11th Canadian Masonry Symposium, Toronto, Ontario, May 31- June 3, 2009

A STUDY OF WALL TIE FORCE DISTRIBUTION IN VENEER WALL SYSTEMS (STAGE 1)

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ABSTRACT

The performance of both cavity and veneer wall systems is critically dependant on the effective performance of the ties which connect the outer and inner leaves. In veneer construction the ties are the principal means of support of the external masonry leaf as they transfer the veneer loads to the structural back-up frame. In cavity construction, the ties allow the sharing of load between the two masonry leaves, with the tie forces being influenced by the relative stiffness of the leaves and the nature of the support for each leaf.

In recent years there have been attempts to model this behaviour analytically with varying degrees of sophistication. These studies have shown that the distribution of forces in the ties is dependant on a range of factors, with the tie force certainly not just being a function of the tributary loading area for the tie.

The Masonry Research Group at the University of Newcastle is involved in an on-going study of wall tie behaviour with a view to developing more realistic wall tie design rules. Some results on the behaviour of ties in cavity walls have been presented previously. This paper reports a study on typical Australian brick veneer walling systems which has concentrated on developing techniques to accurately monitor individual tie forces in veneer walls subjected to lateral loads. A convenient method for measuring individual tie forces is presented, together with confirmation that tie force redistribution occurs in veneer systems once ties reach their individual capacity.

KEYWORDS: wall ties, veneer walls, forces

INTRODUCTION

Cavity and veneer masonry walls are used in many countries in domestic and commercial buildings. The details of the construction vary from country to country but the basic principle of creating a cavity to prevent the ingress of moisture remains the same. Their structural behaviour depends on a number of factors such as support conditions, relative stiffness of the leaves and the tie characteristics. The forces in the individual ties are therefore not simply a function of their nominal tributary loaded area, but the result of the interaction of all of these various factors.

A veneer walling system typically consists of a masonry veneer connected across a cavity by ties to a flexible structural back-up (usually a timber or steel frame) by wall ties. When the system is subjected to lateral load from wind or earthquake the loads are transmitted to the back-up system by the wall ties in a mechanism which is a function of the stiffnesses of the veneer, the back-up and the wall ties, the wall support conditions and the tie characteristics and layout. The ties typically have axial stiffness and strength in tension and compression, but negligible shear capacity. They therefore assist in the sharing of load between the leaves but full composite action is not achieved.

Because of the lack of a rational method for the design of wall ties, masonry codes often contain deemed-to-satisfy requirements rather than systematic procedures for the design of wall ties. A comprehensive summary of North American research, current practice and design procedures has been produced by Drysdale et al [1]. The Australian Masonry Code [2] has both deemed-to-satisfy and first principles design procedures based on recent research [3]. However, these procedures have been developed from the analytical modelling of typical Australian practice without comprehensive experimental verification (the focus of the current study at Newcastle). It is clear that further research is required to produce comprehensive and realistic design rules.

CURRENT AUSTRALIAN PRACTICE

Wall ties in Australia are available in a number of sizes and shapes and are usually made from galvanized mild steel or stainless steel in areas of high corrosion risk. When installed correctly, the ties are required to have the appropriate level of strength and stiffness in accordance with the Australian Masonry Code. Veneer ties are commonly strip ties nailed or screwed to the timber or steel back-up frame. A parallel manufacturing standard contains testing procedures to determine the in-situ tie characteristics [4]. The test procedure involves building the wall tie into the joint of a masonry/stud wall couplet simulating the appropriate form of construction and then subjecting the assemblage to tensile and/or compressive forces with the cavity displacement being monitored. This procedure is similar to that used in the current investigation and is described below.

The most common Australian application of veneer construction is in housing, which accounts for a large proportion of the Australian brick consumption. An important feature of this form of construction is that the outer skin of masonry veneer is unsupported at the top. As shown in Figure 1, the veneer thus relies entirely on the wall ties for support, and the top row of ties tends to act as a de-facto top support. When the wall system is subjected to a lateral load, the distribution of forces in the ties will be influenced by the deflection of the back-up – the more flexible the back-up, the higher the force in the top row of ties. This is illustrated in Figure 2 which shows typical tie force distributions for a veneer wall (from the detailed analysis of this behaviour by Page et al. [3]. Because of the non-linear load-deformation characteristics of the ties, at higher levels of applied lateral load it is likely that tie force redistribution will occur from the highly loaded ties near the top of the wall to ties located lower down. The nature and extent of this redistribution is currently unknown, with the current AS3700 design procedures not including this effect.

The current research at the University of Newcastle is aimed at developing a feasible and convenient method for measuring the in-situ tie forces, and using that technique, to experimentally determine the distribution of tie forces in a veneer wall system and thus assess whether the current Australian code design method is appropriate.

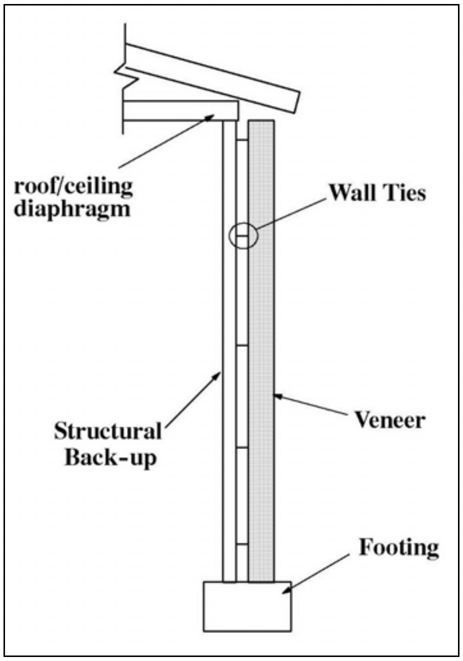

Figure 1: Typical Australian veneer construction

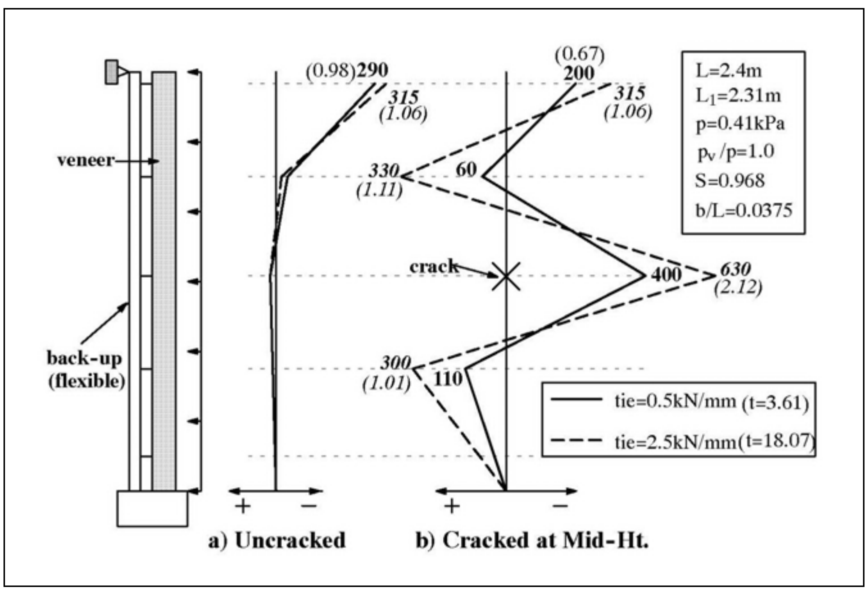

Figure 2: Tie force distribution for veneer walls [3]

EVALUATION OF TIE CHARACTERISTICS

The Australian standard tie calibration test was adapted for the purpose of assessing the in-situ wall tie characteristics. The testing arrangement is shown in Figure 3. The masonry for the couplets and the later veneer wall tests was constructed from typical extruded clay bricks and a 1:1:6 mortar (brick dimensions 230 mm long x 110 mm thick x 76 mm high). A commonly used steel strip tie was used. The veneer back-up was typical Radiata pine stud walling (75mm x 50 mm studs at 600 mm centres). As required by the Standard, the couplet specimens were constructed in the normal horizontal configuration with a 50 mm cavity with the tie located symmetrically in the bed joint mortar and screwed to the timber stud. After curing for 7 days the specimen was rotated into a vertical position and clamped in the Instron testing machine as shown in Figure 3. A compressive load was then induced through a constant displacement of the machine cross head. Both cross head displacement and displacement across the cavity were recorded. Ten couplets were tested in this manner. The resulting load – cavity displacement curves are shown in Figure 4. It can be seen that there is some inherent variability (due to local timber crushing adjacent to the fastener, possible movement in the mortar joint etc), but the trend is clear. It is therefore reasonable to adopt a mean curve in the experiments that follow.

Figure 3: Tie calibration tests.

VERIFICATION OF TIE PERFORMANCE

The most effective way of observing the contribution of the wall ties in both cavity and veneer walling systems is to test a full scale walling specimen. The mean calibration curve (Figure 4) can then be used to calculate the in-situ tie force in each tie from the cavity displacement measured as the lateral load in the wall is increased. This was attempted in an initial set of tests on a cavity walling system, but some problems were encountered in monitoring the individual forces in the wire cavity ties [5]. It was therefore decided to investigate a veneer walling system using a similar approach, but where easier access to the wall ties was possible. The key factor in tests of this nature is a reliable and representative method of monitoring individual tie forces under both initial loading conditions and in the non-linear range for the more heavily loaded ties when force redistribution will occur.

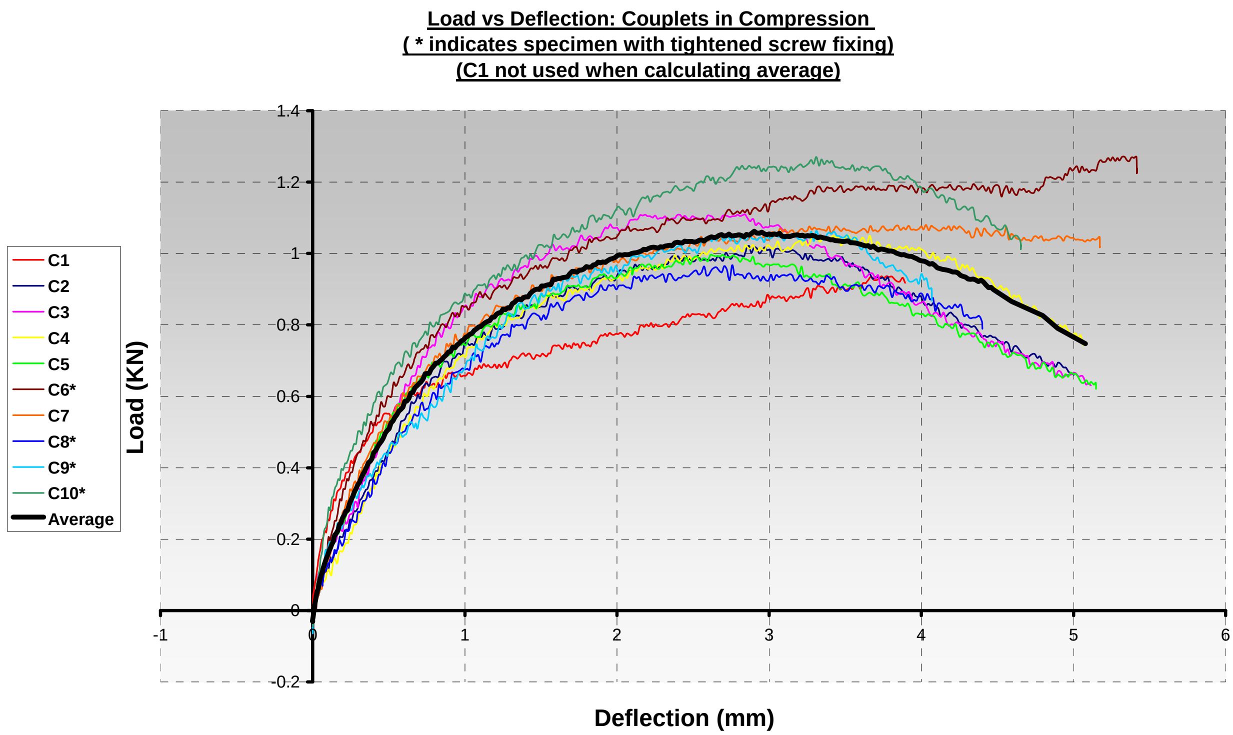

Figure 4: Load-cavity displacement curves for veneer couplets.

Preliminary veneer wall test

A preliminary test, similar in nature to that previously reported for a cavity wall [5] was initially performed to assess the proposed method of tie force measurement. The testing arrangement is shown in Figures 5 and 6. The back up frame was constructed from two, 75 mm x 50 mm studs, top and bottom plates and noggings. The studs were at 600mm centres to reflect common practice. For ease of access, no plasterboard was attached to the stud system. The masonry veneer (110 mm thick x 1200 mm wide x 2400 mm high) was constructed from the same extruded clay bricks and 1:1:6 mortar as used for the couplet tests. During construction stainless steel strip ties were installed in two vertical rows 600mm apart located symmetrically about the centre of the wall and in line with the studs of the timber back up frame. The ties were located every seventh course and screw fixed to the studs. The relative movement between the veneer and the wall studs at each tie location was then monitored during the test by a potentiometer mounted at each tie location.

As shown in Figure 6, a static lateral load was applied to the outer leaf of the masonry through an air bag system, with the top of the veneer leaf unsupported (as is typical for the outer leaf of veneer construction). The inner stud wall was supported top and bottom by stiff reaction beams extending across the wall. The loading frame was a closed system with tension rods connecting the air bag system to the inner leaf supporting beams. The force in each rod was monitored by load cells mounted on each rod. This allowed the equilibrium of the overall (closed) system to be checked and thus confirm the accuracy of the air bag loading as the test progressed. As can be seen in Figure 5, the top reaction beam was suspended from above to allow the beam support to rotate in plan and thus self-align parallel to the wall.

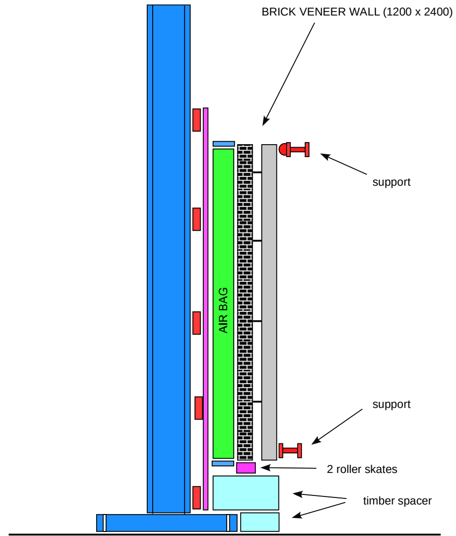

Figure 5: Test of veneer wall **Figure 6: Veneer wall test – schematic**

It should be noted that the testing arrangement did not directly simulate an actual veneer wall since all of the lateral load was applied to the outer leaf. The nature of the base support of the loaded leaf was also not typical. As previously discussed, this preliminary test was aimed at developing a valid procedure for monitoring in-situ tie forces rather than simulating a real wall.

One of the undesirable features of the test was the need to include the unknown frictional forces at the base of the wall in any overall equilibrium check to compare the applied load to the sum of the measured tie forces. To minimise this effect, two "skates" (two dimensional roller bearings) were located at the base of the masonry veneer, but it must be assumed that some friction was still present. During the test, the air bag pressure was progressively increased at a slow rate and the cavity displacements at each tie location continuously monitored. Overall wall displacements, air bag pressure, forces in the support tie rods and any movements of the supports were also continuously observed.

Although the observed tie force distribution was similar in form to that predicted analytically [3], there was still a significant discrepancy in the overall equilibrium check for the test (equating the sum of the observed tie forces and assumed base friction to the applied air bag force). A problem was also encountered with the rig itself, when excessive movement at the base of the wall resulted in contact between the plate supporting the "skates" and the veneer frame, thus significantly changing the boundary conditions.

Because of these problems, prior to repeating the test, an alternative method was sought to verify the method of tie force measurement and the ability of the ties to undergo force redistribution. This is described below.

Simplified wall tie test

Because of the difficulties encountered in the full scale tests in verifying the method of the in-situ measurement of tie forces, an alternative test was devised to allow the assessment of the proposed in-situ measuring method. The key aspects of wall tie performance which had to be reflected were the confirmation of the method of measuring the forces in individual ties using the wall tie calibration curve, and the ability of the measuring technique to reproduce the tie force redistribution which occurs once the heavily loaded ties reach their capacity. This was achieved using a testing rig which consisted of a single horizontal timber stud supported by three ties screwed to the side of the stud and embedded in three brick couplets in a manner similar to that in an actual wall. A load cell was located beneath each supporting couplet to directly measure each tie force which could then be compared directly to the load obtained from the measured cavity displacement at each tie location using the mean tie calibration curve from Figure 4. To prevent lateral twisting or longitudinal instability of the stud supported on the relatively flexible ties, the stud was restrained laterally and longitudinally with appropriately pinned timber members as shown in Figure 7. Cavity displacements at each tie location were measured by potentiometers located each side of the stud with the readings averaged to allow for any stud twisting. As shown in Figure 7, the load was applied through a loading tree and two loading points located symmetrically on the specimen.

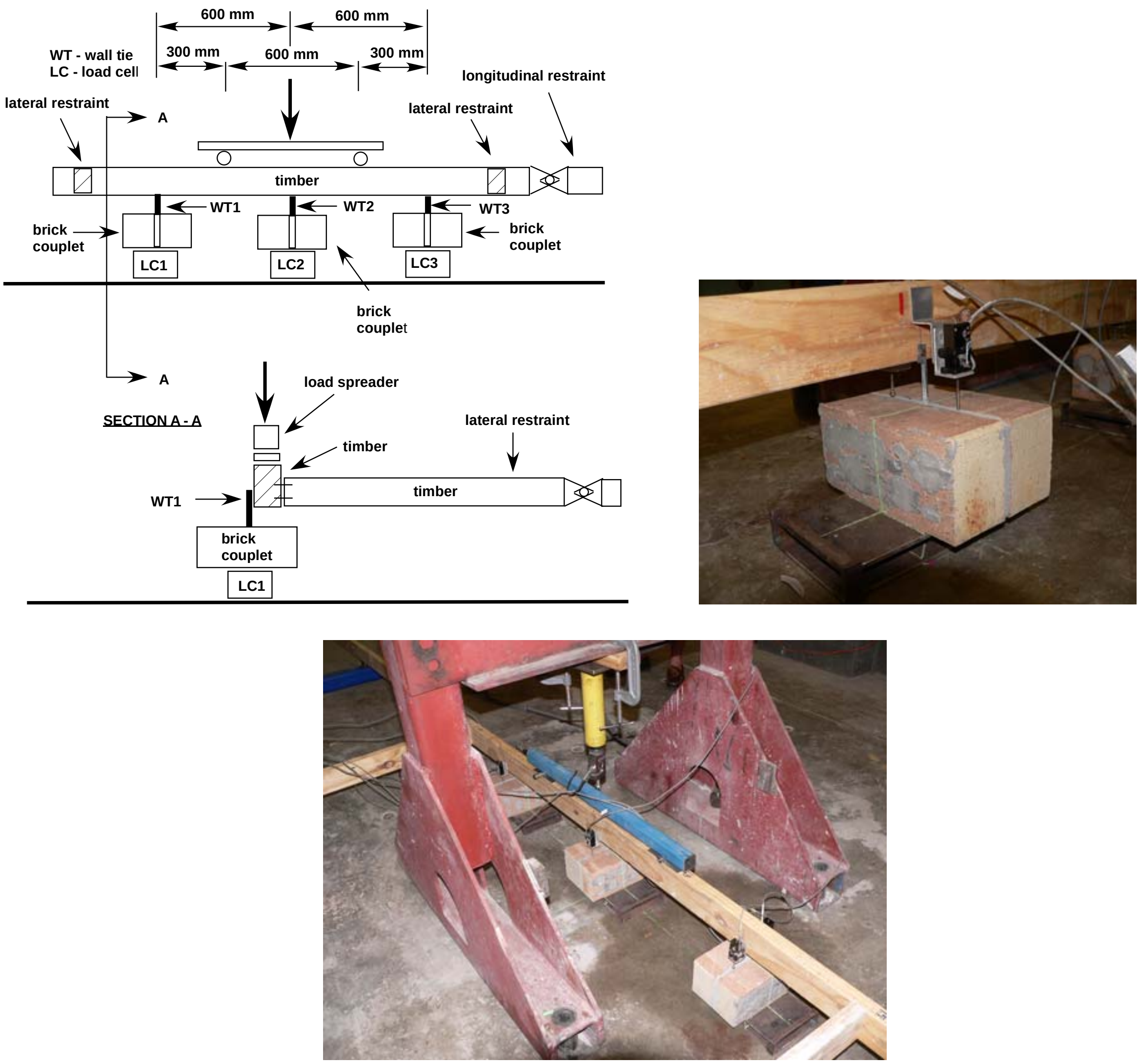

Figure 7: Simplified wall tie test

The load was applied slowly, with the tie displacements and corresponding load cell forces being continuously monitored. Even though the load was applied symmetrically, due to its location, the load in Tie 2 was expected to be greater. Due to the inherent variability of the tie properties, it was also reasonable to expect some non-uniformity of tie force distribution to be observed. This was the case, with Tie 2 being the most heavily loaded and the first to exhibit a buckling failure (see Figure 8). Shortly after, this was followed by the buckling of Tie 3.

Figure 8: Tie buckling at positions 2 & 3

The loading history of the three ties is given in Figure 9 which shows the variation in measured force in each tie (via the load cells) against time. It can be seen that the most heavily loaded tie WT2 (LC2) fails first, followed very quickly by WT3. Tie WT1 did not fail but unloaded due to the non-uniform deflection of the timber stud. When the load was again increased, WT1 resisted a greater force than WT3 as expected. Some post buckling capacity still remains, indicating that there would be the potential for redistribution and load sharing in a real wall with a large number of ties. A clearer picture of the force redistribution could be obtained if the test was performed under controlled displacement, and this will be incorporated in future tests.

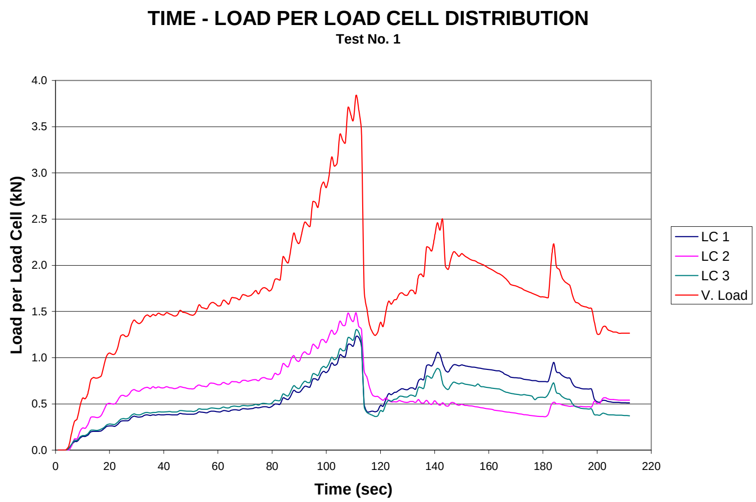

Figure 9: Loading history for the ties (as recorded by load cells)

The effectiveness of the method of tie force measurement can be assessed by comparing the tie force measured directly from each load cell to the force in each tie derived from the measured cavity displacement and the mean tie calibration curve from Figure 4. These comparisons are shown in Figures 10 to 12.

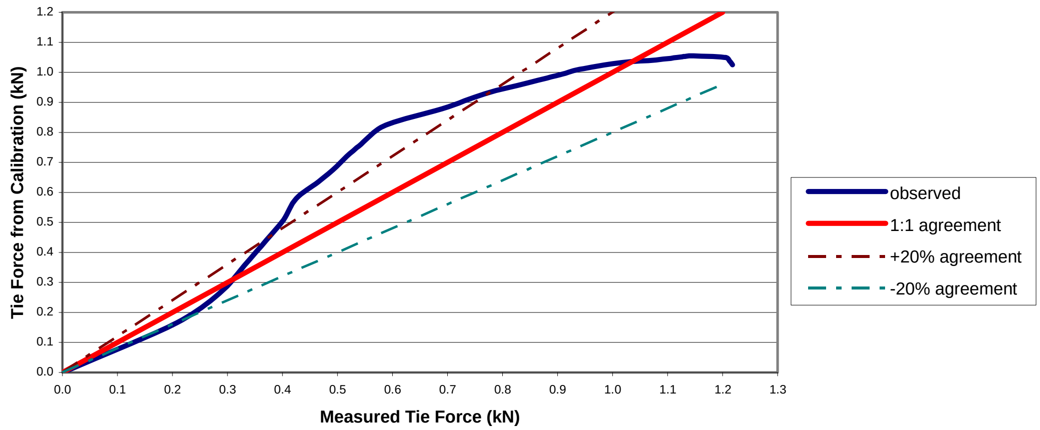

Figure 10: Measured vs calibration tie force – Tie 1

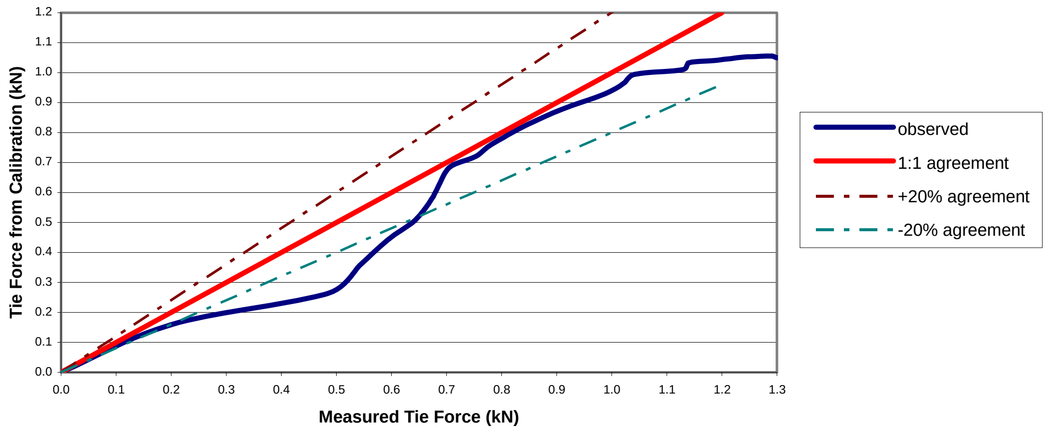

Figure 11: Measured vs calibration tie force – Tie 2

It can be seen that in all three cases, the correct general trends were obtained. Some inherent variability must be expected due to the nature of the tie connection, as well as the effects of averaging the tie calibration curves. Variability will be the result of factors such as possible local timber crushing adjacent to the fastener, movement of the tie in the mortar joint, variability in the stiffness of the tie itself, and possible effects of stud twisting on the measured cavity displacement. All of these effects will have an influence on the inelastic behaviour of the ties. Further tests are proposed with extra restraint to prevent possible stud twist, as well as the use of displacement control to slow down the failure mechanism and allow a more detailed study of the force redistribution mechanisms. Certainly the results are encouraging enough to continue refining the technique to eventually allow the testing of full veneer wall systems and the potential refinement of the tie design method used in the Australian Masonry Code.

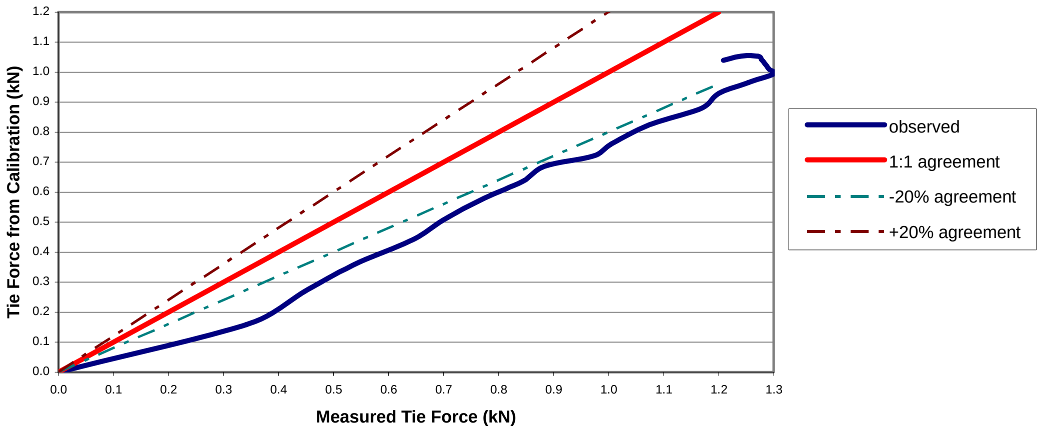

Figure 12: Measured vs calibration force – Tie 3

CONCLUSION

This paper has described part of an on-going investigation into the behaviour and design of veneer wall systems. Initial attempts at a full scale veneer wall test in which individual tie forces were measured were unsuccessful. A simplified verification test for the proposed method of tie force measurement was therefore developed. Some problems were encountered in the first of these tests, but the results are encouraging enough to refine the method in subsequent tests with a view to reducing the variability of results. Once refined, the method will be used in conjunction with full scale wall tests to more accurately define the behaviour of veneer wall systems, particularly with regard to the nature of the tie force distribution.

ACKNOWLEDGEMENTS

The assistance of the Civil Engineering staff in the School of Engineering and the financial support of the Masonry Research Group by Think Brick Australia is gratefully acknowledged.

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