UNIVERSITI PUTRA MALAYSIA

STRUCTURAL BEHAVIOUR OF DISTRESSED AND STRENGTHENED POST-TENSIONED BOX GIRDER BEAMS

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STRUCTURAL BEHAVIOUR OF DISTRESSED AND STRENGTHENED POST-TENSIONED BOX GIRDER BEAMS

By

RACHAEL BUKOLA OHU

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

August 2007
DEDICATION

To God Almighty

And my Wonderful Family
STRUCTURAL BEHAVIOUR OF DISTRESSED AND STRENGTHENED POST-TENSIONED BOX GIRDER BEAMS

By

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August 2007

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Box girder prestressed concrete beams are used widely in bridge construction due to its efficient structural response under flexural as well as torsional loading. Prestressing can be either internally or externally applied to a beam. Every year, many prestressed concrete bridge girders are damaged due to accidental load and/or due to an aggressive environment surrounding the bridge. Corrosion and/or snapping of prestressing cables will cause serious damage in the bridge structure.

Many researchers have covered the strengthening of prestressed concrete girders under flexure or under shear. Very limited research is available on the significance of different strengthening techniques under combined shear–flexural loading. Furthermore, torsional load is another important aspect which needs to be considered when discussing the strengthening techniques effect.
This research covers the effect of snapping of externally prestressed cables on the structural behaviour of box girder bridge beams subjected to a combined flexural – shear – torsional load. Five full scale box-girder beams were cast and tested experimentally. The first beam specimen acted as a control beam while in the remaining four beam specimens, 15% of the prestressing cable area was snapped. After snapping, one specimen was tested till failure and the other three specimens are strengthened using different techniques and tested till failure. To restore the beam capacity, three different strengthening techniques were used under the same load combination. The techniques adopted for this research are externally bonded CFRP laminates, extra longitudinal prestress cables and vertical prestressing applied by using bolts and nuts system.

The results show that snapping of 15% of the prestressing cable will result in a 74% increase in deformation at service load and a 22% decrease in ultimate load. Furthermore, the snapping of the prestress wire will increase the stresses in the cables by 70% as compared to the unsnapped beam. All the strengthening techniques used can effectively restore the beam capacity at service and overcome the effect of cable snapping, however, at ultimate the restorative capacity of one of the strengthening techniques could not be fully established due to a localized failure.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

KELAKUAN STRUKTUR DAN TEKNIK PENGUKUHAN RASUK KOTAK PASCA TEGASAN BERMASALAH

Oleh

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Ogos 2007

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Galang rasuk kotak konkrit pra-tegasan digunakan secara meluas di dalam pembinaan jambatan disebabkan oleh respons strukturnya yang efisien di bawah kenaan beban lenturan dan juga beban kilasan. Pra-tegasan dapat dikenakan ke atas sesuatu rasuk sama ada secara dalaman atau luaran. Setiap tahun, terdapat banyak galang jambatan konkrit pra-tegsan yang rosak disebabkan oleh beban tambahan dan/atau suasana persekitaran jambatan yang agresif. Pengakisan dan/atau pemutusan kabel pra-tegasan akan mengakibatkan kerosakan yang serius bagi stuktur sesuatu jambatan.

Ramai penyelidik telah menjalankan penyelidikan yang merangkumi kaedah pengukuhan galang konkrit pra-tegasan di bawah kenaan lenturan atau di bawah kenaan ricih. Walaubagaimanapun, penyelidikan terhadap kepentingan pelbagai teknik pengukuhan di bawah kenaan beban gabungan ricih-lenturan adalah begitu terhad. Tambahan pula, beban kilasan merupakan satu lagi aspek penting yang perlu diberi pertimbangan apabila membincangkan tentang kesan teknik pengukuhan.

Hasil ujian menunjukkan bahawa pemutusan sebanyak 15% bagi kabel pra-tegasan akan mengakibatkan sebanyak 74% peningkatan di dalam ubah bentuk pada beban perkhidmatan dan 22% penurunan keupayaan pada beban muktamad. Tambahan pula, pemutusan dawai pra-tegasan akan meningkatkan tegasan di dalam kabel sebanyak 70% berbanding rasuk yang tidak mempunyai pemutusan. Teknik pengukuhan yang digunakan dapat mengembalikan kapasiti rasuk secara berkesan dan mengatasi kesan pemutusan kabel.
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I certify that an Examination Committee has met on 2nd August 2007 to conduct the final examination of Rachael Bukola Ohu on her Master of Science thesis entitled “Structural
Behaviour Of Distressed and Strengthened Post-tensioned Box Girder Beams” in accordance with Universiti Putra Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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Date: 15th November 2007

DECLARATION
I hereby declare that this thesis is based on my original work, except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or any other institution.

RACHAEL BUKOLA OHU

Date: 1st October 2007

TABLE OF CONTENTS
# DEDICATION

# ABSTRACT

# ACKNOWLEDGEMENTS

# APPROVAL

# DECLARATION

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATIONS/NOTATIONS

## CHAPTER

### 1 INTRODUCTION

1.1 Historical review of external prestressing

1.2 Significance of the Study

1.3 Statement of the Problem

1.4 Objectives of the study

1.5 Scope of the study

### 2 LITERATURE REVIEW

2.1 Introduction

2.2 Box beam Bridges

2.2.1 Structural action of a Box beam

2.2.2 Loading in beams

2.2.3 Interaction between bending, shear and torsion

2.2.4 Shear and Principal Stresses

2.2.5 Review of Combined actions on Box beams

2.3 Snapping of Prestress wires

2.3.1 Investigations on the effect of Corrosion

2.4 The Need for Strengthening

2.4.1 Deterioration and Rehabilitation

2.4.2 Selecting an Appropriate Method

2.4.3 Different Strengthening Techniques

2.5 External Prestressing

2.5.1 Review of External prestressing

2.6 Carbon Fibre Reinforced Polymer (CFRP)

2.6.1 Flexural Strengthening With CFRP

2.6.2 Shear Strengthening With CFRP

2.6.3 Torsional Strengthening with CFRP

2.7 Vertical Prestressing

2.8 Concluding Remarks

### 3 MATERIALS AND METHODS
<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Properties of CFRP</td>
</tr>
<tr>
<td>3.2</td>
<td>Properties of Sikadur 30 adhesive</td>
</tr>
<tr>
<td>3.3</td>
<td>Mechanical properties of bolts and nuts</td>
</tr>
<tr>
<td>4.1</td>
<td>Loss of prestress</td>
</tr>
<tr>
<td>4.2</td>
<td>Experimental cracking loads</td>
</tr>
<tr>
<td>4.3</td>
<td>Theoretical cracking loads</td>
</tr>
<tr>
<td>4.4</td>
<td>Experimental – Theoretical cracking loads</td>
</tr>
<tr>
<td>4.5</td>
<td>Experimental – Theoretical ultimate loads</td>
</tr>
</tbody>
</table>

**LIST OF FIGURES**

xiii
<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Typical view in Box Girder bridge with externally deflected tendons</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Some prestressing techniques</td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Injaka Bridge in South Africa (NCE 1998)</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Swanport bridge in Australia</td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>2.3</td>
</tr>
<tr>
<td>I – girder and box beam section</td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Eccentric load on a box beam</td>
<td></td>
</tr>
<tr>
<td>2.4</td>
<td>2.7</td>
</tr>
<tr>
<td>Shear stress in members due to torsion</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>2.8</td>
</tr>
<tr>
<td>Components of deformation due to eccentric loading</td>
<td></td>
</tr>
<tr>
<td>2.6</td>
<td>2.8</td>
</tr>
<tr>
<td>General case of loading on beam cross-section</td>
<td></td>
</tr>
<tr>
<td>2.7</td>
<td>2.10</td>
</tr>
<tr>
<td>Simulated behaviour of RC box section and equivalent flat slab</td>
<td></td>
</tr>
<tr>
<td>2.8</td>
<td>2.13</td>
</tr>
<tr>
<td>Distribution of corrosion damage related to prestress method</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>2.15</td>
</tr>
<tr>
<td>Labelling of unbroken wires of tendon with single broken outer wire</td>
<td></td>
</tr>
<tr>
<td>2.10</td>
<td>2.25</td>
</tr>
<tr>
<td>Test set-up and details</td>
<td></td>
</tr>
<tr>
<td>2.11</td>
<td>2.28</td>
</tr>
<tr>
<td>Typical crack pattern of specimens</td>
<td></td>
</tr>
<tr>
<td>2.12</td>
<td>2.30</td>
</tr>
<tr>
<td>Geometry of beam with mechanical blocking device of tendon at central support</td>
<td></td>
</tr>
<tr>
<td>2.13</td>
<td>2.30</td>
</tr>
<tr>
<td>Cross – section of box beam</td>
<td></td>
</tr>
<tr>
<td>2.14</td>
<td>2.36</td>
</tr>
<tr>
<td>Various repair schemes for damaged beams</td>
<td></td>
</tr>
<tr>
<td>2.15</td>
<td>2.42</td>
</tr>
<tr>
<td>Strengthening structures for shear with traditional methods</td>
<td></td>
</tr>
<tr>
<td>2.16</td>
<td>2.43</td>
</tr>
<tr>
<td>Typical cracking pattern of beams</td>
<td></td>
</tr>
<tr>
<td>2.17</td>
<td>2.47</td>
</tr>
<tr>
<td>Failure pattern of test beams</td>
<td></td>
</tr>
<tr>
<td>2.18</td>
<td>2.50</td>
</tr>
<tr>
<td>Typical cross-section of retroffited beam</td>
<td></td>
</tr>
<tr>
<td>Section</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>3.1</td>
<td>Cross-section of box beam</td>
</tr>
<tr>
<td>3.2</td>
<td>Beam layout and section details for reinforcement and prestress wires</td>
</tr>
<tr>
<td>3.3</td>
<td>Sika Carbodur XS514 cut into strips</td>
</tr>
<tr>
<td>3.4</td>
<td>Sikadur 30 Components A and B</td>
</tr>
<tr>
<td>3.5</td>
<td>Spreading Sikadur 30 on CFRP strip</td>
</tr>
<tr>
<td>3.6</td>
<td>Strain condition corresponding to CFRP rupture</td>
</tr>
<tr>
<td>3.7</td>
<td>CFRP wrap configuration for flexure and torsion strengthening</td>
</tr>
<tr>
<td>3.8</td>
<td>Vertical prestress with bolts and plates</td>
</tr>
<tr>
<td>3.9</td>
<td>Formwork for beams</td>
</tr>
<tr>
<td>3.10</td>
<td>Reinforcement cage with polystyrene box</td>
</tr>
<tr>
<td>3.11</td>
<td>Compressive cube test</td>
</tr>
<tr>
<td>3.12</td>
<td>Curing of beams after casting</td>
</tr>
<tr>
<td>3.13</td>
<td>Simultaneous stressing of both sides</td>
</tr>
<tr>
<td>3.14</td>
<td>Strain measurement during prestressing</td>
</tr>
<tr>
<td>3.15</td>
<td>Test setup</td>
</tr>
<tr>
<td>3.16</td>
<td>Beam Support rigidly fixed to strong floor</td>
</tr>
<tr>
<td>3.17</td>
<td>Beam fixed with top plates and bolts</td>
</tr>
<tr>
<td>3.18</td>
<td>Hydraulic cylinder</td>
</tr>
<tr>
<td>3.19</td>
<td>Point of snapping</td>
</tr>
<tr>
<td>3.20</td>
<td>Cutting with concrete grinder</td>
</tr>
<tr>
<td>3.21</td>
<td>Snapped wires</td>
</tr>
<tr>
<td>3.22</td>
<td>Roughening and cleaning</td>
</tr>
<tr>
<td>3.23</td>
<td>Bonding of CFRP strip to beam</td>
</tr>
</tbody>
</table>
3.24 CFRP in position at soffit
3.25 CFRP in position at sides
3.26 Beam with Extra longitudinal prestress wire
3.27 Beam after strengthening
3.28 Torque wench hand tool
4.1 Load – deflection curves for PB1 & PB2 at 275kN (service load)
4.2 Load – deflection curves for PB1 & PB2 at ultimate loads
4.3 Load – deflection curves of snapped & strengthened beam with CFRP
4.4 Load – deflection curves of snapped & strengthened beam with E.E.P
4.5 Load – deflection curves of snapped & strengthened beam with V.P
4.6 Load – deflection curves at ultimate loads
4.7 Deformation locations as taken on beams
4.8 Vertical deformations along beam span at load 165kN
4.9 Vertical deformations across beam width at 165kN
4.10 Lateral deformations between deviators at load 165kN
4.11 Vertical deformations along beam span for strengthened beams 404kN
4.12 Vertical deformations across beam width for strengthened beams 404kN
4.13 Lateral deformations between deviators at 404kN
4.14 Strain gauge locations for PB1
4.15 Load-∆fps curve for PB1 at unloaded side
4.16 Load-∆fps curve at PB1 at loaded side
4.17 Strain gauge locations for PB2
4.18 Load-∆fps curve for PB2 at unloaded side
4.19 Load-Δfps curve for PB2 at loaded side
4.20 Strain gauge locations for PB3
4.21 Load-Δfps curve for PB3 at unloaded side
4.22 Load-Δfps curve for PB3 at loaded side
4.23 Strain gauge locations for PB4
4.24 Load-Δfps curve for PB4 unloaded side
4.25 Load-Δfps curve for PB4 at loaded side
4.26 Strain gauge locations for PB5
4.27 Load-Δfps curve for PB5 at unloaded side
4.28 Load-Δfps curve for PB5 at loaded side
4.29 Load-Δfps curves for snapped beams at selected locations
4.30 Beam description
4.31 Cracking pattern PB1
4.32 Cracking pattern PB2
4.33 Cracking pattern PB3
4.34 Cracking pattern PB4
4.35 Cracking pattern PB5
4.36 Experimental ultimate loads for all beams
4.37 Theoretical – Experimental Ultimate loads
4.38 Crack pattern and mode of failure PB1
4.39 Crack pattern and mode of failure PB2
4.40 Crack pattern and mode of failure PB3
4.41 Crack pattern and mode of failure PB4
4.33 Cracking pattern PB3
4.44 Cracking pattern PB4
4.45 Cracking pattern PB5
4.46 Experimental ultimate loads for all beams
4.47 Theoretical – Experimental Ultimate loads
4.48 Crack pattern and mode of failure PB1
4.49 Crack pattern and mode of failure PB2
4.50 Crack pattern and mode of failure PB3
4.51 Crack pattern and mode of failure PB4
4.52 Crack pattern and mode of failure PB5
4.53 Experimental ultimate loads for all beams
4.54 Theoretical – Experimental Ultimate loads
4.55 Crack pattern and mode of failure PB1
4.56 Crack pattern and mode of failure PB2
4.57 Crack pattern and mode of failure PB3
4.58 Crack pattern and mode of failure PB4
4.59 Crack pattern and mode of failure PB5
4.60 Experimental ultimate loads for all beams
4.61 Theoretical – Experimental Ultimate loads
4.62 Crack pattern and mode of failure PB1
4.63 Crack pattern and mode of failure PB2
4.64 Crack pattern and mode of failure PB3
4.65 Crack pattern and mode of failure PB4
4.66 Crack pattern and mode of failure PB5
4.67 Experimental ultimate loads for all beams
4.68 Theoretical – Experimental Ultimate loads
4.69 Crack pattern and mode of failure PB1
4.70 Crack pattern and mode of failure PB2
4.71 Crack pattern and mode of failure PB3
4.72 Crack pattern and mode of failure PB4
4.73 Crack pattern and mode of failure PB5
4.74 Experimental ultimate loads for all beams
4.75 Theoretical – Experimental Ultimate loads
4.76 Crack pattern and mode of failure PB1
4.77 Crack pattern and mode of failure PB2
4.78 Crack pattern and mode of failure PB3
4.79 Crack pattern and mode of failure PB4
4.80 Crack pattern and mode of failure PB5
4.81 Experimental ultimate loads for all beams
4.82 Theoretical – Experimental Ultimate loads
4.83 Crack pattern and mode of failure PB1
4.84 Crack pattern and mode of failure PB2
4.85 Crack pattern and mode of failure PB3
4.86 Crack pattern and mode of failure PB4
4.87 Crack pattern and mode of failure PB5
4.88 Experimental ultimate loads for all beams
4.89 Theoretical – Experimental Ultimate loads
4.90 Crack pattern and mode of failure PB1
4.91 Crack pattern and mode of failure PB2
4.92 Crack pattern and mode of failure PB3
4.93 Crack pattern and mode of failure PB4
4.94 Crack pattern and mode of failure PB5
4.95 Experimental ultimate loads for all beams
4.96 Theoretical – Experimental Ultimate loads
4.97 Crack pattern and mode of failure PB1
4.98 Crack pattern and mode of failure PB2
4.99 Crack pattern and mode of failure PB3
5.00 Crack pattern and mode of failure PB4
5.01 Crack pattern and mode of failure PB5
5.02 Experimental ultimate loads for all beams
5.03 Theoretical – Experimental Ultimate loads
5.04 Crack pattern and mode of failure PB1
5.05 Crack pattern and mode of failure PB2
5.06 Crack pattern and mode of failure PB3
5.07 Crack pattern and mode of failure PB4
5.08 Crack pattern and mode of failure PB5
5.09 Experimental ultimate loads for all beams
5.10 Theoretical – Experimental Ultimate loads
5.11 Crack pattern and mode of failure PB1
5.12 Crack pattern and mode of failure PB2
5.13 Crack pattern and mode of failure PB3
5.14 Crack pattern and mode of failure PB4
5.15 Crack pattern and mode of failure PB5
5.16 Experimental ultimate loads for all beams
5.17 Theoretical – Experimental Ultimate loads
5.18 Crack pattern and mode of failure PB1
5.19 Crack pattern and mode of failure PB2
5.20 Crack pattern and mode of failure PB3
5.21 Crack pattern and mode of failure PB4
5.22 Crack pattern and mode of failure PB5
5.23 Experimental ultimate loads for all beams
5.24 Theoretical – Experimental Ultimate loads
5.25 Crack pattern and mode of failure PB1
5.26 Crack pattern and mode of failure PB2
5.27 Crack pattern and mode of failure PB3
5.28 Crack pattern and mode of failure PB4
5.29 Crack pattern and mode of failure PB5
5.30 Experimental ultimate loads for all beams
5.31 Theoretical – Experimental Ultimate loads
5.32 Crack pattern and mode of failure PB1
5.33 Crack pattern and mode of failure PB2
5.34 Crack pattern and mode of failure PB3
5.35 Crack pattern and mode of failure PB4
5.36 Crack pattern and mode of failure PB5
5.37 Experimental ultimate loads for all beams
5.38 Theoretical – Experimental Ultimate loads
5.39 Crack pattern and mode of failure PB1
5.40 Crack pattern and mode of failure PB2
5.41 Crack pattern and mode of failure PB3
5.42 Crack pattern and mode of failure PB4
5.43 Crack pattern and mode of failure PB5
5.44 Experimental ultimate loads for all beams
5.45 Theoretical – Experimental Ultimate loads
5.46 Crack pattern and mode of failure PB1
5.47 Crack pattern and mode of failure PB2
5.48 Crack pattern and mode of failure PB3
5.49 Crack pattern and mode of failure PB4
5.50 Crack pattern and mode of failure PB5
5.51 Experimental ultimate loads for all beams
5.52 Theoretical – Experimental Ultimate loads
5.53 Crack pattern and mode of failure PB1
5.54 Crack pattern and mode of failure PB2
5.55 Crack pattern and mode of failure PB3
5.56 Crack pattern and mode of failure PB4
5.57 Crack pattern and mode of failure PB5
5.58 Experimental ultimate loads for all beams
5.59 Theoretical – Experimental Ultimate loads
5.60 Crack pattern and mode of failure PB1
5.61 Crack pattern and mode of failure PB2
5.62 Crack pattern and mode of failure PB3
5.63 Crack pattern and mode of failure PB4
5.64 Crack pattern and mode of failure PB5
5.65 Experimental ultimate loads for all beams
5.66 Theoretical – Experimental Ultimate loads
5.67 Crack pattern and mode of failure PB1
5.68 Crack pattern and mode of failure PB2
5.69 Crack pattern and mode of failure PB3
5.70 Crack pattern and mode of failure PB4
5.71 Crack pattern and mode of failure PB5
5.72 Experimental ultimate loads for all beams
5.73 Theoretical – Experimental Ultimate loads
5.74 Crack pattern and mode of failure PB1
5.75 Crack pattern and mode of failure PB2
5.76 Crack pattern and mode of failure PB3
5.77 Crack pattern and mode of failure PB4
5.78 Crack pattern and mode of failure PB5
5.79 Experimental ultimate loads for all beams
5.80 Theoretical – Experimental Ultimate loads
5.81 Crack pattern and mode of failure PB1
5.82 Crack pattern and mode of failure PB2
5.83 Crack pattern and mode of failure PB3
5.84 Crack pattern and mode of failure PB4
5.85 Crack pattern and mode of failure PB5
5.86 Experimental ultimate loads for all beams
5.87 Theoretical – Experimental Ultimate loads
LIST OF ABBREVIATIONS/NOTATIONS
A or $A_c =$ cross sectional area

$A_{CFRP} =$ cross sectional area of CFRP strip

$A_{ps} =$ area of prestressing tendons

$A_s =$ area of tension reinforcement

$A_s' =$ area of steel in compression

$A_{st} =$ area of transverse steel in flange

$A_{sv} =$ cross sectional area of two legs of a link

$b =$ width or effective width of the section or flange in compression zone

$b_w =$ web width

$b_f =$ plate width

$d =$ effective depth to centroid of steel area $A_{ps}$ or nominal diameter of fastener

$d_{CFRP} =$ depth of CFRP

$d_a =$ depth to centroid of compression zone

$d_s' =$ depth of compression reinforcement

$d_{st} =$ depth of tension reinforcement

$\delta =$ deflection

$e =$ eccentricity

$\varepsilon_{cu} =$ strain at top of concrete fibre

$\varepsilon_{CFRP} =$ strain in CFRP

$E_c =$ modulus of elasticity of concrete

$E_{CFRP}$ or $E_{frd} =$ elastic modulus of CFRP or FRP

$E_s$ or $E_p =$ modulus of elasticity of steel

$f_{ci} =$ concrete strength at transfer
\( f_{cu} = \) concrete strength at service

\( f_{cp} = \) design compressive stress at centroidal axis due to prestress

\( f_{\text{CFRP}} = \) stress in CFRP

\( f_{etm} = \) tensile strength of concrete

\( f_{\text{max/min}} = \) principal tensile stress

\( f_{pb} = \) design tensile stress in tendons

\( f_{\text{pe}} = \) design effective prestress in tendons after all losses

\( f_{pu} = \) ultimate tensile stress of tendons

\( f_y \) or \( f_{yv} = \) characteristic strength of reinforcement

\( f_y' = \) characteristic strength for compression reinforcement

\( f_{yt} = \) characteristic strength for tension reinforcement

\( f_t = \) maximum design principal tensile stress

\( F_{\text{bst}} = \) design bursting tensile force

\( F_T = \) tensile force in bolt

\( h_{\text{max/min}} = \) larger or smaller dimension of rectangular section

\( I_{xx} = \) net moment of inertia

\( L \) or \( l = \) span of beam

\( L_{\text{max}} = \) maximum anchorage length

\( M_u = \) ultimate moment of resistance

\( \eta = \) percentage loss

\( P_i = \) initial prestressing force

\( P_{cr} = \) cracking load

\( P_T = \) tensile capacity
$P_{ult} = \text{ultimate load}$

$\rho_{bb} = \text{bearing strength of bolt}$

$\rho_{bs} = \text{bearing strength of connected parts}$

$S_{CFRP} = \text{CFRP spacing}$

$S_v = \text{spacing of links along the member}$

$ti = \text{wall thickness}$

$t_{CFRP} = \text{CFRP thickness}$

$T = \text{applied torque or torsion}$

$T_{CFRP} = \text{torsional strength}$

$T_{max} = \text{maximum force in CFRP bonded to concrete}$

$\tau_v = \text{torsional shear stress}$

$V_{co} = \text{design ultimate shear resistance of section uncracked in flexure}$

$V_{cr} = \text{design ultimate shear resistance of a section cracked in flexure}$

$v = \text{design shear stress}$

$v_{min} = \text{minimum torsional shear stress}$

$v_t = \text{torsional shear stress}$

$v_{tu} = \text{maximum combined shear stress (shear + torsion)}$

$\nu_c = \text{design concrete shear stress}$

$x = \text{depth of neutral axis}$

$y_{po} = \text{half side of loaded area}$

$y_o = \text{half the side of the end block}$

$Zt \text{ or } Zb = \text{top or bottom section modulus}$

$\sigma_b = \text{stress at bottom fibre}$
\( \sigma_t = \text{stress at top fibre} \)

\( \sigma_{ci} = \text{initial allowable compressive stress at transfer bottom fibre} \)

\( \sigma_{cs} = \text{allowable compressive stress at top fibre at service} \)

\( \sigma_{ti} = \text{initial allowable tensile stress at transfer in top fibre} \)

\( \sigma_{ts} = \text{allowable tensile stress in bottom fibre at service} \)
CHAPTER 1

INTRODUCTION

1.1 Historical Review of External Prestressing

In 1934, in France, Eugene Freysinnet repaired the Le Havre Station by using stressing wires and went on to develop the art of prestressed concrete to a high level.Franz Dischinger built the first externally prestressed concrete bridge from 1935 – 1937 in Aue, Germany. Steel with tensile strength of 500N/mm² was used at the time but due to the low tensile steel, considerable losses in the prestress force occurred and the bridge had to be re-stressed twice in 1962 and in 1980 (Virlogeux, 1989) and (Tandler, 2001) and was finally demolished in 1994 (Landschaftverband Westfalen-Lippe, 2001). Since then, several other bridges have been prestressed using this technique because of its’ increased durability effect on concrete which has made it popular.

External prestressing is a special technique of the post-tensioning method of prestressing, where prestress force is applied to the concrete after it has hardened. The external tendons are placed outside the section to be stressed and the forces are only transferred at the anchorage blocks or at the deviators as shown in Figure 1.1.
In general, there are mainly two post-tensioning techniques available; internal prestressing and external prestressing. Although internal prestressing is similar to external prestressing, the difference between them lies in the position of the tendon layout. Internal prestressing involves the laying of tendons within the cross-section while in external prestressing, the tendons are laid outside the cross-section of the structure. Figure 1.2 shows some of the post-tensioning techniques available.