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Loading Effects on Timber Truss to Wall Connection in a Contemporary House

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Abstract

Windstorms are one of the major causes of severe damage to houses and other infrastructure. An assessment of previous studies on damage to timber framed houses shows that the roof is the most vulnerable part of a house, and that failures take place at inter component connections (i.e. cladding to batten, batten to truss connection and truss or rafter to top plate connection). The failure of roof structures during extreme windstorms emphasises the need to study their response. The stability of the roof structure mainly depends on their inter-component connection response to wind loading. The roof to wall connection is an important inter-component connection for the structural stability of a house during strong winds, by providing a continuous load path from the roof to the foundation. The aim of this study is to assess the loading effects on roof to wall connections of a typical brick veneer contemporary house. A numerical model of the representative house was developed and the result shows the load sharing and the structural response. This result also shows that the structural system stability will improve with elements such as ceiling and ceiling cornice sharing the load.

Introduction

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 labourers working to engineering design specifications. 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 contemporary brick veneer house is shown in Figure 1. Windstorms produce spatially and temporally varying wind pressures that generate fluctuating wind loads and stresses on the structure (Holmes 2007). The Australian standard AS 4055 (2006) provides design wind loads for design and construction of houses in Australia. Wind tunnel studies also provide wind load distribution on house structural systems. However, only limited data is available on the load distribution in inter-component connections, progressive damage due to connection failures and the structural response of the house to wind loading.

The roof to wall connection is a potential source of vulnerability in the load path of a house structural system. This connection should be designed to transfer the uplift and lateral load. In a timber framed structure, connections are commonly made by either nail, nail plate, bolt and nuts, screws and straps or a combination of these elements. The uplift capacity of these connections is given in the Australian standard AS 1684.2 (2010) and the manufacturer`s specification. This uplift capacity is based on results of individual component tests subject to static or cyclic loading. This paper focused on the loading effects and load sharing on roof to wall connections of a typical house structure.

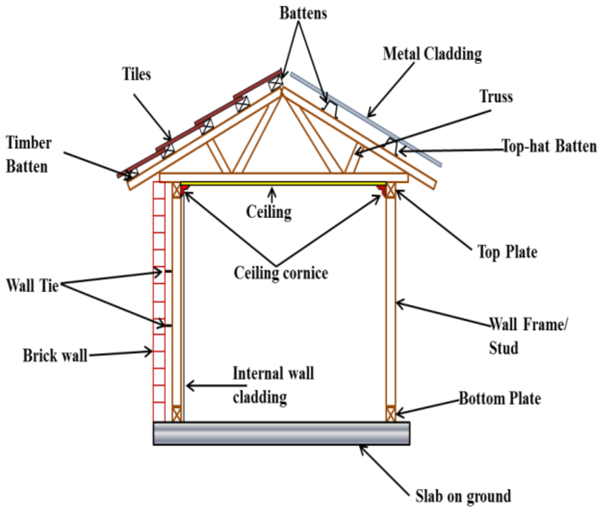

Figure 1. Schematic diagram of a brick veneer contemporary house structural system.

Representative Contemporary House

A field survey of contemporary houses under construction around Brisbane, Australia was conducted by a team from the Cyclone Testing Station, to determine their structural system. The survey details are the overall dimensions of house, roof slope, shape, type of connections and type of construction. Construction defects were also recorded in this survey. Based on this field survey, a representative house was obtained. This is a single storey, timber framed brick- veneer construction with 21.5^0 pitch hip-end roof. The spacing of timber trusses and metal top-hat battens were at 600mm. The roof cladding was metal sheet which is attached to battens and the trusses are fixed to wall top plates with triple grips. This study investigates the loading effects and load sharing on roof to wall connections of the representative house, which consists of five general trusses, ten top hat battens, corrugated steel roof cladding, two ribbon top plates, eight wall studs, two bottom plates, wall lining, ceiling and ceiling cornice.

Roof to Wall Connection

In accordance with the field survey, the triple grip is widely used to connect the wall top-plate and trusses or rafters in the house structural system in non-cyclonic regions of Australia. Missing nails are a common construction defect in this connection. Design of this connection is mainly based on the uplift capacity as specified in Australian standard AS 1684.2 (2010), but this standard does not account for construction defects. Experimental tests and numerical modelling for structural response of roof to wall triple grip connections by Satheeskumar *et al* (2014) have identified the critical nails and their locations to mitigate failure of the roof to wall triple grip connection subject to wind loading. The uplift capacity of triple grip connections with construction defects (i.e. missing nails) has also been estimated, which can be used to assess the vulnerability of houses to windstorms.

Numerical Model of the Representative Contemporary House

A three dimensional (3D) general truss region of the representative contemporary house model as shown in Figure 2 was assembled and subjected to load by using ABAQUS (6.12-3) finite element software. To simplify the development of this model, material properties within each of the components used in this model are isotropic. The model was used to predict the roof to wall connection stiffness variation with additional elements (i.e. roof cladding, wall cladding, ceiling, and ceiling cornice), structural response and also determine the load sharing of the house structure.

The model consists of nine separate parts: corrugated steel roof cladding, top hat battens, truss, top-plate, wall studs, bottom plate, wall lining, ceiling and ceiling cornice. A two-node linear beam element (B31) was used to assemble the truss, wall studs and battens. An eight-node linear brick element (C3D8R) was used to assemble the top plate, bottom plate and ceiling cornice. Roof cladding, wall lining and ceiling were assembled with a four node shell element (S4R). A non-linear spring element was used to represent each roof to wall triple grip connection and linear spring elements were used to represent cladding to batten and batten to truss connections. In x, y, and z directions stiffness of the nonlinear spring elements were obtained from the experiments and numerical model of triple grip connection (Satheeskumar *et al* (2014)) and the linear spring stiffness was obtained from previous studies by Henderson (2010) and Jayasinghe (2012).

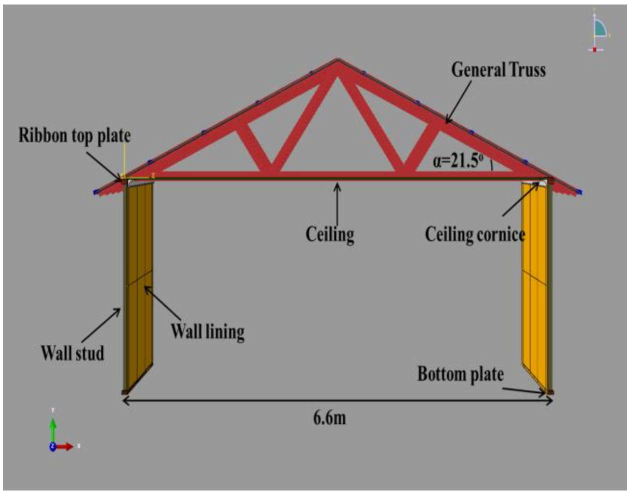

Figure 2. The numerical model of representative contemporary house.

Analysis

Numerical model analyses were run for seven cases (i.e. Cases 1 to 7) in order to find the load sharing effect of installing additional elements (i.e. roof battens, roof cladding, wall structure, ceiling and ceiling cornice). Details of the numerical model used in each case are shown in Table 1. The loads were applied only to one side of the house structural systems because the geometry of the house model is symmetric. Figure 3 shows the plan view of the numerical model and Trusses A, B, C, D and E. This figure also shows the battens numbered 1 to 10 and loading directions.

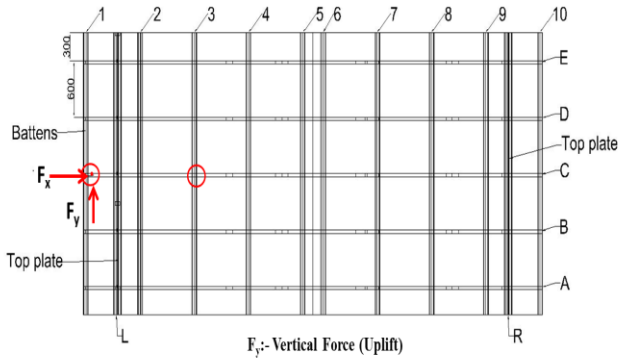

Figure 3. The plan view of the numerical model of the representative contemporary house.

Results

In the initial stage of this study, the model was subject to 1kN uplift load perpendicular to roof surface. This analysis was to determine the load sharing and distribution within the house structure. Simulated wind loads obtained from a wind tunnel study will be applied to the model in the next stage of this study. Figures 4, 5, 6 and 7 illustrate the y (vertical) direction reaction coefficient (i.e. reaction force divided by the applied load) obtained in each case. The numerical model was subjected to 1 kN load at either position C1 or C3. Figures 4 and 6 show the reaction coefficient variation when the load was applied at C1, and Figures 5 and 7 when the load was applied at C3.

Figures 4 and 5 show the roof to wall connection reaction coefficient when adding additional elements to the roof structure. Those figures also show a decrease of reaction force at Truss C with the addition of elements (i.e. battens, roof cladding). This clearly indicates that the loads are shared between the adjacent trusses and their connections through the battens, roof cladding and top plates. Those figures also show that the reaction coefficient of roof structure decreases when the position of applied load moves from C1 to C3. This shows the roof to wall connection experiences larger stresses when the load acts at the edge regions of the roof structure.

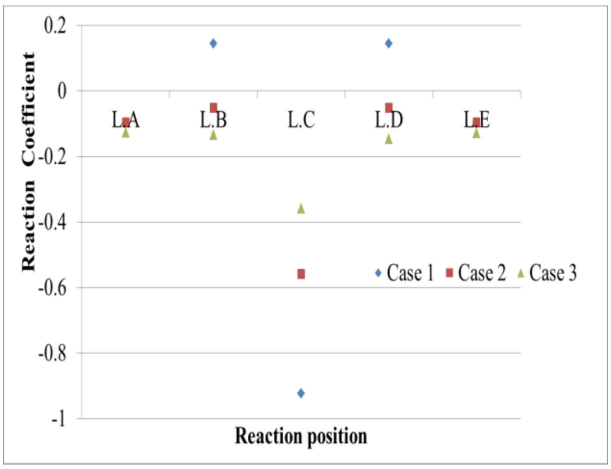

Figure 4. The Y direction reaction coefficient within the roof structure at the top plate along the line L, loading at C1

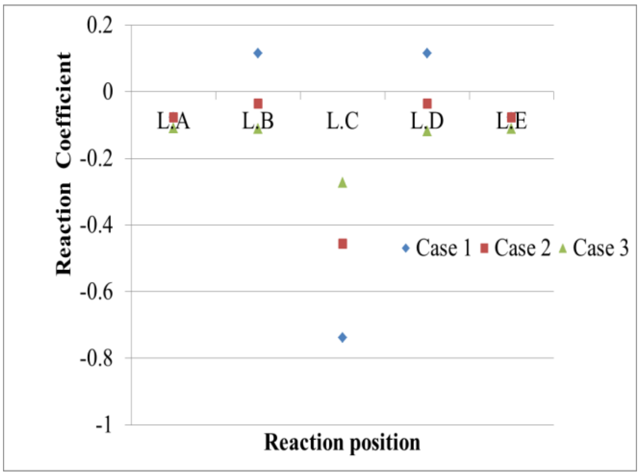

Figure 5. The Y direction reaction coefficient within the roof structure at the top plate along the line L, loading at C3

Figures 6 and 7 show the y (vertical) direction reaction coefficient along line L at the bottom surface of the bottom plate. Those figures also indicate that the y direction reaction coefficient is high when there is no wall lining, ceiling and ceiling cornice. Those figures indicate that the installation of the ceiling does not significantly affect the reaction forces if ceiling cornice is not installed. This shows that the wall lining, ceiling and ceiling cornice increase the load sharing capacity from roof to foundation.

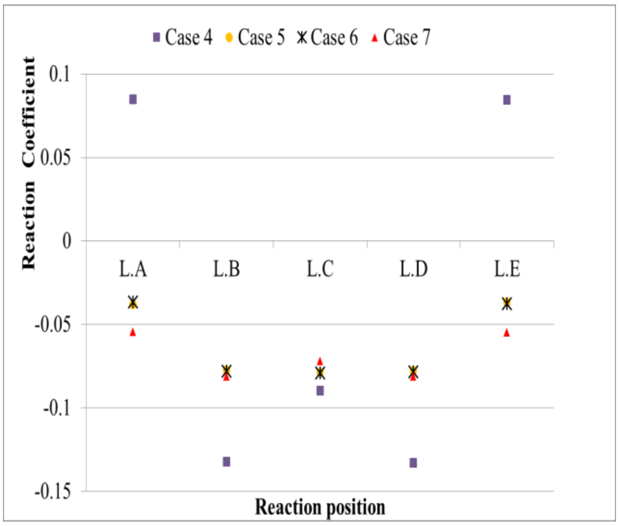

Figure 6. The Y direction reaction coefficient within entire structure at the bottom plate along the line L, loading at C1

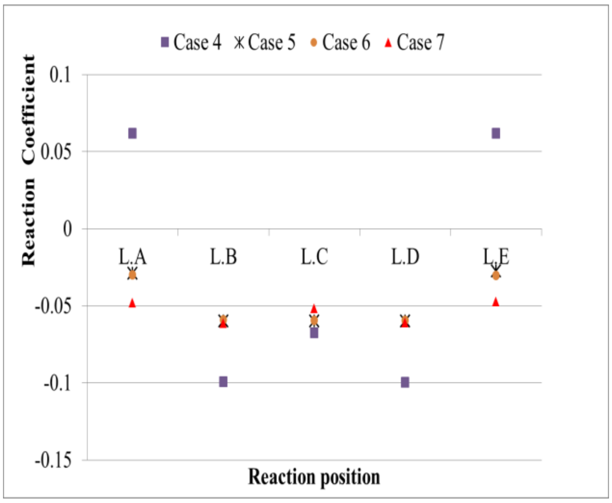

Figure 7. The Y direction reaction coefficient within entire structure at the bottom plate along the line L, loading at C3

Figure 8 shows the vertical displacements (i.e. the gap between the top plate and the truss which is opened up due to the applied load) of the roof to wall connection at Truss C for all seven cases. This figure shows the vertical displacement is significantly reduced when ceiling cornices are installed, an indication that ceiling cornices contribute to an increase of the roof to wall connection stiffness. This figure also shows that the deflection of the roof to wall connection reduces when the applied load is moved from C1 to C3.

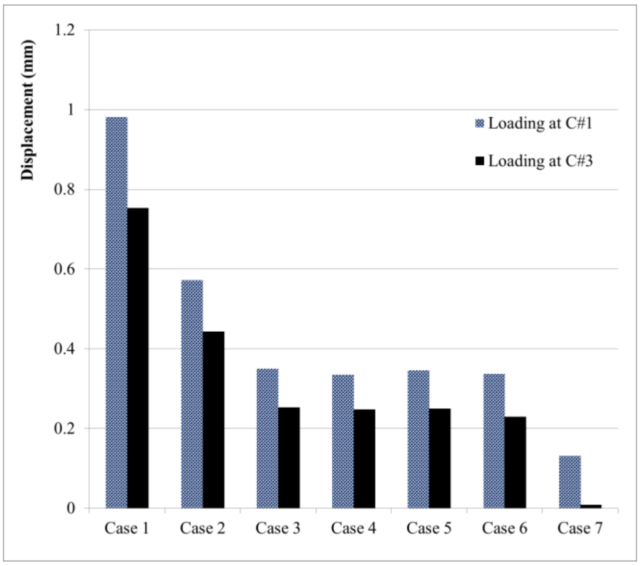

Figure 8. The roof to wall connection y (vertical) direction displacement at Truss C in all cases along line L.

Table 1. Details for each case of the numerical model

Case	Model detail	Location of the applied load	Location of the reaction force	Location of the vertical displacement
	Roof Structure			
1	Model assembled with the Truss C and two ribbon top plate located along the line L and R. A fixed boundary condition was subject at the bottom surface of the top plate	Uplift loads were applied along the Truss C on the batten to truss connection position (i.e. C1, C2, C3, C4 and C5).	At the bottom surface of the top plates on the roof to wall connection position (i.e. LA, LB, LC, LD, LE, RA, RB, RC, RD and RE)	At the truss on the location LC and RC
2	Model consist of five trusses, 10 battens and two ribbon top plate. The boundary condition is similar as Case 1	On the battens at same positions as Case 1	Same as Case 1	At the truss on the location LA, LB, LC, LD, LE and RA, RB, RC, RD, RE
3	Roof cladding was added to the Case 2 model	On the roof cladding at same positions as Case 1	Same as Case 2	Same as Case 2
	Roof and Wall Structure			
4	The wall structure was added to the Case 3 model. A fixed boundary condition was subject at the bottom surface of the bottom plate and there is no horizontal movement (x direction) on the top plate along the line R (U1=0)	Same as Case 3	Reaction forces measured on the bottom surface of the bottom plate at the same location in Case 3	Same as Case 2
5	The wall lining was added to the Case 4 model and the boundary conditions is similar as Case 4	Same as Case 3	Same as Case 4	Same as Case 2
6	Ceiling was added to the Case 5 model and the boundary conditions is similar as Case 4	Same as Case 3	Same as Case 4	Same as Case 2
7	Ceiling cornice was added to the Case 6 model and the boundary conditions is similar as Case 4	Same as Case 3	Same as Case 4	Same as Case 2

Conclusions

This paper focused on understanding the loading effects and load sharing of the roof to wall connection in timber framed structures. A numerical model was developed and the analysis results showed that: i) the strength and the stiffness of the roof to wall connection will increase if the structural system has wall lining, ceiling and ceiling cornice installed; ii) adjacent roof trusses share wind loads through connections of roof cladding, battens and top plate, and iii) roof to wall connections are subjected to larger loads if the external load is applied to the edge surface of the roof structure.

As an alternative to full scale tests, numerical models must be validated by experimental results. Therefore full-scale test will be carried out to validate the numerical model developed herein. Both experimental and numerical results will be the basis for the development of vulnerability models of timber framed structures subjected to windstorms.

Acknowledgments

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