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Evaluating the SWS bolted connection strength of Bitis wood

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Abstract

The current study was conducted to evaluate the strength of the steel-wood-steel (SWS) bolted connections of Bitis wood. The wood was chosen because it is commonly used as the structural elements of the as-built floor and roof diaphragms in Malaysian unreinforced masonry (URM) buildings. This present work was performed to continue the initiation of the wood database development for the purpose of retrofitting the wall-diaphragm connections of the URM building. The bolted connection testing was the main experimental investigation, where a total of eighteen groups of different connection configurations were tested, each consisting of ten specimens. The embedding strength tests, moisture content and density tests were also conducted to determine the wood's basic properties. The results obtained from this experimental study were utilized for verifying the prediction effectiveness of the existing design equations, namely the Malaysian Timber Standard (MS544-5), the European Yield Model (EYM), and the Row Shear Model (RSM). From the comparison made between the prediction values and the experimental results, the MS544-5 was found to be too conservative, whereas a combination of the EYM and RSM is recommended for predicting the bolted connection strength of the Bitis wood.

1. Introduction

It has long been recognized that the main issue with the as-built characteristic of an unreinforced masonry (URM) building is the discontinuity between its vertical and horizontal structural elements. An absence of the connection between the masonry walls and the timber floor diaphragms was found to be the main weakness causing the building to perform poorly in resisting the lateral load from earthquakes [1, 2, 3]. Thus, all countries over the world that still have this type of buildings must seriously confront retrofitting interventions due to the locality of these buildings that can be easily found in the main city areas, which typically use as commercial or residential purposes. Many reconnaissance reports [4, 5, 6] on damaging earthquakes show various catastrophic failures of masonry construction, supporting the claim that the unreinforced masonry buildings are not only dangerous to the occupants but also to the nearby pedestrians, including the neighboring public and private properties. All major collapses of masonry walls are mainly caused by the lack of wall-diaphragm connections. Therefore, this present study was carried out to continue the initiation of [7, 8, 9] in developing the wood database for the design of wall-diaphragm connections to retrofit the URM buildings. The wall-diaphragm connections are

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comprised of two major parts, which are the wall anchorages and the diaphragm connections [10, 11, 12, 13]. The former can be in the form of a through-bolt anchor connected with an external bearing plate or a dowel-type anchor drilled into the wall. The latter is typically a bolted steel cleat to the timber floor joists or to the timber roof rafters. Because the design details of the latter part are not provided by [12, 13], the next discussion focuses on the existing Malaysian timber code, in particular the bolted joint design procedures.

Referring to the Malaysian Timber Standard (MS544-5) [14] under clause 11.2.3, it outlines an equation to determine the permissible load, F_{adm}, of a bolt system loaded parallel to grain. The equation is given by:

$$F_{adm} = k_1 k_2 k_{16} k_{17} F \tag{1}$$

where, k_1: Factor of duration of load given in Table 4 of [14], k_2: Factor of 1.0 for dry timber or 0.7 for wet timber, k_{16}: Factor of 1.25 for the bolts that transfer load through metal side plates of adequate strength and the bolts are a close fit to the holes in these plates provided that b/d > 5 (where b denotes the effective timber thickness and d is the bolt diameter) or 1.0 otherwise, k_{17}: Factor for multiple bolted connections given in Table 15 of [14], F: Basic working load as derived in clause 11.2.2 of [14]. From clause 11.2.2 of [14], it can be seen that the design method considers only a ductile failure mode. The standard only reflects a brittle failure mode by applying the k_{17} value of less than one for connections with five bolts and more. This is not in agreement with the international timber engineering community because the criteria in the timber standards to determine the capacity of bolted joints shall be from an established mechanical model that is capable of identifying each conceivable failure mechanism [15]. Many published works [16, 17, 18, 19, 20] found that the geometric configurations of the bolted joints, such as the end distance, e_t, and spacing between bolts, s_b, can significantly control the mode of failure. From [7, 8, 9, 21, 22], the standard was identified as providing a very conservative design capacity for bolted joints in local hardwoods like Meraka and Nyatoh. Thus, this present experimental work continues the bolted connection study on the Bitis wood evaluation.

Besides utilizing the experimental data of the bolted connection on the Bitis wood for evaluating the effectiveness of the existing timber standard of the MS544-5 [14], this current study also examines the efficiency of the European Yield Model (EYM) and Row Shear Model (RSM). The EYM represents the mechanical models of the ductile failure mode developed by Johansen [23], whereas the RSM demonstrates the mechanical models of the brittle failure mode established by Quenneville [15]. Details of both design equations of the EYM and RSM can be found in [9], but herein the authors highlight and discuss the important parameters involved in both theories. In each possible failure mode as per EYM theory, the most important parameter in the design equation for determining the resistance of bolted timber joints, R, is the embedding strength of the wood, denoted as f_h. The absence of this parameter in the existing code of MS544-2 [24] makes the efficacy valuation of the EYM theory to estimate the bolted connection strength on local hardwood is impossible to be assessed. Besides providing the test data on bolted connection strength of local hardwood that was also found to be very limited, this present study conducted the embedding strength test on Bitis wood using the ISO/DIS 10984-2 [25] for the use of the EYM efficiency verification.

For the design equation in the RSM theory, the authors focus the discussion on the parameters of the wood shear strength parallel to the grain, f_v, and the calibration factor, CF. From [8], it was identified that the f_v value can be taken directly from Table 4 of [24]. However, it makes the prediction capacity of RSM became unacceptably under-designed. The use of the correlation of the f_v equivalent to $17.8G^{1.24}$, which can be obtained from Table 4-11a of the Wood Handbook [26], was recommended. Thus, this present study provides