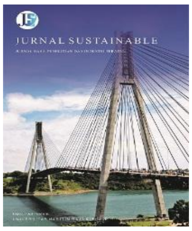


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# Displacement Characteristics of Stiffened Column-Beam End-Plate Joints: A Comparative Study


Muhamad Zulfakar[1,*], Dwi Cahya Rada[2]

[1,2]Jurusan Teknik Perkapalan, Fakultas Teknik dan Teknologi Kemaritiman, Universitas Maritim Raja Ali Haji

[1,2]Jl. Politeknik Senggarang, Tanjungpinang 29100

[*]Corresponding Author: muhamad.zulfakar@umrah.ac.id



***Abstract***—This study investigates the mechanical behavior of extended end-plate moment connections in steel structures, with a focus on the variations in stiffener angle and position. Utilizing finite element analysis (FEA), three models featuring different stiffener configurations were assessed to evaluate their rotational capacity and displacement characteristics. The results indicate that adding a stiffener to the moment connection between the beam and the column at the bottom of the connection increases the rotational capacity by 32.60% when comparing the flush type of end plate to a model with a 45° single rib stiffener. Additionally, the implementation of double stiffeners significantly enhances the rotational capacity, improving performance by up to 59.85% compared to unstiffened configurations. Increasing the angles of the stiffeners further optimizes load distribution and structural integrity. These findings highlight the importance of stiffener design in moment connections, particularly regarding rotational capacity. Future research should explore the effects of bolt pretension and the use of varied bolt diameters for further optimization.



***Keywords***—Extended end-plate connection, stiffener angle, finite element analysis, steel beam-column connections.



***Intisari***—Penelitian ini menyelidiki berbagai mekanisme yang terjadi pada sambungan momen pelat ujung yang diperpanjang pada struktur baja, dengan berfokus pada variasi sudut dan posisi pengaku. Dengan memanfaatkan analisis elemen hingga (FEA), tiga model dengan konfigurasi pengaku yang berbeda dievaluasi untuk menilai kapasitas rotasi dan karakteristik perpindahannya. Hasil penelitian menunjukkan bahwa penambahan pengaku pada sambungan momen antara balok dan kolom di bagian bawah sambungan meningkatkan kapasitas rotasi sebesar 32,60% saat membandingkan pelat ujung sambungan berada rata dengan permukaan dengan model yang menggunakan pengaku rusuk tunggal 45°. Selain itu, implementasi pengaku ganda secara signifikan meningkatkan kapasitas rotasi, memperbaiki kinerja hingga 59,85% dibandingkan dengan konfigurasi tanpa pengaku. Peningkatan sudut pengaku lebih lanjut mengoptimalkan distribusi beban dan integritas struktural. Penemuan ini menunjukkan pentingnya desain pengaku dalam sambungan momen, khususnya terkait kapasitas rotasi. Penelitian di masa mendatang sebaiknya mengeksplorasi efek prategang baut dan penggunaan diameter baut yang bervariasi untuk optimasi yang lebih lanjut.



***Kata kunci***—Sambungan pelat ujung yang diperpanjang, sudut pengaku, analisis elemen hingga, sambungan balok-kolom baja.

# I. INTRODUCTION

One fundamental objective in structural optimization is minimizing the weight or volume of a structure. In steel frames, beam-column connections constitute only a small fraction of the total structural weight. However, these connections can incur substantial manufacturing costs due to their complex assembly, which involves multiple components produced through different fabrication methods, often requiring specialized finishing processes [1].

In traditional designs, joints are assumed to be ideally pinned or fully rigid; however, joints have finite rotational stiffness and can be considered as semi-rigid. An important aspect in the analysis of these joints is that their behaviours are decoupled from the analysis of the structure. However, the rotational behaviour of joints should be considered as it has a profound influence on the optimization of the design of the entire steel frame [2].

End-plate connections serve as critical junctions in steel frame structures, transferring loads and moments between beams and columns. These connections are fundamental elements in structural design, especially for earthquake-resistant buildings where connection performance directly influences the overall structural integrity. The "strong column-weak beam" principle, a cornerstone of earthquake-resistant design, requires connection zones to possess sufficient strength to ensure plastic hinges form in the beam rather than at the connection or column [3]. This design approach promotes ductile behavior and prevents catastrophic structural failure during seismic events.

End-plate connections have become increasingly popular in contemporary steel construction due to their numerous advantages over traditional connection types. They offer ease of fabrication, precision in assembly, efficient erection processes, and superior seismic performance characteristics [4]. These connections can be categorized based on their configuration as either flush end-plates (where the plate aligns with the beam flanges) or extended end-plates (where the plate extends beyond the beam flanges), with each type offering distinct mechanical properties and applications [5].

The performance of end-plate connections depends on various geometric parameters, including end-plate thickness, bolt diameter, bolt arrangement, and critically, the presence and configuration of stiffeners [2]. While unstiffened connections may be sufficient for moderate load conditions, stiffeners become essential in high-stress scenarios, particularly in seismic zones or where significant moment transfer is required. Research has consistently demonstrated that properly designed stiffeners can substantially enhance connection strength, stiffness, and ductility – all crucial properties for robust structural performance [6].

End-plate connections are broadly classified into two main categories based on their geometric configuration:

*Flush End-Plate Connections:* In this configuration, the end-plate is flush with the beam flanges, providing a compact connection profile. These connections are simpler to fabricate but generally offer lower moment resistance compared to their extended counterparts. Flush end-plates typically exhibit semi-rigid behavior and may be preferred in situations where space constraints exist or where maximum moment transfer is not the primary design consideration[7].

*Extended End-Plate Connections:* These connections feature end-plates that extend beyond the beam flanges, allowing for additional bolt rows and consequently increased moment capacity. Recent research indicates that extended end-plate connections can provide approximately 48% higher moment resistance compared to flush end-plate connections [4]. This superior performance makes extended end-plates particularly suitable for moment-resisting frames in seismic regions where connection strength and ductility are paramount [8].

Both connection types can be further categorized based on the number and arrangement of bolts, with configurations ranging from four bolts (two per horizontal row) to eight bolts or more (four per horizontal row) [6], [8]. The selection of connection type depends on several factors including required moment capacity, available fabrication capabilities, construction constraints, and anticipated loading conditions.

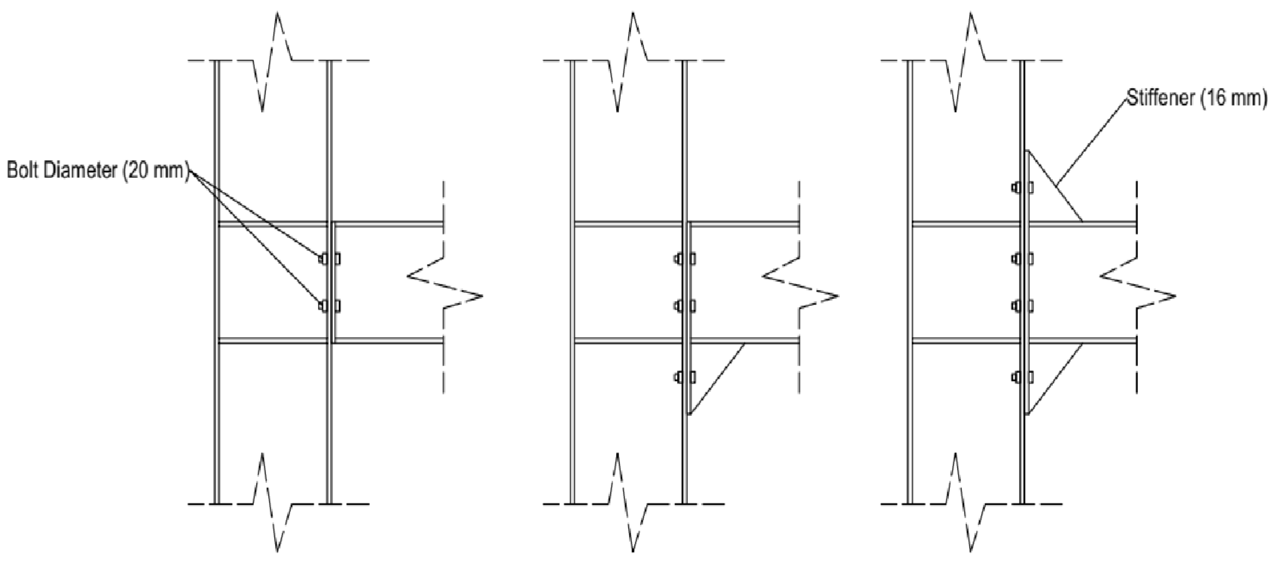
Finite element analysis (FEA) has emerged as an indispensable tool for detailed investigation of end-plate connection behavior, particularly when studying complex geometric configurations such as varied stiffener angles and positions [2], [9]. Modern FEA software such as ANSYS enables three-dimensional modeling that accurately captures material and geometric non-linearities, contact interfaces, bolt pretension, and progressive damage mechanisms [2], [4], [10], [11].

## II. METHODS

This study analyzed three distinct models of extended end-plate connections, as shown in Figure 1. The specimens were constructed from S235 steel, which has a nominal yield strength of 235 MPa. A summary of the specific material properties and parameters for these specimens can be found in Table 1. The steel properties utilized in the analysis are as follows: Young's modulus (E) = 210 GPa, Poisson's ratio (v) = 0.3, and density = 7850 kg/m³.

**Table 1.** Model Parameters

| Column Profile | Beam Length | Beam Profile | Plate Thickness | Plate Angle | Bolt Diameter |
|---|---|---|---|---|---|
| H.250.125.6.9 | 1000 | H.200.100.5.8 | 16 | 45° | 20 |
| H.250.125.6.9 | 1000 | H.200.100.5.8 | 16 | 60° | 20 |
| H.250.125.6.9 | 1000 | H.200.100.5.8 | 16 | 75° | 20 |

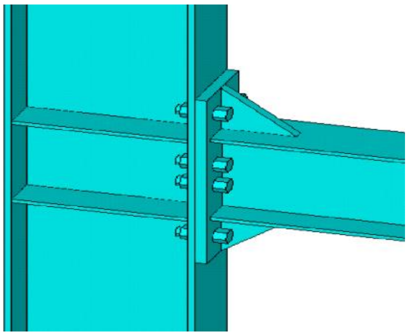



**(a)** Unstiffened **(b)** Bottom Stiffened **(c)** Double Stiffened

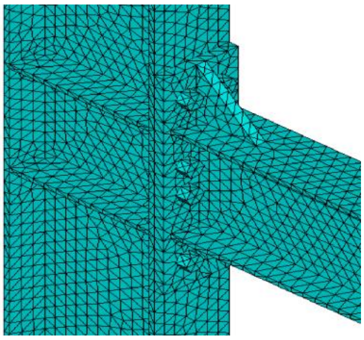
**Figure 1.** Detail of model

## III. Result and Discussion

As shown in Figure 2, the 3D model represents a detailed geometric representation of the structural system, incorporating key features such as material properties, boundary conditions, and loading scenarios. The mesh applied to the model consists of discretized elements that facilitate numerical analysis through finite element methods (FEM). The element size and type are selected based on accuracy requirements and computational efficiency, ensuring appropriate resolution for stress distribution and deformation analysis. This mesh refinement is essential for capturing localized effects, minimizing numerical errors, and enhancing the overall reliability of the simulation results.



**(a)** 3D Model Double Stiffener



**(b)** Mesh Detail

**Figure 2.** ANSYS Model

The first model does not have a rib stiffener, representing the flush type of end-plate connection as shown in Figure 3. The maximum displacement at the beam's end, where the loads are applied, is 0.0874 m.

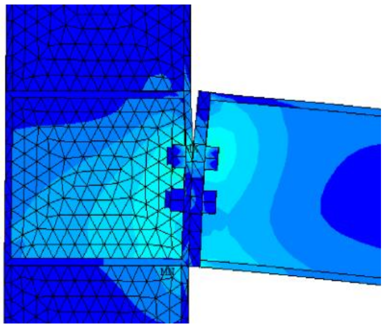
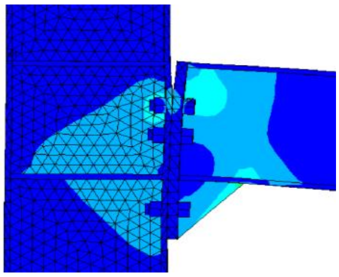
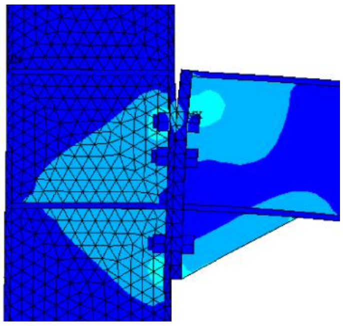


**Figure 3.** Deformed Shape and von Mises Stress for the Model Without Stiffener

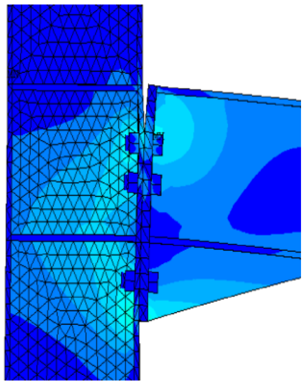
The second model incorporates a rib stiffener at the bottom of the end-plate connection between the beam and the column, aiming to improve structural performance by reinforcing the connection. Three distinct stiffener angles—45°, 60°, and 75°—are analyzed to evaluate their effects on displacement and stress distribution. Figure 4 presents the results, illustrating how the addition of stiffeners significantly enhances the rotational capacity of the connection. This improvement occurs because the stiffener increases the rigidity of the joint, reducing localized deformations and optimizing load transfer. Furthermore, increasing the stiffener angle modifies the force distribution path. A higher angle, such as 75°, allows for a more effective redistribution of stresses, ensuring that the load imposed on the beam is transferred more uniformly to the column. Consequently, this configuration mitigates excessive stress concentrations, reducing the risk of premature failure and improving overall connection efficiency.



**(a)** Angle of Stiffener 45°



**(b)** Angle of Stiffener 60°



**(c)** Angle of Stiffener 75°

**Figure 4.** Deformed Shape and von Mises Stress for the Model Without Stiffener

When comparing the flush type of end plate to a moment connection that includes a stiffener between the beam and column at the bottom of the connection, it is evident that the addition of the stiffener significantly enhances the rotational capacity of the connection. Specifically, the rotational capacity increases by 32.60% when using a single rib stiffener with a 45° angle. Additionally, increasing the rib stiffener angle from 45° to 60° results in an approximate increase in rotational capacity of 11.53%. Furthermore, an increase in angle from 45° to 60° again yields a rise in rotational capacity of about 10.88%.

**Table 2.** Results of the Bottom Stiffened Model

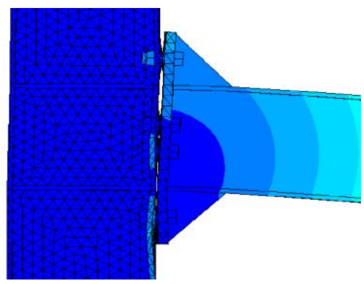
| Model | Maximum Displacement (m) |
|---|---|
| Without Stiffener | 0.0874 |
| 45° Bottom Stiffener | 0.0589 |
| 60° Bottom Stiffener | 0.0521 |
| 75° Bottom Stiffener | 0.0457 |

The third model features double stiffeners at both the top and bottom of the connection as shown in Figure 5. The displacements and rotations are detailed in the Table 3. Notably, increasing the rib stiffener angle from 45° to 60° results in an increase in rotation capacity of approximately 9.01%. Additionally, increasing the angle from 45° to 60° leads to a further increase in rotation capacity of about 15.08%.

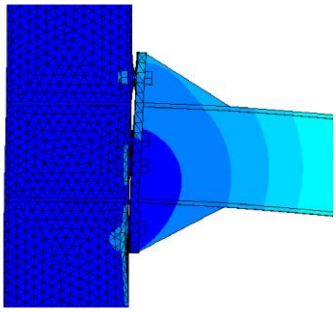
**Table 3.** Result of the Double Stiffened Model

| Model | Maximum Displacement (m) |
|---|---|
| Without Stiffener | 0.0874 |
| 45° Double Stiffener | 0.0351 |
| 60° Double Stiffener | 0.0319 |
| 75° Double Stiffener | 0.0217 |

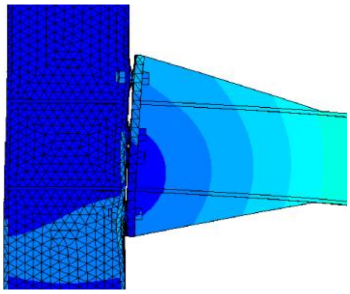
When comparing the flush type end-plate to the extended end-plate connection, it is evident that the rotation capacity of the extended end-plate is significantly higher. This indicates that the extended end-plate and its rib stiffeners contribute substantially to enhancing the performance of the end-plate connection. Specifically, there is a 59.85% increase in rotation capacity when comparing the flush type end-plate (model without stiffeners) to the double rib stiffener at a 45° angle.



**(a)** Angle of Stiffener 45°



**(b)** Angle of Stiffener 60°



**(c)** Angle of Stiffener 75°

**Figure 5.** Deformed Shape and von Mises Stress of the Double Stiffened Model.

## IV. CONCLUSION

This study presents a three-dimensional finite element model for analyzing end-plate steel connections and the effect of various parameters on connection behavior. The key findings from this research are summarized as follows:

1. The rotation capacity of extended end-plate connections is significantly higher than that of other configurations. This indicates that the extended end-plate and its rib stiffeners make a remarkable contribution to improving the behavior of end-plate connections.
2. Adding a stiffener to the moment connection between the beam and the column at the bottom of the connection increases the rotational capacity by 32.60% when comparing the flush type of end-plate to a model with a 45° single rib stiffener.
3. Implementing double stiffeners at both the bottom and the top of the moment connection enhances the rotational capacity by 59.85% when comparing the flush type of end-plate to a model with a 45° double rib stiffener.
4. For the single stiffened model, increasing the rib stiffener angle from 45° to 60° results in a rotation capacity increase of approximately 11.53%. Similarly, this change from 45° to 60° shows a rotation capacity increase of about 10.88%.
5. For the double stiffened model, increasing the rib stiffener angle from 45° to 60° leads to a rotation capacity increase of about 9.01%, while this change from 45° to 60° yields an increase of around 15.08%.

Future studies could incorporate the effects of bolt pretension and examine the behavior of connections involving different bolt diameters to further enhance structural performance

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