SEISMIC PERFORMANCE OF MASONRY VENEERS ON TIMBER FRAME BACKING

Roger H. Shelton¹, and Andrew B. King²

1. ABSTRACT

This paper presents the initial findings of research into veneer/frame interaction which has been undertaken at the Building Research Association of New Zealand (BRANZ). The work has involved a combination of experiment and analysis, of both individual veneer elements, and complete veneer systems. The common practice in New Zealand of face nailing veneer ties to the backing frame has been shown to be inadequate in providing anchorage to the veneer under the displacements associated with severe seismic actions. Standard test methods and code criteria at present (in New Zealand or elsewhere in the world) do not identify this shortcoming. The paper concludes with recommendations for changes to tie installation practices, and indicates a more realistic and practical method of demonstrating satisfactory seismic performance.

2. INTRODUCTION

Brick masonry veneer tied to a framed backing structure is a very popular form of domestic construction in New Zealand. The masonry may be of either clay or concrete units, bedded in a cement mortar. The backing frame has traditionally been constructed of timber, although lightweight cold-formed steel framing is slowly being introduced.

While the general approach to domestic building construction has been imported from

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¹ Structural engineer. Building Research Association of New Zealand
² Head of Structures. Building Research Association of New Zealand
overseas, principally the UK and Australia, there are some features unique to New Zealand which have an influence on the seismic behaviour of masonry veneer. Until relatively recently, veneer ties used in New Zealand were "butterfly" wire ties, nail fixed to the side of the stud some time after the veneer was laid and the mortar cured. In the 1970's, with the recognition of the importance of building insulation, building paper fixed to the outside of the timber frame became universally used in brick veneer work in New Zealand, and ties evolved into the face fixed metal strips commonly used today. The face fixing is achieved by nailing as the bricklayer proceeds, and one manufacturer has developed an ingeniously tie with the nails already incorporated in the body of the tie. Another construction feature universal in New Zealand is the practice of laying ties "dry" on top of the bricks during installation and thus laying of mortar on the top only, rather than bedding them on mortar. Therefore ties are not surrounded with mortar, as is common practice in other countries.

New Zealand has experienced a number of damaging earthquakes over the years, most notably that which devastated the city of Napier in 1931. As a result, masonry is perceived by the building industry and public alike as a poor performer under earthquake attack. Some of their concerns are justified. It is a relatively heavy material and therefore subject to high inertial loading, it is brittle and non ductile and, because it is made up of individual units requiring inter-connection, can be adversely affected by poor workmanship. However, that is no reason to write off an otherwise satisfactory building system. Holgate (2) said: "Since the Napier (1931) earthquake, brick construction has received severe criticism in some quarters, but the writer submits such criticism was very ill-advised, being based solely on superficial inspection of the area of destruction. It is quite safe to say no material, however good, would be of any use against earthquakes if the design and workmanship were faulty." This statement is apparently as true today as it was in 1932.

A careful study of the reports of these earthquakes shows that much of the damage occurred to forms of construction which are not permitted today and that many examples of damage were caused by poor workmanship or plain ignorance of sound building practice. Nevertheless, two particular problem areas are common to most accounts of damage. These are, failure of ties anchoring the veneer to the frame and damage at corners due to deflection incompatibility between two intersecting planes of veneer. BRANZ's research to date has concentrated on the former problem. The latter is due for investigation in the next year.

A survey of the literature available on the subject has shown that the combination of veneer construction on a timber frame backing structure in a seismic environment is not common except in New Zealand. Thus, solutions developed in New Zealand may not necessarily be applicable to other areas of the world.

Amongst those researchers who have attempted to quantify the distribution of forces applied to ties in the composite action under face loads there appears to be a discrepancy in the level of force applied to each tie. Those carrying out simple elastic analyses have found that tie loads are much higher at stiff points of support such as at floors or roofs, and much lower within the span of the more flexible studs. The most extreme example of this was reported by Lapish and Allen (3), where tie loads were shown to increase up from 3 to 8 times the
load based on tributary area, depending on what axial stiffness was assumed in the calculation. This finding has been confirmed (more or less) by static testing simulating wind loading and seems to be independent of whether steel or timber framing is being used as backing. However, this phenomenon has not been reported by any of the workers carrying out dynamic face load testing.

A further discrepancy observed amongst those workers considering seismic loading is the influence of the actual dynamic response of the wall system on the overall level of tie loads. Most were content to apply "code loads" in the same way as for wind loads. Only KPFF (4) considered earthquake input spectra, and found the resulting tie load levels to be greatly different to the levels assumed in the code loadings. This is an important area for further investigation.

3. ELEMENTAL TIE TESTS

The critical links between the masonry veneer and its backing structure are the veneer ties. There is ample evidence (5),(6),(7) of unsatisfactory earthquake performance which can be attributed to lack of adequate veneer anchorage due to both poor durability and mechanical inadequacy of the ties.

Test methods intended to demonstrate tie compliance with the relevant building code (8),(9),(10),(11) are generally based on a monotonic axial tensile load to failure, or to a specified deflection. Those test methods which do specify specimen construction in detail call for a purpose made brick couplet and make no attempt to simulate the anchorage conditions of a tie installed in a typical "as constructed" wall. The New Zealand masonry construction standard (12) also prescribes a specimen construction method which does not simulate as built installation methods. However the test method itself is rather different to those described above. Recognising the fact that seismic ground motion is random in direction, magnitude and duration, the method prescribes a displacement controlled, cyclic test regime that subjects the ties to in-plane as well as axial loading.

BRANZ has carried out 6 series of tests on veneer ties. (In total, 164 tests on 4 different types of ties, using both concrete and clay bricks) The test method used was based on the New Zealand masonry code test method (12) utilising the set up shown in figure 1.

Actuator 2 is used to apply 4 preliminary cycles of load to a displacement of ±10 mm. This is intended to simulate seismic action in the horizontal plane of the wall. A flexible, framed backing structure will undergo significantly greater in-plane displacements than the relatively rigid veneer, and this section of the test ensures that the tie is capable of withstanding this level of displacement before it is called upon to perform its primary role of restraining the veneer under face loading. Following this, actuator 1 is used to apply incrementally increasing cycles of axial load up to a maximum displacement of ±10 mm.
At an early stage of the test programme, one series of specimens was constructed as a complete wall rather than as brick couplets as prescribed by the various code test methods. This construction method was adopted because it was expected to more closely reflect the actual in-situ condition of ties in practice. This proved to be of great significance to the project. Upon dis-assembly for testing, it was found that the majority of ties were slightly loose in their mortar bedding. Discussions with the bricklayer suggested that the hammering action while driving the tie fixing nails, was sufficient to deflect the studs enough to disturb the partially hardened bedding mortar of the row of ties below. The resistance of this series of ties to axial loading was so poor that the series of tests was curtailed. Such poor performance in practice would not have been identified by any of the test methods referred to above.

Subsequent tests were designed to investigate the parameters leading to this effect. It was found that concrete bricks were slightly less susceptible to this lack of anchorage than clay bricks because their slower rate of moisture absorption meant that the mortar remained more plastic during the time of installation, and thus more compliant to the hammering action. Also, the pattern of deformations on the portion of the tie embedded in the mortar had an effect on the bond. Ties laid on a mortar bedding rather than dry on top of the bricks (thus being fully surrounded by mortar) also performed better.
However the most promising solution to emerge was screw fixing of the ties to the backing studs, rather than nailing. Screws used for the tests were self drilling types normally used for fixing roof cladding. Bricklayers, once the need was explained, were happy to install them using power screwdrivers commonly used in the construction industry. This method has the dual advantage of less disturbance during installation, and higher pullout resistance during axial loading. Figure 2 compares framing deflections measured during the installation of both screw fixed and nail fixed ties. Typical examples of axial load/displacement plots for the two methods of fixing are shown in figure 3.

![Deflection of stud during tie installation](image)

**Figure 2.** Deflection of stud during tie installation

![Axial load/displacement plots](image)

**Figure 3.** Plots of axial load/displacement for nail fixed and screw fixed ties

4. **DYNAMIC FACE LOADING TESTS**

Two full sized, 2 storey clay brick veneer walls were built and subjected to increasing amplitudes of sinusoidal acceleration in the out-of-plane direction (face loading). The tests are more fully described by Lawrance and Stevenson (13). The two wall specimens were
identical except for the method used to install the ties. Specimen 1 ties were installed using normal New Zealand bricklaying trade practice:

a. The backing frame was erected, with building paper attached to its face.
b. Four courses of bricks were laid on a concrete foundation.
c. Ties, at the required spacing, were laid directly on top of the upper brick course.
d. The ties were nailed to the faces of the studs of the backing frame.
e. Mortar was placed on top of the ties and the next four courses of bricks laid.
f. Steps c, d, and e were repeated until the veneer had reached full height.

The ties of specimen 2 were installed using the following measures to ensure satisfactory anchorage in the bedding mortar:

a. The ends of the ties were bent down 4 mm to improve keying in the mortar.
b. Ties were laid in a bed of mortar as well as being covered by the next course.
c. A reduction of stud vibration during hammering was achieved by using a sledge hammer as a dolly behind the stud.

While some of these measures would be impractical in normal building construction, for the purposes of the test they served merely to ensure that the tie anchorage was adequate for comparison with the first specimen. These two tests were conducted before the screw fixing solution had emerged during the later series of the elemental tests described in section 3 above.

For both walls, tie forces, veneer accelerations, framing and veneer displacements, all increased as the level of input acceleration was increased. Significantly however, all of these increases occurred at a lower level of input acceleration in the case of the first wall than for the second wall. A typical example of these results (tie force) is shown in figure 4.

Figure 4. Tie force comparison
Veneer cracking also occurred at lower acceleration levels for the first wall. The natural frequency for the first wall was consistently lower, due to the tie slippage, and, as might be expected, the damping was higher. The total wall reactions measured at first floor and roof levels were, however, similar for both walls.

The most striking feature of the test was the great difference in performance achieved once steps had been taken to assure adequate tie anchorage. This was graphically demonstrated during the first test, when a large portion of veneer became completely detached and fell in a most alarming manner at the end of the test.

5. IN-PLANE TEST

A full sized brick veneer on a timber framed backing wall was built and subjected to static in-plane loading followed by face loading. The specimen was intended to represent a typical domestic single-storey wall configuration and included a window opening and a 1.2 m framed return wall at each end. The primary function of the test was to calibrate a finite element computer model which is reported elsewhere (14). A general view of the specimen is shown in figure 5.

![In-plane test specimen](image)

**Figure 5.** In-plane test specimen.

The timber backing wall was built in accordance with typical New Zealand construction practice, and was lined on the inner face with 9.5 mm plasterboard. No other in-plane bracing was used, as is common practice in domestic construction. The veneer was constructed of 70 mm wide clay bricks in cement mortar. Bond wrench testing of couplets made during wall construction, showed that a brick/mortar bond strength of between 250 and 1100 kPa was achieved. As shown in figure 5, the veneer was built on a concrete filled steel beam mounted on rollers so as to enable monitoring of the horizontal reaction at the base of the veneer under the applied load. Veneer ties were mild steel strip ties 25x1.2 mm in section with the inner end bent up for fixing to the face of the framing. They were fully bedded in mortar and screw fixed to the framing for optimum performance as indicated by
the elemental tie tests. One of the ties was instrumented with a load cell and potentiometer to monitor load and deflection under the applied load. Its location is shown in figure 5.

The applied in-plane cyclic loading sequence is shown in figure 6. A top plate displacement of ±32 mm is typical seismic racking testing of building elements and would be expected to occur during severe earthquake actions.

![Figure 6. In-plane test, load history.](image)

Although the ties were simple, low cost strip ties commonly used in New Zealand and elsewhere, they were easily able to accommodate a displacement of that magnitude by rotating about the single screw fixing. Typical results from an intermediate stage of the test are presented in figure 7. It can be seen that the frame and veneer are each resisting about half the applied load. At the next deflection increment, the 900 mm pier cracked at sill level and began rocking under the imposed displacements.

![Figure 7. In-plane wall test results.](image)
At the completion of the in-plane testing, the uncracked 1.8 m pier was isolated from the remainder of the specimen and subjected to face loading (placing the ties in tension) by means of air bags. This extension to the test was principally intended to provide qualitative results only, and thus was not fully instrumented. Mid height deflection of both studs and veneer was recorded as well as airbag pressure. Pressure was monotonically increased until wall failure. Veneer cracking first occurred at the window sill level at a pressure of 2.5 kPa, followed soon after by cracking at the veneer base. An approximate assessment of the magnitude of stress and strain in the veneer at this point, gave values of 1500 kPa and 0.0004 respectively. At the conclusion of the test (at a pressure of 7.5 kPa), although veneer cracking and deflection were very severe and the connection of the studs to top plate was undergoing gross distortion, the veneer remained attached to the wall.

Although only an indicative test, the face load test did show that the screw fixed ties were capable of withstanding an axial load in tension in the order of 1.6 kN after previously undergoing considerable in-plane distortions.

6. DEVELOPMENT OF CODE TIE PERFORMANCE CRITERIA

A solution to the problem of adequate mechanical tie anchorage is at hand. (The corresponding issue of durability may not be quite so clear cut) Although further development and testing is still required, it would appear that screw fixing to both timber and steel backing framing is economically and technically feasible. Traditionally, code specified standards for veneer ties have been prescriptive (15) and it could be argued that making screw fixing mandatory could be handled in the same way. However, innovation and improved performance is stifled by this approach, and building codes worldwide are now tending toward performance based standards. This requires a definitive statement of performance criteria.

A good starting point is the list suggested by de Vekey (16). However, this does not address the issue of seismic performance and this is the thrust of the research currently underway at BRANZ. For the reasons outlined in section 3 above, the test regime consisting of in-plane cyclic displacement followed by axial cyclic displacement, is appropriate for a seismic environment. However, the nature of the pass/fail criteria are not so easily resolved.

Criteria based on elasto-plastic ductility have been advanced and found their way into test methods (12). This is the approach used for assemblies forming the primary load-resisting elements of the structure (17). However veneer ties are not really required to behave in a ductile manner during earthquake excitation in so far as their displacement ductility determines the response of the primary structure. Rather, as secondary elements, they are required to exhibit toughness, where toughness is defined in this context as the ability to survive a number of cycles of (inelastic) displacement without a significant loss of strength. It is contended by many researchers that the actual load history is not important, and a simple cyclic regime will provide a sufficient test. For example Park (17) states "Instead a more simple displacement history can be applied to enable an assessment to be made as to whether the structure is tough enough to be likely to perform satisfactorily during a severe earthquake." The essence of the definition of toughness as used in the metallurgical field

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relates to the amount of work required to cause fracture as indicated by the area under a stress/strain curve. A practical analogy to this under a cyclic loading regime is to add together the peak loads resisted during each half of the displacement cycle, stopping this accumulation when the peak load falls below 80% of the maximum load resisted.

This measure is proposed as a performance indicator for evaluating veneer ties. The method is straightforward to apply under test by either manually reading gauges and adding, or automatically by electronic processing. The performance indicator still needs to be related in a consistent way the inertial loads applied during earthquake excitation of the supporting structure but it has already been found to be an effective "filter" of tie toughness.

7. CONCLUSIONS

A major improvement in the seismic performance of masonry veneer on timber frame backing can be achieved by 2 changes to New Zealand tie installation practice. These are:

- Face fixing to the framing by screwing.
- Installing the ties on bedding mortar rather than dry on the bricks

This improvement in performance was demonstrated by (typically) two or three times the axial load resistance under the elemental tie tests. The resulting improved tie anchorage, showed up in the dynamic tests as an ability to withstand double the input acceleration before failure. Screw fixing of the ties in the in-plane test allowed them to accommodate over 30 mm of in-plane distortion prior to providing adequate face load restraint to the veneer.

Test methods intended to quantify tie performance should ensure that specimen construction simulates field construction as far practicable. Seismic tie testing should include in-plane loading as well as axial loading. Development of the tie performance indicator is a promising avenue towards matching code performance criteria with expected levels of applied seismic loading.

8. REFERENCES
