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3D Finite Element Modelling of Fin-plate and End-plate Connections

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Abstract: The analysis of three-dimensional finite element modelling of fin-plate and end-plate connections is essential in the domain of structural engineering because of the extensive application of these connections in steel structures, including buildings, bridges, and industrial facilities. These connections are crucial for maintaining the stability and integrity of structures by efficiently transferring loads between beams and columns. The main aim of this study is to create and evaluate a finite element model for comparing the Fin-plate connection to a steel tubular column with the End-plate connection to a steel tubular column. The finite element software was used to model all the connection components, including the tubular column, fin plate, and end plates. Both models were given identical parameters, material specifications, loadings, and boundary conditions. The experimental and numerical analyses of these components are conducted using finite element models. The discovered results were correlated with the experimental findings conducted by other researchers. The findings demonstrated that the created model is suitable for analysing and designing connections between end plates and fin plates with steel tubular columns. The study in this field also aids in the creation of design guidelines and standards, improving the capacity to anticipate and depend on steel connections in real-world applications.

Keywords: *Finite Element model, Steel tubular columns, Fin-plate connections, End-plate connections.*

Introduction

The main reason for the widespread use of moment resistant joints with extended connecting end plates is mostly due to the straightforward and cost-effective nature of their design, manufacture, and installation procedures. These connections are commonly utilized to attain inflexible connection characteristics. Steel buildings sometimes require minimal detailing to meet design requirements [1]. This issue is overcome by utilizing the most recent semi-rigid design philosophy. This technique provides increased flexibility compared to fully-restrained design by using connection quality as variables in the design process [1, 2]. Steel connections serve the purpose of connecting various steel members, hence ensuring a robust and reliable construction. The predominant forms of steel couplings include bolted, welded, and riveted. Bolted connections are the most cost-effective choice, but they provide the lowest level of strength [1,2].

In order to ensure a robust structural design, it is essential that the connections between different parts of the structure have the capacity to effectively redistribute loads in the event of component failure [2]. Eurocode 3, the European standard for steel construction, offers calculations for welded and bolted connections of steel I-beams and H-columns [2, 21]. Nevertheless, there is a scarcity of research regarding the behavior of connections to hollow or concrete-filled tubular (CFT) columns. These columns are becoming more prevalent in tall, multi-story buildings and offer structural benefits such as a smaller column cross-sectional area and built-in fire-resistance due to the concrete in-fill [3]. Contemporary regulations such as LRFD and Eurocode acknowledge the financial influence of connections on the design and production of frames. Consequently, the design rules for moment-resisting connections were revised [3, 4]. Existing design methodologies are unable to accurately simulate three-dimensional (3-D) physical systems due to the presence of intricate material and geometrical nonlinearities, friction, slippage, contact, bolt-end plate interactions, and failures [4, 5, 22]. The finite element method is currently regarded as a valuable supplement to design model calibrations. Contemporary steel-framed structures incorporate “composite beams’’ that consist of ribbed and curved steel sheets [5, 6]. The headed stud shear is affixed to the upper flange of the steel I section beam once the concrete has been poured into composite slab beams supported by thin and profiled steel sheeting [6, 23].

The Research Objectives (RO) of this study are as follows:

R01: To develop 3D finite element models for CFST columns connected to steel I beams via fin plate and end plate connections.

RO2: To compare the results obtained from the finite element models with existing literature on similar connections.

RO3: To propose a comprehensive 3D finite element model that incorporates all essential criteria for the analysis and design of both fin plate and end plate connections between CFST columns and steel I beams.

Materials and Methods

The materials and methods can be elucidated by employing the subsequent headings.

Geometry and Material Properties

To analyse the composite frame behaviour, simpler numerical models need to be created for CFST column connections. The composites are predicted perfectly in [11, 12] by detailed FE models. These models may also be utilised for behavioural research but are difficult to create routines and to analyse frames. On the other hand, simpler models in the analysis of frames are computationally highly efficient.

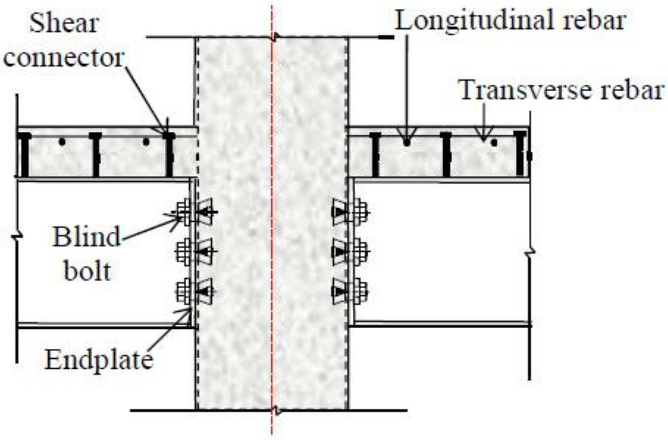

Figure 7: Simple representation of end-plate connections [13]

Pinned or rigid connections may easily be recreated with different connection design software's. However, for semi-rigid connections, one connector element can define either the predicted moment-rotation ratio with analytical models or many connector elements with a computed stiffness of each component was studies in [14]. There might be a convergence difficulty when many connection components are employed, which renders it difficult to analyse big frames. On the other hand, if the moment-rotation connection is recognised, the single connector element can only be used for frame analysis.

The finishing plates consist of a fin plate welded to a steel tube and structural bolts fixed on a steel beam. This on-site connection form is easy to set up. Fin plate connections are less rigid than weld and tube wall rips are common [12].

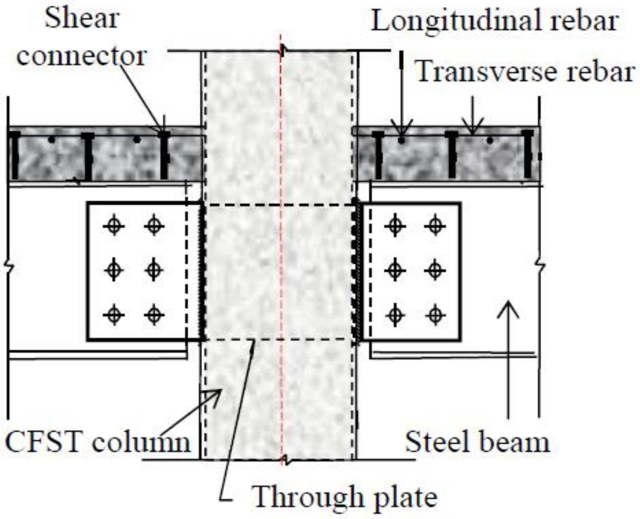

Figure 8: Simple representation of fin-plate connections [13]

Conversely, in through plate connections, a steel plate is inserted into the hollow section and then welded to the opposite surfaces during the connection process. These connections offer the benefit of much increased load resistance to the cross component, resulting in better capacity compared to fin plate connections, despite the difficult and costly production procedure [15].

Fin-Plate Connections

The fin plate connection consists of a plate that is welded to the CFST column in the workshop. On-site, the supporting beam web is bolted to the plate to create a simple connection, as shown in Figure 1. The flanges of the beam are not connected to the column.

A group of academics has done a significant analytical investigation on the tensile behavior of welded plate connections to concrete-filled tube (CFT) columns. In their study, Pan et al. (2018) [7] performed a series of tests to develop a yield line mechanism for a transverse branch plate that is connected to circular CFTs and subjected to axial force. The discovery was made that the addition of concrete in-fill significantly enhanced the strength of these connections. The strain distribution in tubes filled with material was more localized near the junction as opposed to empty tubes, suggesting a distinct mechanism for withstanding external forces. Therefore, during the development of the mechanism for filled tubes, the yield lines were focused on the region of the column face that encompasses the connection, including the weld. This mechanism was compared to the test findings, which showed a satisfactory level of agreement. Nevertheless, the trials' failure was not regarded as the ultimate failure load, but rather as a load determined by the General Yield Point Method.
[8].

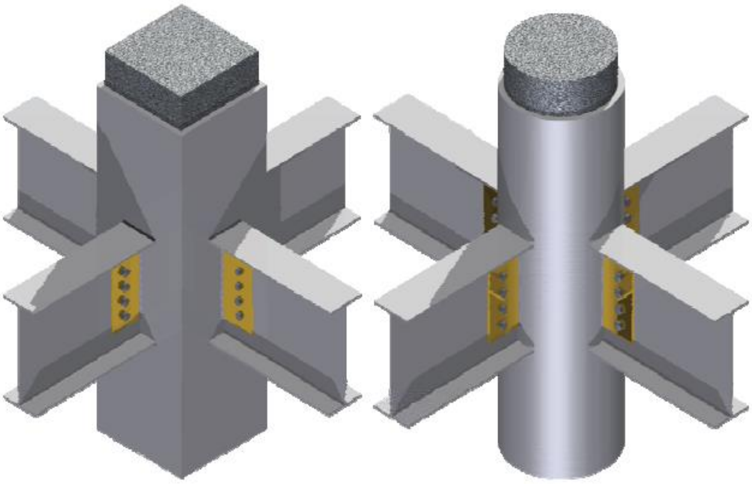

Figure 1: Fin-plate connections [9]

Three-dimensional finite element modelling of Steel tubular column to Steel I Beam by Fin plate connection

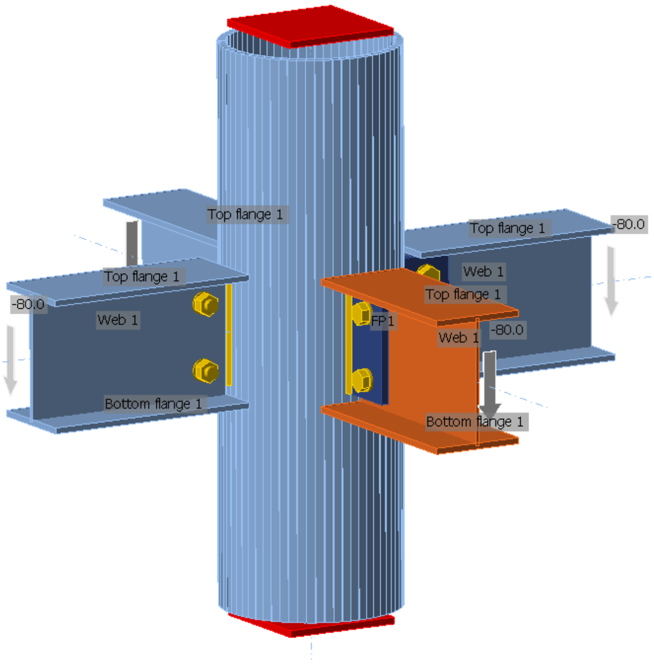

Figure 2: 3-D FE model of Fin-plate connections

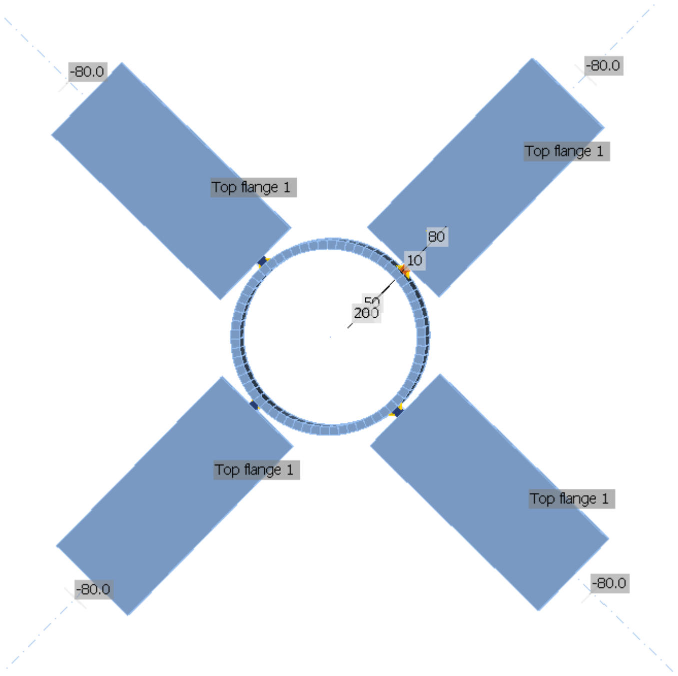

Figure 3: 3-D FE model of Fin-plate connections

End Plate Connections

End-plate connections (ECs) are commonly employed in civil engineering due to their strong flexural resistance. ECs in steel structures exhibit partially restricted behaviour, affecting force distribution and structure displacement. Thus, ECs should be built to reflect their true structural behaviour. To accomplish this, first determine the moment-rotation curve of ECs, and then consider their nonlinearity in structural analysis and member design. Accurately predicting the moment-rotation characteristics of ECs (such as initial stiffness and ultimate moment) is crucial for engineering purposes. The objective of this research is to develop new equations that can effectively predict the initial stiffness and ultimate moment of ECs when subjected to shear stress and moment [10].

CFST structures are increasingly used in multi-storey buildings because of their outstanding seismic performance, characterized by their superior strength, flexibility, and ability to absorb large amounts of energy. Bolted endplate connectors have gained popularity in construction practice for linking composite beams to CFST columns in framed building constructions due to their simple manufacture and assembly process. These joints can be classified as either flush or extended endplate types, depending on the desired strength and stiffness [10]. In a bolted endplate joint, the endplate is commonly welded to the end of the steel beam. The assembly is fastened to open-section columns or CFST and hollow-section columns using blind bolts, which can be inserted from the exterior of the steel tube.

The behavior of bolted endplate composite joints has been extensively investigated using analytical techniques, finite element models, and experimental testing. However, these experiments were limited to conventional composite couplings, in which the steel beams and open section column were connected using standard bolts [1]. There hasn't been many research done on how the blind bolting method behaves when joining steel beams to CFST columns in composite joints.

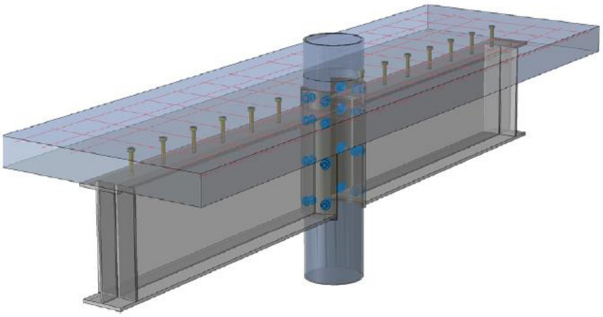

Figure 4: End-plate connections [13]

Connections to the endplate can be split into three kinds based on the endplate length: header end, extended and flush.

If the measurement of the endplate is not as much of as the depth of the steel beam it is said to be a header endplate connection, whereas, if the length of endplate is larger than the height of steel beam it is termed as an extended endplate connection. And if the endplate's length matches to that of the depth of steel, is it a flush endplate connection. The flush plate is stronger than the header endplate connections, but has a lower capacity than the extended endplate connection [11].

Three-dimensional finite element modelling of Steel tubular column to Steel I Beam by End plate connection

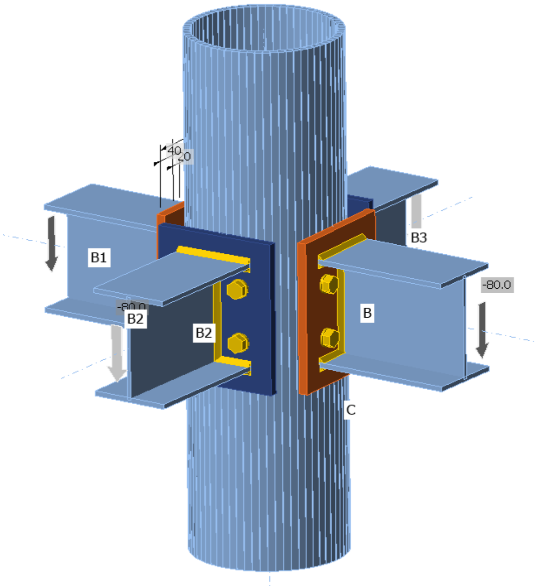

Figure 5: 3-D FE model of Fin-plate connections

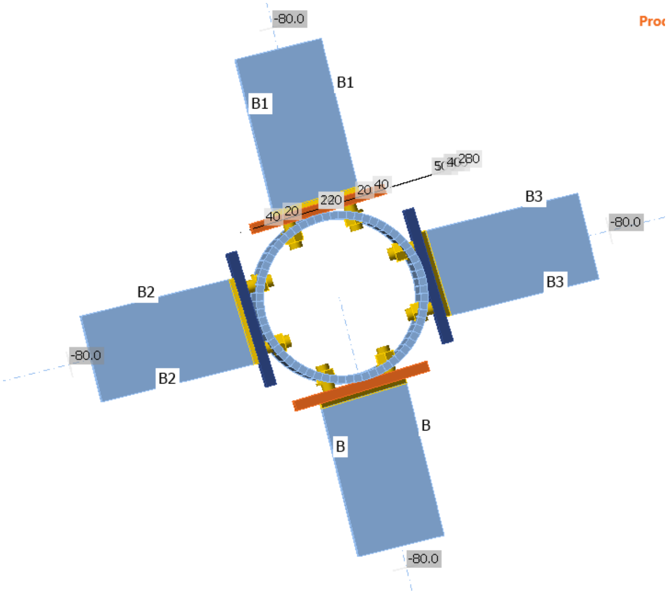

Figure 6: 3-D FE model of Fin-plate connections

Results and Discussion

The results of this study can be explained on the basis if the research objectives.

R01: To develop 3D finite element models for CFST columns connected to steel I beams via fin plate and end plate connections.

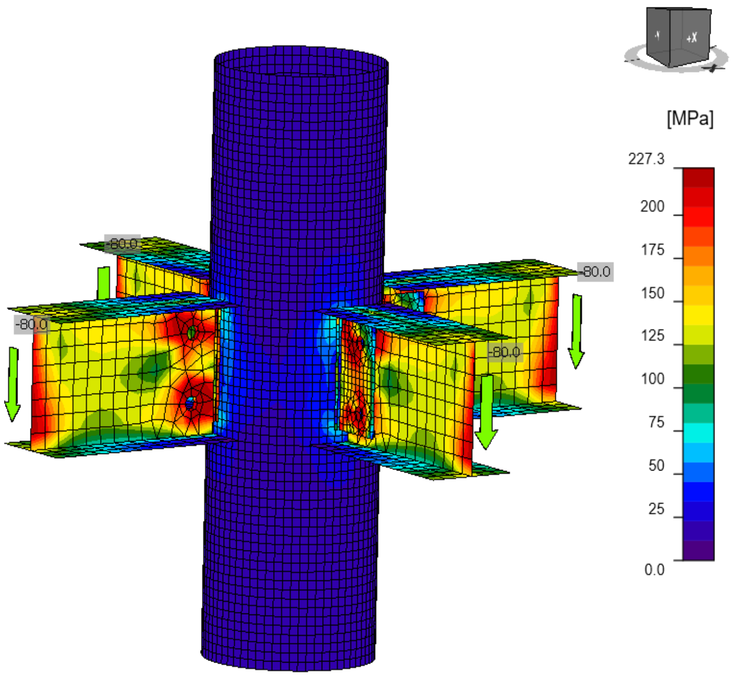

Figure 9: Analysis results for fin-plate connections

Welding the steel platform at the end of a steel beam and attaching it to a CFST column using structural bolts from the outside of the tube creates endplate connections. Based on endplate length, endplate connections are header end, extended, or flush. Header endplate connections have a length less than the steel beam's depth, whereas extended endplate connections have a length greater than the beam's height. A flush endplate connection occurs when the endplate length matches the steel depth. The flush plate is stronger than the header endplate connectors but less capable than the extended endplate [11].

CFST columns to composite beams with blind-bolted endplate connections are suitable for multi-story buildings because to their ease of production and assembly. In their CFST column connection experiments, a composite slab increased initial stiffness and bending resistance. Thus, the CFST column with composite slabs and blind-bolted endplate connectors [12] is the focus. A novel method employed by Katwal et al. [12] in five trials on CFST column connections using blind bolted endplates on hollow concrete columns. Stud spacing and reinforcing percentage were examined. Partial shear-connected composite joints become more ductile. Increased reinforcing increased ultimate moment capacity. A 1.0–1.5 percent reinforcement rate was favourable.

RO2: To compare the results obtained from the finite element models with existing literature on similar connections.

Two composite connections' static and dynamic load performance. Both specimens behaved similarly, although the static loading capacity was larger. Thus, loading type affected composite connection behaviour. Thai et al. (2017) [13] tested four blind bolted endplate connections representing the internal composite region. The effects of various CFST column shapes and endplates (four bolt rows extended and three bolt rows flush) were examined. All four specimens failed ductility and rotated significantly. Despite the distorted plate in the bolt row next to the concrete plate, the bolt ran as far as possible from it. The concrete splits outside the column stretched to the dome, creating a cross split that ran the dome's length. At times, the circular CFST column had 13.5% and 18.3% more composite connection than a square column with similar section capacity. Extended terminals improve moment resistance and initial stiffness by 15% and 22.6%, respectively, compared to composite connections with flat end plates.

RO3: To propose a comprehensive 3D finite element model that incorporates all essential criteria for the analysis and design of both fin plate and end plate connections between CFST columns and steel I beams.

The test results obtained from Tao et al., 2017 [13] and the predictions from [11] were used to verify the 3D FE model proposed on the basis of Moment and Rotation curves [18]. The curves are in a very good agreement to the test results as well as the predictions.

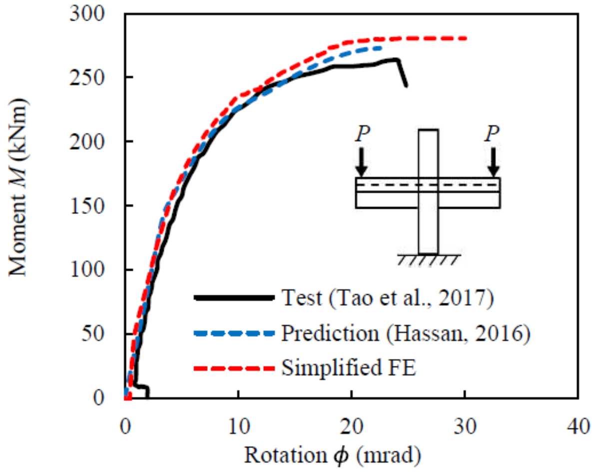

Figure 10: Moment-Rotation curves for Model-1

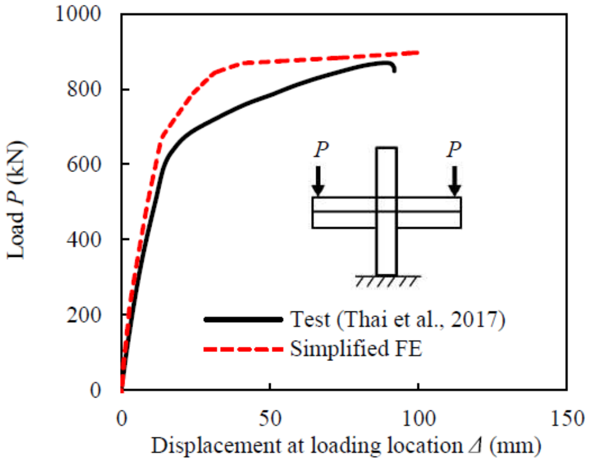

Figure 11: Load Displacement curves for Model-1

The test results obtained from Thai et al., 2017 was used to verify the 3D FE model proposed on the basis of Load-displacement curves. The curves match with the test results as well as the predictions.

Similarly, as shown in fig.12 the test results obtained from Tao et al., 2017 and the predictions from [11, 17] were used to verify the 3D FE model proposed on the basis of Moment and Rotation curves. The curves are in a very good agreement to the test results as well as the predictions.

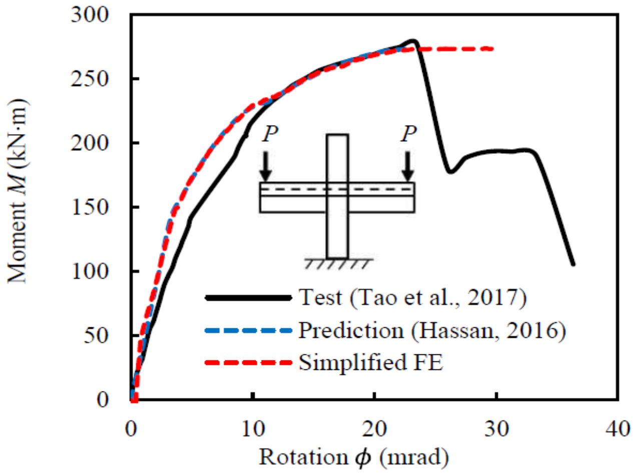

Figure 12: Moment-Rotation curves for Model-2

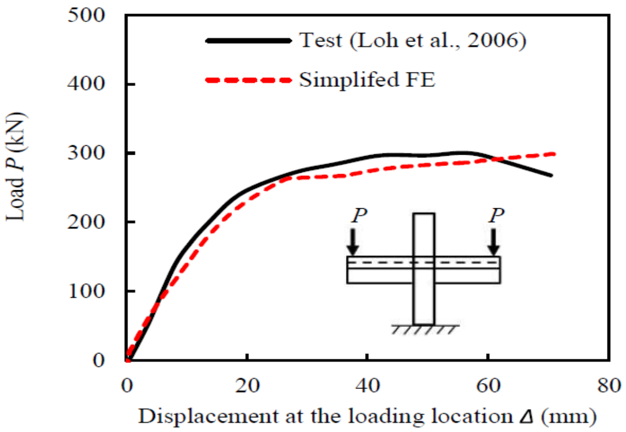

Figure 13: Load Displacement curves for Model-2

The test results obtained was used to verify the 3D FE model proposed on the basis of Load-displacement curves. The curves are in a very good agreement to the test results as well as the predictions.

Conclusion

This study examined connection moment-rotation behaviour from initial rigidity to ultimate moment capacity. Finite element analysis determines connection mechanical properties and fracture mechanisms. Both types of connections' initial stiffness and maximum bending moment have been calculated using novel equations. This study's key finding includes Eurocode 3 and Tao's models slightly overestimated ECs' initial stiffness, although Thai et al. were conservative. A semi-empirical equation was constructed to calculate ECs' initial stiffness based on their mechanical behaviour [19]. Comparing this equation to experimental data assessed its correctness. The recommended equation is more accurate than Tao, Thai et al., and Eurocode 3[14]. Eurocode 3, Gong, and AISC equations slightly overstate Eurocode's last minutes [19]. The flush end plate fracture mechanism was proposed using validated finite element analysis. This technique yielded a unique equation for ECs' ultimate moment [20, 24]. Test data was used to verify the new equation. The proposed equation is more accurate than Gong, Eurocode 3, and AISC formulae. The study used ECs with two or four bolts under tension, which are common in engineering, but the results may not apply to ECs with six or more bolts. This study focuses on bolts under pretension loading, thus future research should examine snug-tightened joints.

Limitations and Future Scope

This study can be further scrutinized by modifying the different components used for the analysis such as the loading, stress, member sizes, and configurations of the bolts and welds also, the diameter as well as the length of the connections.

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