	20.80	20.41	20.67	20.82	20.78	20.73
24	0930 to 1030	24	20.70	20.22	20.83	20.91	20.56	20.18	20.95	20.56	20.37	20.72	21.05	20.86	20.79

Table B-19 (b): 24 hr. slab (edge) temperature values (measured and calculated) for Mix C for 24 hr. cloudy and humid condition at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	19.90	21.03	19.80	19.85	20.02	20.47	20.14	20.08	20.04	20.04	20.46	20.25
2	1130 to 1230	20.95	22.58	21.03	20.99	20.77	21.46	20.85	20.81	20.60	20.60	20.72	20.66
3	1230 to 1330	22.34	23.45	22.21	22.28	21.83	22.33	21.74	21.78	21.47	21.47	21.87	21.67
4	1330 to 1430	23.37	24.08	23.52	23.44	22.75	23.01	22.22	22.48	22.19	22.19	22.41	22.30
5	1430 to 1530	24.15	24.63	24.02	24.08	23.41	23.62	23.16	23.28	22.85	22.85	23.02	22.93
6	1530 to 1630	24.79	25.13	24.87	24.83	23.97	24.10	24.07	24.02	23.32	23.32	23.54	23.43
7	1630 to 1730	25.19	24.75	25.47	25.33	24.44	24.17	24.58	24.51	23.73	23.73	23.88	23.80
8	1730 to 1830	25.07	24.20	25.19	25.13	24.58	24.06	24.69	24.63	23.97	23.97	24.11	24.04
9	1830 to 1930	24.59	23.70	24.70	24.65	24.33	23.78	24.50	24.41	23.87	23.87	24.05	23.96
10	1930 to 2030	23.98	23.05	24.05	24.02	23.97	23.38	24.07	24.02	23.65	23.65	23.84	23.75
11	2030 to 2130	23.40	22.77	23.52	23.46	23.56	23.11	23.66	23.61	23.39	23.39	23.53	23.46
12	2130 to 2230	22.93	22.47	23.04	22.98	23.21	22.85	23.32	23.27	23.17	23.17	23.41	23.29
13	2230 to 2330	22.41	22.12	22.52	22.47	22.85	22.51	23.00	22.92	22.84	22.84	23.00	22.92
14	2330 to 0030	22.02	21.83	21.96	21.99	22.52	22.24	22.68	22.60	22.57	22.57	22.89	22.73
15	0030 to 0130	21.70	21.52	21.80	21.75	22.23	21.96	22.38	22.30	22.32	22.32	22.68	22.50
16	0130 to 0230	21.49	21.37	21.57	21.53	21.94	21.76	21.96	21.95	22.08	22.08	22.21	22.14
17	0230 to 0330	21.24	21.10	21.09	21.17	21.70	21.53	21.89	21.80	21.87	21.87	21.97	21.92
18	0330 to 0430	20.96	20.96	20.90	20.93	21.54	21.34	21.68	21.61	21.66	21.66	21.87	21.76
19	0430 to 0530	20.76	20.95	20.88	20.82	21.34	21.27	21.51	21.43	21.54	21.54	21.72	21.63
20	0530 to 0630	20.68	20.83	20.77	20.72	21.23	21.16	21.34	21.28	21.42	21.42	21.66	21.54
21	0630 to 0730	20.56	20.80	20.68	20.62	21.10	21.08	21.17	21.14	21.30	21.30	21.51	21.41
22	0730 to 0830	20.59	21.01	20.70	20.64	21.10	21.17	21.14	21.12	21.29	21.29	21.42	21.36
23	0830 to 0930	20.70	21.00	20.85	20.78	21.10	21.15	21.16	21.13	21.27	21.27	21.49	21.38
24	0930 to 1030	20.79	21.14	20.94	20.86	21.12	21.22	21.20	21.16	21.28	21.28	21.51	21.40

Table B-19 (c): 24 hr. slab (edge) temperature values (measured and calculated) for Mix C for 24 hr. cloudy and humid condition at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (ºC) at 17.5 cm				Temperature (ºC) at 20 cm				Temperature (ºC) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	20.40	19.74	20.63	20.51	20.41	19.57	20.53	20.47	20.38	19.53	20.40	20.39
2	1130 to 1230	20.82	19.99	20.97	20.89	20.80	19.64	20.91	20.85	20.86	19.54	20.97	20.92
3	1230 to 1330	21.41	20.86	21.44	21.42	21.32	20.51	21.45	21.38	21.44	20.40	21.58	21.51
4	1330 to 1430	21.89	21.61	22.01	21.95	21.74	21.28	21.91	21.83	21.88	21.19	22.05	21.97
5	1430 to 1530	22.42	22.30	22.59	22.50	22.22	21.99	22.47	22.34	22.41	21.92	22.55	22.48
6	1530 to 1630	22.87	22.77	23.07	22.97	22.64	22.47	22.76	22.70	22.84	22.40	22.94	22.89
7	1630 to 1730	23.23	23.44	23.41	23.32	23.04	23.29	23.12	23.08	23.21	23.29	23.34	23.28
8	1730 to 1830	23.48	23.93	23.66	23.57	23.29	23.93	23.43	23.36	23.36	23.99	23.51	23.43
9	1830 to 1930	23.56	23.96	23.71	23.63	23.37	24.05	23.51	23.44	23.40	24.15	23.51	23.46
10	1930 to 2030	23.50	23.88	23.65	23.57	23.33	24.05	23.51	23.42	23.35	24.18	23.47	23.41
11	2030 to 2130	23.35	23.62	23.53	23.44	23.30	23.80	23.47	23.39	23.28	23.92	23.40	23.34
12	2130 to 2230	23.26	23.42	23.41	23.34	23.17	23.61	23.29	23.23	23.11	23.73	23.29	23.20
13	2230 to 2330	23.08	23.10	23.21	23.14	22.97	23.28	23.12	23.05	22.89	23.40	23.00	22.95
14	2330 to 0030	22.87	22.82	22.99	22.93	22.79	23.01	23.02	22.90	22.66	23.12	22.89	22.78
15	0030 to 0130	22.68	22.59	22.87	22.78	22.60	22.79	22.99	22.80	22.48	22.91	22.62	22.55
16	0130 to 0230	22.48	22.32	22.59	22.53	22.41	22.50	22.78	22.60	22.28	22.60	22.41	22.35
17	0230 to 0330	22.28	22.14	22.41	22.35	22.24	22.32	22,61	22.24	22.08	22.42	22.21	22.15
18	0330 to 0430	22.09	21.89	22.22	22.16	22.05	22.06	22.47	22.26	21.89	22.15	22.00	21.94
19	0430 to 0530	21.92	21.74	22.12	22.02	21.90	21.87	21.99	21.94	21.74	21.95	21.91	21.82
20	0530 to 0630	21.79	21.62	21.98	21.88	21.76	21.75	21.99	21.87	21.61	21.81	21.82	21.71
21	0630 to 0730	21.66	21.47	21.81	21.74	21.63	21.58	21.88	21.75	21.60	21.64	21.81	21.71
22	0730 to 0830	21.60	21.39	21.76	21.68	21.60	21.46	21.82	21.71	21.59	21.50	21.81	21.70
23	0830 to 0930	21.60	21.36	21.77	21.69	21.60	21.42	21.81	21.71	21.50	21.45	21.77	21.64
24	0930 to 1030	21.60	21.33	21.77	21.69	21.60	21.36	21.81	21.71	21.50	21.38	21.76	21.63

Table B-19 (d): 24 hr. slab (edge) temperature values (measured and calculated) for Mix C for 24 hr. cloudy and humid condition at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	Temperature (°C) at 25 cm				Temperature (°C) at 27.5 cm				Temperature (°C) at 30 cm				Temperature (°C) at 40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1030 to 1130	20.28	19.62	20.41	20.35	20.22	19.84	20.98	20.60	20.19	20.19	20.20	20.20	21.02	21.02	21.05	21.03
2	1130 to 1230	20.80	19.69	21.01	20.90	20.78	20.10	20.97	20.87	20.77	20.77	20.80	20.78	21.89	21.89	21.92	21.90
3	1230 to 1330	21.44	20.55	21.62	21.53	21.49	20.96	21.97	21.73	21.61	21.61	21.70	21.65	23.36	23.36	23.40	23.38
4	1330 to 1430	21.97	21.35	22.11	22.04	22.08	21.75	22.28	22.18	22.40	22.40	22.50	22.45	24.29	24.29	24.23	24.26
5	1430 to 1530	22.53	22.08	22.71	22.62	22.65	22.47	22.98	22.82	23.10	23.10	23.20	23.15	24.93	24.93	24.93	24.93
6	1530 to 1630	23.00	22.57	23.18	23.09	23.12	22.98	23.28	23.20	23.64	23.64	23.70	23.67	25.36	25.36	25.44	25.40
7	1630 to 1730	23.33	23.44	23.51	23.42	23.34	23.73	23.48	23.41	24.17	24.17	24.20	24.18	25.68	25.68	25.75	25.71
8	1730 to 1830	23.48	24.10	23.70	23.59	23.48	24.26	23.62	23.55	24.46	24.46	24.50	24.48	25.40	25.40	25.49	25.44
9	1830 to 1930	23.50	24.25	23.73	23.62	23.37	24.35	23.54	23.45	24.45	24.45	24.50	24.48	24.88	24.88	24.89	24.89
10	1930 to 2030	23.40	24.25	23.65	23.52	23.27	24.27	23.45	23.36	24.24	24.24	24.30	24.27	24.20	24.20	24.29	24.25
11	2030 to 2130	23.28	24.00	23.42	23.35	23.09	24.03	23.22	23.15	24.00	24.00	24.00	24.00	23.55	23.55	23.60	23.57
12	2130 to 2230	23.07	23.78	23.21	23.14	22.85	23.77	23.01	22.93	23.69	23.69	23.70	23.69	23.22	23.22	23.30	23.26
13	2230 to 2330	22.83	23.45	23.02	22.92	22.58	23.43	22.81	22.70	23.33	23.33	23.40	23.37	22.87	22.87	22.90	22.89
14	2330 to 0030	22.58	23.16	22.79	22.69	22.35	23.12	22.62	22.48	23.02	23.02	23.05	23.03	22.60	22.60	22.63	22.61
15	0030 to 0130	22.37	22.94	22.52	22.44	22.15	22.90	22.31	22.23	22.78	22.78	22.80	22.79	22.36	22.36	22.40	22.38
16	0130 to 0230	22.17	22.64	22.30	22.23	21.96	22.61	22.12	22.04	22.50	22.50	22.50	22.50	22.13	22.13	22.20	22.17
17	0230 to 0330	21.98	22.44	22.12	22.05	21.79	22.38	21.91	21.85	22.24	22.24	22.30	22.27	21.98	21.98	21.98	21.98
18	0330 to 0430	21.78	22.17	22.00	21.89	21.62	22.11	21.86	21.74	21.98	21.98	21.99	21.99	21.76	21.76	21.80	21.78
19	0430 to 0530	21.62	21.96	21.93	21.77	21.54	21.91	21.72	21.63	21.80	21.80	21.82	21.81	21.67	21.67	21.70	21.69
20	0530 to 0630	21.55	21.81	21.78	21.67	21.40	21.75	21.65	21.53	21.62	21.62	21.65	21.63	21.60	21.60	21.60	21.60
21	0630 to 0730	21.49	21.64	21.61	21.55	21.30	21.59	21.58	21.44	21.49	21.49	21.50	21.49	21.60	21.60	21.60	21.60
22	0730 to 0830	21.43	21.50	21.59	21.51	21.30	21.48	21.57	21.44	21.44	21.44	21.45	21.44	21.60	21.60	21.64	21.62
23	0830 to 0930	21.41	21.46	21.59	21.50	21.32	21.44	21.58	21.45	21.38	21.38	21.40	21.39	21.63	21.63	21.62	21.62
24	0930 to 1030	21.47	21.38	21.64	21.56	21.40	21.37	21.61	21.50	21.35	21.35	21.35	21.35	21.60	21.60	21.62	21.61

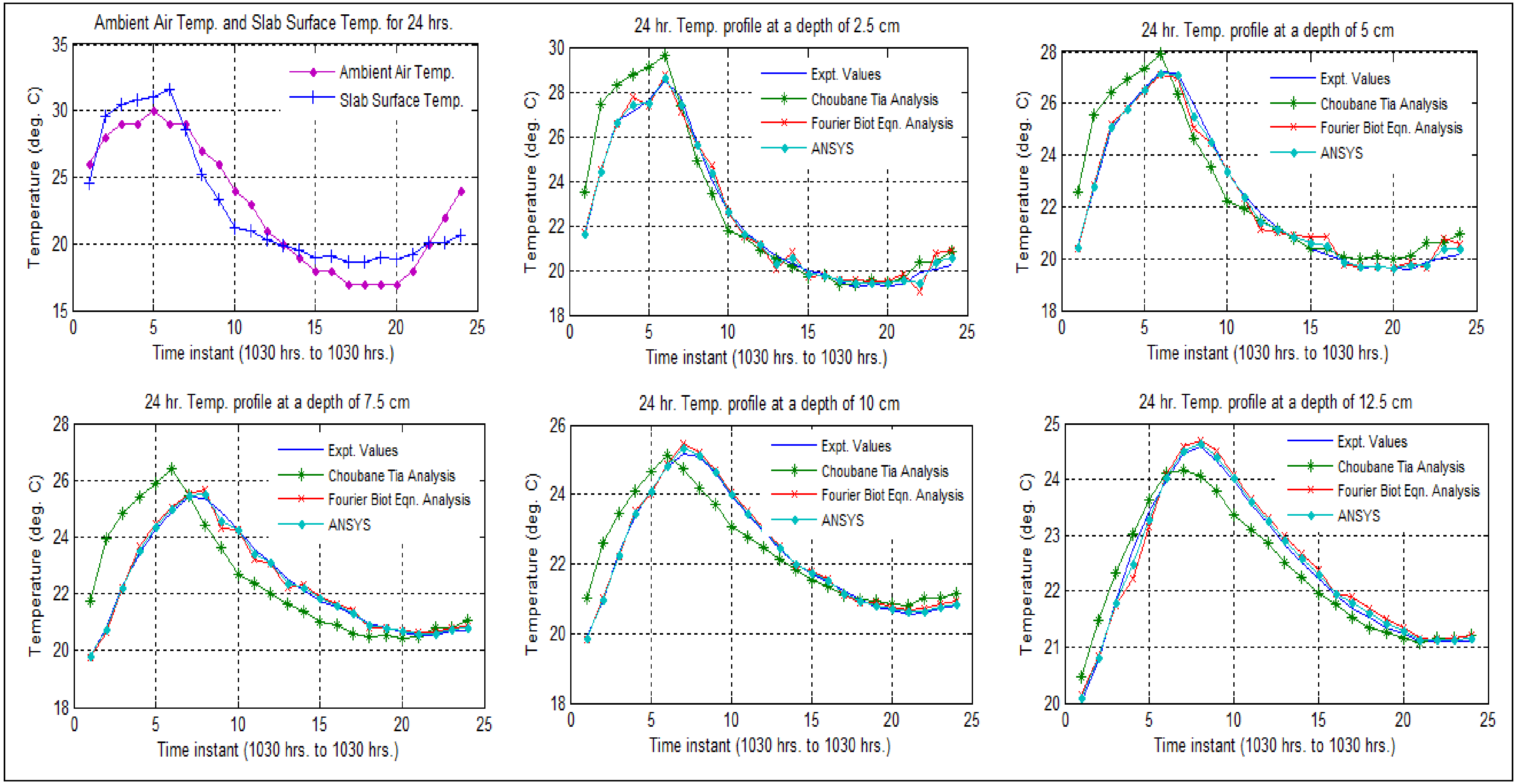


Fig. B-37 (a): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix C for 24 hr. cloudy and humid condition (surface to 12.5 cm)

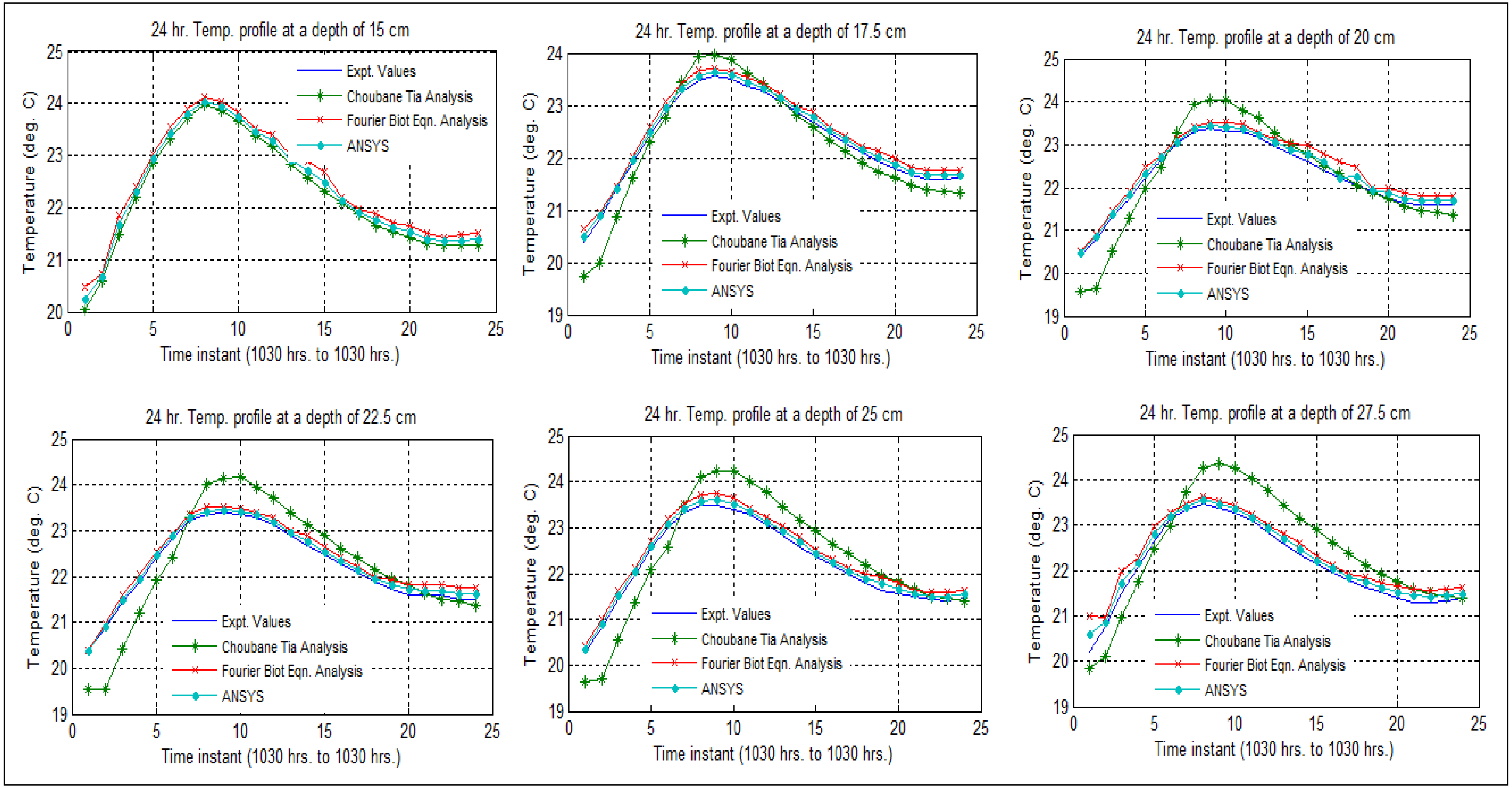


Fig. B-37 (b): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix C for 24 hr. cloudy and humid condition (15 cm to 27.5 cm)

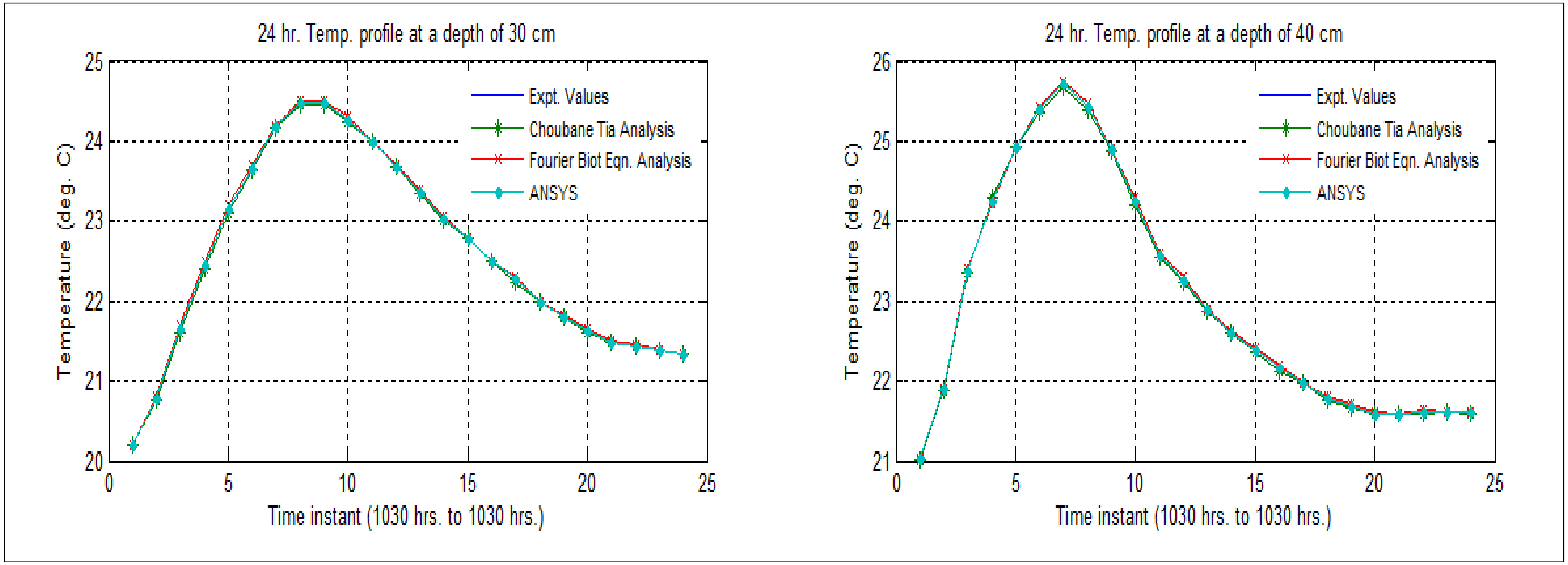


Fig. B-37 (c): 24 hour slab (edge) temperature profile (measured and calculated) at various depths for Mix C for 24 hr. cloudy and humid condition (30 cm & 40 cm)

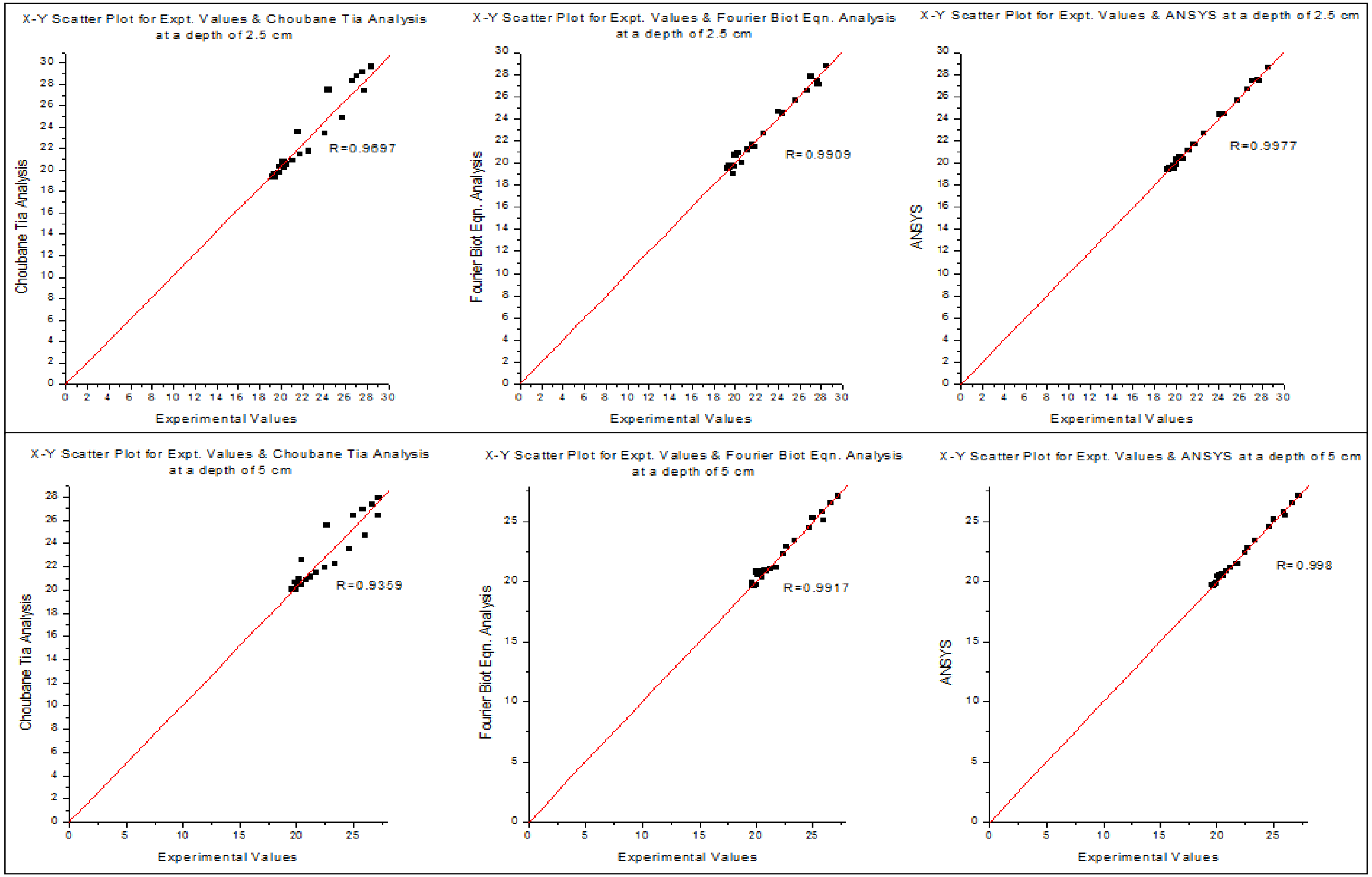


Fig. B-38 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

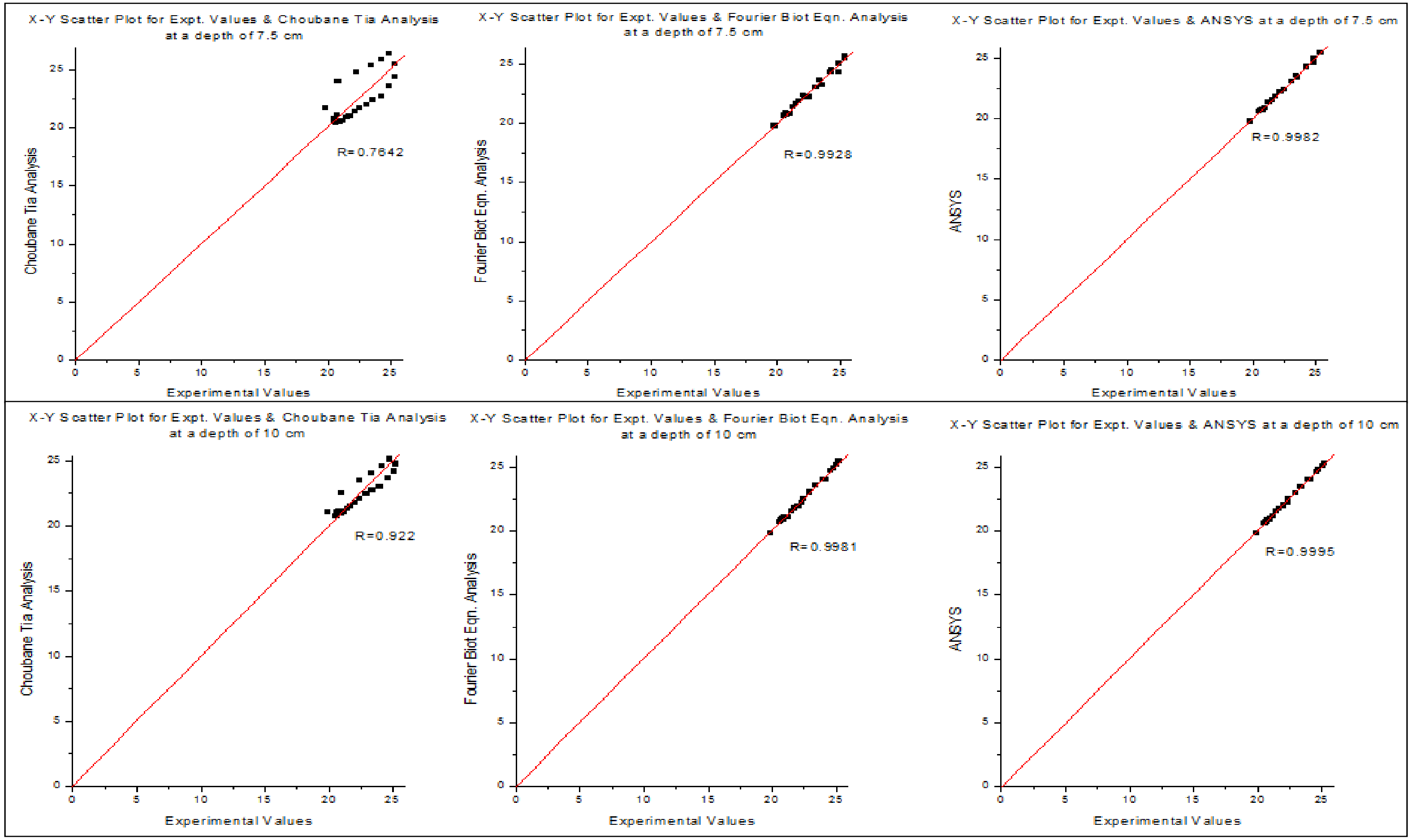


Fig. B-38 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

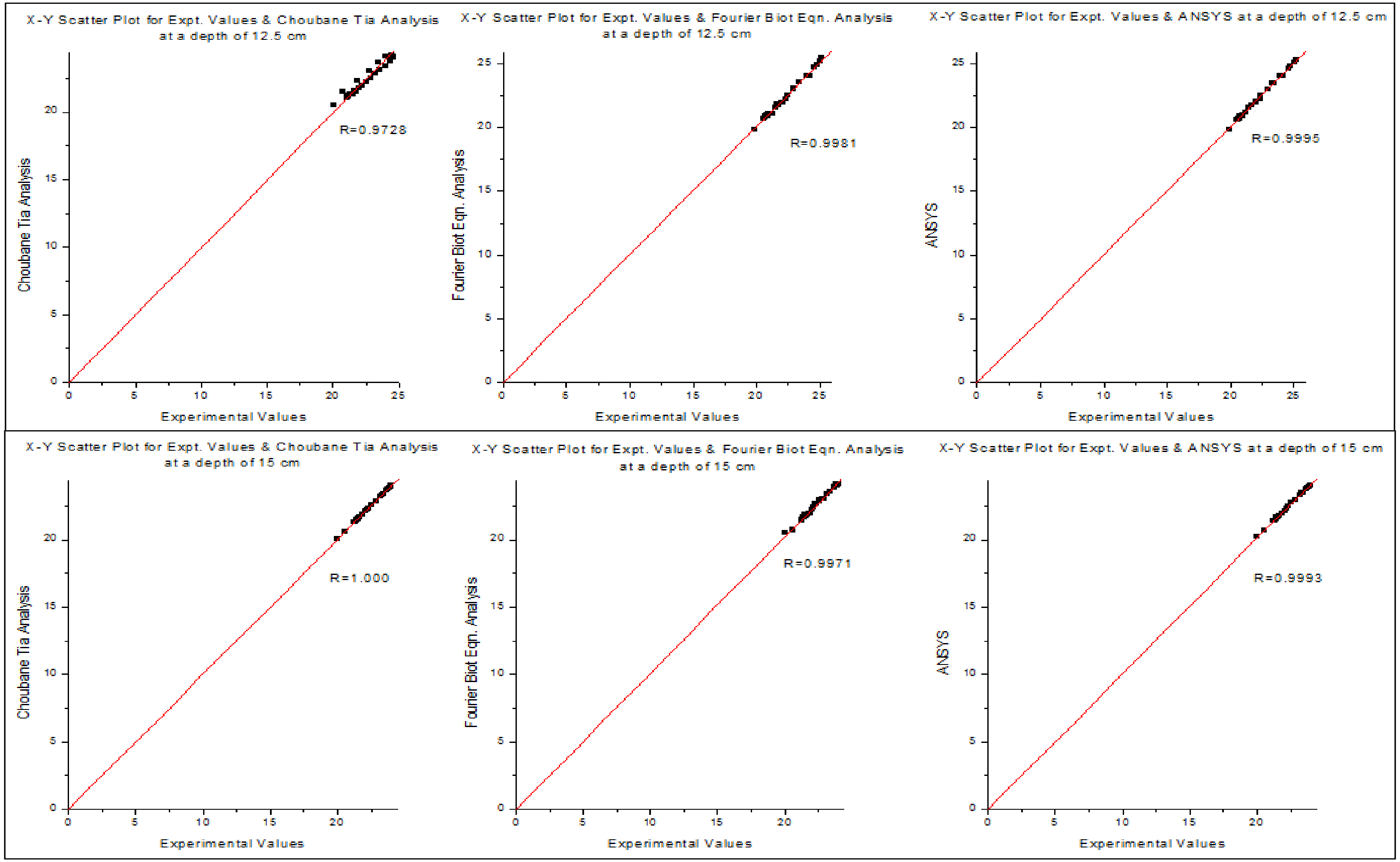


Fig. B-38 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

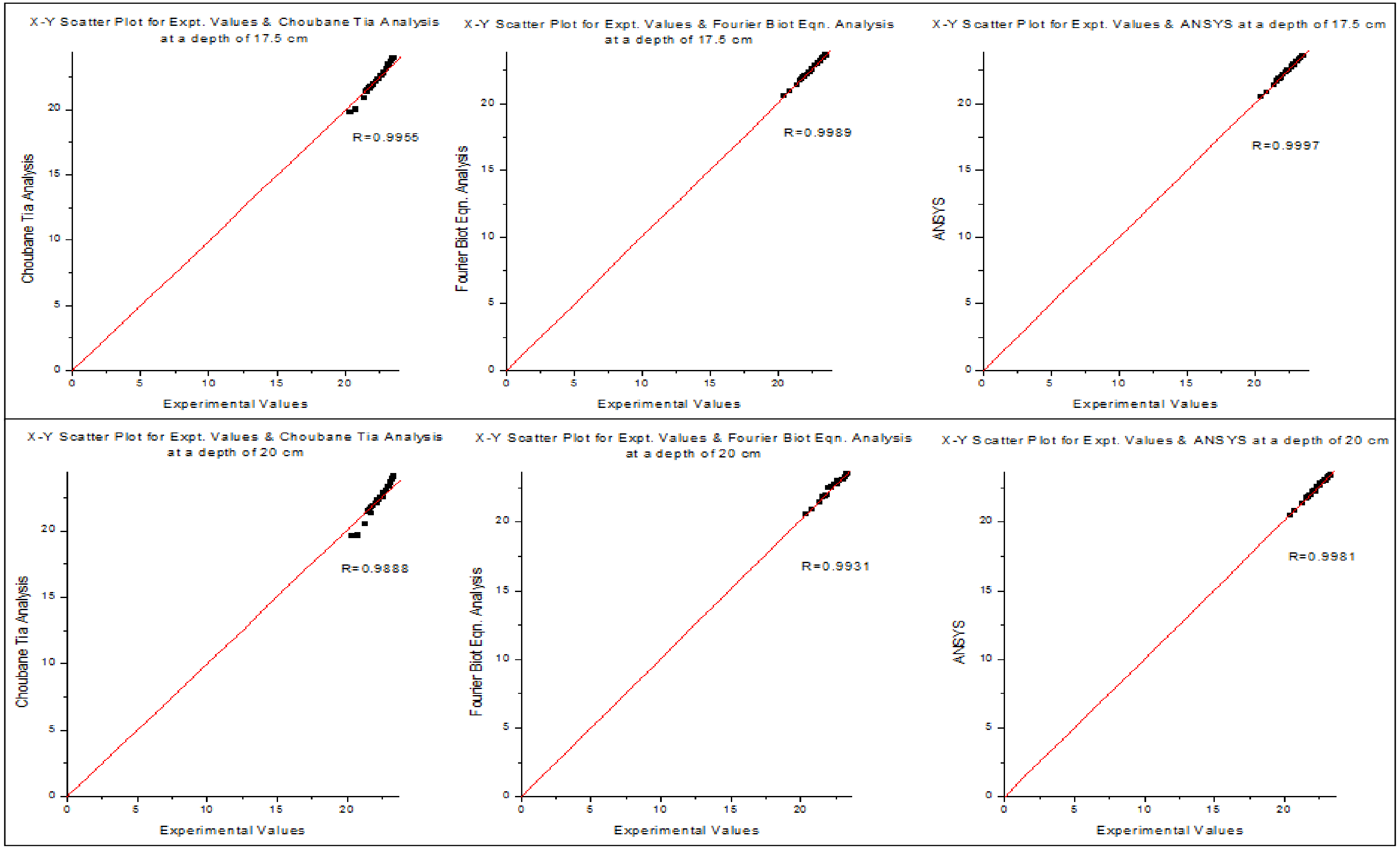


Fig. B-38 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

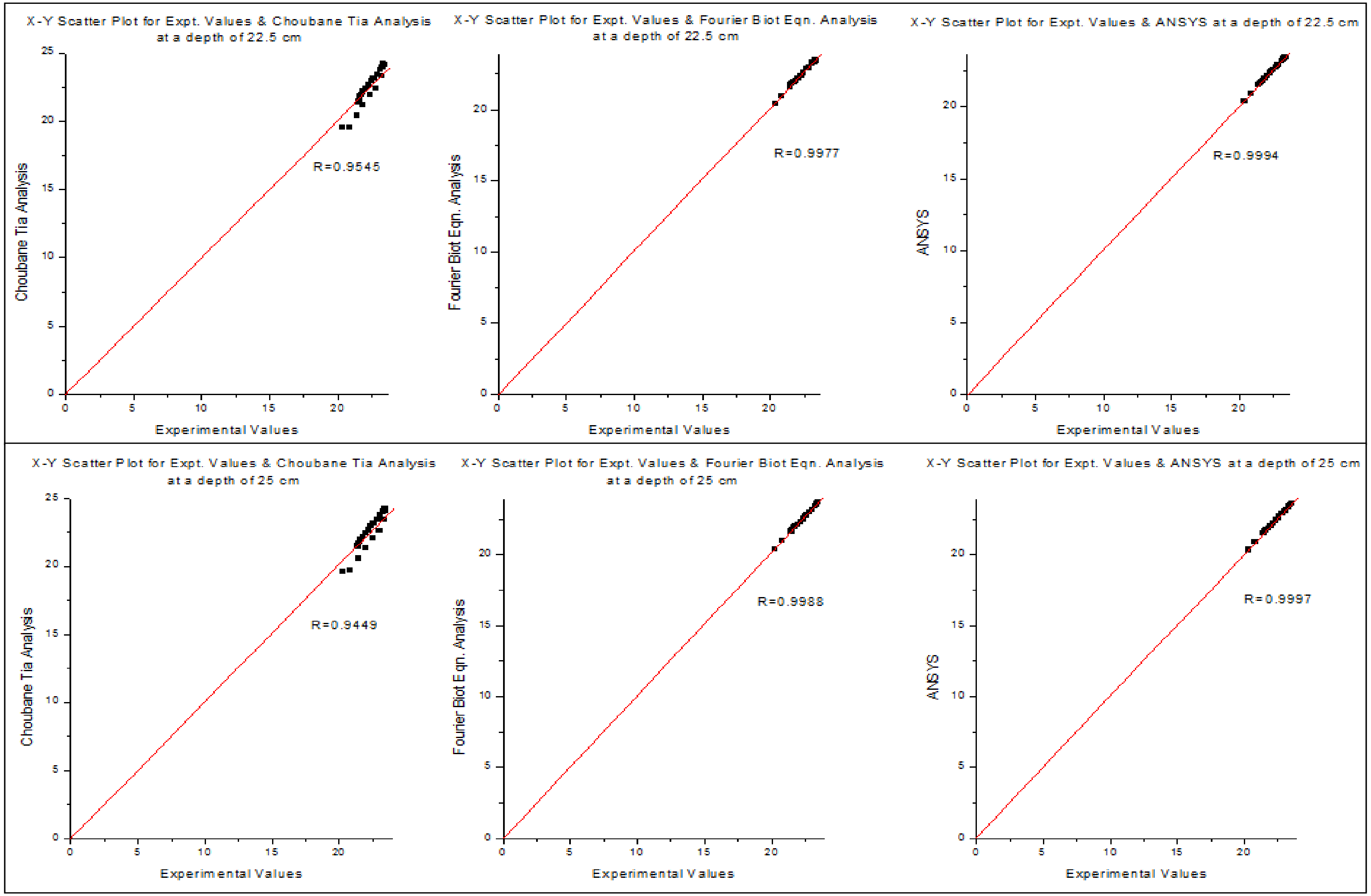


Fig. B-38 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

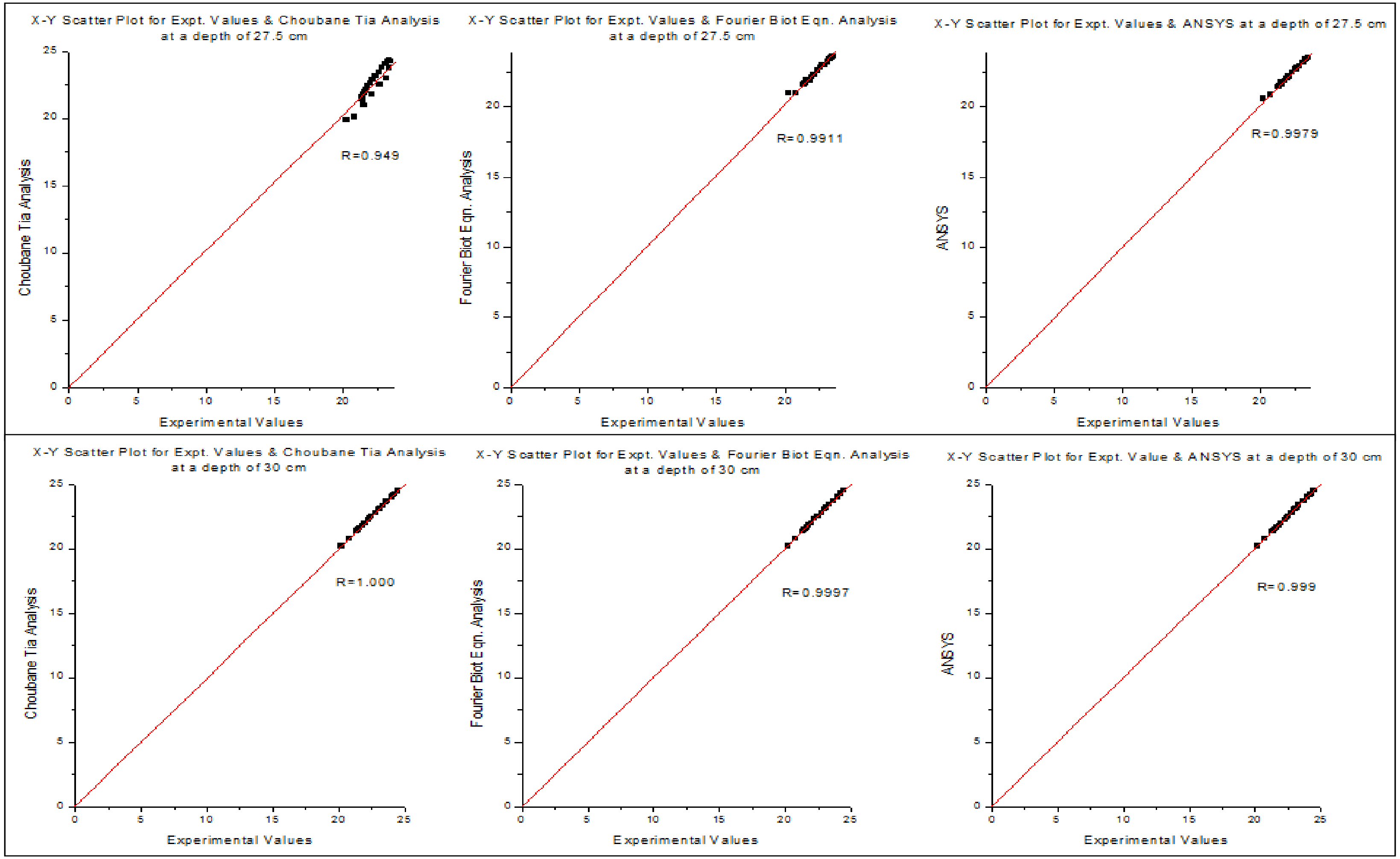


Fig. B-38 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

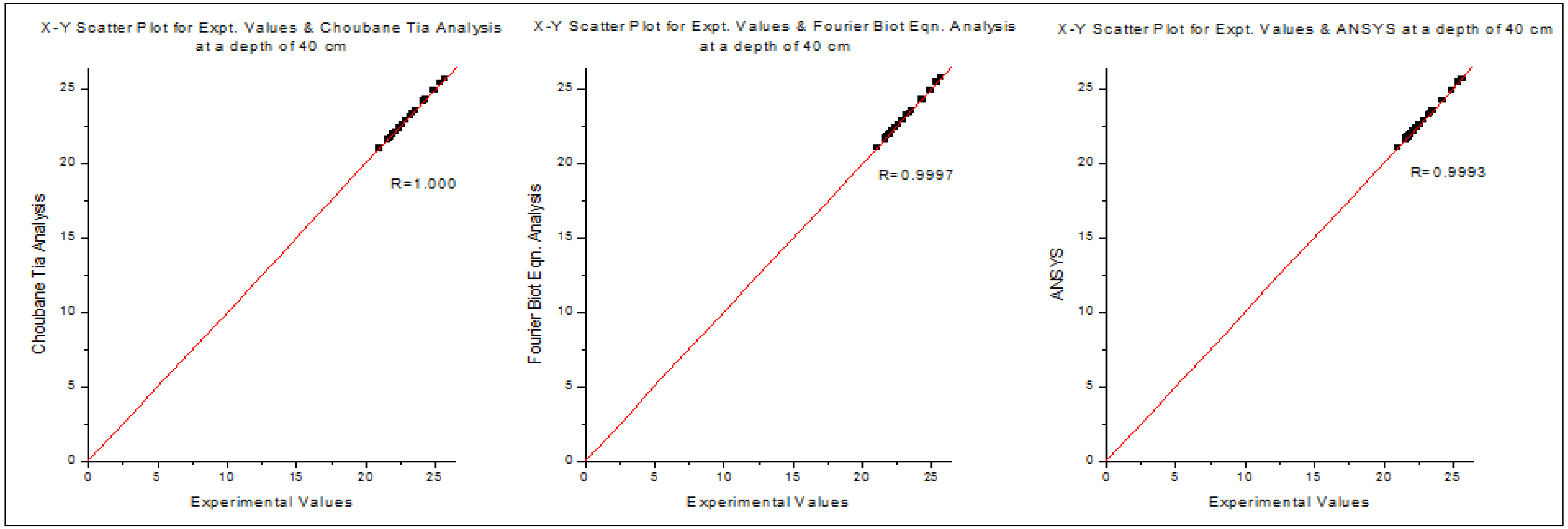


Fig. B-38 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

Table B-20 (a): 24 hr. slab (D) temperature values (measured and calculated) for Mix C for 24 hr. cloudy and humid condition at 2.5 cm, 5 cm & 7.5 cm

S. No.	Time Instant	Ambient Air Temp.	Slab surface	Temperature (°C) at 2.5 cm				Temperature (°C) at 5 cm				Temperature (°C) at 7.5 cm			
		(°C)	(°C)	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	26	24.49	22.68	23.59	22.71	22.69	21.84	22.80	21.40	21.62	20.99	22.11	20.79	20.89
2	1200 to 1300	28	28.15	25.86	26.35	25.96	25.91	24.58	24.78	24.19	24.38	23.10	23.44	23.55	23.32
3	1300 to 1400	29	28.58	27.62	26.72	27.81	27.71	26.47	25.11	26.67	26.57	25.10	23.74	25.49	25.29
4	1400 to 1500	29	29.64	28.61	27.63	28.88	28.75	27.46	25.88	27.03	27.24	26.15	24.40	26.82	26.48
5	1500 to 1600	30	30.39	29.44	28.32	29.57	29.50	28.37	26.53	28.62	28.50	27.09	25.02	27.56	27.33
6	1600 to 1700	29	29.66	30.51	27.90	30.25	30.38	29.35	26.39	29.42	29.38	28.15	25.11	28.43	28.29
7	1700 to 1800	29	26.78	29.34	25.87	29.56	29.45	28.70	25.09	28.31	28.50	28.19	24.45	28.73	28.46
8	1800 to 1900	27	24.84	26.88	24.56	26.73	26.80	26.79	24.32	26.14	26.46	26.89	24.13	26.72	26.80
9	1900 to 2000	26	23.27	25.07	23.49	25.72	25.40	25.19	23.68	25.47	25.33	25.58	23.85	25.30	25.44
10	2000 to 2100	24	21.96	23.48	22.55	23.47	23.47	23.70	23.05	23.31	23.51	24.40	23.49	24.20	24.30
11	2100 to 2200	23	21.51	22.49	22.21	22.35	22.42	22.66	22.83	22.23	22.44	23.38	23.34	23.14	23.26
12	2200 to 2300	21	20.98	21.71	21.81	21.00	21.36	21.82	22.52	21.00	21.41	22.56	23.12	22.00	22.28
13	2300 to 0000	20	20.61	21.22	21.48	21.86	21.54	21.26	22.22	21.91	21.58	21.89	22.85	21.94	21.91
14	0000 to 0100	19	20.15	20.80	21.06	20.66	20.73	20.80	21.85	20.77	20.79	21.47	22.51	21.86	21.66
15	0100 to 0200	18	19.88	20.35	20.80	20.47	20.41	20.34	21.59	20.66	20.50	21.01	22.26	21.78	21.40
16	0200 to 0300	18	19.81	20.21	20.70	20.58	20.39	20.15	21.47	20.72	20.44	20.71	22.12	20.82	20.77
17	0300 to 0400	17	19.36	19.93	20.32	19.41	19.67	19.88	21.15	19.61	19.74	20.39	21.84	20.75	20.57
18	0400 to 0500	17	19.59	19.87	20.44	19.35	19.61	19.71	21.16	19.57	19.64	20.13	21.77	20.73	20.43
19	0500 to 0600	17	19.65	20.00	20.43	20.35	20.17	19.80	21.09	19.57	19.69	20.10	21.64	20.73	20.41
20	0600 to 0700	17	19.55	19.91	20.29	19.29	19.60	19.71	20.93	19.53	19.62	20.01	21.46	20.71	20.36
21	0700 to 0800	18	19.94	20.00	20.55	20.62	20.31	19.78	21.07	19.75	19.76	20.00	21.50	20.84	20.42
22	0800 to 0900	20	20.51	20.51	20.93	20.89	20.70	20.17	21.29	20.59	20.38	20.25	21.59	20.37	20.31
23	0900 to 1000	22	20.78	20.94	21.10	20.50	20.72	20.53	21.38	20.64	20.58	20.55	21.61	20.04	20.29
24	1000 to 1100	24	22.32	21.53	22.25	21.42	21.47	21.03	22.17	20.24	20.63	20.88	22.10	20.42	20.65

Table B-20 (b): 24 hr. slab (D) temperature values (measured and calculated) for Mix C for 24 hr. cloudy and humid condition at 10 cm, 12.5 cm & 15 cm

S. No.	Time Instant	Temperature (°C) at 10 cm				Temperature (°C) at 12.5 cm				Temperature (°C) at 15 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	20.67	21.53	20.62	20.64	20.28	21.06	20.39	20.34	20.70	20.70	20.46	20.58
2	1200 to 1300	21.98	22.33	21.64	21.81	21.16	21.44	21.32	21.24	20.79	20.79	20.76	20.77
3	1300 to 1400	23.56	22.62	23.38	23.47	22.31	21.74	22.43	22.37	21.11	21.11	21.17	21.14
4	1400 to 1500	24.68	23.20	24.51	24.59	23.33	22.25	23.50	23.41	21.58	21.58	21.63	21.61
5	1500 to 1600	25.60	23.78	25.57	25.59	24.21	22.81	24.18	24.20	22.12	22.12	22.29	22.21
6	1600 to 1700	26.53	24.07	26.69	26.61	24.98	23.27	25.05	25.02	22.71	22.71	22.67	22.69
7	1700 to 1800	27.01	23.93	27.13	27.07	25.62	23.55	25.91	25.76	23.30	23.30	23.45	23.37
8	1800 to 1900	26.75	23.99	26.42	26.58	25.77	23.89	25.24	25.50	23.83	23.83	24.02	23.93
9	1900 to 2000	26.00	23.99	26.12	26.06	25.43	24.11	25.10	25.27	24.21	24.21	24.35	24.28
10	2000 to 2100	25.15	23.85	25.11	25.13	24.95	24.13	25.07	25.01	24.33	24.33	24.53	24.43
11	2100 to 2200	24.36	23.77	24.48	24.42	24.39	24.09	24.15	24.27	24.32	24.32	24.52	24.42
12	2200 to 2300	23.61	23.60	23.50	23.56	23.79	23.97	23.59	23.69	24.23	24.23	24.44	24.33
13	2300 to 0000	23.07	23.35	22.98	23.03	23.29	23.73	23.42	23.36	24.00	24.00	24.19	24.10
14	0000 to 0100	22.58	23.05	22.71	22.65	22.89	23.46	22.95	22.92	23.75	23.75	23.98	23.86
15	0100 to 0200	22.12	22.80	22.24	22.18	22.47	23.21	22.61	22.54	23.50	23.50	23.76	23.63
16	0200 to 0300	21.76	22.64	21.90	21.83	22.12	23.03	22.24	22.18	23.31	23.31	23.47	23.39
17	0300 to 0400	21.54	22.40	21.72	21.63	21.83	22.83	21.92	21.87	23.12	23.12	23.26	23.19
18	0400 to 0500	21.26	22.26	21.34	21.30	21.59	22.63	21.71	21.65	22.88	22.88	22.96	22.92
19	0500 to 0600	21.13	22.08	21.30	21.22	21.43	22.42	21.59	21.51	22.65	22.65	22.86	22.75
20	0600 to 0700	21.00	21.89	21.11	21.06	21.29	22.22	21.39	21.34	22.44	22.44	22.55	22.50
21	0700 to 0800	20.90	21.84	20.91	20.90	21.15	22.10	21.30	21.23	22.28	22.28	22.37	22.32
22	0800 to 0900	20.96	21.83	20.95	20.96	21.14	22.01	21.28	21.21	22.12	22.12	22.26	22.19
23	0900 to 1000	21.14	21.79	21.30	21.22	21.20	21.93	21.35	21.27	22.02	22.02	22.13	22.07
24	1000 to 1100	21.29	22.04	21.42	21.36	21.26	21.97	21.39	21.33	21.91	21.91	22.04	21.98

Table B-20 (c): 24 hr. slab (D) temperature values (measured and calculated) for Mix C for 24 hr. cloudy and humid condition at 17.5 cm, 20 cm & 22.5 cm

S. No.	Time Instant	Temperature (°C) at 17.5 cm				Temperature (°C) at 20 cm				Temperature (°C) at 22.5 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	20.58	20.45	20.64	20.61	20.38	20.30	20.54	20.46	20.64	20.26	20.81	20.72
2	1200 to 1300	20.83	20.36	20.98	20.91	20.66	20.16	20.72	20.69	21.05	20.18	21.07	21.06
3	1300 to 1400	21.33	20.73	21.46	21.40	21.17	20.59	21.27	21.22	21.77	20.70	21.88	21.82
4	1400 to 1500	21.99	21.17	22.12	22.05	21.74	21.04	21.89	21.81	22.65	21.17	22.86	22.76
5	1500 to 1600	22.72	21.71	22.89	22.81	22.39	21.57	22.47	22.43	23.41	21.70	23.55	23.48
6	1600 to 1700	23.36	22.38	23.49	23.43	23.03	22.28	23.17	23.10	24.15	22.43	24.27	24.21
7	1700 to 1800	24.05	23.18	24.14	24.09	23.56	23.19	23.73	23.65	24.87	23.33	25.04	24.96
8	1800 to 1900	24.63	23.82	24.76	24.69	24.06	23.85	24.13	24.10	25.26	23.93	25.41	25.34
9	1900 to 2000	24.87	24.28	25.03	24.95	24.30	24.32	24.41	24.36	25.30	24.34	25.45	25.38
10	2000 to 2100	24.88	24.46	25.06	24.97	24.32	24.51	24.41	24.37	25.15	24.49	25.31	25.23
11	2100 to 2200	24.72	24.46	24.81	24.77	24.22	24.50	24.32	24.27	24.93	24.44	25.12	25.02
12	2200 to 2300	24.46	24.37	24.57	24.51	23.99	24.40	24.14	24.07	24.59	24.31	24.82	24.70
13	2300 to 0000	24.14	24.15	24.29	24.22	23.70	24.17	23.91	23.80	24.18	24.08	24.29	24.24
14	0000 to 0100	23.81	23.91	23.99	23.90	23.41	23.95	23.69	23.55	23.80	23.86	24.00	23.90
15	0100 to 0200	23.49	23.66	23.68	23.59	23.23	23.70	23.55	23.39	23.46	23.60	23.71	23.58
16	0200 to 0300	23.27	23.45	23.49	23.38	22.97	23.48	23.11	23.04	23.22	23.37	23.59	23.40
17	0300 to 0400	23.03	23.28	23.22	23.13	22.71	23.31	22.99	22.85	22.94	23.20	23.11	23.02
18	0400 to 0500	22.78	23.01	22.98	22.88	22.46	23.01	22.77	22.62	22.68	22.90	22.81	22.74
19	0500 to 0600	22.52	22.76	22.71	22.61	22.24	22.77	22.39	22.31	22.43	22.67	22.61	22.52
20	0600 to 0700	22.31	22.56	22.48	22.40	22.05	22.58	22.17	22.11	22.23	22.49	22.44	22.34
21	0700 to 0800	22.15	22.36	22.31	22.23	21.88	22.36	21.99	21.93	22.06	22.28	22.19	22.12
22	0800 to 0900	22.00	22.18	22.13	22.07	21.74	22.17	21.91	21.83	21.92	22.10	22.02	21.97
23	0900 to 1000	21.91	22.06	22.04	21.97	21.70	22.05	21.88	21.79	21.90	22.00	22.02	21.96
24	1000 to 1100	21.87	21.86	22.02	21.95	21.63	21.81	21.80	21.71	21.90	21.76	22.01	21.96

Table B-20 (d): 24 hr. slab (D) temperature values (measured and calculated) for Mix C for 24 hr. cloudy and humid condition at 25 cm, 27.5 cm, 30 cm & 40 cm

S. No.	Time Instant	25 cm				27.5 cm				30 cm				40 cm			
		Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS	Expt.	Choubane Tia Model	Fourier Biot Eqn.	ANSYS
1	1100 to 1200	20.52	20.33	20.71	20.61	21.21	20.51	21.39	21.30	20.79	20.79	20.80	20.79	21.13	21.13	21.15	21.14
2	1200 to 1300	21.13	20.44	21.23	21.18	22.75	20.92	22.97	22.86	21.63	21.63	21.70	21.66	22.12	22.12	22.11	22.12
3	1300 to 1400	22.06	21.05	22.22	22.14	24.30	21.66	24.57	24.44	22.50	22.50	22.60	22.55	23.13	23.13	23.10	23.11
4	1400 to 1500	23.03	21.57	23.09	23.06	25.14	22.23	25.28	25.21	23.17	23.17	23.20	23.18	23.48	23.48	23.53	23.50
5	1500 to 1600	23.80	22.11	23.91	23.85	25.91	22.80	25.98	25.94	23.76	23.76	23.80	23.78	23.85	23.85	23.83	23.84
6	1600 to 1700	24.58	22.81	24.71	24.64	26.79	23.43	26.98	26.88	24.28	24.28	24.30	24.29	24.08	24.08	24.13	24.11
7	1700 to 1800	25.21	23.61	25.41	25.31	26.93	24.02	26.98	26.95	24.55	24.55	24.60	24.58	24.08	24.08	24.15	24.11
8	1800 to 1900	25.49	24.06	25.70	25.60	26.16	24.23	26.30	26.23	24.44	24.44	24.45	24.44	23.91	23.91	23.89	23.90
9	1900 to 2000	25.37	24.34	25.60	25.48	25.34	24.31	25.51	25.43	24.25	24.25	24.30	24.28	23.60	23.60	23.69	23.65
10	2000 to 2100	25.08	24.39	25.18	25.13	24.66	24.22	24.48	24.57	23.97	23.97	23.98	23.97	23.21	23.21	23.30	23.25
11	2100 to 2200	24.74	24.29	24.91	24.82	24.02	24.04	24.12	24.07	23.70	23.70	23.75	23.72	22.92	22.92	23.00	22.96
12	2200 to 2300	24.29	24.11	24.39	24.34	23.45	23.80	23.59	23.52	23.38	23.38	23.40	23.39	22.69	22.69	22.70	22.69
13	2300 to 0000	23.86	23.87	24.00	23.93	23.06	23.53	23.17	23.12	23.08	23.08	23.10	23.09	22.47	22.47	22.50	22.49
14	0000 to 0100	23.46	23.65	23.81	23.63	22.69	23.31	22.81	22.75	22.85	22.85	22.90	22.87	22.31	22.31	22.30	22.31
15	0100 to 0200	23.20	23.38	23.58	23.39	22.33	23.04	22.42	22.38	22.57	22.57	22.60	22.58	22.14	22.14	22.20	22.17
16	0200 to 0300	22.89	23.15	23.00	22.94	22.04	22.80	22.17	22.11	22.32	22.32	22.40	22.36	22.01	22.01	22.00	22.01
17	0300 to 0400	22.60	22.96	22.89	22.75	21.75	22.58	21.89	21.82	22.08	22.08	22.10	22.09	21.85	21.85	21.80	21.83
18	0400 to 0500	22.32	22.67	22.61	22.46	21.60	22.32	21.86	21.73	21.85	21.85	21.90	21.88	21.70	21.70	21.78	21.74
19	0500 to 0600	22.11	22.46	22.38	22.24	21.49	22.15	21.77	21.63	21.72	21.72	21.70	21.71	21.63	21.63	21.66	21.64
20	0600 to 0700	21.91	22.30	22.17	22.04	21.35	22.00	21.64	21.49	21.60	21.60	21.65	21.63	21.60	21.60	21.60	21.60
21	0700 to 0800	21.75	22.10	22.00	21.88	21.28	21.85	21.59	21.44	21.50	21.50	21.50	21.50	21.60	21.60	21.60	21.60
22	0800 to 0900	21.65	21.97	21.91	21.78	21.38	21.77	21.68	21.53	21.52	21.52	21.53	21.52	21.60	21.60	21.59	21.60
23	0900 to 1000	21.60	21.90	21.87	21.74	21.44	21.75	21.77	21.61	21.56	21.56	21.57	21.56	21.60	21.60	21.58	21.59
24	1000 to 1100	21.60	21.72	21.86	21.73	21.58	21.68	21.90	21.74	21.64	21.64	21.65	21.64	21.60	21.60	21.57	21.59

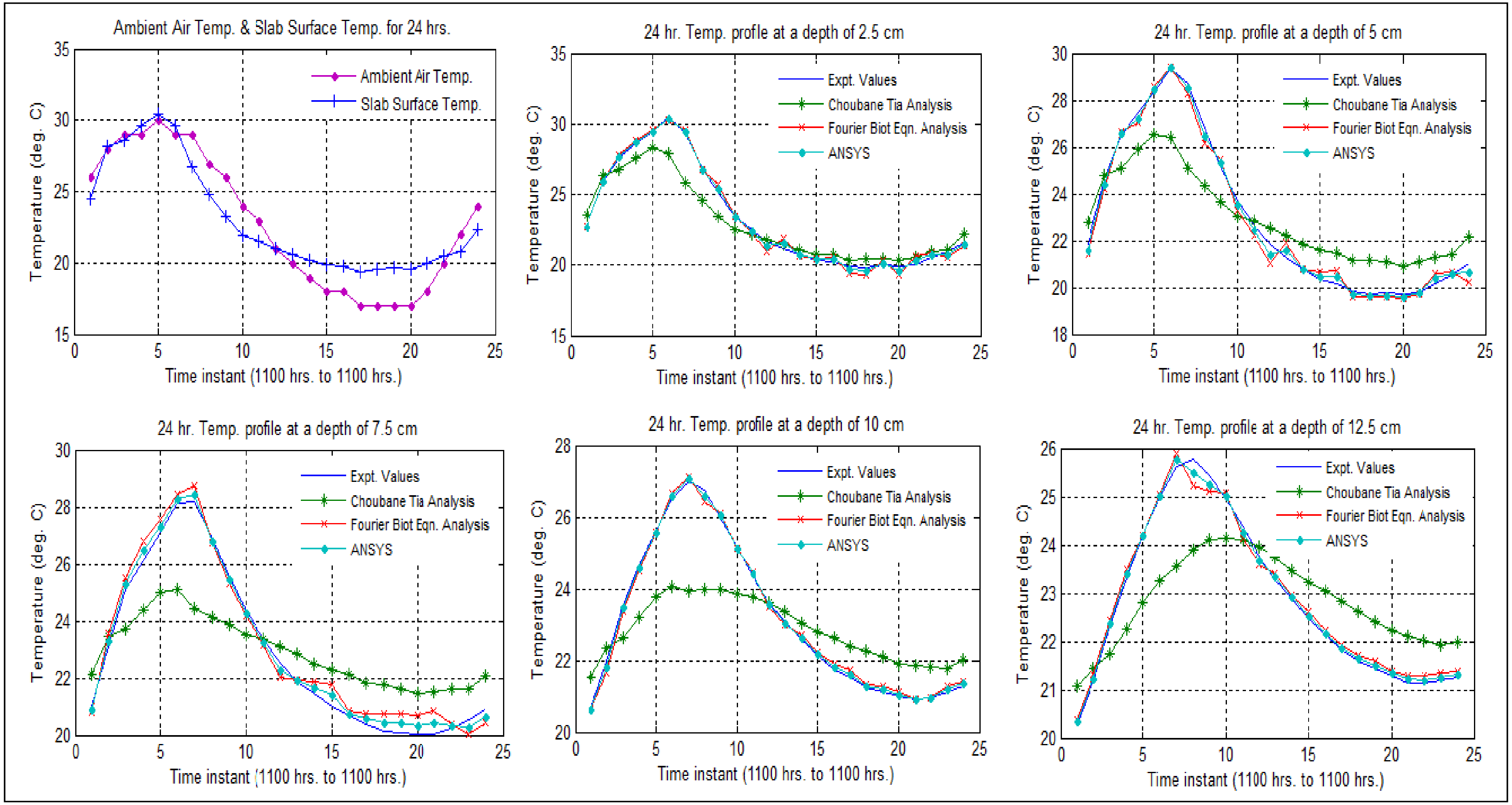


Fig. B-39 (a): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix C for 24 hr. cloudy and humid condition (surface to 12.5 cm)

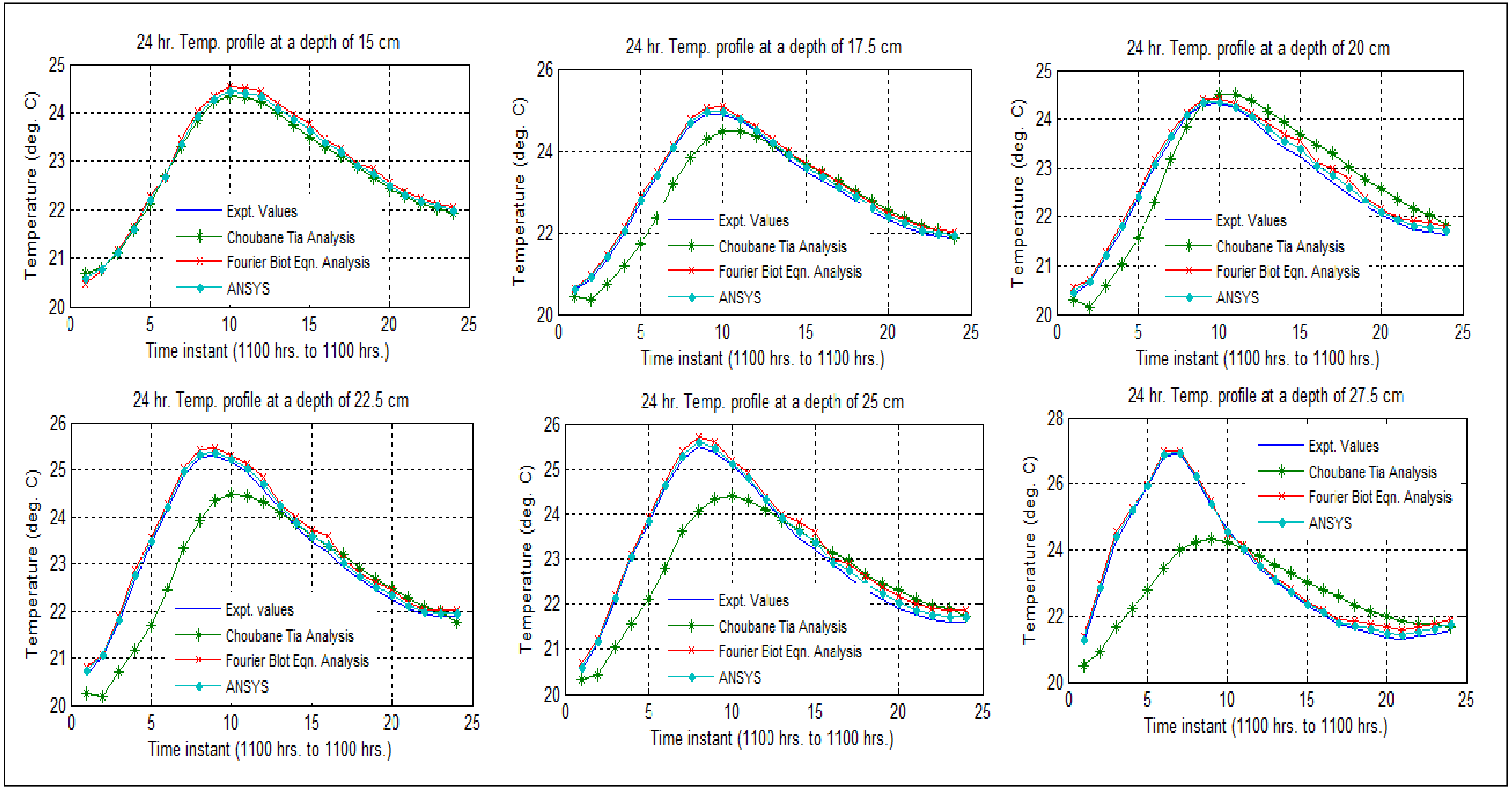


Fig. B-39 (b): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix C for 24 hr. cloudy and humid condition (15 cm to 27.5 cm)

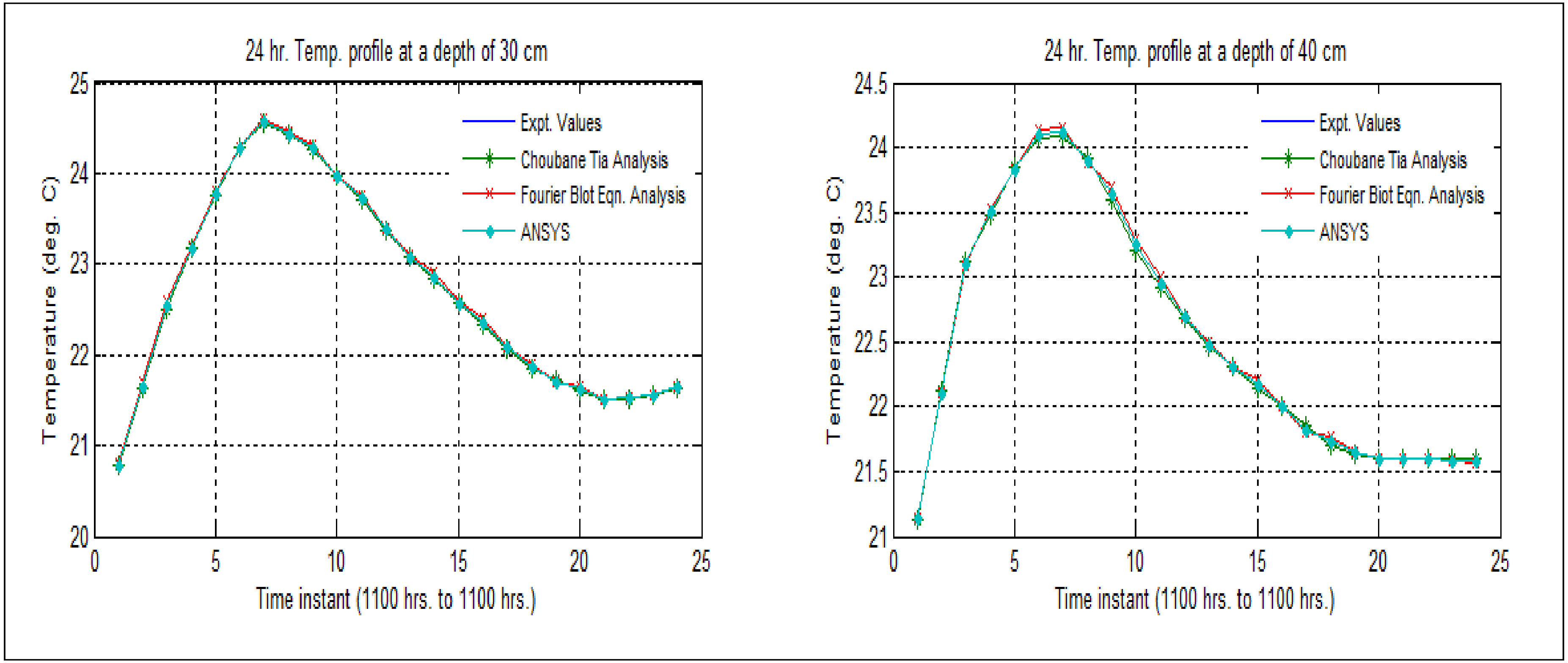


Fig. B-39 (c): 24 hour slab (D) temperature profile (measured and calculated) at various depths for Mix C for 24 hr. cloudy and humid condition (30 cm & 40 cm)

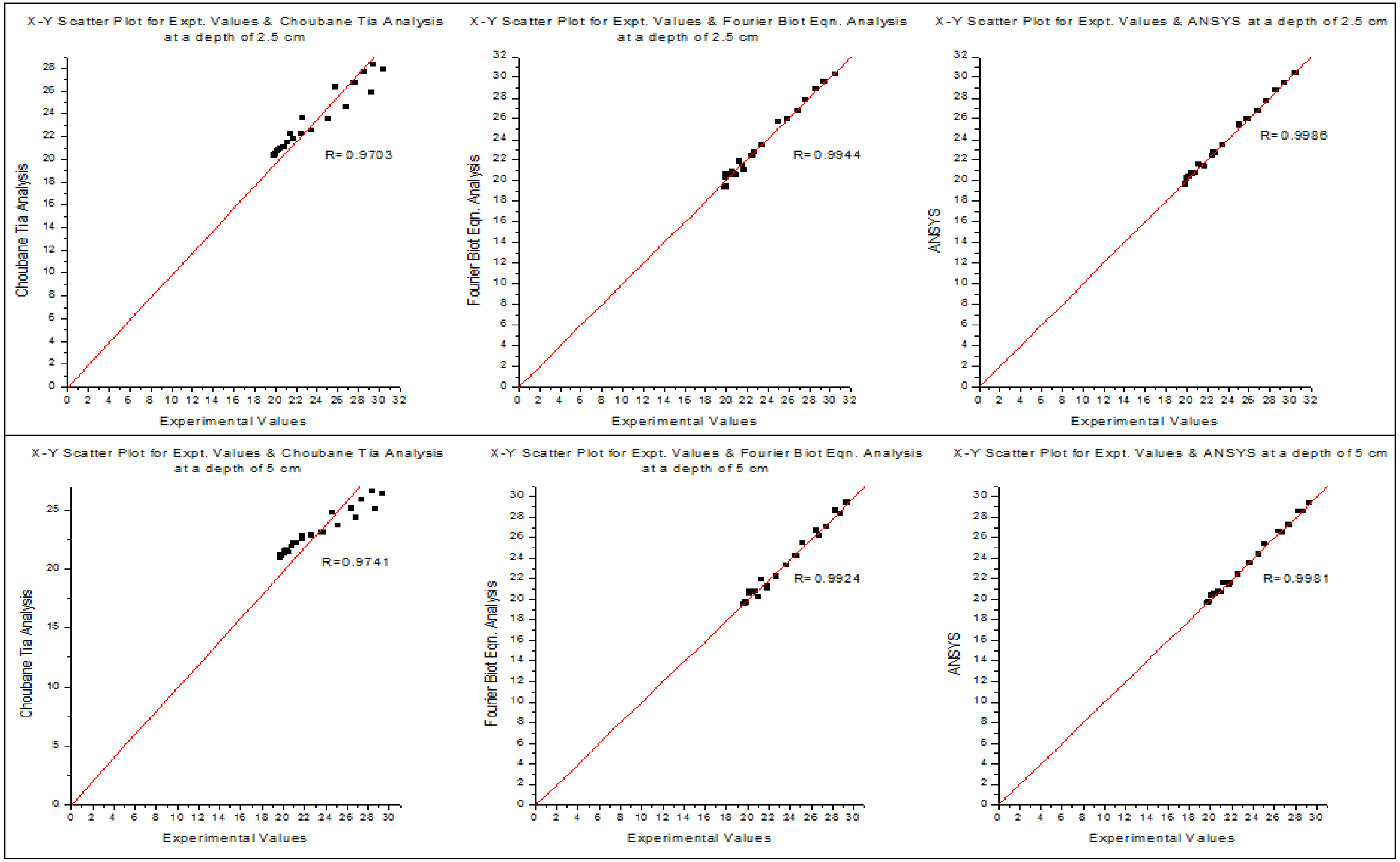


Fig. B-40 (a): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 2.5 cm & 5 cm

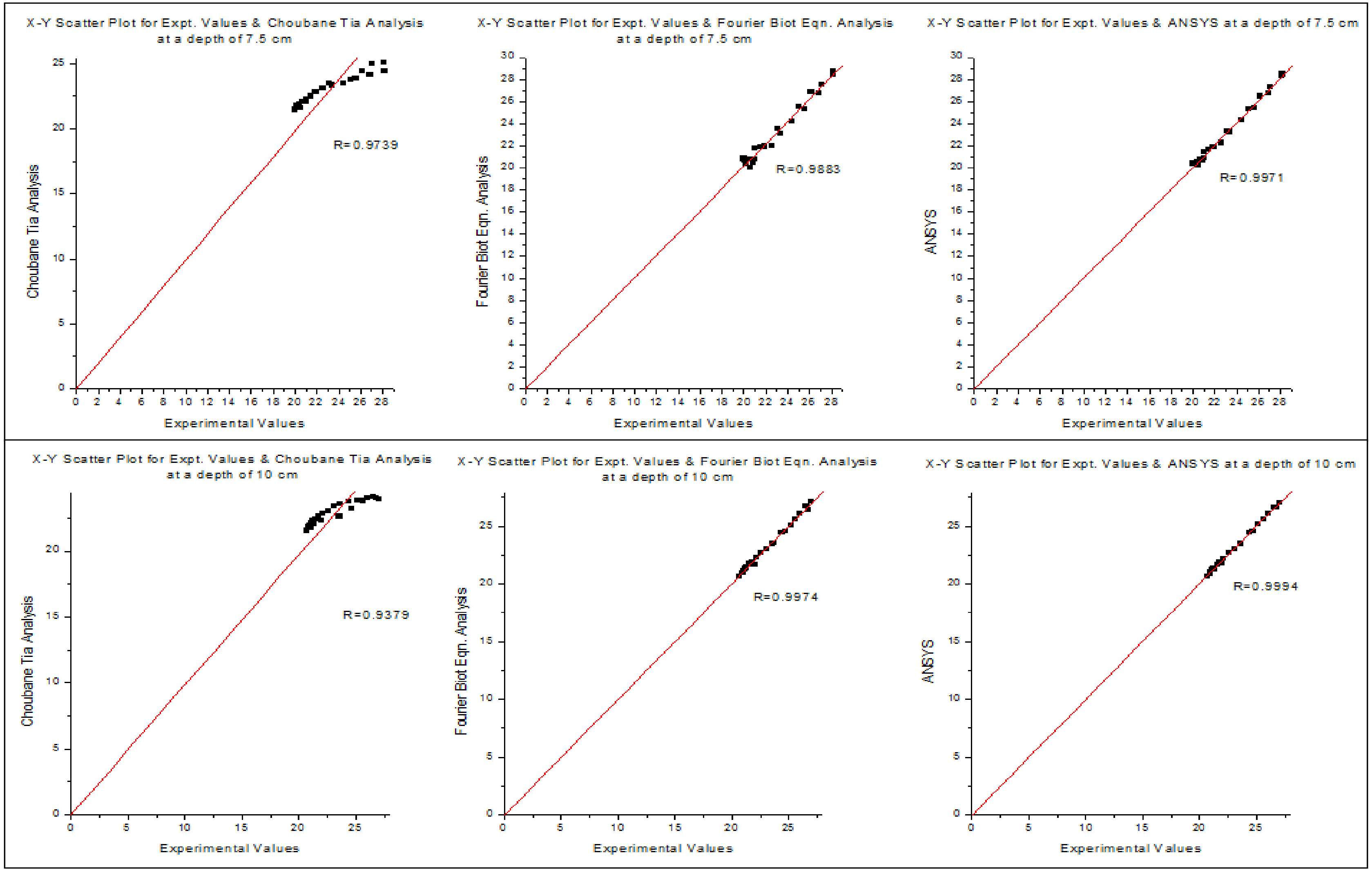


Fig. B-40 (b): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 7.5 cm & 10 cm

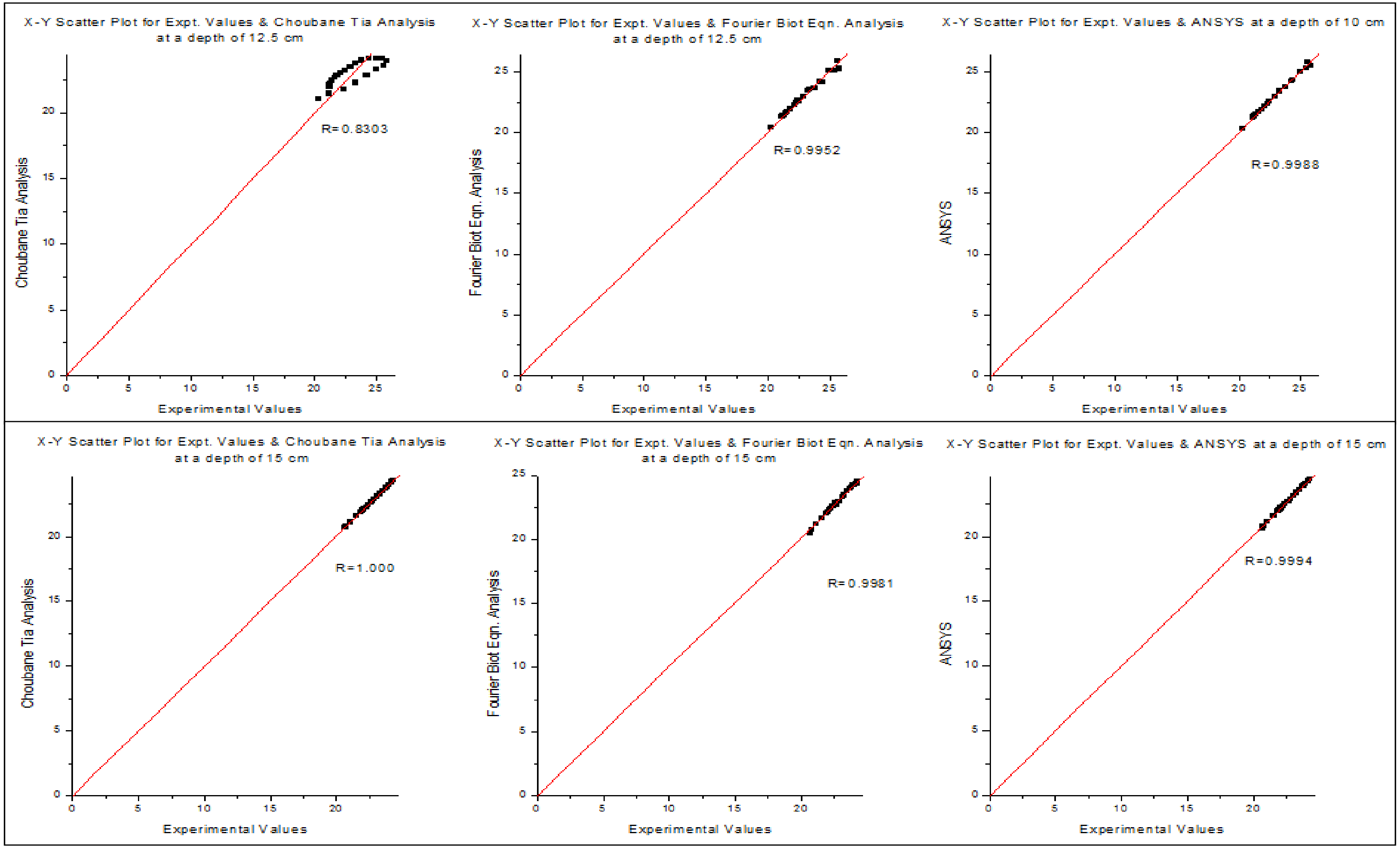


Fig. B-40 (c): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 12.5 cm & 15 cm

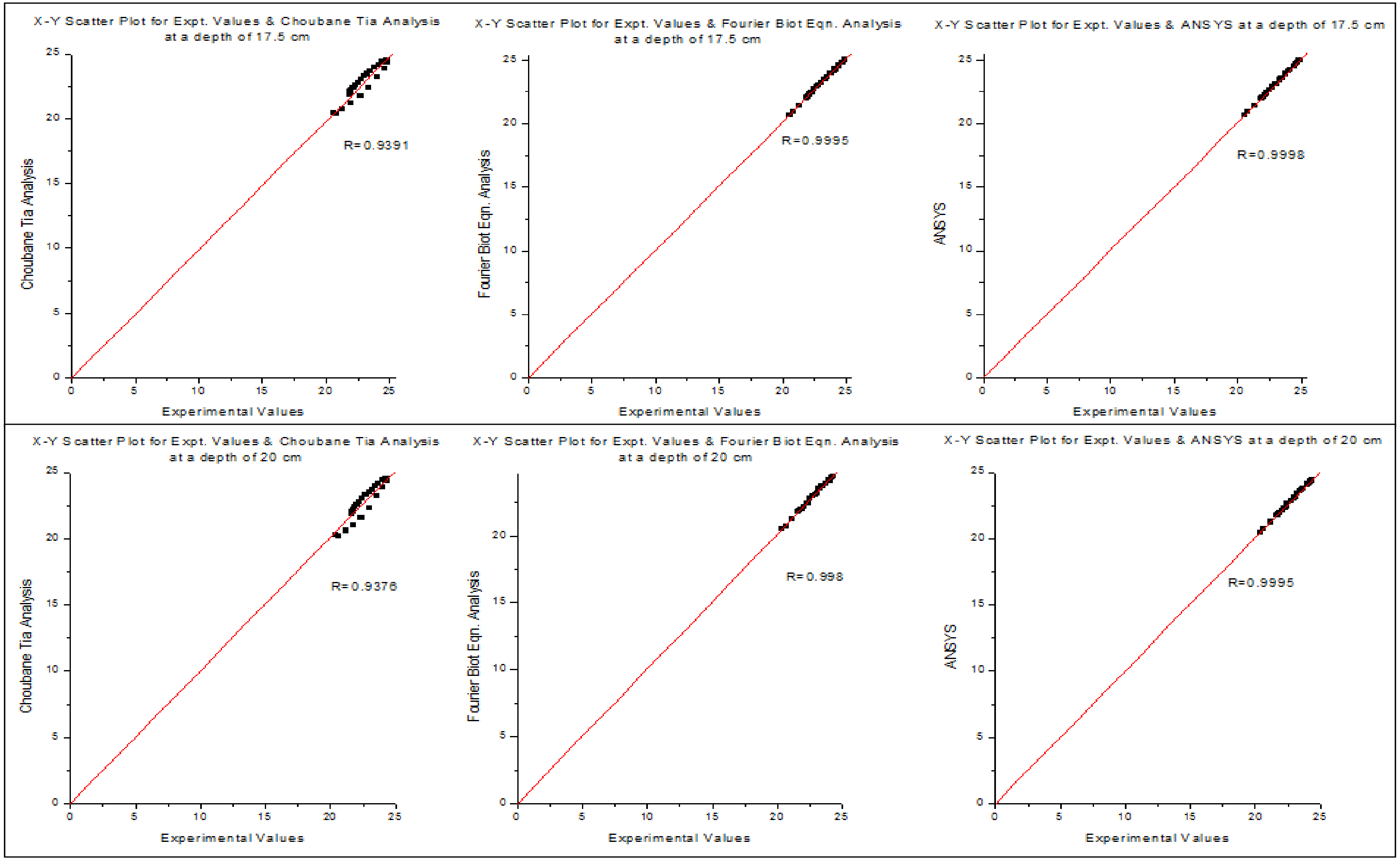


Fig. B-40 (d): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 17.5 cm & 20 cm

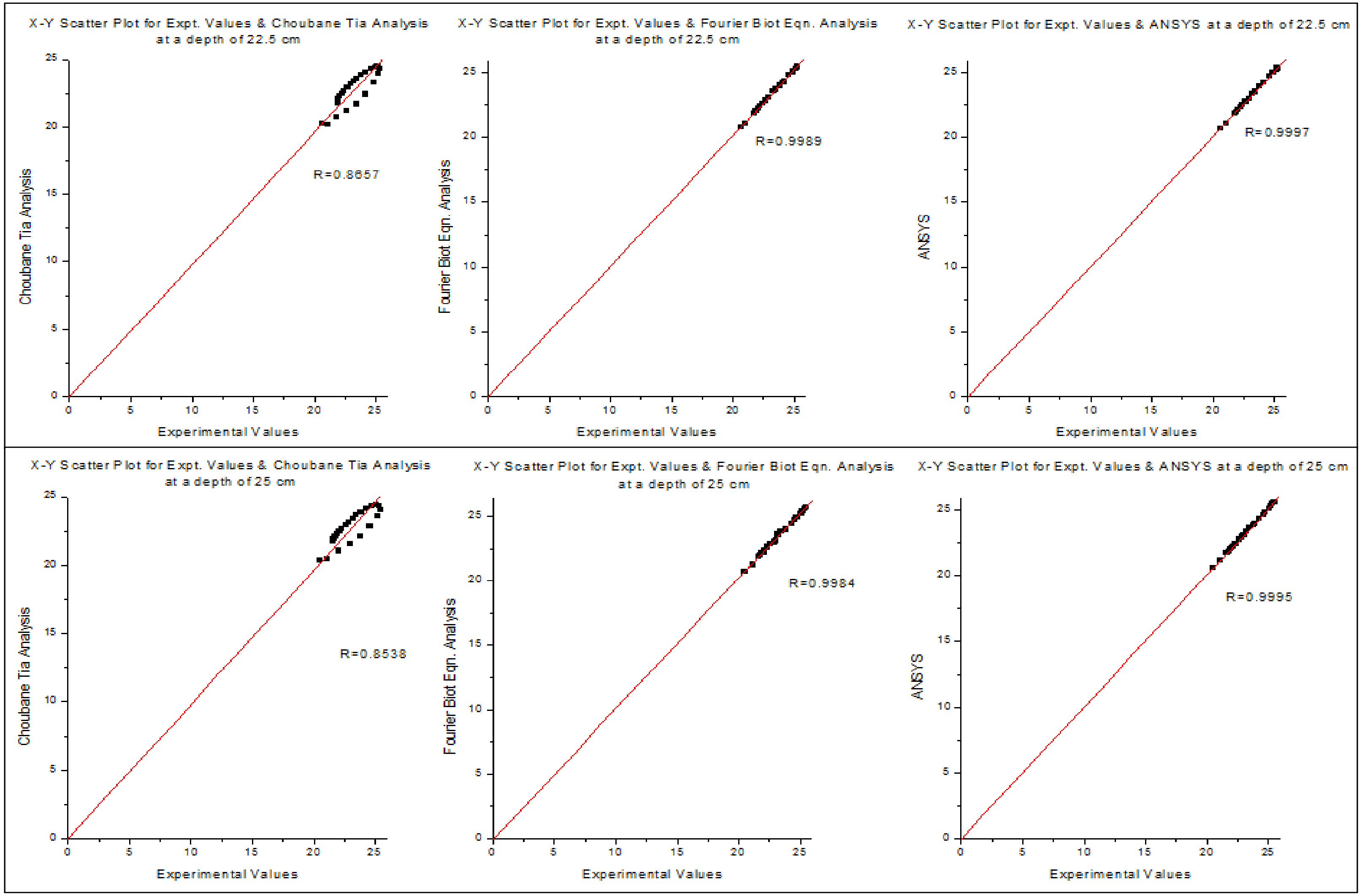


Fig. B-40 (e): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 22.5 cm & 25 cm

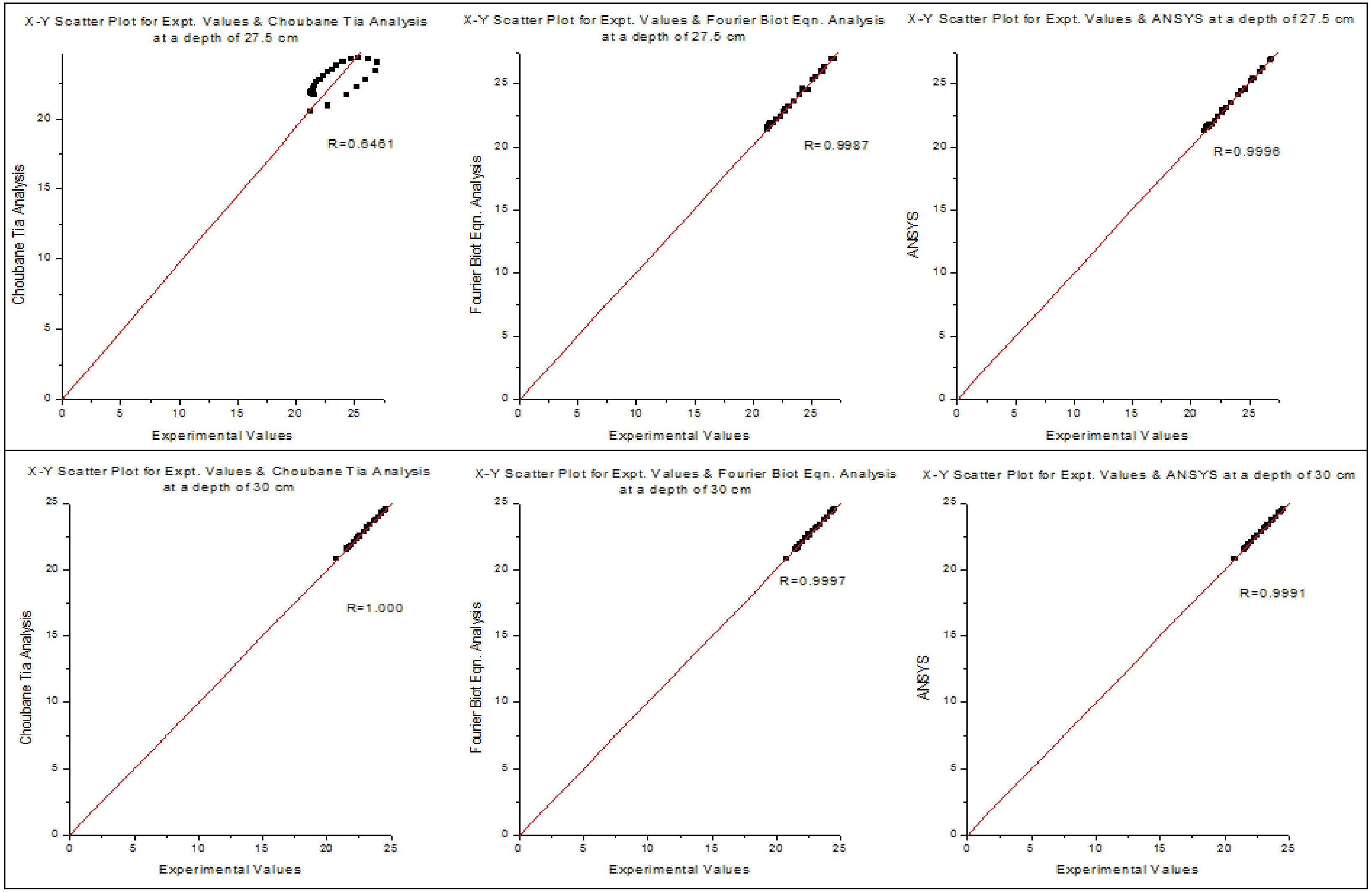


Fig. B-40 (f): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 27.5 cm & 30 cm

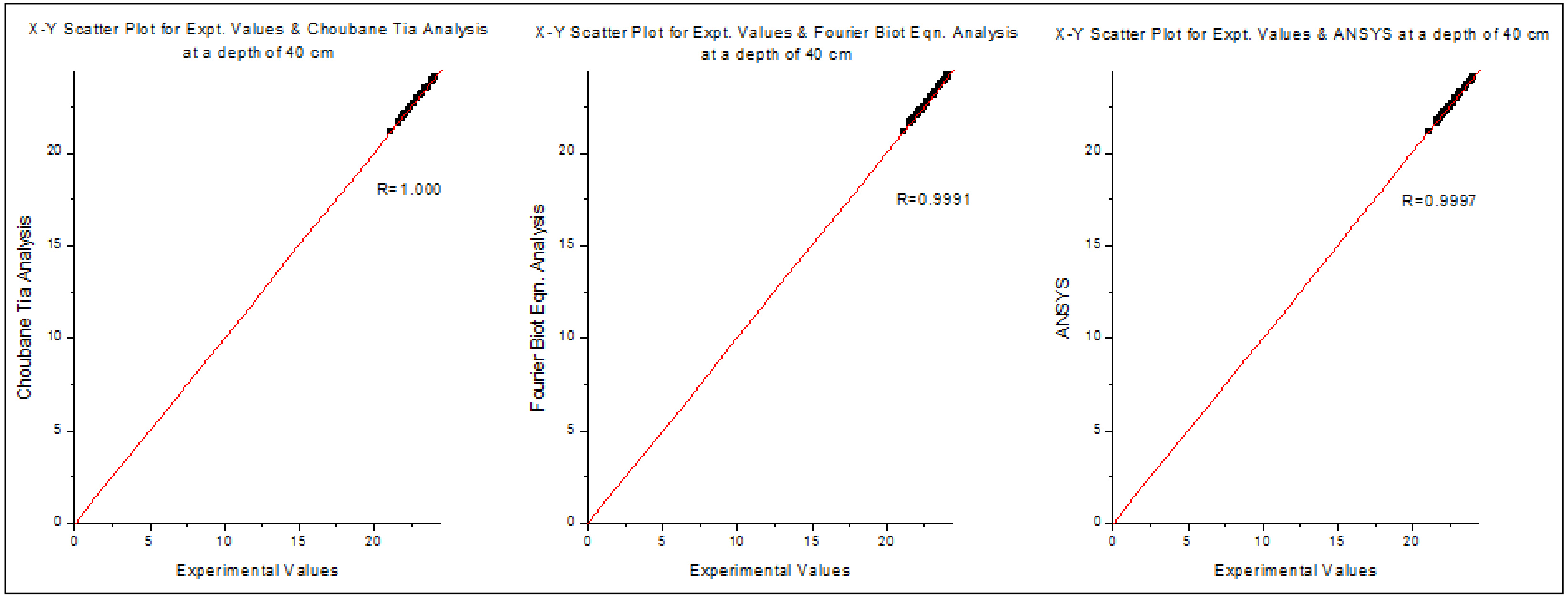


Fig. B-40 (g): X-Y Scatter Plot for Temperature values measured experimentally & estimated numerically at 40 cm

APPENDIX C

List of Standard Code of Practice

ACI 122R-02	Guide to Thermal properties of concrete and masonry systems (2002).
ACI 211-4R-08	Guide for selecting proportions for High Strength Concrete using Portland cement and other cementitious materials (2008).
ASTM C33-13	Standard Specification for Concrete Aggregates (2013).
ASTM C177-13	Standard Test Method for Steady State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded Hot Plate Apparatus (2013).
ASTM C295-12	Standard guide for Petrographic Examination of Aggregates for Concrete (2012)
ASTM C332-09	Standard Specification for Lightweight Aggregates for Insulating Concrete (2009).
EFNARC	The European Guidelines for Self Compacting Concrete – Specification, Production and Use. European Federation of National Associations Representing Producers and Applicators of Specialist Building Products for Concrete (2005).
IRC 44: 2008	Guidelines for cement concrete mix design for pavements (2008).
IRC 58:2011	Guidelines for the Design of Plain Jointed Rigid Pavements for Highways (2011).
IS 383: 1970	Indian Standard Specification for Coarse and Fine Aggregates from Natural Sources for Concrete (1970 – Reaffirmed 1997).
IS 456: 2000	Indian Standard Plain and Reinforced Concrete – Code of Practice (2000).
IS 516: 1959	Indian Standard Method of Tests for Strength of Concrete (1959).
IS 2386: 1963 (Part I)	Indian Standard Method of test for aggregate for concrete Part I Particle Size and Shape (1963 – Reaffirmed 1997).
IS 2386: 1963 (Part III)	Indian Standard Method of test for aggregate for concrete Part III Specific Gravity, Density, Voids, Absorption and Bulking (1963 – Reaffirmed 1997).
IS 2386: 1963 (Part IV)	Indian Standard Method of test for aggregate for concrete Part IV Mechanical Properties (1963 – Reaffirmed 1997).
IS 2386: 1963 (Part VIII)	Indian Standard Methods of Test for Aggregates for Concrete Part VIII Petrographic Examination (1963 – Reaffirmed 1997)

IS 3346: 1980	Indian Standard for Method of the Determination of Thermal Conductivity of Thermal Insulation Materials (Two Slab Guarded Hot Plate Method) (1980 – Reaffirmed 2004).
IS 3812: 2003 (Part 1)	Indian Standard: Pulverized Fuel Ash – Specification (Part 1) for use as a pozzolana in cement, cement mortar and concrete (2003).
IS 3812: 2003 (Part 2)	Indian Standard Pulverized Fuel Ash – Specification (Part 2) for use as admixture in cement mortar and concrete (2003).
IS 9103: 1999	Indian Standard Concrete Admixtures – Specifications (1999).
IS 10262: 2009	Indian Standard for Concrete Mix Proportioning – Guidelines (2009).
IS 12269: 1987	Indian Standard Specification for 53 grade Ordinary Portland Cement (1987 – Reaffirmed 1999).
IS 13311: 1992 (Part 1)	Indian Standard, Non Destructive Testing of Concrete – Methods of Test, Part 1 – Ultrasonic Pulse Velocity (1992).
IS 13311: 1992 (Part 2)	Indian Standard, Non Destructive Testing of Concrete – Methods of Test, Part 2 – Rebound Hammer (1992).

APPENDIX D

Acknowledgement List

1. Registrar, BITS Pilani
2. Aditya Birla Group Science and Technology Centre, Mumbai.
3. Prof. S. S. Deshmukh, Associate Dean, SWD, BPHC.
4. Dr. K. Rajitha, Assistant Professor, Dept. of Civil Engg. BPHC.
5. Dr. Chandu Parimi, Assistant Professor, Dept. of Civil Engg. BPHC.
6. Mr. J. Kalayan Rama, Lecturer, Dept. of Civil Engg. BPHC.
7. Prof. A. K. Gupta, Associate Professor, Dept. of Mechanical Engg. BPHC.
8. Dr. N. Jalaiah, Assistant Professor, Dept. of Mechanical Engg. BPHC.
9. Dr. Syed Mujaheed Hussaini, Lecturer, Dept. of Mechanical Engg. BPHC.
10. Mr. Khalid Anwar, Lecturer, Dept. of Mechanical Engg. BPHC.
11. Dr. Aklad Iqbal, Assistant Professor, Dept. of Mathematics, BPHC.
12. Dr. K. GopiKrishna, Dept. of Civil Engg. NIT Warangal.
13. Dr. M. V. N. Sivakumar, Assistant Professor, Dept. of Civil Engg. NIT Warangal.
14. Dr. M. Venu, Associate Professor, Dept. of Civil Engg. Malla Reddy College of Engg.
15. Prof. Sudhir Patil, Associate Professor, MIT Pune.
16. Prof. Y. V. D. Rao, Head, Mechanical Dept. BPHC and Faculty In-charge, ESD, BPHC.
17. Dr. D. Jayakrishna, Assistant Professor, Dept. of Mechanical Engg. NIT Warangal.
18. Mr. Satyendra Tripathi, Research Scholar, CSIR, SRF, Dept. of Civil Engg. BPHC.
19. Mr. I. Naga Babu, Research Scholar, CSIR, SRF, Dept. of Civil Engg. BPHC.
20. Mr. Mahesh Kumar Reddy, Research Scholar, Dept. of Biology, BPHC.
21. Mr. Gangaram Pallikonda, Research Scholar, Dept. of Chemistry, BPHC.
22. Mr. Sai Sudhakar M, Research Scholar, Dept. of Chemistry, BPHC.
23. Mr. Avala Shankar, Technical Assistant, Dept. of Civil Engg. BPHC.
24. Mr. T. M. Basha, Technical Assistant, Dept. of Civil Engg. BPHC.
25. Mr. S. Ghouse Mulla, Technical Assistant, Dept. of Civil Engg. BPHC.
26. Mr. Rajesh Rao, Technical Assistant, Dept. of Civil Engg. BPHC.
27. Mr. Hemant Kumar, Technical Assistant, Dept. of Civil Engg. BPHC.
28. Mr. Surya Narayana, Technical Assistant, Dept. of Mechanical Engg. BPHC.
29. Mr. Jagadeeshwar Reddy, Technical Assistant, Dept. of Mechanical Engg. BPHC.

30. Mr. Sarma, Technical Assistant, Central CAD Lab. BPHC.
31. Mr. Bali Reddy, Workshop Instructor, BPHC.
32. Mr. Praveen Kumar, ARD, BPHC.
33. Ms. Lakshmi, SRCD BPHC.
34. Mr. Karthik Teja M, Research Scholar, Dept. of Mechanical Engg. BPHC.
35. Mr. ShanmukhaSundaram VR, Research Scholar, Dept. of Mechanical Engg. BPHC.
36. Mr. Prakash Mohan, Research Scholar, Dept. of Civil Engg. BPHC.
37. Ms. Bharati Prasad, Research Scholar, Dept. of Civil Engg. BPHC.
38. Faculty Members from various departments of BPHC.
39. Staff from various departments of BPHC.
40. Fellow Research Scholars from various departments of BPHC.
41. Mr. Naveen Reddy, In-charge, Stores, BPHC.
42. EHD, BPHC.
43. Stores BPHC.
44. Accounts Dept. BPHC.
45. Students Welfare Division (SWD), BPHC.
46. Mr. Bhooshan Dixit, Area Sales Manager, Sika Chemicals, Pune.
47. Mr. Venkateshwarulu Bommaraju, BASF Chemicals, Secunderabad.
48. Ms. Priyanka Patra, BASF Chemicals, Secunderabad.
49. Perl-Tech, Ahmedabad.
50. Eternal Engineering Pvt. Ltd. Pune
51. Mr. S. Kanjilal, Sutra Instrumentation Pvt. Ltd.
52. Forevision Laboratory, Hyderabad.
53. AIMIL India.
54. HEICO, India.
55. Mr. Girish, Thermopads, Secunderabad.
56. Ms. Sravya Kamlapuram, Alumnus Dept. of Civil Engg. BPHC.
57. Mr. Vikram Kumar Reddy, Alumnus Dept. of Civil Engg. BPHC.
58. Mr. Vivek Kumar, Alumnus, Dept. of Civil Engg. BPHC.
59. Mr. Siddhartha Shrivastava, Alumnus, Dept. of Electronics Engg. BPHC.
60. Mr. A. V. K. Sandeep, Alumnus, Dept. of Civil Engg. BPHC.
61. Mr. Jayesh Kasture, Alumnus, Dept. of Civil Engg. BPHC.
62. Mr. Rathish Arumugam, Alumnus, Dept. of Civil Engg. BPHC.
63. Mr. Adarsh Padmanabhan, Alumnus Dept. of Civil Engg. BITS Pilani.

64. Mr. Vignesh, Alumnus, Dept. of Civil Engg. BPHC.
65. Mr. Vivek Kannan, Alumnus, Dept. of Civil Engg. BPHC.
66. Mr. A. B. Yeswanth, Alumnus, Dept. of Civil Engg. BPHC.
67. Ms. Spoorthi Soanker, Alumnus, Dept. of Civil Engg. BPHC.
68. Mr. Varun Soni, Alumnus, Dept. of Civil Engg. BPHC.
69. Mr. Mithun Murthy, Alumnus, Dept. of Civil Engg. BPHC.
70. Mr. Pankaj Munjal, Alumnus, Dept. of Civil Engg. BPHC.
71. Ms. Paromita Nath, Alumnus, Dept. of Civil Engg. BPHC.
72. Mr. Vineel Kumar Bapatla, Alumnus, Dept. of Civil Engg. BPHC.
73. Mr. Sajith Nair, Alumnus, Dept. of Civil Engg. BPHC.
74. Mr. Rahul Dornal, Alumnus, Dept. of Civil Engg. BPHC.
75. Mr. M. Harikrishna, Alumnus, Dept. of Civil Engg. BPHC.
76. Mr. Sharabh Kochar, Alumnus, Dept. of Mechanical Engg. BPHC.
77. Mr. Swaroop Ji M. R., Alumnus, Dept. of Civil Engg. BPHC.
78. Mr. Dhiraj Wakode, Alumnus, Dept. of Civil Engg. BPHC.
79. Mr. Aaron Vaz, Alumnus, Dept. of Civil Engg. BPHC.
80. Ms. Reshmi Nambiar, Alumnus, Dept. of Civil Engg. BPHC.
81. Mr. T. Pawan Kumar, Alumnus, Dept. of Civil Engg. BPHC.
82. Mr. A. Anil Reddy, Alumnus, Dept. of Civil Engg. BPHC.
83. Mr. Mandar Ganbavale, PG Student, Dept. of Civil Engg. BPHC.
84. Mr. Digambar Kumbhar, PG Student, Dept. of Civil Engg. BPHC.
85. Mr. Dhruv Sood, PG Student, Dept. of Civil Engg. BPHC.
86. Mr. Darshan Pujara, PG Student, Dept. of Civil Engg. BPHC.
87. Mr. Sangeet Sharma, PG Student, Dept. of Civil Engg. BPHC.
88. Mr. Bhupesh Singhala, PG Student, Dept. of Civil Engg. BPHC.
89. Mr. Ameya Dashputre, Research Assistant, Dept. of Petroleum Engg. MIT Pune.