Analysis study of extended end plate connection due to cyclic load using finite element method

Y S Yoganata1*, B Suswanto1, D Iranata1, and D Irawan1

1 Civil Engineering Department, Faculty of Civil, Planning, and Geo Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

*Corresponding author’s e-mail: budi_suswanto@ce.its.ac.id

Abstract. In steel frame structures, the connection is very important element to design, especially for earthquake resistant structures. How to choose the material and dimension are very important things in steel connection to receive the load. Nowadays, the application of joints using extended end-plate has become popular because of it easy fabrication, the erection, and precise seismic performance. This connection is used to connect beam to column or connect the two beams. As a study material, we’ll make the detail of steel connection due to cyclic load using Abaqus 2017. In this research, we will remodel the connection from previous research with a end-plate modification using finite element method. The dimension of beam is I - 360 x 170 x 12 x 8 and the column is I - 213 x 222 x 10 x 7 with the thickness of end plate is 15 mm and using Grade 8.8 bolts. There are 3 types variation model, one for verification of previous research, and the other two were modified connections. The result of the study is Extended End-Plate can affect the value of the displacement. Connection using Extended End-Plate has smaller displacements, so its better to receive the loads that can cause the collapse. Extended End-Plate also affects the value of lateral load that can be borne. Connection using Extended End-Plate can receive the greater lateral loads, so its more stable and stronger to holding the loads. From the three specimens analyzed, the first model has the best performance where there are extended end plates on both sides.

1. Introduction
Infrastructure in Indonesia must be designed as an earthquake-resistant building because of so many earthquake happened. If an earthquake occurs, the structure will have vertical and lateral movement. Generally, steel has tensile strength and it will be attracted until failure with the specific load limit. Damage can occur on the columnbeam or the connecting part, depending on the quality of the material and dimensions used.

When a partial strength connection is used in the moment resisting frame (MRF), the friction occurs in the location of the plastic hinge from the beam or column to the connection. When this friction occurs, it is very important to consider the characteristics of the beam to column connection. The application of partial-strength connection is a common and relatively inexpensive solution to be applied in MRF if we compared to full-strength joint types. Previous studies have shown that detail, this connection can also be an alternative to structures that located in seismic regions, enabling the precise of control and response of dissipative elements.
Today, the application of Bolt Extended End-Plate (BEEP) has become popular because of its easy in fabrication, erection and the precise seismic performance. This joint is for connecting a beam to column or connecting two beams together. The BEEP connection is included in ANSI 2010 / AISC 358, and the results of the seismic test is the BEEP can provide the considerable seismic toughness and durability.

Because of the number of this tests is limited, numerical simulations need to be done. A more accurate finite element model for parametric analysis is very important. Therefore, more detailed study of the variables that affecting the end-plate capacity is needed to design steel beam-column joints using extended end plate. This study refers to previous research by Doh, et al. For a more detail description of BEEP behaviour, an analysis using finite element method will be done. Displacement of the load, and the rotation caused by the moment will be detailed in this study. So, we get a thorough behaviour about it.

2. Method
The method is to make beam-column joint modelling in the Abaqus program. The modelling is based on the previous research by Doh, et al [4] as verification and be determiner to continue the other models.

2.1 Numerical Program
In the Abaqus program, the connection is modelled with the following stages:
a. Parts consist of columns, beams, end plates and bolts.
b. The contact between the beam and the end plate uses Tie-Constraint type. As for the contact between the end-plate with column and bolts with beam and end-plate uses the friction type.
c. The nut is modelled together with a bolt.

Figure 1. Layout of the connection using Abaqus 2017. At this step, the all parts are combined to be one.
2.2 Material Properties
a. The material used for all parts is shown in Table 1.

| Material        | Detail                  | $F_y$ N/mm² | $F_u$ N/mm² | $E$ N/mm² |
|-----------------|-------------------------|-------------|-------------|-----------|
| Column          | 213 x 222 x 10 x 7     | 248         | 483         | 207000    |
| Beam            | 360 x 170 x 12 x 8     | 248         | 483         | 207000    |
| End-Plate       | Thick of 15 mm          | 248         | 483         | 207000    |
| Bolt            | Radius of 20 mm         | 634         | 827         | 210000    |

The table above is a detailed quality of each material that inputted into the Abaqus in the material properties module.

b. Steel Density value of 7850 kg/m³ and Poisson ratio of 0.3.

2.3 Load
The load is of two types, the first is a concentrated load of 100 kN. The second is the cyclic load according to AISC regulations. The load is located at the end of the beam.

Figure 2. Cyclic Loading System. The load is inputted in the load module with a concentrated load type, whereas the cyclic load is inputted in the boundary condition module.

2.4 Specimen Details
The modelling is in three specimens, there are an extension of the end-plate used for the specimen PS-1 with an end-plate extension on both sides, for the specimen PS-2, there was an extension of the end-plate on the left side, whereas for specimen PS-3, there is no extension on either side of the end-plate. The column height is 1900 mm and the beam length is 1500 mm. The details of each connection model in Abaqus is depicted at figure 3 to figure 5 and listed in table 2.
Figure 3. Detail of Specimen PS-1.

Figure 4. Detail of Specimen PS-2.

Figure 5. Detail of Specimen PS-3.

In figure 3 to 5 we can see the detail of each material used, there are column, beam, end plate, and bolts. For the length of column is 1900 mm and 1500 mm for beam. There are differences in end plate size and number of bolts in each specimen. The diameter of bolt is 20 mm for all specimen.

Table 2. Size detail of model.

| Part              | PS-1       | PS-2       | PS-3       |
|-------------------|------------|------------|------------|
| L. Column (mm)    | 1900       | 1900       | 1900       |
| L. Beam (mm)      | 1500       | 1500       | 1500       |
| End-Plate (mm)    | 218x528x15 | 218x485x15 | 218x442x15 |
| Number of Bolt    | 8          | 6          | 4          |
2.5 Finite Element Analysis Method

Finite element method analysis is performed in all three specimen variations. The results of the modelling will be compared to one another, so the most effective connection results are obtained. Finite element method analysis is obtained from the modelling results using Abaqus program. Here are the few indicators to analyze the modelling results:

1. End-Plate Capacity Analysis on joints
   To obtain the ability of end-plate in the beam-column connection to accept the cyclic load, starting from the first yield to the ultimate yield.

2. Ductility
   The ductility factor of structure (µ) is taken from the ratio between the ultimate deviation and the first yield deviation. Ductility value of each specimen needs to be considered in choosing the right method to applied in high-rise buildings.

3. Envelope Curve
   The graph between displacement and lateral load will show which specimen is able to holding the largest lateral load. The envelope curve is obtained from the peak load in one cycle from each cycle of the lateral loading.

4. Hysteretic curve
   The Hysteretic curve will show an increase and decrease displacement while the cyclic load is working. Through the Hysteretic curve, the relative dissipation ratio for each specimen is obtained.

5. Modified Connection Failure Patterns in End-Plate Parts
   After all processes have been completed, a failure pattern is obtained in the connection structure of the entire specimen. Observations on the occurrence of deformation due to loading will be displayed in this parameter.

3. Result and Discussion
   a. Verification Of Previous Research

In figure 6, the stress distribution that occurs has a similar pattern. The beam is bending to the right side because of the load at the end of beam by 100 kN.
Figure 7. Verification Graph of Moment-Rotation.
Both graphs have the same pattern, although the moment value of the PS-1 modelling results is greater than the results of the Doh, et al. modelling along the curve. But we can see that the difference is not too large.

Table 3. Verify PS-1 Modelling.

| No  | Variation | Mmax (kN.m) | Θ (rad) |
|-----|-----------|-------------|---------|
| 1   | Doh, et al. | 132.45      | 0.1137  |
| 2   | PS-1      | 133.65      | 0.1098  |
| Difference |           | 1.2         | 0.0039  |

From the table we can see that the difference is very small. Then the next modelling can be analysis using other variations and adding the cyclic loads.

b. Result and Analysis
Other variations modelling is carried out to obtain the connection behaviour due to cyclic load. Following are the results of numerical analysis using Abaqus.

c. Stress Distribution

Figure 8. Result of S-Mises of the three specimens.

Figure 8 shows the stress distribution in all specimens connection model. Generally, that figure shows the same yielding pattern. Only at the PS-3, yielding is also occurs at the end of the column.
d. **Ductility**

**Table 4. Ductility Factor.**

| Specimen | Displacement while | Ductility (µ) |
|----------|--------------------|---------------|
|          | First yield (mm)   | Ultimate (mm) |               |
| PS-1     | 12.196             | 48.580        | 3.983         |
| PS-2     | 17.996             | 58.749        | 3.265         |
| PS-3     | 23.141             | 70.286        | 3.037         |

Specimen PS-1 has the highest ductility value, it means that the extended end-plate can increase the value of ductility if applied to steel structures as listed at table 4.

e. **Envelope Curve**

Figure 9. Envelope Curve. Maximum lateral load capacity for PS-1 is greater than PS-2 and PS-3. Therefore, the PS-1 connection is more able to receive the load than the other variations.

f. **Rotational Stiffness**

**Table 5. Value of rotational stiffness.**

| Specimen | Moment (Nmm) | Rotation (rad) | Rotational Stiffness (N.mm/rad) |
|----------|--------------|----------------|----------------------------------|
| PS-1     | 136398.300   | 0.0345         | 3956.869                         |
| PS-2     | 114995.250   | 0.0417         | 2756.914                         |
| PS-3     | 106473.900   | 0.0499         | 2133.596                         |

Specimen PS-1 has the highest rotational stiffness value. This means the PS-1 is the best connection to receive the force. Even this is also affected by the extended end-plate on both sides as listed in table 5.
g. Energy Dissipation

![Graphs](image)

(a) Momen-Rotation Graph of PS-1.
(b) Momen-Rotation Graph of PS-2.
(c) Momen-Rotation Graph of PS-3.

**Figure 10.** Momen-Rotation Graph.

From the figure (a), (b), and (c) we can see the differences of the pattern. PS-1 has the highest moment value, but smallest rotation. PS-1 is the best connection to be applied.

| Specimen | Cyclic Area (kN.mm) | Total Area (kN.mm) | Ratio of Energy Dissipation (β) |
|----------|---------------------|--------------------|-------------------------------|
| PS-1     | 2208.752            | 8986.635           | 0.246                         |
| PS-2     | 2075.095            | 9026.891           | 0.230                         |
| PS-3     | 2435.136            | 10701.247          | 0.228                         |

**Table 6.** Value of ratio of energy dissipation.

The relative dissipation energy ratio of the three specimens is greater than 1/8 (0.125), so it is still meets the required criteria or in other words, the structure still can maintain the stability before it collapses. The specimen PS-1 is the most stable in accepting the load at the maximum displacement level as listed in Table 6.

h. Failure Pattern

Observation of the failure patterns starts from the beginning to the end of the modelling. For specimen PS-1 the failure occurs in bolts, yield in column body and wings, while for beam it is relatively safe. Whereas for PS-2 and PS-3 the failures occur in bolts, yield in column bodies and ends of beam bodies. This is because there is no extended end-plate either on the right side of the PS-2 or on both sides of the PS-3. In the PS-2 and PS-3, the failure mode of column body is caused by a transverse pressure at the
end positive load step then pull out on the right side of bolts, and generally yielding also occurs in the end plate.

4. Conclusion
From the three modelling, we get the conclusion as follows:

a. From the analysed of ductility values, it can be concluded that the PS-1 is the most able to maintain the stability due to cyclic load that cause the first yielding, while maintaining the strength and rigidity. From these explanations it can be concluded that the extended end-plate is able to increase the value of ductility if applied to the steel structures.

b. The PS-1 connection has the highest rotational stiffness value, it is the most rigid when compared to the other two specimens. This means the PS-1 connection is the best connection type to receive the force. Even this is also affected by the extended end-plate on both sides.

c. Based to the results of the analysis, the ratio of relative dissipation energy in the three specimens is greater than 1/8 (0.125). However, when compared between three specimens, specimen PS-1 has the largest relative dissipation ratio (β) value of 0.246, it means the PS-1 connection is the most able to absorb the energy by external loads. The PS-1 connection is the most stable in accepting the load at the maximum displacement level.

d. Extended end plate makes the displacement value to be smaller, but it can receive greater lateral forces.

References
[1] American Institit of Steel Construction (AISC) 360 2016 Spesification of Structural Steel Buildings (American National Standards Institute)
[2] AISC 2005 Seismic Provisions for Structural Steel Buildings (Chicago, Illinois)
[3] Augusto H, Silva L S, Rebelo C and Castro J M 2017 Cyclic behaviour characterization of web panel components in bolted end-plate steel joints J. Const. Steel Res. 133 310–33.
[4] Bahaz A, Amara S, Jaspart J P and Demonceau J F 2017 Analysis of the Behaviour of Semi Rigid Steel End Plate Connections EDP Sciences 02058
[5] Diaz C, Martí P, Victoria M and Querin O M 2011 Review on the modelling of joint behaviour in steel frames J. Constr. Steel Res. 67 741–58
[6] Doh S I, Chin S C and Fakih K A 2018 Behavior of extended end-plate steel beam to column connections The Open Civ. Eng. J. 250-62
[7] Eladly 2019 Behaviour of stainless steel beam-to-column bolted connection part 1: simplified FE model J. Constr. Steel Res. 164 105784
[8] Elsabbagh A, Sharaf T, Nagy S and ElGhandour M 2019 Behavior of extended end-plate bolted connections subjected to monotonic and cyclic loads Eng. Struc. 190 142–59
[9] Gödrich L, Wald F, Kabeláč J and Kuříková M 2019 Design finite element model of a bolted T stub connection component J. Constr. Steel Res. 157 198–206
[10] Haghollahi A and Jannesar R 2018 Cyclic behavior of bolted extended end-plate moment connections with different sizes of end plate and bolt stiffened by a rib plate Civ. Eng. J. 4 1
[11] Ismail R E S Fahmy, Khalifa, and Mohamed 2016 Numerical study on ultimate behaviour of bolted end-plate steel connections Latin Americ. J. Sol. Struc. 13 1-22
[12] Liu X, Ataei A and Bradford M A 2017 Computational modelling of the moment-rotation relationship fordeconstructable flush end plate beam-to-column composite joints J. Constr. Steel Res. 129 75–92
[13] Silviana 2017 Studi kekuatan sambungan batang tarik pelat baja dengan alat sambung baut J. Inotera ISSN 2581-1274 2 26-31
[14] Standar SNI 1726-2012 2012 Standar Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung (Badan Standarisi Nasional)
[15] Standar SNI 1729-2015 2015 Tata Cara Perencanaan Struktur Baja Untuk Bangunan Gedung (Badan Standarisi Nasional)
[16] Standar SNI 03-1729-2002 2015 Tata Cara Perencanaan Sambungan baut Pada Struktur Baja (Badan Standarisasi Nasional)

[17] Zhao Y, Bu Y and Wang Y 2019 Study of stainless steel bolted extended end-plate joints under seismic loading Thin-Walled Structures 144 106255