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A HYBRID SYSTEM FOR ENHANCING RACKING PERFORMANCE OF TIMBER PANELS

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ABSTRACT: Timber frame can offer many aesthetic and structural benefits over other construction materials, for example effective insulation for energy efficiency, sustainable design and ease and speed of construction. For all the known benefits of using timber frame there are certain limitations that are often linked to its strength and stiffness performance in connection systems. A key design limitation of timber frame structures is that the lateral resistance to wind loads becomes increasingly difficult to accommodate as opening sizes increase. These limitations are restricting the potential for market growth as clients are increasingly asking for detached dwellings with relatively large openings in their shorter/narrow walls and for multi-storey buildings often with large openings.
This research aimed to resolve the issues arising from the lack of racking resistance in timber frame buildings and is focused on developing a structural reinforcement system for the timber frame market. This will facilitate the construction of detached dwellings and multi-storey buildings with large spans and openings. The system will allow greater architectural flexibility whilst being simple to install and cost effective.

KEYWORDS: Timber frame, Shear wall, Racking resistance, Large openings

1 INTRODUCTION

To overcome the difficulty of insufficient racking resistance in large openings in building elevations; designers utilise a hierarchy of solutions to resist the wind loads. The most commonly used solutions are 1) reducing fastener spacing, 2) using double sheathing, 3) increasing the thickness of sheathing, and 4) utilising large stiff panels or steel portals. However, on-site there are a number of problems with using current solutions for example warping of sheathing by reducing fastener spacing, in particular, in humid construction conditions, and differential settlement between the timber frames and steel portals, which also limits the architectural scope for popular features such as picture windows.
This research aimed to address the problems arising from racking in timber framed buildings and is focused on developing a hybrid structural reinforcement system for the timber frame market, in order to facilitate the construction of detached dwellings and multi-storey buildings with large spans and openings. The main objective was to develop a system which permits greater architectural flexibility whilst being simple to install and cost effective.

The development of the concept started with a parametric evaluation of the stiffness of the existing systems used to provide racking resistance in timber platform frame construction. The study has significant importance in identifying and selecting the right combinations of stiffness and strength levels achievable at the connections and in particular at the foundation level, based on the current UK design/construction practices. This then led to a more detailed analytical and experimental examination of the connections' component configurations and their effects on the performance of timber frames. The concept has been gradually developed into a range of effective moment resisting hybrid timber portals to limit the moment and uplift demands on the foundations for a range of applications. The development of the products, named "Strong-Portals", required detailed understanding of the factors which contributed to improving racking performance of structural timber systems. Structural modelling and numerical evaluation of the timber fastener systems, augmented with laboratory testing and detailed knowledge of UK construction methods, have helped make the project a success.

2 BACKGROUND

The term 'shear wall' is usually used for vertical elements such as walls when appropriately designed to transmit force in its own plane. Horizontal floor diaphragms are designed to transfer loads to shear walls which carry the loads to the foundations. In the structural design of timber the lateral resistance of the walls to carry wind loads transferred from diaphragm is known as

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racking resistance. The difference between a shear wall and an ordinary stud wall is that a shear wall in timber construction is a load bearing wall that is designed to take racking loads in addition to vertical loads [1].

Openings in shear/racking resisting walls can have a considerable effect on their performance. In the design of timber framed buildings it is often necessary to provide appropriate rigid framing structure to be able to transfer shear loads around the opening. In cases where there are large openings such as garage or patio doors or large windows etc. the racking performance becomes a design issue as it limits the resistance from the available area of the shear wall.

There has been considerable research on racking resistance of timber frame panels in the past and a large amount of data related to the performance of timber has been published internationally. Various solutions have been proposed to improve the lateral resistance of shear walls. Karalic et al. [2] in 1997 developed a prefabricated reinforcing structure comprising a rectangular frame with triangular structures along the entire length which provided more resistance to horizontal forces as compared with standard stud walls.

Midply developed by Karacabeyli et al. [3] is a structural shear wall system for severe earthquakes. It utilizes a novel arrangement of sheathing and framing members to give higher lateral resistance but pose problems regarding the insulation and installation of services.

To enhance the shear capacity of walls, Pryor S. [4] developed channel metal strip reinforcement for the edges of sheathing. This considerably improved the tear out resistance of nails and prevented the nails from pulling out. However, with increased capacity; the requirement for uplift from hold-down considerably increased.

Griffiths [5] investigated the performance of shear walls in the mid to late 80's based on UK methods of construction which provided the empirical basis for British Standard BS 5268-6.1[6].

The investigation carried out by Minjuan et al. in 2010 [7] on the racking performance of walls using Chinese wood based panels sheathed with gypsum or magnesium oxide board, demonstrated good stiffness properties.

Yasumura [8] carried out research on racking resistance of wood-framed shear walls with various opening configurations using experimental work and finite element analysis.

The investigation on racking performance of wood shear walls consisting of finger-joined studs carried out by Meng et al. [9] suggested a very small reduction in racking capacity as compared to unjoined studs.

Salenikovich and Payeur [10] performed a study investigating the correlation between lateral resistance and the magnitude of the vertical distributed load applied to a light-frame wall.

Shim and Hwand et al. [11] developed a hybrid model using traditional Korean timber construction and light frame constructions to help with the increase in timber demand in Korea. The study was carried out to define the lateral load resistance of hybrid structures under cyclic lateral load.

Leitch and Hairstans [12] carried out a series of racking tests to assess the accuracy of simplified plastic model for the prediction of racking strength. The study also highlighted the need for a "stiffness check" in order to ensure the structures do not suffer from excessive deflections.

3 METHODS

A parametric evaluation of the effects of variation in stiffness properties in the joints and foundations of a timber portal frame of typical 2.4 m x 2.4 m dimensions with 10 kN racking load was carried out, as shown in Figure 1.

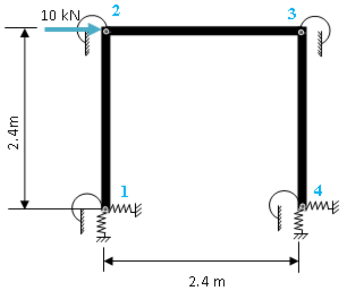

Figure 1: *Analysis model*

The study considered the eave joints to possess rotational springs only (i.e. rotationally semi-rigid). However, the foundations were permitted to have both translational and rotational springs. Then the effects of connection stiffness, from fully rigid to fully pinned conditions, on the structural behaviour of the portal frame was evaluated. Sample results are shown in Figure 2.

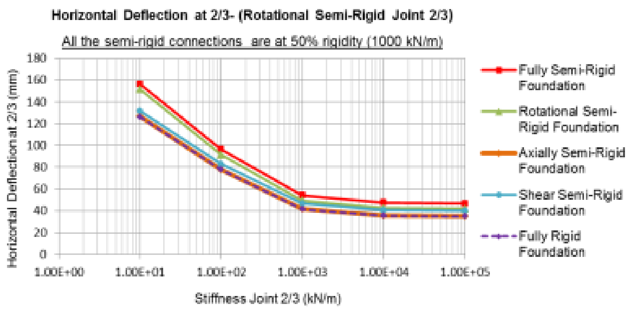

Figure 2: *Comparison of horizontal deflection at eave joints of portal for varying stiffness levels at foundation*

The results of the study showed that there is considerable reduction in lateral deformation of the frame with the increase in the rotational stiffness of the eave joints from 0% (fully pinned) to about 50% rigidity levels. However, further increasing the stiffness/rigidity of the eave joints resulted in little to no improvement in performance of the portal.

The development of the concept for the portal system involved a series of tests in order to achieve the best strength and stiffness combination for the portal. Two sets of tests were carried out on:

i. a series of full-scale eave-joints utilising differing header and column materials, nail spacing and metal work compositions in order to determine the best combination of materials and joint configurations.
ii. a series of full-scale portals to prove the developed concepts and to determine structural performance characteristics.

3.1 CONNECTION DETAILS

A total of 32 full-scale joints with a range of member and component configurations were designed and manufactured. Replicate prototype joints with column and beam members of solid C24 timber, LVL Kerto-S as well as boxed hollow sections made with solid studs and OSB/3 sheathing or Finnish birch plywood were constructed. A range of hybrid jointing systems was also developed and manufactured using specially designed metalwork components by Simpson Strong-Tie, UK. Replicate joints were also produced using both nailed and screw fixings. The aim was to develop an optimum joint configuration by examining the effects of different component configurations on the structural behaviour of the connection systems, in particular, on their stiffness characteristics, structural integrity as well as on their ease and speed of manufacture/assembly.

3.1.1 JOINT TEST SETUP

The test setup for the joints used is given in Figure 3. The joint corresponds to closing joint in the portal indicated as (3) in Figure 1. The leg lengths and the loading arrangement were designed to simulate, where possible, the loading combinations as those in the full-size portal frame.

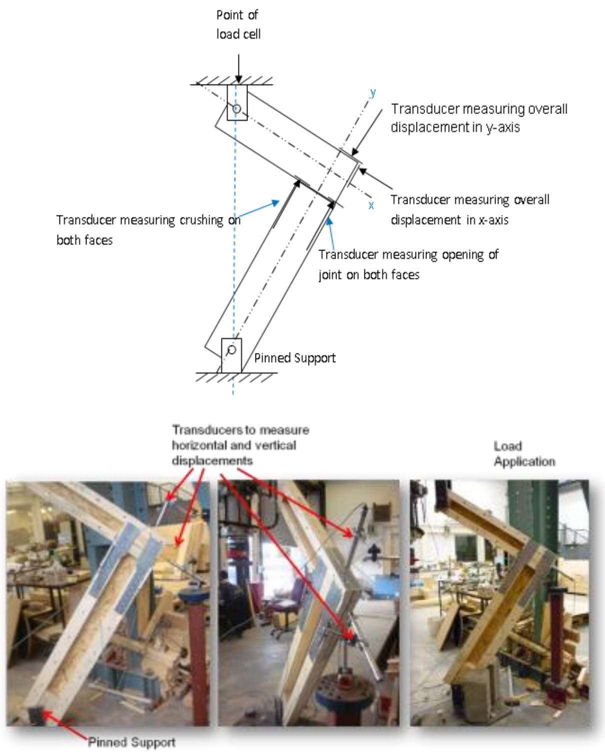

Figure 3: *Joints Test Setup*

As mentioned earlier, a comparative study was carried out using different combinations of sheathing material and fasteners. Metal straps for connecting the column to the header members were profiled and optimised to enable the joint to carry the maximum moment by using different fastener configurations for outer and inner connecting straps and in turn to provide maximum stiffness.

3.1.2 MODES OF FAILURE

Two failure modes, for all joint types tested, were observed. These were the splitting of header and shearing of OSB which occurred at extreme load levels, as shown in Figure 4.

Figure 4: *Mode of failure of joints*

3.2 PORTAL TESTING

Following the successful outcome of the joint tests, a series of full-scale portal frames was designed and constructed utilising the key features from the tested joints. This aimed to bring together the optimised features developed during the connection development work. A total of eight portal frames were manufactured and were tested in accordance with the requirements of BS EN 594: 2011 [13]. The tests were designed to further optimise the structural performance of the frames, “Strong-Portals”, and to fine-tune their factory production and on-site assembly details. The beam-to-column connections in Strong-Portals are designed to resist the induced moments generated with the application of racking loads, which in turn reduces the moment and uplift requirements from the foundation. Therefore it gives the designers the flexibility to use concrete pad foundations for portals that can easily be adapted to beam and block floors, with some modification, as widely used in the United Kingdom. In Figure 5 a typical “Strong-Portal” during test preparation is shown.

Strong-Portal is a hybrid structural system which enables efficient utilisation of strength of timber and engineered wood products in a high performance racking resisting frame. Some details are illustrated in Figure 6.

4 SUMMARY

The output of this project is the introduction of a new concept to the timber frame industry as a result of a highly successful collaboration between industrial and academic partners. The concept has provided a practical solution that eliminates the problems associated with current options and will also interface simply with the traditional timber frame panels.

Figure 5: *A Strong-Portal during test preparation.*

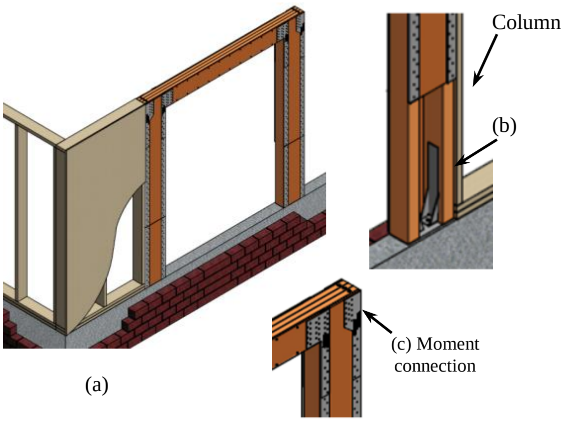

Figure 6: *(a) Typical Installation of Strong-Portal (b) Hold-down detail (c) Moment Connection joint.*

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