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STRUCTURAL BEHAVIOUR OF PRESTRESSED CONCRETE HOLLOW BEAMS

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By

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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
Mo	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

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Chairman : Dr. S.A. Salam (December 1988 - July 1992)

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Faculty : Engineering

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 nutral pada keadaan muktamad terletak di bawah bebibir atas. Walaubagaimanapun, jika paksi nutral terletak di bebibir atas, kemampuan menanggung beban muktamat 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 ilustrated 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.

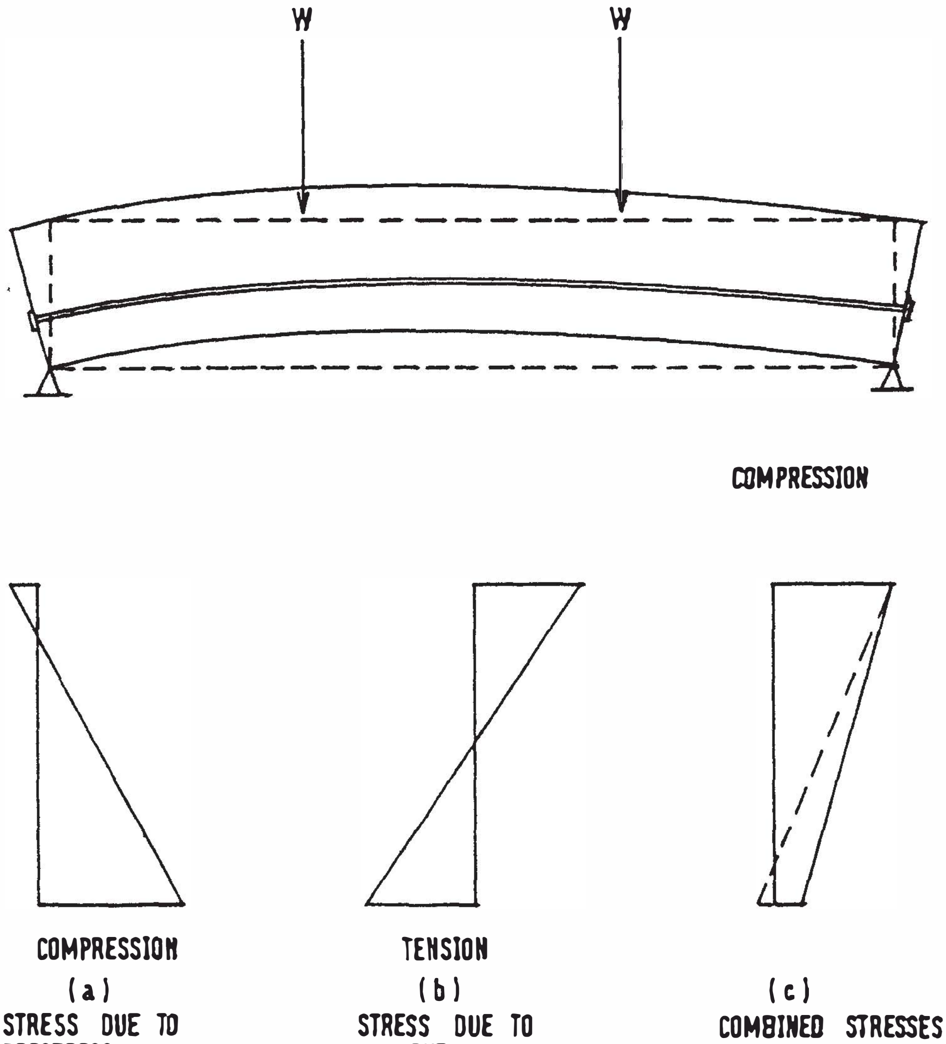

Figure.1 – General Principle of Prestressed Concrete.

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 I-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