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Load sharing and structural response of roof–wall system in a timber-framed house

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ABSTRACT

Full-scale tests were carried out on a part of representative brick veneer contemporary house to assess the loading effects on roof to wall connections and load sharing. Tests were carried out at each stage of construction: bare frame followed by the installation of roof battens and cladding, wall lining, ceiling, etc. These construction stages were used to assess the contribution of the structural and lining (i.e. ceiling, ceiling cornice and wall lining) elements to the load sharing and response of the timber-framed house structure to wind loading. Results of the full-scale test show that the vertical reaction force at the loaded truss support was reduced by about 20% when the lining elements were added to the system with structural elements (i.e. truss, batten and roof cladding). The vertical load sharing of the timber-framed house through the roof to wall connection (RWC) depends on the stiffness of the RWC and the truss location (i.e. whether located at the end or middle). The contribution of the lining elements to the vertical load sharing is about 15–20%. The lateral load resistance of RWCs significantly increased, when ceiling, ceiling cornice and wall lining were added to the structural system. The outcome of this study can be used to assess the structural response and vulnerability of these houses to windstorms.

1. Introduction

Timber-framed houses comprise the highest percentage of building structures in Australia. These timber-framed houses are affected by windstorms [1–7]. Therefore, the structural stability of these houses in windstorms is essential to ensure the safety of occupants and minimize the impacts of damages to the community. A timber-framed house structure is a complex three-dimensional (3D) system, an assembly of several components such as the walls, floors and roof. These components are connected by inter-component connections such as cladding to batten, batten to truss, roof to wall, and wall to foundation connections. Wind loads acting on the roof and walls are transferred to the foundation via these inter-component connections, but little is known about the structural behaviour and load sharing between these components and connections. Determining the structural response and the load sharing is necessary to assess timber-framed house structural performance.

The structural response of a timber-framed house to wind loading may be investigated by conducting experimental tests or numerical modelling on the individual elements, partial assemblies' components and full-scale testing. The individual and partial assemblies components tests, such as the connections test (i.e. roof to wall connection, cladding to batten connection, batten to truss connection, stud to top-plate and bottom plate connection, and ceiling joint, etc.), and tests on the wall and roof structure, could reveal the strength and stiffness of the elements. However, these tests may not provide a proper evaluation of the strength and stiffness of the whole house structure. Thus, full-scale testing could be required to assess the structural response and load sharing of the timber-framed house structure. Morrison et al. [8], Henderson et al. [9], Habte et al. [10], Canino et al. [11], Gupta and Kuo [12], Kasal et al. [13,14], Shanmugam et al. [15,16], He et al. [17], Thampi [18], Datin and Prevatt [19], Pfretzschner [20], Wolfe [21,22], Gupta [23], and Guha and Kopp [24], studied the performance of timber-framed houses in North America, using full-scale test and numerical model analyses. In non-hurricane regions of North America, houses have wood sheathing on the wall and roof, and roof trusses are toe-nailed to the wall top-plate. Modern

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houses in non-cyclone regions of Australia are brick veneer wall, metal roof cladding and roof trusses that are tied with triple grip connections to the wall top-plate. These variation in construction result in differences in their structural response to wind load.

Boughton and Reardon [25–27] carried out a range of full-scale tests on houses at the Cyclone Testing Station, James Cook University, Townsville, Australia. These studies qualitatively investigated the performance of Australian timber-framed houses, focusing on the response of wall structure and roof (uplift strength) to wind loads. Reardon and Henderson [28] showed that the contribution of various structural and lining components such as ceiling and ceiling cornice, and wall lining results in improvement of strength and stiffness of timber-framed houses subjected to wind loads. However, these studies did not assess the load sharing of the individual connections and structural components in the whole-of-house structure.

This paper presents, a full-scale test on a structure representing part of a contemporary house to quantitatively determine the structural response and load sharing based on the reaction measured at the roof to wall connection (RWC) and the foundation (i.e. bottom plate). This study also evaluates the effect of the lining elements (i.e. wall lining, ceiling and ceiling cornice) to the load sharing.

1.1. Representative contemporary house

Contemporary houses in many parts of Australia are brick veneer structures with metal or tile clad roofs that are built by trained builders using skilled and/or semi-skilled construction workers according to engineering design specifications. These houses are designed and constructed to wind classifications specified in AS 4055 [29] AS 1684.2 [30] and AS/NZS 1170.2 [31]. The metal cladding is fixed to metal top-hat battens, which are attached to timber trusses that are spaced at regular intervals along the walls. The roof trusses are fixed to the wall top-plate using various methods, depending on wind loading and building regulations. The schematic diagram of a brick veneer contemporary house structural system is shown in Fig. 1.

A field survey of contemporary houses under construction such as those shown in Fig. 2 around Brisbane, Australia was carried out by a team from the Cyclone Testing Station. The survey data were compared with their certified engineering drawings. The surveyed features include the overall dimensions of house, roof slope, shape and type of construction. In addition, the field survey also recorded construction defects.

Based on the field survey, a representative house was obtained, which is a single storey, timber-framed, brick-veneer construction, with 21.5° pitch hip-end roof. The spacing of timber trusses is nominally at 600 mm and the metal top-hat battens at 850 mm. The roof cladding is metal sheet, which is attached to battens, and the trusses are fixed to the wall top-plate with triple grips.

2. Full-scale test structure

This study investigated the loading effects and load sharing of the general truss region (i.e. middle part of the house) of the representative house by conducting a full-scale test. In Australia, the middle part of the contemporary representative house roof structure is constructed with general trusses (see Fig. 2). The test structure consists of five general trusses, top-hat battens, corrugated steel roof cladding, ribbon top-plate, wall studs, bottom plate, wall lining, ceiling and ceiling cornice. The length and width of the full-scale test structure, as shown in Figs. 3 and 4, are 6.6 m and 3.3 m, respectively, and the roof pitch is 21.5° with an overhang of 0.45 m. This test structure excluded the exterior brick veneer wall which generally transfers the lateral wind loads to the timber frame through the wall ties. The omission of these exterior walls does not affect the load sharing from roof to wall, when the roof structure is subjected to wind load.

2.1. Construction detail of the full-scale test structure

The roof of the full-scale test structure was constructed with five general trusses spaced at 600 mm, and connected to the two ribbon top-plates as shown in Fig. 5. Each ribbon top-plate consisted of two 90 × 35 mm, Machine Graded Pine (MGP) 10 timber blocks connected by skew nails spaced at 300 mm. Framing anchors (i.e. triple grips, see Fig. 2), with ten of 2.8 mm diameter and 30 mm length hand nails per connection were used to fix the trusses to the ribbon top-plates. Eight 2.7 × 0.78 × 0.8 mm, 0.42 BMT corrugated metal sheets were used for the roof cladding in the test structure. The metal roof cladding was attached to the metal top-hat battens (40 × 40 × BMT 0.55) with three M6-11 × 50 Hd/Seal screws per corrugated metal sheet based on the cladding manufacturer's specification [32]. The metal top-hat battens were spaced 480 mm, at the edge of roof and 850 mm for

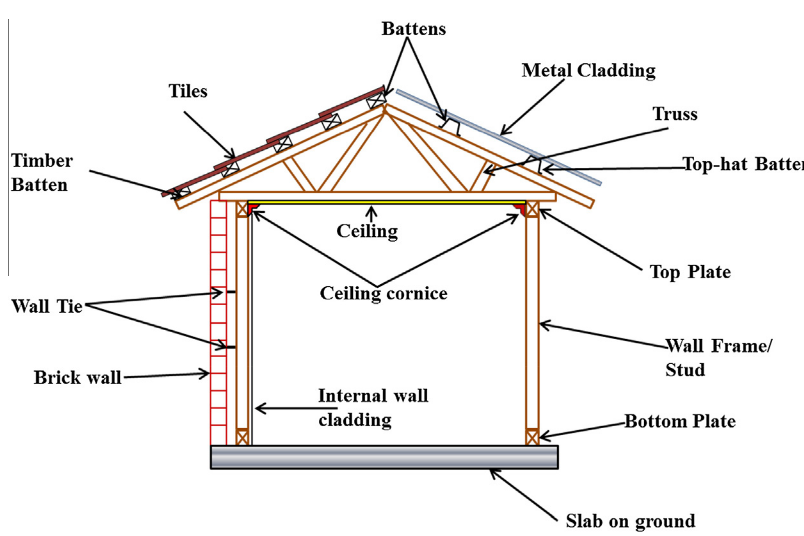

Fig. 1. The structural system in a brick veneer contemporary house.