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Behavior-modified T-stub steel connection against cyclic loads

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Abstract

This study investigates the structural behavior of a Modified T-Stub steel connection under cyclic loading through both numerical simulations and experimental testing. The primary objective is to evaluate whether the Modified T-Stub connection meets the criteria for Special Moment Frame (SMF) Prequalification, as outlined in SNI 7972:2020. Two test specimens were analyzed: Specimen 1 (WF 450x200x9x14) and Specimen 2 (WF 500x200x10x16), each paired with a WF 588x300x12x20 column. Numerical simulations were conducted using IDEA StatiCa and ANSYS software, while experimental testing was performed at the PUPR Laboratory. In the laboratory, an actuator was used to push the column with a 100-ton capacity, and we installed 21 strain gauges and 19 transducers to check deformation and strain in the members. The numerical analysis revealed that Specimens 1 and 2 reached drift ratios of 5% and 4%, respectively, meeting the required seismic performance standards. Experimental results confirmed similar findings, with drift ratios of 4% and 5%, and plastic moments exceeding 502 kN·m for Specimen 1 and 603 kN·m for Specimen 2. The yield load for Specimen 1 is 179 kN, and the yield load for Specimen 2 is 224 kN. Tension and compression at the flange for Specimen 1 are 1644 kN, while compression and tension at the flange for Specimen 2 are 1816 kN. Both approaches showed that plastic deformation occurred in the beam segment beyond the connection, indicating effective energy dissipation. These findings validate the Modified T-Stub as a viable alternative for prequalified moment-resisting connections in seismic steel structures. The practical implication is a simplified installation process for steel beams that enhances construction efficiency in terms of time and cost while maintaining seismic safety compliance. The rotation for Specimen 1 and Specimen 2 are 5% and 4%, respectively, which meets the AISC regulation if the connection is a Special Moment Frame Prequalification.

Keywords: Experimental, Numerical, Special moment connection prequalification, T-stub modified.

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1. Introduction

The influence of earthquakes on structures can have fatal consequences, particularly for those made of steel material [1]. Research into the failure of steel structures due to the impact of earthquakes intensified after the 1994 Northridge earthquake. According to the FEMA-350 failure report, the failure of buildings with steel structures occurs outside of expected parameters, primarily due to brittle connections. Typically, failures occur at the welded joints between the lower wing beam and the wing column, resulting in welding failures. This can lead to the development of cracks in the wing column behind the welding joints. Additionally, in the construction industry, practitioners are required to continuously innovate and create methods that facilitate easy implementation to achieve good efficiency in both time and cost [2].

Connection types prequalified in SNI 7972:2020, such as 8ES and T-Ganda, become a number of connections taken as reference to modify the steel connection. The modification is done by converting 8ES to Single-T with welding in the lower wing beams section and bolting in the wing section on the beam.

The research on the Modified T-Stub connection aims to understand the behavior of the connection under cyclic loading through both numerical and experimental approaches. Numerically, the analysis is conducted using IDEA StatiCa and Ansys software to examine the response of the connection to cyclic loads [3]. Experimentally, the testing is carried out in the laboratory to directly observe the behavior of the connection under such loads. Additionally, the study aims to define the prequalification criteria for the connection to meet the Special Moment Connection Prequalification standards [4].

This research has several limitations. It involves two test specimens: the first specimen uses a WF 588x300x12x20 column and a WF 450x200x9x14 beam, while the second uses a WF 588x300x12x20 column and a WF 500x200x10x16 beam. The materials used include ST41 steel with mechanical properties of fy = 300 MPa and fu = 400 MPa, A325M bolts with fy = 660 MPa and fu = 830 MPa, and E70xx weld material with fy = 57,000 psi and fu = 70,000 psi. The numerical analysis is performed using IDEA StatiCa and Ansys software, and the cyclic loading test is conducted at the Laboratory of the Directorate of Housing and Settlement Engineering, Ministry of Public Works and Housing (PUPR).

The benefits of this research are to demonstrate that the Modified T-Stub connection can be used as a prequalified special moment connection, and that the implementation method for steel beam installation becomes easier and more time-efficient [5].

2. Literature Review

There are 10 connections regulated by prequalification in SNI 7972-2020 (AISC 358-16). Connection beam to deep steel column system frame bearer moment special and also intermediate must capable of accommodating a minimum drift of 0.04 rad and resistance minimum flex 0.8 M_p from capacity moment plastic beam [6].

A number of connections used as reference modify connection that is Eight-bolt with stiffeners (8ES), Bolted Flange Plate Moment Connections (PSB), and Double T-Moment Connections. SNI does not limit use of connection other types that do not listed, only just before connection used need existence a series of prequalification tests based on SNI 7860-2020 and approved by the authorized party [7].

Bolted Flange Plate (BFP) connections are modified moment connections specifically aimed at streamlining construction costs while retaining seismic style. Based on the results of the study, all specimens fulfill AISC Seismic Provision criteria with a minimum drift of 0.06 rad. During the bolt slip test, it was observed that slip occurred more frequently, and the slip-bearing deformation has a significant impact on the total deformation [8].

The experimental connection to the burden cyclic with the '24 bolted extended end-plate connection with haunces' specimen was carried out at Politehnica University of Timisoara, showing that the connection plate end extension given by the bolt with elbow is capable of fulfilling the prequalification for seismic application and demonstrates stable performance under cyclic loading [9].

3. Methodology

3.1. Experimental Study on Modified T Stub Steel Connection

Full-scale Modified T Stub Steel Connection: all the specimens meet the requirements of the AISC Seismic Code for Structural Steel Buildings for special moment frame beam-column connections. The lateral bracing distances for the specimens are determined in accordance with these requirements. The vertical displacements are applied by hydraulic actuators at the beam ends, as shown in Figure 3.

The loading is started at 0.375% radian and incrementally until the specimen fails. The applied load is measured by a load cell mounted on the actuator. Transducer TR1 in Figure 3 measures the total displacement of the beam ends while the horizontal displacement of the column is recorded by TR4 and TR7. The moment-rotation relationships at the column surface are obtained for all the specimens using the data measured by these instruments.

In this study, Specimen No. 1 is selected as the base model. For this specimen, the loading is applied at a distance of 2810 mm from the column face. The details of this relationship are shown in Figure 3.

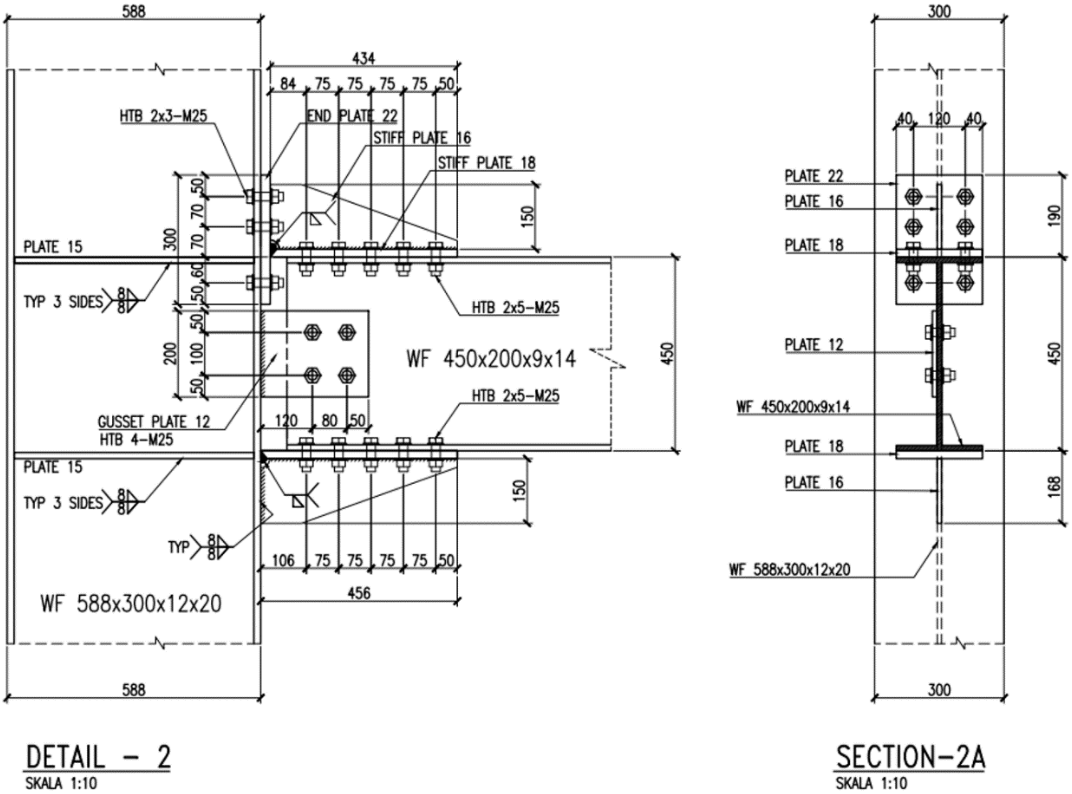

Figure 1.
Specimen 1.

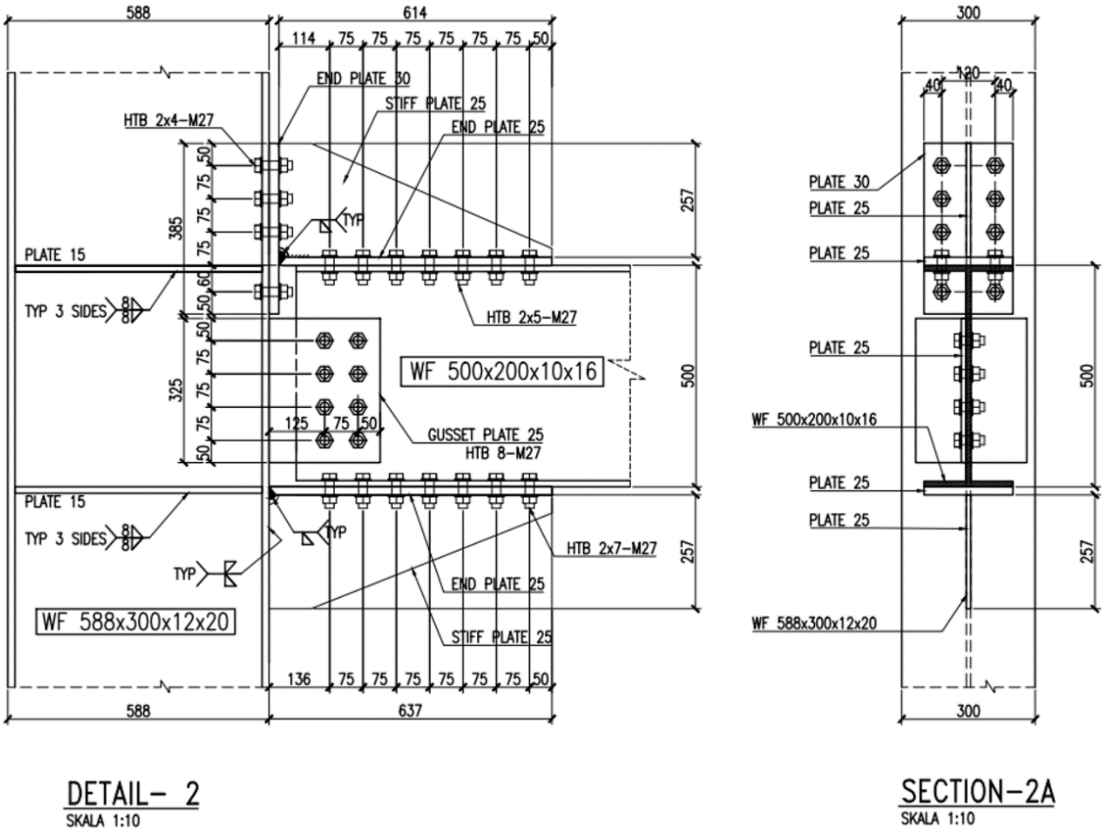

Figure 2.
Specimen 2.

Specimen No. 1 failed due to buckling of the flange at the end of the joint support when a deformation angle of 0.05 radians was reached during the test. The applied load beam end displacement and moment at Specimen No. 1. Specimen No. 4 failed due to buckling of the flange at the end of the joint support when a deformation angle of 0.04 radians was reached during the test. The applied load beam end displacement and moment at Specimen No. 4. The two specimens above have met the requirements of a special moment frame prequalification connection.

The instrumentation used in this experimental study is.

- 25 Linear Variable Displacement Transducers (LVDT).
- 11 Strain Gauges.
- Two load cells.

LVDT 1 is used to measure the maximum deformation to determine the rotation of the Modified T Stub Steel Connection.

LVDTs from 2 to 25 are used to control the movement of the test specimen sample to determine whether there is deformation in the out-of-plane direction.

Strain gauge to control the strain on the plate and bolts. In this study, it is assumed that the moment at the modified T stub steel connection is the actuator force (P) multiplied by the distance from the connection beam to the column support of 2,810 mm.

M = P.L

The load on the actuator is adjusted to 6 radian cycles, with an actuator capacity of 100 tons, and the column is given a load of 1 ton. In this test object, the column is assumed to be a joint but the right side is made a pin so that it can move vertically.

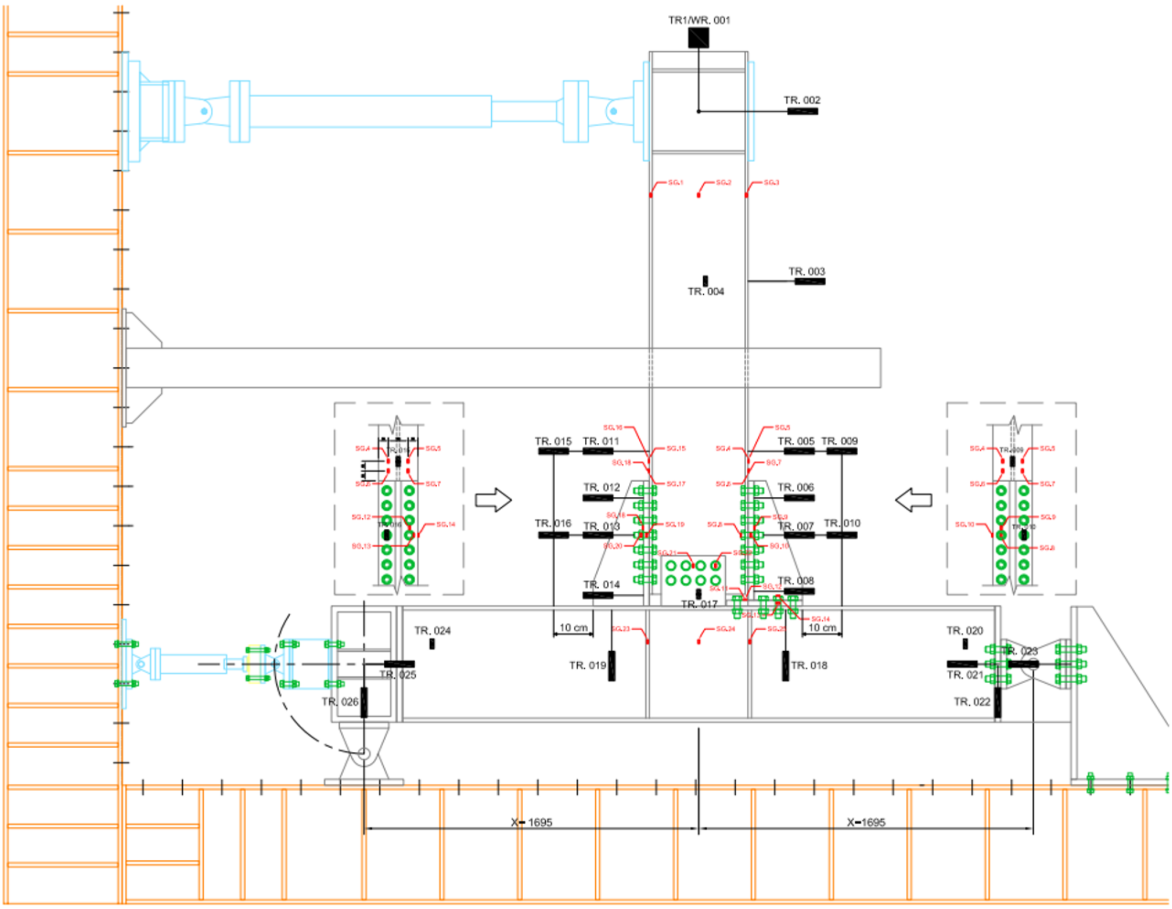

Figure 3.
Instrumental.

The study utilizes both numerical and experimental methods to test the Modified T-Stub Connection specimen. The specimen uses a high ductility profile criterion for seismic design and construction [10]. The first test object employs a WF column profile of 588x300x12x20 with a WF beam profile of 450x200x9x14, as shown in Figure 4. The second test object uses a WF column profile of 588x300x12x20 with a WF beam profile of 500x200x10x16, as shown in Figure 5.

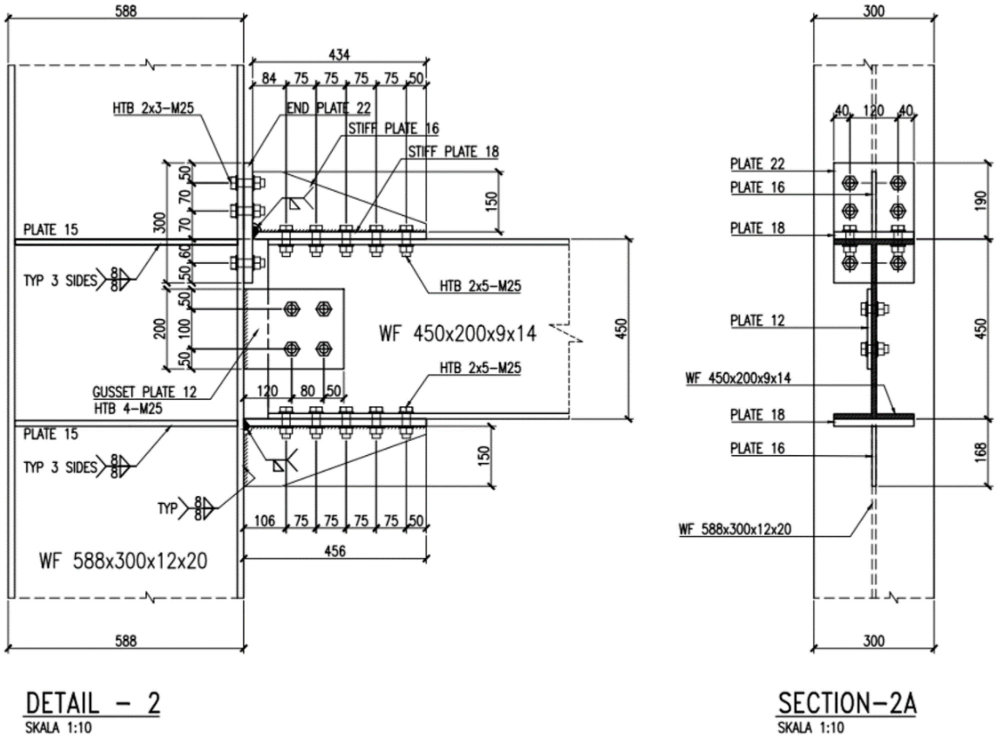

Figure 4.
Details of Test Object Connection 1.

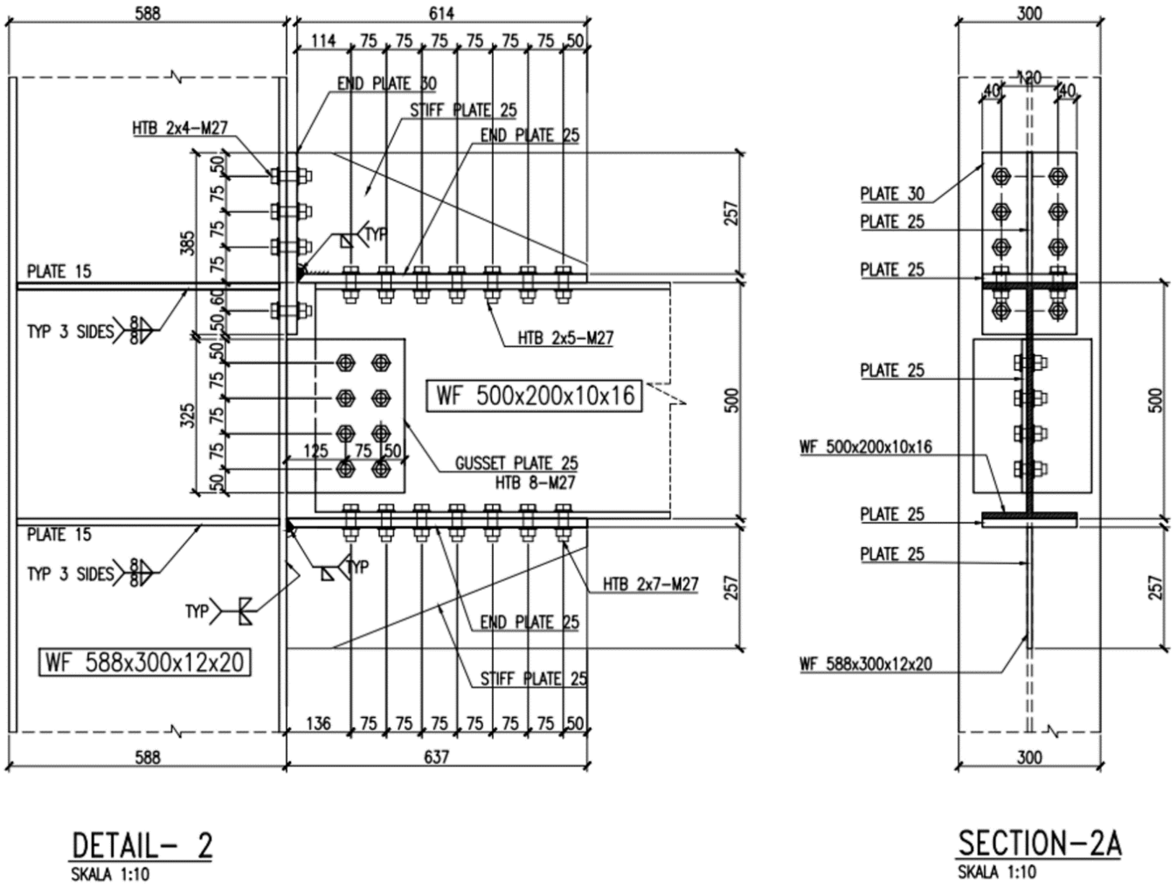

Figure 5.
Details of Test Object Connection 2.

Testing numerical done as preliminary design or determination profile the connection that will be used. Specimen done modeling and analysis use *Idea Statica* and *Ansys software.* Modeling and analysis test object 1 is displayed following.

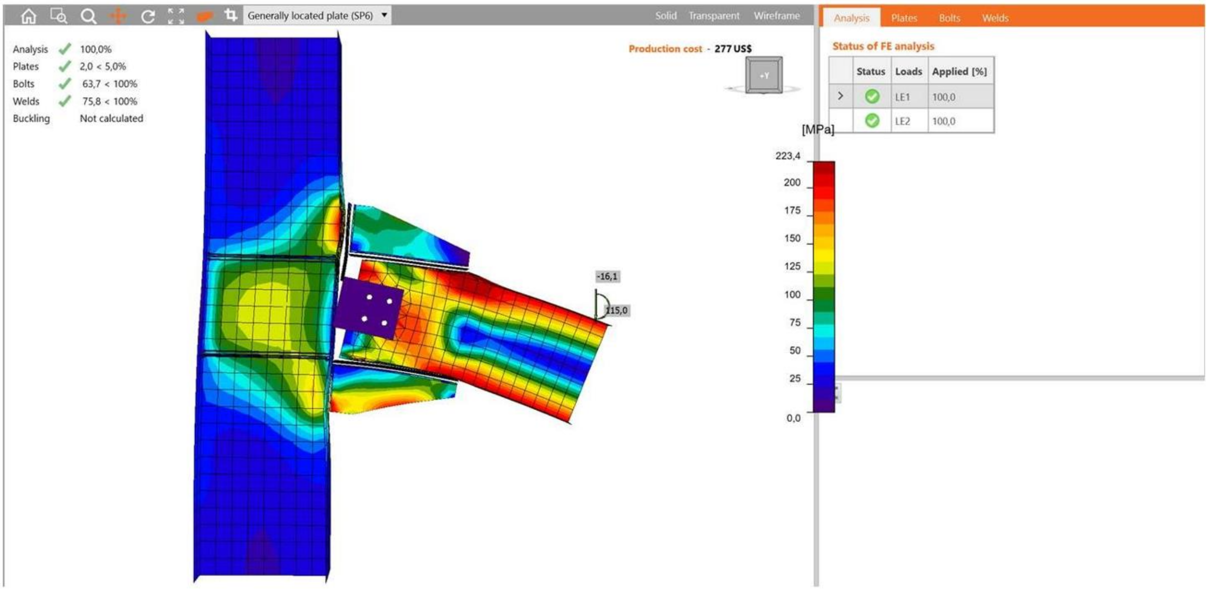

Figure 6.
Model and analysis of Test Object 1 (*Idea Statica).*

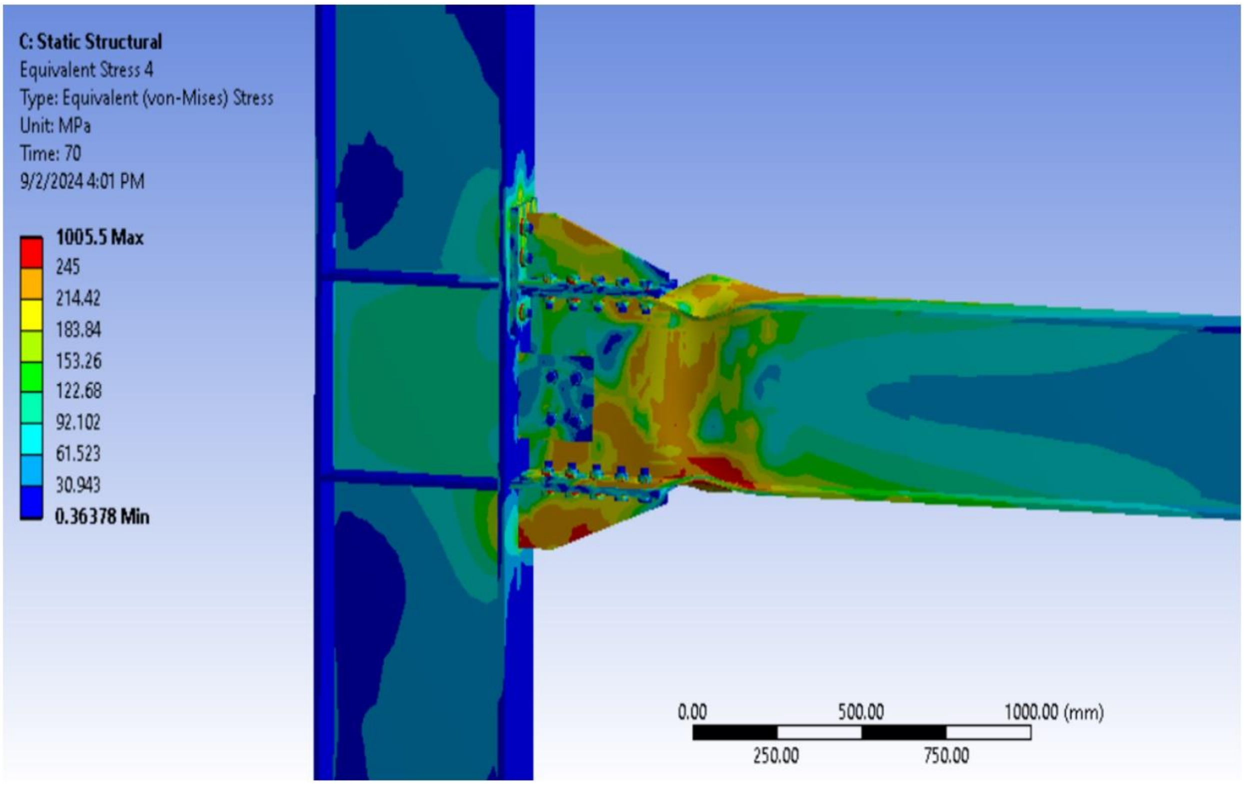

Figure 7.
Model and analysis of Test Object 1 (*Ansys).*

Then modeling test object 2 is shown under This.

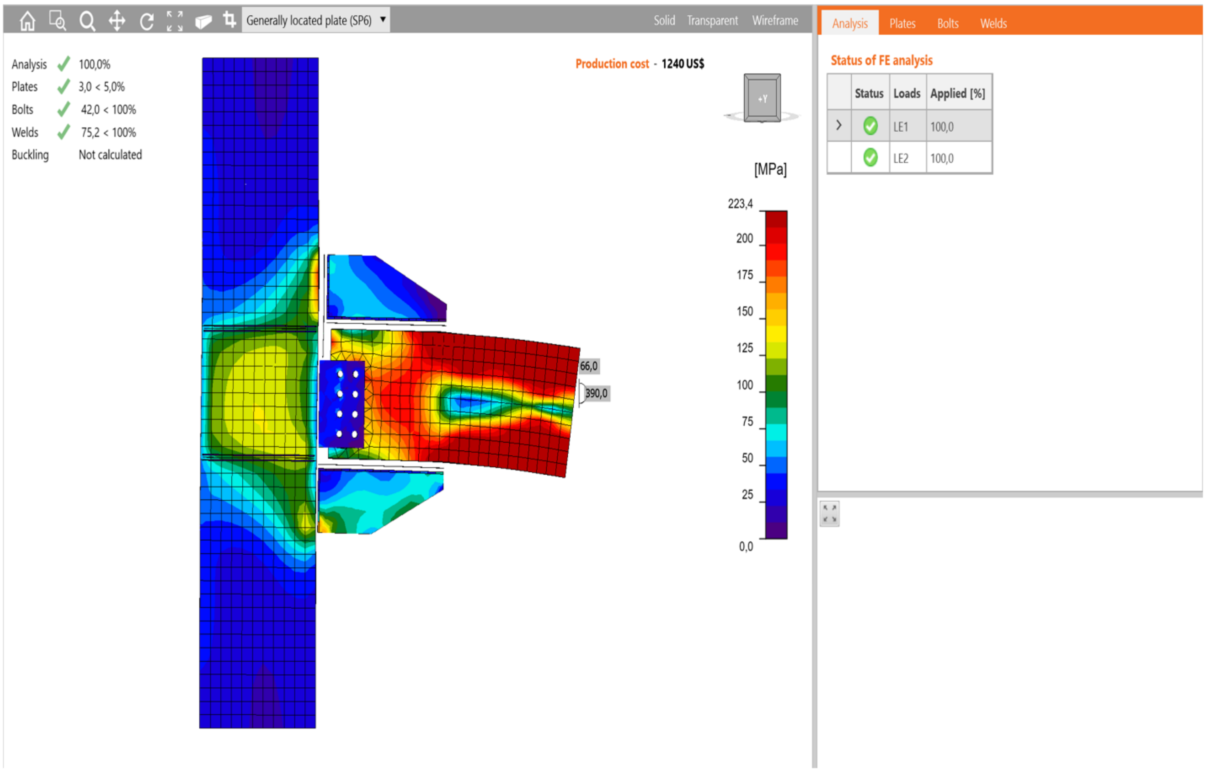

Figure 8.
Model and analysis of Test Object 2 (*Idea Statica).*

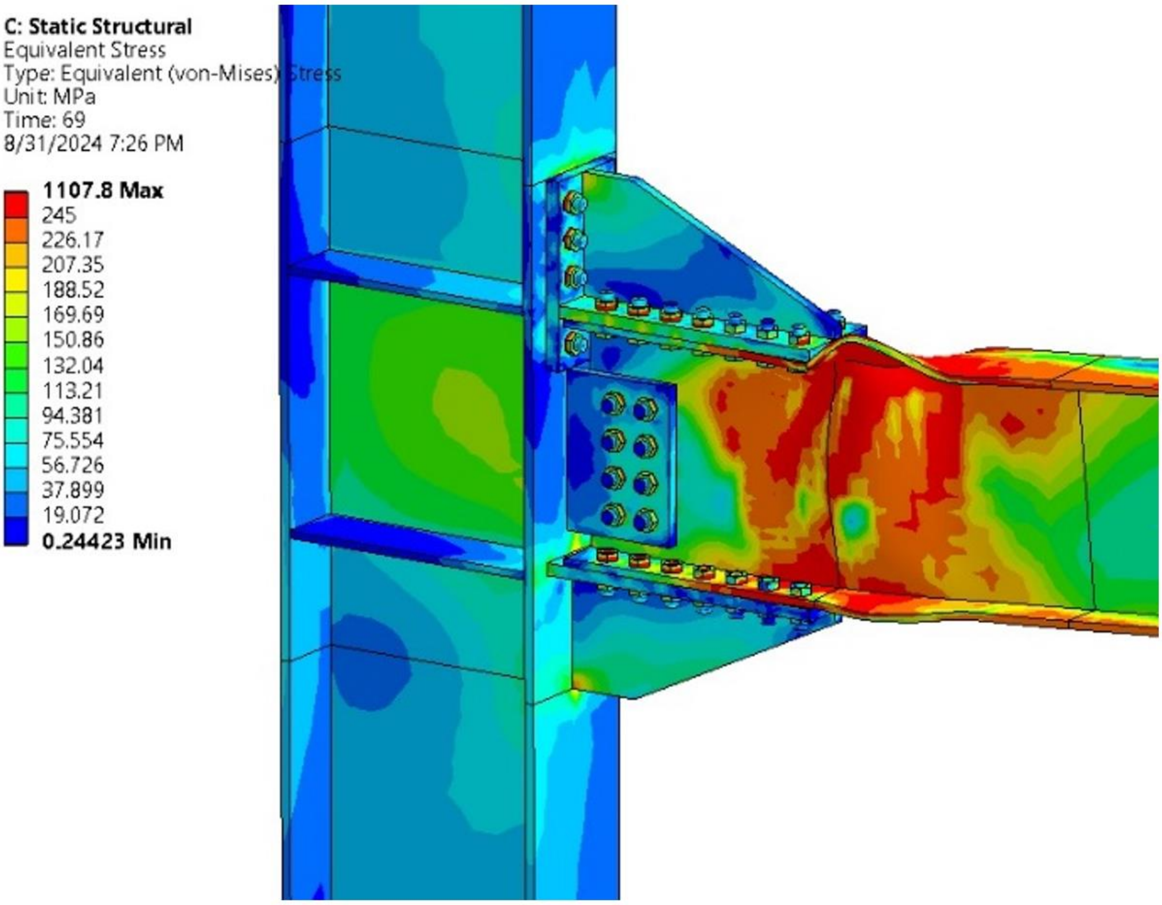

Figure 9.
Model and analysis of Test Object 2 (*Ansys).*

Testing experiments with the creation of test object models and test instruments. Documentation specimen complete test object with testing instruments carried out in the Laboratory of the Directorate of Housing and Settlement Engineering Development, Ministry of PUPR.

Figure 10.
Test Object Specimen 1.

Figure 11.
Test Object Specimen 2.

Test tools used in the experimental Modified T-Stub connection are made with a series steel profile as a retaining frame test object, with a hydraulic actuator implemented to simulate the burden of an earthquake at work.

Figure 12.
Documentation tool Puskim Lab Testing.

Figure 13.
Documentation LVDT Transducer Installation.

4. Results and Discussion

Based on preliminary profile results from the Idea Statica test, an analysis of the cyclic use burden is carried out using ANSYS. The analysis results for test object 1 indicate that the drift ratio is 5% with a plastic moment of 503 kN.m. For test object 2, the drift ratio is known to be 4% with a plastic moment of 603 kN.m. The following analysis output is displayed in ANSYS, along with the hysteresis diagrams of test object 1 and test object 2.

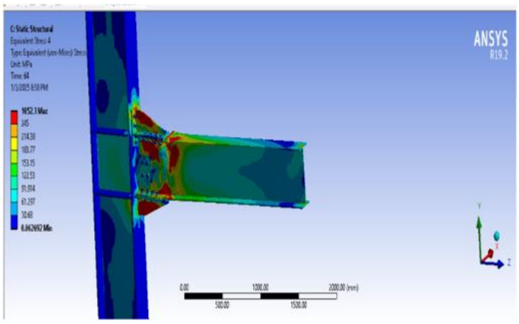

Figure 14.
Analysis output ansys wf 450x200x9x14.

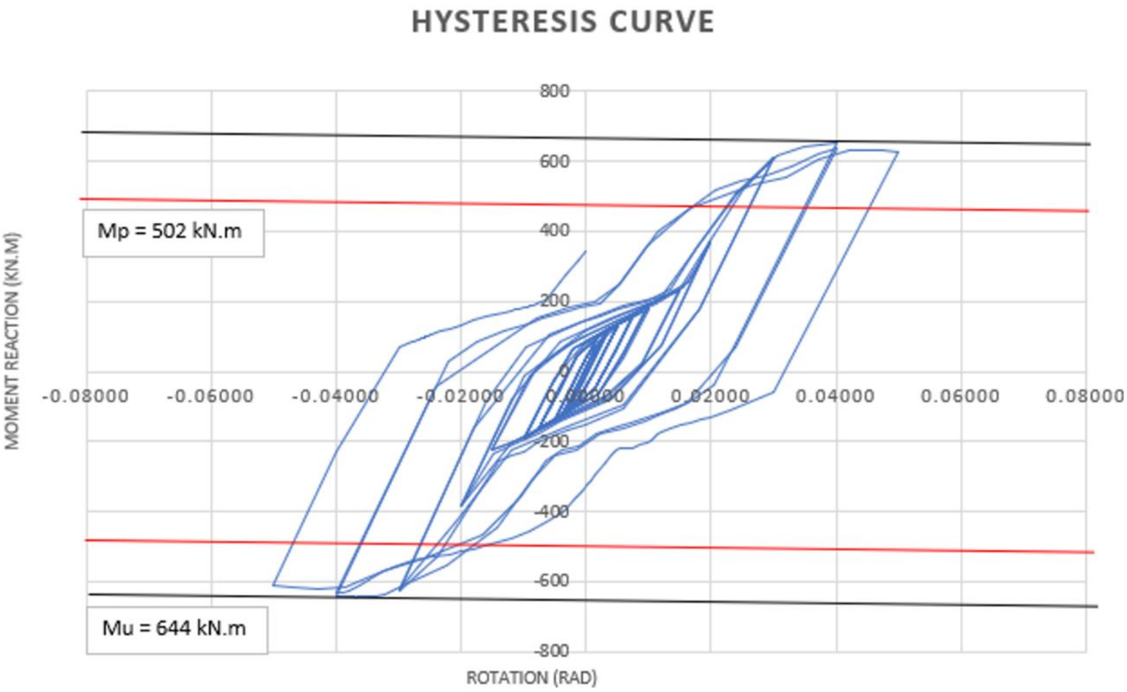

Figure 15.
Output hysteresis diagram for WF 450x200x9x14.

In the numerical analysis graph of test object 1 with Ansys, it shows a drift ratio of 5% radians. This has met the requirements for special pre-qualification moment connections. In the SNI for Pre-qualification Steel, it is stated that the minimum is 4% radians, with a plastic moment of 502 kN.m and an ultimate moment when buckling occurs of 644 kN.m.

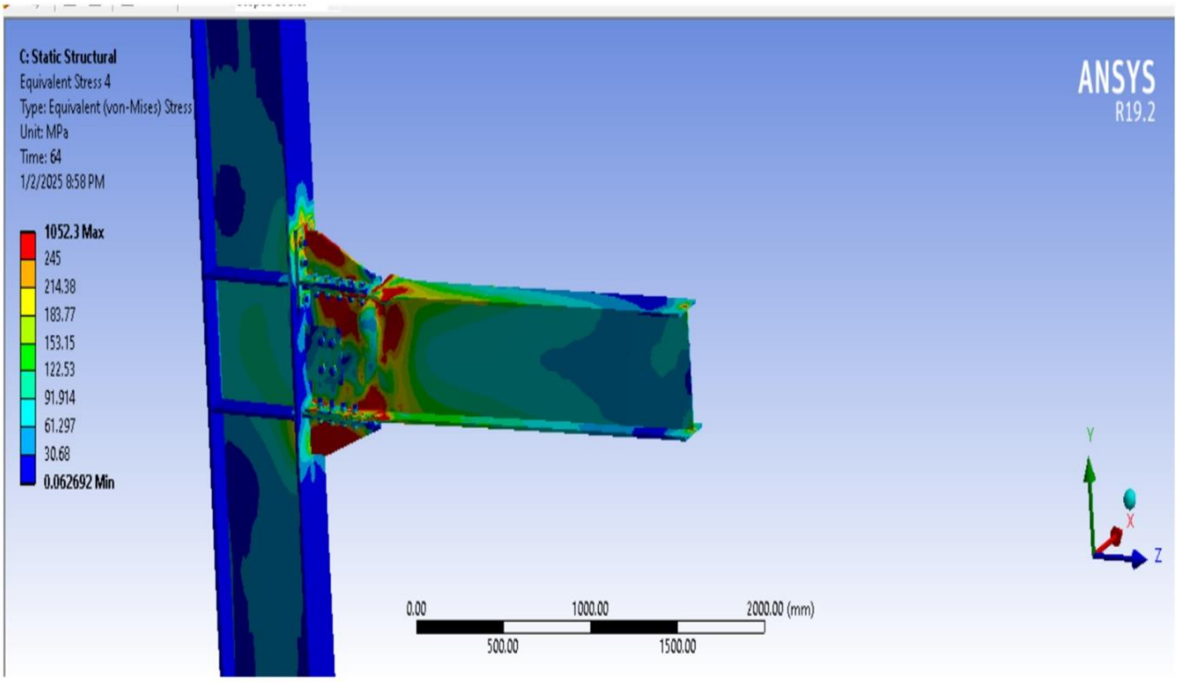

Figure 16.
Analysis output ansys wf 500x200x10x16.

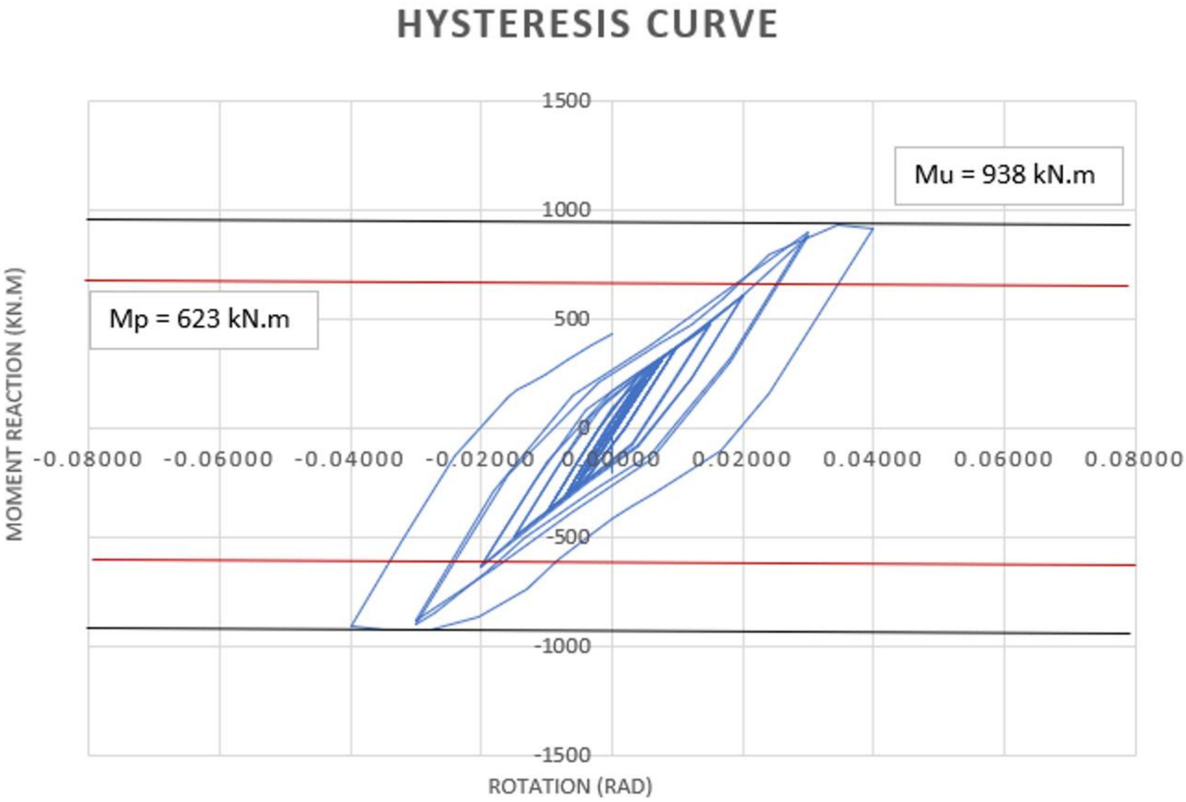

Figure 17.
Output hysteresis diagram WF 500x200x10x16.

In the numerical analysis graph of test object 2 with Ansys, it shows a drift ratio of 4% radians. This has met the requirements for a special prequalification moment connection. In the SNI Prequalification Steel, it is stated that a minimum of 4% radians is required, with a plastic moment of 603 kN.m and an ultimate moment when buckling occurs of 938 kN.m.

Research results from the experimental tests indicate that object 1 obtained a drift ratio of 4%, while object 2 obtained a drift ratio of 5%. It can be said that both already fulfill the SNI prequalification requirements 7972:2020.

Figure 18.
Cyclic test results test object 1.

Figure 19.
Cyclic test results test object 2.

Based on the results of testing the connection, it is still seen as safe or not yet at risk of collapse due to the consequences of cyclic loading. Displacement occurs in the beam outside the plate with the confessor or connection.

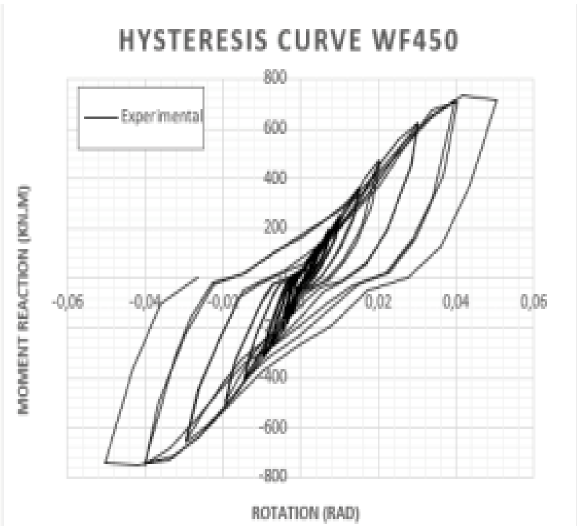

Figure 20.
Output hysteresis diagram of test object 1.

In the experimental result analysis graph of test object 1, the lab results show a drift ratio of 5% radians. This has met the requirements for a special prequalification moment connection. In the SNI Prequalification Steel, it is stated that a minimum of 4% radians is required, with a plastic moment of 503 kN.m and an ultimate moment when buckling occurs of 712 kN.m. Buckling on the flange occurs with a compressive force on the flange of 1644 kN on the bolt connection of test object 1. Web buckling occurs at an ultimate moment of 740 kN.m on test object 1.

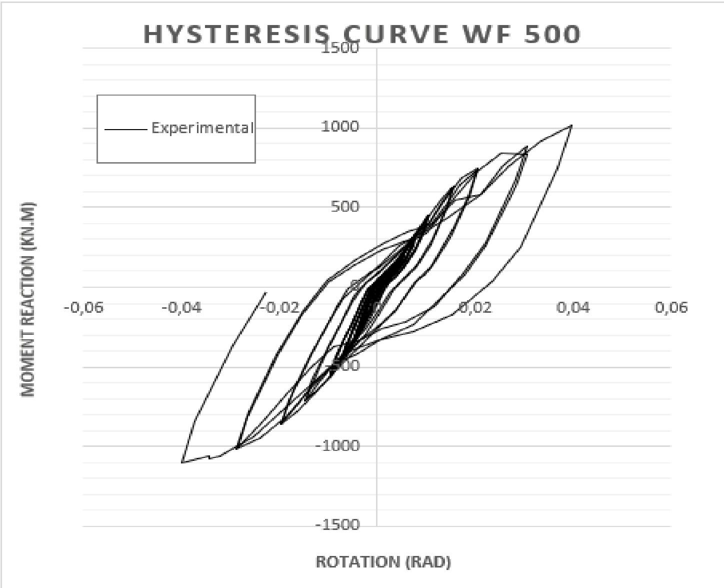

Figure 21.
Experimental result analysis.

In the experimental result analysis graph of the second test object, the lab results show a drift ratio of 4% radians. This has met the requirements for a special prequalification moment connection. In the SNI Steel Prequalification, it is stated that a minimum of 4% radians is required, with a plastic moment of 601 kN.m and an ultimate moment when buckling occurs of 1101 kN.m. Buckling on the flange occurs with a compressive force on the flange of 1816 kN on the bolt connection of test object 2. Web buckling occurs at an ultimate moment of 908 kN.m on test object 2.

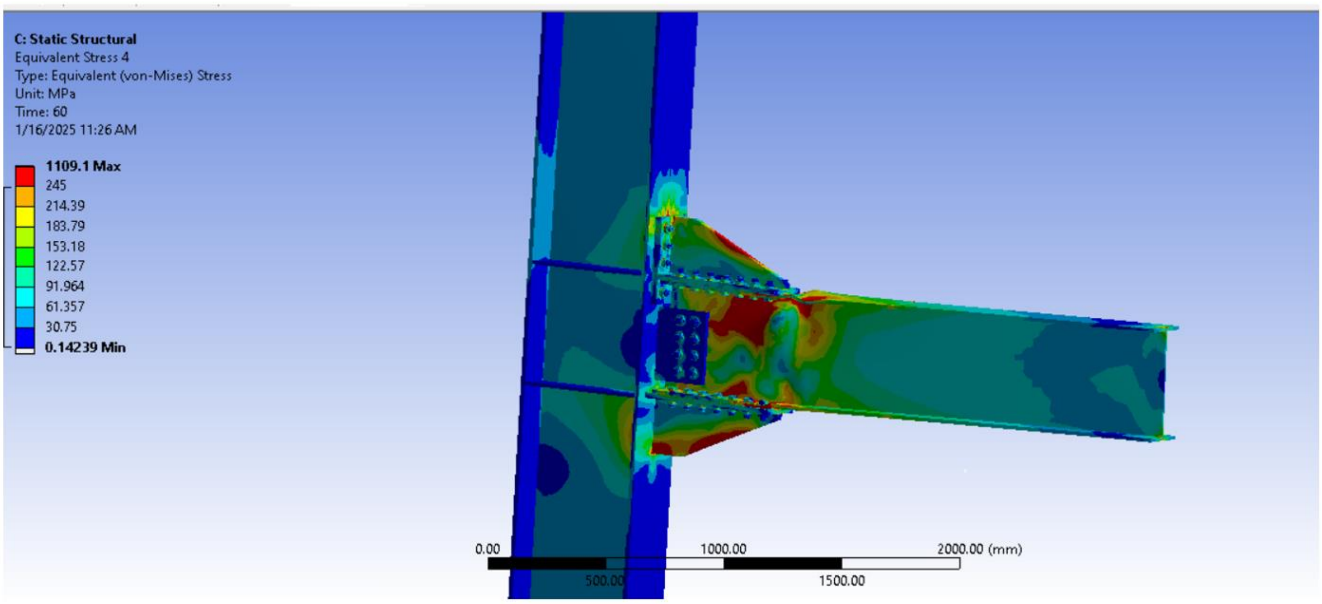

Figure 22.
Output hysteresis diagram of test object 2.

From the results of the numerical analysis and the experimental results, a hysteresis diagram was plotted to understand how the results differ. Here, the diagram will be displayed.

Plotting the hysteresis curve of the 1st object WF 450 x 200 x 9 x 14 between numerical and experimental results, from the analysis results with Ansys and numerical there is a difference of about 3%. Between Ansys and experimental, there is the same figure at the peak drift ratio of 5% radians.

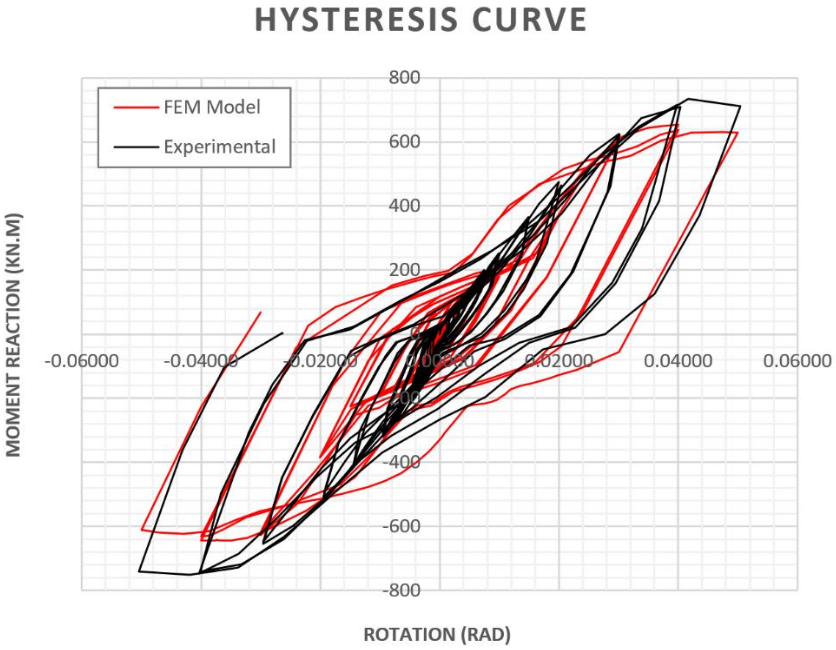

Figure 23.
Plotting the hysteresis diagram of test object 1.

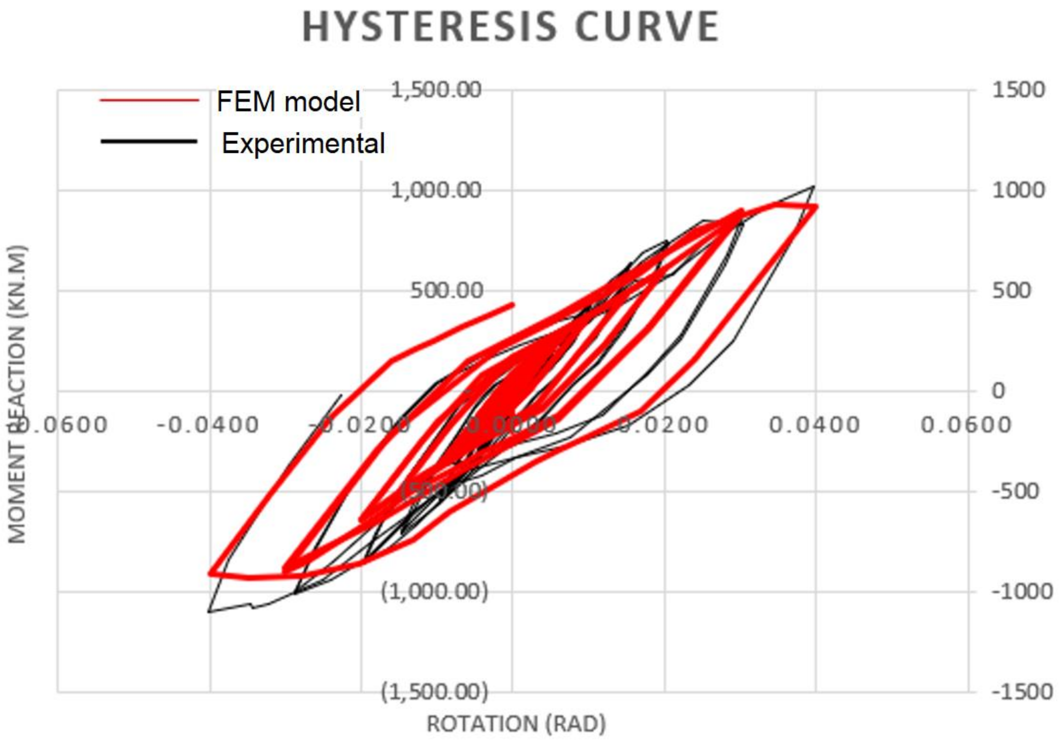

Figure 24.
Plotting the hysteresis diagram of test object 2.

Plotting the hysteresis curve of the 2nd object WF 500 x 200 x 10 x 16 between numerical and experimental results, from the analysis results with Ansys and Numerical, there is a difference of about 4%, between Ansys and Experimental have the same figure at the peak drift ratio of 4% radians.

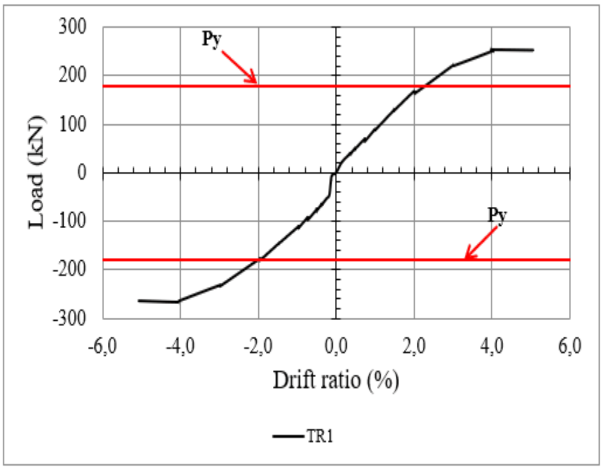

Figure 25.
Graph of an object's backbone test object 1.

The backbone graph output is obtained from the peaks load on the actuator and the load melting on test object 1, resulting in an experimental value of 179 kN.

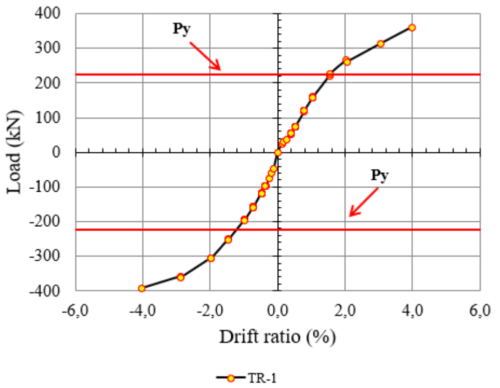

Figure 26.
Graph of an object's backbone test object 2.

Backbone graph output is obtained from peaks load on the actuator and load melting on test object 1, resulting in an experimental value of 224 kN.

Comparison of T Stubs Connections according to SNI 7860:2020 with Modified T Stub Single T. T Stubs Connection Image according to SNI 7860:2020 with Modified T Stub Single T. In the prequalification connection contained in SNI 7860:2020, the connection is made of double T both top and bottom flange with connections in the column and in the flange using bolts and without stiffeners or stiffeners in the Double T Connection. In the Modified T Stub Single T, for Single T, only the top flange is used with bolt connections on the column and flange, and added stiffener plates or stiffeners. At the bottom connection, a bolt flange plate is used with connections to the column using welding and bolts on the flange, also with added stiffener plates to reduce the thickness of the plate.

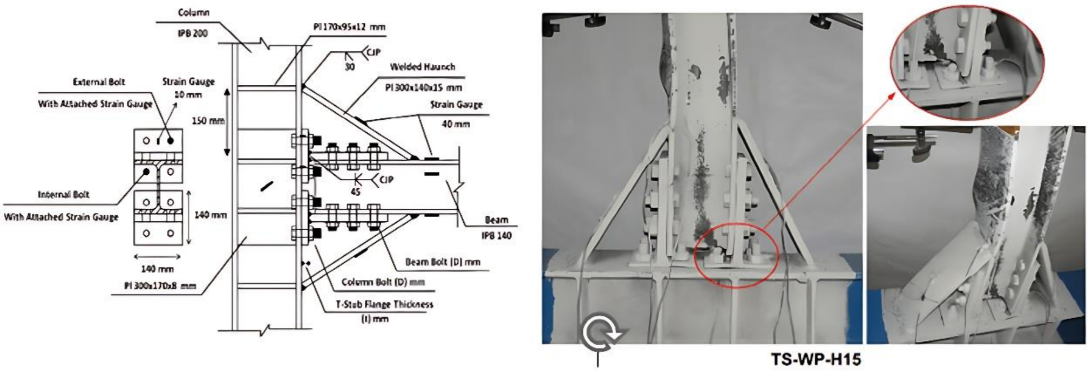

Figure 27.
Comparison with similar case experiments.
Source: Saberi, et al. [11].

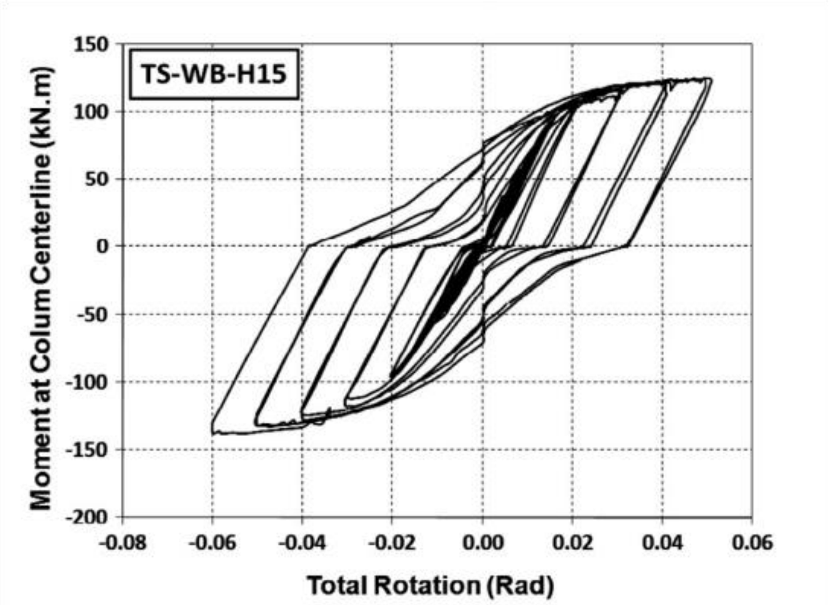

Figure 28.
Prequalification Rotation Connection Limits.

From the graphic image of the prequalification rotation connection limits, it can be explained that.
For special moment frame radian connections, the minimum rotation must be met of 0.04 radians.
For intermediate moment frame radian connections, the minimum rotation must be met of 0.02 radians.
For ordinary moment frame radian connections, the minimum rotation must be met of 0.01 radians.
From the backbone graph of test object 1 and test object 2 above, the following data can be concluded.

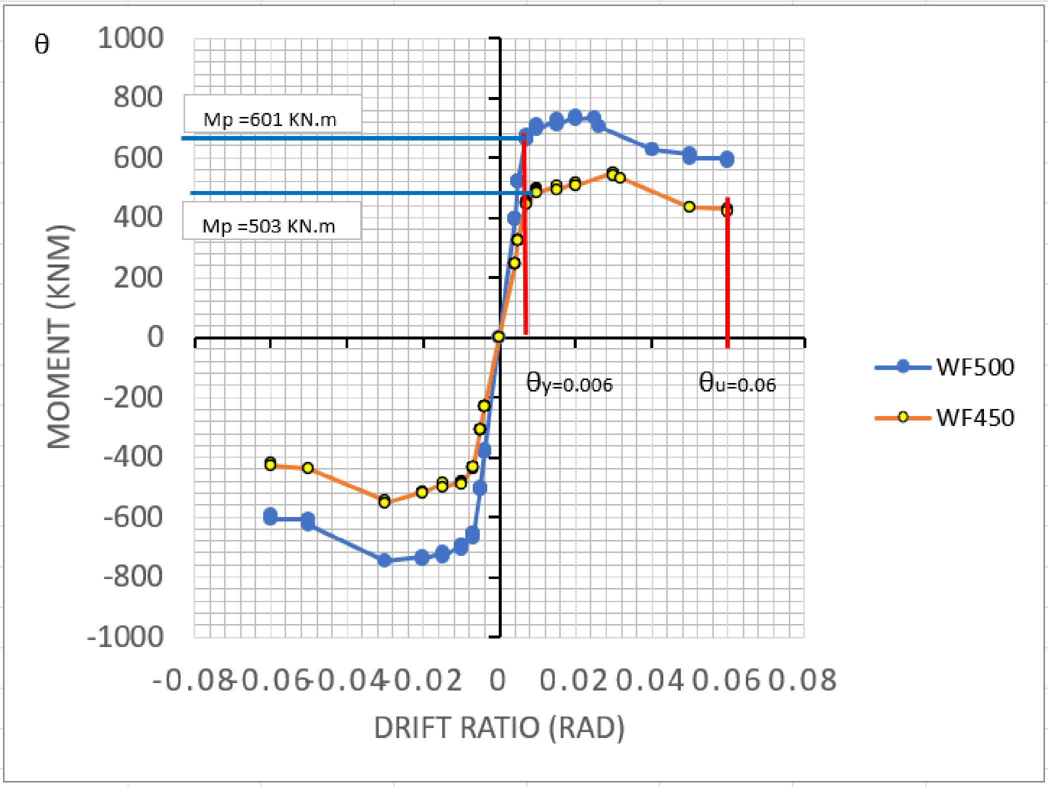

Figure 29.
Ductility of Modified T-stub Steel connection.

5. Conclusion

1. The results of numerical analysis using ANSYS indicate that the occurrence of plastic joints at the edge end happens after connection or in the beam member. The modified T-Stub connection of test object 1 and test object 2 still strongly withstands cyclic loads. The drift that occurs at the connection is 5% rad, which already fulfills the drift

limits for Special Moment Connection Prequalification. Mp (Plastic Moment) and Mu (Ultimate Moment) for test object 1 are 502 kN.m and 644 kN.m, respectively, while for test object 2, they are 623 kN.m and 932 kN.m.

2. Test results of experimental connection joints in plastic occur on the beam after the end connection. The drift ratio that occurs for test object 1 is 5% rad, and for test object 2, it is 4% rad. The capacity of test object 1 is known as Mp of 503 kN.m and Mu of 712 kN.m. For test object 2, Mp is 601 kN.m and Mu is 1.10 kN.m.
3. Based on testing numerically and experimentally, as well as plotting results, both hysteresis diagrams show that the Modified T-Stub connection already fulfills the criteria for Special Moment Connection Prequalification, with a minimum drift ratio requirement of 4% rad.

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