Out-of-plane adobe wall veneer performance from a novel quasi-static and dynamic tilt test

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ABSTRACT: Exterior house brick veneers and those of pressed earth bricks performed poorly in the Christchurch earthquake sequence. Adobe (sun dried earth) bricks are currently used as 150mm thick veneers, sometimes internally. Improvements to wall integrity and fixing were developed but needed to be validated for wider use. Reversing tilt tests were carried out on 1.8m and 2.4m wall panels and a 3m high x 4m wide wall with 1.9m opening built on hinged footings to apply out-of-plane loads. An excavator was used to move the wall by cyclic tilting backwards up to 45 degrees (0.71g) and forward 80 degrees (0.98g). Additionally the excavator induced dynamic out-of-plane accelerations into the 2.4m wall panel to a peak value of 2.64g without failure. Following this a similar procedure was applied to the large 3m wall with lintel, static loads were applied first, followed by out-of-plane vibrational accelerations of 1.64g. Cracking was observed but there was no brick dropout or evident tie failures. These accelerations and tests provided confidence in this simple but effective tilt test methodology and strengthened confidence in the adobe veneer system proposed for use in New Zealand.

1 INTRODUCTION

1.1 Historic and Modern Earth Buildings around Christchurch and Kaikoura

In early New Zealand there was a lot of house and cottage construction using walls made of earth from near the construction site. There are only a small number of modern (post 1940) earth houses in New Zealand. Four historic earth buildings were surveyed following the Christchurch earthquakes and 22 following the Kaikoura earthquakes of which five suffered serious damage and three more had collapsed walls. Of the modern earth buildings 22 were surveyed following the Christchurch earthquakes and 19 following the Kaikoura earthquakes. All those that used the reinforcing and roof support systems as designated in the NZ Earth Building Standards had satisfactory performance.

1.2 Stabilised Earth Veneers

Figure 1. Double skin pressed earth brick walls illustrating worst case veneer problems Christchurch

Exterior burnt brick house veneers often performed poorly in the Christchurch earthquake sequence as was somewhat expected for those constructed prior to 1996 (Dizhur et al., 2013, Beattie & Thurston, 2010). External veneers of unreinforced cement stabilised pressed earth bricks were among the worst observed failures in modern earth buildings in the Christchurch events (see Figure 1) (Morris et al., 2010). A less serious reinforced veneer failure was also observed near Kaikoura in an area subjected to severe shaking in 2016 as shown in Figure 2.

Figure 2. Damage to reinforced pressed earth brick veneer in zone of high accelerations near Kaikoura 2016 (Photo's G North)

1.3 Adobe Veneers

Adobe (earth mixed with straw and sun dried) bricks are sometimes used in protected locations as external veneers, however the advantages of the adobe walls including acoustic quality, humidity control and thermal mass are better achieved as an internal wall within an insulated and weather protected system. For this reason, one of the more frequent uses of adobe currently is as 150mm thick internal veneers. One house with both external and internal veneers near Blenheim was subjected to moderate shaking in the Kaikoura earthquake and had minimal cracking. Based on the observations in Christchurch (Morris & Walker, 2011), standard construction details for adobe veneer now include additional direct fixing using a nail or screw from the brick tie vertically into the adobe brick itself and horizontal geogrid mesh in every second mortar bed of the veneer. These improvements were considered to be adequate for low wall heights but need to be validated for wider use and for interior use.

1.4 Previous Out-of-plane Test methods

Out-of-plane static testing of walls is often undertaken using air bags (Griffith, et al. 2007) but this is unsatisfactory for veneers loaded away from the frame. Out-of-plane static tests have also been undertaken using tilt tests of whole buildings (Turer 2004, Zegarra 2000). Dynamic tests are best achieved on earthquake shake tables which are widely used but expensive. Some lower cost shock table options have been developed (Keightly 1986, Jagadish 2004) but are still complex to fabricate.

2 METHODOLOGY

2.1 Objectives

Our new procedure is for relatively inexpensive testing adjacent to the adobe production yard. The test was designed to allow gravity loads to deform the timber support frame in a way that is typical of what is proposed in walls in practice. This deformation allows some cracking in the mortar due to the difference in timber frame stiffness and accounts for any resulting negative influence on the available bond within the masonry. Additionally, we aimed to minimise cost, avoid freight of large quantities, avoid the wait of a month for mortar drying in the lab, and take advantage of the masonry workmanship available at the yard.

2.2 **Setup**

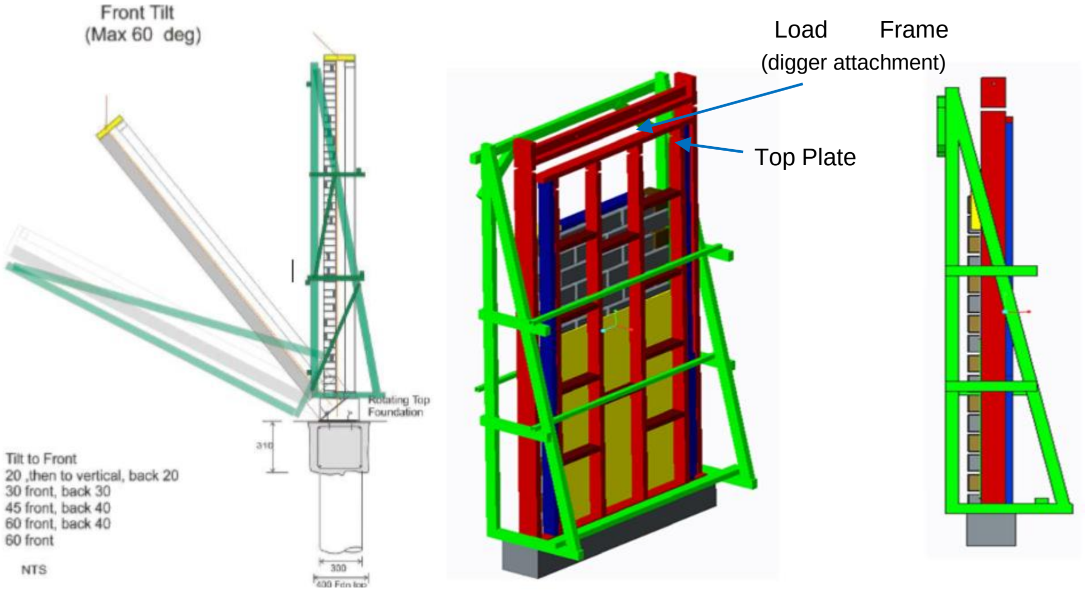

Figure 3. Illustrations of the tilt procedure, the measurement frame rotates with the wall base.

Figure 4. Front views of individual wall specimens on two separate hinged concrete bases and wall with opening and lintel - both bases connected. (Top of external load frame not shown.)

In order to undertake the tests, the site was first prepared with a 4.6m long reinforced concrete foundation beam cast into the ground with additional piles. Specimen walls were constructed on an additional concrete footing with a bi-directional hinge attached to the fixed pile foundation. The wall is built within a distinct load frame that simulates the top of a wall that is moderately well supported, either by other perpendicular walls or to a ceiling diaphragm as shown in red in Figure 3. This frame is also used to tilt the frame without loading the wall. A further instrumentation reference frame is attached to the foundation but is independent of the wall and load frame and is shown in green.

The 3.0m wide by 4.0m long wall panel was a significant mass so substantial steel sections were used to strengthen and stiffen the load frame.

Wall specimen materials used are in accordance with the Half Brick Specification amendment outlined in the Materials and Workmanship standard NZS 4298. They are constructed under a further amendment under consideration for NZS 4299 (Standards New Zealand 1998). Specimen wall dimensions are shown in Figure 4. The veneer wall construction consisted of an adobe veneer made from adobe half bricks and earth mortar. The veneer was screw fixed using Lumberlok brick ties to a ply covered light timber frame.

Triax 160 geogrid mesh is placed between every second course of bricks. There are brick ties every second course secured to the bricks with a nail and then screwed to the timber frame. The adobe bricks measure 280mm by 130mm and are 150mm deep weighing up to 8kg each.

The walls were lightly pre-stressed with a vertical compression force of 5kN (approximating the mass of the wall at one third-height) acting on the top plate, this ensured that as walls were tilted, a simulated self-weight always acted towards the footing. This maintained some equivalent compression on the mortar interface during tilting allowing near typical veneer shear response to the out-of-plane loading.

2.3 **Instrumentation**

Figure 5. Camera, accelerometers and devices measuring deformations to the reference frame.

Key instruments used included: Portal Gauges measuring deformations, LVDT's (Linear Variable Differential Transducers) measuring deformations, Accelerometers measuring acceleration at the top of the wall, Data acquisition system, Motion and still cameras attached to the wall and external to the wall.

Figure 5 shows the instrument layout and independent reference frame for the 1.8m wall.

2.4 Procedure

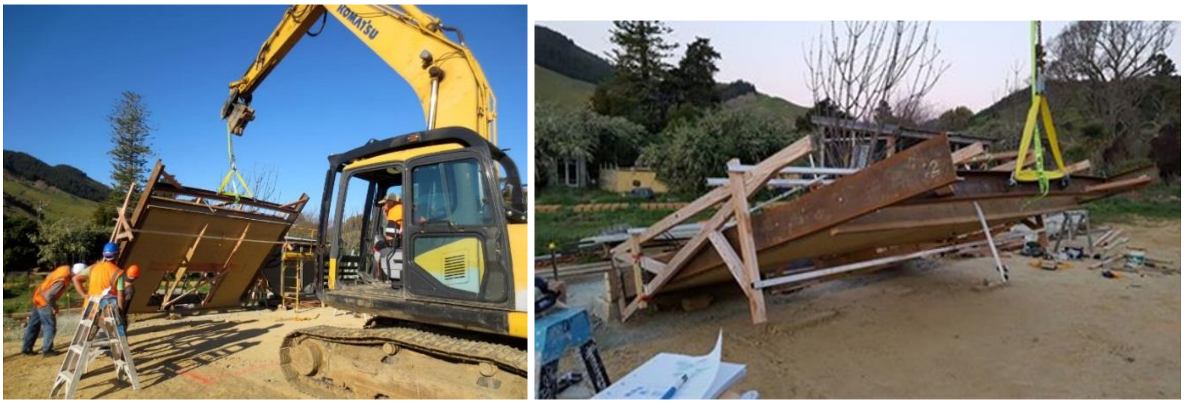

Figure 6. Both bases were connected for the static tilt test of the 3m high panel with lintel (Photo Idema)

Testing took place in two phases, initial proof of concept tests in April 2016 of a 1.8m and 2.4m wall; then in September testing of the 3.0m high lintel wall.

Walls were progressively tilted both forward and back in increments of 10-15 degrees as previously shown in Figure 3. The walls were tilted using excavators to these pre-determined angles and then held at these angles until the wall stabilised and the instrumentation readings settled. A strop was used to connect the load frame to the excavator, the load frame is connected to the ends of the wall top plate. The rigid load frame was fixed to the footing. The footing hinge could rotate allowing the wall to tilt.

After static testing the 2.4m wall it had minimal damage and was spontaneously subjected to a simulated dynamic test. This was carried out by tilting the wall to 60 degrees and then vigorously shaking the support frame with the excavator. Body forces in the wall caused deformation in the top plate where accelerations were measured. This action was successful and still caused minimal damage. Initially the 3.0m lintel wall was double studded. After the initial static tests the secondary studs were removed and it still had minor static load damage. The dynamic procedure was then applied to the 3.0m lintel wall.

3 RESULTS

3.1 Static and dynamic tests of wall panels

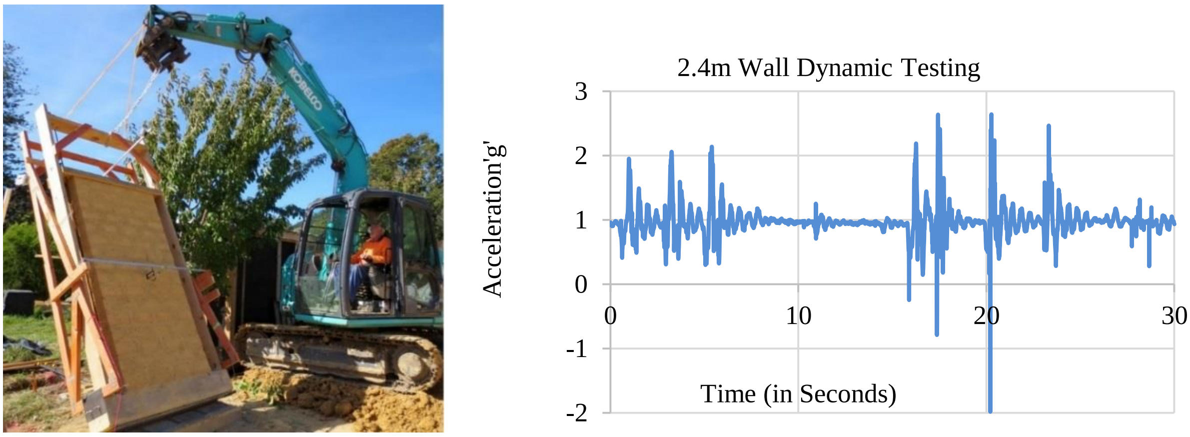

Figure 7. Tilt of 1.8m wall and dynamic accelerations up to 2.64g induced by shaking

Static and dynamic test results exceeded expectations and did not show any significant damage to the 1.8m or 2.4m walls. This proved it was feasible to go ahead with the building and testing of the 3.0m high lintel wall. The tests on the 1.8m and 2.4m walls showed that the walls were capable of withstanding significant dynamic loading as shown in Figure 6 where the 2.4m wall was subjected to an equivalent upper wall lateral acceleration of 2.64g without damage.

3.2 Static Test of 3m high wall with opening - Deformations

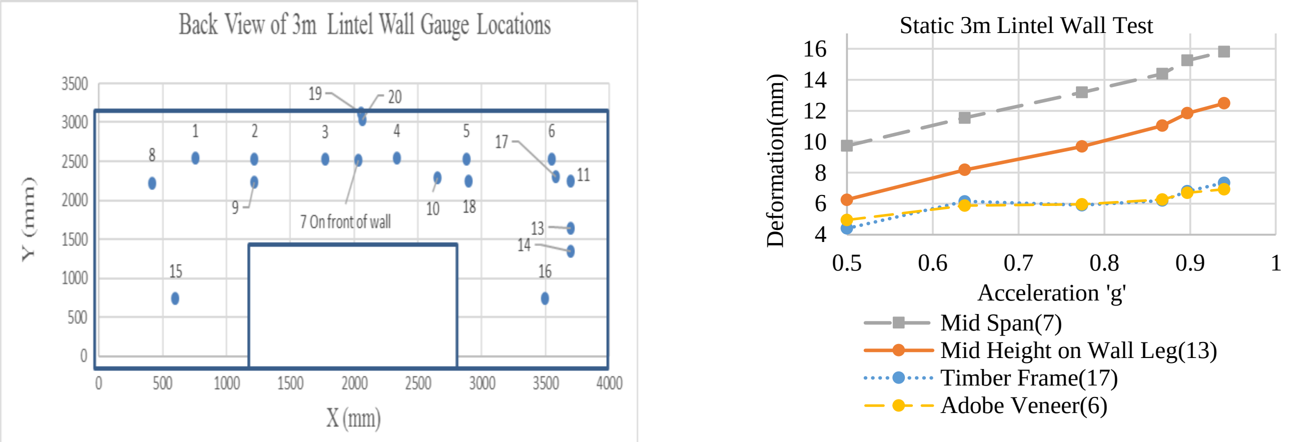

Figure 8. Static deformations as tilt induces out-of-plane loads

The numeral in the graph legend in Figure 8 refers to the instrument type and position as shown. The tilt angle was used to determine the effective out of plane acceleration as a proportion of gravity. The maximum ‘g’ on the graph of 0.94g = 70 degrees of tilt.

Measurements also indicated that the timber frame deformed by the same amount as the adobe veneer with no slip on the ties, so components of the wall acted in unison (governed by the flexural strength of the timber frame). This is important as wall failure is often due to the bricks detaching and falling.

The deformation vs ‘g’ or tilt relationship can be considered linearly proportional. This shows that the wall’s response is uniform to at least 0.94g.

3.3 Static Test of 3m high wall - Crack propagation

At 30 degrees (0.5g) the first cracks were noted. The horizontal cracking indicated one way bending between the top bond beam and the base. The narrowest point between the edge supports adjacent to the lintel was the position of the largest measured deformations.

As the tilt increased there was further dominance of this one-way bend, however the diagonal cracking shows how the restraint of the veneer by the top plate interplays with the unrestrained side edge where larger deformation is experienced. When static tests were completed the horizontal cracks were more extensive but vertical cracking above the lintel was now evident indicating a two-way bend. A stress concentration at the lintel’s ends is evident from both horizontal and vertical cracking.

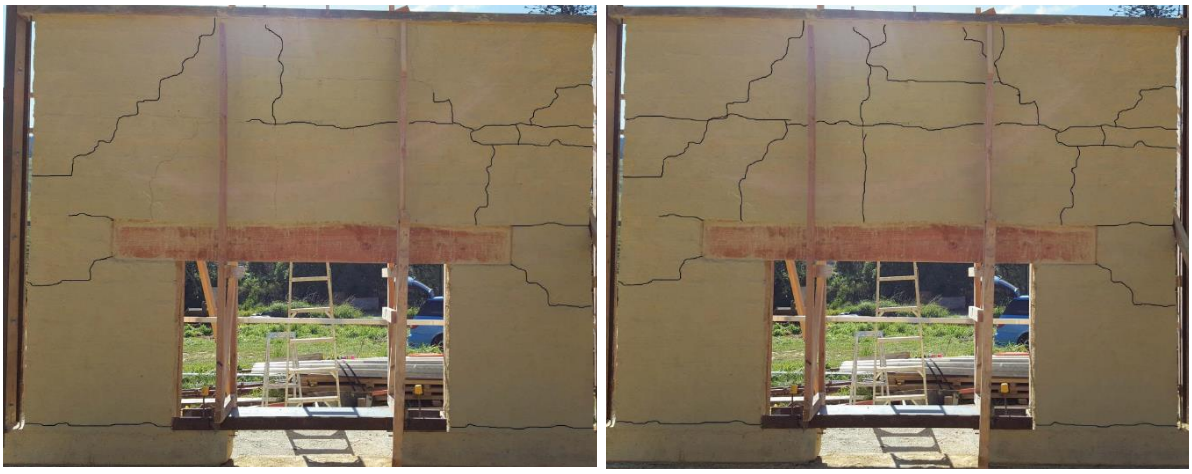

Figure 9. Cracking highlighted at the end of static testing (0.86g) and after dynamic testing

As shown in Figure 9, the cracking at the end of static load tests is drawn on the photo. Following the dynamic tests a complete horizontal crack midway between the lintel and top plate shows that strong one-way bending has occurred here. Two-way bending effects were confirmed by vertical cracks and diagonal corner cracks relating to the support conditions and became nearer to symmetrical. Only mortar and mortar interface cracks were observed suggesting a stronger brick to mortar strength ratio.

3.4 Dynamic Test of 3m high wall

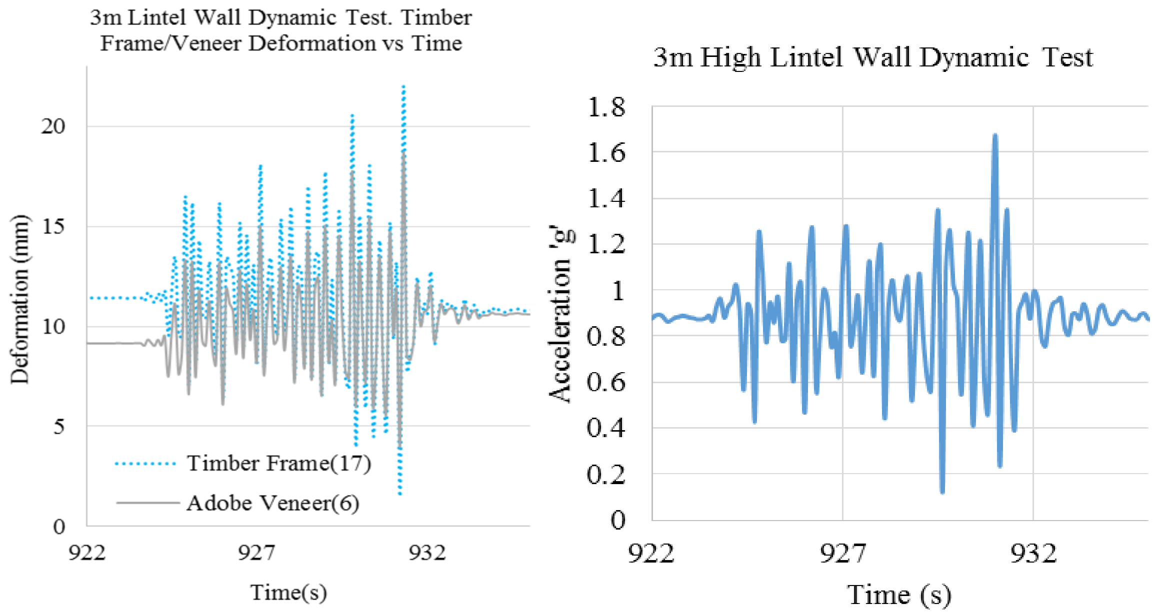

Figure 10a and 10b. Induced deformations and accelerations in the 3m high wall with lintel

Dynamic testing attained a maximum 1.64g as shown in Figure 10b. This is less than the 2.64g applied to the 2.4m wall, possibly due to the differing loading strop's ability to absorb shock. The 2.4m test also had a chain which came into play when the elastic strop used was over extended causing a jolt. Wall size and operator dexterity could also have contributed. This is still a good result to achieve this level of load and the wall remained intact.

Figure 10a shows that under dynamic loading there is no significant evidence of any brick tie slip marked by the similar in-phase veneer and timber deformations. This is consistent with the static tests.

The dynamic action is applied via the steel load frame, with the top plate spanning between legs of the load frame with accelerations measured mid-plate. This system applies significantly greater accelerations at the top of the wall, in this lintel case this is the area of critical out-of-plane interest.

4 CONCLUSIONS

These tests have demonstrated that very good out-of-plane performance can be achieved for adobe wall veneers.

The 2.4m wall showed no significant damage having withstood a lateral acceleration of 2.64g. The 3.0m Lintel wall was subjected to an equivalent 1.64g without serious or life threatening damage. These exceeded the maxima of PGAs experienced during the Christchurch and Kaikoura earthquakes but require further interpretation in terms of overall building dynamics.

Comparison between the 3.0m wall's deformations between the timber frame and adobe veneer show no evidence of brick tie slippage or failure.

For completeness, testing of the 3m high wall should be continued to examine the loading at failure and hence the final failure mode of the wall. There were some limited instrumentation failures so results of the test would be best repeated to obtain clear deformed shapes and gain further precision. In particular, the dynamic response of the instrumentation frame was significant when considering deformations and this needs to be improved.

This novel, but simple, tilt test provided good, useful and measurable static performance data comparable to that of the loadings experienced in a large earthquake.

The effectiveness of the dynamic test relied on the operator of the excavator, stiffness limitations of the load transfer system, and the system of attachment of the excavator. While we obtained some very useful results, there is a level of uncertainty about what accelerations would be achieved on a new series of tests. An additional limitation is that the accelerations are zero at the base and vary with height. With further development of the system the accelerations applied could be better controlled and this simple low cost approach to preliminary out-of-plane masonry testing would be reliable and useful.

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