IN-PLANE STIFFNESS AND STRENGTH OF ADJUSTABLE WALL TIES

C.R. Williams[1] and A.A. Hamid[2,3]

[1]Graduate Student, Dept of Civil, Architectural & Environmental Engineering, Drexel University, 3141 Chestnut Street, Philadelphia, PA, 19104, crw22@drexel.edu

[2]Professor, Dept of Civil, Architectural & Environmental Engineering, Drexel University, 3141 Chestnut Street, Philadelphia, PA, 19104, hamidaa@drexel.edu

[3]Adjunct Professor, Department of Civil Engineering, McMaster University, JHE-301, 1280 Main Street W., Hamilton, ON, L8S 4L7, hamida@mcmaster.ca

ABSTRACT

In current construction practice, when a masonry veneer is installed on the face of a building, the veneer is tied to the main structural support of the building by the use of mechanical ties. Today's masonry veneers are not designed to act as an in-plane lateral load resisting element of the overall structure. Although this is how the veneers are designed, many mechanical ties actually do transfer in-plane lateral load between the structure and the veneer. For this reason, building codes dictate either to isolate the veneer or to reinforce it to ensure its steadfastness in a lateral event. Reinforcing the veneer has made the design option of using brick veneer in high seismic areas very unpopular. To better study the transfer of loads between a structural element and a veneer, the stiffness and strength properties of the tie linking the two must be known. This paper will show the development and practical usage of a testing method to measure the in-plane lateral stiffness of a brick tie. A custom testing apparatus has been designed and constructed to allow for testing the ties as they would perform in-situ, that is embedded into mortar joints in a concrete block back-up wall on one end and a brick veneer on the other. Three different types of adjustable wall ties were used in the test program. Load-displacement curves will be presented to provide needed data for analytical modeling of cavity block-brick veneer walls under in-plane lateral loading.

KEYWORDS: adjustable wall ties, brick veneer, cavity walls, tie stiffness, tie strength

INTRODUCTION

This paper represents a portion of a research exercise into the seismic performance of brick veneer. The brick veneer, for purposes of this research, is taken to be a non-load bearing barrier between the structural components of a building and the environment. It is assumed that the veneer does not contribute to the structural support offered by the main load resisting system, and is acted upon by environmental effects and its own self weight [1]. Environmental effects include lateral events such as wind and seismic loading, as well as any forces caused by the effects of water and heat. The overall research program encompasses in-plane seismic loading of brick veneer walls and load transfer from the veneer, through the tie, to the lateral force resisting system (LFRS). In this case, that LFRS is a concrete masonry shear wall. This paper presents

the in-plane stiffness and strength of adjustable ties. Knowing the specific performance characteristics of the tie is crucial in accurately designing a wall utilizing that tie. It is to be noted that currently in the United States the performance criteria of wall ties are not a factor in veneer wall design [2]. In Canada [3], and many other countries, wall design is based on the characteristics of the actual tie used, resulting in a more efficient and economical wall design.

TIE PROPERTIES
Wall ties transfer a portion of the load imparted on them by the back-up to the veneer. The stiffness of the tie determines the amount of lateral load imparted on the veneer by the back-up wall during a lateral event. Three ties were used for this test program:
- Tie T1: Tie which allows vertical movement between the veneer and the back-up wall (Figure 1.a). An example is the eye & pintle tie [4].
- Tie T2: Tie which allows for both vertical and horizontal in-plane movement of the veneer and the (Figure 1.b). For examples, see references 5 and 6.
- Tie T3: Tie which allows for only horizontal in-plane movement of the veneer (Figure 1.c). For an example, see reference 7.

Because of the very low stiffness of tie T1 in the horizontal direction, low-level horizontal forces will be developed in the veneer. Depending on the level of displacement, the adjustable ties T2 and T3 become engaged. Once engaged, the initial stiffness of the tie dictates the amount of horizontal load transfer and the level of stress on the veneer. Knowing these values, one can use the allowable stress in the veneer to determine the maximum allowable inter-story drift of the back-up wall below which the veneer will not be over-stressed. This is important for performance-based design.
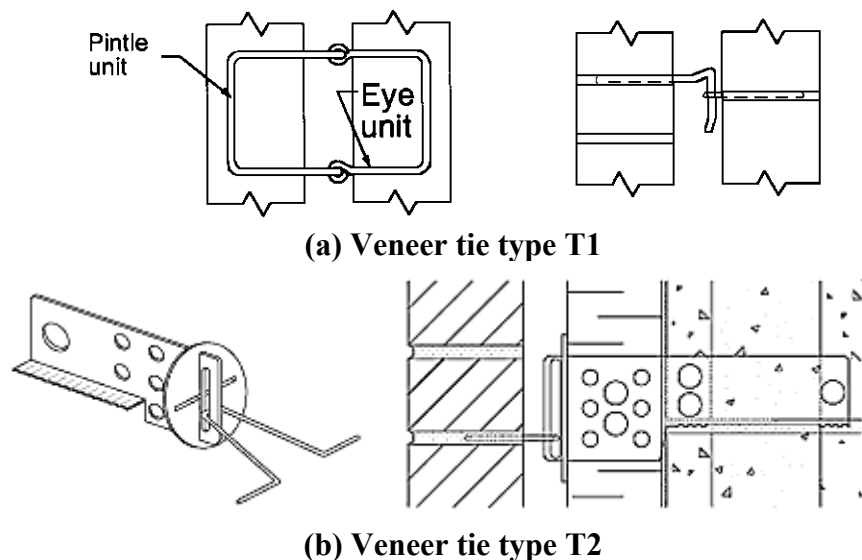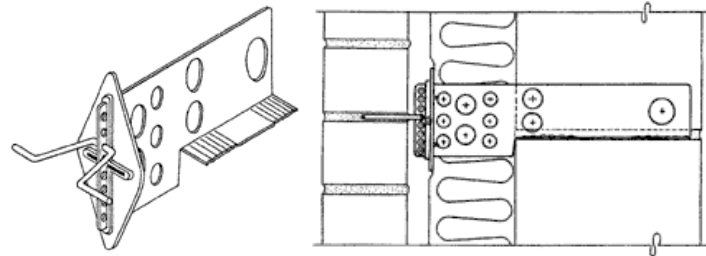

(a) Veneer tie type T1

(b) Veneer tie type T2

**Figure 1 – Ties Used In This Research Program**

(c) Veneer tie type T3

Figure 1 (continued) – Ties Used In This Research Program
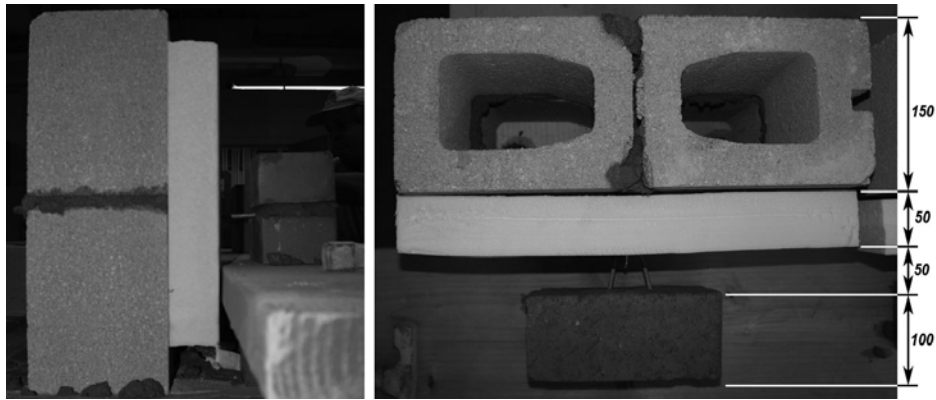
SPECIMEN DESIGN
The performance value needed from each of the ties is its in-plane lateral stiffness. The individual brick tie is not as simple to test as the units from the two wythes of masonry are. Because that the ties are a combination of two separate components (the plate and the v-shaped wire) along with that each of the two components is embedded into a mortar joint of their respective wythe of masonry, the testing of the tie alone is not indicative of its performance in-situ. To achieve performance levels comparable to those in the field, it was determined that the ties must be tested with all components interacting as they ultimately do. This meant that the plate must be embedded into a mortar head joint between concrete blocks, the extended portion of the plate must be surrounded by 50 mm (2 in) (for these particular ties) of rigid insulation within the cavity and that the wire must be embedded into the bed joint of clay brick masonry. Conducting a test in the proper manner, with all of these conditions met, meant designing not only the specimen, but also the apparatus to properly test that specimen.

Since these specimens include multiple concrete blocks and clay bricks, size and weight became a consideration for ease of handling. The minimum amount of masonry necessary for an accurate representation of the in-situ condition is two concrete blocks (one full and two half blocks) and two clay bricks. To minimize both weight and the overall thickness of the specimen, 150 mm (6 in) block was used for our mock back-up. Figure 2.a shows a design sketch of the test specimen and Figure 2.b for photographs of a constructed specimen.
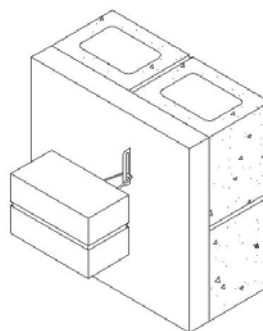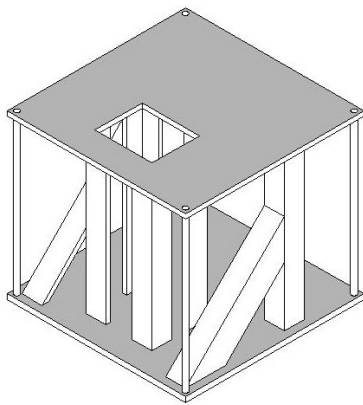

(a) Design sketch of test specimen (tie T2 shown)
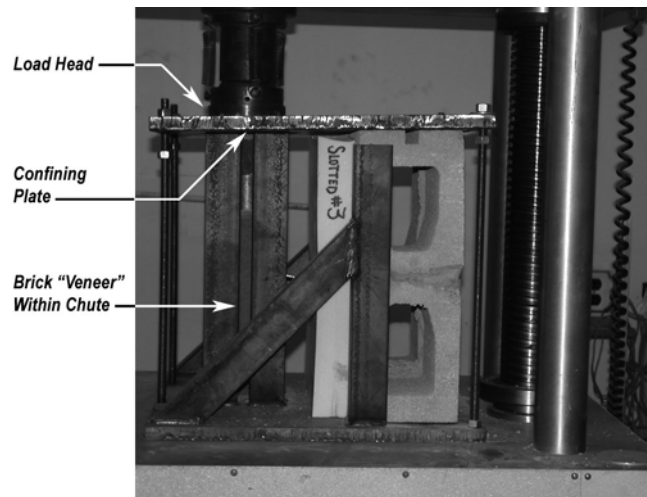**Figure 2 – Test Specimen**

(b) Side view and top view of test specimen
Figure 2 (continued) – Test specimen

Once the specimen design was complete, a custom apparatus for restraining the specimen during testing was designed and constructed. A major consideration in designing the testing frame was the choice of a method in which the specimens were to be tested, measured and observed. The availability of a new, computer-controlled, screw-drive Tinius-Olsen compression/tension testing machine provided the ability to easily and accurately apply a load, while simultaneously recording displacement. Since the movement to be measured is the differential displacement (and corresponding load) between the back-up and the veneer, one wythe of masonry must be acted upon by a measurable force, while the other wythe is restrained from moving. Due to the size and weight of the back-up portion of the specimen, it was determined that restraining the back-up and loading the much smaller and lighter veneer portion of the specimen would be most appropriate. A custom testing frame was then designed that restrained all movement of the 150 mm (6 in) CMU (mock back-up), while allowing movement of the mock veneer.

(a) – Design sketch of testing apparatus   **(b) – Test specimen under load**

Figure 3 – Test setup

A problem arose in that the two-brick mock veneer swings in all directions on the wire through the steel plate of ties T2 and T3. To limit motion of the bricks to a linear, unidirectional, in-plane motion, a vertical chute was formed with four lengths of steel angle. These angles were fixed to a steel base plate. That base plate, along with a top plate, was used to confine the specimen and restrict any movement of the mock back-up. Finally, to allow for load application to the end face of the bricks, a hole was cut in the top plate that allowed access to the inside of the chute.

It is to be noted that the test specimen does not allow for the beneficial effect of higher bond due to compression from the self-weight of the veneer above. This may have some effect on tie performance.

TESTING AND INSTRUMENTATION

After all of the planning, design and construction, everything was in place for testing to commence. Each specimen was turned on its side so that the lateral, in-plane desired motion of the mock veneer was moving in a vertical path. The rotated specimen was then lowered on to the base plate of the frame, with the bricks inside of the chute. The top plate was placed and lowered until it rested on the concrete block mock back-up. Tie rods allowed clamping of the top plate that securely held the back up in place during testing. The entire frame apparatus was placed on the table of Tinius-Olsen testing machine and aligned so that the load head on the Tinius-Olsen machine was centered over the opening in the top plate. A short steel column was placed in the chute, resting on the end of the two-brick mock veneer. This rigid member was used to transfer the load from the load head on the machine, to the specimen within the chute. The load head was lowered until making contact with the column and all displacements and loading readings were zeroed in the recording software. Load was applied at a rate of 5mm/min (0.2 in/min) while time, load and displacement were recorded at a rate of 200 times per minute.

TEST RESULTS

Tie T1, specimen one, failed at first application of the load. The eye portion of the two-part tie was not embedded sufficiently into the bed joint between the concrete blocks, and dislodged from the mortar bed joint almost instantaneously. No reading of load was recorded.

The second T1 specimen was only slightly more useful. Again, the mortar bond to the wire eye was insufficient and the wire shifted upon initial loading. The wire did not break free, and the loading caused the wire to bend gradually as load was applied. The graph (Figure 4) shows that although there was no initial stiffness, the load did increase to 0.38 kN (86 lb) at a displacement of 21.8 mm (0.9 in) before the wire completely dislodged from the mortar.

The third T1 specimen was the first that performed as anticipated and gave an accurate value of the stiffness of the two-piece wire system. Upon application of the load, the tie exhibited an initial stiffness of 0.144 kN/mm (819.8 lb/in) up to 0.57 kN (127.4 lb). Upon reaching this point, the wire began to bend and the load temporarily dropped. Once load carrying capacity was restored, the load climbed to the range of 0.71 kN (160 lb) where it fluctuated in the ±0.09 kN (20 lb) range until 0.72 kN (162.8 lb) at 26.4 mm (1.0 in) of deflection when the wire broke free of the mortar and slipped.

The fourth and final T1 specimen, like the three previous, exhibited a completely unique performance under the loading. While the wire eye remained embedded in the mortar upon initial application of the load, there was much less resistance to the load than exhibited in Specimen #3. Specimen #4 performed with an initial stiffness of 0.229 kN/mm (1320 lb/in) up to 0.22 kN (49.9 lb). As you can see in Figure 4, this is a higher value of stiffness than was exhibited by Specimen #3, but the wire legs of the tie began to bend and the stiffness broke at only 40% of the load of Specimen #3. The wire continued to bend under loading up to 0.45 kN (100.9 lb) at which point the wire became dislodged from the mortar and slipped. From then on, the load increased gradually to approximately 0.58 kN (130 lb) where the load caused constant displacement with no additional load capacity.
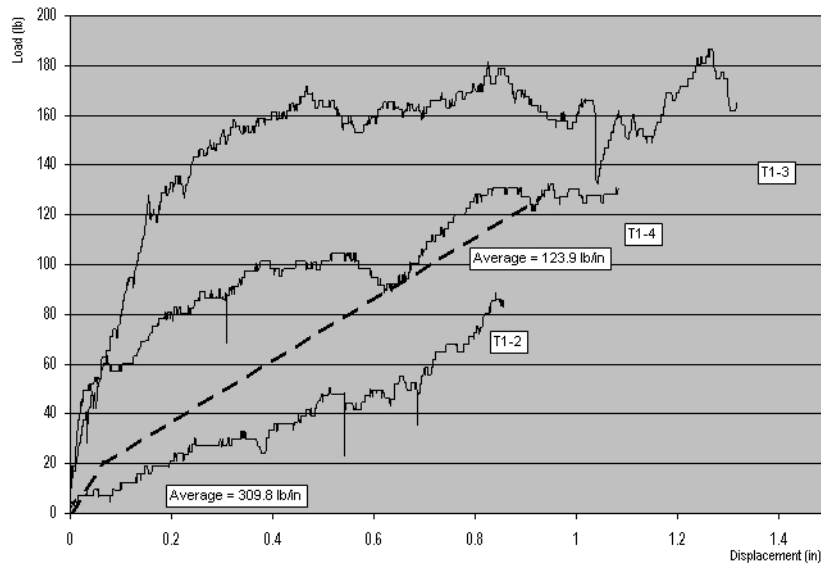

Figure 4 - Load-Displacement curve for T1 ties

While not all ties performed the same under the identical loading conditions, all the values recorded will still be used. Figure 4 shows the load-displacement curves for the T1 specimens. The biggest variable seemed to be the bond strength of the eye portion of the tie in the mortar bed joint of the back-up wall. While quality assurance/quality control can help to minimize these types of problems in the real world, they cannot be eliminated, and thus, the results of the tests in which the bond failed will be included in the calculations to determine the average stiffness of the T1 ties. That average, composed of Specimens #2, #3 and #4, was found to be 0.05 kN/mm (309.8 lb/in).

Testing of the five specimens constructed utilizing tie T2 were the first exploration into a tie specifically designed with in-plane lateral load conditions in mind. Before testing, it was expected that the initial stiffness would be much greater than the wire T1 ties as well as having a much higher load capacity before failure.

Upon initial loading, the specimen performed just as expected. The initial stiffness was linear up to a load of 1.25 kN (280 lb) with a displacement of 7.9 mm (0.31 in). When the initial break in linearity was reached, the loading continued to approximately 1.38 kN (310 lb) when the first

sign of distress appeared. The mortar in the bed joint between the two bricks began to show signs of bond breakage. The "V"-shaped wire portion of the tie was rotating about its flat base in the slot in the block shear connector. That rotation was too much for the mortar bed joint between the brick, and the mortar was sheared off from between the two bricks. Immediately, concern was raised as to the remainder of the specimens. One aspect of the test design that is not similar to the in-situ application of these ties is the inherent compressive stress at the bed joint of the brick veneer due to the self-weight of the brick.

Slotted Specimen #2 performed considerably different right from the initial application of the load. Rather than displaying a high initial stiffness and then a drastic drop in stiffness due to deformation of the connector plate, this specimen began to deform quite early on. The deformation came in the form of the slot in the plate being pulled apart (Figure 6a). The outermost portion of the plate (outside of the slot) is only connected to the rest of the plate at the top and bottom, leaving the length of the slot, where the wire applied load to the plate, unsupported. The V-shaped wire twisted the outer portion of the plate and once the two were in full contact, the moving bricks continued to deform the connector plate. The slot widened slightly and the bricks moved so far that the wire was actually pulling the tie away from its place in the head joint of the concrete blocks (out-of-plane loading). While not testing the plate in pure bending, this was the second consecutive test that proved correct the decision to test the ties in a small mock wall specimen due to the complex interactions of all of the individual components.

Specimen #3 performed very similarly to Specimen #2. Although displaying a relatively high initial stiffness of 0.17 kN/mm (997 lb/in) up to a load of 0.88 kN (197 lb), the same deformation of the connector plate occurred and the load resistance dropped drastically. It is interesting to note that Specimens #2 and #3 were acting in the same manner under load and their load-displacement curves are nearly identical at each change in stiffness. The only real difference in performance between the two is the initial stiffness mentioned previously.

Specimen #4 performed in a manner similar to Specimen #1 in that it did not fail early in the test like the previous two specimens. Actually, the load-displacement curve for Specimen #4 matches up perfectly with that of Specimen #1 up to the point where its mortar failed. Specimen #4 did not fail and continued to provide load resistance to a load of over 2.67 kN (600 lb). The specimen, however, did display a significant ductile behavior in its displacement from 20.8 mm (0.8 in) to 31.9 mm (1.26 in) with an increase in load capacity of only 0.2 kN (45 lb) over that displacement.

Specimen #5 performed very similar to Specimens #1 and #4 in the initial stages of the testing procedure. Those three specimens' plots grouped extremely well to give an apparent accurate stiffness of the ties. When the 1.33 kN (300 lb) value was reached, however, Specimen #5 the stiffness did not break like #1 and #4, but rather continued up to a load of 3.52 kN (791 lb) before a drop in stiffness was observed. This value is significantly higher than any of the other specimens. The apparent cause for this unique behavior can possibly be attributed to a manufacturing characteristic of the system. The wire V-tie portion of the tie appears to be formed by use of a large press utilizing a shaped die. That die, on some wires, deformed the circular cross-section of the wire, leaving a flat spot in the inner portion of the radius at each end of the flat at the bottom of the "V". In this test, that flat spot hooked itself on to the slot in the

connector plate. Upon loading the brick, rather than transferring an in-plane lateral load to the plate, the forces acted more like an out-of-plan lateral load, pulling the plate away from the blocks it was installed between.
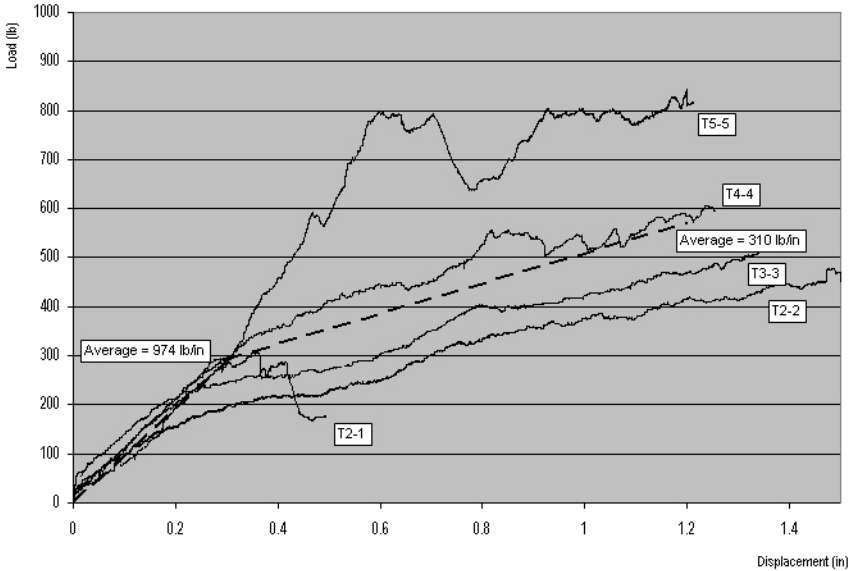

Figure 5 - Load-Displacement curve for T2 ties

| (a) T2 tie after testing | (b) T3 tie after testing (rigid insulation removed for clarity) |

Figure 6 – Tie failure modes

The testing of the T3 tie constructed specimens was expected to return results with the highest stiffness and load capacity of the three types of specimens. In these ties, the wire "V" is confined to a punched hole in the connector plate, which restrains the wire from rotating laterally. Additionally, the steel between the individual holes acts as bridging and provides support, restraining the outer edge of the plate from deflecting as the slotted tie did. Since that deformation was the point of failure for the T2 ties, the support added to the T3 tie connector would expectedly increase the stiffness.

Specimen #1 behaved in a manner exhibiting high stiffness of the connector plate, as compared to that of the slotted tie. Upon initial application of the load, the stiff tie immediately began resisting the increasing load. For the most part, the load increased to 2.38 kN (535 lb) with a stiffness of 0.25 kN/mm (1421 lb/in) before the first drop, which was due to minor slippage. The high stiffness can be attributed to the fact that a portion of the load was being applied torsionally to the steel plate due to the fact that the "V" could not rotate. This torque on the outside portion of the steel plate was not great enough to bend the plate, so the plate's ability to resist the applied load was large. Additional slippage of the wire tie within the connector plate took place at various points in the testing, but all were only limited. Finally, at a load of 3.41 kN (766 lb), the plate began to yield under the applied moment. The plate bent about its support point at the face of the concrete block, and the loaded end slowly began deflecting. The load continued to increase throughout this deflection up to a value of 3.69 kN (829 lb), when the load finally dropped and the plate began to bend significantly.
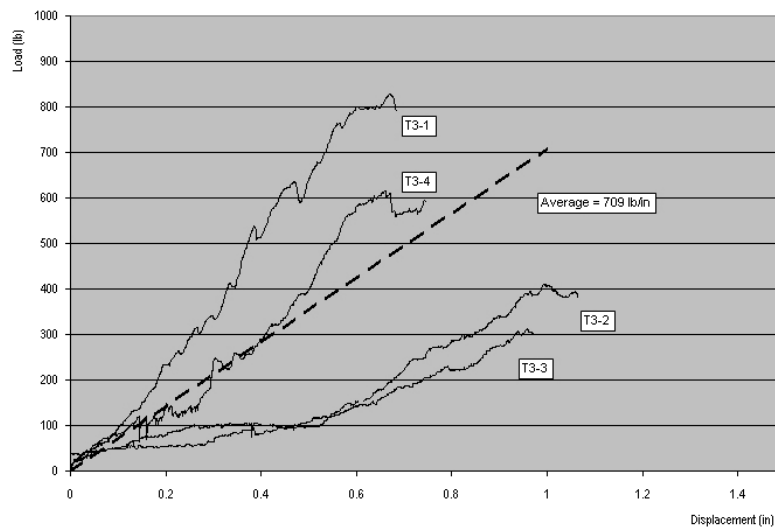

Figure 7 - Load-Displacement curve for T3 ties

The second and third T3 specimens performed very similarly to each other. In both tests, the wire "V" did not bind within the hole in the plate. Since the wire rotated within the hole the load that the wire transferred from the brick to the plate was applied as a vertical point load on the edge of the plate, as opposed to an applied moment as observed in Specimen #1. The plate began to deflect almost immediately upon application of the load. The load-displacement curves for these two tests both show the low stiffness characteristic of a soft, ductile material. A similar characteristic of both curves is an increase in stiffness beyond the range of 12.7 mm (0.5 in). Specimen #3 reached a maximum load capacity of 1.36 kN (306 lb), while Specimen #2 reached a maximum of 1.82 kN (410 lb), and while the load capacity was 33% higher in #3 than it was in #2, the displacement corresponding to that load value was only 0.9 mm (0.04 in) different.

The final T4 specimen was tested without the two inches of rigid foam insulation in place around the extended plate of the tie. Observing the graph, one can see that while the load values were not as smooth under the constant displacement, the stiffness was almost exactly the average of all four of the specimens. Up until a displacement of 12.7 mm (0.5 in), the normalized stiffness of Specimen #4 and the trend line for the average of all specimens is almost collinear. Beyond 13.0

mm (0.5 in), however, the stiffness quickly increased and the load reached a maximum value of 2.74 kN (615 lb). Upon reaching this load capacity, the plate began to deflect quite quickly, and the load dropped accordingly (Figure 6b). The test was terminated as the tie was exhibiting a zero stiffness, continuously deflecting with no change in load capacity.

CONCLUSION

The most useful results can be found by comparing the stiffness of the three ties tested in the serviceability limit state within the initial, linear-elastic response. Tie T1 exhibited an initial stiffness of 0.05 kN/mm (309.8 lb/in), 0.17 kN/mm (974 lb/in) for tie T2 and 0.12 kN/mm (709 lb/in) for tie T3. Test results presented herein clearly demonstrate that T1 ties have a very low stiffness, and therefore, transfer a very minimal amount of load between the wythes of masonry, even at high tie displacements. Conversely, the high stiffness exhibited by ties T2 and T3 show a higher load transfer upon engagement of the adjustable "V" tie.

REFERENCES

1. Drysdale, R. G., Hamid, A. A., and Baker, L. R., "Masonry Structures – Behavior and Design," Second Edition, *The Masonry Society*, Boulder, CO, 1999.
2. The Masonry Standards Joint Committee, "Building Code Requirements for Masonry Structures," ACI 530/ASCE 5/ TMS 402, American Society of Civil Engineers, and The Masonry Society, Detroit, New York, and Boulder, 2002.
3. Canadian Standards Association. "Connectors for Masonry" CSA-A370-94, CSA, Rexdale, Ontario, February 1994.
4. #262 Double Eye Rod Anchor/#263 Double Anchor Tie (Pintle). Heckmann Building Products Inc, 30 April 2005. <http://www.heckmannbuildingprods.com/262-263.htm>.
5. Adjustable Anchor and Tie System for Cavity Wall Construction BL-507. BLOK-LOK Limited, 30 April 2005. <http://www.blok-lok.com/pdf/BL-507.pdf>.
6. Slotted Block Tie (Type I). FERO Corporation, 26 September 2004. <http://www.ferocorp.com/pages/sbt1.html>.
7. Bock Shear Connector. FERO Corporation, 26 September 2004 <http://www.ferocorp.com/pages/bsconn.html>.