NON-LINEAR ANALYSIS OF A SYMMETRIC FLUSH END PLATE BOLTED BEAM-TO-COLUMN STEEL CONNECTION

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ABSTRACT

Most connections that fasten beams to columns are deformable and exhibit a non-linear behaviour between conditions fully fixed and perfectly pinned. Connection flexibility affects both force distribution and deformation in beams and columns of the frame and must be accounted for in a structural analysis. This problem can be solved by conducting a non-linear analysis, which addresses both the geometric non-linearity and connection flexibility.

The linear elastic analysis assumes that the deformations are relatively small and the equilibrium equations can be formulated with respect to initial geometry.

To see the differences between the above approaches on moment capacity of the connection, a model of A Symmetric Flush End Plate Bolted Beam-to-Column connection model has been analysed using both approaches above. This model will be made similar to the model that had an experimental data for verification.

From non-linear computer analysis the moment capacity model is found to be 7.8 kNm compared to experimental data, 8.8 kNm.

The moment capacity resulted from linear analysis is found to be 19.5 kNm which is 2.5 time the non-linear analysis result or 2.216 above the experimental data.

The results of this study shows an agreement with previous researchers that the connection behaves in between pinned and fully rigid and possess some rotational stiffness.

ABSTRAK

Kebanyakan sambungan yang mengikat rasuk kepada tiang boleh merubah dan mempamirkan sifat ketidaklelurusan di antara keadaan sambungan tegar dan sambungan pin. Kebolehlenturan sambungan memberi kesan kepada pengagihan daya dan kelenturan rasuk dan tiang dalam satu-satu kerangka dan perlu diambil kira dalam analisa struktur. Masalah ini boleh diselesaikan dengan menjalankan analisa ketidaklelurusan yang mana boleh menyelesaikan masalah ketidaklelurusan geometri dan kelenturan sambungan.

Analisis lelurus menganggapkan perubahan secara relatifnya adalah kecil dan persamaan keseimbangan boleh dibuat berdasarkan geometri asal.

Bagi mengetahui perbezaan di antara kedua-dua pendekatan di atas tentang kapasiti momen bagi sesuatu sambungan, satu model sambungan plat hujung sedatar antara rasuk dan tiang telah dianalisa mengunakan kedua-dua pendekatan di atas. Model ini dibuat berdasarkan model yang telah diuji untuk tujuan pengesahan.

Dari analisis tidak lelurus kapasiti moment model adalah 7.8 kNm berbanding dengan 8.8 kNm dari data ujikaji.

Momen kapasiti yang terhasil dari analisis lelurus adalah 19.5 kNm di mana 2.5 kali dari keputusan analisis tidak lelurus atau 2.216 melebihi dari data ujikaji.

Keputusan dari kajian ini menunjukan persamaan dengan penyelidik-penyelidik terdahulu yang mana perlakuan sambungan adalah di antara sambungan pin dan tegar serta mengandungi sedikit kekuhan putaran.

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$\underline{a}^{(e)}$	Nodal displacement vector
$\underline{\underline{B}}^{(e)}$	Strain-displacement matrix
BS 5950	British Standard 5950
$\underline{\underline{D}}^{(e)}$	Matrix of elastic constants
da	Depth of end plate
$\underline{F}$	Concentrated loads
$\underline{f}$	Nodal body forces vector
g	Bolt gauge
$\underline{\underline{K}}a$	Structure stiffness matrix
k_i	Structure stiffness
kNm	kiloNewton metre
la	Angle cleat length
M	Moment
$\underline{N}^{(e)}$	Displacement interpolation or shape function matrix
$\underline{N}_s^{(e)}$	Interpolation functions for the surface of the elements
P	Axial force
$\underline{R}$	Structure force vector
$\underline{R}_b$	Force vector due to element body load
$\underline{R}_s$	Force vector due to element surface tractions
$\underline{R}_o$	Force vector due to initial stresses and strains
$\underline{R}_c$	Force vector due to concentrated loads
t	Thickness
$\underline{t}$	Surface forces
ta	End plate thickness
$t+\Delta t$	Values at time $t+\Delta t$
$\underline{u}$	Displacement vector
$\underline{u}^{(e)}$	Nodal point displacement
ΔA	Incremental load vector
ΔD	Incremental displacement vector

ΔM	Change in end moment during load increment
$\Delta\theta r$	Change in relative spring rotation during load increment
ε	Strains
$\varepsilon_o^{(e)}$	Initial strain
$\underline{\sigma}$	Stress vector
$\underline{\sigma}_o^{(e)}$	Initial stress
$\delta\underline{a}^i$	Change in displacement for the i^{th} iteration
$\delta\underline{\varepsilon}$	Virtual displacement vector
$\underline{\psi}(a)$	Residual force vector
η	Step length multiplier for line search
γ_ψ	Euclidian residual norm
γ_d	Euclidian displacement norm
λ_d	Load factor
Φ	Angle of rotation
$\Sigma(\ )$	Summation
%	Percent

CHAPTER 1

INTRODUCTION

1.1 General

Most connections designed in the past are assumed either perfectly pinned or fully rigid. Recent studies however, revealed that the connection that fastens beams to columns using angles, plates, welds and bolts are deformable and exhibit a non-linear behaviour between conditions fully fixed and perfectly pinned.

Connection flexibility affects both force distribution and deformation in beams and columns of the frame and must be accounted for in a structural analysis.

The linear elastic analysis assumes that the deformations are relatively small and the equilibrium equations can be formulated with respect to initial geometry.

These two approaches required an in-depth study so that a proper guideline could be produced for steel designer and fabricator.

1.2 Problem Statements

Non-linear analysis of connection is complicated as there is no direct solution to the problem. All design calculations have to be verified by the full-scale lab test. This may take some time and involved a high cost. With the availability of computer software nowadays, the problem may be solved in a short time and much cheaper. Therefore, the computer model of the connection that is close to the reality need to be developed.

1.3 Objective Of This Research

The objective of this research is to study the capacity of a beam-to-column connection under linear and non-linear analysis.

For non-linear analysis, the beam-to-column connection will be modelled and analysed using computer aided finite element method. The Moment-Rotation (M-ϕ) curve produced by computer analysis will then be compared with the available experimental data.

The non-linearity variables will be adjusted to make the M-ϕ curve produced by the computer analysis as close as possible to the M-ϕ curve produced by the experiment. The moment capacity of the connection will be determined from the M-ϕ curve produced.

Linear analysis will be carried out in accordance to BS 5950 and this result will be compared with the moment capacity resulted from the non-linear analysis.

1.4 Scope of This Study

This study involves modelling and analysing a symmetric flush end plate bolted beam-to-column steel connection using both linear and non-linear approach.

In order to verify the computer results, the connection configurations that had experimental data will be chosen for computer modelling.

The assumed variables in the computer model will be adjusted by trial and error so that the Moment-Rotation (M-ϕ) curve obtained from the computer analysis is as closed as possible to the experiment.

A linear analysis will be carried out on the same model as per BS 5950 to compare its moment capacity with the above.

1.5 Contents of Report

Chapter 2 of this report will discuss on the classifications connection and previous study that had been done on the subject. The theory of non-linear and linear analysis will be covered in Chapter 3. In Chapter 4, the methodology of creating the connection model using finite element method and application of computer software LUSAS will be explained in detail. The result of the computer analysis will be analysed and discussed in Chapter 5. Chapter 6 will include the conclusion and recommendation for future study.

REFERENCES

1. J.Y Richard Liew, C.H. Yu, Y.H. Ng. and N.E Sahnmugam. *Testing of Semi-Rigid Unbraced Frames for Calibration of Second-order Inelastic Analysis.* Great Britain: Elsevier Science Ltd: 1997

2. L.F.L Ribeiro, R.M.Gonesalves and C.A.Castiglioni. Beam-to-Column End Plate Connections- An Experimental Analysis. *Journal of Constructional Steel Research.* 1998,46:1-3(304)

3. Balaur S.Dhillon, W.O'Malley III. Interactive Design of Semirigid Steel Frames. *Journal of Structural Engineering,* 1999. 125(5): 556-564.

4. Kee Dong Kim and Michael D.Engerlhardt. Beam-Column Element for Nonlinear Seismic Analysis of Steel Frames.*Journal of Structural Engineering.* 2000. 126(8): 916-924

5. S.O. Degertekin and M.S Hayalioglu. Design of non-linear semi-rigid steel frames with semi-rigid column bases. *Electronic Journal of Structural Engineering,* 2004, 4

6. Zaini Abd.Rahman. *Analisis Sambungan Menggunakan Kaedah Unsur Terhingga.* Undergraduate Project Report. Universiti Teknologi Malaysia; 2000

7. Jim Butterworth. *Finite Element Analysis of Structural Work Beam to Column Bolted Connections.* FEA Ltd. U.K.

8. W.M.C M^{c}Kenzie . *Design of Structural Steelworks.*
London: Mcmilan Press Ltd.1998

9. LUSAS.*Modeller User Manual Ver.13.*United Kingdom: FEA Ltd.

10. D.J.Laurie Kennedy and Mona A.Hafez. A study of end plate connections for steel beams. *Canadian Journal of Civil Engineering,* 1984. Vol. (11): 139-149

11. N R B Krishnam Raju and J Nagabhusshanam. Non Linear Structural analysis Using Integrated Force Method. *Sadhana*, 2000. 25(4): 353-356

12. J.P. Jaspart. General report: Session on connections. *Journal of Constructional Steel Research, 2000*. 55: 69-89

13. John C.Ryan, Jr. *Evaluation of Extended End-Plate Moment Connections Under Seismic Loading.* Master Thesis.Virginia Polytechnic Institute and State University.

14. British Standards Institution. *Structural use of steelwork in Building-Part 1.* London, BS 5950-1. 1990

15. The British Constructional Steelwork Association Ltd. *Joints in Steel Construction – Moment Connections.* London: The Steel Construction Institute. 1996

16. Steel Technology Centre, Faculty of Civil Engineering University Teknologi Malaysia. *Steelworks Design Guide Using Locally Produced Steel Section 1st Ed.* STC 1998

17. The Steel Construction Institute. *Steel Designer's Manual 5th Ed.* United Kingdom: Blackwell Science.2000