**Ministry of Higher Education**
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**University of Diyala**
**College of Engineering**

# Structural Behavior of Semi-Rigid Connections Plane Steel Frames

A Thesis Submitted to Council of College of Engineering, the University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

**By**

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بسم الله الرحمن الرحيم

﴿وَيَسْأَلُونَكَ عَنِ الرُّوحِ قُلِ الرُّوحُ مِنْ أَمْرِ رَبِّي وَمَا
أُوتِيتُم مِّنَ الْعِلْمِ إِلَّا قَلِيلًا﴾

الإسراء (85)

*To My Mother.......*

*Acknowledgments*

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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.

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# 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 |
| Θ | Rotation of the connection |
| λ | Rigidity index |
| $\{\partial_{\varepsilon}\}^T$ | Elements of virtual strain vector |
| $\{\sigma\}$ | Elements of real stress vector |
| $\{\varepsilon\}$ | Strain vector |
| μ | 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.

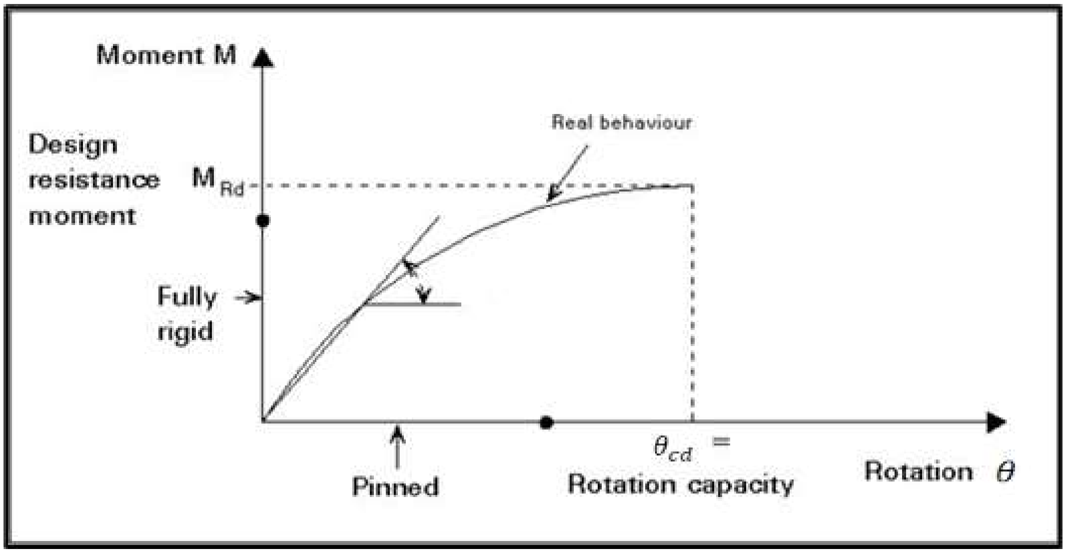


*Figure (1-1)*: *Moment-rotation relationship of the beam-column connection proposed by (Chen and Lui, 1987).*

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.

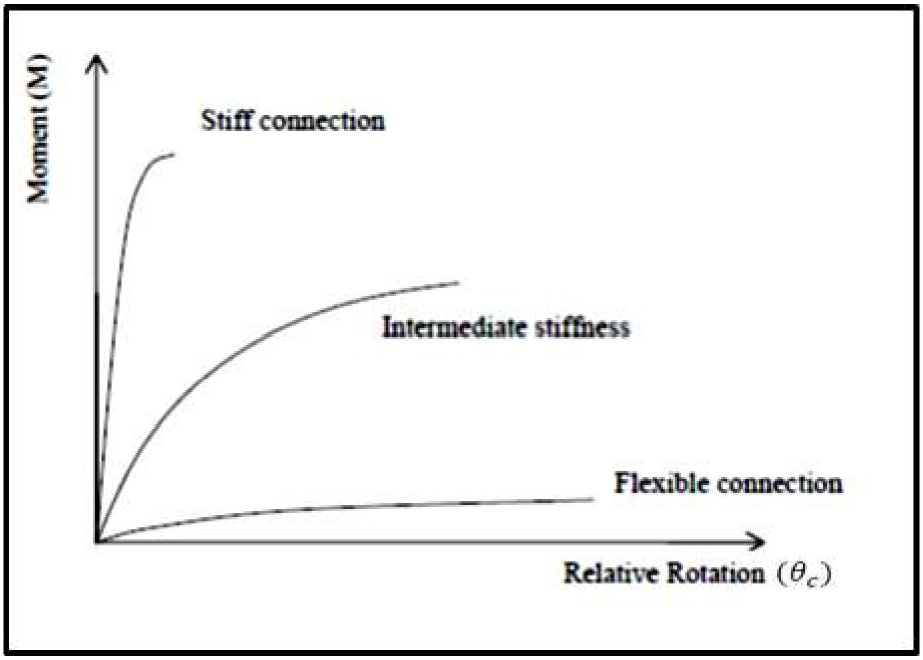


*Figure (1-2): Moment-relative rotation relationship.*

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.