



**UNIVERSITI PUTRA MALAYSIA**

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

**RACHAEL BUKOLA OHU**

**FK 2007 51**

**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*



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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POST-TENSIONED BOX GIRDER BEAMS**

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**RACHAEL BUKOLA OHU**

**August 2007**

**Chairman : Waleed Thanoon, PhD**

**Faculty : Engineering**

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 kenaaan 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-tegasan 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 kenaaan lenturan atau di bawah kenaaan ricih. Walaubagaimanapun, penyelidikan terhadap kepentingan pelbagai teknik pengukuhan di bawah kenaaan 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.



Kajian ini merangkumi kesan pemutusan kabel pra-tegasan luaran terhadap tindakan struktur rasuk jambatan kotak galang yang tertakluk kepada beban gabungan lenturan-ricih-kilasan. Lima rasuk kotak galang berskala penuh telah disediakan mengikut acuan dan diuji di makmal. Spesimen rasuk yang pertama bertindak sebagai rasuk kawalan, sementara bagi empat rasuk lain, 15% daripada keluasan kabel pra-tegasan telah di putuskan. Selepas pemutusan berlaku, satu spesimen telah diuji sehingga gagal dan tiga spesimen lagi telah diperkukuhkan menggunakan pelbagai teknik pengukuhan dan seterusnya diuji sehingga gagal. Untuk mengembalikan kapasiti rasuk, tiga teknik pengukuhan yang berbeza telah digunakan di bawah kombinasi bebanan yang sama. Teknik yang diambil di dalam kajian ini adalah dengan menggunakan lapisan CFRP yang diikat secara luaran, kabel pra-tegasan dengan pemanjangan tambahan dan kenaan pra-tegasan secara menegak dengan menggunakan sistem bolt dan nat.

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.

## ACKNOWLEDGEMENTS

First and foremost I give thanks to God Almighty through which all things are possible.

Secondly, deep and sincere thanks go to my supervisors, Prof. Dr. Waleed Thanoon, Assoc. Prof. Dr. Mohd. Saleh Jaafar and Assoc. Prof. Dr. Jamaloddin Noorzaei, for their advice, suggestions and guidance that enabled me to complete this work.

In addition, my gratitude goes to En Halim Othman, Fazely and Salahudeen, the technical staff of the concrete and structural laboratory, for their assistance during the preparation and testing stage of this work.

Deep thanks go to my friends and colleagues too numerous to mention here, some of which are Mr Masoud, Seyed Jamal Hakim, Ali Naghshineh for their help in many ways and to Dr. Abdulkarim and his family for being there to listen and encourage me.

Finally, I give my heartfelt, special and loving thanks to my father Prof. J.O Ohu, my mother Mrs F.B Ohu, my siblings Daniel, David and Sarah and to my loving husband Theophilus Babatunde Medeiros, for their prayers, financial and moral support and encouragement that saw me through this study.

I certify that an Examination Committee has met on 2<sup>nd</sup> 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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**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: 1<sup>st</sup> October 2007

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4.42 Crack pattern and mode of failure PB5

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## **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

$d_h$  = depth to centroid of compression zone

$d_s'$  = depth of compression reinforcement

$d_{st}$  = depth of tension reinforcement

$\delta$  = deflection

$e$  = eccentricity

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

$\epsilon_{CFRP}$  = strain in CFRP

$E_c$  = modulus of elasticity of concrete

$E_{CFRP}$  or  $E_{fd}$  = 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

$f_{CFRP}$  = stress in CFRP

$f_{ctm}$  = tensile strength of concrete

$f_{max/min}$  = principal tensile stress

$f_{pb}$  = design tensile stress in tendons

$f_{pe}$  = 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

$F_{bst}$  = design bursting tensile force

$F_T$  = tensile force in bolt

$h_{max/min}$  = larger or smaller dimension of rectangular section

$I_{xx}$  = net moment of inertia

$L$  or  $l$  = span of beam

$L_{max}$  = 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

$P_{ult}$  = ultimate load

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

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

$S_{CFRP}$  = CFRP spacing

$S_v$  = spacing of links along the member

$t_i$  = wall thickness

$t_{CFRP}$  = CFRP thickness

$T$  = applied torque or torsion

$T_{CFRP}$  = torsional strength

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

$\tau_v$  = torsional shear stress

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

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

$v$  = design shear stress

$v_{tmin}$  = minimum torsional shear stress

$v_t$  = torsional shear stress

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

$v_c$  = design concrete shear stress

$x$  = depth of neutral axis

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

$y_o$  = half the side of the end block

$Z_t$  or  $Z_b$  = top or bottom section modulus

$\sigma_b$  = stress at bottom fibre

$\sigma_t$  = stress at top fibre

$\sigma_{ci}$  = initial allowable compressive stress at transfer bottom fibre

$\sigma_{cs}$  = allowable compressive stress at top fibre at service

$\sigma_{ti}$  = initial allowable tensile stress at transfer in top fibre

$\sigma_{ts}$  = allowable tensile stress in bottom fibre at service

# CHAPTER 1

## INTRODUCTION

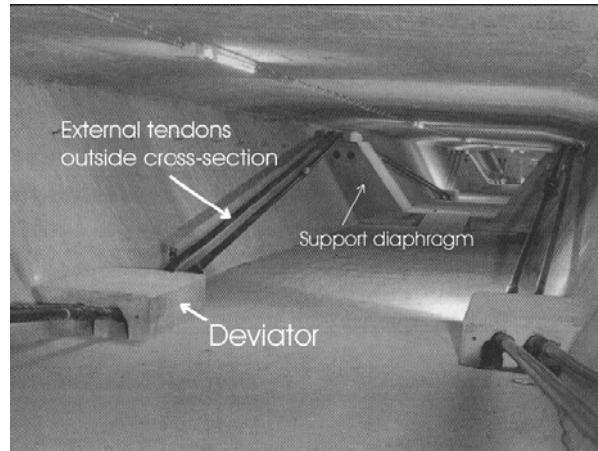
### 1.1 Historical Review of External Prestressing

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  $500\text{N/mm}^2$  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.

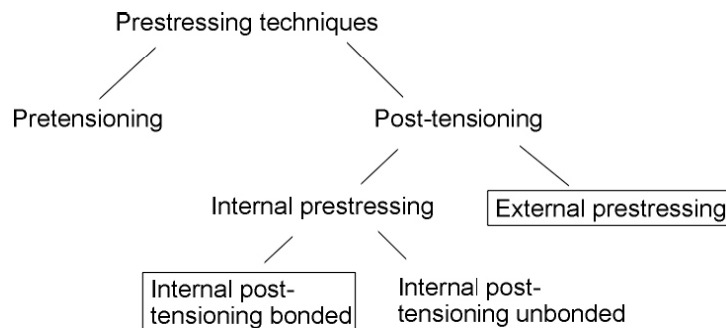






**Figure 1.1: Typical view in box Girder Bridge with externally deflected tendons (Tandler, 2001)**

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.



**Figure 1.2 Some prestressing techniques (Tandler, 2001)**