

**Ministry of Higher Education  
and Scientific Research  
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College of Engineering**



# **Structural Behavior of Semi-Rigid Connections Plane Steel Frames**

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿وَيَسْأَلُونَكَ عَنِ الرُّوحِ قُلِ الرُّوحُ مِنْ أَمْرِ رَبِّي وَمَا أُوتِيتُمْ مِنَ الْعِلْمِ إِلَّا قَلِيلًا﴾

الاسراء (85)

*To My Mother.....*

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## Abstract

The beam column connection region is considered an important subject especially in terms of designing and analyzing steel frames. The beam-column connection behavior is in between the perfect pin and fully rigid case. This behavior of the connection is called semi-rigid connection. This study aims to investigate the effect of semi-rigid connection on the structural behavior of steel frames.

In this study, finite element method was used for the numerical analysis of semi-rigid connection of different cases. The ANSYS program is used for the finite element modeling. The semi-rigid connections were modeled as linear and non-linear elastic rotational spring, using COMBIN14 and COMBIN39 element. Two types of materials were used, linear elastic and non-linear elastic-plastic.

The numerical models produced by the finite element method were validated with the results of other studies achieved using different approaches to check the accuracy and validity of the analysis of finite element models. Due to the validation cases, it can be established that the finite element method is capable of simulating the behavior of steel frames with semi-rigid connections.

The case studies investigated are support type, number of stories, bracing and existence of lateral load in both linear and non-linear states. The behavior of bending moment diagram, shear force diagram, load capacity, load-displacement curve and moment-rotation curve were studied. In all cases, three different rotational stiffness were used to investigate the change of semi-rigid stiffness on the behavior of the frame.

The results have shown that the decrease in the stiffness of semi-rigid beam-column connection can increase the displacement of the frame and decrease the ultimate load capacity. In support type case, the results showed that if semi-rigid

beam-column connection is used with rotational stiffness of  $25EI/L$ ,  $15EI/L$  and  $10EI/L$  will increase the vertical displacement with percentage (11.64%, 11.54% and 16.0%) % respectively for pinned-pinned support type with non-linear stiffness.

In multi-story frame, if semi-rigid connection is used with stiffness  $10EI/L$ ,  $7EI/L$  and  $4EI/L$  can rise the horizontal displacement by (45.3%, 52.1% and 70.3%)% respectively for three stories frame and by (43.0%, 45.6% and 46.8%) % for five stories frame respectively.

The existence of bracing system can eliminate the influence of the beam-column connection with semi-rigid stiffness in the horizontal displacement, while changing from unbraced to braced frame can increase the vertical displacement by 4.4% in semi-rigid analysis of rotational stiffness  $10EI/L$ .

The existence of the lateral load can increase the effect of the semi-rigid beam-column connection and decrease the moment strength capacity.

The analysis of semi-rigid beam-column connection frames can indicate the realistic behavior of the frame. This process presents the importance of the beam-column connection with semi-rigid stiffness in the analysis and design of the steel frames for more accurate results.

# Table of Contents

<i>Acknowledgments</i> .....	VI
Abstract .....	VII
Table of Contents .....	IX
List of Figures .....	XI
List of Tables .....	XVII
List of Symbols .....	XIX
Chapter One .....	1
1.1 Introduction .....	1
1.2 Semi-Rigid Connections .....	1
1.3 Objectives .....	4
1.4 Scope .....	4
1.5 Methodology .....	4
1.6 Layout .....	5
Chapter Two .....	6
2.1 Introduction .....	6
2.2 Beam-Column Connection .....	6
2.3 Classification of Beam-Column Connection .....	7
2.4 The Connection of Semi-Rigid Framing in Designing Specification and Standards .....	8
2.5 Mathematical Modeling of Semi-Rigid Connection .....	9
2.5.1 Linear Model .....	9
2.5.2 Polynomial Model .....	10
2.5.3 Three Parameter Model .....	12
2.5.4 Four – Parameter Power Model .....	13
2.6 Previous Studies on Semi-Rigid Connections .....	14
2.7 Summary .....	24
Chapter Three .....	25
3.1 Introduction .....	25
3.2 Formulation of Stiffness Matrix of Regular Finite Element Model .....	26
3.3 ANSYS Computer Program .....	29

3.4 Finite Element Modeling of the Numerical Model -----	30
Chapter Four -----	32
4.1 Introduction-----	32
4.2 Numerical Models -----	32
4.2.1 One bay – one story frame with linear analysis -----	32
4.2.2 One-bay one-story frame with non-linear analysis-----	37
4.2.3 Two-bay six story frame-----	45
Chapter Five-----	53
5.1 Introduction-----	53
5.2 Linear Analysis of Semi-Rigid Beam-Column Connection -----	53
5.2.1 Effect Semi-Rigid Beam-Column Connection on Different Support Type -----	53
5.2.2 Semi-Rigid Beam-Column Connection Effect on Different Story Number -----	67
5.3 Non-Linear Analysis of Semi-Rigid Beam-Column Connection (Yan Model) -----	78
5.3.1 Semi-Rigid Beam-Column Connection Effect on Different Support Type -----	79
5.3.2 Yan model (Non - Linear Behavior of Beam-Column Connection with Semi-Rigid Stiffness) -----	94
5.4 Semi-Rigid Beam-Column Connection Effect on Bracing of Frame-----	106
5.4.1 One Bay One Story Frame -----	106
5.4.2 Two-Bay One-Story Frame-----	111
5.5 Semi-Rigid Beam-Column Connection Effect on Multi-Story Building with Different Lateral Loading Cases-----	118
5.5.1 Semi-Rigid Beam-Column Connection Effect on One-Bay Four-Story Frame with Lateral Load-----	118
5.5.1 One-Bay Four-Story Frame Without Lateral Load-----	124
5.6 summary of the numerical analysis -----	129
Chapter Six -----	130
6.1 Conclusions-----	130
6.2 Recommendations -----	131
References:-----	132
APPENDIX A -----	1
APPENDIX B -----	1
المستخلص-----	175



## List of Figures

Figure (1-1): Moment-rotation relationship of the beam-column connection proposed by (Chen and Lui, 1987). .....	2
Figure (1-2): Moment-relative rotation relationship. ....	3
Figure (2-1): Beam-column connection deformation (Khalifa, 2011). ....	7
Figure (2-2): Moment – rotation behavior for various beam-column connection (Xu 2005). .	8
Figure (2-3): Semi-Rigid representation and effects according to the three-parameter model (Xu 2005). ....	13
Figure (2-4): Four – parameter model of semi-rigid connection. ....	14
Figure (3-1): Flow chart diagram of modeling process in ANSYS. ....	31
Figure (4-1): One bay – one story steel frame (Chan and Chui, 2000). ....	33
Figure (4-2): Finite element model of one bay – one story frame. ....	33
Figure (4-3): Bending moment diagram for the numerical model of ANSYS with rigid connection. ....	34
Figure (4-4): Bending moment diagram of rigid connection model (Chan and Chui, 2000). .	34
Figure (4-5): Structural model illustrate the location of the torsional springs used in the numerical model, where $k_b$ is the rotational stiffness of beam-column connection. ....	36
Figure (4-6): Bending moment diagram for the numerical model of ANSYS with semi-rigid connection. ....	36
Figure (4-7): Bending moment diagram provided from (Chan, and Chui, 2000) with semi-rigid connection. ....	37
Figure (4-8): One-bay one-story frame structure model with non-linear properties (Yan, 2007). ....	38
Figure (4-9): Stress-strain curve for steel material. ....	39
Figure (4-10): Moment-Rotation curves for the numerical model of beam-column connection (Yan, 2007). ....	40
Figure (4-11): Implementation of COMBIN39 in the numerical model (Yan, 2007). ....	40
Figure (4-12): Modelling of one bay – one story structure with non-linear analysis. ....	41
Figure (4-13): Load-Displacement curve at the top left corner (node 2) in x-direction for rigid connection model. ....	42
Figure (4-14): Deflected shape in x-direction of one-story one-bay with rigid connection at critical loads (Yan, 2007). ....	42

Figure (4-15): Load-Displacement curve at the top left corner (node 2) in x-direction for semi-rigid connection model.....	43
Figure (4-16): Deflected shape in x-direction of one-story one-bay non-linear semi-rigid connection at critical loads (Yan, 2007). .....	43
Figure (4-17): Bending moment diagram for the numerical model of ANSYS with rigid connection. ....	44
Figure (4-18): Bending moment diagram for the numerical model of ANSYS with semi-rigid connection. ....	44
Figure (4-19): Geometry and loading of Vogel calibration frame (Vogel, 1985). ....	46
Figure (4-20): Bending moment diagrams of two- bay six-story frame for finite element analysis with rigid beam-column connection. ....	48
Figure (4-21): Bending moment diagrams of two- bay six-story frame for finite element analysis with semi-rigid beam-column connection.....	49
Figure (4-22): Bending moment diagrams of 6-story frame for finite element analysis with rigid beam-column connection (Chan and Chui, 2000).....	50
Figure (4-23): Bending moment diagrams of 6-story frame for finite element analysis with semi-rigid beam-column connection (Chan and Chui, 2000).....	51
Figure (4-24): Load-displacement curve for the horizontal displacement at node 39 of the frame. ....	52
Figure (5-1): One bay – one story steel frame (Chan and Chui, 2000) with fixed-fixed support.....	54
Figure (5-2): Rotational joint stiffness value effect on load-vertical displacement at node 3 of Chan and Chui frame with fixed-fixed support type. ....	55
Figure (5-3): Rotational joint stiffness value effect on load-horizontal displacement at node 4 with fixed-fixed support type.....	56
Figure (5-4): Moment-Rotation curve of semi-rigid beam-column connection at node 2, with different stiffness values for fixed-fixed support type.....	57
Figure (5-5): One bay – one story steel frame (Chan and Chui, 2000) with fixed-pinned support.....	58
Figure (5-6): Rotational joint stiffness value effect on load-vertical displacement at node 3 fixed-pinned support type. ....	59

Figure (5-7): Rotational joint stiffness value effect on load-horizontal displacement at node 4 fixed-pinned support type. ....	60
Figure (5-8): Moment-Rotation curve of semi-rigid beam-column connection at node 2, with different stiffness values for fixed-pinned support type. ....	61
Figure (5-9): One bay – one story steel frame (Chan and Chui, 2000) with pinned-pinned support.....	63
<i>Figure (5-10): Rotational joint stiffness value effect on load-vertical displacement at node 3 pinned-pinned support type.....</i>	<i>64</i>
Figure (5-11): Rotational joint stiffness value effect on load-horizontal displacement at node 4 pinned-pinned support type.....	65
Figure (5-12): Moment-Rotation curve of semi-rigid beam-column connection at node 2, with different stiffness values for pinned-pinned support type. ....	65
Figure (5-13): Load-vertical displacement at different support type at 10 EI/L for Chan and Chui model.....	67
Figure (5-14): Geometry and loading of braced one-bay three-story frame.....	68
Figure (5-15): Load-displacement curve in y-direction at node 10 with different stiffness values of one-bay three-story frame. ....	70
Figure (5-16): Load-displacement curve in x-direction at node 11 with different stiffness values of one-bay three-story frame. ....	71
Figure (5-17): Moment-Rotation curve of semi-rigid beam-column connection at node 9, with different stiffness values for one-bay three-story frame of Chan and Chui model.....	72
<i>Figure (5-18): Geometry and loading of braced one-bay five-story frame. ....</i>	<i>74</i>
Figure (5-19): Load-displacement curve in y-direction at node 16 with different stiffness values of one-bay five-story frame. ....	75
Figure (5-20): Load-displacement curve in x-direction at node 17 with different stiffness values of one-bay five-story frame. ....	77
Figure (5-21): Moment-Rotation curve of semi-rigid beam-column connection at node 15, with different stiffness values of three-story frame of Chan and Chui model.....	77
Figure 5-22): One bay – one story steel frame (Yan, 2007) with fixed-fixed support. ....	80
Figure (5-23): Rotational joint stiffness value effect on load-vertical displacement at node 3 of Yan frame with fixed-fixed support type. ....	80

Figure (5-24): Rotational joint stiffness value effect on load-horizontal displacement at node 4 of Yan frame with fixed-fixed support type. ....	82
Figure (5-25): Moment-Rotation curve of semi-rigid beam-column connection at node 2, with different stiffness values for fixed-fixed support type of Yan model.....	83
<i>Figure (5-26): One bay – one story steel frame (Yan, 2007) with fixed-pinned support. ....</i>	<i>85</i>
Figure (5-27): Rotational joint stiffness value effect on load-vertical displacement at node 3 of Yan model fixed-pinned support type. ....	86
Figure (5-28): Rotational joint stiffness value effect on load-horizontal displacement at node 4 of Yan model fixed-pinned support type. ....	86
Figure (5-29): Moment-Rotation curve of semi-rigid beam-column connection at node 2, with different stiffness values for fixed-pinned support type of Yan. ....	87
Figure (5-30): One bay – one story steel frame (Yan, 2007) with pinned support.....	90
Figure (5-31): Effect of rotational joint stiffness value on load-vertical displacement at mid span of Yan model pinned-pinned support type. ....	91
Figure (5-32): Rotational joint stiffness value effect on load-horizontal displacement at node 4 of Yan model pinned-pinned support type.....	92
<i>Figure (5-33): Moment-Rotation curve of semi-rigid beam-column connection at node 2, with different stiffness values for pin-pin support type of Yan. ....</i>	<i>92</i>
Figure (5-34): Load-vertical displacement at different support type at 10 EI/L for Yan model. ....	94
Figure (5-35): Geometry and loading of braced one-bay three-story frame (Yan Model).....	96
Figure (5-36): Modeling of one-bay three-story frame in ANSYS with non-linear semi-rigid beam-column connection. ....	96
<i>Figure (5-37): Load-displacement curve in y-direction at node 10 with different stiffness values of one-bay three-story frame. ....</i>	<i>97</i>
Figure (5-38): Load-displacement curve in x-direction at node 11 with different stiffness values of one-bay three-story frame. ....	98
Figure (5-39): Moment-Rotation curve of semi-rigid beam-column connection at node 9, with different stiffness values for one-bay three-story frame of Yan model.....	99
Figure (5-40): Geometry and loading of braced one-bay five-story frame (Yan Model).....	101
Figure (5-41): Modeling of one-bay five-story frame in ANSYS with non-linear semi-rigid beam-column connection. ....	101

Figure (5-42): Load-displacement curve in y-direction at node 16 with different stiffness values of the frame.....	103
Figure (5-43): Load-displacement curve in x-direction at node 17 with different stiffness values of the frame.....	104
Figure (5-44): Moment-Rotation curve of semi-rigid beam-column connection at node 15, with different stiffness values for one-bay five-story frame of Yan model.....	105
Figure (5-45): Modeling of braced one-bay one-story frame in ANSYS.....	107
Figure (5-46): Effect of rotational joint stiffness on Load-horizontal displacement at point 4 for braced one-bay one-story frame.....	108
Figure (5-47): Effect of rotational joint stiffness on Load-vertical displacement at point 3 for braced one-bay one-story frame.....	108
Figure (5-48): Moment-Rotation curve of semi-rigid beam-column connection at node 2, with different stiffness values for braced one-bay one-story frame. ....	110
Figure (5-49): Geometry and loading of braced two-bay one-story frame.....	112
<i>Figure (5-50): Modeling of braced two-bay one-story frame in ANSYS. ....</i>	112
Figure (5-51): Load-displacement curve in y-direction at point (F) with different stiffness values for unbraced frame.....	114
Figure (5-52): Load-displacement curve in y-direction at point (F) with different stiffness values for braced frame.....	114
<i>Figure (5-53): Deformed shape of braced semi-rigid frame with <math>(10EI/L)</math> rotational stiffness. ....</i>	115
Figure (5-54): Load-displacement curve in x-direction at point (G) with different stiffness values for unbraced frame.....	115
Figure (5-55): Load-displacement curve in x-direction at point (G) with different stiffness values for braced frame.....	116
Figure (5-56): Moment-Rotation curve of semi-rigid beam-column connection at node B, with different stiffness values for unbraced two-bay one-story frame. ....	116
Figure (5-57): Moment-Rotation curve of semi-rigid beam-column connection at node B, with different stiffness values for braced two-bay one-story frame. ....	117
Figure (5-58): Geometry and loading of one-bay four-story frame with lateral load.....	119
Figure (5-59): Modeling of one-bay four-story frame in ANSYS with linear semi-rigid beam-column connection and lateral load. ....	120

<i>Figure (5-60): Load-displacement curve in y-direction at node 13 with different stiffness values of the frame with lateral load. ....</i>	121
Figure (5-61): Load-displacement curve in x-direction at node 14 with different stiffness values of the frame with lateral load.....	122
Figure (5-62): Moment-Rotation curve of semi-rigid beam-column connection at node 12, with different stiffness values with lateral load. ....	123
Figure (5-63): Modeling of one-bay four-story frame in ANSYS with linear semi-rigid beam-column connection and lateral load. ....	124
Figure (5-64): Load-displacement curve in y-direction at node 13 with different stiffness values of the frame without lateral load.....	125
Figure (5-65): Load-displacement curve in x-direction at node 14 with different stiffness values of the frame without lateral load.....	127
Figure (5-66): Moment-Rotation curve of semi-rigid beam-column connection at node 12, with different stiffness values without lateral load. ....	127

## List of Tables

Table (2-1): Types of the connection according to the rotational stiffness, AISC. ....	9
Table (2-2): Polynomial model factors computed from least square method.....	11
Table (4-1): Bending moment magnitudes at different nodes of one story – one bay frame rigid connection. ....	35
Table (4-2): Bending moment magnitudes at different nodes of one story – one bay frame semi-rigid connection.....	37
Table (4-3): Section properties. ....	38
Table (4-4): Analysis Results.....	43
Table (4-5): Section properties. ....	47
Table (4-6): Maximum bending moment magnitudes (kN-m) at different points of the frame. ....	50
Table (5-1): Rotational joint stiffness effect on vertical and horizontal displacement and maximum bending moment. ....	55
Table (5-2): Rotational joint stiffness effect on vertical and horizontal displacement and maximum bending moment. ....	59
Table (5-3): Rotational joint stiffness effect on vertical and horizontal displacement and maximum bending moment. ....	63
Table (5-4): Rotational joint stiffness effect on vertical and horizontal displacement and on the maximum moment of three-story frame. ....	69
Table (5-5): Rotational joint stiffness effect on vertical and horizontal displacement and on the maximum moment of five story frame. ....	76
Table (5-6): Rotational joint stiffness effect on vertical and horizontal displacement and maximum bending moment with fixed-fixed support. ....	81
Table (5-7): Rotational joint stiffness effect on vertical and horizontal displacement and maximum bending moment with fixed-pinned support.....	85
Table (5-8): Rotational joint stiffness effect on vertical and horizontal displacement and maximum bending moment with pinned-pinned support. ....	90
Table (5-9): Rotational joint stiffness effect on vertical and horizontal displacement and on the maximum moment of three-story frame. ....	97
Table (5-10): Rotational joint stiffness effect on vertical and horizontal displacement and on the maximum moment of five-story frame. ....	103

Table (5-11): Rotational joint stiffness effect on vertical and horizontal displacement and maximum bending moment of braced and unbraced frame.....	109
Table (5-12): Section properties. ....	112
Table (5-13): Effect of rotational joint stiffness on vertical displacement at point (F) of braced and unbraced frame. ....	113
Table (5-14): Rotational joint stiffness effect on vertical and horizontal displacement and on the maximum moment of four-story frame with lateral load.....	121
Table (5-15): Rotational joint stiffness effect on vertical and horizontal displacement and on the maximum moment of four-story frame.....	126
Table (5-16): Summary of the maximum displacement for different case studies.....	130



## List of Symbols

Symbol	Meaning
$A^s$	Shear area
$A$	Cross section area of the element
$[B]$	Strain-displacement relationship for nodal
$[D]$	Constitutive matrix (the elasticity stiffness matrix)
$dv$	Infinitesimal volume of the element
$E$	Modulus of elasticity for the material modeled
$EI$	Flexural rigidity
$F^s$	Shear deflection constant
$F_1$	Force element from pervious iteration
$\{F_i^n\}$	restoring load vector corresponding to the element internal loads
$\{F\}$	Force vector applied at the node of element
$G$	Shear modulus of elasticity
$I$	Moment of inertia
$K$	Stiffness of the connection area
$[K_i^T]$	Jacobian matrix (tangent matrix)
$[K^e]$	Stiffness matrix of the element
$[K]$	Overall stiffness matrix of the structure
$M$	Applied moment
$M_0$	Reference moment
$[N]$	Shape function matrix
$n$	Shape parameter
$R_{Ki}$	Tangent connection stiffness
$R_e$	Initial stiffness of the connection
$R_p$	Plastic stiffness
$\{R\}$	Residual vector
$[u]$	Nodal displacement vector
$\{U\}$	Global body displacement vector
$W_{int}$	internal work (strain energy)

$W_{ext}$	external work done by the applied force
$\Theta$	Rotation of the connection
$\lambda$	Rigidity index
$\{\partial_\varepsilon\}^T$	Elements of virtual strain vector
$\{\sigma\}$	Elements of real stress vector
$\{\varepsilon\}$	Strain vector
$\mu$	Frame imperfection

# Chapter One

## Introduction

### 1.1 Introduction

Steel structures are widely used in the recent years. The steel structures usually consist of beams, columns and the connections between them. The connection between columns and beams have an important role of the behavior of steel structures. In most engineering designs, the beam-column connections are assumed to be perfect rigid or fully pinned connection, however, in actual practice, there is no perfect rigid connection or fully pinned connection. The rigid connection can provide flexibility and pinned connection can provide rigidity. In other words, the behavior of the connection can fall between the rigid and pinned behavior and the beam-column connection should be considered as connection with semi-rigid rotational stiffness connections (Dave and Savaliya, 2010).

### 1.2 Semi-Rigid Connections

Steel frames consist of beams, columns and beam-column connections. Beam-column connections transfer the forces and moments from beam to column including axial forces, shear forces and bending moments. Theoretically, there are two main types of connections; fully rigid connections and fully pinned connections. The rotation of bolted and welded connections can relate to the moment applied of the connection, which is led to the fact that there is no rigid or pinned connections. However, there is a rotational stiffness with different values that can make the behavior of the connection either close to rigid or simple connection, this behavior is called semi-rigid beam-column connection (Khalifa, 2011).

Figure (1-1) shows the behavior of the beam-column connections (Chen and Lui, 1991). Where  $\theta$  is the rotation deformation occurred in joint area of the beam and

column between the beam and column,  $M$  is the moment applied and  $K$  is the rotational stiffness.

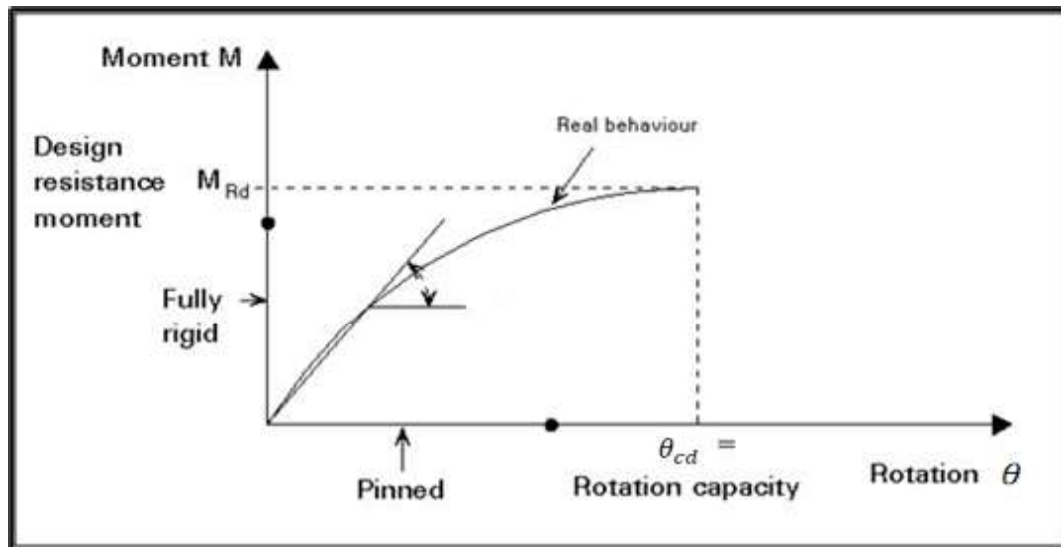


Figure (1-1): Moment-rotation relationship of the beam-column connection proposed by (Chen and Lui, 1987).

The behavior of pinned connection can be represented by the  $\theta$ -axis of the figure and  $M = 0$ , and the fully-rigid connection is represented by the  $M$ -axis with  $\theta = 0$ . The semi-rigid connection can be represented by the curve lying between these two axes, with allowing the moment to transferred from the beam to the column and rotation in the connection (Kruger et. al., 1995). (Yan, 2007) classified the beam-column connection into three categories as shown in Figure (1-2). Experiments indicated that the  $M$ -  $\theta$ , curve have non-linear behavior for all types of connection. This can represent the importance of beam-column connection on the design basis of steel structures. Moreover, the simplest method for modeling the behavior if beam-column connection is linear model which will be used for this study.

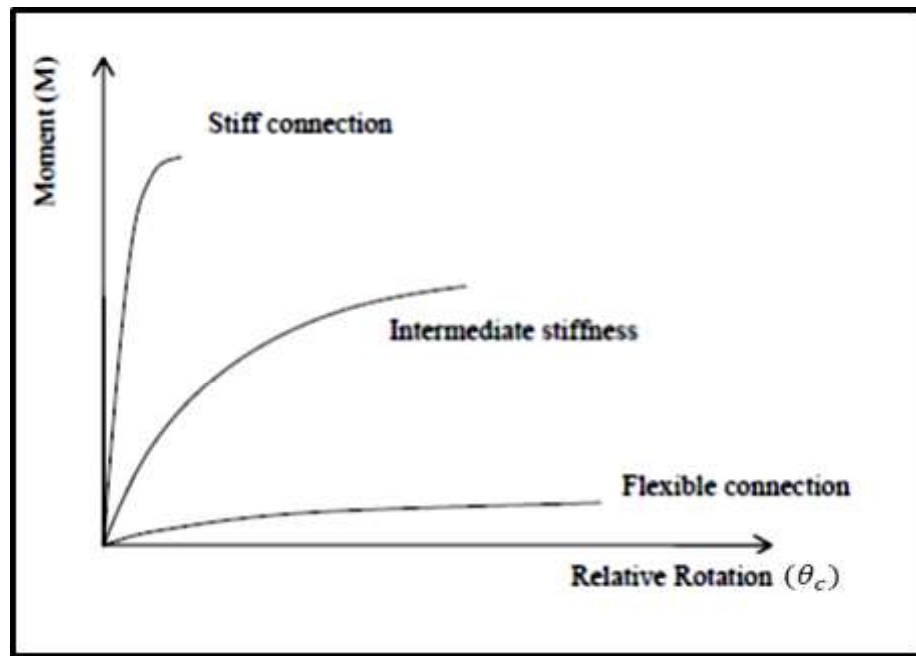


Figure (1-2): Moment-relative rotation relationship.

The identified rotational beam-column connection stiffness can have a big influence on the total behavior of the structure. If the beam-column connection is ignored, the behavior of the structure will approach ideal response which will give inaccurate results comparing with behavior of semi-rigid connection with realistic rotational stiffness (Mohammed, and Ismael, 2019). The influence of connection must be considered in engineering practice (Rezaiee-Pajand, M. et.al., 2011).

(Yan, 2007) stated that if the connection stiffness is ignored in the analysis the predicated response is unrealistic compared to that of actual structure.

Nethercot, et al., (1998) Kapgate and Kadam (2015) stated that the investigations with experiments specimens on the behavior of steel connections show that simple connections may have some rotation stiffness, while rigid connections may have some flexibility properties. Bending moment transformation among members is related to the function of the relative rotation change.

### **1.3 Objectives**

Most of steel structural analysis is calculated with ignoring the actual behavior of the beam-column connection. This might outcome with inaccurate results leading to economic and safety effects. In reality the connections behavior is between the rigid and fully flexible behavior. This study investigates the behavior of semi-rigid connection frames and its effects on the load, bending moment shear force, load displacement, and the ultimate displacement of the frame.

at the joint area with different parametric studies such as:

- 1- Support type (fixed-fixed, fixed-pinned and pinned-pinned).
- 2- State of bracing (braced and unbraced).
- 3- Number of frame stories.
- 4- Presence of lateral load

### **1.4 Scope**

The scope of study can be limited to the following:

- 1- Two-dimensional plane frame.
- 2- Semi-rigid beam-column connection.

### **1.5 Methodology**

Previous analyses and experiments were applied on investigation of the beam-column connection. The numerical analysis in this study were compared and validate for accuracy with other researches. Three main models were used for the validation of the finite element numerical model. The second part of the thesis was concerned on the investigation of the beam-column connection with semi-rigid stiffness on different cases such as support type, bracing status, number of stories and lateral load existence. The stiffness of the semi-rigid connection was chosen in a range that can represent the effect of the semi-rigid connection on the

behavior of the beam. The results of the semi-rigid connection frame will be studied and compared with the results obtained from the rigid connection frame.

## **1.6 Layout**

The thesis consists of six chapters, which are as follows:

**Chapter one:** It includes an introduction on the semi-rigid beam-column connection and justification, methodology and layout of the thesis.

**Chapter two:** It discusses the literature review of the semi-rigid beam-column connection and the types of connection numerical models.

**Chapter three:** It describes the finite element numerical methods and the elements used in the numerical analysis of rigid and semi-rigid connection in both linear and non-linear analysis.

**Chapter four:** It includes the validation of the numerical analysis used in this study.

**Chapter five:** It includes the cases that was investigated in the thesis in details, with the comparison of the results with the rigid case.

**Chapter six:** It represents the conclusions, recommendations and suggestions for future studies.