UNIVERSITI PUTRA MALAYSIA

SERVICE LIMIT CRITERIA FOR DEFLECTION AND CRACKING IN PARTIALLY PRESTRESSED BEAMS

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MASTER OF SCIENCE
(STRUCTURAL ENGINEERING)

UNIVERSITI PERTANIAN MALAYSIA

1985

SERVICE LIMIT CRITERIA FOR DEFLECTION AND CRACKING IN PARTIALLY PRESTRESSED BEAMS

By

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A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Structural Engineering.

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1985

An abstract of the thesis presented to the senate of University Pertanian Malaysia in partial fulfilment of the requirements for the Degree of Master of Science.

SERVICE LIMIT CRITERIA FOR DEFLECTION AND CRACKING IN PARTIALLY PRESTRESSED BEAMS.

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ABSTRACT

This thesis has been concerned with the primary objective of studying the serviceability behavior of partially prestressed concrete beams. Seven simply supported rectangular beams were tested on an effective span of 2.745 m subjected to two third point loadings. The variables were the amount of prestressing wires and ordinary reinforcement steel. The effect of bond was also investigated. Four beams were fully bonded by using pressurised grouting while three other beams were tested unbonded.

Crack widths and deflections were recorded at various loadings and crack propagations observed. The results obtained were compared

with theoretical values proposed by various authors. Results were also compared with the service limit criteria for cracking and deflection according to the British Standards code of practice, CP 110 : 1972.

It was observed that the service limit criteria for cracking and deflection as set out by the code are too conservative for rectangular beams tested. It was found that the existing theory greatly underestimates the ultimate as well as service load carrying capacity and overestimates crack widths of partially prestressed concrete beams. It was also found that the nature of bonding has a great influence on crack widths and deflections. Bonded beams greatly improve on serviceability by having increased load carrying capacity and reduced crack width.

Translation in Bahasa Malaysia

Sebuah abstrak tesis yang disampaikan kepada Senat Universiti Pertanian Malaysia bagi memenuhi secara separa keperluan bagi Ijazah Master Sains.

KRITERIA HAD KHIDMAD BAGI PESONGAN DAN KERETAKAN RASUK-RASUK PRATEGASAN SEPARA

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ABSTRAK

Tesis ini bertujuan menjalankan kajian mengenai kelakuan kebolehkhidmatan rasuk-rasuk konkrit prategasan separa. Tujuh buah rasuk berkeratan segi empat tepat tersokong secara mudah diuji di atas jarak berkesan 2.745m dengan dua bebanan titik ketiga. Pembolehubah terdiri dari jumlah dawai prategasan dan keluli tetulang biasa. Kesan ikatan telah juga dikajikan. Empat buah rasuk yang digunakan terikat penuh melalui turapan tekanan dan tiga buah rasuk yang lain telah diuji tanpa ikatan.

Kelebaran retak dan pesongan telah direkodkan pada beberapa bebanan dan perombatan retak telah diperhatikan. Hasil kajian yang diperolehi dibandingkan dengan nilai-nilai teori

yang telah dicadangkan oleh beberapa penyelidik. Hasil kajian tersebut telah juga dibandingkan dengan kriteria had keboleh-khidmatan untuk keretakan dan pesongan mengikut Kanun Amalan Piawaian British CP110:1972.

Adalah diperhatikan bahawa kriteria had kebolehkhidmatan untuk keretakan dan pesongan sebagaimana yang ditetapkan oleh kanun tersebut, rasuk keratan segi empat tepat yang diujikan terlalu konservatif. Telah didapati bahawa teori yang sedia ada memberi anggaran rendah terhadap keupayaan membawa beban muktamad dan khidmat dan memberi anggaran tinggi terhadap kelebaran retak bagi rasuk konkrit prategasan separa. Telah juga didapati keadaan ikatan mempunyai pengaruh yang mendalam ke atas kelebaran retak dan pesongan. Rasuk terikat mempunyai kebolehkhidmatan yang lebih baik dengan keupayaan membawa beban yang lebih dan lebar tetak yang berkurangan.

ACKNOWLEDGEMENT

The author wishes to express his profound gratitude and thanks to his supervisors, Ir. Abang Abdullah Abang Ali, Associate Professor and Dean, Dr. S.A. Salam, Associate Professor of Civil Engineering and Ir. Syed Mansur Syed Junid, Head of the Dept. of Civil and Environmental Engineering, of the Faculty of Engineering, Universiti Pertanian Malaysia, for their continued guidance, encouragement and help to make this study a success.

The author also wishes to extend his thanks to Mr. Halim, Mr. Ghazali and Mr. Quddus, technicians, Structures Lab. for their help in laboratory testing.

Thanks are due to Khatijah for a neat typing of the manuscript. Thanks are also to Universiti Malaya for granting permission to use their library and media facilities.

Last but not the least, my sincere gratitude is due to the Mara Institute of Technology, Shah Alam, for the kind permission to undertake the above study and research.

C O N T E N T S

LIST OF NOTATIONS

A	Area of section
A_p	Area of prestressing steel
A_s	Area of non-prestressed steel
A_{sv}	Cross-sectional area of the two legs of a link
a_{cs}	Average crack spacing
A_t	Concrete area in tension
b	Breadth of a section
c	Cover to reinforcement
d_p	Distance of prestress steel from top fibre of the section
d_t	Distance of non-prestressed steel from top fibre of the section
e	Eccentricity of prestressing force
E_p	Young's modulus of elasticity for prestressing steel
E_c	Young's modulus of elasticity for concrete
f	Bending stress
f_l	Overall flexural tensile stress in concrete
f_p	Stress in prestress steel at ultimate
f_s	Stress in non-prestressed steel at ultimate
F_{sp}	Force in prestress steel
F_{st}	Force in non-prestressed steel
F_c	Force in concrete block
F_{cu}	Characteristic strength of concrete
F_u	Ultimate load carrying capacity of a section
f_{ct}	Fictitious tensile stress in concrete

f_{nt}	Stress in prestress steel at any load level beyond decompression load
f_d	Stress in prestress steel corresponding to the decompression load
f_{pu}	Characteristic strength of prestressing wire
f_y	Characteristic strength of reinforcing bars
f_{cp}	Compressive stress at the centroidal axis due to prestress
f_t	Maximum principal tensile stress
f_{pt}	Stress due to prestress
G_k	Dead load on the beam
h	Total depth of a beam
I	Moment of inertia about neutral axis
K	A constant in Bennett-Chandrasekhar formula
L	Span of beam
M	Bending moment
M_u	Ultimate moment capacity of a section
M_o	Moment necessary to produce zero stress
M_c	Cracking moment
n	Modular ratio
P_i	Initial prestressing force
P_e	Effective prestressing force
P_{cr}	Cracking load
Q_k	Imposed service load on the beam
r	Radius of gyration of a section
S_v	Spacing of link along the member
V_{co}	Ultimate shear resistance of a section uncracked in flexure
v_{max}	Maximum shear stress

v_c	Ultimate shear stress in concrete
V_{cr}	Ultimate shear resistance of a section cracked in flexure
W	Crack width in mm
W_{max}	Maximum crack width in mm
x	Distance of neutral axis from the top fibre
y	Distance of a fibre from the neutral axis
y_b	Distance to the bottom fibre from the neutral axis
z_1	Lever arm for prestress steel force
z_2	Lever arm for non-prestressed steel force
ε_p	Strain in prestress steel at ultimate
ε_t	Strain in non-prestressed steel at ultimate
Δ_1	Deflection at mid span of the beam due to two point loads
Δ_2	Deflection due to self weight u.d.l at mid span of beam
Δ_3	Deflection at mid span due to effective prestress force
Δ_{max}	Maximum total deflection at mid span of the beam
$\sum o$	Sum of the circumferences of the reinforcing elements
γ_m	Partial factor of safety of material

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CHAPTER 1

INTRODUCTION

1.1 General

In the limit state design of concrete structures, the limit state criteria of deflection and cracking are the two service limit criteria which need to be satisfied. This is required for reinforced concrete structures as well as for prestressed concrete structures. In partially prestressed concrete beams, this is important since limited cracking is allowed in this type of structure. Compliance with the limit state requirements for deflection and cracking requires a reasonably good estimate of maximum deflection and the width of cracks. As more and more prestressed concrete beams incorporating bonded reinforcing bars (partially prestressed) are built today, crack control is becoming more significant.

1.2 Partially prestressed concrete beams

Consider a simply supported prestressed concrete beam with eccentric tendons and subjected to external loads as shown in Fig. 1.1(a). In the midspan of the beam the concrete section will have a stress distribution as follows:

Fig 1.1 (b) Uniform compression due to the prestress only. This component of stress is considered axial for uniformity.

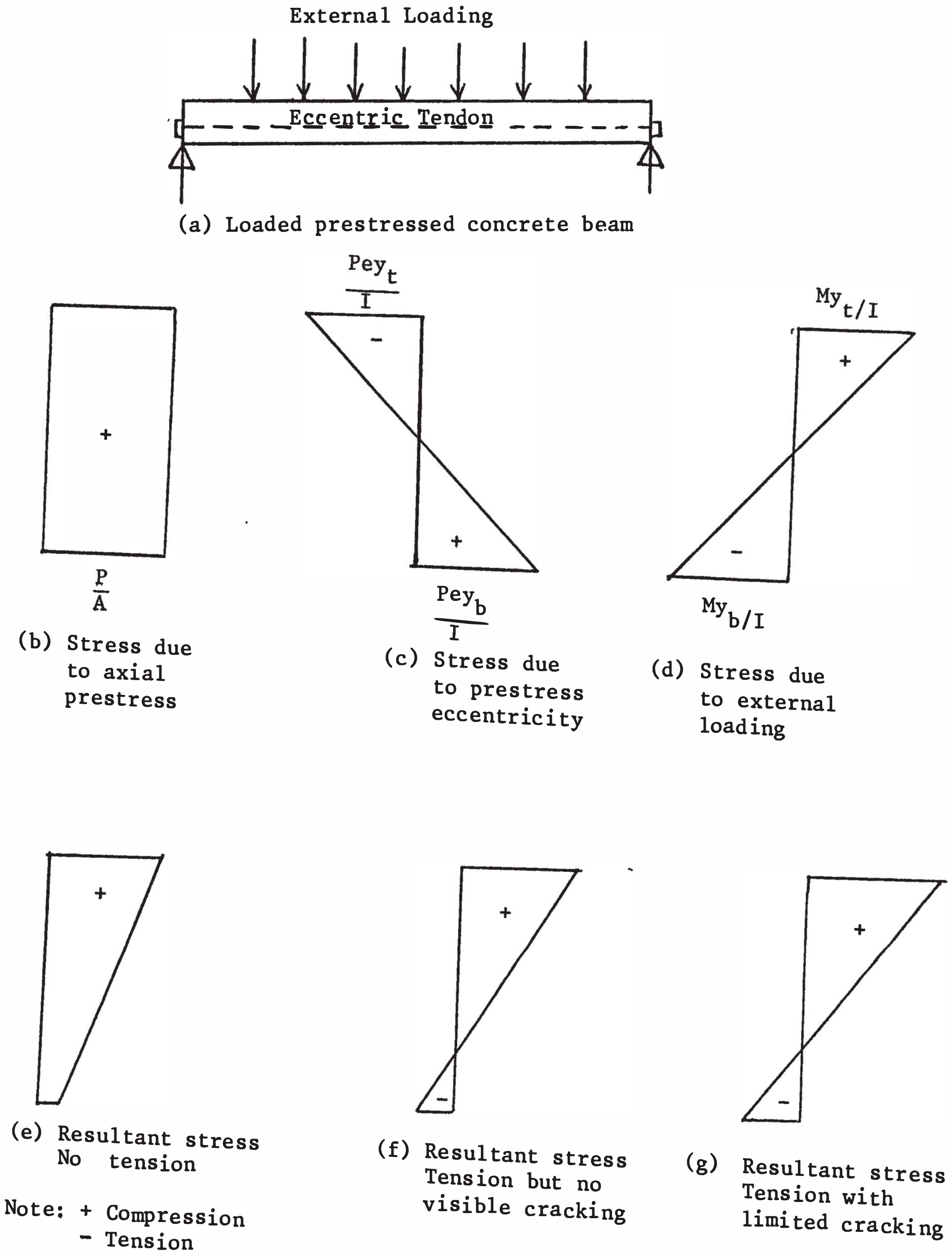

FIG. 1.1 STRESS DISTRIBUTION IN PRESSTRESSED CONCRETE SECTION

Fig. 1.1 (c) Stress due to the eccentricity, e of prestressing force. This component stress will cause tension at the top fibre and compression at the bottom fibre.

Fig. 1.1 (d) Stress due to the external applied load. This stress will cause compression at the top fibre and tension at the bottom fibre.

When the prestressing force and the external load act together, the net resultant stress will be the algebraic sum of the stresses described in (b), (c) and (d). The resultant stress distribution can be any of the following types:

Fig. 1.1 (e) No tensile stress at the bottom fibre i.e the whole section is under compression. The stress diagram can be trapezoidal or triangular depending on whether there will be a compressive stress at the bottem fibre or the stress will be zero.

Fig. 1.1 (f) Tensile stress at the bottom fibre but with no visible crack.

Fig. 1.1 (g) Tensile stress at the bottom fibre but with visible cracks.

Based on these three resultant stress conditions, CP 110 (clause 2.2.3.2) classifies prestressed concrete structures into three categories, namely:

Class 1 : No tensile stress.

Class 2 : Tensile stress but no visible cracking.

Class 3 : Tensile stress but surface width of cracks not exceeding 0.2 mm.

According to the classification by CP 110, partially prestressed concrete structures fall under class 3 category. It is also noteworthy that CP 110 restricts the width of cracks to 0.2 mm in prestressed concrete structures and not 0.3 mm as in reinforced concrete. This is due to the fact that the percentage of steel in prestressed concrete is less than that of reinforced concrete and a wider crack will have severe effect on the prestressing tendons which are susceptible to corrosion and environmental changes.

A partially prestressed concrete beam is prepared by introducing a limited number of reinforcing bars in addition to the prestressing tendons. The addition of a few reinforcing bars significantly improve load carrying capacity and flexural behavior of the beam. This also makes it economical as the cost of reinforcing steel is only a small fraction of the expensive prestressing tendons and the cost associated with prestressing.

Partially prestressed concrete may be defined as concrete reinforced with a combination of prestressed and non prestressed reinforcements in which prestress is induced of such magnitude and distribution that the stresses resulting from the dead weight of the structure and from externally applied load are counteracted so as to minimize tensile stresses and cracking in the tension zone of a member.