SHEAR CONNECTORS FOR MASONRY CAVITY WALLS

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ABSTRACT

Current design procedures for a masonry cavity wall system do not consider the exterior brick veneer to act as a structural component. A connector was developed to transfer shear between the brick veneer and the back-up wall. With the use of this shear-resisting connector, composite load carrying action is achieved between the brick veneer and back-up wall, resulting in a wall system with a changed and improved load resisting capacity.

Preliminary testing was conducted on two masonry cavity walls subjected to positive lateral loads. The first wall used conventional wire truss reinforcement while the second used the proposed shear connector. The test results demonstrated very effectively the superior performance of the second wall. Not only did it fail at a lateral positive unit load twice that of the first wall but also exhibited much smaller lateral deflections at comparable loads at all stages of loading. Also, the wall system with the shear connector exhibited at failure, greatly improved ductility as compared to that of the wall with conventional wire truss tie reinforcement.

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INTRODUCTION

Presently, brick exterior veneer in a building is used primarily for aesthetics and to provide a weathering surface. No consideration is given to utilizing the veneer as a structural component. All lateral loads (i.e. wind and earthquake) acting on the brick veneer must be transferred to a back-up wall system by means of appropriately designed ties. In most cases, the back-up wall consists of concrete masonry units and is designed to resist all of the applied loads.

The performance of such a system can be changed and improved greatly by providing a connector between the veneer and the concrete masonry back-up wall, capable of resisting shear. The use of such connectors will cause the wall system to act as a Vierendeel truss.

This study, conducted at the University of Alberta, describes the development of such a shear resisting connector and reports the findings of a preliminary test program carried out to evaluate this system.

DEVELOPMENT OF SHEAR CONNECTOR

The shear connector developed and used in the experimental part of this project is shown in Figure 1 and Photo 1. It consists of a plate with holes and slots, cross-legs, one bent rod tie, and is installed in the concrete masonry back-up wall as follows. Two cross rods are inserted into holes a and b and embedded into the mortar joint of the block wall as shown in Figure 2. The plate which forms the body of the connector is extended to within 7 mm (0.3") of the expected position of the brick veneer (7 mm being the tolerance allowed under the guidelines of CSA Standard CAN3-S304-M78: Clause 3.14[1]).

The connection into the brick veneer is achieved by inserting a bent rod tie (Figure 1: Part D) into one of several holes in the plate enabling horizontal placement of the tie in the brick mortar joint as shown in Photo 2. A slot is utilized to accept a wedge which in turn holds rigid insulation tight against the masonry block back-up wall.

The height, H, of the main plate of the shear connector is one brick and mortar joint high. This permits the horizontal placement of the tie into the brick veneer mortar joint. The thickness, t, of the main plate can be adjusted to allow for the transfer of shear forces of various magnitudes. The length, L, of the plate can be altered to accommodate varying dimensions of the back-up wall, the insulation, and the air space.

The proposed connector is capable of transferring shear across the cavity between the brick veneer and the block back-up wall. This wall system, spanning vertically between floors, thus acts as a Vierendeel truss in resisting lateral loads. For design, a model of the proposed wall system is shown as a truss in Figure 3. An actual wall system with a concrete block back-up wall utilizing shear connectors is illustrated in Figure 4.

THEORETICAL EVALUATION

For a wall located in Edmonton, Alberta, Canada, as shown in Figure 4, the unit wind load is of the order of 1.5 kPa (30 psf). In a wall system with shear connectors having the ability to transfer shear across a cavity, the following structural actions occur. For positive lateral loads, the brick veneer would act as the compression member and the back-up wall as the tension member. For negative lateral loads, the reverse would be true.

Analyzing this wall system as a Vierendeel Truss with positive pressure on the brick face, the forces acting on the elements of the truss are shown in Figure 3. A tributary area of 240,000 mm^2 (2.6 ft^2) per connector is considered in this analysis.

Under a unit load of 1.5 kPa (30 psf), the maximum compressive stress on the brick veneer is 0.083 MPa (12.0 psi) and the maximum tensile stress in the block wall is 0.116 MPa (16.9 psi). The maximum shear in the connectors is 4.1 kN (920 lb) and occurs at the first shear connector from the top and bottom.

To ensure that the worst case conditions could be modelled in a wall system, Type N mortar was chosen for both the veneer and back-up walls. The capacity of the wall assembly can be increased by using Type S or M mortar, or by introducing vertical reinforcement.

Under negative loading, comparable loads would be less critical than those for positive loading. This is because tensile stresses on the brick resulting from the loads are less due to a higher mortar area of the brick than of the block face shell.

EXPERIMENTAL PROGRAM

Two 1200 mm (48") long x 3200 mm (126") high wall assemblies were constructed in the laboratory to investigate the performance of the shear connector. Type N mortar was used for both veneer and back-up walls. The masonry units were 190 x 190 x 390 mm (8" x 8" x 16") lightweight standard blocks, and 57 x 90 x 190 mm (2-1/4" x 3-5/8" x 7-5/8") clay bricks.

The cavities for the walls were as follows. The cavity for Wall #1 was 75 mm (3"), including 50 mm (2") of insulation in the form of rigid plank styrofoam made by Dow Chemical under the name of Styrofoam S/M. The wall system relied on a 3 rod, 3.66 mm diameter (#9 gauge) wire truss joint reinforcement, embedded in every third course to connect the two wythes, as shown in Photo 3.

Wall #2 incorporated the shear connector and had a cavity of 100 mm (4") including 75 mm (3") of insulation of the same type as Wall #1. The connectors were spaced at 400 mm (16") horizontally and 600 mm (24") vertically, as shown in Photo 4.

The walls were cured in a laboratory environment with the humidity at 30% for 28 days prior to testing.

TEST RESULTS AND DISCUSSION

Wall #1 failed at a unit load of 1.24 kPa (25 psf) with a maximum deflection of 1.4 mm (0.06"). Wall #2 achieved an ultimate unit load of 2.48 kPa (50 psf) with a maximum deflection of 16 mm (0.63"). Failure occurred by exceeding the tensile strength of the mortar in the block back-up wall. The walls returned to their original shape when the load was removed. Photo 5 shows the cracks in the block back-up wall as a result of tensile failure of Wall #2.

Load vs. centerline lateral deflection diagrams are presented in Figures 5 and 6. These figures show that the shear connectors in Wall #2 increased the ultimate unit load over that of Wall #1 by 100%, even with an increase in the cavity width of 33% in Wall #2 over Wall #1. Although the ultimate lateral deflection of Wall #2 exceeded that of Wall #1, its deflections were consistently smaller than those of Wall #1 at similar loads. Therefore, the use of this shear connector has both reduced the lateral deflection of the wall system at lower loads, and greatly increased the ductility of the system at higher loads. The load deflection relationships of the block and brick components of both walls are compared in Figures 7 through 10.

Upon disassembly of the failed walls, the shear connectors were found to be undamaged, even though the design unit load of 1.5 kPa (30 psf) was exceeded. The deformation of the wire truss reinforcement of Wall #1 is shown in Photo 6.

CONCLUSIONS AND RECOMMENDATIONS

1. The preliminary test results, though limited, provided the following conclusions:

   a. The Vierendeel Truss analysis was satisfactory at modelling a wall system utilizing shear connectors.

   b. The shear connectors did indeed create composite wall action under positive lateral pressure. That is, they are capable of transferring shear between the exterior brick veneer and the back-up wall.

   c. Wall strength was doubled by replacing the conventional wire truss reinforcement with shear connectors, even though cavity width was increased by 33%.

d. Under comparable loads, the lateral deflection of the wall system using shear connectors was consistently less than that of the wire truss reinforcement. Such reduction in deflection will minimize crack width and water penetration in an actual structure.

2. It is recommended that further studies be carried out, regarding shear connector implementations in masonry wall systems. At present, studies are being conducted to examine the behaviour of shear connectors with reinforced walls and different mortar types, and to determine optimum connector placement and spacing.

3. Factors affecting the performance of such a system relating to the physical properties of the materials (concrete masonry and burned clay masonry) must also be investigated.

REFERENCES

1. CAN3-S304-M78, "Masonry Design and Construction for Buildings", Canadian Standards Association, Rexdale, Ontario, 1984.

Figure 1. Shear Connector

Figure 2. Shear Connector Application with Concrete Block

Figure 3. Vierendeel Truss Model

Figure 4. Wall Sytem Utilizing Shear Connectors

Figure 5. Load vs Centerline Lateral Deflection for Concrete Block Back-up Walls

Figure 6. Load vs Centerline Lateral Deflection for Brick Veneer Walls

Figure 7. Block Wall Deflection for Wall #1

Figure 8. Block Wall Deflection for Wall #2

Figure 9. Brick Wall Deflection for Wall #1

Figure 10. Brick Wall Deflection for Wall #2

Photo 1. Shear Connector Used in Study

Photo 2. Interaction of Rod Tie with Shear Connector and Brick Veneer

Photo 3. Wire Truss Joint Reinforcement in Block Wall #1

Photo 4. Shear Connectors in Block Wall #2

Photo 5. Tensile Failure in Block Mortar Joint of Wall #2

Photo 6. Deformation of Wire Truss Reinforcement of Wall #1

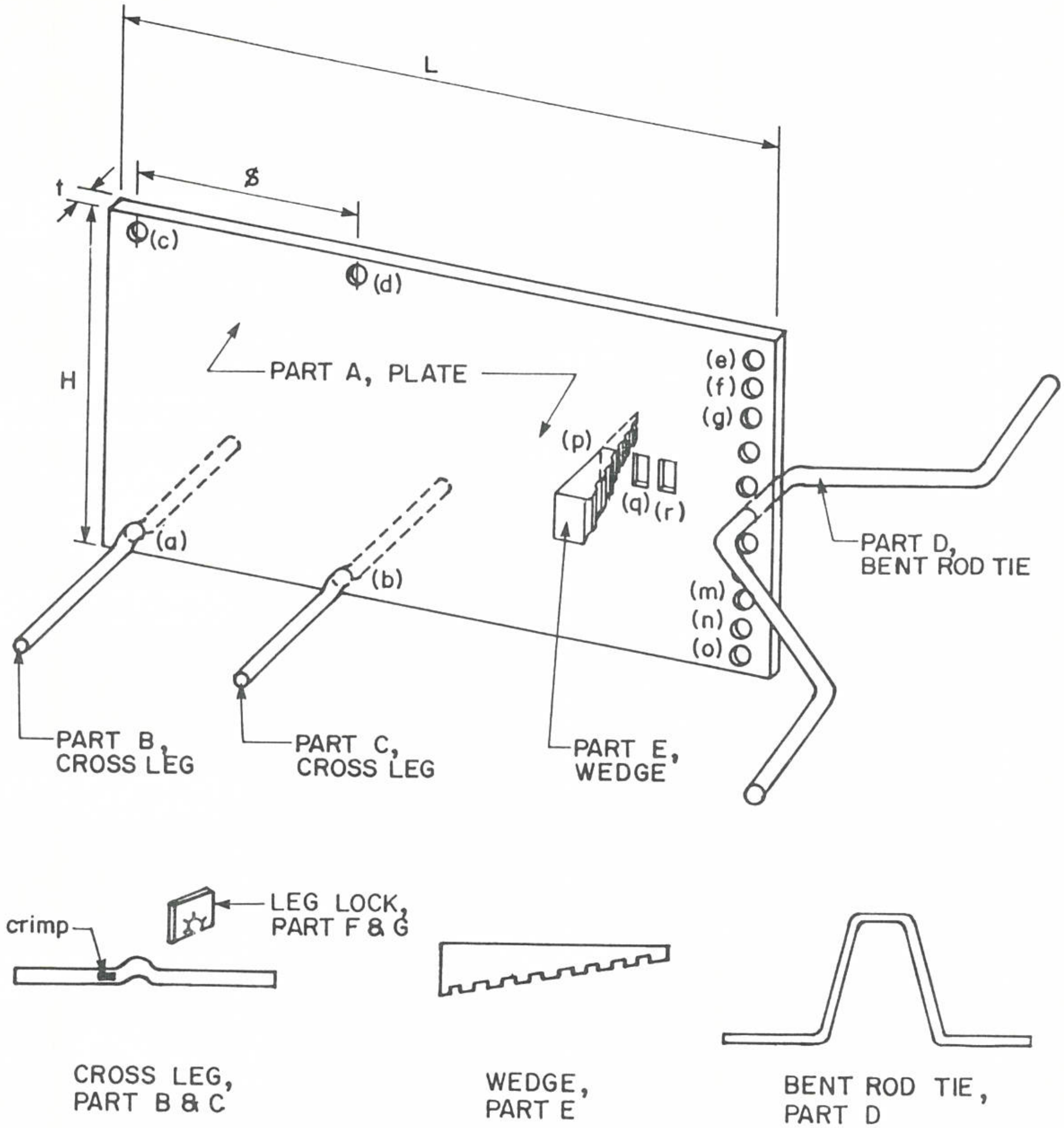


Figure 1. Shear Connector

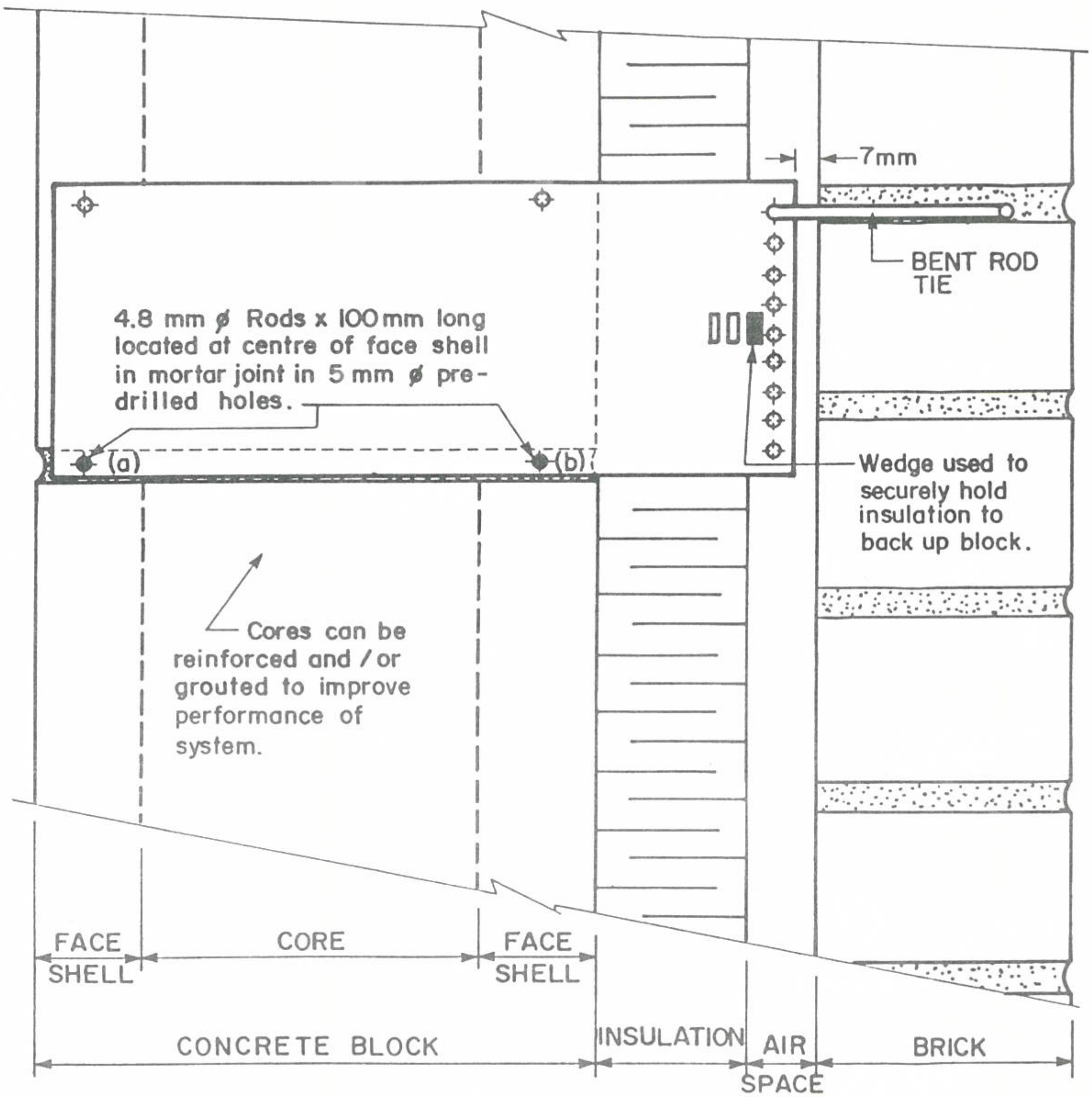
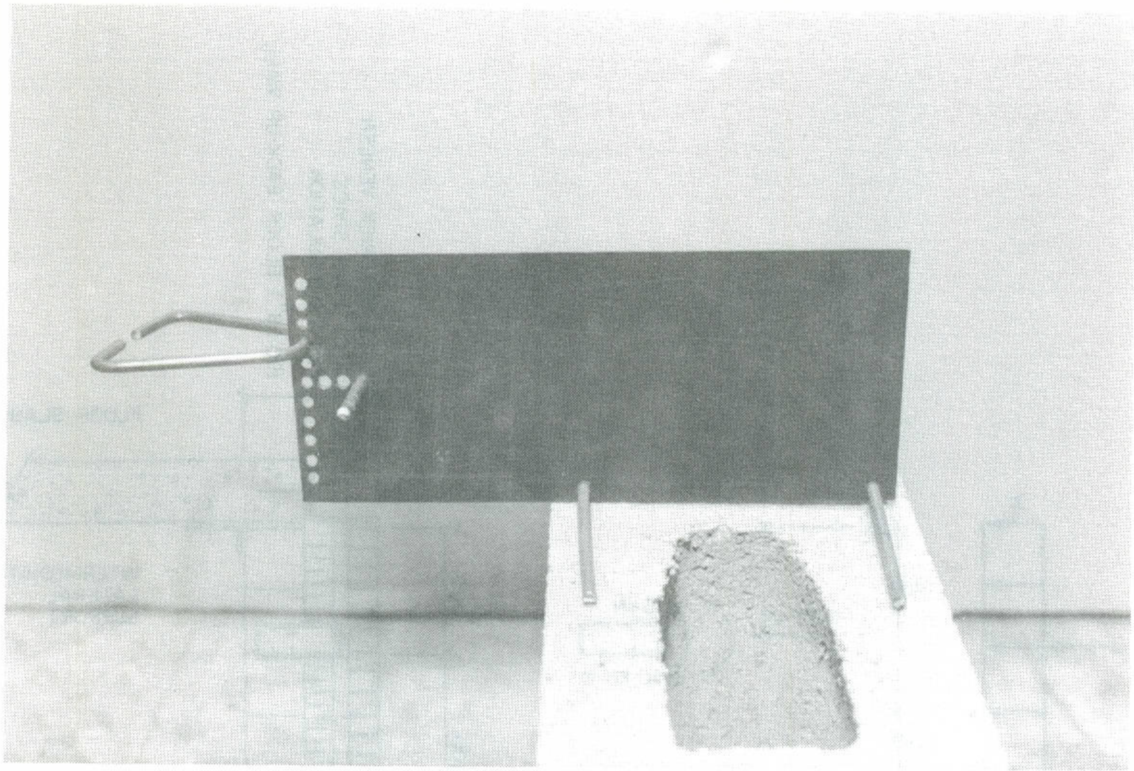


Figure 2. Shear Connector Application with Concrete Block



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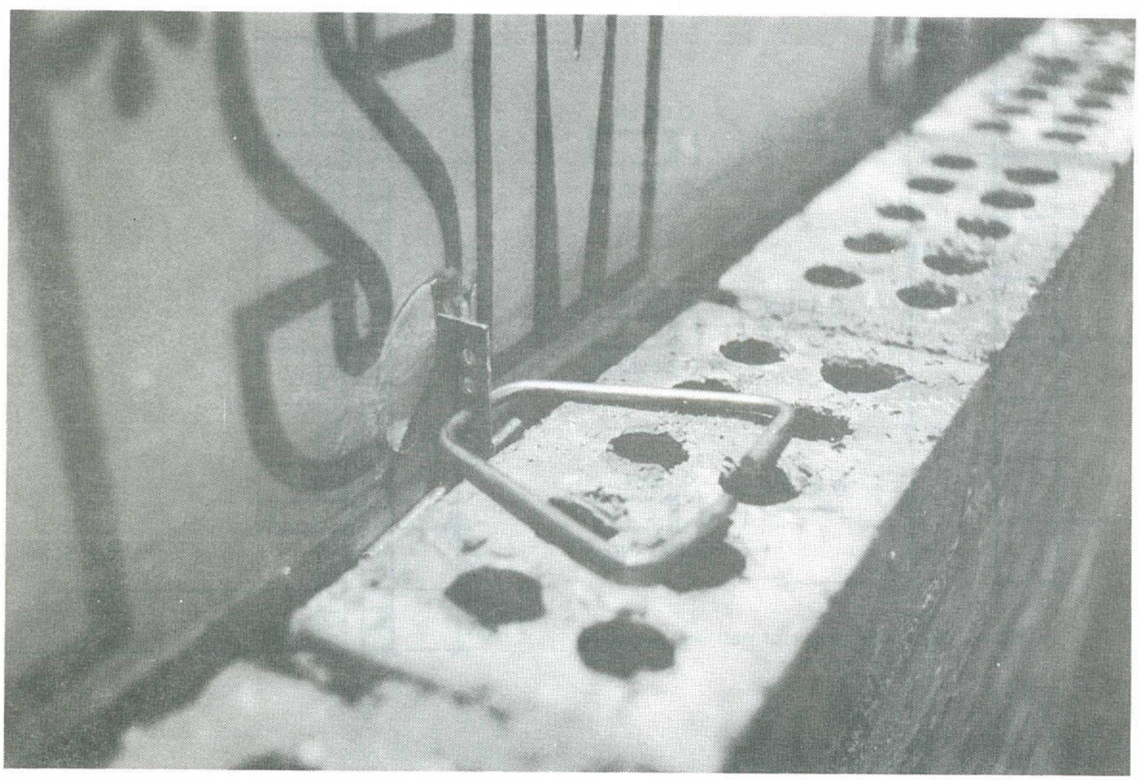

Photo 2. Interaction of Rod Tie with Shear Connector and Brick Veneer

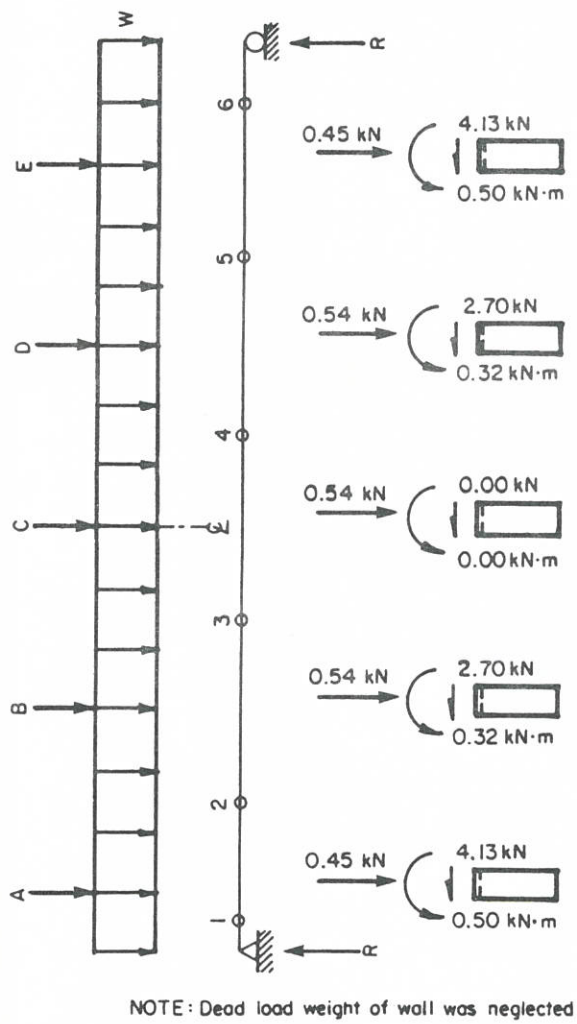

Figure 3. Vierendeel Truss Model

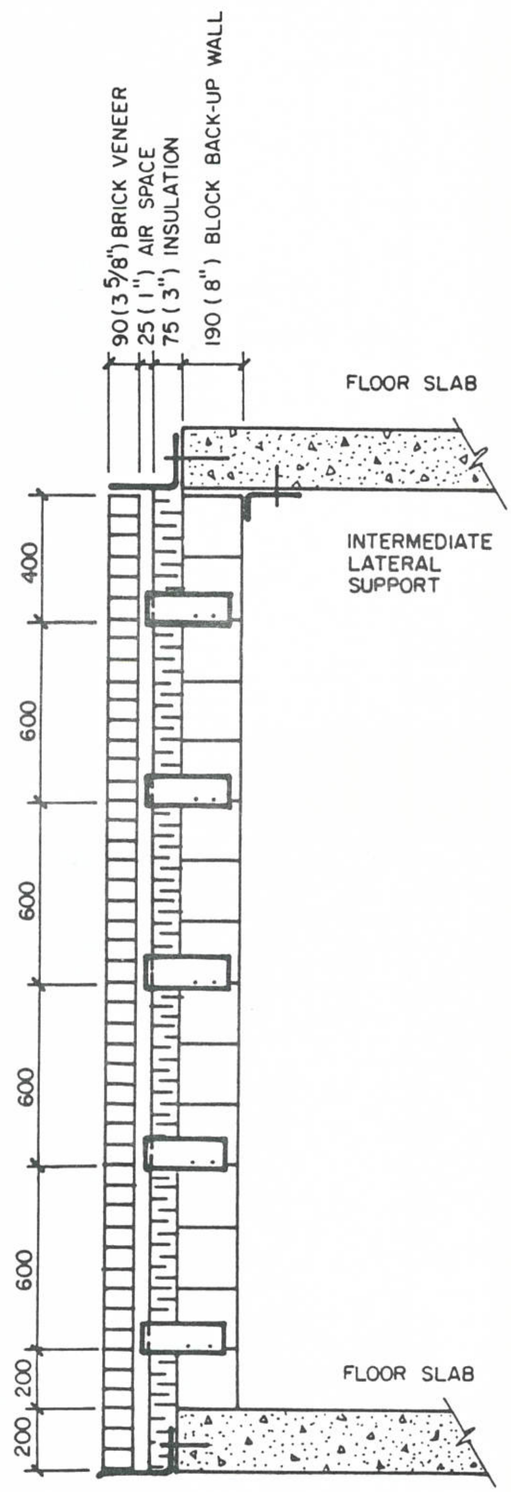

Figure 4. Wall System Utilizing
Shear Connectors

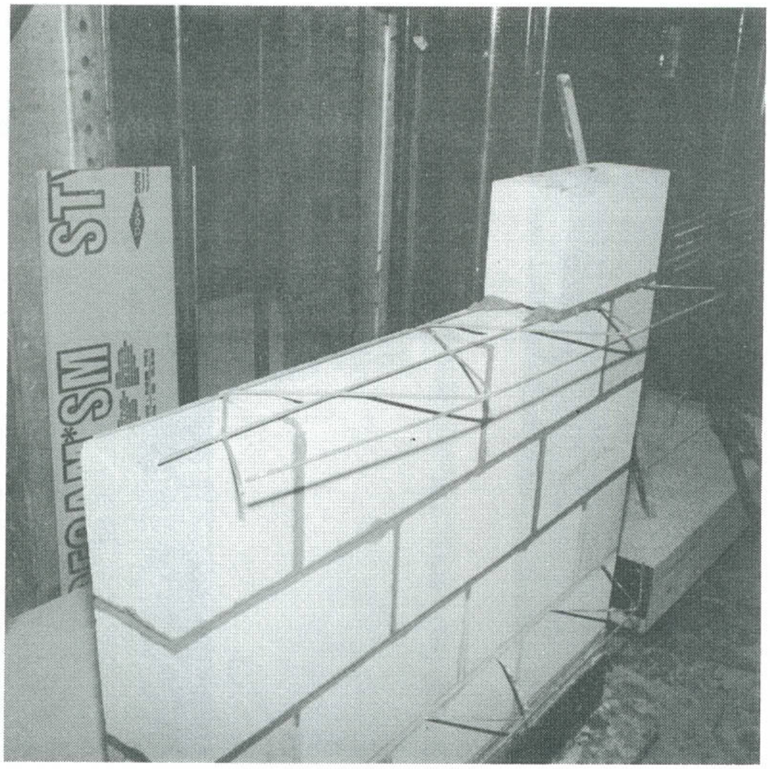

Photo 3. Wire Truss Joint Reinforcement in Block Wall #1

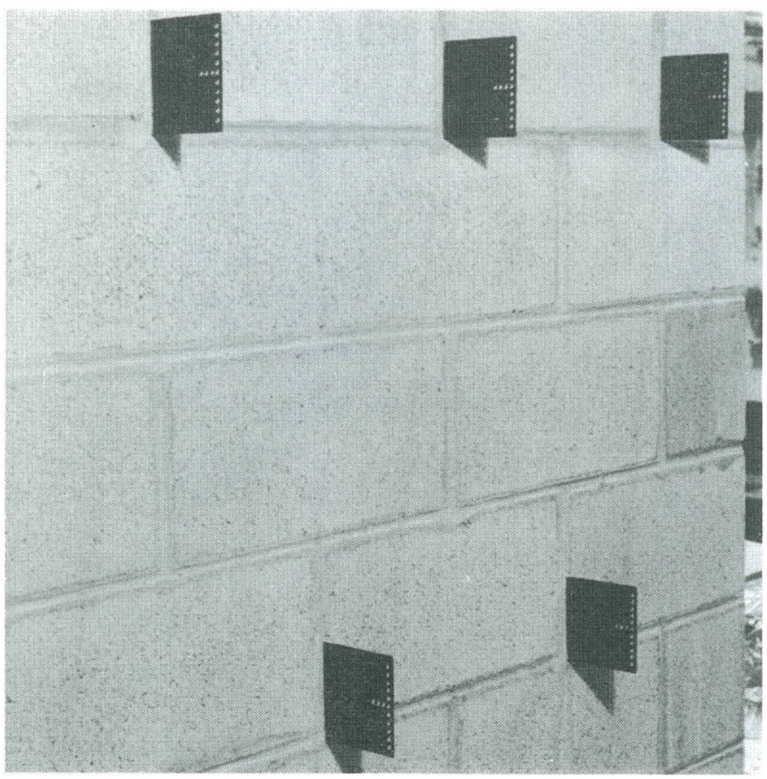

Photo 4. Shear Connectors in Block Wall #2

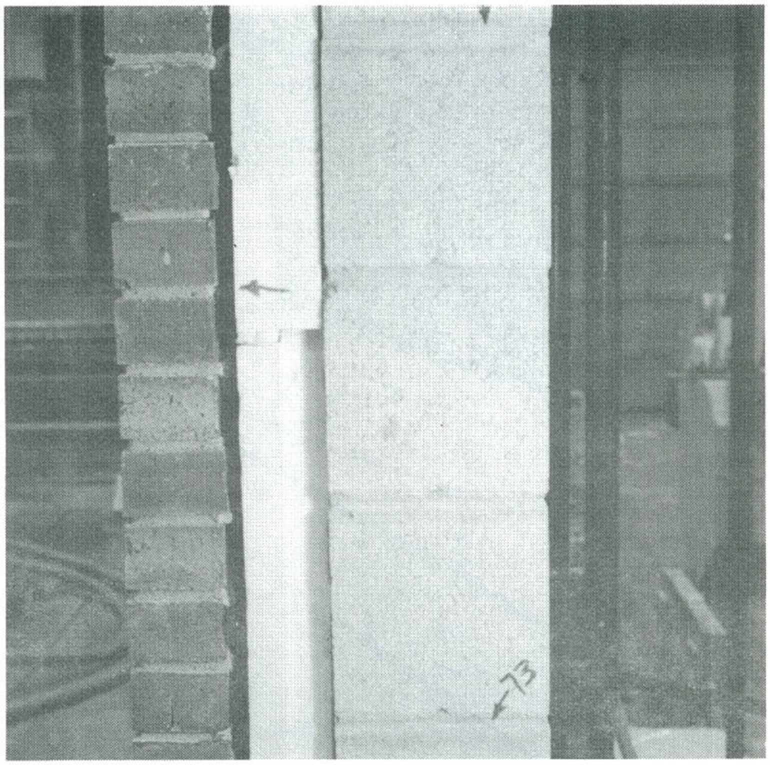

Photo 5. Tensile Failure in Block Mortar Joint of Wall #2

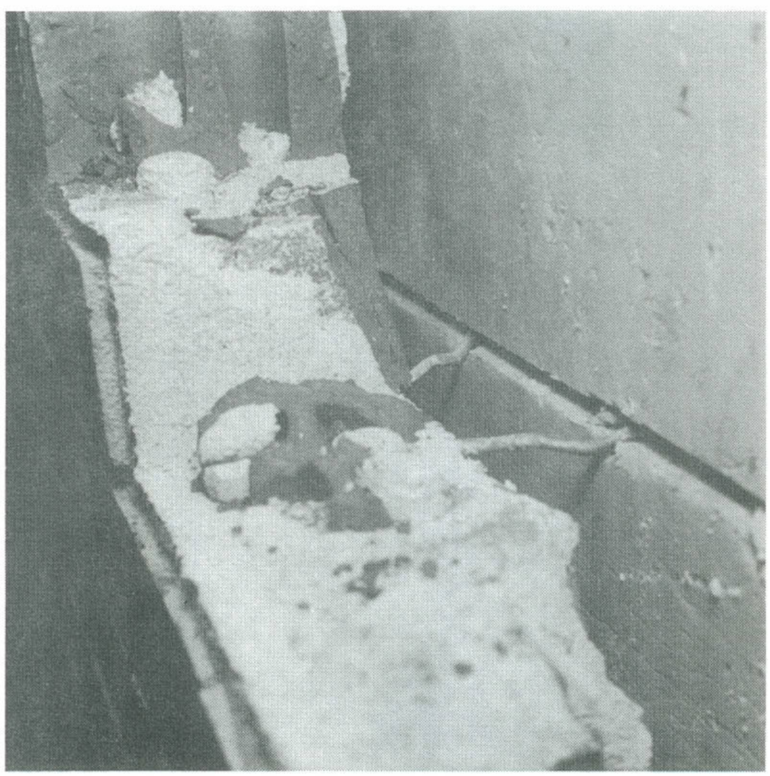

Photo 6. Deformation of Wire Truss Reinforcement of Wall #1

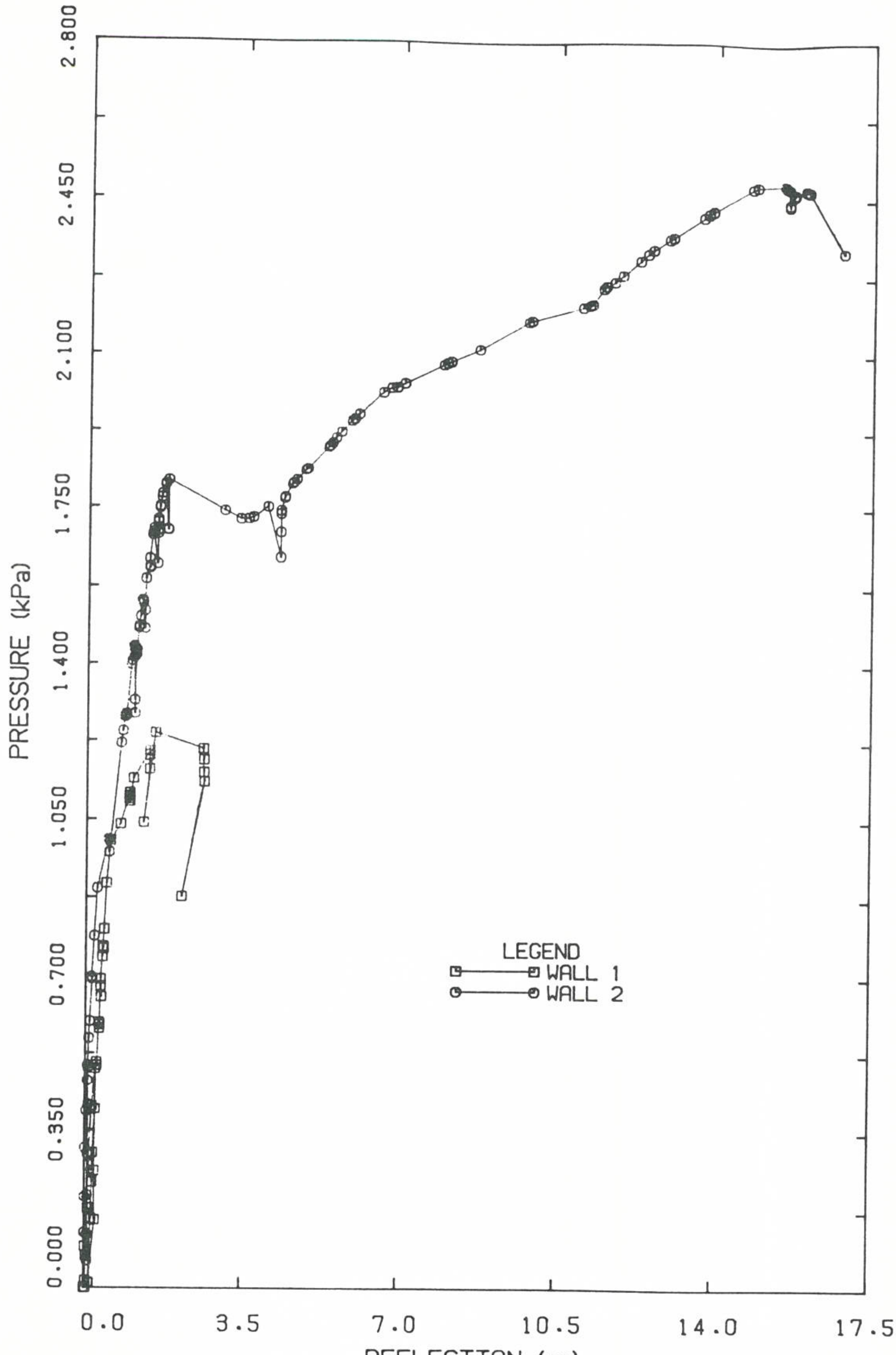

Figure 5. Load vs Centerline Lateral Deformation for Concrete Block Back-up Walls

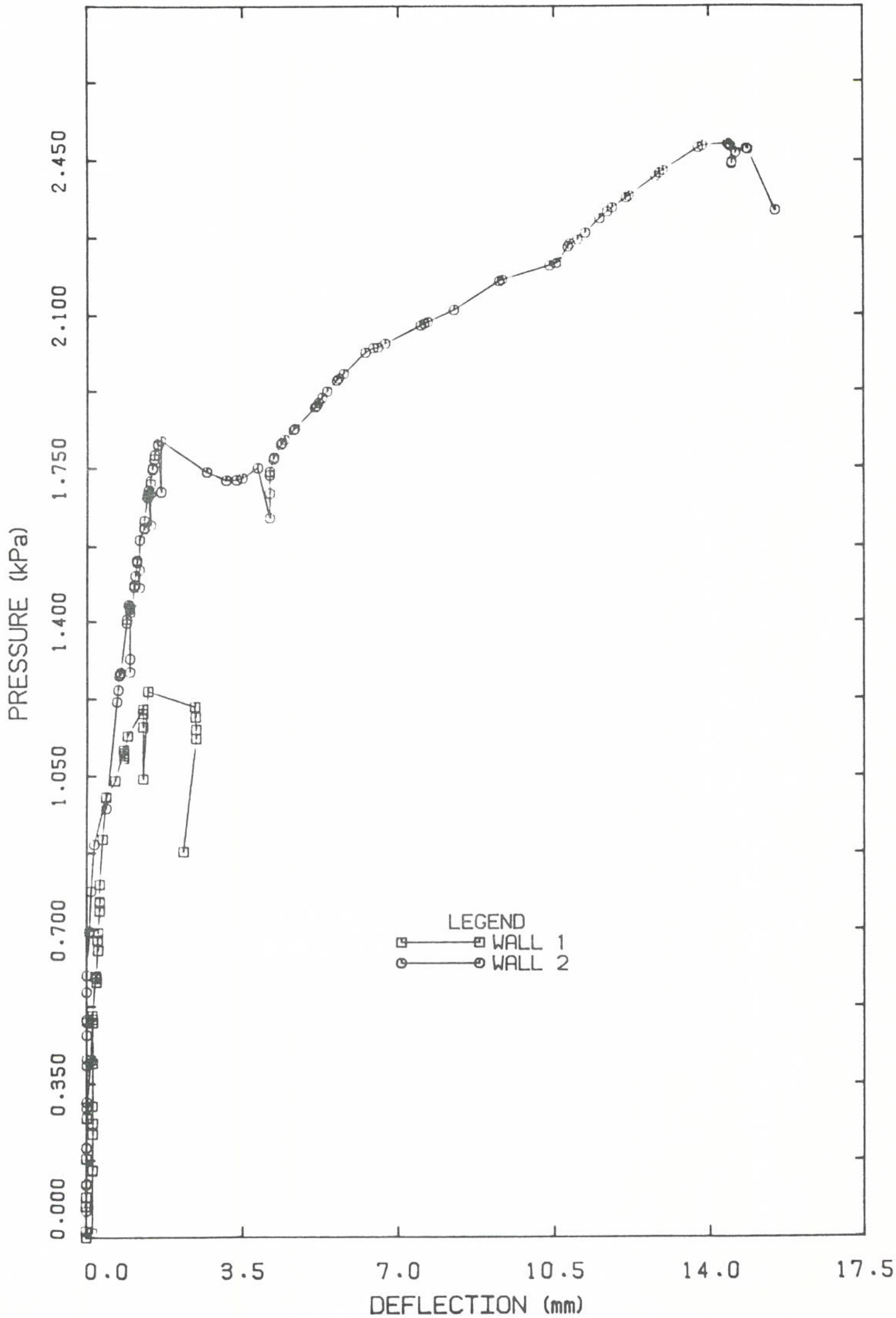

Figure 6. Load vs Centerline Lateral Deflection for Brick Veneer Walls

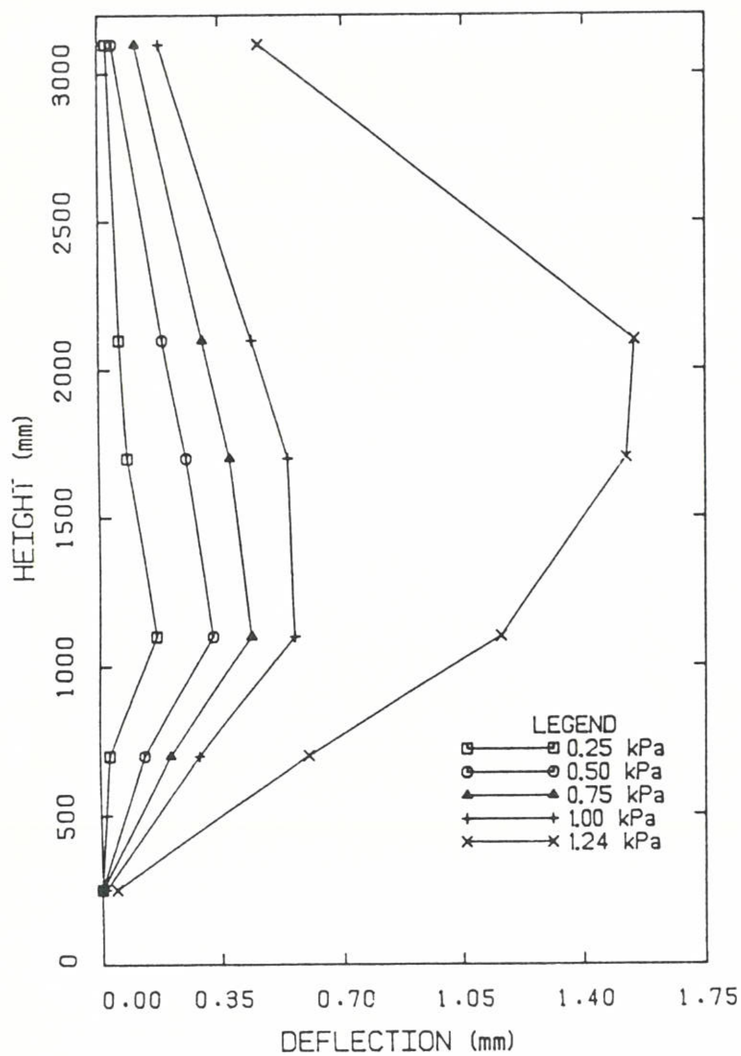

Figure 7. Block Wall Deflection for Wall #1

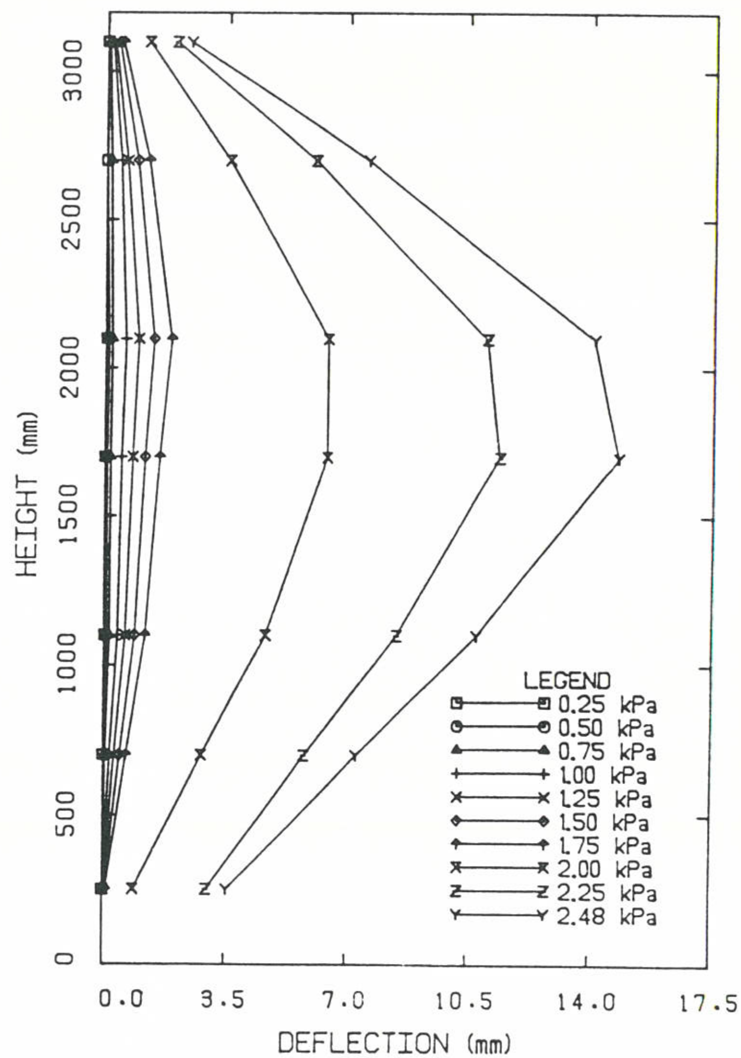

Figure 8. Block Wall Deflection for Wall #2

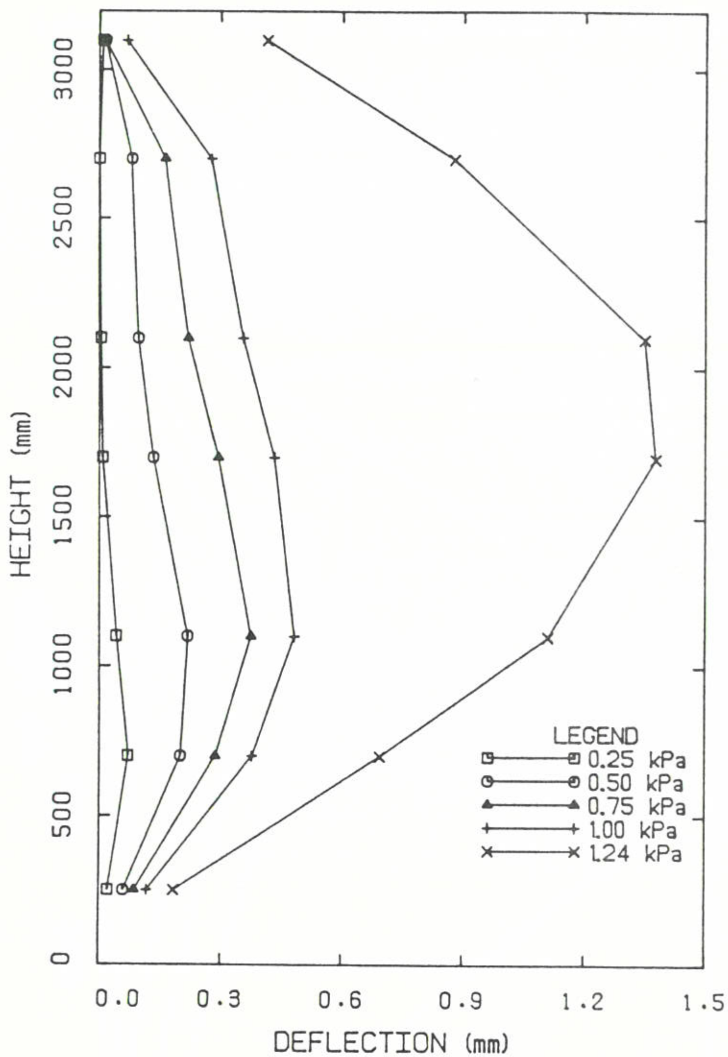

Figure 9. Brick Wall Deflection for Wall #1

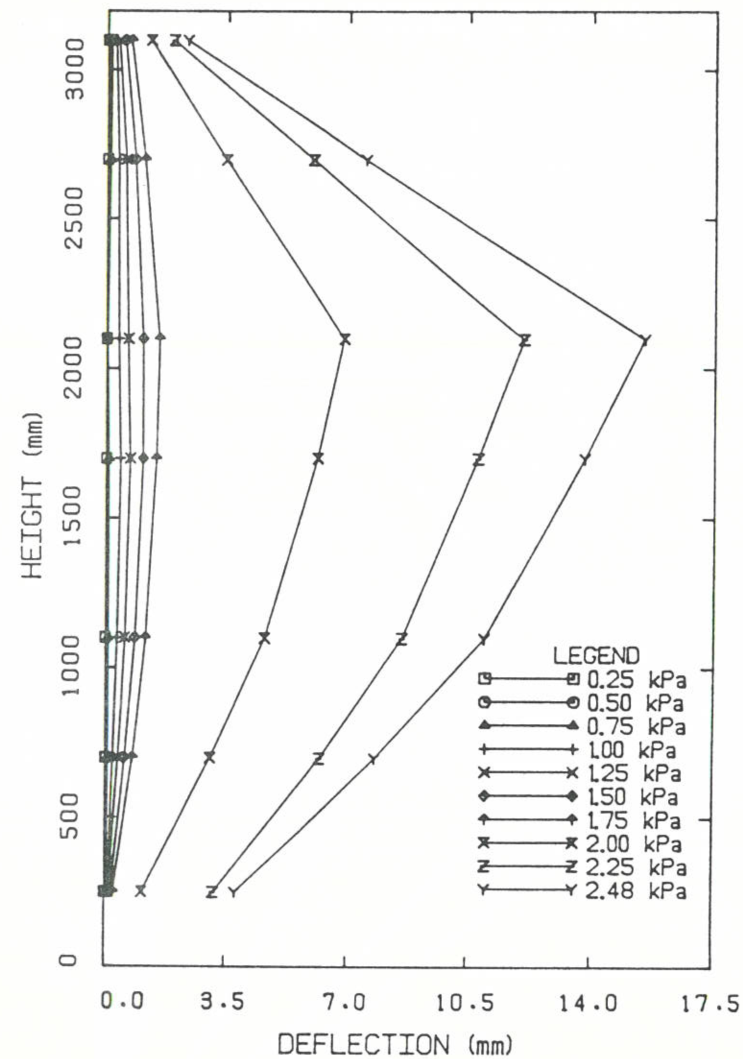

Figure 10. Brick Wall Deflection for Wall #2