

# TABLE OF CONTENTS

---

CHAPTER	TITLE	PAGE NO.
	Acknowledgements	II
	Abstract	III
	Table of contents	V
	List of Figures	VIII
	List of Tables	XIV
	List of Symbols	XV
	<b>Chapter 1 Introduction</b>	
1.1	Background	1
1.2	Motivation	4
1.3	Aim of the Present Investigation	4
1.4	Organisation of the Thesis	4
	<b>Chapter 2 Literature Review</b>	
2.1	Introduction	6
2.2	Static Buckling	7
2.2.1	Plates	7
2.2.2	Cylindrical Panels	13
2.3	Parametric Instability	17
2.3.1	Plates	17
2.3.2	Cylindrical Panels	21
2.4	Dynamic Buckling	23
2.5	Failure Studies	27
2.6	Need for Further Research	28
2.7	Objectives of the Present Study	29
	<b>Chapter 3 Theory and Finite Element Formulation</b>	
3.1	Introduction	30
3.2	Finite element formulation	31
3.2.1	Shell element	31
3.2.2	Modelling composite layup	32
3.3	Governing Equations	33
3.3.1	Static buckling	35
3.3.2	Vibration	35
3.3.3	Post-buckling	35
3.3.4	Dynamic Buckling	36
3.3.5	Failure studies	36
3.3.5(a)	Azzi-Tsai-Hill theory	36
3.3.5(b)	Maximum Stress theory	37
3.3.5(c)	Tsai-Hill theory	37
3.3.5(d)	Tsai-Wu theory	37
3.4	Problem Description	38
3.4.1	Laminated composite plate	38
3.4.2	Laminated composite cylindrical panel	41
3.4.3	Laminated composite cylindrical panel with cutout	43
3.4.4	Laminated composite stiffened cylindrical panel	45
3.5	Dynamic buckling criterion	46
3.6	Summary	47

Table of contents

<b>Chapter 4 Dynamic buckling of laminated composite Plate</b>		
4.1	Introduction	48
4.2	Convergence and Validation studies	48
4.2.1	Convergence and Validation of static buckling load	49
4.2.2	Validation of shock spectrum	52
4.2.3	Validation of dynamic buckling load of a plate	53
4.2.4	Validation of dynamic buckling load of an orthotropic plate	54
4.3	Dynamic buckling studies	55
4.3.1	Effect of loading duration	61
4.3.2	Effect of loading function	62
4.3.3	Effect of imperfection	63
4.3.4	Effect of rectangular pulse load on a rectangular plate	65
4.3.5	Effect of sinusoidal pulse load on a rectangular plate	67
4.4	Summary	68
<b>Chapter 5 Dynamic buckling behavior of laminated composite cylindrical panel</b>		
5.1	Introduction	69
5.2	Convergence and Validation studies	70
5.2.1	Convergence and Validation of static buckling load	70
5.2.2	Convergence of dynamic load	71
5.3	Dynamic buckling studies	72
5.3.1	Effect of loading duration	78
5.3.2	Failure of Cylindrical panel	79
5.3.3	Effect of aspect ratio	81
5.3.4	Effect of curvature	83
5.3.5	Effect of loading function	85
5.3.6	Effect of boundary conditions	90
5.4	Shock Spectrum of a Cylindrical Panel	92
5.5	Summary	94
<b>Chapter 6 Dynamic buckling of laminated composite cylindrical panel with cutout</b>		
6.1	Introduction	95
6.2	Convergence and Validation studies	96
6.2.1	Convergence and validation of static buckling load of a plate with cutout	96
6.2.2	Validation of static buckling load for a composite plate with cutout	97
6.2.3	Validation of natural frequency of a cylindrical panel with cutout	98
6.3	Dynamic buckling studies	100
6.3.1	Effect of loading duration	101
6.3.2	Failure of the cylindrical panel with cutout	103
6.3.3	Effect of loading function	105
6.3.4	Effect of curvature	106
6.3.5	Effect of size of the cutout	108
6.3.6	Effect of the shape of the cutout	112
6.3.7	Deformation of cylindrical panel with a cutout	117
6.4	Summary	125
<b>Chapter 7 Dynamic buckling of laminated composite stiffened cylindrical panel</b>		
7.1	Introduction	126
7.2	Convergence and Validation studies	127
7.2.1	Convergence and Validation studies of static buckling load of stiffened plate	127
7.2.2	Validation of static buckling load of a stiffened cylindrical panel	129

		<i>Table of contents</i>
7.2.3	Validation of natural frequency of a stiffened plate	130
7.3	Dynamic buckling studies	132
7.3.1	Effect of loading duration	133
7.3.2	Failure of stiffened cylindrical panel	135
7.3.3	Effect of loading function	137
7.3.4	Effect of curvature	139
7.3.5	Effect of aspect ratio of the stiffener	141
7.3.6	Effect of stacking sequence	143
7.3.7	Deformation of stiffened cylindrical panel	149
7.4	Summary	157
<b>Chapter 8 Conclusions</b>		
8.1	Introduction	158
8.2	General conclusions	159
8.3	Laminated composite plates	160
8.4	Laminated composite cylindrical panels	162
8.5	Laminated composite cylindrical panels with cutouts	164
8.6	Laminated composite stiffened cylindrical panels	165
	Strengths of the investigation	167
	Limitations of the investigation	167
	Impact of the present investigation on the research community	169
	Future scope of the investigation	169
	List of Publications	170
	References	173
	Brief Biography of the Candidate	200
	Brief Biography of the Supervisor	201

---

## LIST OF FIGURES

FIGURE NO.	TITLE	PAGE NO.
Fig. 1.1	Load vs Time plot for Parametric Instability	2
Fig. 1.2	Load vs Time for Dynamic Buckling Analysis	2
Fig. 1.3	Change in deformation due to the action of rectangular pulse load on a typical cylindrical panel	2
Fig. 3.1	Shell elements (a) S4R element (b) S3 element	32
Fig. 3.2	Stacking scheme in (a) Laminated composite plate (b) Parallel stacking scheme in a stiffened cylindrical panel (c) Perpendicular stacking scheme in a stiffened cylindrical panel	33
Fig. 3.3	Laminated composite plate (a) Geometry (b) Simply supported boundary conditions (c) Geometry of rectangular plate in Abaqus (d) Model analyzed in Abaqus	40
Fig. 3.4	Plate with imperfection in the form of first mode shape	40
Fig. 3.5	Pulse loading functions (a) Rectangular (b) Sinusoidal (c) Triangular	41
Fig. 3.6	Laminated composite cylindrical panel (a) Geometry (b) Geometry of the curve extruded in Abaqus (c) Model analyzed in Abaqus	42
Fig. 3.7	Boundary conditions for the cylindrical panel (a) Simply supported boundary conditions (BC1). (b) Two edges simply supported and two clamped (BC2). (c) Three edges simply supported, and one edge clamped (BC3). (d) Three edges simply supported, and one edge free (BC4).	43
Fig. 3.8	Laminated composite cylindrical panel with a general shaped cutout (a) Geometry (b) Simply supported boundary conditions (c) Geometry of the panel with cutout drawn in Abaqus (d) model analyzed in Abaqus	44
Fig. 3.9	Plan of the cutout shape (a) Circular (b) Square (c) Square-Rotated	45
Fig. 3.10	Laminated composite stiffened cylindrical panel (a) Geometry (b) Simply supported boundary conditions (c) Geometry of the panel with stiffener drawn in Abaqus (d) model analyzed in Abaqus	46
Fig. 4.1	Pre-buckling boundary conditions for a composite plate	50
Fig. 4.2	Convergence study of a plate with $b/h=100$ (a) $b/a=2$ and stacking scheme ( $\theta^\circ/-\theta^\circ/\theta^\circ$ ); $\theta=0^\circ$ (b) $b/a=2$ and stacking scheme ( $\theta^\circ/-\theta^\circ/\theta^\circ$ ); $\theta=90^\circ$ (c) $b/a=1$ and stacking scheme ( $\theta^\circ/-\theta^\circ/\theta^\circ/-\theta^\circ/\theta^\circ$ ); $\theta=45^\circ$ .	50
Fig. 4.3	Plot for a plate with $b/a=1$ , $a=0.5m$ , $h=0.005a$ and imperfection= $0.2h$ (a) transverse displacement vs in-plane load curve (b) Validation study of shock spectrum of the plate subjected to dynamic loading ( $N_{dyn}=3 \times N_{st}$ )	53
Fig. 4.4	Validation study of dynamic buckling behaviour of a plate with $b/a=1$ , $b/h=200$ , imperfection= $0.05h$ , subjected to sinusoidal pulse load	54
Fig. 4.5	Validation study of dynamic buckling behaviour of an orthotropic plate with $b/a=1$ , $b/h=200$ , imperfection= $0.05h$ , subjected to rectangular pulse load	55
Fig. 4.6	Non-dimensional Time vs Non-dimensional Displacement for a plate with $b/a=1$ , $b/h=100$ , imperfection= $0.2h$ and stacking sequence ( $0^\circ/90^\circ/90^\circ/0^\circ$ ), when subjected to rectangular pulse load.	58
Fig. 4.7	Non-dimensional Time vs Failure index (Tsai-Wu criterion) for a plate with $b/a=1$ , $b/h=100$ , imperfection= $0.2h$ and stacking sequence ( $0^\circ/90^\circ/90^\circ/0^\circ$ ), when subjected to rectangular pulse load.	58
Fig. 4.8	Non-dimensional Load vs Non-dimensional Displacement along with the of deformation for a plate with $b/a=1$ , $b/h=100$ , imperfection= $0.2h$ and stacking sequence ( $0^\circ/90^\circ/90^\circ/0^\circ$ ), when subjected to rectangular pulse load. Deformation scale Factor=10.	59
Fig. 4.9	Non-dimensional Load vs Failure Index (Tsai-Wu criterion) along with the of deformation for a plate with $b/a=1$ , $b/h=100$ , imperfection= $0.2h$ and stacking sequence ( $0^\circ/90^\circ/90^\circ/0^\circ$ ), when subjected to rectangular pulse load. Deformation scale Factor=10.	60

<b>Fig. 4.10</b>	Non-dimensional Load vs non-dimensional Displacement for composite plate with $b/a=1$ , $b/h=100$ imperfection = 20% subjected to rectangular pulse load.	61
<b>Fig. 4.11</b>	Plot for laminated composite plate with $b/a=1$ and imperfection =10% for various loading functions <b>(a)</b> Non-dimensional Load vs Non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion)	62
<b>Fig. 4.12</b>	Plot for laminated composite plate with $b/a=1$ and subjected to rectangular pulse load for various imperfections <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion)	63
<b>Fig. 4.13</b>	Plot for laminated composite plate with $b/a=1$ and subjected to sinusoidal pulse load for various imperfections <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion)	64
<b>Fig. 4.14</b>	Plot for laminated composite plate with $b/a=1$ and subjected to triangular pulse load for various imperfections <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion)	64
<b>Fig. 4.15</b>	Non-dimensional Load vs non-dimensional Displacement for laminated composite plate with $b/a = 2$ $b/h=100$ and for various imperfections subjected to rectangular pulse load <b>(a)</b> stacking sequence $(\theta/- \theta/ \theta)$ , $\theta=0^\circ$ <b>(b)</b> tacking sequence $(\theta/- \theta/ \theta)$ , $\theta=30^\circ$ <b>(c)</b> tacking sequence $(\theta/- \theta/ \theta)$ , $\theta=45^\circ$ <b>(d)</b> tacking sequence $(\theta/- \theta/ \theta)$ , $\theta=60^\circ$ <b>(e)</b> tacking sequence $(\theta/- \theta/ \theta)$ , $\theta=90^\circ$	66
<b>Fig. 4.16</b>	Deformed shape of the laminated composite plate with $b/a=2$ , $b/h=100$ , stacking sequence= $(\theta/- \theta/ \theta)$ and subjected to rectangular loading function. imperfection =5%. Deformation scale factor = 10. <b>(a)</b> Imperfection =5% and $\theta=0^\circ$ <b>(b)</b> Imperfection =10% and $\theta=30^\circ$ <b>(c)</b> Imperfection =10% and $\theta=45^\circ$ <b>(d)</b> Imperfection =20% and $\theta=60^\circ$ <b>(e)</b> Imperfection =5% and $\theta=90^\circ$	66
<b>Fig. 4.17</b>	Non-dimensional Load vs non-dimensional Displacement for laminated composite plate with $b/a = 2$ $b/h=100$ and for various imperfections subjected to sinusoidal pulse load <b>(a)</b> stacking sequence $(\theta/- \theta/ \theta)$ , $\theta=0^\circ$ <b>(b)</b> tacking sequence $(\theta/- \theta/ \theta)$ , $\theta=30^\circ$ <b>(c)</b> tacking sequence $(\theta/- \theta/ \theta)$ , $\theta=45^\circ$ <b>(d)</b> tacking sequence $(\theta/- \theta/ \theta)$ , $\theta=60^\circ$ <b>(e)</b> tacking sequence $(\theta/- \theta/ \theta)$ , $\theta=90^\circ$	67
<b>Fig. 5.1</b>	Pre-buckling boundary conditions for a composite cylindrical panel	71
<b>Fig. 5.2</b>	Convergence study of a laminated composite cylindrical panel <b>(a)</b> Non-dimensional static buckling load <b>(b)</b> Dynamic load	71
<b>Fig. 5.3</b>	Non-Dimensional Time vs non-dimensional Displacement for a panel with $b/a=1$ , $a/h=100$ , $R/a =5$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ when subjected to various magnitudes of rectangular pulse load.	74
<b>Fig. 5.4</b>	Non-Dimensional Time vs Failure Index (Tsai-Wu criterion) for a panel with $b/a=1$ , $a/h =100$ , $R/a =5$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ when subjected to various magnitudes of rectangular pulse load.	75
<b>Fig. 5.5</b>	Non-dimensional load vs non-dimensional Displacement for the panel with $b/a=1$ , $a/h=100$ , $R/a =5$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ when subjected to rectangular pulse load along with the deformed shape of the panel at various magnitude of loads. Scale Factor=7.	76
<b>Fig. 5.6</b>	Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for the panel with $b/a=1$ , $a/h=100$ , $R/a =5$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ when subjected to rectangular pulse load along with the deformed shape of the panel at various magnitude of loads. Scale Factor=7.	77
<b>Fig. 5.7</b>	Non-dimensional Load vs non-dimensional Displacement for a panel with $b/a=1$ , $R/a=5$ , $a/h=100$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ for various loading durations <b>(a)</b> subjected to sinusoidal pulse load <b>(b)</b> subjected to rectangular pulse load	78
<b>Fig. 5.8</b>	Plot for laminated composite cylindrical panel with $b/a=1$ , $R/a=5$ , $a/h=100$ , stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ subjected to rectangular pulse load. <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure index	80
<b>Fig. 5.9</b>	Location of node at which the variation of stress and strain with respect to time is observed in Fig. 5.10(a) and Fig. 5.10(b) respectively.	80
<b>Fig. 5.10</b>	Plot for a laminated composite cylindrical panel with $b/a=1$ , $R/a=5$ , $a/h=100$ , stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ subjected to rectangular pulse load corresponding to	80

	point A in Fig. 5.8(b) <b>(a)</b> True Stress ( $\sigma_{xx}$ ) vs non-dimensional Time <b>(b)</b> Logarithmic Strain ( $\epsilon_{xx}$ ) vs non-dimensional Time	
<b>Fig. 5.11</b>	Non-dimensional Load vs non-dimensional Displacement of a cylindrical panel with $R/a=5$ and $a/h=100$ subjected to rectangular pulse load for various aspect ratios. <b>(a)</b> stacking sequence is $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ <b>(b)</b> stacking sequence is $(0^\circ/90^\circ/90^\circ/0^\circ)$	82
<b>Fig. 5.12</b>	Non-dimensional Load vs non-dimensional Displacement of a cylindrical panel with $R/a=5$ and $a/h=100$ subjected to sinusoidal pulse load for various aspect ratios. <b>(a)</b> stacking sequence is $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ <b>(b)</b> stacking sequence is $(0^\circ/90^\circ/90^\circ/0^\circ)$	82
<b>Fig. 5.13</b>	Plot for a laminated composite cylindrical panel with $b/a=1$ , $a/h=100$ , stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ and $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to rectangular pulse load for various $R/a$ ratios <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure index (Tsai-Wu criterion)	84
<b>Fig. 5.14</b>	Plot for a laminated composite cylindrical panel with $b/a=1$ , $a/h=100$ , stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ and $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to sinusoidal pulse load for various $R/a$ ratios <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure index (Tsai-Wu criterion)	84
<b>Fig. 5.15</b>	Plot for a laminated composite cylindrical panel with $R/a=5$ , $a/h=100$ , stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ subjected to rectangular and sinusoidal pulse load for various $b/a$ ratios. <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion)	86
<b>Fig. 5.16</b>	Plot for a laminated composite cylindrical panel with $R/a=5$ , $a/h=100$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to rectangular and sinusoidal pulse load for various $b/a$ ratios. <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion)	87
<b>Fig. 5.17</b>	Deformed shape of the laminated composite cylindrical panel with $b/a=1$ , $R/a=10$ , $a/h=100$ , subjected to rectangular pulse load. <b>(a)</b> maximum displacement at the center corresponding to loading at which dynamic buckling occurs for a cross-ply laminate <b>(b)</b> maximum failure index (Tsai-Wu criterion) corresponding to loading at which first ply failure occurs for a cross-ply laminate <b>(c)</b> maximum displacement at the center corresponding to loading at which dynamic buckling occurs for an angle-ply laminate <b>(d)</b> maximum failure index (Tsai-Wu criterion) at the corners corresponding to loading at which first ply failure occurs for an angle-ply laminate.	89
<b>Fig. 5.18</b>	Deformed shape of the laminated composite cylindrical panel with $b/a=1$ , $R/a=10$ , $a/h=100$ , subjected to sinusoidal pulse load. <b>(a)</b> maximum displacement at the center corresponding to loading at which dynamic buckling occurs for a cross-ply laminate <b>(b)</b> maximum failure index (Tsai-Wu criterion) near the edges corresponding to loading at which first ply failure occurs for a cross-ply laminate <b>(c)</b> maximum displacement at the center corresponding to loading at which dynamic buckling occurs for an angle-ply laminate <b>(d)</b> maximum failure index (Tsai-Wu criterion) at the corners corresponding to loading at which first ply failure occurs for an angle-ply laminate	89
<b>Fig. 5.19</b>	Plot for of the panel with $b/a=1$ , $R/a=5$ , $a/h=100$ , subjected to rectangular pulse load for various stacking sequence and boundary conditions. <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure index (Tsai-Wu criterion)	91
<b>Fig. 5.20</b>	Plot for of the panel with $b/a=1$ , $R/a=5$ , $a/h=100$ , subjected to sinusoidal pulse load for various stacking sequence and boundary conditions. <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure index (Tsai-Wu criterion)	91
<b>Fig. 5.21</b>	Loading functions considered for shock spectrum <b>(a)</b> Exponential pulse load <b>(b)</b> Triangular pulse load <b>(c)</b> Sinusoidal pulse load <b>(d)</b> Rectangular pulse load	93
<b>Fig. 5.22</b>	Plot for laminated composite cylindrical panel with $R/a=10$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ <b>(a)</b> transverse displacement vs in-plane load <b>(b)</b> Shock Spectrum of the subjected to various pulse loads	93
<b>Fig. 6.1</b>	Plate with a square cutout for validation study <b>(a)</b> Geometry <b>(b)</b> Pre-buckling boundary conditions <b>(c)</b> Buckling boundary conditions	96
<b>Fig. 6.2</b>	Plot of static buckling load vs Mesh size of a plate with cutout	97
<b>Fig. 6.3</b>	Cylindrical panel with central cutout for the validation study <b>(a)</b> Geometry <b>(b)</b> boundary conditions	99

<b>Fig. 6.4</b>	Non-dimensional Load vs non-dimensional Displacement for a panel with $R/a=10$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ for various durations of rectangular pulse loading <b>(a)</b> 5% circular cutout area at the centre <b>(b)</b> 20% circular cutout area at the centre	102
<b>Fig. 6.5</b>	Plot for a panel with $R/a=10$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ and 10% circular cutout area subjected to rectangular pulse load <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure index	104
<b>Fig. 6.6</b>	Deformed shape of the panel with $R/a=10$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ and 10% circular cutout area. Scale factor=10. <b>(a)</b> $N_{dyn}/N_{st} = 0.6$ showing the maximum transverse displacement <b>(b)</b> $N_{dyn}/N_{st} = 0.6$ showing the Tsai-Wu Failure Criterion <b>(c)</b> $N_{dyn}/N_{st} = 0.8$ showing the maximum transverse displacement <b>(d)</b> $N_{dyn}/N_{st} = 0.8$ showing the Tsai-Wu Failure Criterion.	104
<b>Fig. 6.7</b>	Plot for a panel with $R/a=10$ , $b/a=1$ , $b/h=100$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ for various loading functions and central cutout areas <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure index (Tsai-Wu criterion)	105
<b>Fig. 6.8</b>	Plot for a panel with $b/a=1$ , $b/h=100$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ , subjected to rectangular pulse load and 5% circular cutout area for various radius of curvatures <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion)	107
<b>Fig. 6.9</b>	Plot for a panel with $b/a=1$ , $b/h=100$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ , subjected to rectangular pulse load and 10% circular cutout area for various radius of curvatures. <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion)	107
<b>Fig. 6.10</b>	Plot for a cylindrical panel with $b/a=1$ , $b/h=100$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ for various cutout areas subjected to rectangular pulse load <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement for panel with $R/a = 10$ , <b>(b)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for panel with $R/a = 10$ <b>(c)</b> Non-dimensional Load vs non-dimensional Displacement for panel with $R/a = 5$ , <b>(d)</b> for panel with $R/a = 5$	110
<b>Fig. 6.11</b>	Plot for a cylindrical panel with $b/a=1$ , $b/h=100$ and stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ for various cutout areas subjected to rectangular pulse load <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement for panel with $R/a = 10$ , <b>(b)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for panel with $R/a = 10$ <b>(c)</b> Non-dimensional Load vs non-dimensional Displacement for panel with $R/a = 5$ , <b>(d)</b> for panel with $R/a = 5$	111
<b>Fig. 6.12</b>	Plot for a panel with $R/a = 10$ , $b/a=1$ , $b/h=100$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ and subjected to rectangular pulse load for various cutout shapes. <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement for panel with 5% cutout area <b>(b)</b> Non-dimensional Load vs non-dimensional Displacement for panel with 10% cutout area <b>(c)</b> Non-dimensional Load vs non-dimensional Displacement for panel with 20% cutout area <b>(d)</b> Non-dimensional Load vs Failure Index for panel with 5% cutout area <b>(e)</b> Non-dimensional Load vs Failure Index for panel with 10% cutout area <b>(f)</b> Non-dimensional Load vs Failure Index for panel with 20% cutout area	113
<b>Fig. 6.13</b>	Plot for a panel with $R/a = 10$ , $b/a=1$ , $b/h=100$ , stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ and subjected to rectangular pulse load for various cutout shapes. <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement for panel with 5% cutout area <b>(b)</b> Non-dimensional Load vs non-dimensional Displacement for panel with 10% cutout area <b>(c)</b> Non-dimensional Load vs non-dimensional Displacement for panel with 20% cutout area <b>(d)</b> Non-dimensional Load vs Failure Index for panel with 5% cutout area <b>(e)</b> Non-dimensional Load vs Failure Index for panel with 10% cutout area <b>(f)</b> Non-dimensional Load vs Failure Index for panel with 20% cutout area	114
<b>Fig. 6.14</b>	Deformed shape of the panel with $R/a=10$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ , 10% cutout area and subjected to rectangular pulse load <b>(a)</b> $N_{dyn}/N_{st} = 0.6$ showing the maximum transverse displacement <b>(b)</b> $N_{dyn}/N_{st} = 0.6$ showing the maximum transverse displacement <b>(c)</b> $N_{dyn}/N_{st} = 0.9$ showing the failure index for Tsai-Wu criterion <b>(d)</b> $N_{dyn}/N_{st} = 0.7$ showing the failure index for Tsai-Wu criterion	115
<b>Fig. 6.15</b>	Deformed shape of the panel with $R/a=10$ , stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ , 10% cutout area and subjected to rectangular pulse load <b>(a)</b> $N_{dyn}/N_{st} = 0.4$ showing the maximum transverse displacement <b>(b)</b> $N_{dyn}/N_{st} = 0.45$ showing the maximum	115

	transverse displacement <b>(c)</b> $N_{dyn}/N_{st} = 0.45$ showing the failure index for Tsai-Wu criterion <b>(d)</b> $N_{dyn}/N_{st} = 0.55$ showing the failure index for Tsai-Wu criterion	
<b>Fig. 6.16</b>	Non-dimensional Load vs Displacement for a panel with $b/a=1$ , $b/h=100$ , $R/a=10$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ and 10% Circular cutout area when subjected to rectangular pulse load along with deformed shape of the panel at various magnitude of loads. Scale factor=10.	119
<b>Fig. 6.17</b>	Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for a panel with $b/a=1$ , $b/h=100$ , $R/a=10$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ and 10% Circular cutout area when subjected to rectangular pulse load along with deformed shape of the panel at various magnitude of loads. Scale factor=10.	120
<b>Fig. 6.18</b>	Non-dimensional Load vs Displacement for a panel with $b/a=1$ , $b/h=100$ , $R/a=10$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ and 10% Square cutout area when subjected to rectangular pulse load along with deformed shape of the panel at various magnitude of loads. Scale factor=10.	121
<b>Fig. 6.19</b>	Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for a panel with $b/a=1$ , $b/h=100$ , $R/a=10$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ and 10% Square cutout area when subjected to rectangular pulse load along with deformed shape of the panel at various magnitude of loads. Scale factor=10.	122
<b>Fig. 6.20</b>	Non-dimensional Load vs Displacement for a panel with $b/a=1$ , $b/h=100$ , $R/a=10$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ and 10% Square-Rotated cutout area when subjected to rectangular pulse load along with deformed shape of the panel at various magnitude of loads. Scale factor=10.	123
<b>Fig. 6.21</b>	Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for a panel with $b/a=1$ , $b/h=100$ , $R/a=10$ , stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ and 10% Square-Rotated cutout area when subjected to rectangular pulse load along with deformed shape of the panel at various magnitude of loads. Scale factor=10.	124
<b>Fig. 7.1</b>	Stiffened plate with a stiffener along the direction of loading <b>(a)</b> Geometry <b>(b)</b> Pre buckling boundary conditions <b>(c)</b> Buckling boundary conditions	128
<b>Fig. 7.2</b>	Stiffened plate with a stiffener in the perpendicular direction of loading <b>(a)</b> Geometry <b>(b)</b> Pre buckling boundary conditions <b>(c)</b> Buckling boundary conditions	128
<b>Fig. 7.3</b>	Non-dimensional static buckling load for various mesh sizes for a stiffened plate <b>(a)</b> Stiffener in the perpendicular direction of loading <b>(b)</b> Stiffener along the direction of loading	129
<b>Fig. 7.4</b>	Stiffened cylindrical panel for the validation study <b>(a)</b> Geometry <b>(b)</b> Pre-buckling boundary conditions <b>(c)</b> Buckling boundary conditions	130
<b>Fig. 7.5</b>	Non-dimensional Load vs Non-dimensional Displacement for panel with $R/a=10$ , $d_s/b_s=1$ and subjected to rectangular pulse load for various durations of loading <b>(a)</b> Stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ <b>(b)</b> Stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$	134
<b>Fig. 7.6</b>	Plot for a panel with $R/a=10$ , $d_s/b_s=1$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to rectangular pulse load <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement <b>(b)</b> Non-dimensional Load vs Failure Index	136
<b>Fig. 7.7</b>	Deformed shape of the stiffened cylindrical panel with $R/a=10$ , $d_s/b_s=1$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to rectangular pulse load. Scale Factor = 3 <b>(a)</b> For maximum transverse displacement at $N_{dyn}/N_{st} = 0.7$ <b>(b)</b> For maximum failure index (Tsai-Wu criterion) at $N_{dyn}/N_{st} = 0.7$ . <b>(c)</b> For maximum transverse displacement at $N_{dyn}/N_{st} = 1$ <b>(d)</b> For maximum failure index (Tsai-Wu criterion) at $N_{dyn}/N_{st} = 1$	136
<b>Fig. 7.8</b>	Plot for a stiffened cylindrical panel with $d_s/b_s=1$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ for both pulse loading functions. <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement for panel with $R/a=20$ <b>(b)</b> Non-dimensional Load vs non-dimensional Displacement for panel with $R/a=10$ <b>(c)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for panel with $R/a=20$ <b>(d)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for panel with $R/a=10$	138
<b>Fig. 7.9</b>	Plot for the stiffened panel with $d_s/b_s=1$ and subjected to rectangular pulse load for various radius of curvatures <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement for panel with stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ <b>(b)</b> Non-dimensional Load vs non-dimensional Displacement for panel with stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ <b>(c)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for panel with stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ <b>(d)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for panel with stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$	141



<b>Fig. 7.10</b>	Non-dimensional Load vs non-dimensional Displacement for the stiffened panel with $R/a = 10$ , $b_s/h=2$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to rectangular pulse load for various aspect ratios of stiffeners	143
<b>Fig. 7.11</b>	Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for the stiffened panel with $R/a=10$ , $b_s/h=2$ , and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to rectangular pulse load for various aspect ratios of stiffeners.	143
<b>Fig. 7.12</b>	Plot for the stiffened panel with stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ for various stiffener aspect ratios. <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement for panel with $R/a=20$ <b>(b)</b> Non-dimensional Load vs non-dimensional Displacement for panel with $R/a=10$ <b>(c)</b> Non-dimensional Load vs non-dimensional Displacement for panel with $R/a=5$ <b>(d)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for panel with $R/a=20$ <b>(e)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for panel with $R/a=10$ <b>(f)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for panel with $R/a=5$	145
<b>Fig. 7.13</b>	Plot for the stiffened panel with stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ for various stiffener aspect ratios. <b>(a)</b> Non-dimensional Load vs non-dimensional Displacement for panel with $R/a=20$ <b>(b)</b> Non-dimensional Load vs non-dimensional Displacement for panel with $R/a=10$ <b>(c)</b> Non-dimensional Load vs non-dimensional Displacement for panel with $R/a=5$ <b>(d)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for panel with $R/a=20$ <b>(e)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for panel with $R/a=10$ <b>(f)</b> Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for panel with $R/a=5$	146
<b>Fig. 7.14</b>	Deformed shape of the stiffened panel for maximum transverse displacement having $R/a=10$ and stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ <b>(a)</b> Panel with $d_s/b_s=1$ at $N_{dyn}/N_{st} = 0.4$ <b>(b)</b> Panel with $d_s/b_s=4$ at $N_{dyn}/N_{st} = 0.325$ <b>(c)</b> Panel with $d_s/b_s=8$ at $N_{dyn}/N_{st} = 0.5$	149
<b>Fig. 7.15</b>	Deformed shape of the stiffened panel for Tsai-Wu failure criterion having $R/a=10$ and stacking sequence $(45^\circ/-45^\circ/-45^\circ/45^\circ)$ <b>(a)</b> Panel with $d_s/b_s=1$ at $N_{dyn}/N_{st} = 0.45$ <b>(b)</b> Panel with $d_s/b_s=4$ at $N_{dyn}/N_{st} = 0.275$ <b>(c)</b> Panel with $d_s/b_s=8$ at $N_{dyn}/N_{st} = 0.3$	149
<b>Fig. 7.16</b>	Non-dimensional Load vs non-dimensional Displacement for the stiffened panel with $R/a=10$ , $d_s/b_s=1$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to rectangular pulse load along with deformed shape of the stiffened panel at various magnitude of loads. Scale Factor=5.	151
<b>Fig. 7.17</b>	Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for the stiffened panel with $R/a=10$ , $d_s/b_s=1$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to rectangular pulse load along with deformed shape of the stiffened panel at various magnitude of loads. Scale Factor=5.	152
<b>Fig. 7.18</b>	Non-dimensional Load vs non-dimensional Displacement for the stiffened panel with $R/a=10$ , $d_s/b_s=4$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to rectangular pulse load along with deformed shape of the stiffened panel at various magnitude of loads. Scale Factor=5.	153
<b>Fig. 7.19</b>	Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for the stiffened panel with $R/a=10$ , $d_s/b_s=4$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to rectangular pulse load along with deformed shape of the stiffened panel at various magnitude of loads. Scale Factor=5.	154
<b>Fig. 7.20</b>	Non-dimensional Load vs non-dimensional Displacement for the stiffened panel with $R/a=10$ , $d_s/b_s=8$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to rectangular pulse load along with deformed shape of the stiffened panel at various magnitude of loads. Scale Factor=3.5.	155
<b>Fig. 7.21</b>	Non-dimensional Load vs Failure Index (Tsai-Wu criterion) for the stiffened panel with $R/a=10$ , $d_s/b_s=8$ and stacking sequence $(0^\circ/90^\circ/90^\circ/0^\circ)$ subjected to rectangular pulse load along with deformed shape of the stiffened panel at various magnitude of loads. Scale Factor=3.5.	156

## LIST OF TABLES

Table No.	Title	Page No.
<b>Table 3.1</b>	Material properties of Graphite/Epoxy lamina (Narita and Leissa, 1990)	39
<b>Table 3.2</b>	Material properties of T300/BSL914C lamina (Hinton <i>et al.</i> , 2004)	39
<b>Table 4.1</b>	Non-dimensional static buckling load of a plate with $b/a=2$ , $b/h=100$ and stacking scheme $(\theta^\circ/-\theta^\circ/\theta^\circ)$ ; $\theta=0^\circ$ .	51
<b>Table 4.2</b>	Non-dimensional static buckling load of a plate with $b/a=2$ , $b/h=100$ and stacking scheme $(\theta^\circ/-\theta^\circ/\theta^\circ)$ ; $\theta=90^\circ$ .	51
<b>Table 4.3</b>	Non-dimensional static buckling load of a plate with $b/a=1$ , $b/h=100$ and stacking scheme $(\theta^\circ/-\theta^\circ/\theta^\circ)$ ; $\theta=0^\circ$ .	51
<b>Table 4.4</b>	Non-dimensional static buckling load of a plate with $b/a=1$ , $b/h=100$ and stacking scheme $(\theta^\circ/-\theta^\circ/\theta^\circ/-\theta^\circ/\theta^\circ)$ ; $\theta=45^\circ$ .	51
<b>Table 4.5</b>	Static buckling load and first natural period for the plate with $b/a=2$ , $b/h=100$ with $b=0.2\text{m}$ and stacking sequence $(\theta^\circ/-\theta^\circ/\theta^\circ)$	57
<b>Table 5.1</b>	Non-dimensional static buckling load for a panel with $b/a=1$ , $b/h=100$ , $R/a=20$ and stacking sequence $(0^\circ/90^\circ/0^\circ/90^\circ/0^\circ)$ .	70
<b>Table 5.2</b>	Static buckling load and first natural period of the cylindrical panel with $a/h=100$ and $a=0.1\text{m}$ for various radius of curvatures and ply orientations	73
<b>Table 5.3</b>	Codes used to represent aspect ratio and loading function in Figs. 6.23–6.26.	86
<b>Table 6.1</b>	Static buckling load for an isotropic square plate with a central square cutout for various length of cutout side to length of plate ratios	97
<b>Table 6.2</b>	Static buckling load for a laminated composite square plate with a central square cutout for various ratios of cutout side to length of the plate	98
<b>Table 6.3</b>	Static buckling load for a laminated composite rectangular plate with stacking sequence is $(90^\circ/45^\circ/-45^\circ/0^\circ)_s$ and a central circular cutout.	98
<b>Table 6.4</b>	Natural frequency for a cylindrical panel with central square cutout for various length of cutout side to length of panel ratios.	99
<b>Table 6.5</b>	Static buckling load and first natural period of the cylindrical panel with cutout having $b/a=1$ , $b/h=100$ with $a=0.1\text{m}$ with various radius of curvatures and stacking schemes.	100
<b>Table 7.1</b>	Non-dimensional static buckling load for a stiffened plate with $b/a=1$ , $b/h=100$ , $b_s/h=2$ and $d_s/b_s=2$	129
<b>Table 7.2</b>	Non-dimensional static buckling load for the stiffened cylindrical panel with $R/a=2$ , $b/a=1$ , $b/h=100$ , $b_s/h=2$ and $d_s/b_s=2$	130
<b>Table 7.3</b>	Natural frequency of a stiffened plate with all edges clamped	131
<b>Table 7.4</b>	Static buckling load and first natural period of the stiffened cylindrical panel having $b/a=1$ , $b/h=100$ , $d_s/b_s=2$ with $a=0.1\text{m}$ with various radius of curvatures and stacking schemes.	132

## LIST OF SYMBOLS

---

$a$	Length of the loaded edge of plate/cylindrical panel
$b$	Length of the non-loaded edge of plate/cylindrical panel
$b_s$	Width of the stiffener
$B_L$	Linear Strain-displacement matrix
$B_{NL}$	Non-linear Strain-displacement matrix
$c$	Length of the side of the cutout
$d_s$	Depth of the stiffener
$E_{11}$	Principal Young's modulus in the material direction
$E_{22}$	Principal Young's modulus in the material direction
$G_{12}$	Shear modulus associated with plane 1-2
$G_{23}$	Shear modulus associated with plane 2-3
$G_{13}$	Shear modulus associated with plane 1-3
$\{F(t)\}$	Force vector
$h$	Thickness of the plate/cylindrical panel
$[K]$	Stiffness Matrix
$[K_G]$	Geometric Stiffness Matrix
$[M]$	Mass Matrix
$\nu_{12}$	Major Poisson's ratio
$\nu_{21}$	Minor Poisson's ratio
$N$	Shape function matrix
$N_{dyn}$	Amplitude of the maximum dynamic load applied to the plate/ cylindrical panel
$N_{st}$	Static buckling load of the plate/ cylindrical panel
$P_{cr}$	Critical buckling pressure
$\rho$	Mass density
$\tau$	Boundary traction over the surface
$T_n$	First natural period of the plate/cylindrical panel

$T_b$	Duration of the applied load for plate/cylindrical panel
$\{u\}$	Displacement vector
$\{\ddot{u}\}$	Acceleration vector
$u$	Displacement along X-axis
$v$	Displacement along Y-axis
$w$	Displacement along Z-axis
$\theta_X$	Rotation about X-axis
$\theta_Y$	Rotation about Y-axis
$\theta_Z$	Rotation about Z-axis
$\omega_n$	Natural Frequency
$X_T$	Tensile strength in the principal material direction
$X_C$	Compressive strength in the principal material direction
$Y_T$	Tensile strength in transverse-to material direction
$Y_C$	Compressive strength in transverse-to material direction
$S_{12}$	Shear strength in the plane 1-2
$S_{23}$	Shear strength in the plane 2-3
$S_{13}$	Shear strength in the plane 1-3
$\sigma_{11}$	Normal stress component in the principal material direction'1'
$\sigma_{22}$	Normal stress component in the principal material direction'2'
$\sigma_{12}$	Shear stress component in the principal material plane 1-2

---



This document was created with the Win2PDF "print to PDF" printer available at <http://www.win2pdf.com>

This version of Win2PDF 10 is for evaluation and non-commercial use only.

This page will not be added after purchasing Win2PDF.

<http://www.win2pdf.com/purchase/>