

PERPUSTAKAAN UMP



0000092779

SEMI-RIGID BEAM TO COLUMN CONNECTION UNDER STATIC LOADING
USING ABAQUS

NORLINA BINTI MUHAMAD NOR

Report submitted in partial fulfilment of the requirements for the award of the degree of
B. Eng (Hons.) Civil Engineering

Faculty of Civil Engineering and Earth Resources

UNIVERSITI MALAYSIA PAHANG

JUNE 2014

ABSTRACT

The connection of beam to column is very essential especially to transfer and distributes the load as well as contributing in the rigidity of the overall structures. A proper design of connection between members is very important for a steel structure to perform its best in sustaining load. As the performance of computers were increasing widely and the availability of computer software, the use of the finite element method (FEM) possible in the current research and design activity. The objectives of this study are to model and simulate a 3D beam to column connection under static loading; to understand the behavior of the connection from moment-rotation graph and obtained the displacement, stiffness and rotation from the graph as well as to determine the types of failure in the connection. This paper presents the semi-rigid beam to column connections using fasteners by using the ABAQUS finite element software code; since Finite Element Analysis (FEA) offers the feasibility to simulate the actual behavior of the joints beam to column connection at low costs and short period of time compared with the experimental tests. A specimen using top and seat angle (SRC-3A) over 6 specimens in previous experimental by Khaled and Suswanto in 2013 was simulated and tested using static loading and the results obtained after the numerical simulation were compared with the experimental data in order to validate the model. Based on the result analysis of moment-rotation, it can be concluded that the connection lies in semi-rigid even though the stiffness of the model in simulation is high compared to experimental which impact to the largest moment of capacity. Lastly, the modes of failure for specimen SRC3-A have been determined which are due to buckling at column flange and plate exactly as in experimental.

ABSTRAK

Sambungan rasuk ke tiang adalah sangat penting terutama untuk memindahkan dan mengedarkan beban dan juga untuk menyumbang kepada ketegaran keseluruhan struktur. Satu reka bentuk yang betul sambungan antara struktur-struktur adalah amat penting bagi struktur keluli untuk melakukan yang terbaik dalam mengekalkan beban. Oleh kerana prestasi komputer telah meningkat secara meluas dan ketersediaan perisian komputer, penggunaan Kaedah Elemen Unsur Terhingga (KEUT) memungkinkan aktiviti penyelidikan ini dan aktiviti reka bentuk. Objektif kajian ini adalah untuk memodel dan mensimulasi 3 dimensi sambungan ke tiang di bawah beban statik; untuk memahami kelakuan sambungan daripada graf momen-putaran dan mendapat anjakan, kekakuan dan putaran daripada graf dan juga untuk menentukan jenis kegagalan dalam sambungan. Kajian ini membentangkan sambungan rasuk separa tegar untuk turus dengan pengikat dengan menggunakan unsur kod perisian ABAQUS; sejak Analisis Unsur Terhingga (AUT) menawarkan kemungkinan untuk mensimulasikan kelakuan sebenar rasuk sendi untuk sambungan tiang pada kos yang rendah dan masa yang singkat berbanding dengan ujian eksperimen. Satu spesimen daripada 6 spesimen dalam eksperimen sebelum ini dengan menggunakan sambungan sudut atas dan bawah (SRC-3A) telah simulasi dan diuji menggunakan pembebanan statik dan keputusan yang diperolehi selepas simulasi berangka telah dibandingkan dengan data uji kaji bagi mengesahkan model. Berdasarkan analisis keputusan graf momen-putaran, ia boleh disimpulkan bahawa sambungan terletak dalam sempadan separa tegar walaupun kekukuhan model dalam simulasi adalah lebih tinggi berbanding dengan eksperimen dimana ia memberi impak ke saat terbesar kapasiti. Akhir sekali, kegagalan spesimen SRC3-A telah disebabkan oleh lengkungan di ruangan bebibir plat dan kegagalan yang diperolehi adalah seperti di dalam eksperimen.

TABLE OF CONTENTS

	Page
SUPERVISOR'S DECLARATION	ii
STUDENT'S DECLARATION	iii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
ABSTRACT	vi
ABSTRAK	vii
TABLE OF CONTENTS	viii
LIST OF TABLES	x
LIST OF FIGURES	xi
CHAPTER 1 INTRODUCTION	
1.1 Background of Study	1
1.2 Problem Statement	2
1.3 Objectives	3
1.4 Scope of Study	3
CHAPTER 2 LITERATURE REVIEW	
2.1 Classification on Connection	5
2.2 General Type of Beam to Column Connection	8
2.2.1 Top and Seat Angle Connection	8
2.2.2 Double Web Angle Connection	9
2.2.3 Top-Seat Angle with Double Web Angle Connection	9
2.3 Loads on Structure	10
2.4 Behavior of Connection	12
2.4.1 Ductility	13
2.4.2 Stiffness	15
2.4.3 Modes of Failure	16
2.5 Finite Element Method	18

CHAPTER 3 RESEARCH METHODOLOGY

3.1	Introduction	19
3.2	Experimental Program Details	20
3.3	Simulation Program Details	20
	3.3.1 Material Properties and Modeling	20
3.4	Simulation Procedure	23
	3.4.1 Preprocessing	24
	3.4.2 Analysis	29
	3.4.3 Visualization	29
3.5	Moment Displacement and Moment Rotation Graph	30

CHAPTER 4 RESULTS AND DISCUSSION

4.1	Moment Displacement	32
4.2	Moment Rotation and Stiffness	32
4.3	Modes of Failure	34
4.4	Performance of the Connection	35
4.5	Factor Contribute to Dissimilarities	35
	4.5.1 Type of meshing	36
	4.5.2 Sliding of bolt	38
	4.5.3 Mechanical properties	38
	4.5.4 Contact interaction between surfaces	38

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1	Conclusion	40
5.2	Recommendations	41
	REFERENCES	42

LIST OF TABLES

Table No.	Title	Page
3.1	Structural steels and bolts used of the specimen	20
3.2	Material properties of the model	25
3.3	Increment size of the model	26
3.4	Number of mesh of the model	28
4.1	Summarization performance of the model	35
4.2	Surface interaction	39

LIST OF FIGURES

Figure No.	Title	Page
2.1	Moment Diagrams for Uniform Loading	6
2.2	Minimum Natural Frequency for Beams of Uniform Mass	6
2.3	Classes of beam to column connection	7
2.4	Top and seat angle connection	8
2.5	Double web angle connection	9
2.6	Top-seat angle with double web angle connection	9
2.7	Connection moment-rotation curve	10
2.8	Monotonic and cyclic loading graph for load versus time	11
2.9	Rotational deformation of a connection	12
2.10	Stress-strain curve	13
2.11	A typical stress-strain curve for steel	14
2.12	A typical stress-strain curve for ductile material	14
2.13	Failure modes for semi-rigid connection	16
2.14	Deformation of seat angle	17
3.1	Abaqus software interface	19
3.2	Detail of beam to column specimen	21
3.3	Detail of top and seat angle connection	21
3.4	Abaqus part methodology	22
3.5	Sequence module of Abaqus	22
3.6	Abaqus module in context bar	23
3.7	Consistent units (Abaqus Manual 6.10)	23
3.8	Part created for the model	24
3.9	Assembled model of beam to column connection	26
3.10	Surface to surface contact interaction	27
3.11	Load and boundary condition applied at beam to column connection	27
3.12	Meshing of beam to column connection	28
3.13	Job monitor in simulation analysis	29
3.14	Moment displacement graph of experimental	30

3.15	Moment rotation graph of experimental	31
4.1	Moment Displacement Relationship Graph	33
4.2	Moment rotation relationship graph	33
4.3	Buckling at column flange	34
4.4	Buckling at plate	35
4.5	Stress distribution at beam to column connection	36
4.6	Fine meshing of beam to column connection	37
4.7	Coarse meshing of beam to column connection	37
4.8	Graph of comparison between type of meshing	37

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The behavior of steel bolted connections continually to be an issues in the steel construction field. The rigidity of the structures could be one of the factors as the structure is too rigid, there are no allowances for the structures to deform to an allowable limit or to respond accordingly to loads particularly at the connection between beam to the column. In practice, connections are usually assumed as either rigid or pinned while in reality, every connection that lies in between these two connections are called semi-rigid or partially restrained connections.

Semi-rigid connections with angles connecting to the web and flanges of the beam and to the column flange are more affordable and uncomplicated to assemble when compared to other joint. Therefore, the use of semi-rigid connections using bolted angles is justified as from previous study, rigid connections are seems to be more expensive and difficult to assemble and this connections also do not have the enough resistance and stiffness to resist the lateral loads.

Semi-rigidity is required in understanding the behavior of connections. According to Demirtas in 2003, semi-rigidity could be used to reduce fixed end moments in rigid connections consequence in an economic benefit. It can be applied to simple connections to increase stiffness and serviceability. In addition, semi-rigidity also can be used to obtain intermediate-strength in the connection. These apparent advantages of semi-rigid connections over typical rigid and simple connections becomes

a disadvantage if the engineer is not provided with the right analysis and design tools (Chen, Yoshiaki and Richard, 1996).

The design of semi-rigid steel frames depends on the joint characteristics, which is the moment-rotation model. This work indicates a great number of experimental tests which resulting a great cost of time and money. By starting from this view point, the Finite Element (FE) method such as ABAQUS software which used in this study represents an interesting alternative to predict the proper and relevant moment-rotation model as well as to analyze the behavior of angle connections under various loading conditions. However, much attention should be given to the selection of appropriate element types, boundary conditions, and contact coefficients when using the finite element method.

Besides that, by using finite element analysis, it can provide a better understanding of the behavior of steel connections under static loads. It is important to perfectly characterize the interaction of the various components of a steel connection such as bolts and welds. For this, it is important to understand and sufficiently model the contact interaction between the various interacting parts of the connection and to correctly specify their constitutive properties.

1.2 PROBLEM STATEMENT

The connection beam to column is very essential especially to transfer and distributes the load as well as to contribute to the rigidity of the overall structures. Thus to respond to various of load, the connection should be allowed to be less rigid and allowed for a degree of flexibility where semi-rigid connection offered the performance as the connection is proposed to analyze as a spring element. The classification of the connection is based on the stiffness from moment-rotation graph resulted from an experimental setup as well as other result such as types of failure or the behavior under the loading in which consumes a lot of time and costly where these were opted by most of the research such as Khaled and Suswanto in 2013. As the wide increasing performance of computers and the availability of computer software, the cost and time spent to analyze and design of semi-rigid steel connection between beam and column

can be reduced. In this study, an experimental setup of beam - column connections was chosen from a study by Khaled and Suswanto (2013) to be modeled and simulate under static loading to determine the behavior, stiffness and the types of failure through the application of ABAQUS software .

1.3 OBJECTIVES

The overall research goal of this project is to determine the performance characteristics of the beam to column connection in order to evaluate its suitability for use in actual steel construction.

1. To model and simulate a 3 dimensional top and seat angle connection under static loading.
2. To understand the behaviour of the connection from moment-rotation graph and obtained the displacement, stiffness and rotation.
3. To determine the types of failure in the connection.

1.4 SCOPE OF STUDY

This study is focused with the study of structural response of a typical semi-rigid beam to column connection. The data from previous experiments titled Experimental Study, Stiffness of Semi-Rigid Beam-to-Column Connections Using Bolt and Angles (Khaled and Suswanto, 2013) was calibrated. In order to study the individual contribution of them, 1 specimen over 6 specimens (in experimental) consist of beam to column connection using top and seat angles (SRC3-A) was prepared to be simulated and compared.

Finite element analysis (FEA) which has been widely used in engineering industry to simulate the structures and load act on them; was used in this study. The FE model was prepared for three dimensional (3D) simulations of FE code ABAQUS software. Once the model have been verified, it was subjected to simulated concentrated incremental load and the results obtained from this simulation will be used to analyze the behavior of these connections under static loading. This 3D simulation will provide

needed performance characteristics of the connection and parameters where the result of previous experimental testing have obtained stiffness, behavior of connections and failure mode of structure.

CHAPTER 2

LITERATURE REVIEW

2.1 CLASSIFICATION ON CONNECTION

Beam to column connections can be classified according to their types of loads transmit and the scale of those loads, types of members connected and whether they are exposed or hidden. In general, the connections must transmit axial and shear forces and bending and torsional moments. There are many types of beam to column connections and corresponding to their response variables.

Jones in 1980 stated the responses of connection can be classified according to broad ranges of flexural behavior and also can be seen in Figure 2.1 and Figure 2.2 while classes of beam to column connection are shown in Figure 2.3.

1. Pinned connections (flexible).
 - Pinned connection allows relative free rotation between the end of the beam and column and also able to carry the required end reaction.
2. Rigid connections (fixed)
 - Rigid connection are those in which the rotation is reduced to a minimum by the use of heavy connection details.
3. Semi-rigid connections
 - Semi-rigid connections transmit bending moment with some degree of rotation and provide a degree of end restraint somewhere between complete rigidity and complete flexibility.

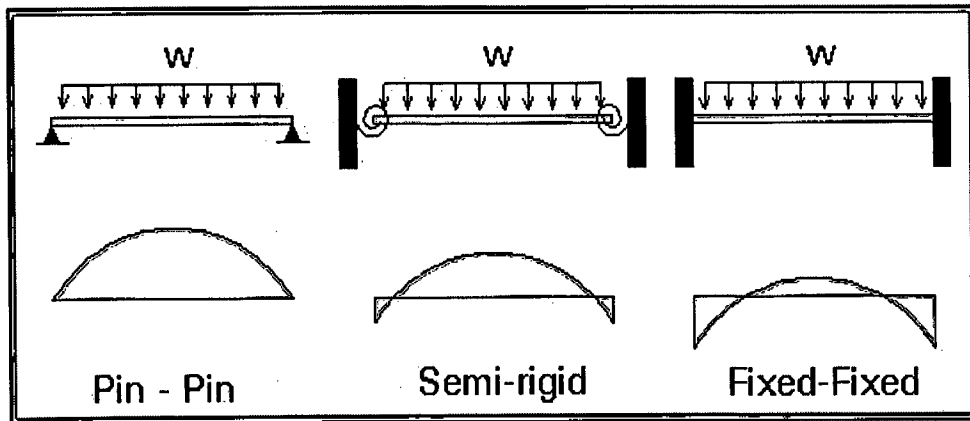


Figure 2.1 : Moment Diagrams for Uniform Loading

Source : McGuire (1995)

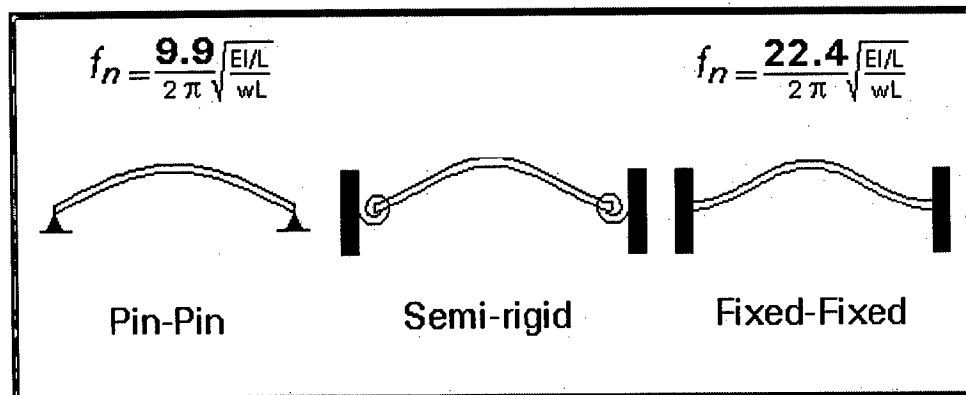
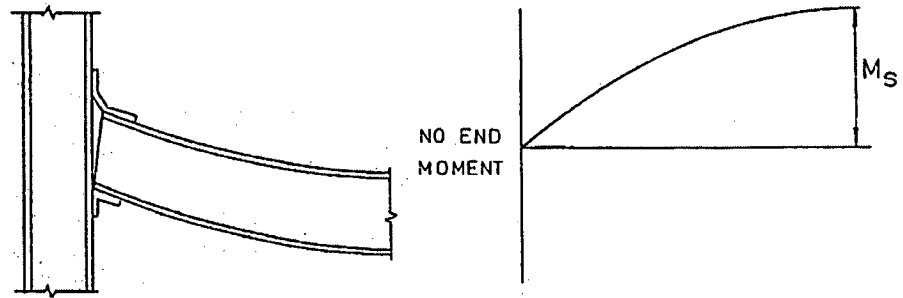


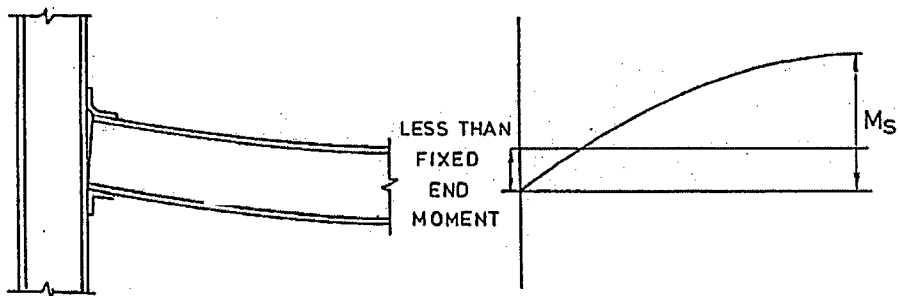
Figure 2.2 : Minimum Natural Frequency for Beams of Uniform Mass

Source : McGuire (1995)

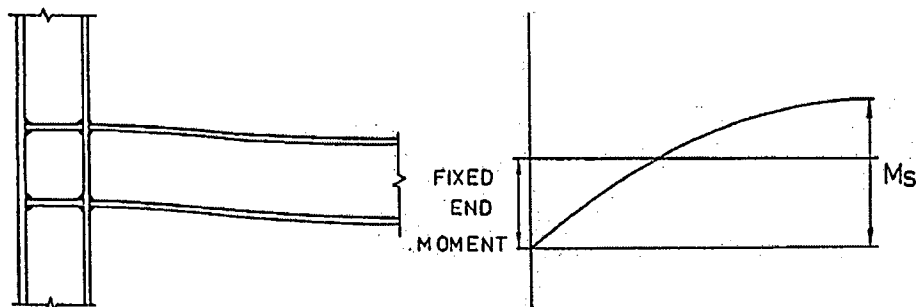
However, according to Kartal et al. in 2010, structural connections should be named according to their moment-rotation curves which are usually derived by fitting suitable curves to the experimental data.



a. Flexible connection



b. Semi-rigid connection



c. Rigid connection

Figure 2.3 : Classes of beam to column connection

Source : Jones (1980)

2.2 GENERAL TYPES OF BEAM TO COLUMN CONNECTION

In design and analysis of steel structures, the rigid assumption results in larger joint stiffness relative to the beam and column stiffness, while the pinned connection assumption results in smaller joint stiffness relative to the connection member stiffness. Beam to column connections are classified according to the physical configuration and the means by which beams and columns are connected. There are some types of fastening connections of steel beam to column which are angles, plates, welds, and bolts. From Khaled and Suswanto (2013) experimental study, top-seat angle and double web angle were proposed but in present study, the type of connection is concerned on bolts and angles which is top and seat angle connection as shown in Figure 2.6.

2.2.1 Top and seat angle connection

Based on AISC (1989), top angle is used to provide lateral support of the compression beam flange while the seat angle is used to transfer only vertical reaction of the beam to the column. It should not give a significant restraining moment at the end of the beam. White (2003) stated that beam stresses due to shear and flexure are transferred to the column through bolted brackets located at the top and bottom of the beam flanges. However according to the experimental result, this connection can transfer not only the vertical reaction but also some end moment of the beam to the column.

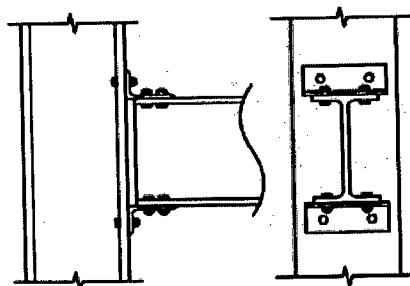


Figure 2.4 : Top and seat angle connection

Source : Chen, Yoshiaki and Richard (1996)

2.2.2 Double web angle connection

A double web-angle connection consists of two angle either bolted or riveted to both column and beam web. Although the connection rigidity of this type of connection is stiffer than single web angle and single plate connection, AISC (1989) consider this type of connection as simple connection or shear connection.

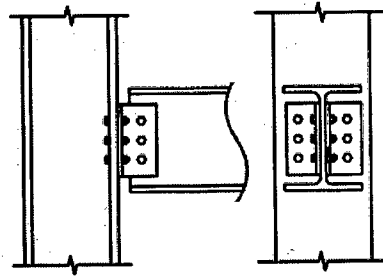


Figure 2.5 : Double web angle connection

Source : Chen, Yoshiaki and Richard (1996)

2.2.3 Top-seat angle with double web angle connection

This type of connection is the combination of top-seat angle and double web angle connection. Double web angle connection is used to improve the connection restraint characteristics and shear transfer of top and seat angle connection.

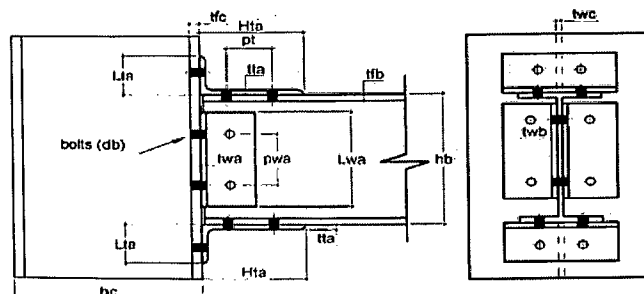


Figure 2.6 : Top-seat angle with double web angle connection

Source : Vellasco et al. (2005)

The typical moment-rotation curve for behavior of variety type of connection of semirigid can be represent in Figure 2.7.

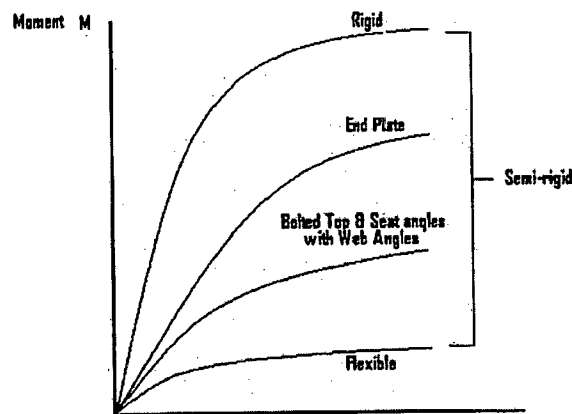


Figure 2.7 : Connection moment-rotation curve

Source : Jones (1980)

2.3 LOAD ON STRUCTURE

Loads usually are classified into two groups which are dead loads and live loads. Dead loads are basically constant during the life of the structure and normally consist of the weight of the structural elements. On the other hand, live loads usually are otherwise. The magnitudes of these loads are not known with great accuracy and the design values must depend on the intended use of the structure.

Basically, there are two types of load or forces that act on structures which are static and dynamic load. Static load or monotonic load which focused in this study are those that are gradually applied and remain in place for long time duration. The live load acting on a structure considered as a static load because it usually varies gradually in magnitude and position while cyclic load are those that are very much time dependent and these either act for a small interval of time or quickly change in magnitude or direction.

According to Sandor in 2000, loading is assumed to be applied on the structure in two different ways; monotonic and cyclic as shown in Figure 2.8. Monotonic loading can be defined as the classical static loading that having the feature which are quasi-static and its intensity is increasing in time. For the cyclic loading, it represent a simplified seismic loading with repeated loading-unloading reversely. Cyclic loading's intensity is high to cause significant plastic strain in the structure.

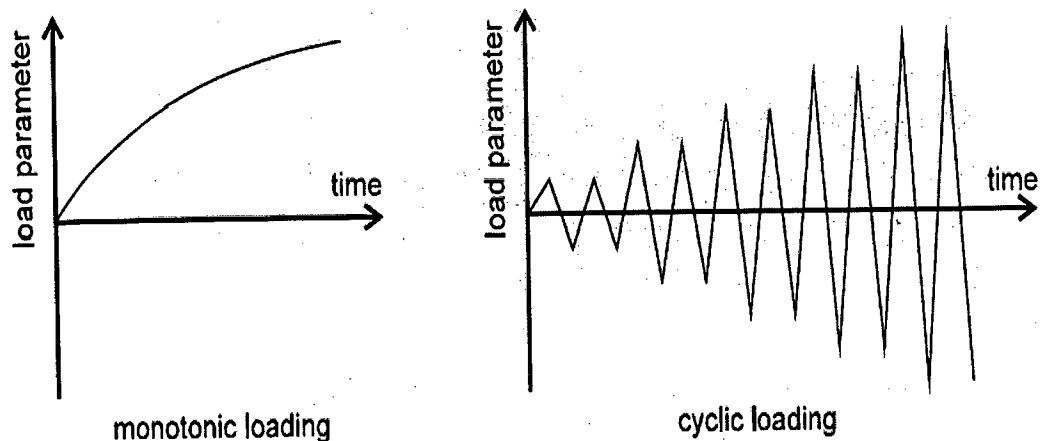


Figure 2.8 : Monotonic and cyclic loading graph for load versus time

Source : Sandor (2000)

There are certain number of experimental under monotonic loading. Elghazouli (1996) have study the ductility of frames with semi-rigid connection while Elnashai, Elghazouli, and Denesh in 1998 have conducted 8 model in experimental to investigate the performance of steel frames with semi-rigid connections consists of top and seat and web angles in order to compare with fully rigid alternatives.

Psycharis and Mouzakis in 2012 have investigated on beam to column connection. Their research was focused on important design aspects and the effect of several parameters on the shear resistance of the connection. Babu and Sreekumar (2012) experimentally studied the behavior of double web angle bolted beam to column connection under monotonic loading using top and seat angle connection. Static half

cycle load tests were performed to compare the energy absorption capacity of various connections.

As for cyclic loading, in 1995, Saqan have evaluated the ductile beam to column connection for use in precast frames, Elnashai, Elghazouli and Denesh (1998), Sultan (2007) and Mahmoud in 2011 have studied performance -based optimal design of semi-rigid connected steel frames.

2.4 BEHAVIOR OF CONNECTION

In practical, the effect of moment on the rotational deformation of connection is the only factor that need to be considered. As shown in Figure 2.9, the connection rotates by amount of Θ_r when a moment, M is applied. The angle Θ_r correspond to the relative rotation between the beam and the column at the connection. Therefore the moment-rotation relation ($M-\Theta$) was graphically illustrated to show the behaviour of a connection.

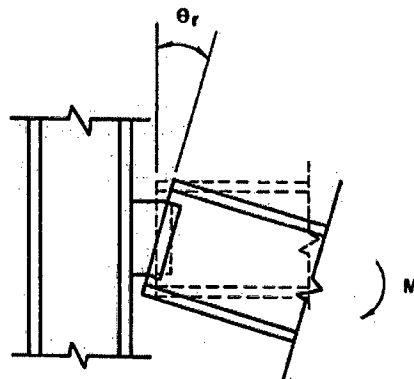


Figure 2.9 : Rotational deformation of a connection

Source : Chen, Yoshiaki and Richard (1996)

Usually, this curve must be the most precise representation of the true behaviour of a connection, but still cannot be considered as its exact representation. Fabrication tolerances, erection procedures and all material quality have a non-negligible influence on the behaviour of a connection (Dumas, Beaulieu and Picard 2004). Besides that,

based on the stress-strain graph, the yield strength also can represent the point where behaviour changes from elastic to plastic. The ultimate tensile strength is the end point of the stress-strain curve to represent the rupture of the material as in Figure 2.10.

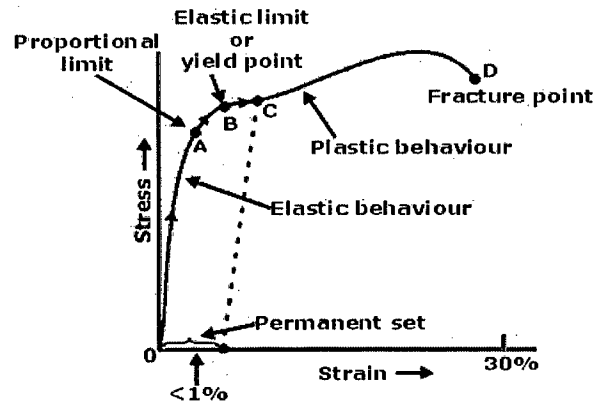


Figure 2.10 : Stress-strain curve

Source : e-CAD Engineering (n.d)

Recent years, many experiments carried out focusing on the behavior of connections have demonstrated that connections behave nonlinearly in the range between the two extremes of fully rigid and frictionless pinned connections. The behavior of the connection can be controlled by different modes related to relative proportions of the components of the connection. White (2003) in his study stated that connections are designed to control inelastic behavior either by flexural yielding of the beam in combination with shear yielding of the column at panel zone, or by flexural yielding of the beam alone.

2.4.1 Ductility

Ductility can be define as a material's ability to deform plastically and then absorbing energy before fracture. Ductility is specified with a non-linear stress-strain behavior as shown in Figure 2.11. Steel is a material that display large post-yield strain capacity prior to failure. This quality allows the material to convert strain energy to thermal energy during deformation (White, 2003).

Babu and Sreekumar in 2012 stated that the joint behavior has a direct influence on the ductility because in order to characterize the behavior of a structure or joint in the plastic range, ductility factor can be one of the parameters. His study showed that ductile behaviour of beam to column connection is improved by increasing the number of bolts on the top and seat angles as well as the thickness of top and seat angles.

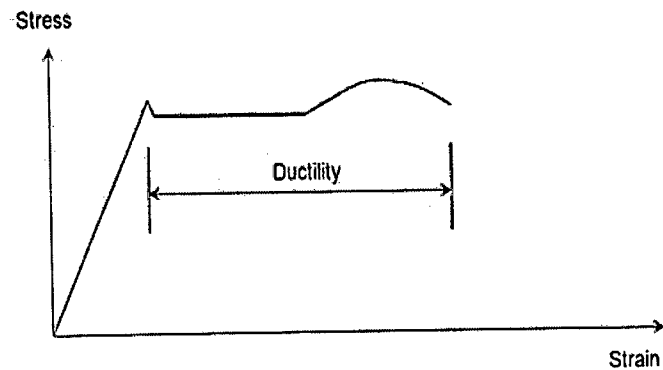


Figure 2.11 : A typical stress-strain curve for steel

Source : Steel Construction Info (n.d)

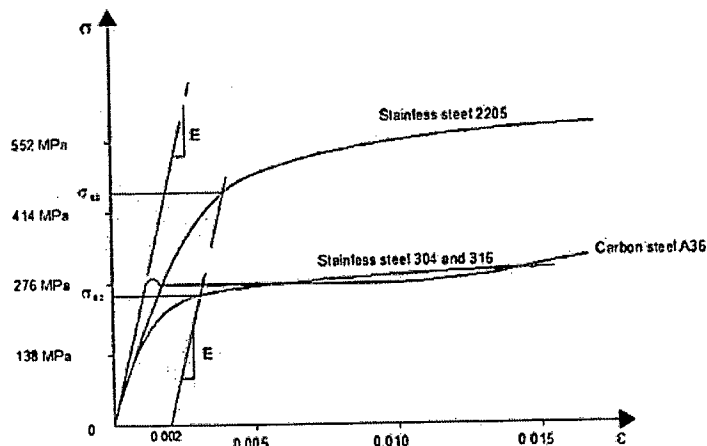


Figure 2.12 : A typical stress-strain curve for ductile material

Source : Steel Construction Info (n.d)

Ductility is needed to increase of ultimate load carrying capacity of a structure and better behavior of a structure in load situations like an earthquake. However, Bogensperger and Moosbrugger (2009) stated that the non-linearity can be ignored in structural calculations in order to be able to perform linear superposition for all load cases.

2.4.2 Stiffness

Stiffness is the rigidity of an object to resist deformation in response to an applied force. The deformations and stiffness-related characteristics of the connections must be considered in terms of serviceability. In designing and analysis of steel structures, pinned connection assumes results in smaller joint stiffness relative to the connecting member stiffness while the rigid connection assumes results in larger joint stiffness relative to the beam and column stiffness, (Demirtas, 2003).

According to Bjorhovde, Colson and Brozetti (1990) the development of connection stiffness models was resulted from the actual stiffness or restraint of connections that lies between the pinned and rigid connections. Accurate calculations of displacements or initial stiffness are needed in design of semi-rigid beam to column connections.

Jones (1980) found that an increase in connection stiffness produces a corresponding decreasing in column deflection and increasing in maximum load capacity. Sultan in 2007 stated that a gap was developed between the surfaces of the contact components of actual connection models compared to the rigid connection model. When the load applied increase the gap will grows bigger. It can be concluded that when the actual load transfer is affected by the gap so the connection strength and stiffness will decrease. In the same time, the results from his FE model showed a larger bolt size gives higher stiffness.

Lin and Asada in 2012 presented that the stiffness will increase when bolt position parameter (diameter) increase in top and seat flange angle connection and double web angle connection. Elnashai, Elghazouli and Danesh (1998) proposed that

changes to the thickness of the top and seat angles can influence the moment capacity and rotational stiffness of the connection however not significantly influence the value of the rotation at the estimated yield point.

2.4.3 Modes of failure

A number of studies were commenced to analyze the reasons for failure of the steel connections. Winter in 1956 categorised the failure of bolted connections into four separate modes which are end pull-out, bearing, net section fracture and bolt shear. Failures will occur in connections with and without welds on the shear connection plates also at column to flange stiffeners (Shipp, 1994). Lin and Asada, 2012 have studied 4 model and found that the failure mode due to tension failure of bolts. The failure mode is illustrated in Figure 2.13. Their study revealed that failure mode 4 is the best one, failure mode 1 and 2 should be avoided in order to achieve enough deformation ability in connection design while failure mode 3 is a possible true failure mode in structural design and therefore it should be included in initial stiffness investigation.

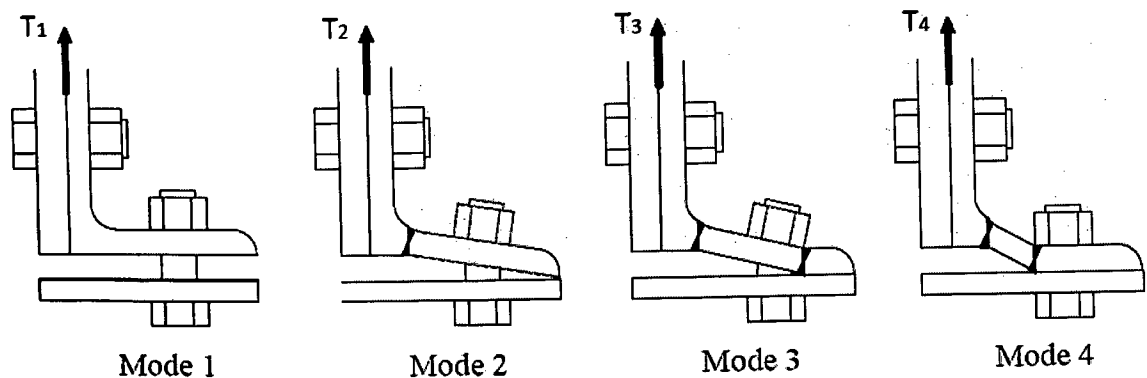


Figure 2.13 : Failure modes for semi-rigid connection

Source : Lin and Asada (2012)