FINITE ELEMENT MODELING AND PROBABILISTIC ANALYSIS OF PRESTRESSED INVERTED T-BEAM WITH WEB OPENINGS

TIE MING

MASTER OF ENGINEERING（CIVIL）

UNIVERSITI MALAYSIA PAHANG

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TIE MING

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SUPERVISORS' DECLARATION

I hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Civil Engineering.

Signature

Name of Supervisor: Dr. Cheng Hock Tian

Position:

Date:

Signature

Name of Co-supervisor: Zahrizan bin Zakaria

Position:

Date:

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for the quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for the award of any other degree.

Signature:

Name : Tie Ming

ID Number : MAC 09002

Date :

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ABSTRACT

Recent trends of structural mechanics applications in finite element analysis demonstrate an increasing demand for efficient analysis tools. This thesis presents a probabilistic analysis approach applied in finite element analysis for modelling prestressed inverted T-beams with web openings structure used in building service system (mechanical, electrical, communications, and plumbing). Prestressed concrete structures are commonly designed to satisfy criteria of serviceability and safety. In order to ensure the serviceability requirement it is necessary to predict the response of these structures under service loads. However, calculation of deflections of prestressed concrete structures is complicated by several factors, including shrinkage and creep of concrete, relaxation of prestressing reinforcement and cracking. Due to the inherent uncertainties in nature, it is difficult to determine the related parameters precisely. Material and geometric properties of the cracked prestressed concrete structure and load systems possess different degrees of uncertainties. Uncertainties of material properties could arise because of limited site investigations and limited material laboratory test and in accurate formula for correlating various material parameters. Uncertainties of geometric properties could be due to variations during fabrication and erection of the structure. The experimental program reported in this study was in the literature review about four prestressed inverted T-beams with circular web openings tested to failure to evaluate the openings' effect on various beam behaviours. Using ANSYS, finite element models were developed to simulate beam deflection behaviour. Comparison of analytical results with the available experimental results for load-deflection relationships showed good agreement between both results. Probabilistic analysis methodology could predict the response (i.e. deflection, stress, strain etc) due to various combination of input variables (i.e. opening radius, Poisson`s ratio, modulus of elasticity, etc). Probabilistic methodology applied in finite element analysis provides an alternative ways to structural analysis of preststressed inverted T-beams with web openings to achieve a robust and reliable design in a more efficient way. In this thesis, Monte Carlo simulation and Latin Hypercube simulation (LHS) was used to analyze the effect of parameter uncertainty for the prestressed inverted T-beams with web openings. From the analysis results, it was observed that the changes in prestressing force, ultimate tensile strength of prestressing steel, elastic modulus of prestressing steel and beam width tend to be the most influencing parameters, which need to be tightly controlled. As a result, from deterministic analysis and probabilistic analysis, it was found that probabilistic analysis tends to be closer to reality than deterministic methods and gives a way of designing for quality.

ABSTRAK

Trend terkini aplikasi mekanik struktur dalam analisis unsur terhingga menunjukkan peningkatan permintaan terhadap peralatan analisis yang cekap. Tesis ini membentangkan pendekatan analisis kebarangkalian yang digunakan dalam analisis unsur terhingga bagi pemodelan prategasan T-rasuk terbalik dengan struktur pembukaan web yang digunakan dalam pembinaan sistem perkhidmatan (mekanikal, elektrik, komunikasi, dan paip). Struktur konkrit prategasan biasanya direka untuk memenuhi kriteria kebolehkhidmatan dan keselamatan. Dalam usaha untuk memastikan keperluan kebolehkhidmatan adalah perlu untuk meramalkan sambutan ini struktur di bawah beban khidmat. Walau bagaimanapun, pengiraan pesongan struktur konkrit prategasan adalah rumit oleh beberapa faktor, termasuk pengecutan dan rayapan konkrit, kelonggaran prategasan tetulang dan keretakan. Disebabkan ketidaktentuan yang wujud dalam alam, ia adalah sukar untuk menentukan parameter yang berkaitan dengan tepat. Sifat bahan dan geometri struktur retak konkrit prategasan dan beban sistem mempunyai darjah berbeza ketidaktentuan. Ketidaktentuan sifat bahan boleh timbul kerana siasatan tapak terhad dan ujian makmal bahan terhad dan dalam formula yang tepat untuk menghubungkaitkan pelbagai parameter bahan. Ketidaktentuan sifat geometri mungkin disebabkan kepada variasi semasa fabrikasi dan pendirian struktur. Menggunakan program pemodelan ANSYS, model unsur terhingga telah dibangunkan untuk mensimulasikan tingkah laku pesongan rasuk. Perbandingan keputusan analisis dengan keputusan ujian makmal dalam kajian ilmiah untuk hubungan beban-pesongan menunjukkan perjanjian yang baik antara kedua-dua keputusan. Metodologi analisis kebarangkalian yang dapat meramalkan tindak balas (iaitu pesongan, tegasan, terikan dan lain-lain) disebabkan oleh kombinasi pelbagai pemboleh ubah (iaitu pembukaan jejari, nisbah Poisson, modulus keanjalan, dan lain-lain). Kaedah kebarangkalian yang digunakan dalam analisis unsur terhingga menyediakan satu lagi cara alternatif analisis struktur pra-tegasan T-rasuk terbalik dengan bukaan web untuk mencapai reka bentuk tegap dan boleh dipercayai dengan cara yang lebih cekap. Dalam karya ini, simulasi Monte Carlo dan Latin Simulasi Hypercube telah digunakan untuk menganalisis kesan yang tidak menentu parameter bagi prategasan T-rasuk terbalik dengan bukaan web. Daripada keputusan analisis, dapat diperhatikan bahawa perubahan daya prategasan, kekuatan tegangan muktamad keluli prategasan, modulus elastik keluli prategasan dan lebar rasuk cenderung menjadi faktor yang paling mempengaruhi parameter, yang perlu dikawal ketat. Hasil daripada kajian ini, perbandingan antara analisis berketentuan dan analisis kebarangkalian, didapati bahawa analisis kebarangkalian cenderung untuk menjadi lebih dekat dengan keadaan sebenar berbanding kaedah berketentuan dan memberikan cara mereka- bentuk untuk kualiti.

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REFERENCES

ACI Committee 318-99, 1999, Building code requirements for reinforced concrete, *Michigan: American Concrete Institute*.

Aleksandar Pavic, Paul Reynolds, Peter Waldron and Kevin Bennett, 2001, Dynamic modeling of post-tensioned concrete floors using finite element analysis, *Finite Elements in Analysis and Design*, Volume 37, pp.305-323.

Alves, T.M.J, and Scanlon, A., 1984, Deflection of prestressed concrete beams with openings, *Symposium of Deflections of Structures*, Annual Convention of the American Concrete Institute, Phoenix, Ariz.

Andrea.Saltlelli, 1999, Electronic sources: Scheme for sensitivity analysis (online). http://en.wikipedia.org/wiki/File:Sensitivity_scheme.jpg.

Audrius.Meskauskas, 2006, Electronic sources: The scientific diagram with the computed (online). http://en.wikipedia.org/wiki/File:Confidenceinterval.png.

Bangash, M.Y.H., 1989, Concrete and concrete structure: numerical modeling and applications, *Elsevier Science Publisher Ltd*., London, England.

Barney, G. B., W. G. Corley, J. M.Hanson, and R. A. Parmelee., 1997, Behavior and design of prestressed concrete beams with large web openings, *PCI Journal*, Volume 22, pp.32-61.

Bulent Mercan, Arturo E.Schultz and Henryk K. Stolarski, 2010, *Finite element modeling of prestressed concrete spandrel beams*, *Engineering Structure*, Volume 32, pp.2804-2813.

B.N.Singh, N.Vyas and P.Dash, 2009, Stochastic free vibration analysis of smart random composite plates, *Structural Engineering and Mechanics*, Volume 31, pp.481-506.

B.Sudret, 2008, Probabilistic models for the extent of damage in degrading reinforced concrete structures, *Reliability Engineering & System Safety*, Volume 93, pp.410-422.

Christopher G. Gilbertson and Theresa M. Ahlborn, 2004, A probabilistic comparison of prestress loss methods in prestressed concrete beams, *PCI Journal*.

Desayi, P. and Krishnan, S., 1964, Equation for the stress-strain curve of concrete, *Journal of the American Concrete Inst*., 61, pp.345-350.

D.V.Val and M.G.Stewart, 2005, Decision analysis for deteriorating structures, *Reliability Engineering and System Safety*, Volume 87, pp.377-385.

Fazilat H.Dar, Judith R.Meakin and Richard M.Aspden, 2002, Statistical methods in finite element analysis, *Journal of Biomechanics*, Volume 35, Issue 9, pp.1155-1161.

George C. Thomos and Constantin G. Trezos, 2006, Examination of the probabilistic response of reinforced concrete structure under static non-linear analysis, *Engineering Structures*, Volume 28, pp.120-133.

G.Falsone and G.Ferro, 2007, An exact solution for the static and dynamic analysis of FE discretized uncertain structures, *Computer Methods in Applied Mechanics and Engineering*, Volume 196, pp.2390-2400.

Ghali, A., Favre, R. and Elbadry, M, 2002, *Concrete structures: Stresses and Deformations*, 3th Edtion, Sponpress, London and New York.

Giuseppe Quaranta, 2011, Finite element analysis with uncertain probabilities, *Computer Methods in Applied Mechanics and Engineering*, Volume 200, Issue 1, pp.114-129.

Graciela N.Doz, Silivia M.Soares and Pablo G.Bignon, 1992, Behaviour of confined prestressed concrete beams, *Advances in Engineering Software*, Volume 15, Issue 2, pp.113-115.

G.Stefanou, 2009, The stochastic finite element method: past, present and future, *Computer Methods in Applied Mechanics and Engineering*, Volume 198, pp.1031-1051.

G. Sathurappan, N.Rajagopalan and C.S Krishnamoorthy, 1992, Nonlinear finite element analysis of reinforced and prestressed concrete slabs with reinforcement modeled as discrete integral components, *Computers & Structures*, Volume 44, pp.575-584.

G.Stefanou and M.Papadrakakis, 2004, Stochastic finite element analsis of shells with combined random material and geometric properties, *Computer Methods in Applied Mechanics and Engineering*, Volume 193, pp.139-160.

H.A. Mang and G. Meschke, 1992, Nonlinear finite element analysis of reinforced and prestressed concrete structures, *Construction and Building Materials*, Volume 6, pp.77-90.

Hammersley, J. M and Handscomb, D.C, 1964, *Monte Carlo Methods*, John Wiley & Sons, New York.

Hemmaty, Y., 1998, Modeling of the shear force transferred between cracks in reinforced and fiber reinforced concrete structures, *ANSYS Conference*, Volume. 1, Pittsburgh, Pennsylvania.

Hock Tian, Cheng, Bashar S. Mohammed and Kamal Nasharuddin Mustapha, 2009, Experimental and analytical analysis of pretensioned inverted T-beam with circular web openings, *International Journal of Mechanics and Materials in Design*, Volume 5, No. 2; pp.203-215.

Huyse, L., Hemmaty, Y. and Vandewalle, L, 1994, Finite element modeling of fiber reinforced concrete beams, *ANSYS Conference*, Volume. 2, Pittsburgh, Pennsylvania.

I.Elishakoff, Y.J.Ren and M.Shinozuka, 1995, Imporve finite-element method for stochastic problems, Chaos Solitons and Fractals, Volume 5, pp.833-846.

Iman R.C, Conover WJ. 1982, A distribution-free approach to inducing rank correlation among input variables, *Communications in Statistics: Theory and Methods B*; 11:1749-842.

Iman, R.L and Conover, W. J, 1980, Sample Sensitivity Analysis Techniques for Computer Models, with an Application to Risk Assessment, *Communications in Statistics, Part A – Theory and Methods*, Volume A9, No.17, pp.1749-1842.

Iman, R.L, Helton, J.C and Campbell, J.E, 1981, An approach to sensitivity analysis of computer models, Part I – Introduction, input variable selection and preliminary variable assessment, *Journal of Quality Technology*, Volume 13, No.3, pp.174-183.

Iman, R.L, Helton, J.C and Campbell, J.E, 1981, An approach to sensitivity analysis of computer models, Part II – Ranking of input variables, response surface validation, distribution effect and technique synopsis, *Journal of Quality Technology*, Volume 13, No.4, pp.232-240.

In-Hwan Yang, 2003, Probabilistic analysis of creep and shrinkage effects in PSC Box Girder Bridges, *KSCE Journal of Civil Engineering*, Volume 7, pp.275-284.

Inkscape, 2008, Electronic sources: A selection of Normal Distribution Probability Density Functions (online). http://en.widipedia.org/wiki/File:Normal Distribution PDF.svg

J.E.Hurtado and A.H.Barbat, 1998, Monte Carlo techniques in computational stochastic mechanics, *Archives of Computational Methods in Engineering*, Volume 5, pp.3-29.

Jin Cheng, C.S.Cai and Ru-cheng Xiao, 2007, Probabilistic response analysis of cracked prestressed concrete beams, *Advances in Structural Engineering*, Volume 10.

J.Ma, J.J.Chen and W.Gao, 2006, Dynamic response analysis of fuzzy stochastic truss structures under fuzzy stochastic excitation, *Computational Mechanics*, Volume 38, pp.283-293.

Joan R.Casas and Cesar Crespo-Minguillon, 1998, Probabilistic response of presstresses concrete bridges to fatigue, *Engineering Structures*, Volume 20, pp.940-947.

J. Turno, G.Ramos and A.C.Aparicio, 2005, FEM study on the structural behavior of segmental concrete bridges with unbounded prestressing and dry joints: Simply supported bridges, *Engineering Structures*, Volume 27, pp.1652-1661.

L.Figiel and M.Kaminski, 2009, Numerical probabilistic approach to sensitivity analysis in a fatigue delamination problem of a two layer composite, *Applied Mathematics and Computation*, Volume 209, pp.75-90.

MacGregor, J.G., 1992, *Reinforced Concrete Mechanics and Design*. Prentice Hall,Inc., Englewood Cliffs, New Jersey.

Mansur, M.A., 1988, *Ultimate Strength Design of Beam with Large Openings*, Int.J.Struct., Volume 8, pp.107-125.

M.G.Stewart and Q.H.Suo, 2009, Extent of spatially variable corrosion damage as an indicator of strength and time-dependent reliability of RC beams, Engineering Structures, Volume 31, pp.198-207.

Mikael.Haggstrom, 2011, Electronic sources: Log-normal distributions (online). http://en.wikipedia.org/wiki/File:Some_log-normal_distributions.svg.

Mohamad N. Mahmood and Akram S. Mahmood, 2010, Nonlinear finite element analysis of prestressed concrete beams subjected to pure torsion, *Conference on Buildings and Infrastructure Technology*, Kuching, Sarawak, Malaysia.

M.Shinozuka and L.C.Shao, 1973, Basic probabilistic considerations on safety of prestressed concrete pressure vessels, *The Second International Conference on*

Structural Mechanics in Reactor Technology, Berlin, Germany.

Muhammad Sigit Darmawan, 2010, Probabilistic assessment of pitting corrosion effect on flexural strength of partial prestressed concrete structures in a chloride environment, *Journal of Civil Engineering and Architecture*, Volume 4, pp.25-32.

Nan Zhang and Chung C.Fu, 2009, Experimental and theoretical studies on composite steel – concrete box beams with external tendons, *Engineering Structures*, Volume 31, pp.275-283.

Novák, D., Teplý, B., and Keršner, Z., 1998, *The role of Latin hypercube sampling method in reliability engineering*, Proceedings of ICOSSAR-97, Kyoto,Japan, pp.403-409.

Oh, B.H. and Yang, I.H, 2000, Sensitivity analysis of time-dependent behavior in PSC box girder bridges, *Journal of Structural Engineering*, ASCE, Volume 126, pp.171-179.

Regan, H.S., and Warwaruk,J., 1967, The Members with Large Web Openings, *PCI Journal*, Volume 12, pp.52-65.

Sauve, J.S.,1970, Prestressed concrete tee-beams with large web openings, *M.Sc.thesis*, University of Alberta.

SAS, ANSYS 11.0 Finite Element Analysis System, 2009, ANSYS Manual Set, *ANSYS Inc*., Southpoint, 275 Technology Drive, Canonsburg, PA 15317, USA.

S.H.Chen, Z.S.Liu and Z.F.Zhang, 1992, Random vibration analysis for large-scale structures with random parameters, *Computers and Structures*, Volume 43, pp.681-685.

S.K. Padmarajaiah and Ananth Ramaswamy, 2002, Afintie element assessment of flexural strength of prestressed concrete beams with fiber reinforcement, *Cement and Concrete Composites*, Volume 24, pp.229-241.

S.S.Rao, 1980, Probabilistic design of prestressed concrete poles, *Building and Environment*, Volume 15, pp.49-56.

S.S Rao and L.Berke, 1997, Analysis of uncertain structural systems using interval analysis, *AIAA Journal*, Volume 35, pp.727-735.

Taejun Cho and Tae Soo Kim, 2008, Probabilistic risk assessment for the construction phases of a bridge construction based on finite element analysis, *Finite Elements in Analysis and Design*, Volume 44, Issue 6-7, pp.383-400.

Tie-jiong Lou and Yi-qiang Xiang, 2006, Finite element modeling of concrete beams prestressed with external tendons, *Engineering Structures*, Volume 28, Pages 1919-1926.

W.Gao, 2006, Stochastically optimal active control of a smart truss structure under stationary random excitation, *Journal of Sound and Vibration*, Volume 290, pp.1256-1268.

W.Gao and N.J.Kessissoglou, 2007, Dynamic response analysis of stochastic truss structures under non-stationary random excitation using the random factor method, *Computer Methods in Applied Mechanics and Engineering*, Volume 196, pp.2765-2773.

Willam, K.J and Warnke, E.P., 1974, Constitutive model for triaxial behavior of concrete, Seminar on Concrete Structures Subjected to Triaxial Stresses, *Proceedings of International Association of Bridge and Structural Engineering Conference*, Bergamo, Italy.

Yu Wang, Zijun Cao, and Siu-kui Au, 2010, Efficient Mote Carlo Simulation of parameter sensitivity in probabilistic slope stability analysis, *Computers and Geotechnics*, Volume 37, Issue 7-8, pp.1015-1022.