**EXPERIMENTAL EVALUATION OF BRICK-TIE-WOOD SUBASSEMBLIES**

Young-Hwan Choi[1] and James M. LaFave[2]

## ABSTRACT

Typical residential and light commercial brick veneer construction in the central U.S. has been characterized with respect to the design methods for wall systems and the types of ties used to attach brick veneer to the backup. The focus of this research is on brick veneer attached to wood framing with corrugated sheet metal ties. As the first step towards a performance evaluation of the behavior of brick masonry veneer with wood stud framing under earthquake loads, tests were performed on brick-tie-wood subassemblies. The strength and stiffness of the ties were evaluated by monotonic tension, monotonic compression, and cyclic tension-compression tests for subassemblies consisting of two standard bricks, one wood stud, and one tie. This type of subassembly represents a localized portion of a full height brick veneer wall system, and the tests capture the performance of the entire subassembly rather than the performance of just the tie. Per common construction practice, galvanized nails were used to attach the ties to the studs in most subassemblies; however, a few subassemblies were constructed using wood screws instead.

Typical failure modes were nail pullout from the wood in nail-connected tension tests, tie pullout from the mortar joint in screw-connected tension tests, and buckling of the tie in both nailed and screwed compression tests. For the cyclic tension-compression tests, the general failure modes were tie fracture in nail-connected specimens and bond failure between mortar and brick or pull out of tie in screw-connected specimens. Envelope curves were generated to compare the cyclic test results to the results of monotonic tension and monotonic compression test results.

**Keywords**: brick, tie, veneer, wood stud, subassembly, cyclic, tension, compression.

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1 Graduate Research Assistant, ychoi3@uiuc.edu, Department of Civil and Environmental Engineering, University of Illinois, 205 N. Mathews Avenue, Urbana, IL 61801.

2 Assistant Professor, jlafave@uiuc.edu, Department of Civil and Environmental Engineering, University of Illinois, 205 N. Mathews Avenue, Urbana, IL 61801.

# INTRODUCTION

## Background

Veneer and cavity wall systems have been widely used in many countries due to advantages such as aesthetic appearance, excellent thermal performance, and prevention of water penetration. Such systems are typically composed of an exterior masonry wall, an interior backup system (separated by a cavity), and ties that connect the exterior masonry wall and interior backup system through the cavity. When design details are such that no axial loads are imposed on the exterior wall except self-weight, and the backup wall carries all the lateral loads, the wall is called a veneer wall. On the other hand, when the exterior wall contributes to the load resisting system, the wall is called a cavity wall.

As the exterior wall transfers lateral loads to the backup system through ties, the properties of the ties become essential to the behavior of veneer wall systems. Some primary functions of ties are to provide a connection between the exterior wall and the backup wall, to transfer lateral loads to the backup, and to permit in-plane movement to accommodate differential material movements. For these functions, ties must satisfy some performance requirements such as adequate strength and stiffness in compression and tension to transfer lateral loads, adequate flexibility to accommodate movements, corrosion resistance, and resistance to moisture transfer across the cavity. Some important factors that affect the distribution of tie forces are the stiffness of the backup wall, tie stiffness and layout, two way bending in the backup wall, the support conditions of the backup system and the exterior wall, and the existence of cracking in the exterior wall

It has been pointed out that a major source of damage in modern buildings during the Newcastle Earthquake in 1989 was movement of masonry walls under out-of-plane loading due to inadequate tying (Page 1991). Wall ties were too largely spaced in some cases, and they were also too flexible or pulled out from the bed joints due to inadequate embedment. In spite of the important role of ties, the first hysteresis loop for veneer wall ties was published little more than a decade ago (Allen 1989). Although this situation is being improved, it is still hard to find comprehensive test data for many connectors.

## Typical Ties in Mid-America

There are many tie systems available in practice. They can be categorized as unit ties, joint reinforcement, and adjustable ties depending on their shapes. Rectangular ties, Z ties, and corrugated sheet metal ties are categorized as unit ties. The Brick Industry Association (BIA) suggests appropriate tie systems for particular wall and backup systems (BIA 1988). Only corrugated sheet metal ties are typically used for wood backup systems. The current Masonry Standards Joint Committee (MSJC) Code specifies prescriptive requirements for corrugated sheet metal ties and their use in veneer walls (ACI/ASCE/TMS 1999).

The study reported herein was done as a basis for the evaluation of performance of brick masonry veneer wall systems over wood framing under seismic loads. Consequently, only corrugated sheet metal ties, which are exclusively used for wood frame construction, were studied.

## SUBASSEMBLY TESTS

### General

### Specimen Type and Testing Plan.

Brick masonry veneer walls with wood backup systems typically consist of an exterior brick masonry wall attached to wood studs by a series of corrugated sheet metal ties. To begin to characterize the behavior of the wall system, brick-tie-wood subassemblies were constructed consisting of two standard bricks, one wood stud (2x4), and one corrugated sheet metal tie. The shape of the corrugated sheet metal tie used in this study is shown in Fig. 1. Although there are two holes for nails or screws, only one hole was used in accordance with typical construction practice. The section of a test specimen is illustrated in Fig. 2. As noted in the drawings, the distance from nail to the 90 degree bend position in the tie was set to 13 mm (½ in.) to comply with the current requirements of the MSJC Code. It should be noted that this type of subassembly represents a localized portion of a full height brick masonry veneer wall system, and therefore the tests capture the local performance of the entire brick-tie-wood subassembly rather than the performance of just the tie.

The brick portions of the test specimens were assembled by local masons using Type N mortar (1:1:6). Per common construction practice, galvanized nails were used to attach the ties to the studs in most subassemblies; however, some subassemblies were constructed using wood screws instead. To simulate possible differential wall movement due to temperature and moisture changes, some specimens were given 6 mm (¼ in.) initial displacement in the longitudinal direction of the wood stud (transverse to the tie surface) before applying load. In addition to monotonic tension and monotonic compression, cyclic loads were also applied. Details of the tests are discussed later. Based on the parameters mentioned previously, the specimens are designated as follows:

N S TE
- TE: TEnsion, CO: COmpression or CY: CYclic
- S: Standard (without initial displacement) or O: Offset
- N: Nail or S: Screw

### Test Set Up and Testing Procedure.

A total of 80 specimens were tested. The exact number of specimens according to their types is given in Table 1. All tests were performed at least 28 days after construction. The test set up is illustrated in Fig. 3. It is similar to that used by others (Simundic et al. 1999). High strength gypsum was used on the bottom surface of the bricks contacting the testing machine bed in order to level the surface, therefore avoiding any unwanted application of loads to the mortar joint. In order to grip the wood stud in the upper part of the testing machine, a small amount of pre-compression was applied to the specimen. The pre-compression force was released before collecting data.

The tests were displacement controlled at a rate of 2.5 mm per minute (0.1 in./min.) for the tension and compression tests. The data logging system of the test machine has a capability of measuring overall displacements and loads. In addition, two external LVDTs were attached, one on each side of the wood stud, to measure the tie displacement within the subassembly.

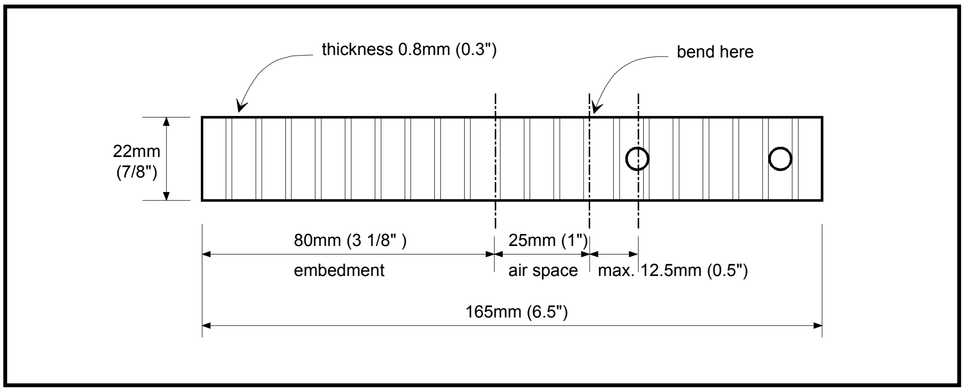


**Figure 1. Corrugated Sheet Metal Tie Used in the Tests**

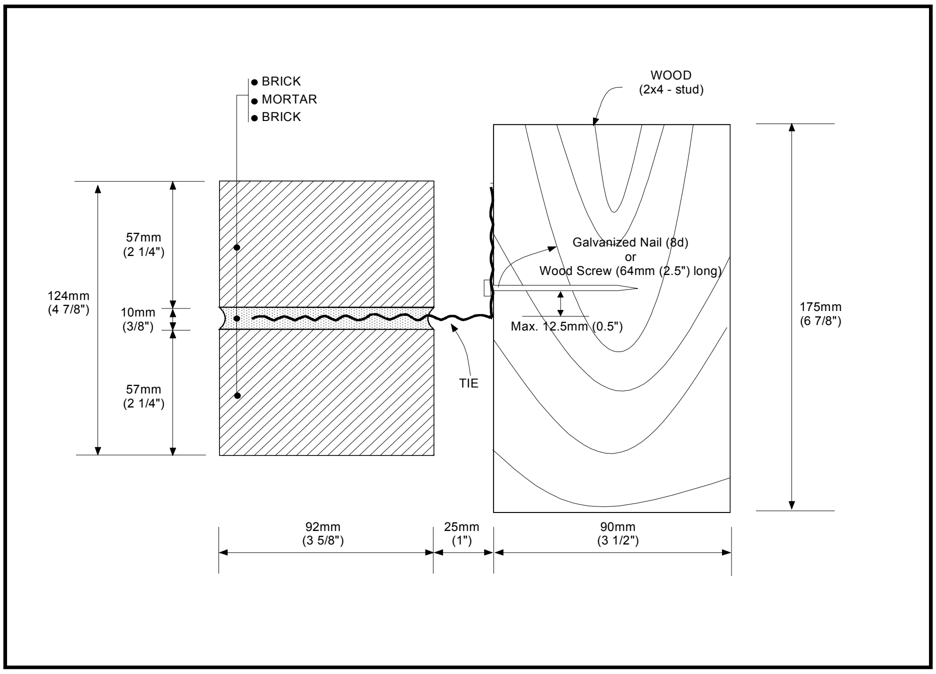


**Figure 2. Section of Test Specimen**

**Table 1. Number of Specimens**

| Standard | | Offset | |
|---|---|---|---|
| NSTE | 20 | NOTE | 3 |
| NSCO | 10 | NOCO | 5 |
| NSCY | 10 | NOCY | 3 |
| | | | |
| SSTE | 10 | SOTE | 3 |
| SSCO | 5 | SOCO | 3 |
| SSCY | 5 | SOCY | 3 |
| | 60 | | 20 |

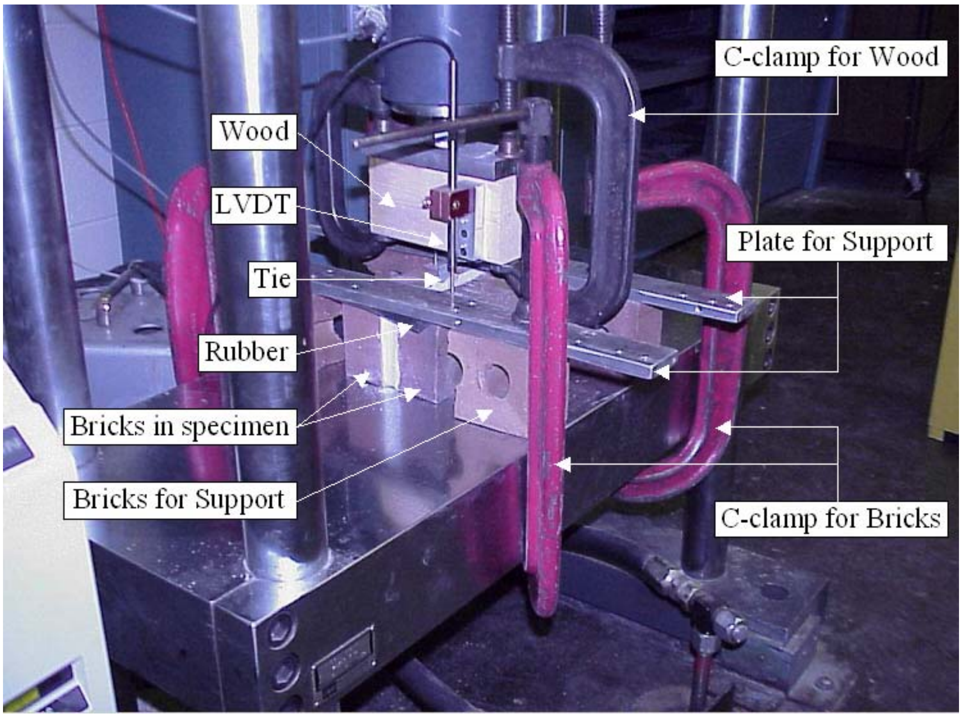


**Figure 3. Test Set Up (Tension Load Test)**

## TEST RESULTS

### Tension Tests.

A total of 36 specimens were tested in tension, 20 of type NSTE, 10 of type SSTE, 3 of type NOTE, and 3 of type SOTE. All type NSTE specimens failed by pullout of the nail from the wood stud. For type SSTE, seven specimens failed by loss of bond strength between mortar and brick, typically resulting in tie pullout or test specimen collapse. Two specimens showed the loss of bond strength between mortar and tie, resulting in a pullout of the tie from the mortar without separation of the masonry units. In one specimen, the screw was pulled out through the tie due to yielding around the tie hole. In each case, type SSTE specimens showed brittle failures (albeit at relatively high loads, as noted below). For type NOTE, two specimens failed by pullout of the nail from the wood stud, and one specimen showed loss of bond strength between mortar and brick. For type SOTE, all specimens failed by loss of bond strength between mortar and brick, resulting in tie pullout or test specimen collapse. These failure mode classifications are similar to those of ASTM (ASTM 1994). Pullout of the nail from the wood stud in a type NSTE specimen is illustrated in Fig. 4.

Typical load-displacement curves for type NSTE specimens are presented in Fig. 5. Stiffness and strength of a subassembly can be determined from these curves. The peak tension loads from all the type NSTE specimens ranged from 0.45 kN to 1.34 kN. Peak loads for the other specimen types ranged from: 1.07 kN to 2.40 kN for type SSTE, 0.76 kN to 0.80 kN for type NOTE, and 0.62 kN to 0.71 kN for type SOTE.

The effects of initial offset were particularly noticeable in screw-connected specimens. In nail-connected specimens, once the corrugated parts of the tie were unfolded, the specimens absorbed the additional force by pulling the nail out of the wood. Therefore, there was no significant difference in the force applied to the mortar joints. In screw-connected specimens, however, once the corrugated parts of the tie were unfolded, the loads were applied to the mortar joint through the tie, as the specimen needed larger loads to pull out the screw. The applied force to the mortar through the tie in type SOTE specimens was not by pure shear to the mortar bond. As the tie sloped due to offset, it generated additional tension force normal to the mortar. This load transfer mechanism resulted in a considerable decrease in peak load capacity in type SOTE specimens compared to type SSTE specimens.

### Compression Tests.

A total of 23 specimens were tested in compression, 10 of type NSCO, 5 of type SSCO, 5 of type NOCO, and 3 of type SOCO. Unlike the tension test specimens, which had a different failure mode for each type of specimen, the behavior in the compression tests were quite consistent. All specimens failed by buckling (or bending) of the tie regardless of the type of specimen. Buckling of the tie in a type NSCO specimen is illustrated in Fig. 6. The use of a screw instead of nail did not have much effect on the behavior of the specimens. From this, it was reasoned that the failure mode in the compression tests was primarily affected by the properties of the tie itself. The peak loads in the compression offset specimens were less than those in the standard compression specimens. Typical load-displacement curves for type NSCO specimens are presented in Fig. 7.

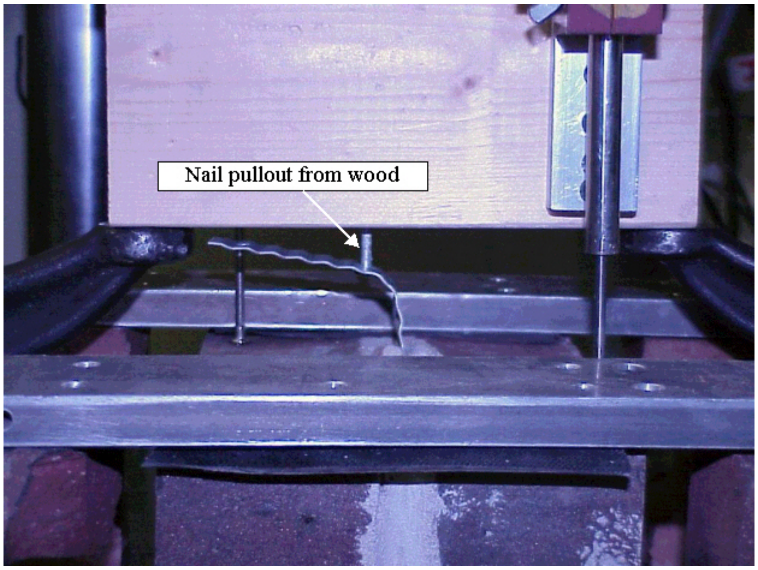


**Figure 4. Tension Failure Mode: Nail Pullout from Wood in Type NSTE Specimen**

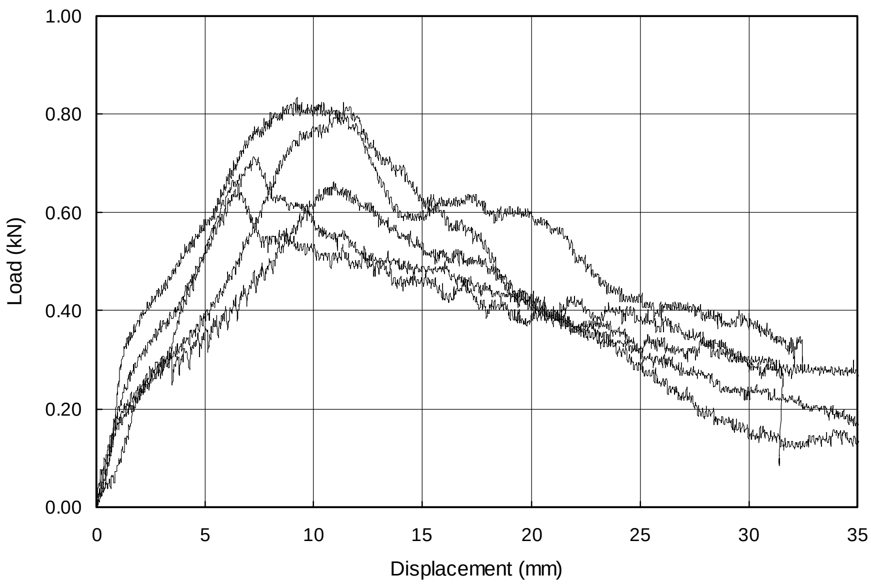


**Figure 5. Typical Load-Displacement Curves for Type NSTE Tension Specimens**

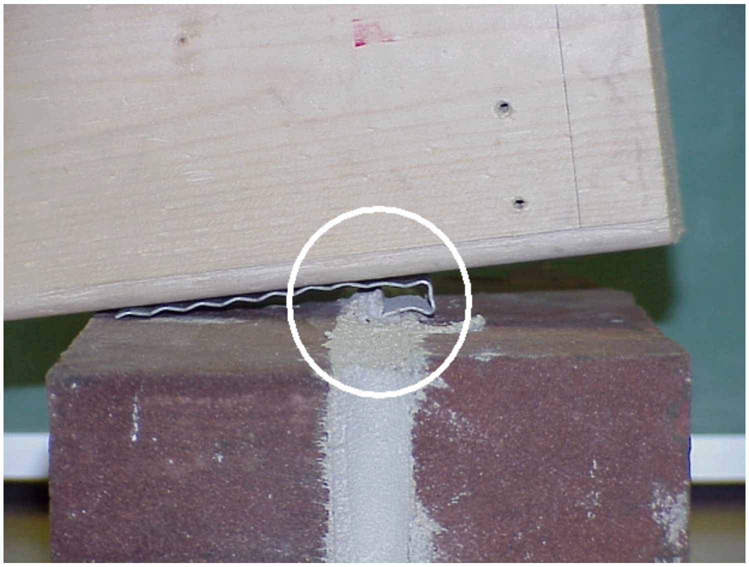

**Figure 6. Compression Failure Mode: Buckling of Tie in Type NSCO Specimen**

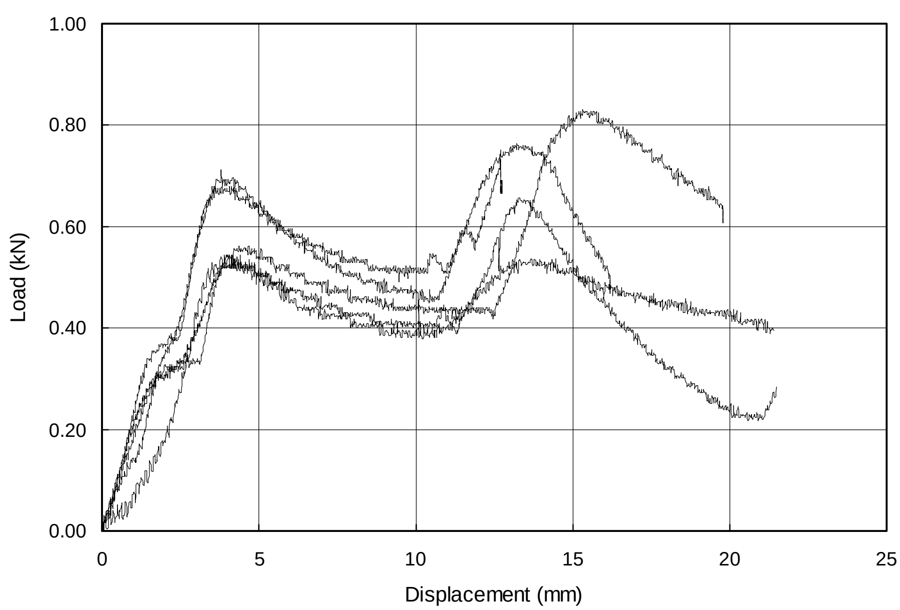


**Figure 7. Typical Load-Displacement Curves for Type NSCO Compression Specimens**

**Cyclic Tests.**

In order to simulate the cyclic behavior of ties in a wall system, cyclic tests on each type of subassembly were performed. Again, the tests were controlled by displacement. Determination of loading history, such as number of cycles, displacement control rate, and maximum displacement to be applied, was based on the monotonic tension and compression tests results. Details on the loading history are presented in Fig. 8. A total of 24 cycles were planned as shown. After each of the 2.5 mm (0.1 in.), 5 mm (0.2 in.), 7.5 mm (0.3 in.), 10 mm (0.4 in.) and 12.5 mm (0.5 in.) displacements, a repeat cycle of the same amplitude was included to capture strength and the stiffness degradation. Displacement was applied at a rate of 1 cycle per minute (0.0167 Hz); therefore, the loading speed (mm/min.) was different for each cycle, as the amplitude was different in each cycle. After 24 cycles, additional displacements were applied in the increment of 1.25 mm (0.05 in.), depending on the status of the specimens, until the final failure of the specimens occurred or until applying more load had no further meaning. Any additional load cycles can be seen in the load-displacement curves.

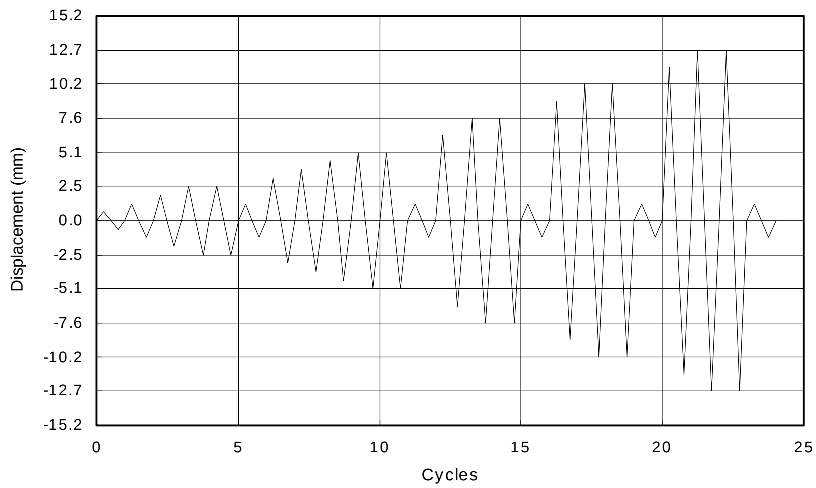


**Figure 8. Displacement History for Cyclic Tests**

A total of 21 specimens were tested cyclically, 10 of type NSCY, 5 of type SSCY, 3 of type NOCY, and 3 of type SOCY. For type NSCY, pullout of the nail was observed first in all specimens. As more cycles were applied after pullout of nail was observed, final failure of these specimens was generally caused by tie fracture. Pullout of the tie due to local failure in bond strength was also observed in a few specimens. Typical load-displacement curves of type NSCY and type SSCY specimens are shown in Fig. 9 and Fig. 10. The screw-connected specimens had the load increase significantly, in the same manner as in monotonic tension. For type SSCY, tie pullout was observed in two specimens, tie fracture in two specimens, and push-through of the tie hole by the screw in one specimen. Type NOCY specimens had a failure mode similar to that of type NSCY. For type SOCY, tie fracture was observed in two specimens, and bond failure between mortar and brick was observed in the other specimen.

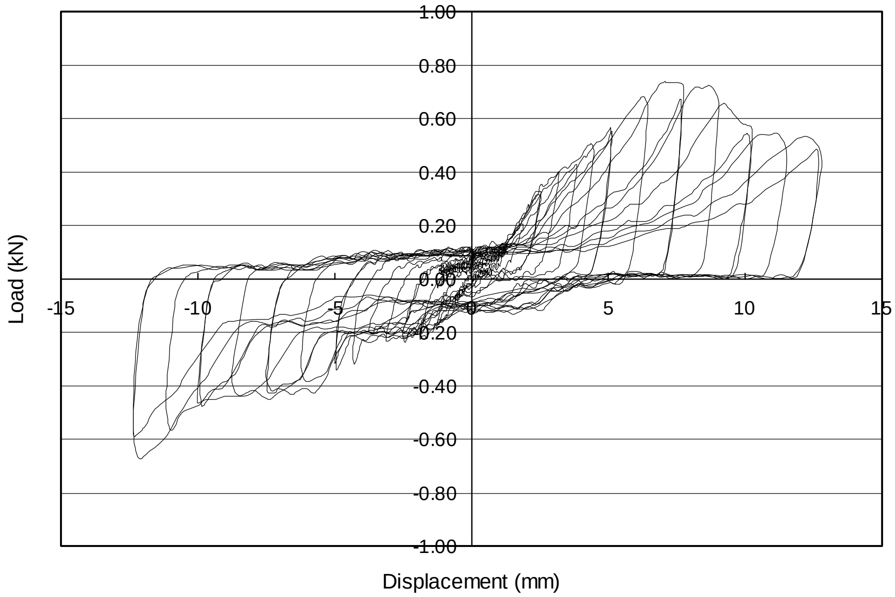


**Figure 9. Typical Cyclic Load-Displacement Curve for Type NSCY Specimen**

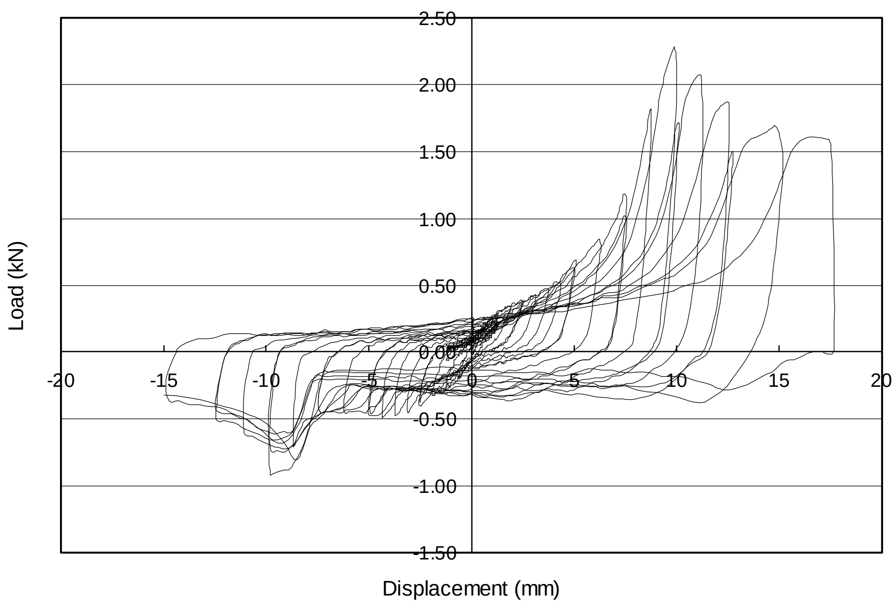


**Figure 10. Typical Cyclic Load-Displacement Curve for Type SSCY Specimen**

In order to compare the cyclic behavior to the monotonic tension and compression tests, envelope graphs from the cyclic tests were developed. The points on the envelope curves represent the maximum load point for each cycle. In this process, the repeat cycles at displacements of 2.5 mm, 5 mm, 7.5 mm, 10 mm and 12.5 mm (that generally showed lower values of load than the first cycle) were removed. Note that the points were determined from the maximum load point in each cycle, not from the displacement. Two envelope curves (tension part and compression part) were generated from each cyclic test. Representative envelope curves for the tension part of type NSCY specimens are presented in Fig. 11. For the purpose of comparison to monotonic tension test results, the maximum value of the x-axis and the y-axis in Fig. 11 are set to those of Fig. 5. As can be seen by comparison of the two figures, the tension part envelope curves are well-matched to those from the monotonic tension tests.

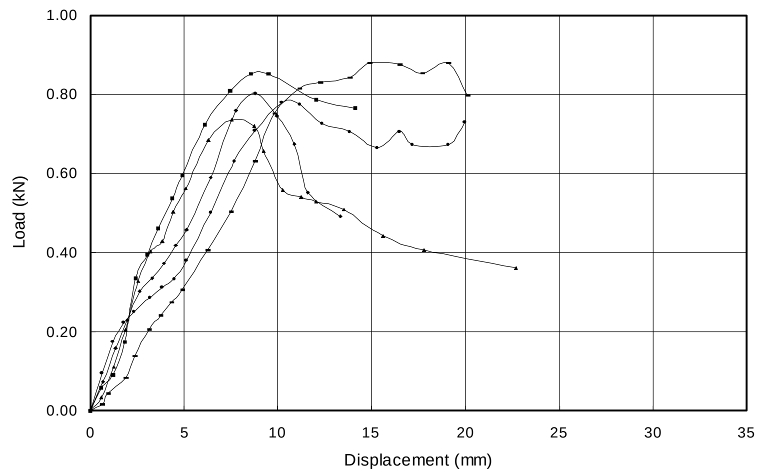


**Figure 11. Typical Tension Envelope Curves for Type NSCY Specimens**

## SUMMARY

As the first step towards the performance evaluation of the behavior of brick masonry veneer with wood stud framing under earthquake loads, tests were performed on brick-tie-wood subassemblies. After typical types of ties used for veneer wall with wood backup in Mid-America were characterized, a total of 80 specimens (Figs. 1-3 and Table 1) were tested under monotonic tension, monotonic compression or tension-compression cyclic loads. When tension was applied (Fig. 5), the general failure modes were pullout of nail (Fig. 4) for nail-connected specimens, and pullout of tie for screw-connected specimens due to the loss of bond strength between mortar and brick. When compression was applied (Fig. 7), all specimens failed by buckling of the tie, irrespective of other parameters (Fig. 6). When specimens were subjected to tension-compression cyclic loads (Figs. 8-10), the general failure modes were fracture of tie in many nail-connected specimens, bond failure between mortar and brick, and pull out of the tie in screw-connected specimens. Envelope curves were generated, and they compared favorably to the results of the monotonic tension and monotonic compression tests (Fig. 11).

Test results achieved in this study will serve as a basis for full-scale wall system tests subject to out-of-plane loads, which are currently under preparation. Based on this experimental study of subassemblies, as well as the wall tests, analytical models of both the wall and subassemblies will be developed.

## ACKNOWLEDGMENT

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