SHAKING TABLE TEST OF A FULL SCALE BRICK VENEER STEEL-FRAMED HOUSE

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ABSTRACT

Brick veneer construction is a very common form for residential structures in Australia and is growing in popularity in New Zealand. The structural frame is made from steel or timber and non-structural brick walls are attached to the frame via brick ties. Under earthquake loading there is a complex interaction between the frame and veneer walls particularly in the out-of-plane direction, where there is risk of brick wall collapse. Given the increase in demand for brick veneer houses with high-strength cold-formed steel, an experimental study was undertaken to assess the overall performance of brick veneer steel framed construction. A full scale one-room Test House was tested on a shaking table. It was subjected to varying levels of the El Centro (ELC) earthquake ranging from moderate serviceability limit state ground motion to well beyond the design maximum considered earthquake for New Zealand. The Test House performed very well, with no brick loss up to 2.6 times ELC earthquake which is well in excess of all performance requirements. This paper presents a summary of the outcomes from the experimental test program.

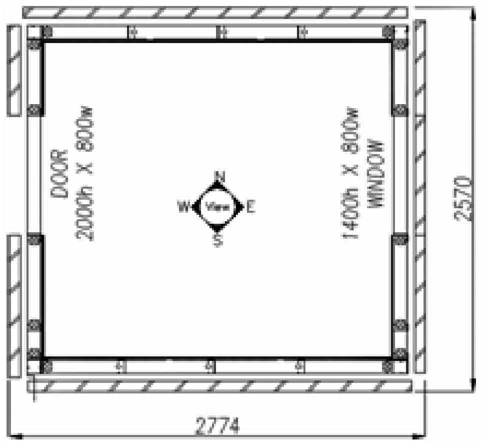
Background

Clay brick veneer is often used for cladding purpose to low-rise residential structures in Australia and New Zealand. In this construction form, the wall system consists of a structural frame, non-structural brick veneer walls and brick ties connecting the veneer and frame. Traditionally, timber has been the most common structural frame used in Australia and New Zealand. However, the use of high-strength cold-formed steel frames in brick veneer construction is steadily increasing in both Australia and New Zealand. While the use of cold-formed steel frames is increasing world wide, Australia and New Zealand are unique in that these markets typically use high strength steel (G550) and very thin sections (0.75mm). Brick veneer walls are generally regarded as non-structural components requiring no specific design but need to comply with prescriptive requirements. However, under seismic excitation, induced inertia forces can lead to potential damage and there is a concern about brick wall collapse either in the in-plane or out-of-plane direction.

To assess the overall performance of brick veneer walls on steel frame, a collaborative research project was initiated between The University of Melbourne, The University of Auckland, Building Research Association of New Zealand (BRANZ), National Association of Steel-Framed Housing in New Zealand (NASH-NZ) and NASH-Australia. A test structure herein known as the "Test House" was designed for a comprehensive seismic test program as described below.

Experimental setup of Test House

The geometric layout and completed Test House structure is shown in Figure 1. The Test House was a full scale single-room structure replicating typical construction practice of a steel-framed brick veneer house as built in New Zealand. It measured approximately 2.6m x 2.8m x 2.4m high. The Test House comprised of a steel frame with brick veneer cladding and plasterboard lining completely constructed using typical full scale components. The framing and bracing members were made of 0.75mm G550 Z275 galvanised steel sections. All the framing connections between plates, studs, noggings and bracing were screwed connections.



(a) Plan of Test House

(b) Completed Test specimen

Figure 1: Full scale Test House geometry

The brick veneer walls were constructed using standard New Zealand 70 series clay brick units measuring 230mm x 70 mm x 76 mm high with standard five core holes. The bricks were bedded with 10mm thick mortar with a standard mix of 1:0.5:4.5. Type B Eagle brick ties were used for connecting the veneer walls to the light steel framing. Polystyrene thermal break strips 40mm wide x 10 mm thick were glued to the external flange of each stud through which the tie screws were drilled. The ties were installed using the "wet-bedding" technique and were placed on the walls at every fourth course to intermediate studs while those around the edges and openings were at every second course. A concrete roof slab weighing 1500kg was used on top of the Test House to simulate the equivalent mass from a house roof. Walls and ceiling were lined with 10mm thick plasterboard secured with screws. Vertical and horizontal joints between plasterboard sheets were finished with paper tape and cement compound.

Instrumentation and testing protocols

Displacements and accelerations were measured at numerous locations on the Test House using Linear Voltage Displacement Transducers (LVDTs) and uniaxial accelerometers respectively. Additionally, strain gauges were installed on specific brick ties to monitor the load in the ties due to out-of-plane veneer deformation. Webcams were installed at strategic locations to monitor the relative movement between the frame and veneer through the cavity.

To assess the performance of the Test House against specific design performance criteria, a design earthquake was selected as input excitation to the shaking table. The selected excitation was the 1940 El-Centro (ELC) earthquake. This earthquake is compliant with the New Zealand Earthquake Loading Standard, NZS 1170.5 (2004). The specific levels of excitation which were targeted are listed in Table 1.

Table 1: Earthquake levels adopted for testing and corresponding performance criteria

Earthquake design level	Scale relative to El-Centro	Required performance limits
Serviceability Limit State (SLS)	0.89 El-Centro	Localised hairline cracking of veneer and lining at most vulnerable locations. No post earthquake remedial work required.
Ultimate Limit State (ULS)	1.28 El-Centro	Noticeable cracking of veneer and linings, brick loss limited to < 5% of bricks or the top two rows above the top row of ties. Visible damage to frame expected but not to be significant and not to reduce ability of frame to support house.
Maximum Considered Earthquake (MCE)	1.72 El-Centro	Significant linings and framing damage but no collapse of framing. Significant brick loss.

The main direction of interest was excitation in the North-South direction. However, the Test House was subjected to excitations in each direction. Before and after each earthquake test, pulses of 5 - 20Hz and swept-sine input with a frequency range of 0.5-30Hz were imposed on the Test House using the shaking table to characterise its dynamic properties. Prior to earthquake shaking, the Test House had a natural frequency of 5.8Hz, which lies within the high energy content of the ELC earthquake. Thus, it could be concluded that the selected record was appropriate for the testing schedule.

EXPERIMENTAL RESULTS

Performance of Test House under design level earthquakes

The Test House was subjected to progressively increasing ground excitation. A summary of the testing sequence and observations made after each test are presented in Table 2. The Test House performed very well in both directions of shaking up to MCE level earthquake (refer Table 2). The Test House performance is considered to be exceptionally good at this intensity of shaking in comparison to the performance criteria outlined in Table 1.

Table 2: Summary of tests performed and observations made

Test No	Earthquake level and direction		Observations
	N-S[1]	E-W[2]	
1	SLS		No damage observable whatsoever.
2	ULS		Minimal hairline cracks in the plasterboard lining at window top corners. Very limited hairline cracks at locations in brick veneer adjacent to opening. No damage to any brick ties, the screws or the thermal break.
3		SLS	No increase in damage from test 2.
4	MCE		Minor increase in cracking of internal plasterboard at window corners. No increase in cracking in brick veneer. No visible damage to any ties.
5		MCE	No increase in damage from test 4.
6	1.16MCE (2.0 El-Centro)		Noticeable rocking of wall brick piers at base of window. Hairline cracks post test extending right across pier base. No bricks lost. No visible damage to any ties. No visible damage to steel framing. Plasterboard cracks in window top corners now remaining open approx 1mm after test.
7	1.34MCE (2.3 El-Centro)		Increased rocking and cracking during test. No new cracks. No bricks lost. No visible damage to brick ties but in plane twisting for the East and West walls. No evidence of pullout of any ties. No visible damage to steel frame.
8	1.51MCE (2.6El-Centro)		Partial failure of connection between the top of diagonal brace and top plate for East and West walls. No bricks lost. No tie pullout from frame or veneer.
9	1.57MCE (2.7El-Centro)		Failure of connection of diagonal brace to top plate in East and West walls. Top 2 rows of bricks lost in East and West walls. No bricks lost from the North and South walls. Minimal to no damage to ties in the North and South walls. No tie pullout from studs in any location.

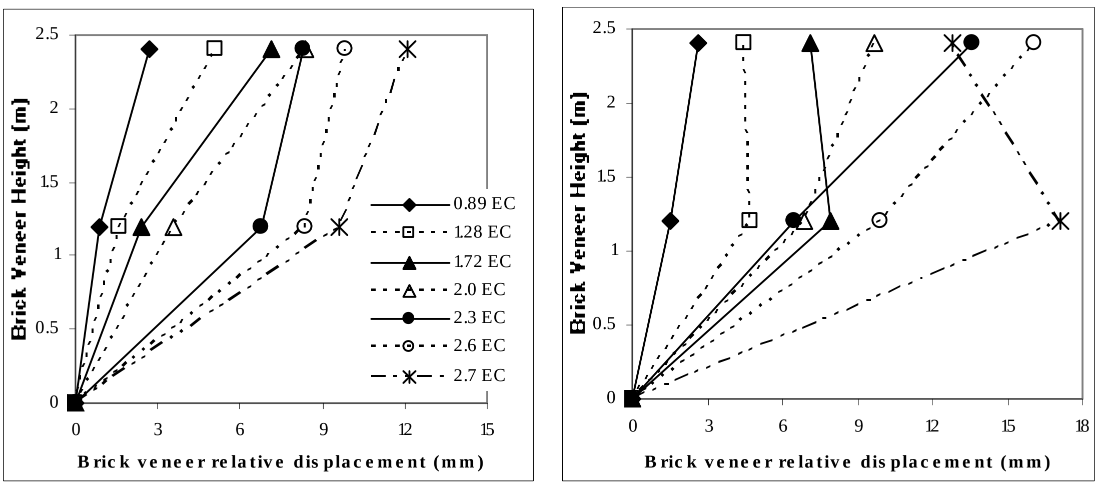
[1]For shaking in the North-South direction, the North and South veneer walls were subjected to out-of plane loading.
[2]For shaking in the East-West direction, the East and West veneer walls were subjected to out-of plane loading.

Performance of Test House beyond design level earthquakes

With no evidence of significant damage on the Test House after applying MCE in each direction, the selected input excitation was further scaled increasingly to impose more severe shaking (refer Table 2). Up to 2.6 times ELC no bricks were lost or any significant damage occurred in the out-of-plane brick veneer walls. This is extremely good performance given the fact that the Test House had already been subjected to 7 high level earthquakes prior to 2.6 times ELC. It is considered impossible for a single house to experience this number and severity of earthquakes during its design life. At the end of 2.6 times ELC, a partial failure of the connection between the top diagonal bracings and top plates on both East and West walls was noticed but no bricks loss or tie pullout from frame or veneer was observed. At the end of the test at 2.7 times ELC, a complete connection failure occurred at the ends of the top diagonal bracing in both in-plane walls (East and West walls). Despite the very large racking displacement of the frame, the brick ties did not separate from the studs or the veneer in the out-of-plane direction.

Assessment of Test House response

Up to the MCE level of shaking when only minor cracking was observed in the plasterboard linings and limited hairline cracks at corners of openings in the veneer, the drift at the top of the frame was 0.42%. With further increase in the excitation intensity, the measured displacement of the top of the frame at 2.7 times ELC indicated a significant racking displacement of 70mm (2.8% drift). At this level of shaking, the bracings failed completely at the top connections in the in-plane walls and hence resulted in the considerable drift. Despite this large drift, the out-of-plane brick veneer walls did not peel off from the frame. The relative displacement between the top of frame and out-of-plane veneer walls (North and South walls) was measured to be a maximum of approximately 16mm from all tests with a corresponding maximum relative displacements at mid-height of approximately 10mm, obtained at 2.6 times ELC. Despite the very large magnitude earthquake induced and the fact that the Test House had already been subjected to severe shaking in both directions (Tests 1-7), the out-of-plane veneer did not fail. This reflects a high degree of resistance and robustness of the connections of the ties at both the stud end as well as the veneer end. Most of these relative displacements would have been accommodated by: (i) flexibility in the flange of the stud; (ii) compressibility of the thermal break and (iii) bending and distortion of the ties. The bending of the ties results from the fact that the line of force along the tie does not coincide with its connection to the stud. Figure 2 shows the deflected profile of the out-of-plane veneer walls for the complete seismic test program undertaken.



(a) North wall (b) South wall

Figure 2: Peak relative displacements between frame and out-of-plane veneer walls

At the MCE level earthquake intensity of shaking in the East-West direction, the maximum relative displacement between the frame and in-plane walls was only 3.4mm. This is significantly smaller than the relative displacement of ±24mm which is imposed by the tie standard AS/NZS 2699.1 (2000) as part of the tie testing procedure. This suggests that the tie test procedure is possibly too conservative.

Conclusions

A Test House constructed of high-strength cold-formed steel frame with brick veneer cladding and plasterboard lining was tested under earthquake loads to assess the performance of the out-of-plane veneer walls. The Test House was subjected to increasing levels of the 1940 El-Centro North-South earthquake record in order to match certain seismic demands specified in NZS 1170.5 (2004). Up to the Maximum Considered Earthquake (1.72 times ELC earthquake), when major brick losses but no collapse of the frame would be considered acceptable, the observed damage to the Test House was minor. Limited hairline cracking in the veneer was observed along with minor cracking of the plasterboard at corners of the openings. At this intensity of shaking, a maximum relative displacement between the frame and out-of-plane veneer of about 8mm was obtained with no visible signs of damage to the veneer walls.

With the exceptional performance up to the MCE intensity, additional excitation tests (refer Table 2) were conducted to establish the ultimate performance level. The Test House survived more severe earthquakes with no loss of bricks up to 2.6 El-Centro earthquake. A racking displacement of about 70mm (2.8% drift) was measured. The maximum relative displacement between the frame and out-of-plane veneer measured was approximately 16mm. Despite the very large racking displacement of the frame and relative movement between the frame and out-of-plane veneer walls, the brick ties in the out-of-plane direction did not separate from the studs or the veneer.

Given that the Test House was designed using conventional methods, constructed from typical components and built using standard techniques, it would be considered to be representative of brick-veneer steel-framed construction in NZ. With its excellent performance under an extremely onerous earthquake testing program, it can be concluded that such form of construction would be expected to exhibit performance considerably better than the performance limit demands in NZS 1170.5 (2004) under the most demanding design seismic conditions in New Zealand.

References

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