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A Review of The Effect of The Bolt Configuration on The Stiffness of Timber Connections

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KEYWORDS

Stiffness equation
Eurocode 5
Steel-wood-steel connection
Numerical models
Multiple linear regression

ABSTRACT

The aim of this research is to investigate the impact of bolt configurations on the stiffness of timber connections. The existing Eurocode 5 equation for stiffness prediction considers only timber density and fastener diameter, limiting its accuracy. Malaysian standards, on the other hand, lack information on stiffness which related factors entirely. This review explores a range of additional factors affecting stiffness, such as bolt spacing, end distance, row spacing, and timber thickness. Findings from recent studies reveal that these parameters significantly affect the stiffness of bolted connections, often leading to more accurate predictions than current design codes allow. Derivation of data analysis by using Multiple Linear Regression (MLR) and numerical models developed using ABAQUS software demonstrate that greater values in these parameters consistently result in increased stiffness. By incorporating these findings into design equations, the research aims to enhance the predictive capability of timber connection stiffness models.

1. INTRODUCTION

Timber has become a popular material in construction due to its sustainability, versatility, and structural efficiency. The stiffness of these connections, encompassing both fastener and local member stiffness, is critical for durable timber structures[1]. Bolted timber connections, however, present a challenge for accurate stiffness prediction. Design codes such as Eurocode 5 are widely used but fail to account for several critical factors, including geometric configurations of the connections. This limitation hinders precise predictions, especially for steel-wood-steel (SWS) connections, which are common in modern timber structures.

In Malaysia, the standards for bolted timber connections lack comprehensive information about stiffness-affecting factors, making it difficult to optimize timber connections in local contexts. Factors such as bolt configuration, spacing, and end distance affect the stiffness, yet are often overlooked in existing models [2]. This review synthesizes findings from eight key studies to identify these factors and propose their inclusion in design equations. By examining experimental and numerical results, this research aims to address gaps in design standards and improve the structural efficiency of bolted timber connections.

2. PROBLEM

The primary problem discovered is the inability of current design standards, particularly Eurocode 5 and the Malaysian Standard, to appropriately estimate the stiffness of bolted timber connections. Eurocode 5 calculates stiffness only based on timber density and bolt diameter, simplifying the complexity of timber connections. Meanwhile, the Malaysian Standard lacking information for stiffness-related issues, resulting in a knowledge vacuum in the local context. These restrictions lead to inferior design predictions, which may result in overdesign or underperformance in timber structures. Previous research has identified multiple factors that affect the stiffness of timber.

3. METHODOLOGY

This review explores the key factors influencing the stiffness of bolted timber connections, with a focus on bolt configurations, timber density, and geometric characteristics. A systematic search was conducted using a scoping method to identify relevant studies. The search was performed on Scopus with keywords such as "timber connection stiffness," "bolted timber joints," and "Eurocode 5 stiffness equation." Only peer-reviewed articles published between 2015 and 2023 that directly addressed these topics were selected for inclusion.

The selection process involved carefully reviewing the titles, abstracts, and full texts of the articles. Key information, such as the study objectives, methods, findings, and limitations, was collected and grouped into themes like geometric factors, material properties, and evaluations of existing design codes. The findings were then compared to spot patterns and gaps, which helped shape recommendations for improving design standards for bolted timber connections.

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Special attention is given to the factors affecting the stiffness, including bolt diameter, timber density, spacing, and end distance. Numerical models developed in ABAQUS software serve as a primary tool for validating findings, alongside comparisons with design standards like Eurocode 5 and MS544-5.

4. RESULTS AND DISCUSSION

The literature highlights substantial advancements in understanding the stiffness of bolted timber connections. [3] found that geometric factors such as bolt diameter, spacing, and edge distance significantly influence stiffness, emphasizing the inadequacies of Eurocode 5, which does not consider these parameters. Confirmed that factors like wood density, bolt spacing, and thickness play crucial roles, with Eurocode 5 overestimating stiffness by up to four times in some cases [4]. [5] validated the Row Shear Model for Nyatoh hardwood, showing it to be more accurate than the conservative MS544-5 standard, enabling better resource utilization.

Dynamic and composite connections further illustrate the need for updated design models. Research done by [6] revealed that proper reinforcement in bolted glulam connections enhances ductility under blast loads but identified gaps in Canadian design provisions for energy dissipation. Dynamic wood crushing improves stiffness but reduces ductility, which reinforcement can address [7]. The timber significantly enhances slip stiffness in timber-concrete composites [8]. According to the research done by [9], the inclined screws provide superior shear strength in cross-laminated timber panels, with material properties like wood density and panel orientation also influencing performance.

Table 1 Literature Matrix Table

Reference	Objective	Problem	Method	Result	Future
Rahim et al., 2022	Study the effect of bolt configurations. Validate numerical models. Evaluate Eurocode 5 stiffness equations.	Eurocode 5 ignores key geometry factors, leading to inaccuracies.	Numerical modeling in ABAQUS. Analyze bolt configurations. Validate with prior studies.	Stiffness increases with bolt size, spacing, and distance. Eurocode 5 underestimates stiffness.	Create equations including geometric parameters for better predictions.
Rahim et al., 2018	Analyze stiffness of bolted connections. Predict stiffness using models. Validate Eurocode 5.	Eurocode 5 excludes key geometry factors.	Analyze experimental data. Test different configurations. Compare with Eurocode 5.	Stiffness depends on density, bolt diameter, and spacing. Eurocode 5 over-predicts stiffness by 4x.	Add geometry factors to Eurocode 5 for better accuracy.
Rahim et al., 2022	Predict SWS connection stiffness. Validate Eurocode 5. Analyze experimental vs. predicted data.	Eurocode 5 fails to include geometric factors.	Test 50 timber samples. Vary connector size and density. Compare results to Eurocode 5.	Stiffness is higher with greater density, bolt size, and thickness. Eurocode 5 predictions are inaccurat	Include geometric parameters in stiffness models.
Ujan et al., 2023	Assess Nyatoh hardwood design equations. Calibrate for shear failure.	MS544-5 underestimates strength, increasing steel use.	Test 10 configurations. Use regression to improve Row Shear Model.	Row Shear Model is more accurate than MS544-5 for Nyatoh hardwood.	Optimize models for better hardwood design efficiency.
Viau & Doudak, 2021	Study glulam beams under blast loads. Create shock tube models.	Current blast design ignores energy dissipation.	Test 14 glulam beams. Add reinforcement. Use two-degree analysis.	Reinforcement improves ductility and energy dissipation.	Update blast design codes for better brittle failure detailing.
McGrath & Doudak, 2021	Test timber under blast loads. Measure dynamic stiffness changes.	Limited knowledge of ductility under dynamic loads.	Conduct static/blast tests. Add reinforcement. Analyze dynamic behavior.	Wood crushing improves stiffness but reduces ductility. Reinforcement prevents splitting.	Refine blast design codes for timber connections.

Shi et al., 2021	Test precast TCC connections. Study screws and notches.	Factors like screws and notches need more study.	Test connections with screws and steel plates. Vary screws, notches, and anchors.	Notches improve stiffness and slip resistance. More screws enhance strength.	Study durability under long-term and dynamic loads.
Judd et al., 2021	Examine CLT-concrete shear slip. Analyze screw configurations.	Screw placement and material effects are unclear.	Shear test CLT-concrete panels. Use cyclic loading. Compare screw configurations.	Inclined screws are strongest. Higher wood density improves stiffness.	Explore other cyclic loads and long-term effects.

4. CONCLUSION

This review addresses the importance of multiple factors in affecting the stiffness of bolted timber connections. The key characteristics include timber density, bolt diameter, end distance, bolt spacing, edge spacing, row spacing, and the number of bolts and rows. These important elements are not fully taken into consideration by current design standards like as Eurocode 5 and MS544-5, which results in projections that are not accurate. Future study should focus on incorporating these factors into a unified stiffness prediction equation that has been validated via experimental and computational analysis. These developments will improve the dependability and effectiveness of timber building, particularly in areas with less developed guidelines of Malaysia.

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REFERENCE

[1] Koch, J. C. (2020). Probabilistic assessment of brittle failure modes of timber connections. Retrieved from CHALMERS UNIVERSITY OF TECHNOLOGY: https://odr.chalmers.se/handle/20.500.12380/301079.

[2] Rahim, N., (2022). The stiffness of steel-wood-steel connection loaded parallel to the grain. Retrieved from BAZA DANYCH ZAWARTOSCI POLSKICH CZASOPISM TECHNICZNYCH: https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-38c50a73-c552-467d-bf6d-4a880405bce9.

[3] Rahim, Nur Liza et al., "Effect of bolt configurations on stiffness for steel-wood-steel connection loaded parallel to grain for softwoods in Malaysia," Archives of Civil Engineering, 68(3), 323-338, 2022. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85140989639&doi=10.24425%2face.2022.141888&partnerID=40&md5=5eaf229a7206900f44c8ef4d18bbc3b6.

[4] Rahim, Nur Liza et al., "Stiffness of bolted timber connection," WCTE 2018 - World Conference on Timber Engineering, 2018. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85058149701&partnerID=40&md5=ffcf3a4bac92ccb3a37de4d016ce8570.

[5] Ujan, Xavier Langit Anak et al., "Validation of shear failure on bolted connection for Nyatoh hardwood," Journal of Engineering Science and Technology, 18(5), 2398–2410, 2023. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85176455507&partnerID=40&md5=7b7eeb35d19b33b49f3f5b46a1bf7658.

[6] Viau, Christian and Doudak, Ghasan, "Behavior and Modeling of Glulam Beams with Bolted Connections Subjected to Shock Tube-Simulated Blast Loads," Journal of Structural Engineering, 147(1), 2021. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85094858526&doi=10.1061%2f%28ASCE%29ST.1943-541X.0002876&partnerID=40&md5=974bf07c9ac827339c079cc52a595a24.

[7] McGrath, Andrew and Doudak, Ghasan, "Investigating the response of bolted timber connections subjected to blast loads," Engineering Structures, 236, 2021. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85103272835&doi=10.1016%2fj.engstruct.2021.112112&partnerID=40&md5=5ab81c9fa1cb6d51ac38ca205aedcb5d.

[8] Shi, B., Yang, H., Ling, Z., and Liu, W. "Experimental investigation on precast connections for prefabricated timber-concrete composite structures." World Conference on Timber Engineering 2021, WCTE 2021, 2021. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85120739798&partnerID=40&md5=5e982443f421b3911ee713f2a2daa131.

[9] Judd, J., Fonseca, F., LeBaron, J., and Closen, M. "Shear slip behavior of composite cross laminated timber concrete panels with self-tapping screw anchors." World Conference on Timber Engineering 2021, WCTE 2021, 2021. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85120751665&partnerID=40&md5=bf9aa927d70d0abd7b1fc39d8d867a9e.