

Twenty years of improvement in the seismic performance of masonry veneer construction

Graeme Beattie¹ and Stuart Thurston²

1. Principal Structural Engineer, BRANZ Ltd, Judgeford, Porirua, New Zealand.
Email: Graeme.Beattie@branz.co.nz
2. Senior Structural Engineer, BRANZ Ltd, Judgeford, Porirua, New Zealand.
Email: Stuart.Thurston@branz.co.nz

Abstract

A lot of clay has flowed through the kilns since the 1989 Newcastle Earthquake. Several significant changes have occurred to make masonry veneer construction safer and stronger over this period, both in the methods of construction of the veneer and the understanding of the seismic behaviour of the veneer panels. These changes have led to the conclusion that masonry veneer construction can be reliably considered to provide some bracing resistance to a light timber framed structure, even if only to resist its own inertial loads. Recent research undertaken at BRANZ has investigated the behaviour of full scale brick veneer single and two storey buildings under slow static and dynamic cyclic loading. This paper describes the developments that have occurred since 1989 and this recent research which has provided the new confidence in the seismic performance of clay brick veneer.

Keywords: Brick veneer, brick ties, earthquake, seismic, veneer construction, bracing

Introduction

Brick veneer has been used for decades as the exterior cladding of our houses in New Zealand and Australia. Statistics show that over 45% of new houses constructed in New Zealand have a clay brick veneer cladding [1] and it is understood that in Queensland at least, brick veneer has been the predominant brick form since the late 1950s [2]. This significant use of brick veneer as a cladding makes it worthy of investigation as a possible bracing system. Its stiffness will mean that in an earthquake it will readily attract the seismic shear forces before the framing and its sheet bracing materials have an opportunity to provide the bracing expected of them.

Performance in Recent Earthquakes

The 1987 Edgecumbe earthquake was the last major earthquake to strike a populated area in New Zealand. This was a magnitude 6.3 earthquake (c.f. Newcastle 5.6). Probably a more relevant measure of the earthquake is its Modified Mercalli intensity. Both earthquakes were judged to be MM 9 at their worst and in such events it is stated that brick veneers are expected to collapse. And indeed they did partially collapse (Figure 1). However, while not so obvious in the photograph, there are significant differences between the veneer in vogue at that time and that being constructed these days in New Zealand. Several points worth noting are that the individual bricks are solid (or may have small holes) in this typical example of the time, the veneer thickness is 100 mm and there are no signs of any brick ties still attached to the wall framing, probably because the nails/staples have pulled out.



Figure 1 Example of brick veneer failure in the 1987 Edgecumbe earthquake

Prior to the 1960s bricks were generally manufactured without vertical core holes.

Developments in Brick Manufacture

The major producer of clay bricks in New Zealand has been Monier and its predecessors at the New Lynn plant. In 1994, the bricks they produced reduced in thickness from 90 mm to 70 mm. Oliver [3] states that this reduction was done primarily to reduce the weight and therefore reduce the cost to transport the bricks from the manufacturing plant in Auckland to the South Island. Oliver also states that the 70 series bricks weigh roughly 40% less than they did in 1931 (a plus for earthquake performance). The new bricks are made by forcing the clay through an extruder which has the hole formers in place and the holes assist the drying and the firing process. Personal communications [4] have revealed that bricks with holes have been around since at least the 1930's. However, the bricks are now much stronger due to better processes and higher firing temperatures.

Also, while not a development of the last 20 years, the mortars are now cement based rather than lime based, resulting in greater bond and compressive strength.

Developments in the connection of veneers to the framing

Several standards are worth mentioning as they have evolved as a result of research findings.

The 1984 version of AS 2699 [5] contained performance requirements for brick veneer ties. The ties were required to be corrosion resistant for the life of the structure. Galvanising was the common process for providing this resistance, although there is evidence to suggest that lightly galvanized wire did not stand the test of time [6]. Minimum characteristic strength and stiffness requirements were stipulated in the Standard and a test procedure was included. The ties were required to be fully embedded in the mortar. Vertical and horizontal displacements of the test brick couplet with respect to the timber framing were required to be applied to simulate possible differential movements in service before the tie was loaded once axially in tension or compression. The strength of the tie was assessed at 1.5 mm displacement and so the ultimate strength of the tie was not determined.

Closely following the Edgecumbe earthquake, in 1989 New Zealand published NZS 4210, Code of Practice for Masonry Construction: Materials and Workmanship [7]. Ties were classified as either stiff or flexible, the latter being able to

accommodate large differential in-plane movements. The ties were required to be tested and classified as either medium duty, heavy duty or extra heavy duty, depending on their minimum characteristic stiffness and characteristic cyclic strength (earlier standards just required the ties to be able to hold twice the weight of the contributing veneer with no test requirements). This was the first time that cyclic testing was required to simulate earthquake loading. There was no requirement for the tie to be fully encapsulated in the mortar.

In the early 1990's, veneer tie research was undertaken by BRANZ [8]. Initially, small specimens were constructed using commonly manufactured "flat" metal ties, face fixed to the studs with nails. The method of construction of the test couplets, stacked upon each other and attached to the same stud, revealed that the vibration from the nailing process for ties higher up the stud caused de-bonding of the tie from the mortar at lower levels in the stack. This was of course what was also happening in the field. Specimens made with screw fixings to the stud were found to have a superior tie-to-mortar bond. Recommendations were made to screw fix the ties and also to fully encapsulate the ties in the mortar.

The year 2000 saw the publication of a joint Australian/New Zealand standard, AS/NZS 2699.1 [9]. This standard replaced AS 2699:1984 and in part, NZS 4210:1989. This standard laid down performance criteria and also some prescriptive requirements for Type A ties (commonly used in Australia) and Type B ties (commonly used in New Zealand). Test exposure requirements were required to be passed to ensure that the ties would suffer no loss in serviceability or performance over the life of the structure. While not stated specifically that ties were to be screwed to non-rigid members (i.e. studs), they were required to be fixed using non-impact methods. The ties were required to be fully encapsulated in the mortar and to be capable of being mechanically keyed within the mortar bed. They were also required to tolerate specified vertical and horizontal differential movements of the veneer and the load-bearing frame. A clearer testing procedure was incorporated in this standard that exercised the tie in the in-plane direction first (to simulate in-plane earthquake loading) before cyclic axial loading was applied. NZS 3604:1999 [10] also included a new provision requiring that there be no vibration of mortar less than 24 hours old, such as might result from the fixing of interior linings.

Full encapsulation of the ties was new for many New Zealand bricklayers and it is fair to say that many have not adopted this practice, finding it easier to lay the ties directly on the bricks (dry bedding), screwing them to the studs and then placing the mortar for the next course. A new issue of NZS 4210 [11] was published in 2001, and in this

latest version, bricklayers are also required to fully encapsulate the ties. Reference is made to AS/NZS 2699.1 for the testing of ties. The Department of Building and Housing has not as yet cited this 2001 version of NZS 4210, so the 1989 version is still considered to be current in terms of the New Zealand Building Code (NZBC). Therefore, in terms of the Building Code, full encapsulation is not required. BRANZ is sympathetic to the stance of the bricklayers because AS/NZS 2699.1 provides clear strength and stiffness performance requirements for ties and believes that if these can be achieved with dry bedded ties then the tie installed this way is fit for purpose. To this end, BRANZ conducted an investigation of the behavior of two typically used dry bedded ties in 2006 [12], subjecting them to the test procedure given in AS/NZS 2699.1. It was found that the performance requirements in AS/NZS 2699.1 could be achieved without the need to fully encapsulate the ties.

Veneer contribution to bracing resistance

BRANZ has been investigating the performance of modern clay brick veneer walls over the last three years. Since 1989, there have been compressive strength (12.5 MPa minimum) and bond strength requirements (200 kPa minimum) for mortar in NZS 4210. However, the 2001 version of the Standard added two statements that “the 28 day compressive strength of the mortar shall not be less than 12.5 MPa for structural compliance with NZS 3604” and “the compressive strength of mortars used for veneer construction shall follow the requirements of the masonry suppliers”. These requirements are less clear cut as the brick veneer could be considered structural if it is providing its own in-plane bracing resistance. Nevertheless, at least one of the major clay brick masonry suppliers does specify a 12.5 MPa compressive strength for mortars used with their product [13]. BRANZ’s research and testing have shown that the seismic performance of brick veneer depends more on the mortar bond strength and this has little correlation with compressive strength.

In its investigation, BRANZ has also recognized the mechanical connection being provided by the mortar as it penetrates the holes in the individual bricks. Full scale one and two storey buildings have been constructed in the BRANZ Structures laboratory and subjected to static and dynamic load testing [1][14]. The buildings were lined with plasterboard to provide the normally expected bracing function. The static testing was designed in such a way that the lateral force transfer from the timber framing to the brick veneer could be measured. It was found that about 60-70% of the lateral load that was applied to the timber frame was transferred by the ties to the veneer. It was clear from the tests that the veneer does not behave as a collection of individual brick elements but as cohesive rocking panels (Figure 2) and that the

rocking panels between openings provide a restoring force, resulting in very little permanent lateral deflection once unloaded. The behavior of the two storey specimen was particularly encouraging.



Figure 2 Views of rocking panels – single and two storey specimens

The inertial forces associated with the mass of the veneer cannot be replicated with static testing. Therefore, two dynamic tests were undertaken on the BRANZ shaking table [15][16]. The models were smaller than the static test models because of the dimensional and weight limitations of the shake table. Nevertheless, it was possible to build a 4.1 m long by 2.5 m wide by 2.4 m high specimen on the shaking table. Window and door openings were included and a driving mass representing the weight of a tiled roof of a 10 m wide house was installed on top of the ceiling framing. These specimens were subjected to sinusoidal shaking that covered the design spectra for Wellington. The performance of the clay brick veneer was very encouraging. The rocking behaviour that had been observed in the static tests also occurred in the dynamic tests. Corner elements rocked as whole bodies, without failure occurring at the junction of the two orthogonal elements. The behavior of such junctions had always been a concern before the testing was undertaken. The longer (more squat) veneer panels also slid as single elements on the veneer/foundation interface in the testing.

BRANZ has proposed a method of taking account some of the bracing function being provided by the veneer in light timber framed structures designed to NZS 3604. A conservative approach has been adopted whereby the veneer is assumed to resist its own in-plane inertia load. Recommendations have also been made to Standards New Zealand for the extension of the scope of NZS 3604 to cover two storey brick veneer construction.

Because the testing undertaken had not been able to fully simulate random multi-directional earthquake motion, further testing of individual walls subjected first to cyclic in-plane loading and then to dynamic out-of-plane loading is reported in a separate paper at this conference [17].

Summary

This paper has attempted to summarise the developments in brick veneer design and construction in New Zealand since the 1989 Newcastle earthquake. It has discussed the changes to the bricks themselves and to the way in which the ties have been connected to the timber framing. It has referred to the changes that have occurred in the related standards and then described research investigations that have been undertaken by BRANZ to take account of the better performance expected in modern veneers. Proposals for changes to the current timber framing standard, based on the results of the research, are discussed and finally reference is made to recent testing that models more closely the random nature of the earthquake motions.

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