



UNIVERSITI PUTRA MALAYSIA

**STRUCTURAL BEHAVIOUR OF PRESTRESSED CONCRETE
HOLLOW BEAMS**

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STRUCTURAL BEHAVIOUR OF PRESTRESSED CONCRETE HOLLOW BEAMS

By

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS	ii
LIST OF TABLES	vii
LIST OF FIGURES	viii
LIST OF PLATES	x
LIST OF NOTATIONS	xi
ABSTRACT	xiv
ABSTRAK	xvi
CHAPTER	
1. INTRODUCTION	
Prestressed Concrete	1
General Principle of Prestressed Concrete	2
Advantages of Prestressed Concrete Hollow Beams .	4
Scope and Objective	5
2. LITERATURE REVIEW	
Selection of the Best Shapes for Prestressed Concrete Under Flexure	7
Prestressed Concrete Hollow Beams	9
Design of Prestressed Concrete Hollow Beams ...	11
Arrangement of Steel of Prestressed Hollow Beams .	12
Summary of Literature Survey	14



3.	THEORETICAL CONSIDERATION	
	Beam Subjected to Third Point Loading	15
	Prediction of Cracking Load and Bending Moment	16
	Prediction of Ultimate Load and Bending Moment .	17
	Location of Neutral Axis	18
	Ultimate Moment Carrying Capacity	23
	Ultimate Load	24
	Prediction of Service Load	24
	Calculation of Deflection	25
4.	MATERIALS	
	Concrete	27
	Cement, Sand and Aggregates	27
	Prestressing Wires	29
	Stirrup Reinforcement	29
	Plastic Tubing, Grease etc.	30
5.	TEST PROGRAMME	
	Beam Specimen Preparation	32
	The Beam Mould	32
	Casting and Curing of Concrete	33
	Test Cubes	34
	Removal of Rectangular Hollow Section and Plastic Tubing	35
	Prestressing	36
	Grouting	37



The Test	36
Testing Machine	36
Setting of the Beam	37
Beam Testing	37
Testing the Cubes	38
Details of Beam Tested	39

6. RESULTS AND DISCUSSIONS OF BEAM TESTS

Beam Test Results	46
Beam S01	46
Beam U01	47
Beam U02	48
Beam U#1	50
Beam U#2	51
Beam U#3	52
Beam U001	54
Beam U002	55
Beam B01	56
Beam B02	57
Discussion	58
Ultimate Load	59
Cracking Load	63
Crack Width and Crack Propagation	64
Strain Gauge Results	65
Service Load	66



Deflection	67
7. CONCLUSIONS AND RECOMMENDATIONS	
Conclusions	97
Ultimate load	97
Cracking	98
Deflection	99
Recommendations for Further Research	100
BIBLIOGRAPHY	111
APPENDIX A	113
APPENDIX B	117
APPENDIX C	149
APPENDIX D	161
CURRICULUM VITAE	172



LIST OF TABLES

	PAGE
1. Properties of Concrete Beam Specimens	31
2. Details of Beams Tested	43
3. Experimental Against Calculated Ultimate Load	70
4. Experimental Against Calculated Cracking Load	71
5. Ultimate Strength of Prestressed Hollow Beams compared to Solid Beam Under Identical Circumstances	72
6. Calculation of Deflection at Service Load	73
7. Experimental Against Theoretical Maximum deflection at Service Load	74
8. Experimental Against Theoretical Maximum Deflection at Actual Cracking Load	75
9. Experimental Against Calculated Cracking Load and Ultimate Load for Unbonded Beams With Variable Weight Reduction	76
10. Experimental Against Calculated Cracking Load and Ultimate Load for Bonded Beam With Variable Weight Reduction	76



LIST OF FIGURES

	PAGE
1. Prestressed Concrete	3
2. Beam Subjected to Third Point Loading	15
3. Stress-strain Relationship at Ultimate (Neutral axis within the flange)	19
4. Stress-strain Diagram for Prestressing Steel	21
5. Stress-strain Relationship at Ultimate (Neutral axis within the web)	22
6. Grading Curve for Coarse, Fine and Combined Aggregate Mc Intosh and Entroy Type Grading	28
7. Details of Beam Tested	44
8. Load Against Deflection Beams U01,U02,S01	77
9. Load Against Deflection Beams U#1,U#2,U#3	78
10. Load Against Deflection Beams U001,U002	79
11. Load Against Deflection Beams U01,U#1,U001	80
12. Load Against Deflection Beams U02,U#2,U002	81
13. Load Against Deflection Beams B01,B02	82
14. Load Against Max. Crack Width Beams U01,U02,S01 ...	83
15. Load Against Max. Crack Width Beams U#1,U#2,U#3 ...	84
16. Load Against Max. Crack Width Beams U001,U002	85
17. Load Against Max. Crack Width Beams B01,B02,S01 ...	86
18. Beam Depth Against Strain, Beam U01	87
19. Beam Depth Against Starin, Beam U02	88
20. Beam Depth Against Strain, Beam U#1	89
21. Beam Depth Against Strain, Beam U#2	90



	PAGE
22. Beam Depth Against Strain, Beam U#3	91
23. Beam Depth Against Strain, Beam U001	92
24. Beam Depth Against Strain, Beam U002	93
25. Beam Depth Against Strain, Beam B01	94
26. Beam Depth Against Strain, Beam B01	95
27. Beam Depth Against Strain, Beam S02	96
28. Beam Details U01	127
29. Beam Details U#1	137
30. Beam Details B01	148



LIST OF PLATES

	PAGE
1. The Casting Mould	101
2. Casting of Beam	102
3. Beam Ready for Stressing	102
4. Crack Measuring Microscope and Demec Gauge	103
5. Grouting Pump	104
6. Prestressing in Progress	104
7. The Beam Testing Frame and Test Set up	105
8. Cracking Pattern of Beam U01	105
9. Cracking Pattern of Beam U02	106
10. Cracking Pattern of Beam U#1	106
11. Cracking Pattern of Beam U#2	107
12. Cracking Pattern of Beam U#3	107
13. Cracking pattern of Beam U001	108
14. Cracking Pattern of Beam U002	108
15. Cracking Pattern of Beam B01	109
16. Cracking Pattern of Beam B02	109
17. Cracking Pattern of Beam S01	110



LIST OF NOTATIONS

a	Distance from top flange to centre of top steel
A	Area of cross-section
A_p	Area of prestressing
A_{ps}	Area of prestressing steel in the tension zone
A_{sv}	Cross-sectional area of the two legs of a links
b	Width or effective width of the section or flange in the compression zone
b_f	Width of flange
b_w	Width of web
C	Total compression force
C_1	Compressive force in concrete block (flange)
C_2	Compressive force in concrete block (web)
C_s	Compressive force of top prestressing steel
d	Effective width to the centroid of steel area
e	Eccentricity of prestressing force
E_c	Young's modulus of elasticity of concrete
E_p	Young's modulus of elasticity for prestressing steel
f_1	Overall flexural tensile stress in concrete
f_{cu}	Characteristic strength of concrete
f_{cp}	Design compressive stress at the centroidal axis due to prestress
f_{pb}	Design tensile stress in the tendon
f_{pu}	Characteristic strength of prestressing wires



f_t	Maximum design principle tensile stress
h	Depth of cross-section
h_f	Depth of top flange
I	Second moment of area of the section
L	Effective span
M_{cr}	Cracking moment
M_D	Self weight moment
M_G	Girder moment
M_o	Moment necessary to produce zero stress in the concrete at the extreme fibre
M_T	Total moment
M_u	Ultimate moment
P_{cr}	Cracking load
P_e	Effective prestressing force
P_i	Initial prestressing force
S_v	Spacing of the links
T	Tensile force
V_c	Design ultimate shear resistance of the concrete
V_{cr}	Design ultimate shear resistance of a section cracked in flexure
V_{co}	Design ultimate shear resistance of a section uncracked in flexure
x	Location of neutral axis from top flange
Z_1	Lever arm to C1
Z_2	Lever arm to C2
Z_3	Lever arm to stop steel
Z_B	First moment of area (below neutral axis)

Z_T	First moment of area (above neutral axis)
ϵ_c	Strain in compression steel
ϵ_s	Strain of top steel due to bending
ϵ_t	Total strain
Δ_1	Deflection at mid span of the beam due to two point loading
Δ_2	Deflection due to self weight U.D.L at mid span
Δ_3	Deflection due to effective prestress (bottom steel)
Δ_4	Deflection due to effective prestress (top steel)
Δ	Total deflection



An abstract of the thesis presented to the Senate of Universiti Pertanian Malaysia in partial fulfilment of the requirements for the degree of Master of Science.

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APRIL 1993

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This thesis is concerned with the primary objective of studying the structural behaviour of prestressed concrete hollow beams. Ten simply supported rectangular hollow beams and one rectangular solid beam were tested on an effective span of 2.80 m subjected to two third point loadings. The variables in the study were the percentage of self weight reduced and the amount of prestressing wires. Eight beams were tested unbonded while the other two beams were fully bonded.



Ultimate loads, cracking loads, crack widths and deflections were recorded at various loadings and crack propagations were observed. The results obtained were compared with theoretical values.

It was observed that due to the absence of material in the hollow portion, compared to a solid beam with similar outside dimensions, the ultimate moment carrying capacity of prestressed hollow beam is reduced if neutral axis of the beam at failure is located below the top flange. However, if the neutral axis of the beams at failure is located within the top flange, then the ultimate moment carrying capacity is at least equivalent to that of a solid beam. It was also observed that the theory on the ultimate moment carrying capacity presented in this thesis gives a fairly good prediction. However, the theory used to predict cracking load as well as deflection was found not suitable for unbonded beams as it greatly underestimates the deflection and overestimates the cracking load. It was also observed that bonding has a great influence on crack widths and deflections. Bonded beams show more uniform crack distribution with reduced maximum crack width and increased ultimate load capacity. From test results, it is recommended that prestressed hollow beams should be made bonded in order to achieve at least the predicted cracking load.



Sebuah abstrak tesis yang dikemukakan kepada Senat Universiti Pertanian Malaysia bagi memenuhi sebahagian daripada kelayakan Ijazah Master Sains.

KELAKUAN STRUKTUR RASUK KONKRIT PRA-TEGASAN BERONGGA

OLEH

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Tesis ini bertujuan menjalankan kajian mengenai kelakuan rasuk-rasuk konkrit pra-tegasan berongga. Sepuluh buah rasuk berongga dan sebuah rasuk padu tersokong secara mudah diuji di atas jarak berkesan 2.80m dengan dua beban titik ketiga. Pemboleh ubah terdiri dari peratus pengurangan beban diri serta jumlah dawai pra-tegasan. Kesan ikatan telah juga dikaji. Lapan buah rasuk telah diuji tanpa ikatan sementara dua buah lagi terikat penuh melalui turapan tekanan.



Beban muktamad, beban retak, lebar retak dan lenturan direkodkan pada tahap beban berlainan dan pembentukan retak diperhatikan. Keputusan yang diperolehi dibandingkan dengan nilai-nilai teori.

Adalah diperhatikan, dengan kehadiran ruang berongga, jika dibandingkan dengan rasuk padu yang mempunyai saiz keratan rentas yang serupa, kemampuan menanggung beban muktamad bagi rasuk berongga akan berkurangan jika paksi neutral pada keadaan muktamad terletak di bawah bebibir atas. Walaubagaimanapun, jika paksi neutral terletak di bebibir atas, kemampuan menanggung beban muktamad bagi rasuk berongga sekurang-kurangnya akan sama dengan kemampuan menanggung beban muktamad bagi rasuk padu. Dapat juga diperhatikan teori beban muktamad yang digunakan dalam tesis ini memberikan satu ramalan yang agak baik. Namun begitu teori-teori yang digunakan bagi meramal beban retak begitu juga lenturan bagi rasuk tidak terikat didapati tidak sesuai memandangkan ramalan yang diberikan adalah jauh dari yang sebenarnya. Adalah diperhatikan juga, ikatan memberi kesan ke atas lebar retak dan lenturan. Rasuk yang terikat mampu mengagihkan retak dengan lebih berkesan seterusnya dapat mengurangkan lebar retak dan meningkatkan beban muktamad. Berdasarkan keputusan ujian, adalah disyorkan supaya rasuk-rasuk berongga dibuat secara terikat untuk mencapai sekurang-kurangnya setakat ketahap beban retak yang diramalkan.



CHAPTER 1

INTRODUCTION

Prestressed Concrete

Prestressed concrete is a very important construction material and its use will continue to grow in the next century. In 1939 Freyssinet introduced an economical way of producing prestressed concrete. Since then, more and more research was done for developing a better understanding of prestressed concrete.

As mentioned by Bate and Bennett (1980), prestressing can be defined as a technique whereby the performance of a structure is improved by the introduction of permanent stress (prestress) so as to cancel some of the stress produced by the dead and imposed load. Mosley and Bungey (1987) defines prestressing as the artificial creation of stresses in a structure before loading, so that the stresses which then exist under load are more favourable than would otherwise be the case.

The principle of prestressing when applied to concrete will result in what we called prestressed concrete. Perhaps one of the best definitions of prestressed concrete is given by



the ACI Committee on prestressed concrete. This definition is :
"Prestressed concrete : concrete in which there have been introduced internal stresses of which magnitude and distribution that the stresses resulting from given external loading are counteracted to a desired degree".

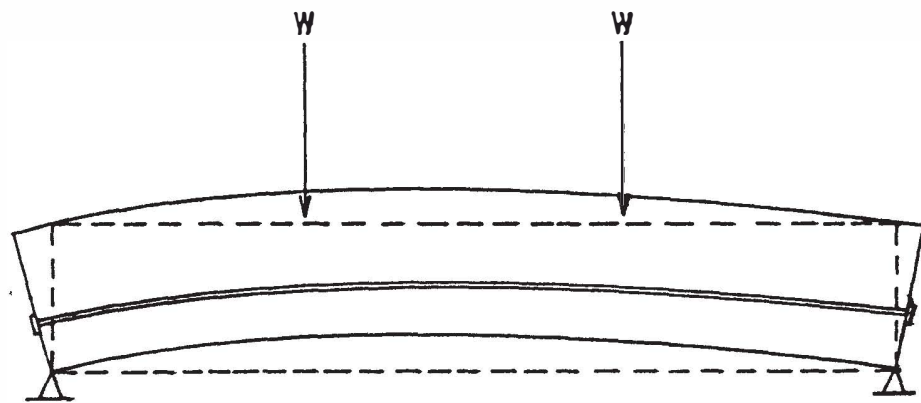
British Standard BS 8110 Part 1: 1985, Clause 4.1.3 classifies prestressed concrete structures into three categories which are as follow:

- a. Class 1 : no flexural tensile stress
- b. Class 2 : flexural tensile stress but no visible cracking
- c. Class 3 : flexural tensile stresses but surface width of cracks not exceeding 0.1mm for members in very severe environments and not exceeding 0.2mm for all other members.

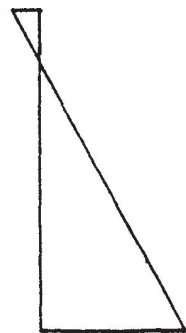
General Principle of Prestressed Concrete

The basic concept of prestressed concrete is illustrated in Figure 1. A very high strength steel tendon has been placed in the duct. After concrete has achieved required strength, the tendon will be stressed prior to external loading. Resulting from the prestressing of tendon (Figure 1.a), the stress in the beam varies from a maximum compression in the bottom fibre to a small tension in the top fibre and causes the beam to deflect upward. When external loads are applied, the stress distribution will be as shown in Figure 1(b). Combined with the stress due to prestress produce a state of stress as in Figure

1(c), where maximum compression or a small tension in the bottom fibre.



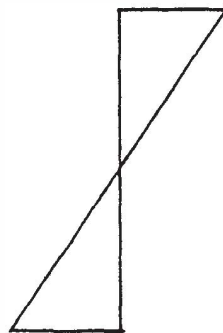
COMPRESSION



COMPRESSION

(a)

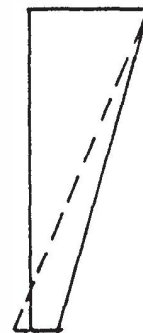
STRESS DUE TO
PRESTRESS



TENSION

(b)

STRESS DUE TO
MOMENT



(c)

COMBINED STRESSES

Figure.1- General Principle of Prestressed Concrete.

Advantages of Prestressed Concrete Hollow Beams

The advantages of considering prestressed concrete hollow beams in concrete design are :

- i) The reduced weight of the member will help in economizing the section; the smaller dead load and depth of members will result in saving materials from other sections of structure, e.g foundation. In precast members, a reduction of weight saves handling and transportation costs.
- ii) Excellent torsional strength, and rigidity combine with good flexural strength as prestressed hollow beams are closed section.
- iii) Low maintenance cost mainly due to its durability. Fatigue test on hollow beams indicate that million of cycles of load applications in excess of design load does not result in any sign of distress (Bender and Kriesel, 1969).

It is also known that when the ratio of dead to live load is large, the use of structural hollow section become significant since the saving in weight is substantial. For prestressed hollow beams the amount of weight that can be reduced depending on width/wall thickness ratio and percentage of weight reduction. It has been known that works on the effect of width/wall thickness ratio on the behaviour of prestressed

beams are fully prestressed where two of them will be grouted with cement grout to make it bonded. Deflection and crack width will be measured at various load levels. Results will be compared with the predicted values. Some conclusions will be drawn, as to what extent the reduction in weight is feasible so far as the increase of deflection and cracking is concerned.

CHAPTER 2

LITERATURE REVIEW

Parr and Maggard (1972) mentions that a survey of bridges built or proposed in the last few years in the United States reveals a growing awareness of at least two items :-

- i) The utilization of materials and cross-section which may be more efficient and economical than those used in the past.
- ii) a more serious consideration of aesthetic requirements.

For that reason the use of thin webbed or hollow structural sections has increased significantly throughout the last decade.

Selection of the Best Shapes for Prestressed Concrete Under Flexure

The simplest form of shape is rectangular and is the most economical as far as formwork is concerned. Lin and Burns (1982) explains that rectangular section has small kern distance and the available lever arm for steel is limited. Rectangular section is not as efficient in the use of concrete as nonrectangular section such as the J-shaped section. Hence



other shapes which are frequently used for prestressed concrete are :

- i) The symmetrical and unsymmetrical I-section
- ii) The T-section
- iii) The inverted T-section
- iv) Box section.

Lin and Burns (1982) added that the suitability of the above shapes depend on certain requirements. The I-section has its concrete concentrated near the extreme fibre so that it can most effectively furnish the compression force. The more the concrete is concentrated near the extreme fibre, the greater will be the lever arm furnished for the internal resisting couple. If the ratio of moment due to self weight to total moment M_G / M_T is sufficiently large, there is little danger of overstressing the flanges at transfer, and concrete in the bottom flange can be accordingly diminished. It may not be economically used, however where M_G / M_T ratio is small, because the center of pressure at transfer may lie below the bottom kern point. Then tensile stress may result in the top flange and high compressive stresses in the bottom flange.

The box section has the same properties as the I-section in resisting moment. For economy in steel and concrete it is best to put the concrete near the extreme fibres of the