

**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 lurus 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 menggunakan kedua-dua pendekatan di atas. Model ini dibuat berdasarkan model yang telah diuji untuk tujuan pengesahan.

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

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

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

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	ACKNOWLEDGEMENT	iii
	ABSTRACT	iv
	ABSTRAK	v
	TABLE OF CONTENTS	vi
	LIST OF TABLES	ix
	LIST OF FIGURES	x
	LIST OF SYMBOLS	xi
CHAPTER 1	INTRODUCTION	1
	1.1 General	1
	1.2 Problem Statements	1
	1.3 Objective Of This Research	2
	1.4 Scope Of This Study	2
	1.5 Contents Of Report	3
CHAPTER 2	LITERATURE REVIEW	4
	2.1 Beam-To-Column Connections	4
	2.2 Connection Classification	5
	2.2.1 Moment Resistance	5
	2.2.3 Rotational Stiffness	6
	2.2.4 Ductility	6
	2.3 Type Of Beam-To-Column Connections	7
	2.3.1 Double Web Angle Cleats	8
	2.3.2 Top And Seat Angles Cleats	8
	2.3.3 End Plate Connections	10
	2.3.4 Tee-Stub Connections	12

	2.4	Previous Research	12
	2.5	Concluding Remarks	17
CHAPTER 3		BEAM-TO-COLUMN CONNECTION ANALYSIS	18
	3.1	Introduction	18
	3.2	Non-Linear Structure	19
	3.2.1	Boundary Non-Linearity	19
	3.2.2	Geometric Non-Linearity	19
	3.2.3	Material Non-Linearity	20
	3.3	Non-Linear Analysis	21
	3.3.1	Iterative Numerical Analysis Method	22
	3.3.2	Finite Element Method	24
	3.3.2.1	Basic Finite Element Equations	24
	3.3.2.2	Finite Element Analysis For Non-Linear Static Structure	27
	3.4	Linear Analysis Of Beam-To-Column Connection	39
CHAPTER 4		A SYMMETRIC FLUSH END PLATE BOLTED BEAM-TO-COLUMN STEEL CONNECTION MODEL	43
	4.1	General	43
	4.2	Connection Configuration	44
	4.3	Element Types	46
	4.3.1	End Plate Element	47
	4.3.2	Bolt Assembly Element	48
	4.3.3	Beam Element	49
	4.3.4	Column Element	50
	4.3.5	Joint Element	50
	4.4	Non-Linear Material Data	52

4.5	Boundary Conditions	53
4.6	Load	53
CHAPTER 5	ANALYSIS OF THE RESULTS AND DISCUSSION	56
5.1	General	56
5.2	Non-Linear Analysis Results	57
5.3	Linear Analysis Results	66
CHAPTER 6	CONCLUSION AND RECOMMENDATION FOR FUTURE STUDY	67
6.1	Conclusion	67
6.2	Recommendation For Future Research	67
	REFERENCES	68
	APPENDIX A	70-104
	APPENDIX B	105-115

LIST OF TABLES

TABLES NO.	TITLE	PAGE
4.1	Joint Configurations	45
5.1	Tabulation Of Displacement Of Node 14109 And Node 12236 Against Load Factor	62
5.2	Tabulation Of Computed Moment And Rotation	63
5.3	Tabulation Of Experimental Data	64

LIST OF FIGURES

FIGURES NO.	TITLE	PAGE
2.1	Moment-Rotation Of Connection	4
2.2	Classification Of Moment Connection By Strength	5
2.3	Classification Of Moment Connection By Rigidity	6
2.4	Classification Of Moment Connection By Ductility	7
2.5	Double Web Angles Cleats Connections	8
2.6	Top And Seat Angle Cleats Connection	9
2.7	Top And Seat Angle Cleats With Double Web Angle	9
2.8a	Examples Of Flush End-Plate Connections-Unstiffened	10
2.8b	Examples Of Flush End-Plate Connections-Stiffened	10
2.9a	Examples Of Extended End-Plate Connections-Unstiffened	11
2.9b	Examples Of Extended End-Plate Connections-Siffened	11
2.10	Tee-Stub Connections	12
3.1	Simply Supported Beam	20
3.2	Loaded Strut	21
3.3	Connection Secant Stiffness Through Load Increments	23
3.4	Illustration Of Newton-Raphson Iteration For A One Degree Of Freedom Response	29
3.5a	Common Forms Of Modified Newton Iterations-Initial Stiffness Method	30
3.5b	Common Forms Of Modified Newton Iterations -KT1 Method	31
3.5c	Common Forms Of Modified Newton Iterations -KT2 Method	32
3.6	Line Search Procedure	33
3.7	Constant Load Level Incremental / Iterative Procedure	37
3.8	Illustration Of Limit Points For A One Degree Of Freedom Response	37
3.9	Modified Arc Length Load Incrementation For A One	

	Degree Of Freedom Response	38
3.10	Beam-To-Column Connection	40
3.11a	Beam-To-Column Connection-Load Paths-At Top Flange	40
3.11b	Beam-To-Column Connection-Load Paths-At Bottom Flange	40
4.1	Three-Dimension View Of Connection Model	44
4.2	Model Configurations	45
4.3	FEA Elements	47
4.4	HX8M Solid Element	47
4.5	End Plate Mesh Arrangement	48
4.6	3D-Bar Element	48
4.7	Complete Bolt Assembly	49
4.8	Shell Element TTS3 And QTS4	49
4.9	Beam And Column Mesh Arrangement	50
4.10	3D Joint Element JNT4	51
4.11	Joint Element JNT4 Employed In The Model	51
4.12	Restrain In X,Y,Z Direction At The Column Base	53
4.13	Restrain In X Direction Along The Model Centreline	54
4.14	Final Arrangement Of Mesh Discretion Of Model	55
5.1	Connection Deformation Plot	57
5.2	Von Mises Stress Plot For End Plate, Bolt And Connecting Column Flange	58
5.3	Von Mises Stress Plot For Column And Beam Web And Far End Column Flange	58
5.4	Node 12236 And Node 14109 Location	59
5.5	Total Load Factor Vs. Vertical Displacement For Node 12236	60
5.6	Total Load Factor Vs. Horizontal Displacement For Node 14109	60
5.7	Graph M - ϕ_j	65

LIST OF SYMBOLS

$\underline{a}^{(e)}$	Nodal displacement vector
$\underline{B}^{(e)}$	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{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+ Δ t	Values at time t+ Δ 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
$\varepsilon_0^{(e)}$	Initial strain
$\underline{\sigma}$	Stress vector
$\underline{\sigma}_0^{(e)}$	Initial stress
$\delta \underline{a}^i$	Change in displacement for the i^{th} iteration
$\delta \underline{\varepsilon}$	Virtual displacement vector
$\underline{\psi}(\mathbf{a})$	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 ($M-\phi$) curve produced by computer analysis will then be compared with the available experimental data.

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

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