Performance of Brick Veneers. Do You Have Confidence In Your Ties?

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ABSTRACT: The stability and construction of veneer on buildings has been questioned following the recent Canterbury earthquake sequence. During a seismic event veneers are vulnerable to being dislodged and have the potential to cause injury. An ongoing investigation is underway into the performance of masonry veneer in and out of plane. Aspects of veneer tie investigations include; spacing frequency, type, installation, condition and associated design features of existing buildings.

In this paper we discuss our approach to the onsite, in-situ investigation of existing veneer walls of different construction types. Conclusions will be drawn from data from the investigations of residential buildings, schools and churches around Canterbury and identify common limitations and performance of typical veneer construction methods.

We will suggest guidelines for the assessment of veneer ties to be utilised in similar buildings throughout New Zealand. These guidelines are aimed to give the engineers confidence in assessing the capacity of an existing masonry veneer in a relatively non-invasive manner for a reasonable cost. Recommendations are also made on how to remedy some common deficiencies that may be found.

1 BACKGROUND

Masonry veneer ties are the connection between the frame of a structure and the mortar that surrounds the desired veneer i.e. brick, block or stonework. Figure 1 indicates tie placement between a wall framing stud and brick work.

An article on seismic effects on veneer (Beattie & Thurston, 2011) advises that newer ties have a greater ability to allow for higher levels of differential settlement than previous ties. On this basis, it can be concluded that the majority of veneer ties will have a relatively low ability to undergo differential settlement. The majority of veneer walls in Canterbury were construction pre 1996. Of the veneer investigated to date, 20% were constructed after 1996. This is likely to be representative across New Zealand.

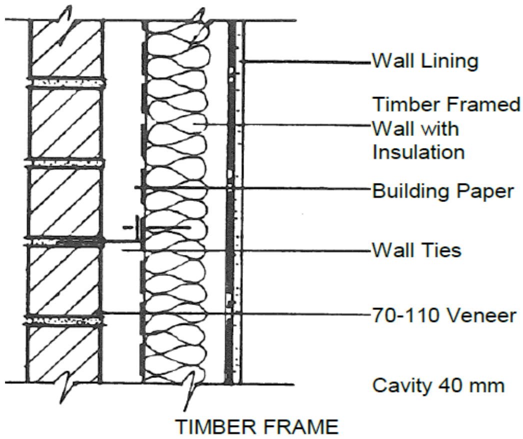

Figure 1. Modern Positioning of veneer tie detail (New Zealand Concrete Masonry Association Inc., 2010)

2 INTRODUCTION

Prior to the Canterbury Earthquake sequence investigation had been undertaken by Shelton and King in 2000 to investigate veneer ties at schools (Shelton & King, 2000). This involved use of a borescope (device for viewing inside walls through a small hole) and locating the veneer ties was found to be difficult. The main findings of this report were that; veneer workmanship varied between schools and re-testing was recommended, and establishing whether ties are connected is critical.

Following the failure of veneer in the Canterbury earthquake sequence and the high number of fatalities from falling bricks (albeit from unreinforced masonry rather than veneer), a very cautious approach has been taken with veneer, in Christchurch (and nationwide). Due to the uncertainty associated with attempting to quantify the likely strength of the veneer has led to the following approach: calculations; investigation, propping, fencing-off, and removal.

1. As there are few guidelines available about checking ties, many see it as difficult and expensive. Current investigations have included removing a section of the veneer or interior wall lining to look at what lies behind it. This is expensive and only provides confidence about the exposed area.

2. In post-earthquake Christchurch, engineers have erred on the side of caution in areas where people could congregate and have in some cases propped walls where there was minimal damage to the building and no damage to the veneer.

3. Alternatively, the veneer was fenced off awaiting further investigation. This could be a costly approach with monthly fence hire.

4. Large areas of veneer have been replaced with lighter cladding material. This has afforded the benefit of upgrading insulation but is expensive.

5. In some Detailed Engineering Evaluations, a %NBS has been assigned to the veneer in order to help quantify the problem.

Figure 2 below shows a school where the brick veneer has been removed and replaced with weatherboard.

Figure 2. Before and after photo of a school showing replacement of brick veneer

This paper outlines the development of an effective and efficient way of investigating the future performance of veneer. Research and development was undertaken as the project requirements of a Bachelor of Engineering Technology at Christchurch Polytechnic Institute of Technology (CPIT) with oversight by Opus International Consultants.

Benefits of investigating a building’s veneer include:

- Better qualification of injury/life risk from veneer failure.
- Reduction in operational downtime due to replacing, fixing and barricading damage to brick veneers.
- Better understanding of the likelihood of further damage.
- Justification for the removal of temporary measures such as fencing and propping.
- The impact of vulnerable veneers for the building owner obtaining building insurance.
- Better understanding of the seismic load path between the veneer and the building as this varies according to the type of veneer tie present.

Performance of masonry veneer has been questioned since the observations made during the recent Canterbury earthquake sequence. Public perception, especially in post-earthquake Christchurch, is that many injuries/fatalities were caused by brick with no differentiation between brick installation types, e.g. chimneys, unreinforced masonry (URM), parapets or veneer. Other common perceptions are that wire ties (constructed with gauge 8 wire) are ineffectual and corrosion due to proximity to the sea is problematic. A study into the behaviour of veneer ties (Dizhur, et al., 2011) (Dizhur, Moon, & Ingham, 2012) incorporating a small sample of wire ties, drew the conclusion that wire ties (Figure 4) were the worst type of tie in terms of veneer failure. These papers did not report on the frequency of ties within the failed veneer. During the investigation into veneer, it is more commonly found that there may be no linear frequency of wire tie positioning within a wall especially where no pre-nailed framework exists. Within the sample to date, there are few ties in the upper portions of walls or within the middle third of the wall in some instances.

Research is currently being undertaken by Christchurch Polytechnic Institute of Technology (CPIT) in conjunction with Opus International Consultants Ltd (Opus) to investigate existing masonry veneers. Currently, over 50 buildings have been inspected to determine the condition of existing masonry veneers. The purpose is to identify how the veneer has been constructed and record how it has performed.

From this research Opus has developed a methodology for the standardised investigation and assessment of masonry veneers. A masonry veneer in this context refers to a heavy weight cladding i.e. brick, concrete block and stone. In particular, we have focussed on timber-framed buildings with masonry veneers tied into the timber framework.

3 METHODOLOGY

To be effective, the technique developed needs to address factors which pose a more significant risk. Although not intended, paper observations were made as to the probable cause and reason for the failure at some of the sites. Veneer damage in the Canterbury earthquake sequence can be distinguished by cracking primarily caused by:

- Vertical acceleration,
- Horizontal acceleration, and;
- Differential settlement.

The technique primarily focuses on how the veneer will perform under horizontal accelerations. Utilising the knowledge gained from previous site investigations (refer to section 4: Key Findings), Opus has developed a standardised approach for multiple site investigations into masonry veneers. The investigation records information on; veneer ties, frequency, type, placement, condition, design features of existing buildings and interaction between veneer and supporting structure. Particular attention needs to be given to veneer at height (above 1.5m), and ‘pillars’ of veneer that infill between doors and windows.

A site checklist form and guidance document was developed. Below is a basic outline of the methodology used:

- Determine wall panel to be investigated, record any distinguishing features i.e. mouldings, ventilation (ensure vents are clear), condition of wall etc.
- With a cover meter (Figure 3), scan the wall to identify location of ties as seen in Figure 4. This should include recording the depth of the ties to confirm installation is over half the thickness of the masonry. Determine spacing between ties to allow the frequency to be obtained. Furthermore, scan at the top of the wall to ensure there is fixity at the most vulnerable part of the wall
- Install a boroscope through existing openings or drilled hole to confirm tie location, type and condition.
- Check that the stud walls are in good structural condition.

Figure 3. Hilti PS 35 cover meter (Hilti (New Zealand) Ltd, 2013)

It is suggested that veneer constructed at differing times should be investigated for a difference in tie alignment and frequency. Experience indicates that if construction of veneer was undertaken by a different tradesperson or there are varied standards or framing within the structure, the ties will be different.

The findings from the on-site investigation should be analysed by a suitably qualified engineer to determine the capacity of the masonry veneer walls.

Figure 4. Internal view of a wire tie

4 KEY FINDINGS

The data of each of the sites was recorded and assessed to give the following findings:

1. Generally, it was found that the veneers displayed a lack of cohesion between the masonry and mortar with 23% bonded with very poor condition mortar. Lack of cohesion can be seen where mortar has shown signs of deterioration.
2. Typically all ties met the current standard NZS4210:2001 of being embedded into the mortar over half the thickness of the masonry; however only 40% of veneer ties meet current code for minimum horizontal and vertical centres.
3. The majority of ties were connected appropriately to the timber framing and these connections met the building code requirements at the time.
4. The veneer was scanned to indicate the location of ties, particularly at high level as this is where seismic demand is the highest. It should be noted that no correlation was found between the location of a structure with respect to the exposure zone (NZS3604:2011 4.2.3) where it was situated, which resulted in higher levels of tie corrosion.

5. We note that using a cover meter to locate ties is outside the primary function of these types of units. Trial cover meter testing confirmed that the Hilti PS35 meets the requirement to locate various tie types.
6. Sill blocks easily become dislodged, especially blocks that are laid on an angle. None were found to have veneer ties.

5 OTHER FINDINGS

Figure 5. Marked brick veneer showing tie layout

The location and frequency of air vents was noted. We expected to see a vent at the bottom of the wall. It is common to see vents covered, for example where an access ramp has been installed. Vents are important for controlling the moisture content of the timber stud walls.

The interaction of the brick veneers with the timber framing and mouldings rarely has been considered. As part of our methodology we required any distinct features such as mouldings under the soffits to be noted. These features have been shown through insitu full scale load testing to interact with brick veneers. It was found that approximately 48% of the investigated stock of buildings had cracking in the piers in particular where piers formed between doors and windows.

If the surface of the veneer is rough, the quality of the scanner readings reduces. In order to improve this quality, more time needs to be spent locating the ties. For example, a typical wall of 50m^2 will take 30 minutes for standard clay bricks but 90 minutes for Hinurera Stone.

6 OTHER OBSERVATIONS

Figure 6. St Teresa's Hall (Google Earth, 2012)

Although the study was primarily aimed at developing a methodology, it became clear that other features of the wall were note-worthy.

Particular detailing features especially at the tops of walls have stopped the veneers from collapsing despite the veneer becoming separated from the framing. This includes a tapered eave soffit and beading placed at the top of the wall between the soffit and the veneer.

It has been observed that the crack pattern seen within the veneer during the investigation does not necessarily conform to the crack patterning in relation to tie placement seen during various seismic load testing by BRANZ within the last 10 years (Thurston & Beattie, Seismic performance of brick veneer houses. Phase 1 Cyclic and elemental testing of clay brick veneer construction, 2008) (Thurston, Critical properties of mortar for good seismic performance of brick veneer, 2011). In general, wire ties seem to have performed well with few showing signs of pull out from the mortar bed. Many failures can be attributed to workmanship; in particular a lack of ties. This may be missing ties or no ties in a particular section of wall; e.g. St Teresa's hall, Figure 6 which was subject to median peak ground acceleration of 0.15g on the 23rd of December 2011 which caused the brick to fall (Bradley & Hughes, 2012).

Two methods of tying have been observed to be less effective. Firstly the use of a wire tie being bent at right angles and fixed to the face of the stud. See Figures 8 and 11. This appears to have been used in the period immediately after the introduction of building paper. The second is a tie that pulls out of the timber very easily, see Figure 10. The case that was encountered was used in 1994 when there was a supply problem with the normal tie. Other problems that may occur are that shown in Figure 9 which shows a tie that is not attached to the stud, or where the mortar has not been well bonded to the ties. This shown in Figure 7 which shows flat screwed ties that have no residual mortar attached to the ties. The building was constructed in 2007 and the block fall occurred over egress routes. We note that the level of shaking may have been high.

Figure 7. Photos of ineffective mortar tie joins

Figure 8. Wire tie attached to the face of a stud

Figure 9. Tie not attached to the stud

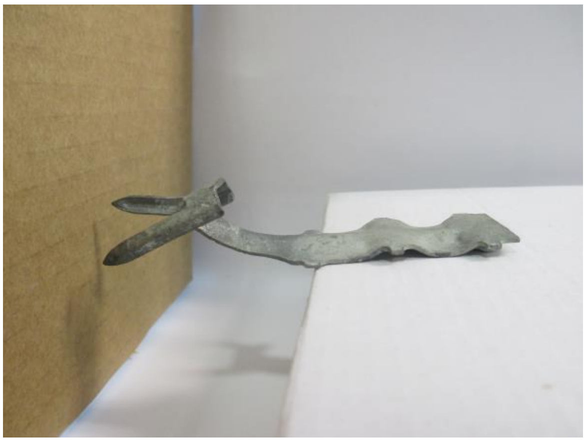

Figure 10. Detail of flat tie

Figure 11. Detail of wire tie attached to face of stud

7 FULL SCALE TEST

Hammersley Park School in Christchurch had buildings that were to be demolished. This provided an opportunity to test the technique. The wall was first scanned. When the wall was demolished the ties could be seen at every position scanned. This was also the case in two other buildings. The veneer testing done at the school is yet to be reported on. The load testing caused significant cracks in the veneer but when the load was removed this crack was undetectable. This suggests that veneers considered to be 'undamaged' based on visual inspection, may be damaged after an earthquake.

8 POTENTIAL SOLUTIONS

Where ties do not meet the standard when installed, or the required, standard additional fixings are likely be required. One retrofit option is installing Helifix ties through the mortar bed from the outside into the timber stud. Consideration of ventilation adequacy is important to ensure longevity of the tie.

9 FURTHER WORK

This work has also highlighted the need for more investigation into the mechanics of shear transfer between the main structure and the veneer. For example, the interaction of in-plane and out-of-plane effects and how the veneer response affects the building in each direction. Modern ties have been subjected to thorough testing but a large percentage of New Zealand's building stock has old veneer ties. More study is recommended into area.

10 CONCLUSION

Concerns have been expressed about the performance of heavy veneer in an earthquake, in particular on a fall hazard. Permanent solutions of removing it are costly, and temporary solutions such as propping or fencing may not be necessary.

To be more confident about the performance of brick veneer, a testing regime has been developed that focuses on the performance of the veneer ties. The testing locates the ties and identifies areas where there are deficiencies. The type, embedment and fixing to framing is also reported. The method of locating the ties has been found to have close to 100% accuracy on clay brick walls. On rough surfaces, the precision reduces and the time to check a wall increases. Where the ties are found to be insufficient, the number of fixings can be increased by retrofitting. Our investigation and experience indicates that the testing and remedial work can often be undertaken at a reasonable cost when compared with the cost of the temporary solutions currently being used.

The methodology is currently being used to assess schools and it is hoped that it will be developed to provide a national guideline for the assessment of brick veneers.

Further research into the dynamic interaction of veneer and structure would be beneficial to better understand and determine veneer performance.

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