



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
STRUCTURAL ENGINEERING DEPARTMENT

Experimental and Theoretical Study of Large Capacity End-Plate Connections

By
Eng. Riham Refaat EL-Hadary

B.Sc. Civil Engineering
Ain Shams University

A Thesis
Submitted in Partial Fulfillment for the Requirements
of the Degree of Master of Science
in Civil Engineering (Structural)

Supervised by

Prof. Dr.
Ahmed Abdelsalam El-Serwi
Professor of Steel structures and Bridges
Structural Engineering Department
Faculty of Engineering
Ain Shams University

Dr.
Rimon Aziz Samaan
Assistant Professor
Structural Engineering
Department Faculty
of Engineering Ain
Shams University

Cairo – 2015

Examiners Committee

- 1. Prof Dr. Sherif Ahmed Morad** (.....)

Professor of steel structures and bridges,
Dean of Faculty of Engineering,
Cairo University.

- 2. Prof. Dr. Adel Helmy Salem** (.....)

Professor of Steel Structures
Faculty of Engineering
Ain Shams University

- 3. Prof. Dr. Ahmed Abdelsalam El-Serwi** (.....)

Professor of Steel Structures and Bridges
Structural Engineering Department
Faculty of Engineering
Ain Shams University

Acknowledgements

First and foremost, praise and thanks to Almighty Allah, the Most Gracious, the Most Merciful, and peace be upon His Prophet.

The author would like to express her deepest gratitude and appreciation to her supervisor, Prof. Dr. Ahmed Abdelsalam El-Serwi for his valuable guidance, support and encouragement.

She also greatly appreciates the help, guidance and support provided by Dr. Rimon Aziz Samaan throughout all stages of research.

Finally, the author would like to express her heartfelt appreciation to her father, my mother, for their lots of support and encouragement.

STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Master of Science in Structural Engineering.

The work included in this thesis has been carried out by the author in the period from Jan 2011 to Feb 2015.

No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

Date : / /

Signature :

Name : Riham Refaat El-Hadary

ABSTRACT

Bolted moment connections have been very popular due to their ease in fabrication and erection. However a clear understanding of the properties, interaction, and function of every single element is not clear due to their complex behavior.

In this research, an overall literature review has been conducted to identify the state of knowledge and gather the required data. An experimental program has also been conducted on five full scale specimens for rigid, large capacity, moment connections. Two specimens represent flushed end plate connections, other two specimens represent extended stiffened end plate connections and one specimen represent extended stiffened end plate connection. 3-D finite element models using ANSYS (ver.11) that accounts for both geometrical and material non-linearities are developed. Verification of the proposed finite element models has been performed by comparing their results with those of the performed experimental study as well as with the experimental work previously performed by other researches and showed good correlation. A parametric study is performed using the verified finite element model on bolted flushed and extended end plate large capacity moment connections. The studied bolt configurations in the tension side are three rows of bolts for extended and two rows of bolts for flushed end plate

connections with four bolts in one row. Three bolt configurations are studied: the first configuration represent connections without horizontal stiffeners, the second configuration represent connections with horizontal stiffeners below the first row of bolts under the tension beam flange, while the third configuration represents connections with stiffeners below the second row of bolts under the tension beam flange. The studied parameters are: end plate thickness and bolt diameter. In order to develop analytical design equations, regression analysis for the results is performed and design formulae are proposed for the connection bending capacity. Finally, a summary of the work carried out in this thesis, along with the general conclusions obtained from this study are presented.

Table of Contents

Abstract	v
Acknowledgement	vi
List of Tables	xii
List of Figures	xiii
Notations	xx

Chapter 1: INTRODUCTION

1.1 General	1
1.2 End Plate Connections.....	2
1.3 Aim of research	4
1.4 Methodology	4
1.5 Outline of the Dissertation.....	5

Chapter 2: LTERATURE REVIEW

2.1 General.....	8
2.2 Previous research.....	9
2.2.1 End Plate Design.....	9
2.2.1.1 Connections with two bolts in one row.....	11
2.2.1.2 Connections with four bolts in one row.....	14

2.2.2 Bolt Design and pryig force.....	15
2.2.2.1 Connections with two bolts in one row.....	16
2.2.2.2 Connections with four bolts in one row.....	19
2.2.3 Finite Element Modeling.....	21
2.2.3.1 Connections with two bolts in one row.....	21
2.2.3.2 Connections with four bolts in one row.....	23
2.2.4 Experimental Studies.....	24
2.2.4.1 Connections with two bolts in one row.....	25
2.2.4.2 Connections with four bolts in one row.....	25
CHAPTER 3: EXPERIMENTAL PROGRAM	
3.1 General.....	37
3.2 Test Setup.....	38
3.2.1 Column Description.....	38
3.2.2 Beam Description.....	39
3.2.3 End plate Description.....	40
3.2.3.1 Flushed Connections.....	40
3.2.3.2 Extended Unstiffened Connections.....	40
3.2.3.3 Extended Stiffened Connections.....	41
3.3 Material Properties.....	41
3.4 Instrumentations of the Tested Connections.....	41
3.4.1 Strain Gauges.....	41
3.4.1.2 Strain Gauges Used for Phases-1.....	42

3.4.1.3 Strain Gauges Used for Phases-2and phases-3.....	42
3.4.2 Load Cell.....	43
3.4.3 Dial Gauges.....	43
3.5 Test Procedures.....	43
3.6 Specimen description.....	43
3.7 Test Results.....	44
3.7.1 Experimental Results and Discussion of Phase-1.....	44
3.7.1.1 Results and Discussion of Specimen “F20”.....	44
3.7.1.2 Results and Discussion of Specimen “F32”.....	45
3.7.2 Experimental Results and Discussion of Phase-2.....	46
3.7.2.1 Results and Discussion of Specimen “ENS20”.....	46
3.7.2.2 Results and Discussion of Specimen “ENS32”.....	47
3.7.3 Experimental Results and Discussion of Phase-3.....	47
3.7.3.1 Results and Discussion of Specimen “ES20”.....	48
CHAPTER 4: FINITE ELEMENT MODEL	
4.1 Introduction	76
4.2 The Finite Element Method	77
4.3 Model Description	77
4.3.1 Shell Elements.....	78
4.3.2 Solid Element.....	78
4.3.3 Bolt Pretension Force.....	79
4.3.4 Contact element 178.....	79
4.4 Geometric Nonlinearity.....	80
4.4.1 Large Deflection Small Strain Analysis.....	81

4.5 Material Nonlinearity.....	81
4.5.1 Von Mises Yield Criterion.....	84
4.5.2 Modeling of Uniaxial Behavior in Plasticity.....	85
4.5.2.1 Stress-Strain Curve.....	86
4.6 Types of Adopted Finite Element Techniques.....	86
4.7 Finite Element Computer Program Adopted in the Current Study.....	87
4.8 Solution of the Non-Linear Equations.....	88
4.8.1 Static Analysis.....	88
4.8.2 Incremental Control Techniques.....	88
4.8.2.1 Force Control.....	88
4.9 Loads and Boundary Conditions.....	89

CHAPTER5: VERIFICATION OF EXPERIMENTAL AND FINITE ELEMENT MODEL

5.1 Introduction.....	98
5.2 Comparison between Finite Element model and Previous Experimental Results.....	98
5.2.1 Gang et al. (2008).....	98
5.2.1.1 Test specimen.....	98
5.2.1.2 Finite Element Mesh.....	99
5.2.1.3 Connection Rotation	100
5.2.1.4 Comparison between finite element model and experimental results.....	101
5.2.2 Sumner et al. (2003) Experimental Work.....	102

5.2.2.1 Test specimen.....	102
5.2.2.2 Finite Element Mesh.....	103
5.2.2.3 Comparison between finite element model and experimental results.....	104
5.2.3 Mohamed El-demerdash et al (2012) Experimental Work.....	107
5.2.3.1 Specimens Description.....	107
5.2.3.2 Finite Element Mesh.....	107
5.2.3.3 Comparison between finite element model and experimental results.....	107
5.3 Results of the Performed Experimental Programmer.....	109
5.3.1 Meshing of Performed Experimental Work.....	109
5.3.2 Comparing Results of the Finite Element Model to the Current Experimental Test Results.....	110
5.3.2.1 Phase-1 Specimens.....	111
5.3.2.1.1 Specimen “F20”.....	111
5.3.2.1.2 Specimen “F32”.....	112
5.3.2.2 Phase-2 Specimens.....	113
5.3.2.2.1 Specimen “ENS20”.....	113
5.3.2.2.2 Specimen “ENS35”.....	114
5.3.2.3 Phase-3 Specimens.....	114
5.3.2.3.1 Specimen “ES20”.....	115

CHAPTER6: PARAMETRIC STUDIES ON FLUSH END PLATE MOMENT CONNECTIONS

6.1 Introduction.....	145
6.2 Connection Specimen.....	145
6.3 Finite Element Model.....	148
6.4 Results.....	149
6.4.1. Configuration-1 “Case1”.....	149
6.4.1.1. Connection Moment Capacity.....	149
6.4.1.2. Distribution of External Tensile Force in Bolt.....	152
6.4.2. Configuration-2 “Case2”.....	155
6.4.2.1. Connection Moment Capacity.....	155
6.4.2.2. Distribution of External Tensile Force in Bolts.....	156
6.4.3. Configuration-3 “Case3”.....	156
6.4.3.1. Connection Moment Capacity.....	157
6.4.3.2. Distribution of External Tensile Force in Bolts.....	157
6.4.4 Comparison between Ultimate Moments Capacities for three configurations of Connections.....	158
6.4.5 Comparison between External Tensile Force for Three configurations with increasing end plate thickness and Bolt Diameter.....	159
6.4.6 Effect of Adding Stiffener on Deformed Shape of End Plate with Changing Bolt Diameter and End Plate Thickness for the three phases.....	160

CHAPTER7: PARAMETRIC STUYDY ON EXTENDED STIFFENED END PLATE MOMENT CONNECTIONS

7.1 Introduction.....	185
7.2 Connection Specimen.....	185
7.3 Finite Element Model.....	187

7.4 Results.....	188
Configuration-1 “Case1”.....	189
7.4.1.1. Connection Moment Capacity.....	189
7.4.1.2. Distribution of External Tensile Force in Bolts.....	190
7.4.2. Configuration-2 “Case2”.....	193
7.4.2.1. Connection Moment Capacity.....	193
7.4.2.2. Distribution of External Tensile Force in Bolts.....	193
7.4.3. Configuration-3 “Case3”.....	195
7.4.3.1. Connection Moment Capacity.....	195
7.4.3.2. Distribution of External Tensile Force in Bolt.....	196
7.4.4 Comparison between Ultimate Moments Capacities for Three Phases of Connection.....	197
7.4.5 Effect of Adding Stiffener on Deformed Shape of End Plate with Changing Bolt Diameter and End Plate Thickness for three phases.....	198
7.4.6Effect of Adding Stiffener on End Pate Deformed Shape.....	200
CHAPTER 8: PROPOSED DESIGN EQUATIONS AND CHARTS	
8.1 Introduction.....	232
8.2 Proposed Design Equation.....	233
8.2.1 Formation of Design Equation.....	234
8.2.2 Tabulated Values for the Proposed Equation Constants.....	234
8.2.2.1 Extended stiffened end plate connection.....	234
8.2.2.2 Flushed end plate connection.....	236

8.3 Bolt Diameter and Optimum End Plate Thickness Relations.....	237
8.4 Proposed Equation Accuracy.....	238
8.4.1 Accuracy of the Proposed Equation with Respect to Finite Element Analysis Results.....	238
8.5 Summary.....	239
CHAPTER 9: CONCLUSIONS	
9.1Summary	251
9.2Conclusions.....	252
9.3 Suggestions for future Researches.....	252

LIST OF TABLES

Table 3-1: Beam specimen dimension.....	43
Table 3-2: Loading capacity of experimental test.....	44
Table 5-1: Dimensions of verified specimens (mm) tested by Gang et al (2008).....	99
Table 5-2: Comparison between finite element model and experimental results by Gang et al (2008).....	101
Table 5-3: The dimensions for all specimens by sumner et al. (2003).....	104
Table 5-4: Comparison between finite element model and experimental results by Sumner et al. (2003).....	105
Table 5-5: Comparison between finite element model and experimental results by Mohamed El-demerdash et al. (2003).....	108
Table.5-6: The comparison between results of experimental tests and finite element model.....	110

Table 6-1: Ratio of ultimate moment capacities for different bolt diameters for connection with 50mm thick end plate.....	151
Table 6-2: Ratio of ultimate moment capacities for different bolt diameters for connection with 10mm thin end plate.....	151
Table 8 - 1: Equations Constants for Configuration-1.....	234
Table 8 - 2: Equations Constants for Configuration-2.....	235.
Table 8 - 3: Equations Constants for Configuration-3.....	235
Table 8 - 4: Equations Constants for Configuration-1.....	236
Table 8 - 5: Equations Constants for Configuration-2.....	236
Table 8 - 6: Equations Constants for Configuration-3.....	237

LIST OF FIGURES

(Fig.1.1): Connection with four rows of bolts.....	7
(Fig.1.2): Connection with only two rows of bolts.....	7
(Fig.1.3): Typical uses for end plate connections.....	8
(Fig.1.4): Examples of flush end plate connections.....	8
(Fig.1.5): Examples of extended end plate connections.....	8
(Fig.2.1): Flush, Header and Extended end plate connection.....	27
(Fig.2.2): Flushed and extended end plate connection by Salem et al (2010).....	27
(Fig.2.3): Initial imperfections in the end-plate by Gang et al (2006).....	28
(Fig.2.4) Extended end-plate connections by Maggi et al (2005).....	28
(Fig.2.5): Three failure modes of end plate thickness by Maggi et al (2005).....	29