UNIVERSITI PUTRA MALAYSIA

NON-LINEAR ANALYSIS OF REINFORCED AND PRE-STRESSED CONCRETE BEAMS

AHMED M. M. HAMED

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By

AHMED M. M. HAMED

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

December 2002

DEDICATION

To My family,

I dedicate this work

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

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AHMED M. M. HAMED

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Chairman: **Associate Professor Waleed A. Malik Thanoon, Ph.D.**

Faculty: **Engineering**

Reinforced/pre-stressed (RC/PC) concrete is one of the most commonly used construction materials. This composite material demonstrates a highly non-linear behaviour caused by, cracking, crushing, aggregate interlock, bond slip, dowel action, shrinkage, creep, etc. Because the behaviour of reinforced/pre-stressed concrete involves so many non-linear phenomena interacting with one other, the formulation of rational analytical procedures to describe this behaviour is very difficult.

Since the advent of the computer, powerful methods of analysis such as the finite element method and stiffness matrix method have been implemented to study and develop analytical solutions for the non-linear phenomena. However, the success of such analysis depends on a thorough understanding and modeling of the composite material behaviour.

This study describes the development of a non-linear computer code used to predict the non-liner response of reinforced/pre-stressed concrete beams that are subjected to a combined axial force and bending moment. The study discusses a new simplified approach, whereby the non-linear response is captured via a series of sequentially linear steps. The finite element approach with the stiffness matrix method were used to model the beam element structure and generate its stiffness matrix.

A monotonic empirical model for the concrete's stress-strain curve has been implemented to predict both ascending and descending parts of the curve. An idealized bi-linear elasto-plastic in tension and compression model has been assumed for reinforcing and pre-stressing steel.

Concrete and reinforcing/pre-stressing steel are represented by separate algorithms, which when combined together, describe the behavior of the composite reinforced/pre-stressed concrete material.

The Newton-Raphson concept has been implemented in the iteration technique to satisfy equilibrium and compatibility conditions.

Finally, correlation studies between analytical and experimental results have been carried out with the objective to establish the validity of the proposed model. The verification of the program started by comparing the predictions of the non-linear response for a reinforced concrete beam with that of the results which have been obtained experimentally, and by using the finite element method for the same beam. The comparison was made for the failure load, yielding load and load-deflection

relation. Further more, a 6.0m reinforced concrete beam has been investigated in details as a simply supported and as a fixed supported beam. 2.5m prestressed concrete beam also investigated in details.

The comparison study shows that the predictions from the developed program correlate well with the other results. The investigated beam show that the program results are in complete agreement with the assumptions and models considered to develop the code. The results clearly showed the magnitude and locations of cracking, yielding, ultimate load, failure load and ductility requirements. The program may be used as a tool to do parametric study on the behaviour of reinforced and prestressed concrete structures.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

ANALISIS TAK LELURUS RASUK KONKRIT TETULANG DAN PRA-TEGASAN

Oleh

AHMED M. M. HAMED

Desember 2002

Pengerusi: **Profesor Madya Waleed A. Malik Thanoon, Ph.D.**

Fakulti: **Kejuruteraan**

Konkrit bertetulang/konkrit prategasan adalah antara bahan pembinaan yang paling lazim digunakan. Bahan rencam ini memperlihatkan ciri tak lelurus yang paling tinggi disebabkan retakan, penghancuran, panca agregat, gelincir ikatan, aksi dowel, pengecutan, rayap dan sebagainya. Formulasi prosedur beranalisis yang rasional untuk menghuraikan sifat ini adalah amat sukar disebabkan sifat konkrit bertetulang/konkrit prategasan mungkin melibatkan begitu banyak fenomena tak lelurus yang saling bertindak.

Semenjak wujudnya komputer, pelbagai kaedah analisis yang hebat seperti kaedah unsur terhingga dan kaedah matriks kekukuhan telah dilaksanakan untuk mengkaji dan membina penyelesaian beranalisis bagi fenomena tak lelurus. Walau bagaimanapun kejayaan analisis sedemikian bergantung pada pemahaman yang mendalam dan pemodelan kelakuan bahan rencam.

Kajian ini memerihalkan pembinaan kod komputer tak lelurus yang digunakan untuk meramal respons tak lelurus apabila rasuk konkrit bertetulang/konkrit prategasan dikenakan gabungan daya paksian dan momen lentur. Kajian ini membincangkan pendekatan baru yang dipermudahkan, yang melibatkan pemerolehan respons tak lelurus melalui satu siri langkah lelurus yang berjujukan. Pendekatan kaedah unsur terhingga dengan kaedah matriks kekukuhan telah digunakan untuk memodelkan unsure-unsur struktur rasuk dan menjana matriks kekukuhannya.

Model empirik ekanada bagi lengkung tegasan-tekanan konkrit telah dilaksanakan untuk meramal bahagian menaik dan menurun lengkung tersebut. Model dwilelurus terunggul yang bersifat anjal-plastik dari segi tegangan dan mampatan telah diandaikan untuk penetulang dan pemprategasan besi.

Konkrit dan besi bertetulang/besi prategasan diwakili oleh algoritma yang berbeza, yang apabila digabungkan dapat menerangkan kelakuan bahan konkrit rencam bertetulang/prategasan. Konsep Newton-raphson telah dilaksanakan dalam teknik lelaran untuk menentukan nilai terikan pada gentian atas dan bawah pada keratan rentas.

Akhir sekali, kajian korelasi antara keputusan beranalisis dan eksperimen, telah dijalankan yang bertujuan memastikan kesahan model yang dicadangkan. Pengesahan rancangan bermula dengan membandingkan ramalan respons tak lelurus untuk rasuk konkrit bertetulang dengan keputusan daripada eksperimen, dan dengan menggunakan kaedah unsur terhingga bagi rasuk yang sama. Perbandingan telah dibuat berdasarkan

beban kegagalan, beban pengalahan dan hubungan beban-pesongan. Sebagai tambahan sebatang rasuk berukuran 6.0 m telah dikaji secara terperinci sebagai rasuk sokongan mudah dan rasuk sokongan tetap. Kajian perbandingan menunjukkan bahawa ramalan daripada rancangan yang dibina adalah berkorelasi dengan keputusan lain. Kajian terhadap rasuk konkrit berukuran 6.0 m menunjukkan bahawa keputusan komputer bersetuju sepenuhnya dengan anggapan dan model yang telah diambil kira apabila membina kod. Keputusan menunjukkan dengan jelas magnitud dan lokasi retakan, pengalahan, beban muktamad, beban kegagalan, keperluan kemuluran, bahagian melembut dan sebagainya. Komputer kod yang dimajukan boleh digunakan sebagai alat untuk membuat kajian parameter keatas kelakuan struktur konkrit tetulang dan pra-tegasan.

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Finally, a special and immense thanks goes to the author's wife, for being very patient and for sharing the frustrating moments with him.

I certify that an Examination Committee met on 27th December 2002 to conduct the final examination of Ahmed M. M. Hamed on his Master of Science thesis entitled "Non-linear Analysis of Reinforced and Pre-stress Concrete Beams" in accordance with Universiti Pertanian 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 Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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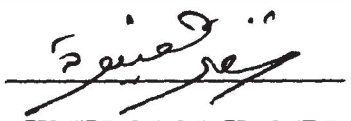
Date: 13 FEB 2003

DECLARATION

I hereby declare that the 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 other institution.



AHMED M. M. HAMED

Date: 6/1/03

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOTATIONS

a_1, a_2, a_3 and a_4	Polynomial constants
Ac, Bc, Cc and Dc	Constants to develop concrete stress-strain curve
Ac	Effective cross section area of concrete
A_{ci}	Area of concrete layer
A_{eff}	Effective axial stiffness
Ap	Effective cross section area pre-stressing steel
A_{pi}	Area pre-stressing steel elements in the layer
A_{ps}	Pre-stressing steel
As	Effective cross section area of reinforcing steel
A_{sc}	Reinforcing steel in compression zone
A_{si}	Area of reinforcement in i^{th} layer
A_{st}	Reinforcing steel in tension zone
b	Width of section
{d}	Nodal displacements
d_i	The distance of i^{th} layer of reinforcement from the top, compression, fiber
$\{d\}_i$	Converged deflection for i^{th} load step
$\{d\}^{Jt}$	Deflection in the current iteration
$\{d\}^{Jt-1}$	Deflection in the previous iteration
$\{D\}_{total}$	Accumulated deflection in the element
EA	Axial stiffness
E_c	Concrete modulus of elasticity in Mpa