

## Table of Contents

<b>Certificate</b>		<b>ii</b>
<b>Declaration by the candidate</b>		<b>iii</b>
<b>Copyright transfer certificate</b>		<b>iv</b>
<b>Acknowledgement</b>		<b>v</b>
<b>Dedication</b>		<b>vi</b>
<b>Table of Content</b>		<b>vii-xi</b>
<b>List of Figures</b>		<b>xii-xvii</b>
<b>List of Tables</b>		<b>xviii</b>
<b>Preface</b>		<b>xix-xxii</b>
<b>CHAPTER 1</b>	<b>INTRODUCTION</b>	<b>1</b>
1.1 General		1
1.2 Strengthening of structures		3
1.4 Composite material		5
1.4 Fibre reinforced polymers/plastic (FRP)		6
1.4.1 Properties of different fibre reinforced plastic (FRP)		9
1.5 Motivation		11
1.6 Organisation of thesis		11
<b>CHAPTER 2</b>	<b>LITERATURE REVIEW</b>	<b>13</b>
2.1 General		13
2.1 Damages analysis of girders		13
2.1 Strengthening techniques of girders		15
2.1 FRP retrofitting of bridges		18
2.1 Critical observations		28
2.1 Scope of present study		28
<b>CHAPTER 3</b>	<b>ANALYSIS OF FIBRE LAMINATED GIRDER</b>	<b>30</b>
3.1 General		30
3.2 Analysis of the girder		31

3.2.1 Numerical analysis of girder	32
3.2.2 Geometric and elastic properties of benchmark problem	32
3.3 Modelling of prismatic girder	34
3.3.1 Convergence study	36
3.3.2 Properties of fibre laminates used in lamination	38
3.3.3 Parametric study	39
3.4 Result and discussions	40
3.4.1 Variation in deflection, tensile stress and strain energy of beams with different aspect ratio (b/d):	42
3.4.2 Variation in frequency with respect to aspect ratio for different modes	43
3.4.3 Variation in deflection with respect to aspect ratio for different modes	46
3.4.4 Variation in deflection, tensile stress and strain energy of beams with different percentage of steel (p %)	48
3.4.5 Variation in frequency with respect to percentage of steel for different modes:	49
3.4.6 Variation in deflection with respect to percentage of steel for different modes:	52
3.4.7 Variation in deflection, tensile stress and strain energy of beams with different uniformly distributed loading intensities (w):	54
3.4.8 Variation in frequency with respect to loading intensity for different modes	55
3.4.9 Variation of deflection with respect loading intensity for different modes	58
3.5 Analysis of prismatic girder with varying length	60
3.6 IRC Loading of prismatic girder	60
3.6.1 Maximum deformation of prismatic girder	61
3.6.2 Maximum Von Mises strain of prismatic girder	62
3.6.3 Maximum compressive Stress of prismatic girder	64
3.6.4 Maximum tensile stress of prismatic girder	65
3.6.5 Maximum Von Mises stress of prismatic girder	67
3.6.6 Strain energy of prismatic girder	68
3.6.7 Frequency of prismatic girder with carbon laminated fibre for different modes	70
3.7 Analysis of I-girder	78
3.6.1 Dimension of I- girder	78
3.6.2 Loading on I- girder	79
3.8 Result and discussion	80
3.8.1 Maximum deformation of laminated I- girder	80
3.8.2 Max Von Mises strain of laminated I- girder	82
3.8.3 Maximum compressive stress of laminated I- girder	83

3.8.4 Maximum tensile stress of laminated I- girder	85
3.8.5 Maximum Von-Mises stress of laminated I- girder	86
3.8.6 Strain Energy of laminated I- girder	88
3.8.7 Frequency of laminated I -girder for different modes	90
3.9 Regression analysis	98
3.9.1 Parametric relations of beam without FRP	98
3.9.2 Parametric relations of beam with single layer FRP	99
3.9.3 Parametric relations of beam with double layer FRP	100
3.9.4 Parametric relations of beam with triple layer FRP	101
3.10 Summary	101
<b>CHAPTER 4 ANALYSIS AND STRENGTHENING OF VEHICLE BRIDGE GIRDER AT PUSA: A CASE STUDY</b>	<b>103</b>
4.1 General	104
4.2 Background of Pusa Bridge	105
4.3 Damage analysis of Pusa bridge	106
4.4 Modeling of bridge girder and deck slab	109
4.4.1 Loading details on bridge	110
4.4.2 Maximum deformation in the girder of Pusa bridge	112
4.4.3 Von-Mises Stress in the girder of Pusa bridge	114
4.4.4 Strain energy in the girder of Pusa bridge	116
4.4.5 Maximum compressive stress in girder	118
4.4.6 Frequency of girder in different Modes	119
4.4.7 Von-Mises strain in the girder	129
4.4.8 Maximum tensile stress in the Pusa bridge girder	130
4.5 Recommendation and procedure of strengthening	132
4.6 Load Testing of bridge	135
4.6.1 Measuring instruments	135
4.7 Result and discussion	140
4.8 Summary	142

<b>CHAPTER 5 ANALYSIS AND STRENGTHENING OF RAIL BRIDGE GIRDER AT RATLAM : A CASE STUDY</b>	<b>142</b>
5.1 General	143
5.2 Background of bridge no 114	144
5.2.1 Details of bridge	144
5.2.2 Cross section details	145
5.2.3 Inspection report of bridge no 114	146
5.3 Numerical analysis of bridge girder	147
5.3.1 Deformation of girder	149
5.3.2 Von Mises strain of girder	151
5.3.3 Maximum compressive stress	153
5.3.4 Maximum tensile stress	155
5.3.5 Maximum Von-Misses stress	156
5.3.6 Strain energy	158
5.3.7 Frequency of girder for different mode shape	160
5.4 Strengthening scheme of girder	169
5.4.1 Strengthening of bridge no 114	170
5.5 Field testing of bridge	171
5.5.1 Testing procedure	172
5.5.2 Testing apparatus of bridge girder	172
5.6 Pre-strengthening test of girder	175
5.6.1 Maximum deflection under static loading before strengthening	175
5.6.2 Maximum deflection under dynamic loading before strengthening	176
5.6.3 Maximum natural frequency under dynamic loading in bridge girder before strengthening	176
5.7 Post strengthening deflection and natural frequency of bridge	178
5.7.1 Maximum deflection under static loading in bridge no 114 after strengthening	178
5.7.2 Maximum deflection under dynamic loading after strengthening	178
5.7.3 Maximum natural frequency in bridge girder after strengthening	179
5.7.4 Post strengthening result for bridge no 114	180
5.8 Result and discussion	181
5.9 Analysis and strengthening of Ratlam-Godhra railway bridge no 54	183
5.9.1 Background of bridge no 54	184
5.9.2 Damage detection in girder of bridge 54	185

5.10	Modelling of Ratlam bridge No 54	186
5.10.1	Strengthening Scheme of Ratlam bridge No 54	187
5.10.2	Testing of Ratlam bridge no 54	188
5.11	Pre and post strengthening results of bridge no 54	189
5.11.1	Pre-strengthening test results	189
5.12	Post-strengthening test results	192
5.12.1	Post-strengthening test results for natural frequency of bridge no 54	193
5.12.2	Result and discussion	194
5.13	Summary	196
<b>CHAPTER 6</b>	<b>CONCLUSIONS</b>	<b>199</b>
6.1	General	199
6.2	Concluding remarks	199
6.3	Future Scope of Study	203
<b>REFERENCES</b>		<b>204</b>

## List of Figures

<b>Figure 1. 1</b>	Concrete beam strengthen using steel plate	4
<b>Figure 3. 1</b>	Schematic diagram of RC beam retrofitting using FRP	32
<b>Figure 3. 2</b>	Benchmark beam used for verification (Prem pal et. al.)	33
<b>Figure 3. 3</b>	Model of simulated beam	35
<b>Figure 3. 4</b>	Support and load bearing block	35
<b>Figure 3. 5</b>	Analysis of load factor in comparison to node counts	37
<b>Figure 3. 6</b>	Relation between calculation times with respect to reduction in error	37
<b>Figure 3. 7</b>	Relation of reduction of error with respect to finer mesh size	38
<b>Figure 3. 8</b>	Static analysis for total deformation	41
<b>Figure 3. 9</b>	Modal analysis for mode shape and total deformation of Mode 4	41
<b>Figure 3. 10</b>	Variation of non-dimensional deflection with respect to aspect ratio	42
<b>Figure 3. 11</b>	Variation of tensile stress with respect to aspect ratio	43
<b>Figure 3. 12</b>	Variation of total strain energy with respect to aspect ratio	43
<b>Figure 3. 13</b>	Variation of mode 1 frequency with respect to aspect ratio	44
<b>Figure 3. 14</b>	Variation of mode 2 frequency with respect to aspect ratio	44
<b>Figure 3. 15</b>	Variation of mode 3 frequency with respect to aspect ratio	45
<b>Figure 3. 16</b>	Variation of mode 4 frequency with respect to aspect ratio	45
<b>Figure 3. 17</b>	Variation of mode 5 frequencies with aspect ratio	45
<b>Figure 3. 18</b>	Variation of Mode I deflection with aspect ratio	46
<b>Figure 3. 19</b>	Variation of Mode 2 deflection with aspect ratio	46
<b>Figure 3. 20</b>	Variation of Mode 3 deflection with aspect ratio	47
<b>Figure 3. 21</b>	Variation of Mode 4 deflection with aspect ratio	47
<b>Figure 3. 22</b>	Variation of Mode 5 deflections with aspect ratio	47
<b>Figure 3. 23</b>	Variation of non-dimensional deflection w.r.t. % of steel	48
<b>Figure 3. 24</b>	Variation of tensile stress with respect to % of steel	49
<b>Figure 3. 25</b>	Variation of total strain energy with respect to percentage of steel	49
<b>Figure 3. 26</b>	Variation of mode 1 frequency w.r.t. percentage of steel	50
<b>Figure 3. 27</b>	Variation of Mode 2 frequency w.r.t. percentage of steel	50
<b>Figure 3. 28</b>	Variation of mode 3 frequency w.r.t. percentage of steel	51
<b>Figure 3. 29</b>	Variation of mode 4 frequency w.r.t. percentage of steel	51
<b>Figure 3. 30</b>	Variation of Mode 5 frequency w.r.t. percentage of steel	51
<b>Figure 3. 31</b>	Variation of mode 1 deflection w.r.t. percentage of steel	52
<b>Figure 3. 32</b>	Variation of mode 2 deflection w.r.t. Percentage of steel	52

<b>Figure 3. 33</b> Variation of mode 3 deflection w.r.t. percentage of steel	53
<b>Figure 3. 34</b> Variation of mode 4 deflection w.r.t. percentage of steel	53
<b>Figure 3. 35</b> Variation of mode 5 deflection w.r.t. percentage of steel	53
<b>Figure 3. 36</b> Variation of deflection w.r.t loading intensity	55
<b>Figure 3. 37</b> Variation of Tensile w.r.t loading intensity	55
<b>Figure 3. 38</b> Variation of total strain energy with respect to loading intensity	55
<b>Figure 3. 39</b> Variation of Mode 1 frequency w.r.t. loading intensity	56
<b>Figure 3. 40</b> Variation of mode 2 frequency w.r.t. loading intensity	56
<b>Figure 3. 41</b> Variation of mode 3 frequency w.r.t. loading intensity	57
<b>Figure 3. 42</b> Variation of mode 4 frequency w.r.t. loading intensity	57
<b>Figure 3. 43</b> Variation of mode 5 frequency w.r.t. loading intensity	57
<b>Figure 3. 44</b> Variation of mode 1 deflection w.r.t. loading intensity	58
<b>Figure 3. 45</b> Variation of mode 2 deflection w.r.t. loading intensity	59
<b>Figure 3. 46</b> Variation of mode 3 deflection w.r.t. loading intensity	59
<b>Figure 3. 47</b> Variation of mode 4 deflection w.r.t. loading intensity	60
<b>Figure 3. 48</b> Variation of mode 5 deflection w.r.t. loading intensity	60
<b>Figure 3. 49</b> Maximum deformation vs span length in composite laminate girder	62
<b>Figure 3. 50</b> Maximum deformation vs no of layer of carbon laminate girder	62
<b>Figure 3. 51</b> Maximum Von Mises strain vs span length in composite laminate girder	63
<b>Figure 3. 52</b> Maximum Von Mises strain vs no of layer of carbon laminate girder	64
<b>Figure 3. 53</b> Maximum compressive stress vs span length in composite laminate girder	65
<b>Figure 3. 54</b> Maximum compressive stress vs no of layer of carbon laminate girder	65
<b>Figure 3. 55</b> Maximum tensile stress vs span length in composite laminate girder	66
<b>Figure 3. 56</b> Maximum tensile stress vs no of layer of carbon laminate girder	67
<b>Figure 3. 57</b> Maximum Von-Mises stress vs span length in composite laminate girder	68
<b>Figure 3. 58</b> Maximum Von-Mises stress vs no of layer of in carbon laminate girder	68
<b>Figure 3. 59</b> Strain energy vs span length in composite laminate girder	69
<b>Figure 3. 60</b> Strain energy vs no of layer of carbon laminate girder	70
<b>Figure 3. 61</b> Frequency in mode 1 vs span length in composite laminate girder	71
<b>Figure 3. 62</b> Frequency of girder in mode 1 with carbon laminated fibre	72
<b>Figure 3. 63</b> Frequency in mode 2 vs span length in composite laminate girder	73
<b>Figure 3. 64</b> Frequency of girder in mode 2 with carbon laminated fibre	73
<b>Figure 3. 65</b> Frequency in mode 3 vs span length in composite laminate girder	74
<b>Figure 3. 66</b> Frequency in mode 3 vs span length in carbon laminate girder	75
<b>Figure 3. 67</b> Frequency in mode 4 vs span length in composite laminate girder	76
<b>Figure 3. 68</b> Frequency in mode 4 vs span length in carbon laminate girder	76
<b>Figure 3. 69</b> Frequency in mode 5 vs span length in composite laminate girder	77

<b>Figure 3. 70</b>	Frequency in mode 5 vs span length in carbon laminate girder	78
<b>Figure 3. 71</b>	Section diagram of I-girder	79
<b>Figure 3. 72</b>	loading plan of I-girder	80
<b>Figure 3. 73</b>	Maximum deformation vs span length in composite laminate girder	81
<b>Figure 3. 74</b>	Maximum deformation vs no of layer of carbon laminate girder	82
<b>Figure 3. 75</b>	Maximum Von Mises strain vs span length in composite laminate girder	83
<b>Figure 3. 76</b>	Maximum Von Mises strain vs no of layer of carbon laminate I girder	83
<b>Figure 3. 77</b>	Maximum compressive stress vs span length in composite laminate girder	84
<b>Figure 3. 78</b>	Maximum compressive stress vs no of layer of carbon laminate I girder	85
<b>Figure 3. 79</b>	Maximum tensile stress vs span length in composite laminate I girder	86
<b>Figure 3. 80</b>	Maximum tensile stress vs no of layer of carbon laminate I girder	86
<b>Figure 3. 81</b>	Maximum Von-Mises stress vs span length in composite laminate I girder	87
<b>Figure 3. 82</b>	Maximum Von-Mises stress vs no of layer of in carbon laminate I girder	88
<b>Figure 3. 83</b>	Strain energy vs span length in composite laminate I girder	89
<b>Figure 3. 84</b>	Strain energy vs no of layer of carbon laminate I girder	89
<b>Figure 3. 85</b>	Frequency in mode 1 vs span length in composite laminate I girder	91
<b>Figure 3. 86</b>	Frequency of girder in Mode 1 with carbon laminated I girder	91
<b>Figure 3. 87</b>	Frequency in mode 2 vs span length in composite laminate girder	92
<b>Figure 3. 88</b>	Frequency of girder in Mode 2 with carbon laminated fibre	93
<b>Figure 3. 89</b>	Frequency in mode 3 vs span length in composite laminate girder	94
<b>Figure 3. 90</b>	Frequency in mode 3 vs span length in carbon laminate girder	94
<b>Figure 3. 91</b>	Frequency in mode 4 vs span length in composite laminate girder	95
<b>Figure 3. 92</b>	Frequency in mode 4 vs span length in carbon laminate girder	96
<b>Figure 3. 93</b>	Frequency in mode 5 vs span length in composite laminate girder	97
<b>Figure 3. 94</b>	Frequency in mode 5 vs span length in carbon laminate girder	97
<b>Figure 4. 1</b>	View of Pusa-Muzaffarpur bridge	105
<b>Figure 4. 2</b>	Cross section of Pusa bridge and its girder	106
<b>Figure 4. 3</b>	Wide flexural crack in full depth of RC girder	108
<b>Figure 4. 4</b>	deterioration in bridge girder	108
<b>Figure 4. 5</b>	Exposed reinforcement of girder	109
<b>Figure 4. 6</b>	Stifling of bearing	109
<b>Figure 4. 7</b>	Loading scheme of the deck slab	110
<b>Figure 4. 8</b>	FEM model of loading of bridge's deck slab	111
<b>Figure 4. 9</b>	Typical deformed girder under static load	111
<b>Figure 4. 10</b>	Typical deformed girder under modal loading	112
<b>Figure 4. 11</b>	Max deformation vs fibre layer for varying length of girder	113
<b>Figure 4. 12</b>	Max deformation vs span length different fibre layer	113



<b>Figure 4. 13</b>	Max Von Mises stress vs span length for different fibre layer combination	115
<b>Figure 4. 14</b>	Max Von Mises stress vs fibre layer with varying length of girder	116
<b>Figure 4. 15</b>	Strain Energy vs span length for different fibre layer combination	117
<b>Figure 4. 16</b>	length of girder vs strain Energy with varying fibre layer	117
<b>Figure 4. 17</b>	Compressive stress vs span length for different composite layer combination	118
<b>Figure 4. 18</b>	Compressive stress vs span length for different CFRP combination	119
<b>Figure 4. 19</b>	Deformed model of Pusa bridge in mode 1	120
<b>Figure 4. 20</b>	Frequency vs span length for different composite layer combination	121
<b>Figure 4. 21</b>	Frequency vs span length for different CFRP layer combination	121
<b>Figure 4. 22</b>	Deformed model of deck slab in mode 2	122
<b>Figure 4. 23</b>	frequency vs nos of fibre layer in mode 2 for different span length	123
<b>Figure 4. 24</b>	Frequency (mode 2) vs no of fibre layer for different span length	123
<b>Figure 4. 25</b>	Deformed model of deck in mode shape 3	124
<b>Figure 4. 26</b>	frequency vs nos. of fibre layer in mode 3 for different span length	124
<b>Figure 4. 27</b>	Frequency (mode 3) vs span length for different CFRP layer combination	125
<b>Figure 4. 28</b>	Deformed model of Pusa bridge in mode 4	126
<b>Figure 4. 29</b>	Frequency vs Nos of fibre layer in mode 4 for different span length	126
<b>Figure 4. 30</b>	Frequency (Mode 4) vs span length for different CFRP layer combination	127
<b>Figure 4. 31</b>	Deformed model of Pusa bridge in mode 5	128
<b>Figure 4. 32</b>	frequency vs nos. of fibre layer in mode 5 for different span length	128
<b>Figure 4. 33</b>	Frequency vs span length in mode 5 for different CFRP layer combination	129
<b>Figure 4. 34</b>	Max. Von-Mises strain vs span length for different composite layer	130
<b>Figure 4. 35</b>	Max von misses strain vs span length for different composite layer	130
<b>Figure 4. 36</b>	Max tensile stress vs no of fibre layer for different span length	131
<b>Figure 4. 37</b>	Max tensile stress vs span length for different CFRP layer combination	132
<b>Figure 4. 38</b>	cross section of strengthening scheme of Girder	133
<b>Figure 4. 39</b>	Side view of strengthening scheme of Girder	134
<b>Figure 4. 40</b>	Treatment of exposed reinforcement and Anti-corrosive paint	134
<b>Figure 4. 41</b>	Girders strengthened by fibre reinforced polymer	134
<b>Figure 4. 42</b>	Arrangement of sensors (LVDTs) at the center of each girder	136
<b>Figure 4. 43</b>	Arrangement and axle load of two trucks for center (top view)	136
<b>Figure 4. 44</b>	Arrangement and axle load of two truck for left lane	137
<b>Figure 4. 45</b>	Arrangement and axle load of two truck for right lane	137
<b>Figure 4. 46</b>	Arrangement and axle load of four truck for case ii static load testing	138
<b>Figure 4. 47</b>	Loaded trucks placed for static load testing	138
<b>Figure 5. 1</b>	Site view of bridge no 114	144
<b>Figure 5. 2</b>	Schematic diagram of bridge model	145

<b>Figure 5. 3:</b> Typical cross section of the bridge	145
<b>Figure 5. 4</b> Severe cracks observed in girder	146
<b>Figure 5. 5</b> Deterioration in bottom deck slab	147
<b>Figure 5. 6</b> Cracks and delamination at bearings	147
<b>Figure 5. 7</b> Loading plan of Indian locomotive Wagon 7 whel axle	148
<b>Figure 5. 8</b> Model of bridge deck slab with girders	149
<b>Figure 5. 9</b> Typical deformed shape of girder at frequency at time 1 second	149
<b>Figure 5. 10</b> Max deformation vs no of layer with varying length of girder	151
<b>Figure 5. 11</b> Max deformation vs length of girder with varying fibre layer	151
<b>Figure 5. 12</b> Maximum von misses strain vs span length for composite girder	152
<b>Figure 5. 13</b> Maximum von misses strain vs span length for carbon fibre	153
<b>Figure 5. 14</b> Maximum compressive stress vs fibre layers	154
<b>Figure 5. 15</b> Maximum compressive stress vs span length	154
<b>Figure 5. 16</b> Maximum vs fibre layers for varying girder	156
<b>Figure 5. 17</b> Maximum vs fibre layers for varying girder	156
<b>Figure 5. 18</b> Max Von Mises stress vs length of girder with varying fibre layer	157
<b>Figure 5. 19</b> Max Von Mises stress vs fibre layer with varying length of girder	158
<b>Figure 5. 20</b> Strain energy vs length of girder with varying fibre layer	159
<b>Figure 5. 21</b> length of girder vs strain Energy with varying fibre layer	159
<b>Figure 5. 22</b> Frequency vs no of fibre layers mode shape 1	161
<b>Figure 5. 23</b> Frequency vs span length in mode shape 1	161
<b>Figure 5. 24</b> Frequency vs span length in mode shape 2	162
<b>Figure 5. 25</b> Frequency vs span length in mode shape 2	163
<b>Figure 5. 26</b> Deformed imaged of girder in mode shape 3	163
<b>Figure 5. 27</b> Frequency vs span length in mode shape 2	164
<b>Figure 5. 28</b> Frequency vs span length mode shape 3	165
<b>Figure 5. 29</b> Deformed imaged of girder in mode shape 4	165
<b>Figure 5. 30</b> Frequency vs span length in mode shape 4	166
<b>Figure 5. 31</b> Frequency vs span length in mode shape 4	167
<b>Figure 5. 32</b> Deformed imaged of girder in mode shape 5	168
<b>Figure 5. 33</b> Frequency vs span length in mode shape 5	168
<b>Figure 5. 34</b> Frequency vs span length in mode shape 5	169
<b>Figure 5. 35</b> Section view of strengthening plan	170
<b>Figure 5. 36</b> Side view of strengthening plan of girder	171
<b>Figure 5. 37</b> strengthening using fibre at site of bridge no 114	171
<b>Figure 5. 38</b> Load applied on the bridge using wagon 7	171
<b>Figure 5. 39.</b> TIPO PM 25 5K MR	172

<b>Figure 5. 40</b>	B& K accelerometer	173
<b>Figure 5. 41</b>	Arrangement of deflection sensor and accelerometer	174
<b>Figure 5. 42</b>	Displacement vs Time under dynamic loading static load	175
<b>Figure 5. 43</b>	Displacement vs time under dynamic loading dynamic load	176
<b>Figure 5. 44</b>	Amplitude Vs frequency under dynamic loading	177
<b>Figure 5. 45</b>	Amplitude vs time for static load after strengthening	178
<b>Figure 5. 46</b>	Displacement vs time under dynamic loading	179
<b>Figure 5. 47</b>	Amplitude Vs frequency variation of girder of 114	179
<b>Figure 5. 48</b>	Reduction in deflection in different loading	182
<b>Figure 5. 49</b>	Change in natural frequency at different fibre layer	183
<b>Figure 5. 50</b>	View of bridge no 54 at site	184
<b>Figure 5. 51</b>	Cross section details of bridge no 54	185
<b>Figure 5. 52</b>	Severe cracks in girder	186
<b>Figure 5. 53</b>	Spalling in diaphragm and girder	186
<b>Figure 5. 54</b>	Section view of strengthening plan	187
<b>Figure 5. 55</b>	Side view of strengthening plan of girder	188
<b>Figure 5. 56</b>	Lamination of bridge no 54 at site	188
<b>Figure 5. 57</b>	Load applied on the bridge using wagon 7 and sensors at site	189
<b>Figure 5. 58</b>	Displacement vs time under static loading	190
<b>Figure 5. 59</b>	Displacement vs time under dynamic loading	190
<b>Figure 5. 60</b>	Amplitude vs. frequency under dynamic load	191
<b>Figure 5. 61</b>	Displacement vs time under dynamic loading	192
<b>Figure 5. 62</b>	Displacement vs time under static loading	192
<b>Figure 5. 63</b>	Displacement vs time under dynamic loading	193
<b>Figure 5. 64</b>	Degression in deflection at different fibre layer	195
<b>Figure 5. 65</b>	Increment in frequency at different fibre layer	196

## **List of Tables**

<b>Table 1. 1</b> Properties of Glass fibre Laminates	9
<b>Table 1. 2</b> Properties of Carbon Fibre Laminates	10
<b>Table 3. 1</b> Properties of carbon fibre laminates used	38
<b>Table 3. 2</b> Properties of glass fibre laminates used (S Glass)	39
<b>Table 3. 3</b> Loading details of Indian locomotive WAGON 7	79
<b>Table 4. 1</b> Deflection readings for static load for two truck	139
<b>Table 4. 2</b> Deflection readings for static load test for four truck	139
<b>Table 4. 3</b> Deflection readings for dynamic load test for two truck	140
<b>Table 5. 1</b> Details of girders and substructure of bridge	145
<b>Table 5. 2</b> Meshing details	147
<b>Table 5. 3</b> Major parameter of loading train (Source: RDSO)	148
<b>Table 5. 4</b> Pre-strengthening test results of Bridge no. 114	177
<b>Table 5. 5</b> Post strengthening result of bridge no 114	180
<b>Table 5. 6</b> Pre-strengthening test results of deflection and natural frequency	191
<b>Table 5. 7</b> Post strengthening test results	193