# APPENDIX-A

# Cost Analysis

**Cost Analysis**

This section deals with cost estimations of strengthening materials (i.e, ECC and FRP) used in this study. The material cost estimations of ECC (PVA-ECC and Poly-ECC) have been reported in Table A.1. This cost estimations are based on the material cost obtained from the suppliers. The material cost is estimated to be ₹ 15610 /$m^3$ for Polyester fiber based ECC (Poly-ECC) and ₹ 41610 /$m^3$ for PVA-ECC. The PVA-ECC is more expensive almost three times that of Poly-ECC as PVA-fibers are brought from Japan whereas Polyester fibers are available in India. The cost estimations of strengthening materials (i.e., FRP, ECC, and Epoxy) used in this study are given in Table A.2.

**Table A.1 Detailed Cost of ECC (Poly-ECC & PVA-ECC)**

| **Sr No** | **Material** | **Type** | **Quantity for 1 $m^3$ in (kg)** | **Unit Cost ₹/kg** | **Total Cost (₹)** |
|---|---|---|---|---|---|
| 1. | Cement | PPC | 620 | 6 | 3720 |
| 2. | Silica Sand | Micro | 620 | 3 | 1860 |
| 3. | Fly-ash | Class-F | 620 | 2* | 1240 |
| 4. | Water | Potable | 290 | 0 | 0 |
| 5. | Super Plasticizer | Master Glenium Sky 8777 | 8.5 | 300 | 2550 |
| 6. | Fiber | Polyester | 26 | 240 | 6240 |
| | | PVA | 26 | 1240 | 32240 |
| **Total Cost of Poly-ECC per $m^3$** | | | | | **15610** |
| **Total Cost of PVA-ECC per $m^3$** | | | | | **41610** |

* Transportation cost

**Table A.2 Material Cost of Strengthening Materials**

| Sr No | Strengthening Material | Material Cost (₹) |
|---|---|---|
| 1. | Carbon Fabrics | 800 /$m^2$/layer |
| 2. | Glass Fabrics | 250 /$m^2$/layer |
| 3. | Pultruded CFRP Bars (8 mm dia) | 440 /m |
| 4. | Hand lay-up CFRP bars (8 mm dia) | 210 /m |
| 5. | ECC sheet (Poly-ECC) of 25 mm thick | 390 /$m^2$/layer |
| 6. | ECC Sheet (Poly-ECC) of 35 mm thick | 545 /$m^2$/layer |
| 7. | ECC sheet (PVA-ECC) of 25 mm thick | 1040 /$m^2$/layer |
| 8. | ECC Sheet (PVA-ECC) of 35 mm thick | 1460 /$m^2$/layer |
| 9. | Epoxy (1 mm thick layer) | 400 /$m^2$/layer |

**Cost Estimation of Masonry Beams with Cement Mortar and ECC as Bed Joint**

The material cost is estimated of Masonry beams with cement mortar and ECC as bed joint as explained in Chapter 4 (Table 4.1). The material cost is estimated to be ₹ 180 total cost / beam for making of control masonry beam with cement mortar as bed joint and ₹ 510 total cost /beam for masonry beams with ECC as bed joint. These masonry beams were strengthened with various strengthening patterns as explained in Section 4.2.1 (Chapter 4). The strengthening area and cost estimation of strengthening materials including bonding agent (epoxy) are given in Table A.3. It may be noted that the cost of control masonry beams is not included to Series #2-6 given in Table A.3. It is observed that the masonry beams strengthened with pultruded CFRP bars are more expensive than the other specimens due to high cost of pultruded bars.

**Table A.3 Cost Estimation of Masonry Beams as described in Table 4.1**

| Series No. | Specimen details | Strengthening Materials | Strengthening Area | Cost (strengthening material +Epoxy) (₹) |
|---|---|---|---|---|
| 1 | Control masonry beams with cement mortar as bed joint | Control Specimens | - | 180 (control beam cost) |
| | Control masonry beam with ECC as bed joint | Control Specimens | - | 510 (control beam cost) |
| 2 | Carbon fiber flexural strengthened masonry beams | Carbon Fabric | 0.19 $m^2$ | 235 |
| | Glass fiber flexural strengthened masonry beams | Glass Fabric | 0.19 $m^2$ | 125 |
| 3 | Carbon fiber U-wrapping shear strengthened masonry beams | Carbon Fabric | 0.20 $m^2$ | 245 |
| | Glass fiber U-wrapping shear strengthened masonry beams | Glass Fabric | 0.20 $m^2$ | 130 |
| 4 | Carbon fiber continuous U-wrapping shear strengthened masonry beams | Carbon Fabric | 0.67 $m^2$ | 800 |
| | Glass fiber continuous U-wrapping shear strengthened masonry beams | Glass Fabric | 0.67 $m^2$ | 430 |
| 5 | Pultruded CFRP bars reinforced masonry beams | Pultruded CFRP bars (8 mm dia) | 3.66 m | 1610 |
| | Hand lay-up CFRP bars reinforced masonry beams | Hand lay-up CFRP bars (8 mm dia) | 3.66 m | 770 |

| | | | | |
|---|---|---|---|---|
| 6 | NSM strengthened masonry beams using pultruded CFRP bars | Pultruded CFRP bars (8 mm dia) | 3.66 m | 1805 |
| | NSM strengthened masonry beams using hand lay-up CFRP bars | Hand lay-up CFRP bars (8 mm dia) | 3.66 m | 965 |

**Cost Estimation of Masonry Beams Strengthened with ECC Sheet**

The material cost is estimated of masonry beams strengthened with ECC sheet as explained in Chapter 4 (Table 4.3). The material cost is estimated to be ₹ 60 total cost /beam for making of control masonry beam and ₹ 110 total cost /unit for control ECC sheet of 35 mm thick. The control masonry beams were strengthened with ECC sheet as described in Section 4.3.1 (Chapter 4). The strengthening area and cost estimation of ECC sheet including bonding agent (cement mortar and epoxy) are given in Table A.4. It may be noted that the cost of control masonry beams is not included in strengthening materials cost to Serial no. #3-6 given in Table A.4. It is observed that the epoxy bonded sandwich beams with ECC on both side are more expensive than the other specimens.

**Cost Estimation of Masonry Walls Strengthened with FRP and ECC**

The material cost is estimated of Masonry walls strengthened with FRP and ECC as explained in Chapter 5 (Table 5.1). The material cost is estimated to be ₹ 250 total cost / unit for making of control masonry walls with and without opening. These masonry walls were strengthened with CFRP and ECC sheet as described in Section 5.2.1 (Chapter 5). The strengthening area and cost estimation of strengthening materials are given in Table A.5. It may be noted that the cost of control masonry wall is not included in strengthening materials cost. It is observed that the masonry walls strengthened with CFRP bars and strips are more expensive than the other specimens.

**Table A.4 Cost Estimation of Masonry Beams as described in Table 4.3**

| Sr. No. | Specimen details | Strengthening Materials | Strengthening Area ($m^2$) | Cost (strengthening material +Epoxy) (₹) |
|---|---|---|---|---|
| 1. | Control masonry beams with cement mortar as bed joint | Control Specimens | - | 60 (Control beam) |
| 2. | ECC Control Beam of depth 35 mm | Control ECC Sheet | - | 110 (Control ECC Sheet) |
| 3. | Epoxy bonded tension strengthened beam with ECC thickness 35 mm on tension face | Poly-ECC 35 mm thick (One layer) | 0.20 | 185 |
| 4. | Cement mortar bonded tension strengthened beam with ECC thickness 35 mm on tension face | Poly-ECC 35 mm thick (One layer) | 0.20 | 115 |
| 5. | Epoxy bonded Sandwich beam with ECC thickness 35 mm on both faces | Poly-ECC 35 mm thick (Two layer) | 0.40 | 370 |
| 6. | Cement mortar bonded Sandwich beam with ECC thickness 35 mm on both faces | Poly-ECC 35 mm thick (Two layer) | 0.40 | 230 |

**Table A.5 Cost Estimation of Masonry Beams described in Table 5.1**

| Sr. No. | Specimen details | Strengthening Materials | Strengthening Area | Cost (strengthening material +Epoxy) (₹) |
|---|---|---|---|---|
| 1. | Control/unstrengthened masonry wall without opening | Control Specimen | - | 250 (Control Specimen) |
| 2. | Control/unstrengthened masonry wall with opening | Control specimen | - | 250 (Control Specimen) |
| 3. | Flexural strengthened masonry wall with CFRP bars | Pultruded CFRP bars (8 mm dia) | 3.84 m | 1830 |
| 4. | Flexural strengthened masonry wall with CFRP bars along with CFRP strips | Pultruded CFRP bars (8 mm dia) and Carbon fabric | 3.84 m + 0.14 $m^2$ (for bars and FRP strips) | 2000 |
| 5. | ECC strengthened masonry wall without opening | Poly-ECC 25 mm thick | 0.37 | 290 |
| 6. | ECC strengthened masonry wall with opening | Poly-ECC 25 mm thick | 0.32 | 260 |