ANALYTICAL ASSESSMENT OF THE BEHAVIOUR OF EXTENDED END PLATE CONNECTION

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ABSTRACT

Steel frame structure with beams and columns was become conventional building structure in construction world. In this study, one out of eight specimens from previous experimental which is specimen FS1a was modelled and simulated using Finite Element Method (FEM) which is ABAQUS/CAE Version 6.10 under static loading. The specimen was model to determine the failure mode at the end plate besides to understand the behaviour of the extended endplate connection. This study was conducted to minimize the cost and time spends for the experiment. The failure modes involved in this analytical model was the weld failure of the assembly beam-end plate which is classified as Mode 1 failure that yielding of the end plate. As a result, moment rotation (M- ϕ) curve was obtained for analytical model in order to determine the capacity and behaviour of the extended end plate in terms of the resistance, stiffness and rotational capacity. The experimental results were used as a basis of comparison with the analytical results given by the component method of Eurocode 3 EN 1993-1-8. A good agreement was noticed between the analytical values and experimental values. Based on the results obtained, it can be concluded that in terms of rigidity, the classification boundaries of beam-to-column connection was rigid connection and the extended end plate connection was designed as partial strength. Comparisons of connection rotation capacity with the equivalent method in Eurocode 3 EN 1993-1-8 show that the end plate has an adequate rotation capacity for plastic analysis.

ABSTRAK

Struktur kerangka keluli dengan rasuk dan tiang telah menjadi struktur bangunan konvensional dalam dunia pembinaan. Dalam kajian ini, satu daripada lapan spesimen daripada eksperimen sebelumnya iaitu specimen FS1a telah dimodelkan dan simulasi menggunakan Kaedah Unsur Terhingga (FEM) daripada ABAQUS / CAE Versi 6.10 di bawah pembebanan statik. Spesimen ini dimodel untuk menentukan mod kegagalan pada plat hujung di samping untuk memahami tingkah laku sambungan plat hujung yang diperluaskan. Kajian ini dijalankan untuk mengurangkan kos dan masa untuk mejalankan eksperimen. Ragam kegagalan yang terlibat dalam model analisis ini adalah kegagalan kimpalan berhimpun plat rasuk-akhir yang diklasifikasikan sebagai Mod 1 kegagalan yang menghasilkan plat akhir. Hasilnya, lengkungan momen putaran (M-ϕ) telah diperolehi bagi model analisis untuk menentukan keupayaan dan kelakuan plat hujung yang diberikan dari segi rintangan, kekakuan dan kapasiti putaran. Keputusan eksperimen telah digunakan sebagai asas perbandingan dengan keputusan analisis yang diberikan oleh kaedah komponen daripada Eurocode 3 EN 1993-1-8. Satu persetujuan yang baik adalah diperoleh antara nilai-nilai analisis dan nilai-nilai eksperimen. Berdasarkan keputusan yang diperolehi, dapat disimpulkan bahawa dari segi ketegaran, sempadan pengelasan sambungan rasuk-ke-tiang adalah sambungan tegar dan sambungan plat hujung yang diberikan telah direka sebagai kekuatan separa. Perbandingan kapasiti putaran berkaitan dengan kaedah yang setara dalam Eurocode 3 EN 1993-1-8 menunjukkan bahawa plat hujung mempunyai kapasiti putaran yang mencukupi untuk analisis plastik.

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h_c	Column section height
b_c	Column section width
t_f	Flange thickness
t_w	Web thickness
h_b	Beam section height
b_b	Beam section width
h_p	End plate height
b_p	End plate width
t_p	End plate thickness
e	Edge distance
w	Gauge of the bolts
e_X	Distance from the upper tension bolt row to the top of the end plate
L_X	Height of the end plate extension in the tension zone (above the beam tension flange)
p	Pitch of the tension bolts
p_{2-3}	Distance between the tension bolt row 2 and the compression bolt row 3
e_{comp}	Distance from the compression bolt row to the bottom of the end plate
f_y	Yield stress
f_u	Ultimate or tensile stress
e_{st}	Strain at the strain hardening point
e_{uni}	Uniform strain
e_u	Ultimate strain
E	Young Modulus

θ_b	Beam rotation
θ_c	Column rotation
δ_{DT1}	Displacement measured by DT1
$M_{j,Rd}$	Connection flexural full plastic resistance
$S_{j,ini}$	Connection initial rotation stiffness
M_{max}	Maximum bending moment attained during the test
M_{max}	Maximum bending moment attained during the test
$F_{tr.Rd}$	Effective tension resistance of the bolt row *r*
h_r	Distance of the *r*-th bolt row
k_1	Stiffness coefficient for the column web in shear
k_2	Stiffness coefficient for the column web in transverse compression
k_{eq}	Equivalent stiffness coefficient
$f_{u,b}$	Tensile strength of a bolt
$k_{eff,r}$	Effective stiffness coefficient relative to bolt row *r*

LIST OF ABBREVIATIONS

FEM	Finite Element Method
FEA	Finite Element Analysis
CAE	Complete Abaqus Environment
M-ϕ	Moment Rotation

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Recently, the need for structural improvements of civil infrastructure all over the world is well known and great amount of research is going on this field. Nowadays, steel frame structure with beams and columns is become conventional building structure in construction world. In civil engineering field, steel is widely used in building construction. Its popularity may be due to the various sizes and the shape of the steel sections to be used.

Steel connection is means of joining the individual members of a structure to form a complete assembly. Historically, most major structural failures have been due to some form of connection failure. The connection is depending on type of loading, strength and stiffness and also economy. Bolting is the preferred method of connecting members on the site. The bolted beam-to-column connections can provide full moment continuity and it is cheaper than welded in terms of numbers of skilled works and cost of construction. Normally, for bolted end plate connections between I-section or H-section beam and column as shown in Figure 1.1 are designed using the approach described in Eurocode 3 EN 1993-1-8; Design of steel structure-Design of joints.

The advantages of using end plate connections are simple and neat. The end plate connections have a single plate welded to the end of the beam. This is bolted to the column flange or web using two or more bolts arranged in pairs. As shown in Figure 1.2, end plate connections may be header, flush or extended. In this study, an extended end plate connection is use and it enables significant transfer of bending between beam and column.

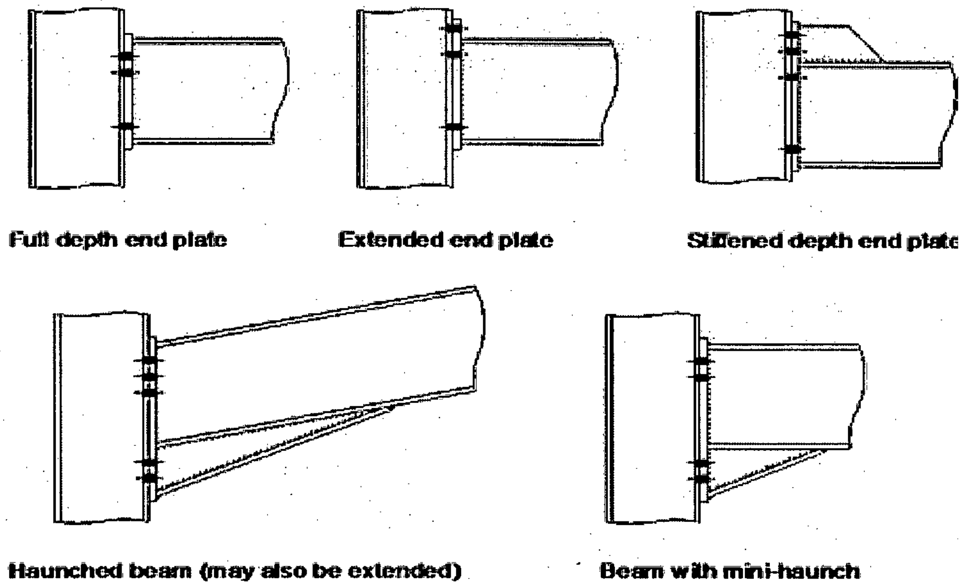
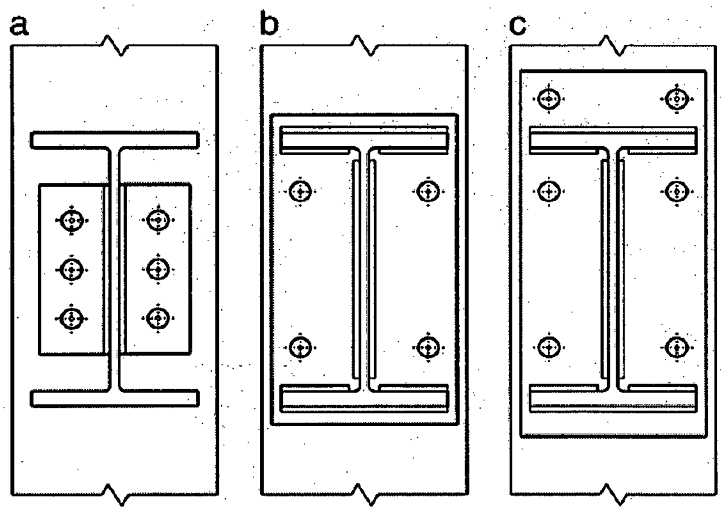


Figure 1.1: Typical bolted end plate beam-to-column connections

Source : Brown, Iles, Brettle and Malik (2013)



(a) Header (b) Flush (c) Extended

Figure 1.2 : Beam-to-column end plate connections

Source : Diaz, Victoria, Marti and Querin (2011)

In this study, Finite Element Method (FEM) was used to model and simulate the beam-to-column extended end plate connection under static load using ABAQUS program. The ABAQUS was released in 1978, develops and globally markets engineering simulation software and technologies widely used by engineers and designers like civil and mechanical engineering. ABAQUS was initially designed to address non-linear physical behaviour. Besides that, ABAQUS also provides a good collection of multiphysics capabilities, and structural-pore capabilities, making it attractive for production-level simulations.

1.2 PROBLEM STATEMENT

Nowadays, the extended end-plate connections are mostly in use as an alternative for fully welded connections and use in resisting moment frames to provide stiffness and rigidity. In previous research by Coelho, Bijlaard and Silva (2004), the behaviour of extended end-plate connections subject to static loading were conducted through extensive experimental programme. Extended end-plate connection is more complicated and more expensive to fabricate as well as time consuming to setup for experimental programme. To minimize the cost and time spend to setup for the experiment, one of the alternatives is to simulate the connection using ABAQUS/CAE. In this study, the extended end-plate to be modelled and simulated using ABAQUS/CAE software was referring to experimental programme conducted by Coelho, Bijlaard and Silva (2004).

1.3 OBJECTIVES

The objectives for this study are following:

a) To model and simulate an extended end-plate connection under static loading using ABAQUS software.
b) To determine the mode of failure in the extended end plate connection.
c) To understand the behaviour of the extended end plate connection from moment rotation (M-ϕ) curve that defines resistance, stiffness and rotation.

1.4 SCOPES OF STUDY

This research is mainly focus on the design of extended end plate connection and focus on the three dimensional (3D) model that simulate the model using Finite Element Software such as, ABAQUS/CAE. Finite Element Analysis (FEA) was use to simulate the model which modelling must show good agreement with the experimental programme result in most cases. This analytical study was model to investigate the mode of failure that occurs under static loading that applied at the bottom of beam flange. The loads that apply to the beam-to-column extended end plate connection were the incremental of 30 kN.

Besides that, the value of elastic Young's Modulus, E for steel was 210000 MPa. For yield strength and plastic strain, all the data were from study of Coelho, Bijlaard and Silva (2004). The thickness of end plate used was 10mm and for bolt properties, M20 Grade 8.8 was used. On the other hand, this simulation also carries out to further understand the behaviour of the extended end plate which has main characteristics: resistance, stiffness and rotation. The modern design codes, Eurocode 3 EN 1993-1-8 were adapted to this study.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In recent years, numbers of studies have been made in designing the beam-to-column connection using extended end-plate and the development in this type is still continued until now. Many researches try to present the easier and simple way to study this connection, for examples comes out with Finite Element Programme such as ABAQUS, ANSYS and so on.

In the study of Faella (2000), the beam-to-column connections play fundamental role in the determination of the real behaviour of steel structures. According to Mohd Mahir (2009), the actual behaviour of joints whether to assume it is ideal condition of hinge or fixed-end restraint is disregarded in the steel frame design. Mohd Mahir (2009) also stated that, the connections which is whether welded or bolted connections give certain degree of resistance against moments and stiffness and ductility against rotational that usually designed as pin or rigid. In short, connections play an important and significant role in transmitting required actions between the individual members.

2.2 CONNECTION

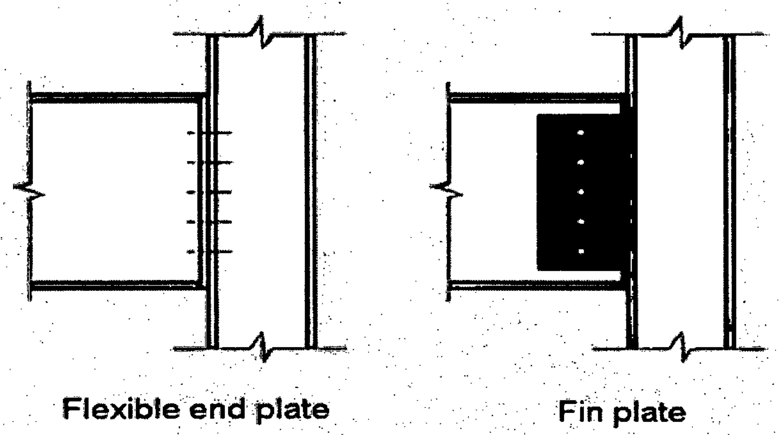
Connections constitute one of the most significant components of a structure although the fact that they occupy a very minor position in it. According to American Institute of Steel Construction (AISC), they classified the connections as simple, rigid or semi-rigid according to their strength, stiffness and ductility. Besides that, Tata Steel Construction explained in their conclusion that the connections can be classified according to the loading conditions, the types of members connected and also according to whether they are exposed or hidden connections. In the study of Ahmet (2013), beam- to- column connections of steel structures were at first made of rivets and welds. Although such connections have the high moment capacity, their behaviour is brittle and therefore they cannot absorb seismic energy well.

Ahmet also studied that the use of simple connections in steel structures for seismic areas definitely necessitates the use of a lateral load resisting frame system. On the other hand, the use of rigid connections allows for the design of a structure to be a moment resisting frame type system. Besides that, connections form an important component of any structure and are designed more conservatively than members. This is because, connections are more complex than members to analyze, and the discrepancy between analysis and actual behaviour is large. (Kaushik, Sharma & Kumar, 2013).

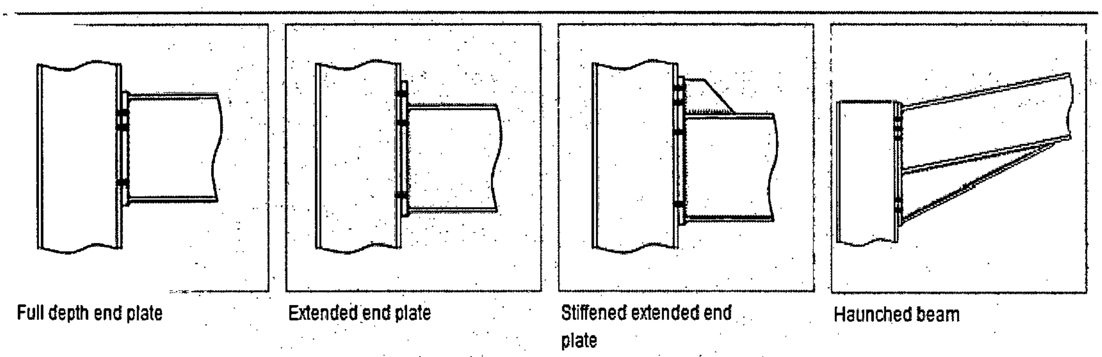
2.2.1 Beam-to-Column Connection

From the previous research, beam-to-column connections commonly can be categorized as simple (pinned connections) or continuous (moment-resisting connections) as shown in Figure 2.1. In simple connections, it is normally design as pinned connection that only transmit end shear and it negligible the resistance to rotation and therefore do not transfer moments. Besides that, the simple connection was classified as braced frame and a beam is designed as simply supported. In practice, continuous connection was associated with unbraced frame which is implies either rigid or full or partial strength connections. Nowadays, the most commonly used moment resisting connections are bolted end plate beam-to-column connections. The bolted beam-to-column connection is less rigid when compared to beam-to-column welded connection, so the end plate connections offer enhanced ductility at the beam-to-column connection.

According to Eurocode 3 EN 1993-1-8, the type of connection either for simple, continuous or semi-continuous can be determined from Table 2.1 which is depending on the classification of the connection and on the chosen method of analysis. For elastic global analysis, the connection should be classified according to their stiffness and the connection should have sufficient strength to transmit the forces and moment acting at the connections. Then, the connections should be classified according to their strength if rigid-plastic global analysis was applied. Lastly, for elastic-plastic global analysis, the connection should be classified according to both stiffness and strength.



(a) Simple connection



(b) Moment-resisting connection

Figure 2.1 : Type of beam-to-column connection

Source : Steel Construction Institute (2013)

Combinations of simple fabrication techniques and speedy site erection that have bolted end plate connection is one of the most popular methods of connecting members in structural steelwork frames. Although it is simple in their use, bolted end plate connection is extremely complex in their analysis and behaviour. Bolted connections, especially end plate types, are being widely used as moment-resistant connections. They have advantages of easy quality control and less assembly time than welded connections. Behaviours of beam-to-column connections play an important role in the response of a steel moment resisting frames structure. It strongly influences the seismic behaviour and energy dissipation capacities of the moment resisting frames. Babu and Sreekumar (2012) discussed that the use of bolted joints allows more energy dissipation and provide good response under lateral loads.

Table 2.1 : Type of connection model

Method of global analysis	**Classification of joint**		
Elastic	Norminally pinned	Rigid	Semi-rigid
Rigid-Plastic	Norminally pinned	Full-strength	Partial-strength
Elastic-Plastic	Norminally pinned	Rigid and full-strength	Semi-rigid and partial-strength Semi-rigid and full-strength Rigid and partial-strength
Type of joint model	Simple	Continuous	Semi-continuous

2.2.2 Rigid Connection

In beam-to-column connection, the connections can be considered as rigid if their rigidity is so large that no significant slope discontinuity exists between the adjoining members. As stated in Eurocode 3 EN 1993-1-8, end plate connection may be assumed that the connection is rigid if both of the following requirements are satisfied; (a) adopting relatively thick end plates and potentially a stiffened column flange and (b) the column web panel shear force does not exceed 80% of the design shear resistance.

According to Eurocode 3 EN 1993-1-8, the rigid connecting can be classified according to strength and stiffness. Besides that, the connection behaviour also has to be considered in determining the type of connection as shown in Figure 2.2. This figure represents that fully welded connection, extended end plate and top and bottom flanges splices could be considered as rigid connections. In Eurocode 3 EN 1993-1-8, beam-to-column connection either braced or unbraced frame can be classified as rigid if it satisfied the condition. Figure 2.3 show the classification boundaries for beam-to-column connection according to Eurocode 3 EN 1993-1-8.

In the study of Aggrawal and Coates (2000), they stated that the connection was assumed to maintain rotational continuity when the fully rigid method of design was applied. From this method of design, these rotations change the moment distribution between beam and the column.

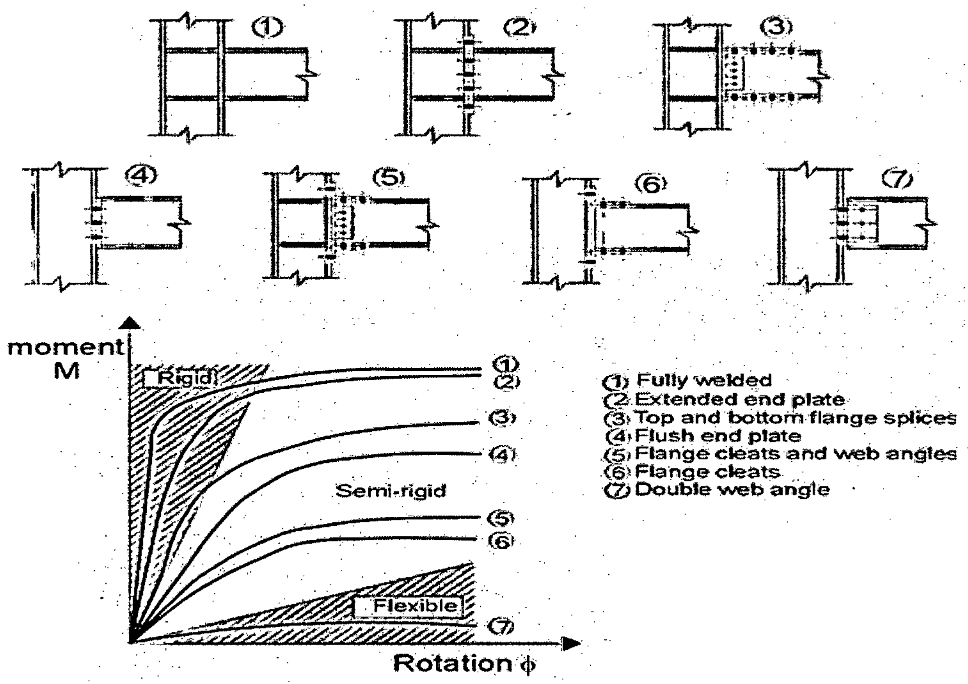
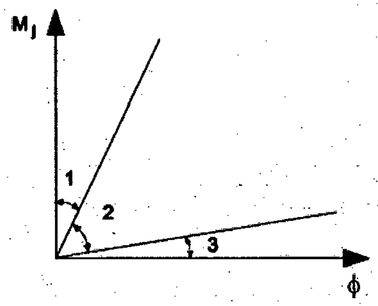


Figure 2.2 : Moment rotation relations of connections

Source : Cosenza, De Luca and Faella (1989)



Zone 1: rigid, if $S_{j,ini} \geq k_b E I_b / L_b$

where:

$k_b = 8$ for frames where the bracing system reduces the horizontal displacement by at least 80 %

$k_b = 25$ for other frames, provided that in every storey $K_b/K_c \geq 0,1$ *)

Zone 2: semi-rigid

All joints in zone 2 should be classified as semi-rigid. Joints in zones 1 or 3 may optionally also be treated as semi-rigid.

Zone 3: nominally pinned, if $S_{j,ini} \leq 0,5 E I_b / L_b$

*) For frames where $K_b/K_c < 0,1$ the joints should be classified as semi-rigid.

Key:

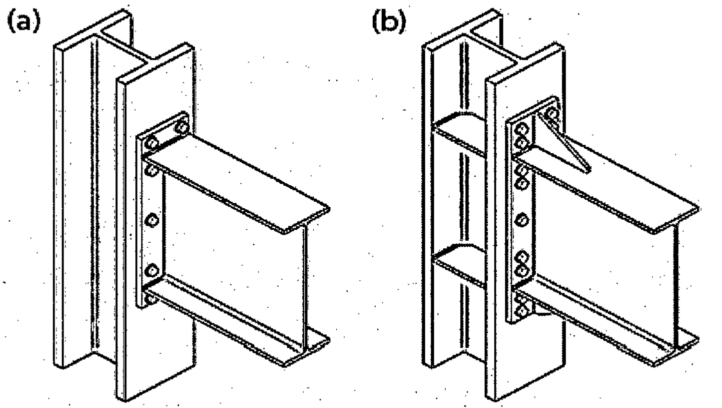
K_b is the mean value of I_b/L_b for all the beams at the top of that storey;
K_c is the mean value of I_c/L_c for all the columns in that storey;
I_b is the second moment of area of a beam;
I_c is the second moment of area of a column;
L_b is the span of a beam (centre-to-centre of columns);
L_c is the storey height of a column.

Figure 2.3 : Classification boundaries for beam-to-column

Source : Eurocode 3 EN 1993-1-8 (2005)

2.2.3 Extended End Plate Connection

An extended end plate connection consists of a plate welded in the fabrication shop to the end of the steel beam as shown in Figure 2.4. As stated by Mohd Mahir (2009), the end plate was pre-drilled and then bolted through corresponding holes in the column flange. She also said that, this type of connection is usually loaded by a combination of vertical shear force, axial force in the beam member and a moment that can be refer in Figure 2.5. In the study of Sumner and Murray (2002), extended end-plate connections consists of a plate that is shop welded to the end of a beam then field bolted to the connecting member.



(a) Without stiffener (b) With stiffener

Figure 2.4 : Extended end plate connections

Source : Mohd Mahir (2009)

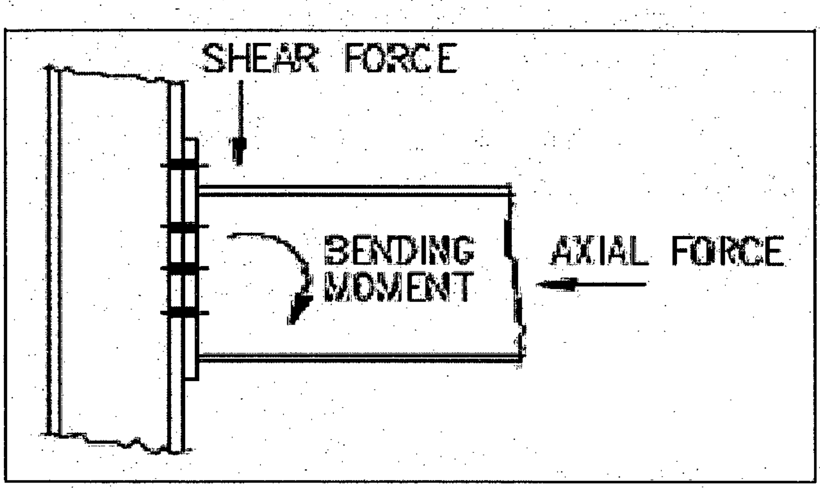


Figure 2.5 : Connection loading

Source : Mohd Mahir (2009)

In the recent study, similar to other type connection, extended end-plate connections also have certain advantages and disadvantages. Its advantage can be listed as below:

a) The connection is use of the optimal combination of erection or fabrication procedures and connective mechanisms; shop-welding and field-bolting.
b) Allowed for the highest-quality welds due to the controlled environment of the fabrication shop.
c) The efficiency of the field bolts allows for the quickest possible construction times.
d) More easily quantifiable capacity of the connection.

The disadvantages of using extended end-plate connection are:

a) A narrower fabrication and erection tolerance is needed.
b) Heat distortion may induce considerable warping of the end-plate.
c) The difficult aspect of extended end plate design has limited its pursuit as a viable moment resisting connection alternative.

2.3 LOADS ON STRUCTURE

Loads can be defined as the overall force to which a structure is subjected in supporting a weight or mass or in resisting externally applied force. In the recent study, the structural loads are forces, deformations, or accelerations applied to a structure or its components. Excess load or overloading may cause structural failure. The loads can be categorized into three types which are dead loads, live loads and cyclic loads.

Dead loads are static forces that are relatively constant in magnitude and fixed in location throughout the lifetime of the structure. Usually the major part of the dead load is the self weight of the structure. The dead load can be calculated accurately from the design configuration, dimension of the structure and density of the material. Then for live loads are usually unstable or moving loads which consists of occupancy loads in buildings and traffic loads on bridges. Besides that, the live loads may change its present location as they are not lifetime part of a structure. So, in structural design live loads are provided a larger safety factor than the others. Lastly, cyclic loads are the application of repeated or fluctuating stresses, strains or stress intensities to location on structural components. The cyclic loads on structure can lead to fatigue damage, cumulative damage, or failure.

2.4 MODE OF FAILURE

In recent years, bolted connections especially with end plate have increased in popularity. They possess the advantages of requiring less supervision and a shorter assembly time than welded joints. In a very recent study by Sherboune and Bahaari (1994), end plate connections usually fail due to plate plasticity in bending and shear, bolt or weld fracture, column web shear failure, and or excessive plasticity of the column flange in bending.

For column flange and end-plate yielding, the approach taken by Steel Construction Institution is representing the yield line patterns that occur around the bolts. Figure 2.6 shows the three possible failures modes that may occur in a bolted end plate moment connection. This approach results in checking against three modes of failures as follows:

(a) Mode 1 : complete flange yielding

The strength of the flange is weaker than the strength of the bolts. Upon failure, the flange will yield but the bolts are still intact.

(b) Mode 2 : bolt failure with flange yielding

The strength of the flange and the bolts are about the same. Both the flange and bolts will yield together upon failure.

(c) Mode 3 : bolt failure

The strength of the bolts is weaker than the strength of the flange. Upon failure, the bolts will yield but the flange is still intact.