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AN EXPERIMENTAL STUDY ON OF HIGH-FIDELITY MODEL OF LIGHT-GAUGE STEEL SINGLE LAP SHEAR SCREW

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ABSTRACT

Connections play a critical role in the design and performance of structures, and failures in these connections can have severe consequences. While extensive research has been conducted on connections in structural design, the majority of studies have focused on HR-structural steel joints, leaving a gap in the understanding of light-gauge steel connectors. This paper aims to bridge that gap by increasing the knowledge on light-gauge steel connections.

Keywords: connections, structural design, failures, HR-structural steel joints, light-gauge steel connectors, bolted connections, hot-rolled steel, light gauge steel, fastener tilting.

1. INTRODUCTION

Structural design plays a crucial role in ensuring the safety and reliability of various constructions. The behavior of connections within structures is of particular importance, as a poorly planned or built link can lead to harmful failures. Extensive studies have been conducted to understand the intricacies of connections in structural design and to ensure their effectiveness. Among these studies, a significant focus has been placed on HR-structural steel joints, which have provided guidelines for designing bolted connections since 1951.While bolted connections share common characteristics, it is essential to recognize the distinctions between hot-rolled steel and light gauge steel. Light gauge steel differs from HR steel in terms of thickness, resulting in unique challenges such as fastener tilting, which can lead to connection failures. Additionally, the methods used to connect light gauge steel differ, including screwing, welding, or bolting, compared to primarily bolted and welded connections in hot-rolled steel structures. These differences necessitate a thorough understanding of the performance and behavior of light-gauge steel connections, prompting research in this field. The study of bolted light-gauge steel connectors began with Winter's research in 1956, marking the initial exploration into this area. While design recommendations for HR-steel bolted joints have been available for over 30 years, it was not until Pekoz's work in 1990 that design recommendations for light-gauge steel connections gained prominence.

Despite the addition of screw-fastened connections to the American Iron and Steel Institute's (AISI) specification for light-gauge steel, the study of light-gauge steel connections remains limited compared to hot-rolled steel. This paper aims to contribute to the existing body of knowledge on light-gauge steel connectors. Previously, screw-secured light-gauge steel connections have only been represented by finite element prototypes within larger light-gauge steel samples, where the screwed fasteners are depicted as linear objects. To address this gap, experimental data will be utilized to define the behavior of screws, allowing for the characterization of larger prototypical structures without relying solely on experimental data. This approach enables the incorporation of various connection characteristics into finite element prototypes. To ensure the relevance of this thesis, it is necessary to conduct a literature review that evaluates existing research on connections. This review will encompass high fidelity prototypical modeling of hot-rolled steel connections, as well as finite element prototypical modeling and experimental data on screw-fastened light-gauge steel connections. By examining the available literature, this study aims to provide a comprehensive foundation for the subsequent finite element prototypical modeling conducted in this research.

2. METHODOLOGY

2.1 Experiment Setup

The prototypical arrangement was carefully designed to replicate the experimental conditions. Certain components that had no significant impact on the connection behavior were excluded from the FEM to reduce computation time. This section discusses the details of the detached parts for the bolt and cold-formed steel (CFS) plies.

2.2 Bolt Prototyping

To simplify the model and ensure accurate connection behavior, the bolt was prototyped as having a thread-free body, a round top, and no washer, unlike the experimental screws. Including threads would have required complex contact definitions and manual meshing. The prototypical screw's head was represented as a cylinder with a specified diameter, while the washer was not included in the model.

2.3 CFS Ply Prototyping:

The dimensions of the CFS plies in the experimental setup differed slightly from the prototypical arrangement. However, the behavior of the plies away from the screw location had minimal impact on the connection behavior. To expedite the prototypical simulation, the dimensions of the plies in the FEM were reduced to 15.2 cm x 13.2 cm, while maintaining the same measurement locations as the experiment.

2.4 Screw Material Characteristics

The material characteristics of the screws were determined based on data provided by the ICC Evaluation Service for the Simpson X-Screws. The substantial characteristics of the steel used in finished screws differ from those used in the prototypical due to case hardening. The prototypical focused on the screw's shearing behavior, and the material properties were estimated based on the shear strength using a formula from the American Institute of Steel Construction.

2.5 Ply Material Characteristics

The substantial characteristics of the CFS plies were based on ductile coupons from previous experiments. Stress-strain data beyond the ultimate tensile strength was desired to accurately define the ply behavior, but it was not available. To overcome this, calculations were performed to estimate the genuine stress and strain beyond the maximum tensile strength.

3. MODELING AND ANALYSIS

The modeling and analysis process involved several steps to accurately represent the behavior of the connections and investigate their performance using the finite element method. The following steps outline the methodology:

3.1 Geometry and Meshing

The first step was to create the geometry of the components involved in the connection. This included the bolt, CFS plies, and any additional parts specific to the experimental setup. The geometry was created based on the specifications provided in the study. Once the geometry was defined, it was meshed to discretize the components into small elements. The meshing process aimed to capture the key features and variations in stress and strain accurately. The appropriate element type and size were chosen for each component to ensure an optimal mesh.

3.2 Material Properties

The material properties of the components were assigned based on the information provided in the study. The properties of the bolt, CFS plies, and any other materials involved were defined, including elastic modulus, yield strength, and Poisson's ratio. The material behavior, such as isotropic or anisotropic, was also considered.

3.3. Contact Definitions

Contact between the different components in the connection was defined to simulate their interaction accurately. Contact surfaces were identified, and appropriate contact properties such as friction coefficients and contact algorithms were assigned. This step was crucial to capture the load transfer and deformation behavior between the components.

3.4. Boundary Conditions

Boundary conditions were applied to replicate the loading and constraints present in the experimental setup. Fixtures, supports, and loads were defined based on the specifications provided. These boundary conditions ensured realistic loading conditions and allowed for the analysis of the connection's response to external forces.

3.5 Analysis

The FEM model was then subjected to various analysis techniques to investigate the behavior of the connection. This included static analysis to assess the stress distribution and deformation under applied loads. Additional analyses such as modal analysis, dynamic analysis, or fatigue analysis could be performed depending on the objectives of the study. The analysis results were examined to evaluate the performance of the connection. Factors such as stress concentration, load-bearing capacity, deformation, and failure modes were analyzed to draw conclusions and make recommendations.

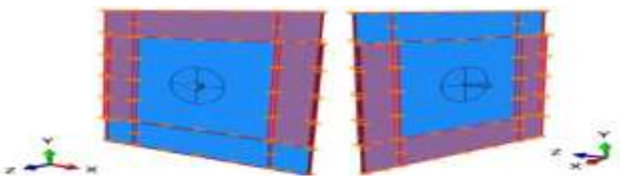

Figure 1: Physical constraints that prevent movement outside of the plane. Left: the subject's front. Right: the subject's back.

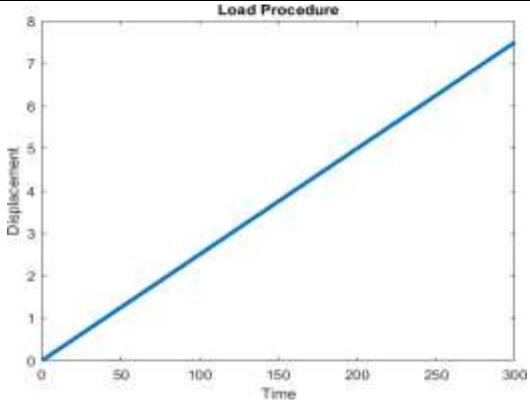

Figure 9 Prototypical loading procedures and experiments by Pham and Moen (2015)

4. RESULTS AND DISCUSSION

Experiments 5454 and 9797 failed owing to screws shearing, as was stated in the catastrophe manners section. The next section discusses these prototypical' behavior and peak load.

The 5454 prototypical max load was 6.09 kN, while the experiments' average initial peak load was 6.16 kN per Corner (2014). Thus, the peak load discovered using the prototypical is 1.1% less than the peak load of the experiment. Due to a difference in the peak utilized, Corner's consequences for apex loading were compared for the 5454 experiments instead of Pham and Moen's.

Table 1: Correlation of design and experimental stiffness for the 5454-layer design

% of Peak Load	Model (kN/mm)	Test 1 (kN/mm)	Test 2 (kN/mm)	Test 3 (kN/mm)
40	6.84	9.36	10.03	7.95
80	4.10	3.91	3.31	3.63
100	0.93	0.48	0.39	0.41

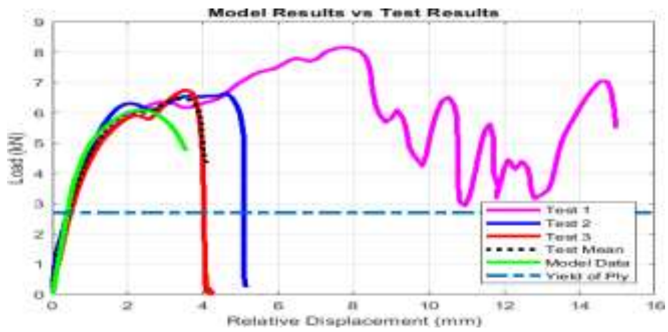

Figure 39: 5454 prototypical vs experiment results

5. CONCLUSION

Based on the research conducted to create a Finite Element Model (FEM) that accurately captured the behavior of light-gauge steel, solitary lapped screw attached contacts, the following conclusions can be drawn:

- Verification with Experimental Data: The prototypes were compared to the assessments conducted by Pham and Moen (2015) to validate their accuracy. It was found that when layer 1 and layer 2 had similar depths, the prototypes performed well, showing good agreement in terms of peak load, stiffness, and failure mode compared to the experimental results.
- Peak Load and Failure Mode Agreement: The prototypes generally matched the experimental results for peak load and failure mode. The peak load values showed a maximum error of 10.5% with a few prototypes, while the failure modes of most prototypes were similar to those observed in the experiments. One prototype (5454) showed a different failure mode, but upon closer inspection, it was found that the screw behavior in the prototype closely resembled the experimental failure mode.
- Overall Connection Stiffness: The overall stiffness behavior of the prototypes showed decent agreement with the experiments, indicating that the prototypes captured the general connection stiffness well. The joining stiffness behavior was found to be strongly influenced by the contact behavior between the screw and the hole in the normal direction. It was suggested that improving the contact in this direction could enhance the stiffness of the connections in each prototype.

- Layer Thickness Variation: When layer 1 and layer 2 had different thicknesses, the prototypes had reasonably good predictions of the failure mechanism and general connection stiffness behavior observed in the experiments. However, the agreement in terms of peak load was generally poor in this case, with a maximum percentage error of 33% compared to the experimental results.

In conclusion, the developed prototypes based on the FEM approach showed promising results in capturing the behavior of light-gauge steel, solitary lapped screw attached contacts. The prototypes demonstrated good agreement with experimental results for layer combinations with similar depths, while some limitations were observed when dealing with layer thickness variations. Improving the contact behavior between the screw and the hole in the normal direction was identified as a key factor in enhancing the stiffness of the connections. Further refinements and adjustments to the FEM approach could lead to even better accuracy in predicting the behavior of such connections.

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