ABSTRACT

Title of Thesis: FINITE ELEMENT ANALYSES OF PARTIALLY REINFORCED MASONRY SHEAR WALLS

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Partially reinforced shear walls are used in regions of relatively low seismic risk. Nevertheless, these structures should be capable to resist some lateral motion. The purpose of this paper is to examine the behavior of in-plane cyclic load tests of typical partially-grouted masonry shear walls and the capability of FEM/I in simulating their response. FEM/I is a nonlinear finite element program originally developed for reinforced masonry shear walls with a uniform grid of orthogonal reinforcement at close spacing. FEM/I has successfully simulated the response of fully grouted uniformly distributed reinforced masonry walls [Ewing, 1987]. FEM/I uses a smeared property approach in which the reinforcing steel and masonry composite is modeled as a single material. The applicability of FEM/I to partially grouted partially reinforced masonry shear walls is measured by comparing FEM/I force-displacement cycles, peak lateral forces, strains, energy dissipation and crack patterns with those generated from the experimental tests conducted at the National Institute of Standards and Technology.

Partially reinforced shear walls can be modeled in FEM/I by smearing the steel over the blocks which are grouted and reinforced. The ungrouted blocks can be modeled as reinforced blocks with a reinforcement ratio of zero. This approach was shown to be adequate when the displacements and cracks were small. As the cracks increase in size, the smeared property assumption can no longer adequately represent the wall's geometry and it's property. The result is a poor prediction of both local and global behavior at large displacements.

The ratio of the lateral loads at the first major event (FME) demonstrate a good relationship in the forces generated by FEM/I for each wall with the exception Wall 1. Results from Walls 3, 5, 9 and 11 exhibit FEM/I was able to predict the lateral load adequately up to the FME. The ratio of the lateral load up to the FME ranges from 0.9 - 1.3. After the occurrence of the FME, FEM/I overpredicts the lateral load considerably. In each of the finite element analyses, FEM/I overestimated the peak strength of the masonry specimens. The FEM/I models for Wall 11 and Wall 3 produced the best prediction of the peak strength. The difference for these two walls in the FEM/I predicted maximum lateral load and experimental data were 31% and 41%, respectively. Individual force displacement cycles are plotted at the various stages in the displacement history. FEM/I performs fairly well in predicting the force displacement response of the experiment. Walls 3, 5, 9 and 11 exhibit a good force displacement relationship for the first half of their displacement history until the development of major cracks. Wall 7 corresponded well with the experiment during the initial stages (Cycles 1 -17) of its displacement history.

FEM/I did not produce good results in representing the cracking pattern generated by the experimental study. The inability of modeling the crack pattern is also shown in the differences in the plots for the amount of energy dissipated. FEM/I did reasonably well in the prediction of yielding in the vertical reinforcement. Local stress and strain of masonry predicted by FEM/I did not match the experimental data.

FINITE ELEMENT ANALYSES OF PARTIALLY REINFORCED MASONRY SHEAR WALLS

by

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DEDICATION

To Ray Love, Dorothy Love, Steve Cowan and Michelene Waters. Without their understanding, love and constant support this work would not have been possible

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Introduction

The purpose of this research paper is to examine in-plane cyclic load tests of partially-grouted masonry shear walls with bond beams and the capability of FEM/I program in simulating the response of partially-grouted masonry shear walls. The comparison is based on experimental data collected from the tests conducted at the National Institute of Standards and Technology (NIST) and data generated from FEM/I. FEM/I is a nonlinear finite element program originally developed for reinforced masonry shear walls with a uniform grid of orthogonal reinforcement at close spacing. For the fully grouted uniformly distributed reinforced masonry walls, FEM/I has produced good estimates of monotonic envelope curves as well as the sequence of major events including yielding of the reinforcement, masonry cracking and masonry crushing [Ewing, 1987]. A layered model was used throughout to represent the fully grouted uniformly distributed reinforced masonry shear walls. In the layered model, one layer represents the masonry and the other represents the reinforcement. The partially-grouted masonry walls in this study do not have such a layer of steel, as the flexural reinforcing bars are concentrated in the exterior vertical cells and a bond beam located at mid-height of the walls. FEM/I also assumes that tension cracks are smeared over the elements. Consequently, premature and excess cracking or slippage in the walls will not be well modeled by FEM/I thus producing unrealistic results. The applicability of FEM/I to partially grouted partially reinforced masonry shear walls is measured by comparing experimental force-displacement cycles, peak forces, energy dissipated, local strains and crack patterns with those generated from the experimental test conducted at NIST.

The development of earthquake-resistant design procedures in the United States for fully grouted and reinforced masonry has been validated by experiment and observed performance during recent earthquakes [Fattal, 1993a]. However, reinforced masonry has not gained widespread popularity in the eastern and central United States where seismic hazards are lower than those in the west coast. Cost-effectiveness and competitiveness with other structural materials has often placed fully grouted and reinforced masonry at a disadvantage. In partially-grouted masonry, vertical reinforcement is concentrated in fewer cells than in fully grouted and reinforced masonry, and only those vertical cells with reinforcing bars are grouted.

Industry statistics show that masonry construction represents approximately seven percent of new construction in the United States [Research Needs for Masonry, 1988]. Generally, two types of masonry construction are used in buildings; load bearing and non-load bearing walls. Both types of walls are subjected to lateral forces under seismic excitations. Research information on the behavior of masonry shear walls is limited. Approximately 700 masonry shear wall tests of various types and configurations have been reported worldwide since 1975 [Dikkers, 1991]. Of these masonry shear walls, approximately 60% are fully-grouted heavily-reinforced walls representing the type of construction practice suitable for high seismic risk areas; approximately 30% are ungrouted unreinforced walls representing construction in areas where seismic requirements do not govern their design; and approximately 10% are tests of partially-grouted partially-reinforced walls, suitable for regions of low-to-moderate seismicity, where most of the masonry construction in the United States occurs [Yancey, 1991]. In

addition, the amount of usable experimental data on masonry shear walls is considerably less than the available data from the 700 shear wall tests noted above.

Partially grouted masonry walls are of particular importance because they are cheaper to build than fully grouted walls. Also, it is easier to rehabilitate an ungrouted masonry wall to a partially-grouted wall. Large savings in construction costs are expected from the use of partially-reinforced masonry in place of fully reinforced masonry, but the seismic resistance is inferior to that of fully-grouted and fully-reinforced masonry [Fattal, 1993b]. The challenge lies in quantifying the seismic performance of partially-grouted masonry, as well as verifying the applicability of current analysis and design methods for partially-grouted masonry.

A research program was initiated in the Building and Fire Research Laboratory (BFRL) of the National Institute of Standards and Technology (NIST) to study the seismic performance of partially-grouted masonry shear walls [Schultz, 1994]. An experimental study was designed to determine the influence of horizontal reinforcement ratio and height-to-length aspect ratio on the shear strength and behavior of partially-grouted masonry wall. A secondary goal of the study was to generate physical data on partially-grouted masonry shear walls for the verification of finite element modeling techniques designed for use in fully-grouted fully-reinforced masonry walls.

The response of shear walls subjected to lateral loads can be characterized by the following six major events: (1) tensile cracking of masonry in high flexure zones; (2) vertical bars yield in high flexure zones; (3) tensile shear-induced cracking near center of wall; (4) shear cracks propagate to form rupture plane; (5) yielding of horizontal and

vertical reinforcement; and (6) crushing of masonry in compression at loaded corners [Fattal 1993b]. These events, identified in Figure 1.1, do not necessarily occur in the sequence indicated. Certain events, such as yielding of reinforcement (events 2 and/or 5) may not occur, depending on the amount of reinforcement used, level of axial stress, and aspect ratio of the wall. The evaluation of shear mode response is the objective of the experimental study and each wall is designed so that shear cracking (events 3 and 4) occurs before compressive crushing at the diagonally-loaded corners (event 6). This allows for experimental evaluations of post-cracking gain in strength and deformation capacity.

The following chapters explain the parameters of the masonry walls in the experimental study and the rationale behind their selection as well as background for the finite element analysis.

1.0 EXPERIMENTAL STUDY

1.1 Masonry Wall Specimen Configurations

To achieve the objectives of the experimental phase of the NIST research program on partially-grouted partially-reinforced masonry shear walls, a total of six partially-grouted masonry shear wall test specimens with bond beams were constructed and tested. As illustrated in Figure 1.2, the walls were labeled as Wall 1, Wall 3, Wall 5, Wall 7, Wall 9, and Wall 11. These walls are part of a series of tests conducted at NIST. Additional walls will be tested at a later date. Only the outermost vertical cells of the walls were reinforced vertically and grouted and a single bond beam containing all horizontal reinforcement was placed at mid-height. The remainder of the masonry in the walls was not grouted. An illustration of a typical testing configuration is shown in Figure 1.3. All walls were built with seven courses of masonry for a total height of masonry equal to 1422 mm (56 in.). The first four masonry courses, including the middle course of bond beam units, were placed in a single day. The top three courses of the masonry were placed on the third day, and the remainder of the exterior vertical cells were grouted on the fourth day. Wall lengths equal to 1422 mm (56 in.), 2032 (80 in.), and 2845 mm (112 in.) were used to define three different height-to-length aspect ratios, r, as noted in Table 1.1.

Walls between floors in low-rise construction tend to be longer than they are high, making it commonplace for aspect ratios to be smaller than unity. It is recognized that little experimental information is available for aspect ratios less than unity, and the scarce information available suggests that the greatest influence of aspect ratio on shear strength takes place in this region [Schultz, 1994]. Due to the difficulty in testing stocky masonry

walls ($r < 1$) in the NIST Tri-directional Testing Facility (TTF), realistic wall heights were not employed. The aspect ratios $r_1 = 0.5$, $r_2 = 0.7$ and $r_3 = 1.0$ were selected to cover a wide range of aspect ratios found in typical masonry shear walls. These aspect ratios were selected so that the shear response of the walls could be examined. The likelihood of diagonal cracking through the units versus debonding of the mortar and masonry is higher with the aspect ratios chosen [Fattal 1993b].

For modularity in testing, the height of the specimens was kept constant while the length was varied. Variations in specimen height are not easily accommodated in the testing facility due to headroom requirements. A single height of 422 mm (56 in.) was selected for the following reasons. To produce an aspect ratio of 0.5, the maximum practical width that could be accommodated in the testing facility is 2845 mm (112 in.). Second, in erecting the panels, an odd number of courses were sought so that the single bond beam may be placed at mid-height rather than at a non-zero vertical offset from mid-height. The criteria used for the selection of sizes were comparability with sizes used in previous test conducted at NIST and headroom clearance requirements of the testing facility used to test the specimens.

The placement of horizontal and vertical bars and grout necessitates the use of hollow masonry units with large openings, accordingly concrete block masonry was used. The walls were constructed using two-cell concrete blocks with average length, thickness and height equal to 396 mm (15.6 in.), 195 mm (7.67 in.), and 194 mm (7.63 in), respectively. The units were 51% solid with a minimum face-shell thickness equal to 33.7 mm (1.33 in.). All masonry was face-shell bedded, except for the ends of the walls in

which exterior webs were also bedded. The concrete block met the requirements of ASTM C90 (ASTM 1985), and the mortar was mixed using proportions that satisfy Type S ASTM C270 (ASTM 1989). The grout mix was designed according to ASTM C476 requirements for coarse grout (ASTM 1983). The use of concrete block would also enable insight on behavioral similarities and differences of one of the most common types of masonry used in building construction. Their specified strengths are average values within the ranges of the respective masonry strengths used in building construction. Results of material tests conducted for the concrete block masonry of each specimen are given in Table 1.2. Grout proportion was selected to achieve an uniaxial compressive strength comparable to those of the concrete block units. For all of the specimens, the outer cells contain vertical reinforcement and the bond beam located at mid-height contain horizontal reinforcement as shown in Figure 1.3. These are the only grouted cells within the specimens. The bond beams were formed using bond beam masonry units. Horizontal reinforcement for these specimens is concentrated in these single grouted elements.

1.2 Vertical Reinforcement

As previously stated, the vertical reinforcement is located in the outer cells of the masonry wall specimens. The outer cells, shown in Figure 1.4, are the exterior cells located on each side of the specimens. Since failure in the shear cracking mode is the desired effect, sufficient reinforcement was placed in the outer cells to alleviate the possibility of premature in-plane flexural failure. The value of vertical reinforcement ratio, the total area of vertical bars divided by the gross horizontal cross-sectional area, was

estimated to make the specimens fail in the shear mode. The amount of vertical reinforcement was constant in each specimen, however, because the lengths of the specimens vary with aspect ratio, the steel areas provide different vertical reinforcement ratios. These vertical reinforcement ratios, based on gross area of horizontal sections, are given in Table 1.1 Two #6 Grade 60 deformed reinforcing bars, approximately 2210 mm (87 in.) long and providing 568 mm^2 (0.88 in^2) of steel area, were used to reinforce each outer cell of the masonry wall specimens as shown in Figure 1.4. This amount of reinforcement was deemed necessary to preclude flexural distress of the shear walls. The reinforcing bars extend above and below the 1422 mm (56 in.) height of masonry, and the ends of the bars extend into the pockets of the precast concrete header/footer beams. High-strength, non shrink grout serves to anchor the bars in these pockets. The ends of the vertical bars are threaded and a pair of steel nuts and a steel plate anchors the bars securely in the grout pocket.

1.3 Horizontal Reinforcement

Horizontal reinforcement is needed to prevent the onset of premature shear failure upon inclined cracking. Two horizontal reinforcement schemes, given in Table 1.1, were used for the bond beams to define horizontal reinforcement ratios, based on gross dimensions, that are equal to 0.05% and 0.12%, respectively. The first of these ratios represents the minimum value cited in most building codes and standards of practice for masonry in the United States [MSJC 1992, UBC 1994, NEHRP 1995]. The specimens have either 2-#3 or 1-#4 and 1-#5 Grade 60 deformed reinforcing bars in a single bond

beam which provide horizontal reinforcement ratios of 0.05% or 0.12%. Walls 1,3 and 5 consist of the two #3 bars while walls 7, 9 and 11 consist of one #4 and one #5 bars. This sequence is significant because the effect of increasing the reinforcement within identical specimens can be examined. In each specimen, one bar is placed above the other in the grout pocket, and one bar is placed on either side of the plane defined by the vertical bars as shown in Figure 1.5. The horizontal bars are continuous over the length of the panel. The ends are bent into 180° hooks, and the hooks are looped around the nearest vertical bar in the exterior cell at each end of the wall.

1.4 Precast Concrete Header/Footer Beams

In-plane shear and vertical compression stresses were applied to the walls by means of stiff precast concrete header/footer beams shown in Figure 1.3. The header and footer beams constrain the walls from rotating. They serve the auxiliary purposes of anchoring the vertical reinforcement and providing each wall a connection to the Tri-directional Testing Facility (TTF). The precast concrete header/footer beams, described in Figure 1.6, are prismatic members with a rectangular cross-section. These members feature multiple vertical openings of small diameter that enable lifting of the specimen using high-strength threaded rods. These openings are also used for the placement of the high-strength post-tensioned rods to attach the specimen to the TTF. In addition, the header/footer beams feature a pair of pockets in the shape of a truncated right pyramid, in which the vertical reinforcing bars of the wall panel are anchored (Figure 1.7). The vertical bars are anchored in each pocket. A steel plate, held in place by two steel nuts,

serve as mechanical anchorage for the vertical bars. The header/footer beams were cast using a lightweight concrete, with a 28-day compression strength equal to 34.5 MPa (5000 psi) and a specific weight of 18.85 kN/m^3 (120 lb/ft^3). This was done primarily in order to reduce the overall weight of the header/footer beam while still retaining sufficient strength to withstand the rigors of transportation and testing in the laboratory [Schultz, 1993].

1.5 Test Setup

The assembled specimens were placed in the Tri-Directional Test Facility (TTF) along its east-west axis and tested using the setup shown in Figure 1.8. The TTF is a computer controlled loading apparatus which can apply forces and/or displacements in all six degrees of freedom at one end of a specimen while the other end of the specimen remains fixed (Figure 1.9). The six specimens were displacement controlled with the sign convention of the TTF indicating a positive displacement acting to the west and a negative displacement acting to the east (Figure 1.9). The generation of displacements is accomplished by seven closed-loop, computer controlled actuators. The reaction system is composed of the structural tie down floor and two vertical buttresses. Control software for the TTF generates global force and displacement signals that define the translation and rotation of the upper crosshead along three orthogonal axes. These signals were digitized, recorded and stored along with the strains and displacements measured on the masonry panels.

1.6 Loading History

The displacement history, controlled by the horizontal actuator and subject to cyclic reversals, was imposed on the specimen along the east-west axis (along the in-plane horizontal direction of the masonry wall panel) of the TTF, while a vertical stress of 1.38 MPa (200 psi) was maintained for each wall. The axial stress of 1.38 MPa (200 psi) is representative of axial stress found in masonry walls in buildings. The primary control parameter used in the test was the horizontal displacement, vertical loads were maintained as constant as possible. As the wall cracked and slid, adjustment of control forces resulted in changes in the vertical load. Figure 1.10 shows the time history of the vertical load on the wall. Table 1.3 gives the calculated mean vertical load applied on each wall. For each wall, with the exception of Wall 9 and Wall 11, the mean vertical load resulted in a vertical stress of 1.38 MPa (200 psi) with a standard deviation not higher than 0.07 MPa as shown in Table 1.3.

The lower crosshead of the TTF is fixed, restricting any motion of the base of the specimens. The top crosshead is constrained in all degrees of freedom except for translation along the plane of the wall (east west direction). The east-west displacement history was applied at a slow rate that conforms to the Sequential Phased Displacement procedure developed as part of the TCCMAR program [Porter and Tremel, 1987]. In this procedure, groups of displacement cycles are organized around peak amplitudes that are gradually increased to failure. An idealized plot is shown in Figure 1.11. This procedure uses the displacement that produces the first major event as a benchmark. Peak amplitudes after the initial elastic displacements are tied to the first major event (FME).

The FME is defined as the formation of the first inclined crack and determined by identifying a sharp decrease in stiffness in the masonry specimen. Two distinct types of displacement cycles are featured in the experiment. They are the degradation cycles in which the cycle peak displacement amplitude decreases and the stabilization cycles in which cycle peak displacement amplitude is maintained constant.

1.7 Instrumentation

The shear wall specimens were instrumented with linear variable differential transformers (LVDT), linear strain transducers (LST), and electrical resistance strain gages (ERSG), to monitor wall displacements, masonry strains, and reinforcing bar strains. The total lateral displacement of the wall was measured using three LVDT's attached to a steel frame that were erected adjacent to the TTF as shown in Figure 1.12. Two other LVDT's were used to determine the change in length of the principal diagonals, and six LVDT's were used to measure the vertical shortening/elongation of the exterior cells. A pair of LVDT's were also used to monitor the lift-off/crushing of the bottom corners of the masonry specimen. The linear strain indicators (LST), strain amplifying devices utilizing strain gages mounted of leaf springs shown in Figure 1.13, were placed at various locations to monitor local strains in the masonry. Electrical resistance strain gages, shown in Figure 1.14, are attached to the horizontal and vertical reinforcing bars. They were used to monitor strain changes in the reinforcement.

The instruments described above are in addition to the internal load cells and displacement transducers in the hydraulic actuators of the TTF. The control software for

the TTF generates global force and displacement signals that define the translation and rotation of the upper crosshead along three orthogonal axes. These signals were digitized, recorded, and stored along with the strains and displacement measured on the masonry panels. The cyclic drift histories were applied over several days and adjustments were made to all gauges on the masonry panel to ensure continuity throughout any test. A new day's testing always started with the ERSG, LVDT and LST reset to an initial reading of zero. The reading of each day is then added to the last reading from the previous day.

2.0 FINITE ELEMENT STUDY

2.1 FEM/I Program

The information in this chapter pertaining to FEM/I can be found in Section 3.0 of the reference manual [Ewing 1987]. It is summarized here for convenience to the reader. FEM/I Version 110 is a nonlinear, two-dimensional finite element computer program for the static analysis of reinforced masonry building components. The program contains one nonlinear and one linear material model. The non-linear material model is designed to represent reinforced masonry or reinforced concrete under biaxial loading. The linear model can be used when an elastic analysis is desired. Both models can be subjected to any combination of static loading including concentrated nodal point forces, gravity loads, normal, and tangential distributed edge loads and prescribed nodal point displacements. FEM/I uses a sign convention that a negative sign represents compression and a positive sign represents tension. The program uses an initial stiffness formulation with an incremental solution method. FEM/I allows displacements or forces to be used as the primary excitation. As described in the following sections, non-linear material models were used to represent the masonry wall components. Displacements, identical to those generated in the experimental study, were used as the primary excitation in FEM/I analysis. Chapter 3.0 provides a detailed description of the model calibration for each wall. Data generated from FEM/I analysis where convergence was not met was omitted from any comparisons made to the experimental data.

FEM/I generates a force-deflection file, major event file and an output file. The force-deflection file contains a component of the reaction force and the deflection at a

node that has prescribed displacement The output file contains element stress and strain data. The major event file contains a record of the major events of each element. This includes: load increment at which first tensile cracking occurs in the masonry, maximum and minimum values of the tensile crack orientation, load increment at which the masonry peak strength is reached, load increment at which yielding of the vertical and horizontal reinforcement occurs, load increment at which the damage factor is invoked for the masonry in compression, and maximum strains in the vertical and horizontal reinforcement.

2.2 Analytical Model

The finite element models in FEM/I were developed to represent the in-plane static, nonlinear response of masonry components and walls. The analytical models and the constitutive relations used for reinforced masonry walls account for the various biaxial stress states that can exist in the walls as well as the pre- and post-cracking behavior. The analytical model uses a two-dimensional finite element formulation with nonlinear stress-strain relations for the reinforced masonry. The masonry and reinforcement are modeled separately, and their interaction is included by using four node, isoparametric, plane stress overlay elements and specialized stress-strain relations.

In the layered model, two quadrilateral elements occupy the same space, overlaying each other, where one layer represents the masonry other represents the steel reinforcement. Although the material models for the masonry and reinforcement are described separately, the element is a smeared hybrid element, where the computed strains

are assigned to both materials. The hybrid elements are used only in the regions which reinforcing bars are present. This includes the vertical exterior cells, horizontal bond beam located at mid-height, and header and footer beams of the specimens. The appropriate reinforcement for each is smeared only in these regions thus causing the reinforcing ratios to be different from those calculated in the experimental study given in Table 1.1. The smeared model assumes that the reinforcement is distributed over the whole element and that two components (reinforcement and masonry) are in full bond at the nodes. The bond slip between two components is considered to be a material property of the masonry component in tension and is defined by a tension stiffening model [Ewing, 1987].

The analytical model assumes that tension cracks are smeared over the element. A crack is allowed to form when the principal tensile strain exceeds the cracking strain of the masonry, and the crack forms perpendicular to the direction of principal tensile strain. The model also incorporates a tension crack orientation adjustment approach, where the orientation of the final cracks can be different from the initial cracks. Compressive strength reduction occurs after tensile cracking normal to the principal compressive strains and is based on reinforced concrete research [Vecchio and Collins, 1982]. Additionally, the model includes a compressive strength increase due to lateral compressive confinement. The strength increase depends on the magnitude of the principal compressive stresses that are normal to the principal compressive stresses [Ewing, 1987].

2.3 Compression Models for Masonry Wall Specimens

The material behavior in compression for the grouted concrete block masonry, ungrouted concrete block masonry and lightweight concrete used in the shear wall specimens tested are described by a set of stress-strain relations. The stress-strain curve for each material is shown in Figure 2.1, Figure 2.2 and Figure 2.3 and based on the materials compressive properties of each specimen given Table 1.2. A complete relationship of stress and strain was not developed during material testing of the wall components. The shape factors were determined by fitting equations 2.1, 2.2 and 2.3 with the "Best-Fit" stress-strain analytical model [Hart, 1989]. This model is appropriate for use in computer analyses.

The stress-strain curves are described by two second-order polynomials and an exponential tail defined by the following equations:

$$f(\varepsilon) = f_m\left[A_1\left(\frac{\varepsilon}{\varepsilon_o}\right) - \lambda\left(A_1 - 1\right)\left(\frac{\varepsilon}{\varepsilon_o}\right)^2\right];\ 0 \geq \varepsilon \geq \varepsilon_p \tag{2.1}$$

$$f(\varepsilon) = f_p\left[1 - \frac{\left(\varepsilon - \varepsilon_p\right)^2}{\left(A_2\varepsilon_o - \varepsilon_p\right)^2}\right];\ \varepsilon_p \geq \varepsilon \geq \varepsilon_e \tag{2.2}$$

$$f(\varepsilon) = f_e\left[A'_3 + \left(1 - A'_3\right)\exp\left[-\gamma\left(\frac{\varepsilon - \varepsilon_e}{\varepsilon_e}\right)\right]\right];\ \varepsilon < \varepsilon_e \tag{2.3}$$

where $f(\varepsilon)$ = Principal compressive stress in the masonry; γ = Exponential parameter; ε = Principal compressive strain in the masonry; ε_e = Point of tangency between Equations 2.2 and 2.3; f_m = Uniaxial compressive strength of the masonry; f_e = Compressive stress at point of tangency, ε_e; ε_o = Strain at uniaxial compressive strength, f_m; A_1 = Shape factor

for the rising branch; f_p = Peak uniaxial compressive strength of the masonry; A_2 = Shape factor for the initial falling branch; ε_p = Strain at peak uniaxial compressive strength, f_p ; A_3 = Shape factor for the exponential falling branch; λ = Strength modification factor; and A'_3 = Shape factor for the exponential falling branch.

The lower limit of the exponential branch of Equation 2.3 is controlled by A_3. A_3 is determined by the following equation:

$$A'_3 = A_3\left(\frac{f_m}{f_e}\right) \tag{2.4}$$

The strength modification factor λ, accounts for a strength reduction after tensile cracking normal to the principal compressive strains or strength increase due to lateral compressive refinement. Prior to any strength modification (λ = 1) the peak uniaxial compressive strength, f_p, and the strain at peak strength, ε_p, are equal to f_m and ε_o, respectively. After a strength modification they are functions of λ as given by the following equations:

$$\varepsilon_p = \frac{\varepsilon_0}{\lambda} \tag{2.5}$$

$$f_p = \frac{f_m}{\lambda} \tag{2.6}$$

The exponential parameter γ, is determined by the following equation:

$$\gamma = \frac{2f_m}{\lambda f_e}\,\frac{\varepsilon_e}{\left(1 - A'_3\right)}\,\frac{\left(\varepsilon_e - \varepsilon_p\right)}{\left(A_2\varepsilon_o - \varepsilon_p\right)^2} \tag{2.7}$$

The stress-strain characteristics of the masonry in compression are determined by the following six parameters: f_m, ε_o, A_1, A_2, A_3, and A_4. These parameters are given in the Input Data File section (Appendix B - G) for each specimen.

2.4 Tension Stiffening Models for Masonry Wall Specimens

Three models described below are included in FEM/I to account for the tension stiffening effect in the composite overlay element of the masonry and reinforcement. They include unreinforced masonry model, reinforced masonry model and reinforced concrete model. Each model was used to represent their corresponding sections within the wall specimens. Tensile properties were estimated using values from previous NIST tests. Air-cured masonry prism tests, given in Table 1.2, were conducted to estimate the compression strength of the concrete masonry. The mean of the test data were used to represent the compression strength, f'_m, for each specimen. The modulus of elasticity was then calculated using the relationship 550 f'_m. This is a realistic relationship regardless of whether the assemblage is grouted or ungrouted concrete masonry [Schneider and Dickey, 1987]. Due to the variability in the compression strength test data and calculated modulus of elasticity, FEM/I analyses were conducted using various combinations of the compression strength data. These analyses did not significantly affect the response of the specimens. Thus, using the mean of the compression strength test values is appropriate.

2.4.1 Unreinforced Masonry Tension Stiffening Model

Unreinforced masonry model was used in the region of the masonry walls which is not reinforced. This model contains no tension stiffening effect (Figure 2.4) and is defined by the following equations:

$$f(\varepsilon) = E_t \varepsilon_t ; \; 0 \leq \varepsilon_t \leq \varepsilon_{cr} \tag{2.8}$$

$$f(\varepsilon) = 0; \; \varepsilon_t > \varepsilon_{cr} \tag{2.9}$$

where $f(\varepsilon)$ = Stress in the masonry due to tension stiffening; E_t = Modules of elasticity of the masonry in tension; ε_t = Tensile strain in the masonry; and ε_{cr} = Tensile cracking strain of the masonry.

2.4.2 Reinforced Masonry Tension Stiffening Model

Reinforced masonry model was used in regions of the masonry walls which contained reinforcement. These regions include the two exterior cells and the bond beam located at mid height of the specimens. The stress-strain relation for the exponential tension stiffening model (Figure 2.5) is defined by the following equations:

$$f(\varepsilon) = E_t \varepsilon_t ; \; 0 \leq \varepsilon_t \leq \varepsilon_{cr} \tag{2.10}$$

$$f(\varepsilon) = f_{cr} \left[B_1 + (1 - B_1) \exp\left[-\alpha \frac{(\varepsilon_t - \varepsilon_{cr})}{\varepsilon_{cr}} \right] \right]; \; \varepsilon_t > \varepsilon_{cr} \tag{2.11}$$

in which E_t = Modulus of Elasticity in tension; ε_t = Tensile strain in the masonry; f_{cr} = Tensile cracking strength of masonry; B_1 = Lower limit of the exponential branch; α = Exponential parameter; and ε_{cr} = Tensile cracking strain of the masonry.

2.4.3 Reinforced Concrete Tension Stiffening Model

Reinforced concrete model was used to model the concrete header and footer of the masonry walls which contained reinforcement. The stress-strain relation for the exponential tension stiffening model (Figure 2.6) is defined by the following equations

$$f(\varepsilon) = E_t \varepsilon_t ;\ 0 \le \varepsilon_t \le \varepsilon_{cr} \tag{2.12}$$

$$f(\varepsilon) = \frac{f_{cr}}{1 + (200\varepsilon_t)^{1/2}} ;\ \varepsilon_t > \varepsilon_{cr} \tag{2.13}$$

in which E_t = Modulus of Elasticity in tension; ε_t = Tensile strain in the masonry; and ε_{cr} = Tensile cracking strain of the masonry.

2.5 Bimodular Masonry and Concrete Models

The grouted masonry, ungrouted masonry and concrete models for tensile and compression strains are shown in Figure 2.7, Figure 2.8 and Figure 2.9, respectively. In these figures the compression and tension stiffening models previously defined are combined and illustrate the complete stress-strain curve for each masonry specimen. As stated in Section 2.3, the relationship was determined by fitting the stress-strain curve with the "Best-Fit" analytical model developed by Hart [Hart, 1989].

2.6 Reinforcement Model for Masonry Wall Specimens

The reinforcing steel is represented by a bilinear model as shown in Figure 2.10 and used to represent the reinforcement present in the specimen. The plastic modulus is given by

$$E_{sp} = E_s \left[1 - \frac{E_s}{E_s + H'} \right] \tag{2.14}$$

where E_{sp} = Plastic modulus of the reinforcement; E_s = Modulus of elasticity of the reinforcement; ξ = Bilinear factor; and the strain-hardening parameter is

$$H' = \frac{\xi E_s}{(1 - \xi)} \tag{2.15}$$

3.0 FEM/I ANALYSES OF MASONRY WALL SPECIMENS

3.1 Finite Element Model for Wall 1 and Wall 7

The finite element mesh used in the analysis of Wall 1 and Wall 7 is shown in Figure 3.1. The origin of the coordinate system is represented as a solid circular dot. At this point the x-coordinate is positive to the right and the y-coordinate is positive upwards. The model contains 162 elements and 192 nodes. Four node quadrilateral elements were used to represent the masonry specimen. The concrete header and footer is represented by Elements 1 through 32. The header and footer is subdivided into two materials: concrete containing horizontal and vertical reinforcement and concrete containing only horizontal reinforcement (Figure 3.2). The masonry wall is represented by Elements 33 through 130. The masonry wall is subdivided into four materials: grouted masonry with vertical reinforcement only, ungrouted unreinforced (hollow) masonry, grouted masonry with horizontal and vertical reinforcement, and grouted masonry with horizontal reinforcement (Figure 3.2). As previously stated, the difference between Wall 1 and Wall 7 is the amount of horizontal steel reinforcement located at mid-height of the masonry specimen. A thickness equivalent to twice the face-shell thickness 68.07 mm (2.68 in.) was used to model the sections of the shear wall specimens made of hollow concrete block units.

The concrete base, shown with triangles in Figure 3.1, is pinned at its lowest level at Nodes 1 through 17. The vertical axial stress of 1.38 MPa (200 psi) is applied downward along the top edge of the wall at Elements 117 through 130 and remains constant throughout the displacement history. Lateral displacements were subsequently

applied. The cyclic horizontal displacements were applied at the top of the concrete header at Nodes 176 through 192. These cycles are consistent with those generated during the experiment of Wall 1 and Wall 7 with the exception of a sign reversal (Figure 3.3 and Figure 3.4). The sign reversal is required due to the opposite x - displacement sign conventions of TTF and FEM/I data. Rate of loading is not an input parameter because FEM/I is a static analysis finite element program.

The FEM/I input data files and input descriptions for Wall 1 and Wall 7 are given in Appendix B and Appendix E, respectively. The preparation of the input data follows directly from the model calibration and the instructions given in Section 5.0 of the FEM/I Users Manual [Ewing, 1987]. A description of the input for each wall is provided for clarity.

3.2 Finite Element Model for Wall 3 and Wall 9

Finite element models for Wall 3 and Wall 9 are identical with the exception of the amount of horizontal reinforcement, which is previously noted, and the displacement cycle. The finite element mesh used in the analysis of these walls is shown in Figure 3.5. The origin of the coordinate system is represented as a solid circular dot. The model contains 118 elements and 144 nodes. Four node quadrilateral elements are used to represent the masonry specimen. The concrete header and footer is represented by Elements 1 through 24. The header and footer is subdivided into two materials: concrete containing horizontal and vertical reinforcement and concrete containing only horizontal reinforcement (Figure 3.6). The masonry wall is represented by Elements 25 through 94.

The masonry wall is subdivided into four materials: grouted masonry with vertical reinforcement only, ungrouted unreinforced (hollow) masonry, grouted masonry with horizontal and vertical reinforcement, and grouted masonry with horizontal reinforcement (Figure 3.6). A thickness equivalent to twice the face-shell thickness, 68.07 mm (2.68 in.), was used to model the sections of the shear wall specimens made of hollow concrete block units. The concrete base, shown with triangles in Figure 3.4, is pinned at its lowest level at Nodes 1 through 13. The vertical axial load of 1.38 MPa (200 psi) is applied downward along the top edge of the wall at Elements 85 through 94 and remains constant throughout the displacement history. Lateral displacements were subsequently applied. The cyclic horizontal displacements were applied at the top of the concrete header at Nodes 132 through 144. These cycles are consistent with those generated during the experiment of Wall 3 and Wall 9 with the exception of a sign reversal (Figure 3.7 and Figure 3.8). FEM/I input data files and input descriptions for Wall 3 and Wall 9 are described in Appendix C and Appendix F, respectively.

3.3 Finite Element Model for Wall 5 and Wall 11

The finite element mesh for these specimens are shown in Figure 3.9. The solid circular dot shown in the Figure 3.9 represents the origin of the coordinate system and the sign convention is identical the models described in previous sections (x-coordinate is positive to the right and the y-coordinate is positive upwards). The model contains 85 elements and 108 nodes. Four node quadrilateral elements were used to represent the masonry specimen. The concrete header and footer is represented by Elements 1 through

18. The header and footer is subdivided into two materials: concrete containing horizontal and vertical reinforcement and concrete containing only horizontal reinforcement (Figure 3.10). The masonry wall is represented by Elements 19 through 67. The masonry wall is subdivided into four materials: grouted masonry with vertical reinforcement only, ungrouted unreinforced (hollow) masonry, grouted masonry with horizontal and vertical reinforcement, and grouted masonry with horizontal reinforcement (Figure 3.10). A thickness equivalent to twice the face-shell thickness, 68.07 mm (2.68 in.) was used to model the sections of the shear wall specimens made of hollow concrete block units. The concrete base, shown with triangles in Figure 3.9, is pinned at its lowest level at Nodes 1 through 10. The vertical axial load of 1.38 MPa (200 psi) is applied downward along the top edge of the wall at Elements 61 through 67 and remains constant throughout the displacement history. Lateral displacements were subsequently applied. The cyclic horizontal displacements were applied at the top of the concrete header at Nodes 99 through 108. These cycles are consistent with those generated during the experiment of Wall 5 and Wall 11 with the exception of a sign reversal (Figure 3.11 and Figure 3.12). Appendix D and Appendix G contain the FEM/I input data files and input descriptions for Wall 5 and Wall 11, respectively.

4.0 RESULTS FROM EXPERIMENTAL STUDY AND FEM/I ANALYSIS

4.1 Comparison of Behavior Between Experimental Data and FEM/I Predictions

During the early stages of the experimental tests, all specimens developed cracks in the ungrouted masonry above the bond beam, but there were two distinct cracking modes as illustrated in Figures 4.1 - 4.6. For all specimens except Wall 3, the first cracks were vertical and they formed at the top of the walls near the interface between the grouted vertical cell and the ungrouted masonry. The cracks formed on the leading jamb of the wall (i.e. east jamb for east displacement and west jamb for displacement moving westward) and quickly propagated downward towards the joint between the grouted vertical cell and bond beam as the tests proceeded. For Wall 3, the first cracks were inclined (Figure 4.2). They initiated near the midpoint along the top edge of the wall, and they propagated towards the joint between the bond beam and the vertical cell as Cycles 53 - 72 of Figure 4.2 illustrates. Inclined cracks illustrated in Figure 4.1 and Figures 4.3 - 4.6, formed in the upper half of the masonry panels in Walls 1, 5, 7, 9 and 11. However, these inclined cracks occurred after the vertical cracks were considerably larger than those of the inclined cracks throughout the test. This behavior suggests that the partially grouted and partially reinforced walls behaved as an in-filled frame. Figures 4.1 - 4.6 also illustrate local spalling/crushing occurring in the final cycles of the experiment for Walls 1, 3, 5 and 7.

During the first cycles of the FEM/I analysis, every wall developed widespread cracks as illustrated by the shaded regions in Figures 4.1 - 4.6. The shaded notation for cracking was used because the actual length and orientation of the cracks could not be

determined. The masonry model used to represent the specimens incorporates a tensile crack orientation adjustment approach where the orientation of the final cracks can be different from the initial cracks [Ewing 1987]. These cracks develop much earlier and more widespread than the cracks in the experimental study. For each wall, cracks are present throughout the wall by the fifth cycle. In each model, cracking of the ungrouted sections occur first; followed by cracking in the reinforced grouted sections. Figures 4.1 - 4.6 also illustrate severe crushing of the lower half of each masonry model. With the exception of Wall 3, the crushing of the masonry in the models does not occur in the same location as the spalling of the masonry in the experiment. FEM/I is also unable to model some siding between the wall and the header/footer beam that was observed during the experiment.

Although FEM/I demonstrated an inability to realistically model the cracking pattern generated in the experiment, it was able to predict the force-displacement response of the specimens up to the occurrence of the first major event (FME) as Figure 4.15 illustrates. As stated in Section 1.6, the FME is defined as the formation of the first inclined crack in the experiment and determined by identifying a sharp decrease in stiffness in the masonry wall. The FME's were determined using the force-displacement cycles in Figure 4.13. Using these figures, the cycle displaying a sharp decrease in the stiffness was identified as the cycle containing the FME. The sharp decrease in stiffness represents the formation of a crack in the specimen as illustrated in Figure 4.5. In this figure, Cycle 24 demonstrates initial cracking within Wall 9. This occurs near the same cycle that a decrease in stiffness is identified.

Table 4.1 examines the effectiveness of FEM/I in simulating the response of the specimens by the following calculations: the ratio of the lateral loads at the FME (FEM/I lateral load divided by experimental lateral load); ratio of the peak lateral loads (FEM/I peak lateral load divided by experimental peak lateral load); the amount of energy accumulated at the FME (energy dissipated from FEM/I divided by energy dissipated from experiment); and the amount of energy accumulated at the end of the FEM/I analysis (total energy dissipated from FEM/I divided by energy dissipated from experiment at the end of the FEM/I analysis). In Table 4.1, the ratio of the lateral loads at the FME demonstrate a good relationship in the forces generated by FEM/I for each wall with the exception Wall 1. Results from Walls 3, 5, 9 and 11 exhibit that FEM/I was able to predict the lateral load adequately up to the FME. The ratio of the lateral load up to the FME ranges from 0.9 - 1.3 as shown in Table 4.1. After the occurrence of the FME, FEM/I overpredicts the lateral load considerably. For Walls 3, 5, 7 and 9, the peak lateral load generated by FEM/I is approximately two to three times the peak lateral load obtained in the experiment as shown in Table 4.1.

FEM/I's inability to realistically model the cracking pattern and sliding of the experiment resulted in much lower energy dissipation as shown in Figure 4.16. The large difference in the amount of energy dissipated is also illustrated in Table 4.1 by the ratio of the amount of energy dissipated at the FME and at the end of the FEM/I analysis. FEM/I significantly underestimates the amount of energy dissipated up to the FME. The accumulated energy dissipated ratio's from experimental data at the FME are significantly greater than the accumulated energy dissipated ratio's at end of the FEM/I analysis with

the exception of Wall 1 (Table 4.1). This is another indication that FEM/I only performs well up to the FME. However, low ratio's in the amount of energy illustrate FEM/I's inability to model the sliding between the wall and the header beam throughout the experiment.

Initial vertical cracks in specimens 1, 5, 7, 9 and 11 occurred in response to the horizontal stress concentration between grouted and ungrouted masonry. It is not completely clear why Wall 3 did not exhibit this type of behavior, but it appears that the differences in the actual anchorage conditions for the vertical bars in Wall 3 may have played a role. It is suspected from cracking in the grout pocket that the vertical bars in Wall 3 were not securely anchored in the header/footer beam [McKey, in progress]. It is clear, however, that the cracking mode played a significant role in the post-cracking behavior and resistance of the specimens. For Walls 1, 5, 7, 9 and 11, the vertical cracks dominated the behavior of the walls, as few other cracks formed during the tests. As the header beam of the walls were displaced, the width of the vertical cracks on the leading jamb grew up to 6 mm (1/4 in.). These cracks eventually propagated into the joint between the bond beam and vertical cell with the effect of disturbing the anchorage of the horizontal reinforcement. In addition, sliding displacements were evident between the masonry panels and the header and footer beams, and the mortar joints were damaged by abrasion from sliding [McKey, in progress]. Once the vertical cracks developed, these walls looked and behaved like an infilled frame. The lateral deflection is mainly resisted by the reinforced columns and the masonry infill behaving as a strut.

Wall 3 of the experiment responded in a manner similar to that of the fully-reinforced and fully-grouted masonry walls. Numerous inclined cracks formed following the initial cracks described earlier, and none of these well-distributed cracks opened as widely as did the vertical cracks in the other specimens. Furthermore, some of the inclined cracks propagated into the joint between the bond beam and vertical cell, but this occurred late in the test after yielding of the vertical and horizontal reinforcement. These cracks do not appear to have disturbed the anchorage of horizontal bars as much as the vertical cracks did in Walls 1, 5, 7, 9 and 11.

The horizontal strains were measured at the center of the horizontal bars, because inclined cracks were expected to traverse the bond beam at mid-length. It was expected that at this location, strains would be significantly greater than in regions of minor cracking. Therefore, the measured strain could provide insight on localized behavior of the specimen. Horizontal reinforcement in Wall 3 of the experiment achieved peak strain of 0.002 mm/mm, whereas peak strains in the horizontal reinforcement of the other specimens were a small fraction of the nominal yield strain of steel. Table 4.1 shows that FEM/I predicts yielding in Walls 1, 3 and 5. The cracking pattern in Walls 1, 5, 7, 9 and 11 show cracks near the joint between the vertical reinforcement and the bond beam. This cracking pattern suggests that the location of maximum strain is not at the mid-point of the beam as expected. It is possible that peak horizontal bar strains in these walls were much larger at the ends. In any case, it appears that the cracking mode for these walls decrease the effectiveness of horizontal reinforcement.

4.2 Comparison of Force-Displacement Response in Experimental Study and FEM/I Analysis

Force-displacement plots of each cycle were constructed to examine the force-displacement response for each specimen. The response of all shear wall specimens to the cyclic drift histories were reasonably stable and well-behaved as illustrated in Figures 4.7 - 4.12. Initial response to load was linear. This response was characterized by relatively high stiffnesses. As the peak amplitude of the displacement cycles increased, the header experience some sliding with respect to the wall. This sliding decreased the amplitude of the force and increased the area in the hysteresis loops. Evidence of sliding is illustrated in Cycles 13, 13 and 7 of Figures 4.7, 4.8 and 4.9, respectively, by the widening of the force-displacement hysteresis curves prior to any reinforcement yielding. Cracking in the wall as a result of the large displacement also decreases the stiffness of the wall. As illustrated in Figure 4.13, after the peak strength is reached, the peak strength of each displacement cycle decreased even though the applied displacements increased (with the exception of Wall 1). However, none of the specimens displayed a sudden failure, and the peak resistance of each cycle gradually decreased with load cycles after the FME. The ERGS records show that the steel has yielded at Cycles 28, 60, 24, 33, 30 and 23 for Walls 1, 3, 5, 7, 9 and 11, respectively. Steel yielding also contributes to the widening of the hysteresis loops. Yielding of the reinforcing bars occurred during significant cracking of the specimens, well after the FME.

Individual force-displacement cycles were also constructed to examine the force-displacement response for each wall in the FEM/I analysis in relation to the experimental

study. The response of the models are illustrated in Figures 4.7 - 4.12. The initial response to load was linear and characterized by stiffnesses and peak loads of cycles significantly larger than the experimental results. As the displacement amplitude of the cycles increased, the force-displacement hysteresis curves began to widen as illustrated in Cycles 33, 60, 28 and 33 in Figures 4.7 - 4.12, respectively. However, the widening of these loops are significantly less than those generated from the experimental data. The individual cycles represented in Figures 4.7 - 4.12 illustrate various stages of the displacement history. FEM/I performed reasonably well in predicting the response of some of the walls. For example, Walls 3, 5, 9 and 11 produced force-displacement relationship similar to the experimental data up to the FME. Also, FEM/I results for Wall 7 corresponded well with the experimental data during the initial stages (Cycles 1 - 17) of its displacement history.

During the validation of FEM/I, envelopes were developed to establish the correlation between the analysis and experimental data. In the validation of the fully-grouted fully-reinforced walls, the peak lateral forces from FEM/I compared well with those from the experiment [Ewing, 1987]. Results from the validation of FEM/I for the fully-grouted fully-reinforced walls are described later in this section. Envelopes of force-displacement response were constructed by sequentially scanning each history and collecting all force-displacement coordinate pairs for which the displacement exceeded the previous cycle's peak displacement. Envelopes constructed from experimental data, shown in Figure 4.15, are essentially bilinear. The envelopes have a marked limit of proportionality that strongly resembles a "yielding system," even though there was no

widespread yielding in the walls at this point (Figure 4.15). These envelopes also illustrate the manner in which total lateral load resistance of the walls generally decreased with increasing aspect ratio.

Envelopes of force-displacement response were constructed from FEM/I as shown in Figure 4.15. The force-displacement envelopes from FEM/I and experimental data are quite similar up to the FME. Table 4.1 shows that the peak loads predicted by the FEM/I, are significantly higher than the values generated from the experiment after the FME. In the validation of FEM/I with fully-grouted fully-reinforced masonry walls, the peak loads ranged from 1% to 20% of the experimental peak load [Ewing, 1987]. In the present work, Wall 3 and Wall 11 had the best peak load comparison of the six walls. Wall 11 had a peak load 31 % higher than the experimental peak load and Wall 3 was 41% higher than the experimental peak load. With the exception of Wall 1, the remaining walls had a peak load of approximately 80% greater than its experimental value. Differences in peak loads could be attributed to the variability in the uniaxial compressive strength, as indicated by the prism strength variations given in Table 1.2. Smearing of properties in the masonry model, cracking and sliding of the specimens also contributes to the difference between FEM/I and experimental data. Envelopes generated in Figure 4.15 illustrate that FEM/I performs well in the elastic range but overestimates the peak load as previously mentioned. The envelopes show a marked limit of proportionality which occur near the first major event as defined in Section 1.6. As widespread yielding of the vertical reinforcement occurred in the models, convergence problems occurred in FEM/I when yielding of steel through the wall is coupled with crushing of masonry through the wall.

This is illustrated by comparing Figures 4.19 - 4.24 and Figures 4.1 - 4.6 to Figures 4.7 - 4.12.

4.3 Comparison of Wall Toughness and Strength in Experimental Study and FEM/I Analysis

Energy dissipation capability is an important consideration in seismic design. Energy dissipation through hysteretic damping can reduce the amplitude of seismic response and, thereby, reduce the ductility demand on the structure. The ability of a wall to dissipate energy is defined as the wall's toughness herein. Cumulative energy dissipation, illustrated in Figure 4.16, was obtained by integrating each force-displacement loop and accumulating these areas. The cumulative dissipated energy was normalized by one-half of the product of force and displacement at the limit of proportionality so that specimens with different strengths and stiffnesses can be compared. This product is defined as the energy dissipation factor. In the experimental study, the amount of horizontal reinforcement does not seem to affect the ability of the walls to dissipate energy, but increasing the height-to-length aspect ratio decreases the wall's toughness significantly.

LVDT's were used to measure the total lateral displacement of the shear wall specimens. A portion of the lateral displacement and energy dissipation of the specimen is due to sliding [McKey, in progress]. Plastic deformation and sliding between the header/footer beams and the shear wall specimens widen the force-displacement hysteresis curves, thus increasing the amount of energy dissipated.

As Figure 4.16 illustrates, the amount of energy dissipated for FEM/I analyses is significantly lower than the experiment. The cumulative energy dissipated is related to the amount of cracking occurring in the wall, the sliding between the wall and the header/footer beam, and yielding of the steel. The difference in the cumulative energy dissipated for the FEM/I analyses and the experimental study is due to FEM/I's inability to accurately model the crack behavior and sliding of the walls. Figure 4.16 also shows that the amount of horizontal reinforcement does not seem to affect the ability of the walls to dissipate energy.

Deformation capacity is another measure of toughness. It is defined as the displacement at which lateral load resistance decreases to 75% of the peak load. All specimens except Wall 1 were tested until the peak resistance for a given cycle was less than 75% of the largest horizontal force registered by that wall. In the FEM/I analysis, deformation capacities for Wall 9 and Wall 11 were not reached due to convergence problems. The deformation capacities, which were obtained from the envelopes, are given in Table 4.1. They range from 0.33% to 1% of the height of the masonry wall. These values appear to be low for regions of high seismic risk, but may be acceptable for regions of low seismicity.

4.4 Influence of Parameters on the Performance of Partially Grouted Partially Reinforced Walls

The peak load resisted by the wall specimens, after averaging the values for both loading directions, were divided by net horizontal area to define the ultimate shear

stresses. The net horizontal area was taken as the product of twice the minimum face-shell thickness of the block and the total length of the wall. The additional area due to the grout in the vertical cells was neglected. These ultimate shear stresses show a marked dependence on the aspect ratio as illustrated in Figure 4.17. Figure 4.17 illustrates that increasing the aspect ratio of the specimens has a larger effect on the ultimate shear stress for the walls with a $\rho_h = 0.05\%$. As the aspect ratio doubles from r = 0.5 to r = 1.0, the ultimate shear stresses increases by 42% for specimens with $\rho_h = 0.05\%$ (Wall 1 and Wall 5) and by 28% for specimens with $\rho_h = 0.12\%$ (Wall 7 and Wall 11). Figure 4.18 illustrates that an increase in the horizontal reinforcement ratio has a modest beneficial influence on the ultimate shear stress. The ultimate shear stress in walls with an aspect ratio of r = 0.5 and r = 1.0 increased by 29% and 16% as ρ_h increases from 0.05% to 0.12%, respectively. However, Wall 3 does not fit this trend, as illustrated in Figure 4.18. In fact, the ultimate shear stress for Wall 3 exceeds that of all other specimens. In view of this discrepancy and differences in cracked pattern and horizontal bar peak strain noted in previous sections, it is concluded that Wall 3 was probably constructed differently than the other walls.

The ultimate shear stress obtained from the FEM/I analysis also show a marked dependence on the aspect ratio as illustrated in Figure 4.17. However, its effect is opposite of that observed in the experimental study. As aspect ratio doubles from r = 0.5 to r = 1.0, the ultimate shear stress decreases by 12% for walls with $\rho_h = 0.05\%$ and by 22% for walls with $\rho_h = 0.12\%$ (Figure 4.17). Horizontal reinforcement ratio does not have an influence on ultimate shear stress as shown in Figure 4.18. Walls with aspect

ratios of r = 0.5 (Wall 1 and Wall 7) and 0.7 (Wall 3 and Wall 9) show slight changes when ρ_h is increased, while the slender walls (Wall 5 and Wall 11) show a 13% decrease in ultimate shear stress as ρ_h increases from 0.05% to 0.12%. None of these trends follow those generated from the experiment due to the effects of sliding. Wall 1 and Wall 7 have big loops in some cycles indicating significant sliding. Therefore, the effective displacement during those cycles are equal to the applied displacement minus the sliding displacement which resulted in smaller shear forces. FEM/I does not model the sliding effects therefore producing larger shear forces as illustrated in Figure 4.17.

4.5 Comparison of Local Behavior in Experimental Study and FEM/I Analysis

The local behavior of the shear wall specimens were monitored by electrical resistance strain gauges (ERSG), linear variable differential transformers (LVDT), and linear strain transducers (LST) mentioned in Section 1.7. As illustrated in Figure 1.14, the ERSG were attached to the horizontal and vertical reinforcing bars, and monitored the strain in the reinforcement. Table 4.1 lists the cycles at which yielding of the reinforcement occurs. The LST's are strain amplifying devices that uses strain gauges mounted on leaf springs. They are used to measure the local strains in the masonry. The LST provides a local measurement of masonry strain, while the LVDT gives an average measurement of masonry strain over the gauge length [McKey, in progress].

As shown in Table 4.1, the vertical reinforcement yielded in each specimen. The vertical reinforcement at the top of the walls approached the nominal strain of 0.002 mm/mm, whereas the peak strains at the bottom of the walls were one-third to one-half

the nominal yield strain [McKey, in progress]. The strains were largest near the top of the walls because of the initial vertical cracks which formed at the top of the specimens near the interface between the grouted vertical cell and ungrouted masonry.

Similar to the FEM/I analysis, the vertical reinforcement in each specimen yielded. The yielding of the vertical reinforcement in FEM/I and experimental analyses occur near the same cycle for the ERSG strain gauge located at the top east section of the masonry wall. However, Figures 4.25 - 4.30 illustrate the difficulty FEM/I has in predicting the local behavior of the walls. This is described later in this section.

In the FEM/I analysis, horizontal reinforcement in Walls 1, 3 and 5, $\rho_h = 0.05\%$, achieved peak strains greater than the nominal yield strain of the bar (Table 4.1). As illustrated in Figures 4.19 - 4.24, yielding in Walls 1 and 3 occurs in the ends of the horizontal reinforcement while yielding in Wall 5 occurred throughout its length. No yielding occurred in Walls 7, 9 and 11, which have a horizontal reinforcement ratio of 0.12%. In the experimental analysis, Wall 3 was the only specimen to experience yielding in the horizontal reinforcement.

Figures 4.25 - 4.30 provide an illustration of the local behavior for Wall 3 and Wall 9. Strains at peak displacements in individual cycles for the experimental study and FEM/I analysis were plotted at various locations on the masonry specimen and reinforcing bars. A tensile strain is represented as a positive value and a compressive strain is represented by a negative value. These figures illustrate the limitations in FEM/I's smeared hybrid element in modeling the effect of the reinforced cells. Also, the figures show that the strain data read from the surface of the masonry during the experiment do not compare

well with the FEM/I strains. In fact, the strains in the masonry and steel are identical in the FEM/I result because identical strain in masonry and steel is assumed in the smeared hybrid element. The significant difference in the comparisons for Wall 3 (Figures 4.25 - 4.27) could be partially attributed to sliding and reinforcement anchorage problems during testing, as previously stated [McKey, in progress]. Figures 4.28 - 4.30 illustrate the effect of the vertical cracks in Wall 9. At the onset of minor cracking of the specimen, a significant difference in the direction and magnitude of the strain measurements is shown.

5.0 CONCLUSIONS

5.1 Summary of Experimental Study

A brief summary of the experimental study is provided to highlight some of the important results of the experiment as it relates to the FEM/I analysis. A more detailed description of the experimental study and its results can be found in "Seismic Resistance of Partially-Grouted Masonry Shear Walls" [McKey, in progress].

The data presented suggests that partially-grouted masonry is a viable lateral-load resisting system for regions of moderate and low seismic risk. Resistance to the drift histories is stable and features high initial stiffness and ample energy dissipation. The lateral load resisting mechanism is vastly different from that of fully reinforced masonry walls. Vertical cracks arising from stress concentrations between ungrouted and grouted masonry appear to dominate wall behavior. Increase in height-to-length aspect ratio results in an increase of ultimate shear stress. Increase in height-to-length ratio, however, results in decreasing the wall's toughness (strength deterioration and energy dissipation capacity). Increase in horizontal reinforcement ratio has a modest beneficial effect on ultimate shear stress, but it does not appear to affect the toughness significantly.

5.2 Performance Summary of FEM/I with Experiment

Several points are highlighted below to provide an overview of the performance FEM/I in simulating the response of the specimens tested in the experimental study.

1) Although FEM/I demonstrated an inability to realistically model the cracking pattern generated by the experiment, it was able to predict the force-displacement response of

the specimens up to the FME as Figure 4.15 illustrates. The ratios of the lateral loads at the FME further illustrate this conclusion (Table 4.1). With the exception of Wall 1, this ratio ranges from 0.9 - 1.3 (Table 4.1). After the occurrence of the FME, FEM/I's prediction of the lateral load is less accurate.

2) Each wall in the FEM/I analysis was dominated by masonry cracks. These cracks develop much earlier and more widespread in the FEM/I prediction than in the experimental study as illustrated in Figures 4.1 - 4.6. This inability to realistically model the cracking of the experiment and sliding between the wall and the header/footer beam is also shown in the difference in the energy dissipation plots (Figure 4.16).

3) FEM/I did not model the wall's toughness accurately. Formation of large cracks and sliding between the wall and the header beam were major factors in the under estimation of the wall's toughness.

4) Walls with a horizontal reinforcement ratio, $\rho_h = 0.05\%$ (Walls 1, 3, and 5), exhibited yielding of horizontal reinforcement while those with a $\rho_h = 0.12\%$ (Walls 7, 9, and 11) exhibited no yielding. In the experimental study, Wall 3 was the only wall to exhibit failure of the horizontal reinforcement.

5) FEM/I overestimated the ultimate shear strength of all specimens as shown in Table 4.1 and Figure 4.15. Differences in peak loads could be attributed to the variability in the uniaxial compressive strength, as indicated by the prism strength variations given in Table 1.2, smearing of properties in masonry model, cracking and sliding of the specimens.

6) Each wall in the FEM/I analysis failed in flexure, as shown in Figures 4.19 - 4.24 by the widespread yielding of the vertical reinforcement and in Figures 4.1 - 4.6 by the crushing of the elements at the base of the models. Similar to the FEM/I analysis, each specimen in the experiment experienced failure in the vertical reinforcement. The yielding of the vertical reinforcement in FEM/I and experimental analyses occur near the same cycle for strain measured at the top east section of the masonry wall. However, Figures 4.25 - 4.30 illustrate the difficulty FEM/I has in predicting the local behavior of the walls.

7) The individual cycles represented in Figures 4.7 - 4.12 illustrate at various stages in the displacement history FEM/I performed reasonably well in predicting the response of some of the walls. For example, Walls 3, 5, 9 and 11 exhibit a good force-displacement relationship for the first half of their displacement history.

8) The local behavior of the vertical steel is reasonably predicted by FEM/I.

9) Local behavior of horizontal steel and masonry were poorly modeled by FEM/I due to the appearance of large cracks and the loss of strength in the joint between the horizontal steel and vertical cells.

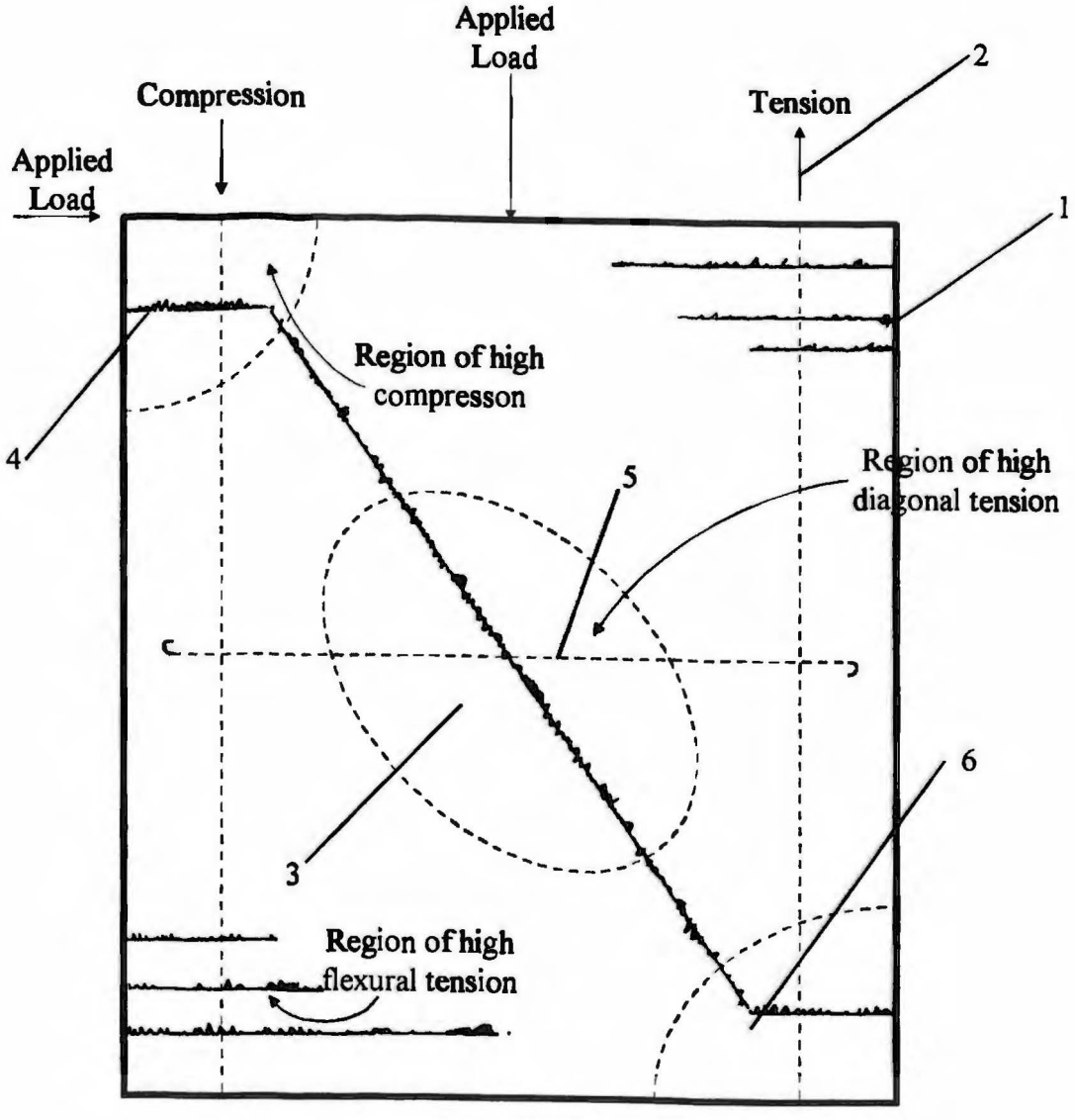
5.3 Recommendations for Future Research

Additional studies need to be conducted on the applicability of using the damage parameter, β, and tension stiffening representations [Ewing, 1987]. The damage parameter is based on reinforced concrete research and needs to be modified for reinforced masonry. Also, parametric studies are needed to identify those properties that have the most influence on components response, and recommendations for controlling the variability of these properties. These properties include but are not limited to: tensile cracking strain of the masonry, ratio of the principal normal tensile strain in the masonry to the principal compressive strain, tensile cracking stress of the masonry, exponential parameter, α, and the exponential branch shape factor, β. FEM/I also could be used to examine masonry specimens which contain more reinforcement than the partially-grouted wall tested in this experimental study but still significantly less than fully-grouted masonry walls. This would aid in determining the sensitivity of FEM/I solutions to variations in the physical and material properties of the finite element model.

Finally, additional walls using joint reinforcement in place of deformed reinforcing bars should be studied. The use of equivalent area for joint reinforcement in lieu of reinforcing bars will allow an assessment of its effect on response relative to conventional reinforcement [Fattal 1993a]. If the joint reinforcement has equivalent effects, the finding will have a major positive economic impact upon the construction industry [Fattal 1993a].

Appendix A

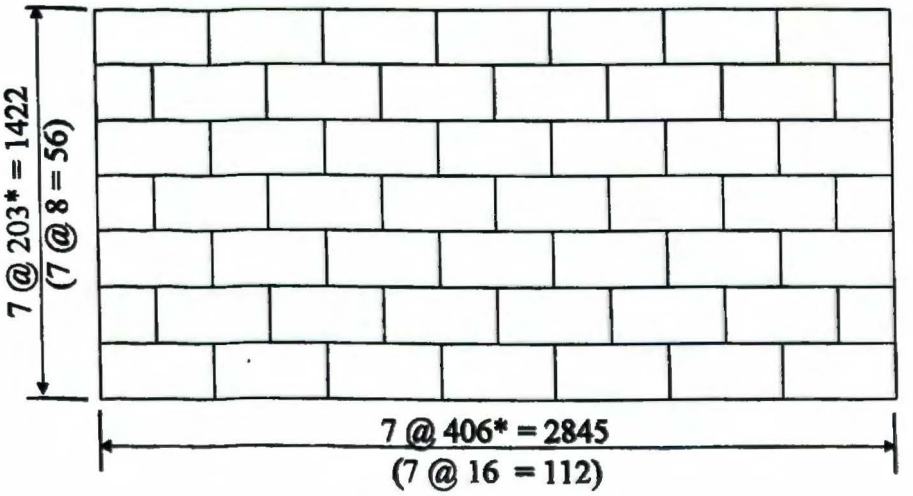
Figures and Tables



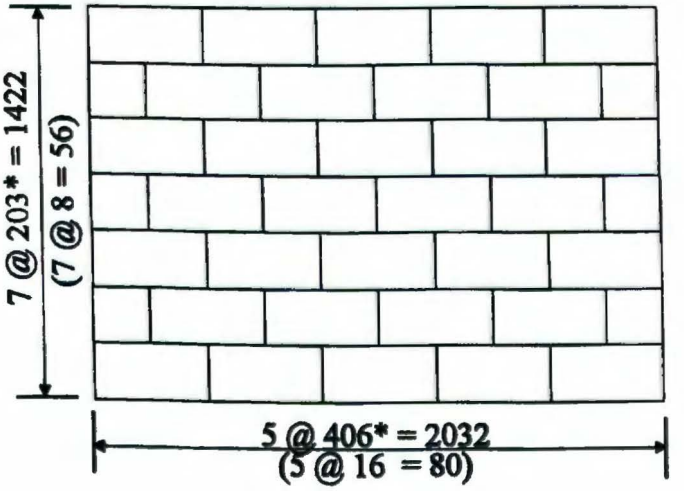
1. Tensile cracking in high flexure zones
2. Vertical bars yield in high flexure zones
3. Tensile shear-induced cracking near center of wall
4. Shear cracks propagate to form rupture plane
5. Yield of horizontal and vertical steel
6. Crushing of masonry in compression at loaded corners

Figure 1.1 Major Events in Shear Wall Response

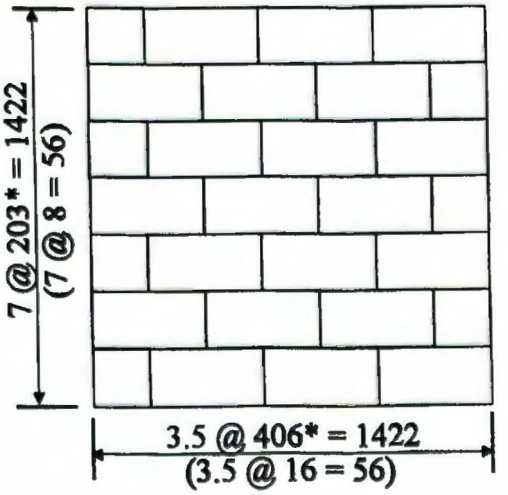
r = 0.5
Walls 1 & 7



r = 0.7
Walls 3 & 9

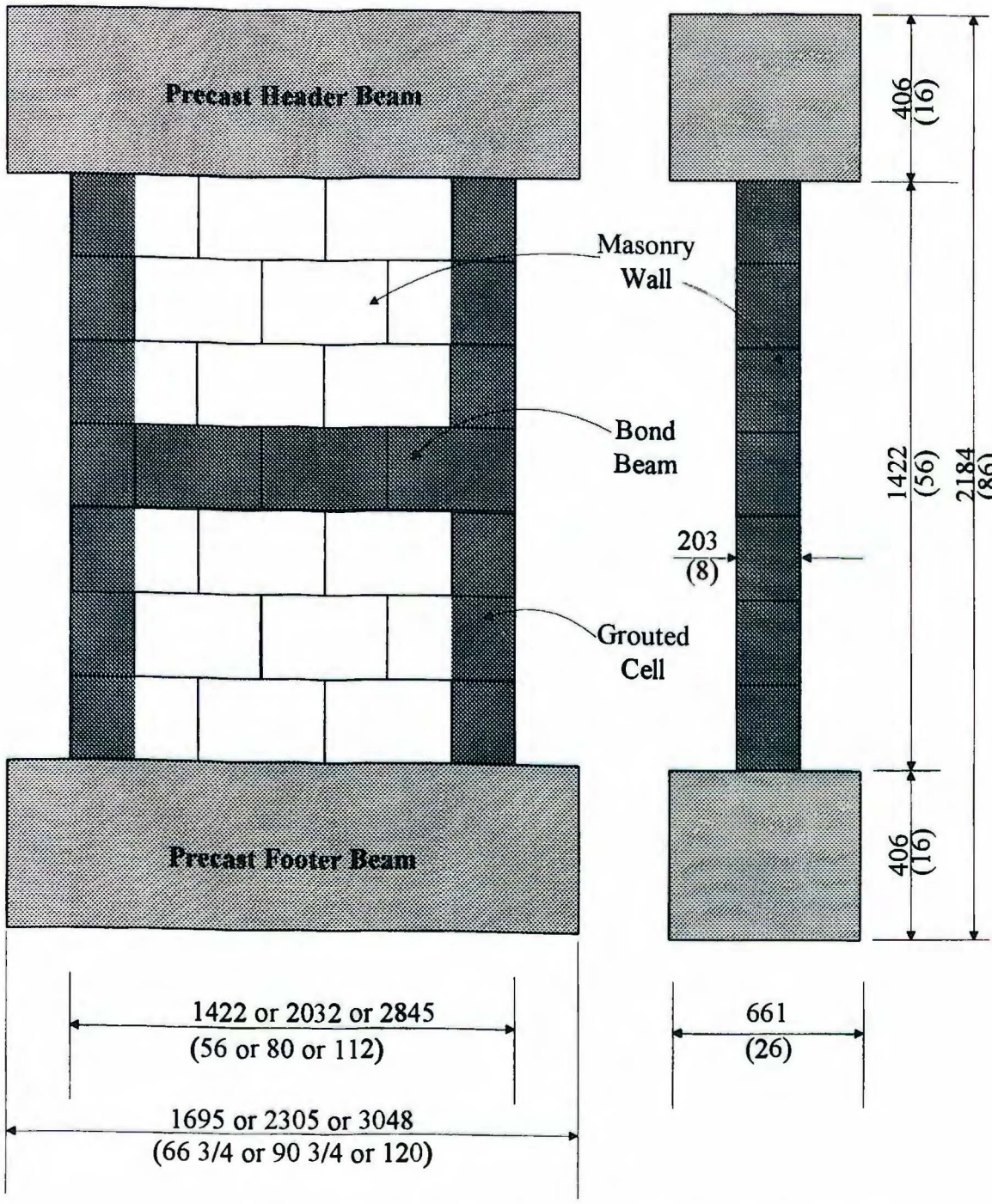


r = 1.0
Walls 5 & 11



*Masonry unit plus one bed joint and one head joint is 203 mm (8 in.) tall and 406 mm (16 in.) long.

Figure 1.2 Masonry Wall Specimen Configurations
All dimensions in mm (in.)



Shaded areas represent grouted, reinforced elements

Elevation **Side View**

Figure 1.3 Grouting Pattern
All dimensions in mm (in.)

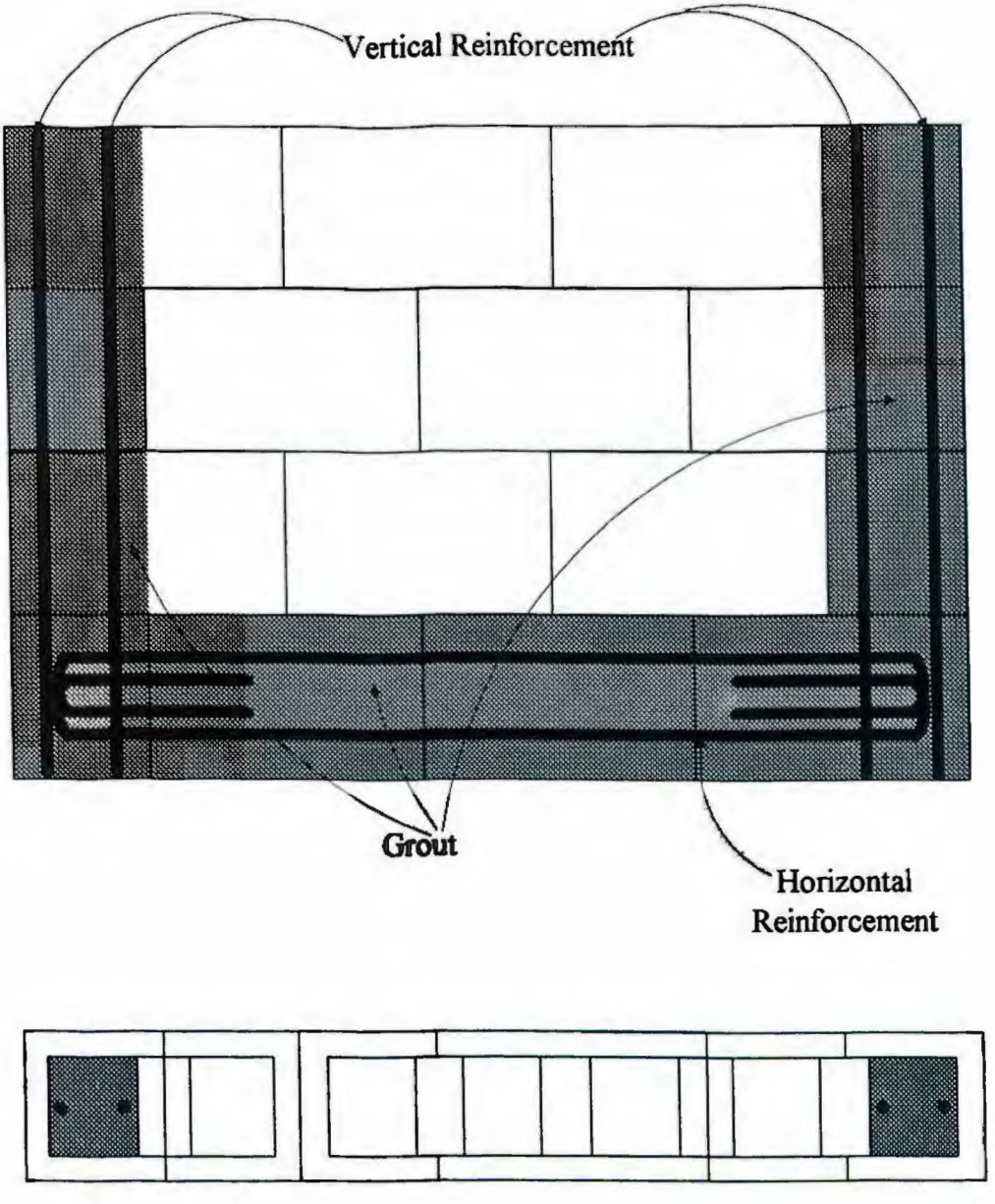


Figure 1.4 Vertical Reinforcement Details

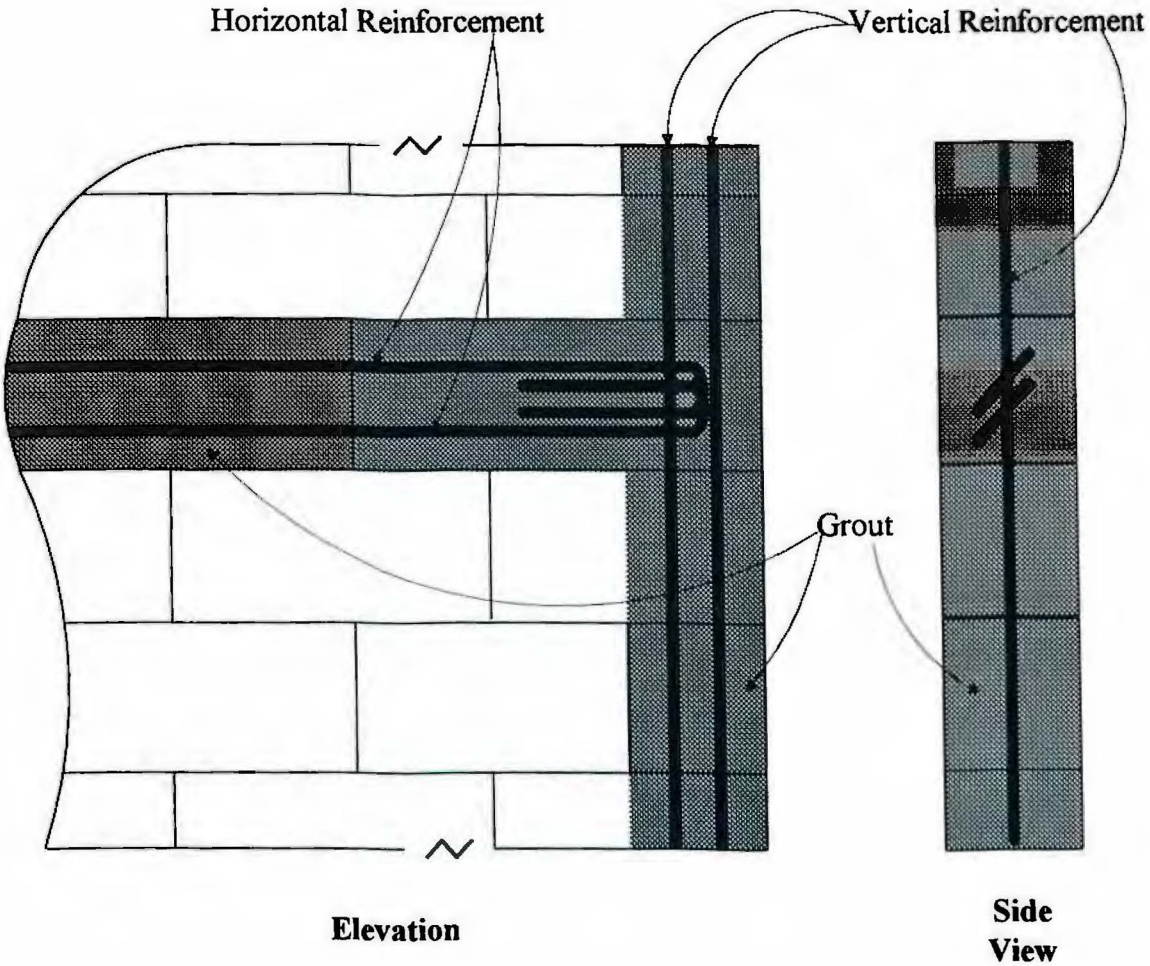
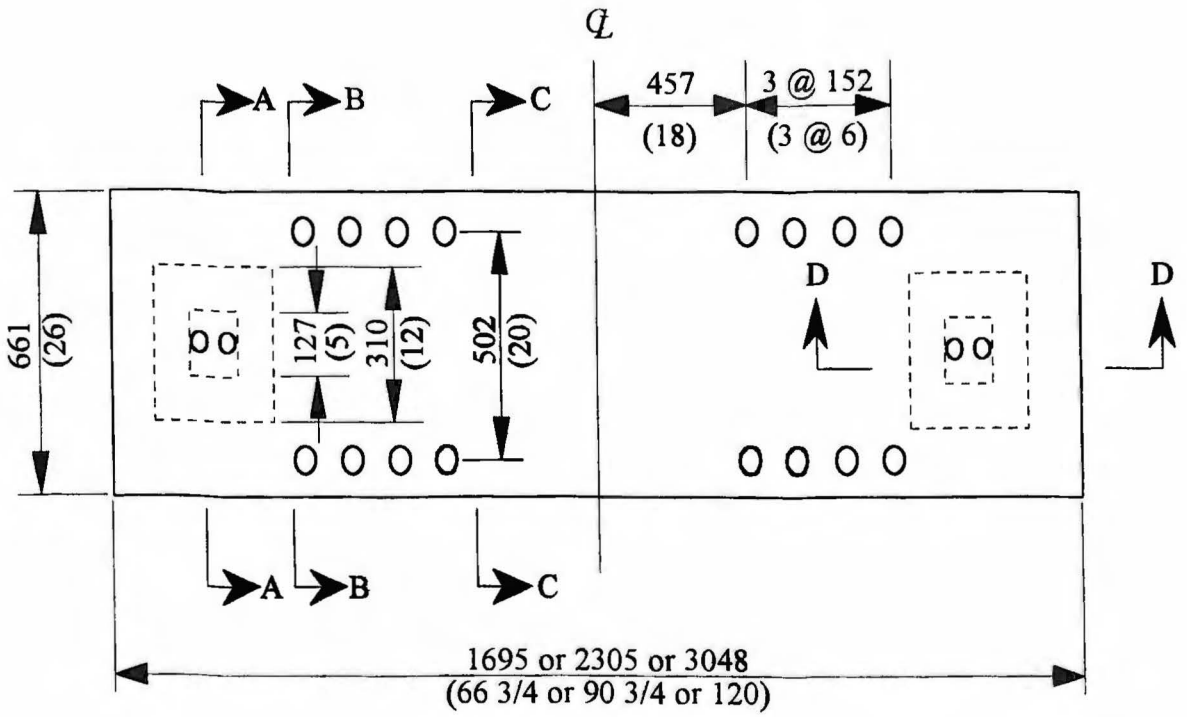
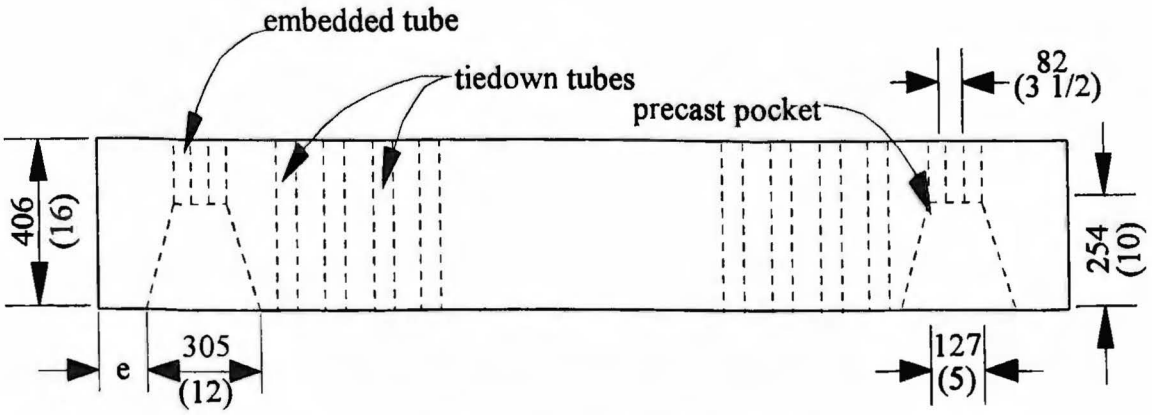


Figure 1.5 Horizontal Reinforcement Details



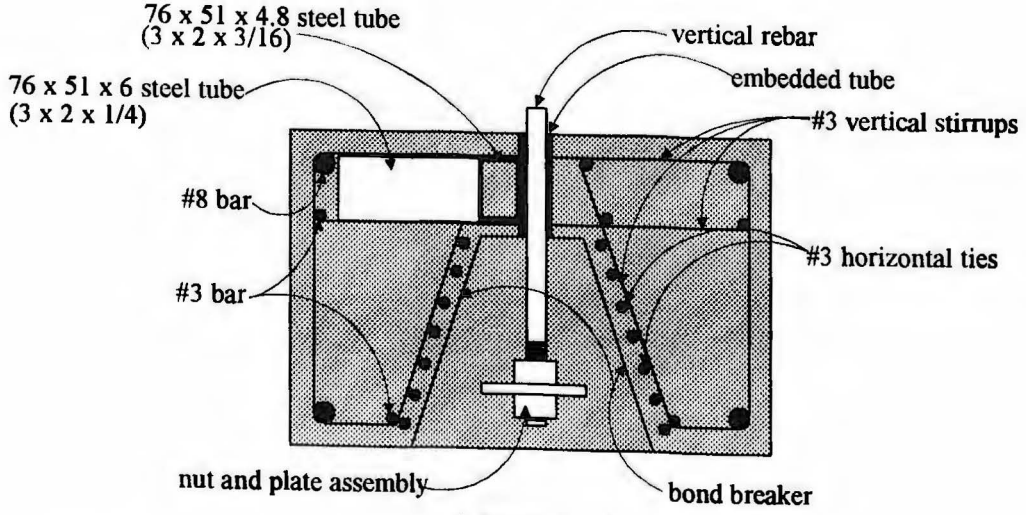
a) Plan



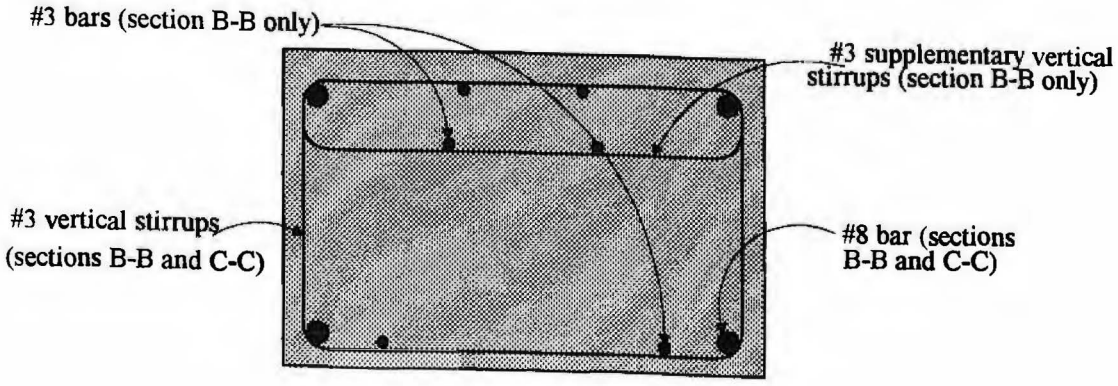
e = 68 (2 11/16) for r = 0.5; e = 86 (3 3/8) for r = 0.7 and 1.0

b) Elevation

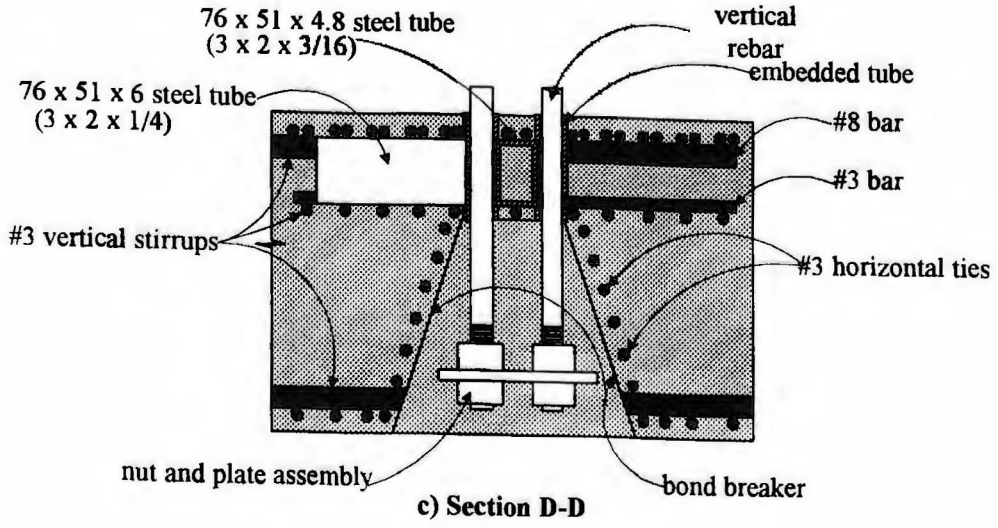
Figure 1.6 Precast Concrete Header/Footer Beam
All dimensions in mm (in.)



a) Section A-A



b) Sections B-B and C-C



c) Section D-D

Figure 1.7 Header/Footer Beam Details
All dimensions in mm (in.)

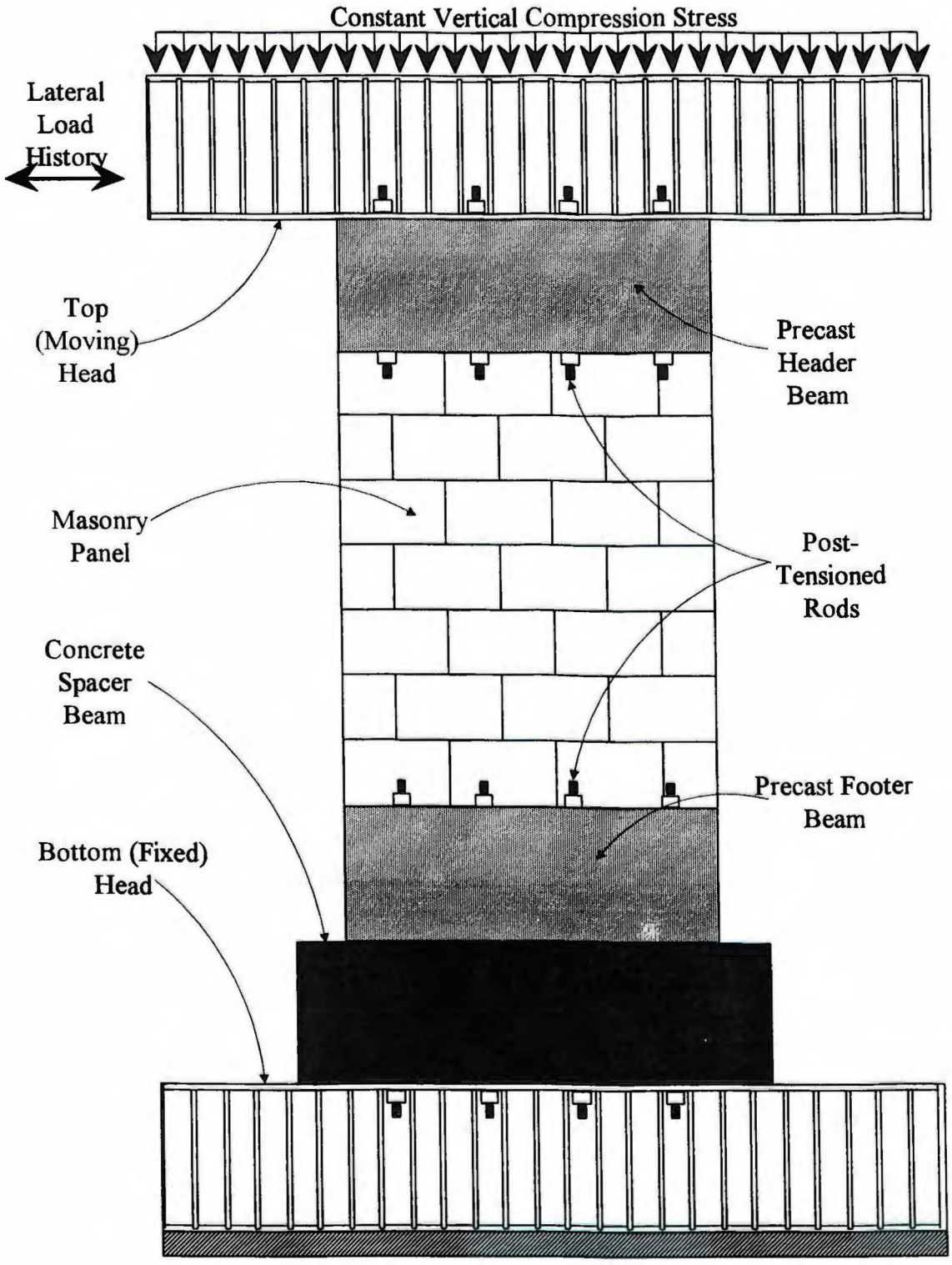


Figure 1.8 Test Setup for Masonry Wall Specimens

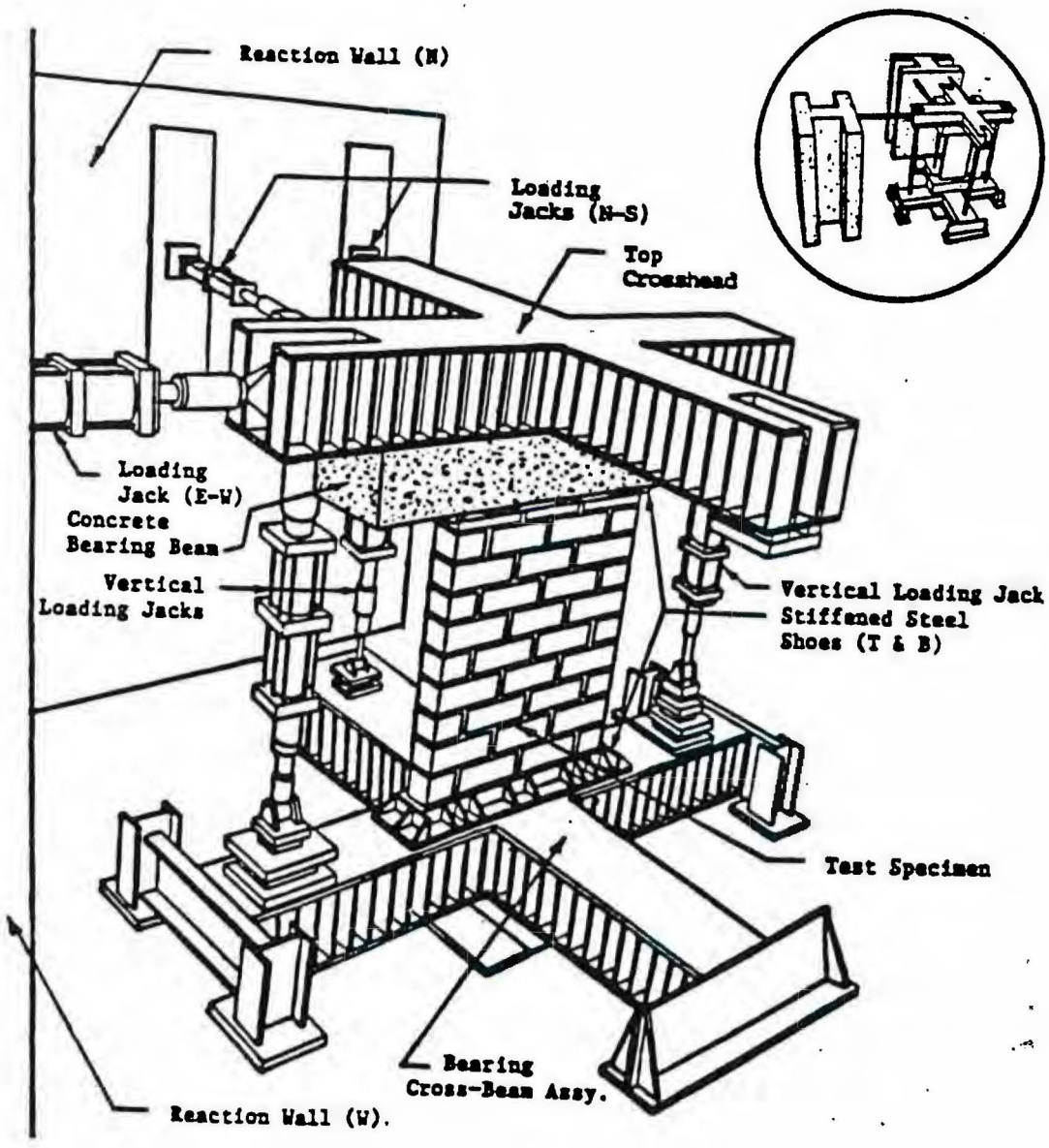


Figure 1.9 Tri-directional Testing Facility

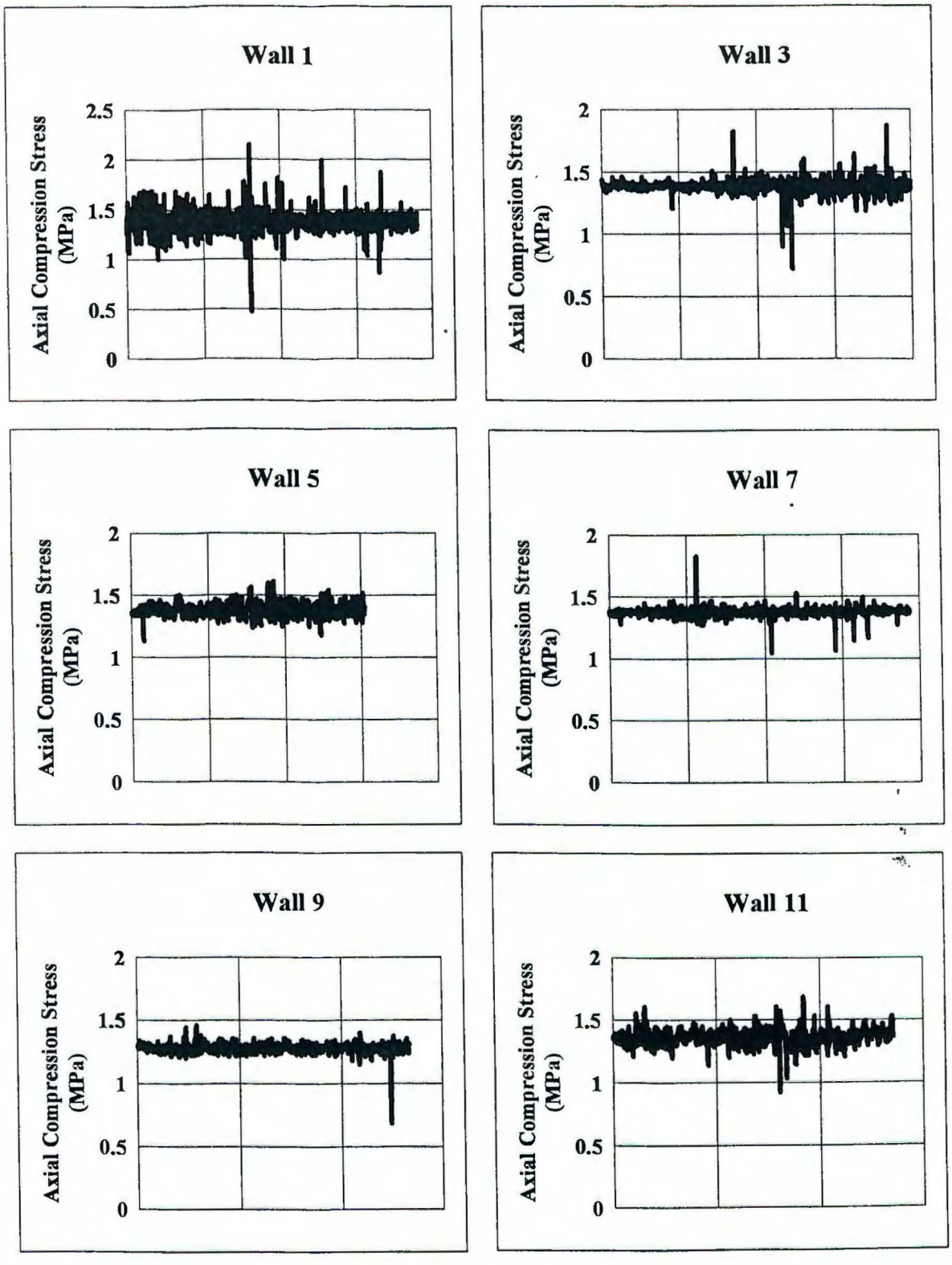


Figure 1.10 Axial Compression Stress Histories on Masonry Wall Specimens

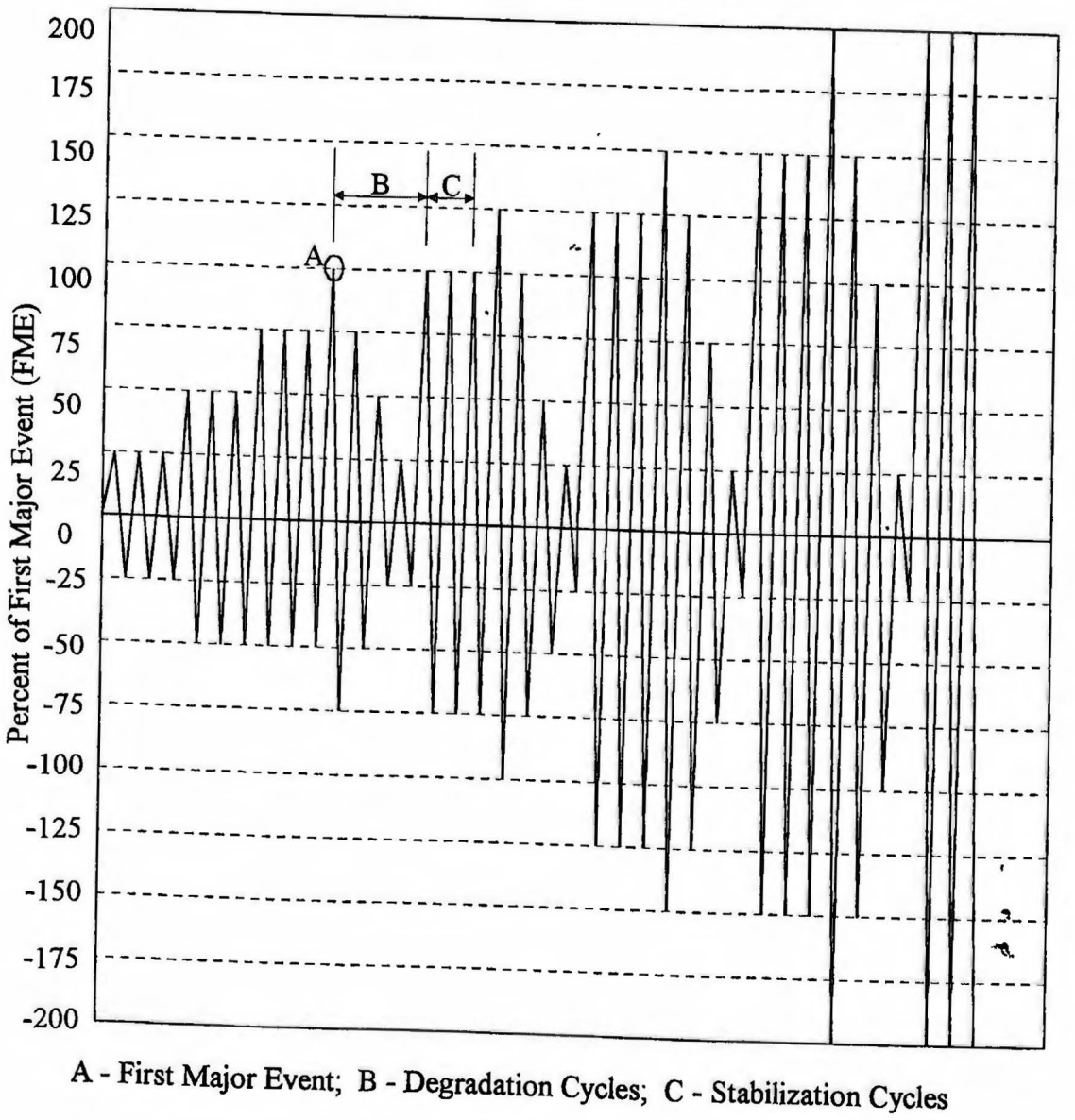


Figure 1.11 Idealized Displacement History

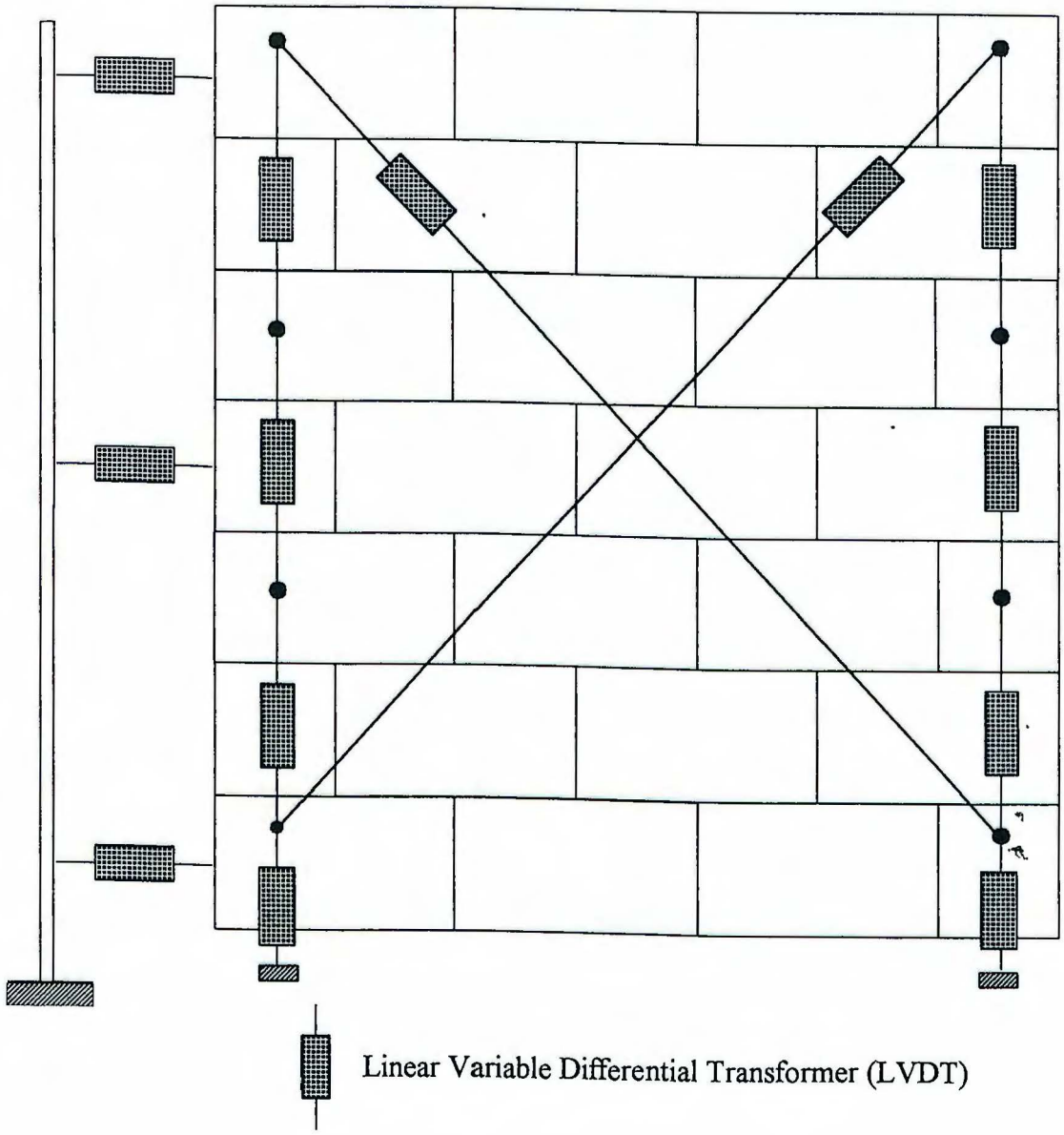
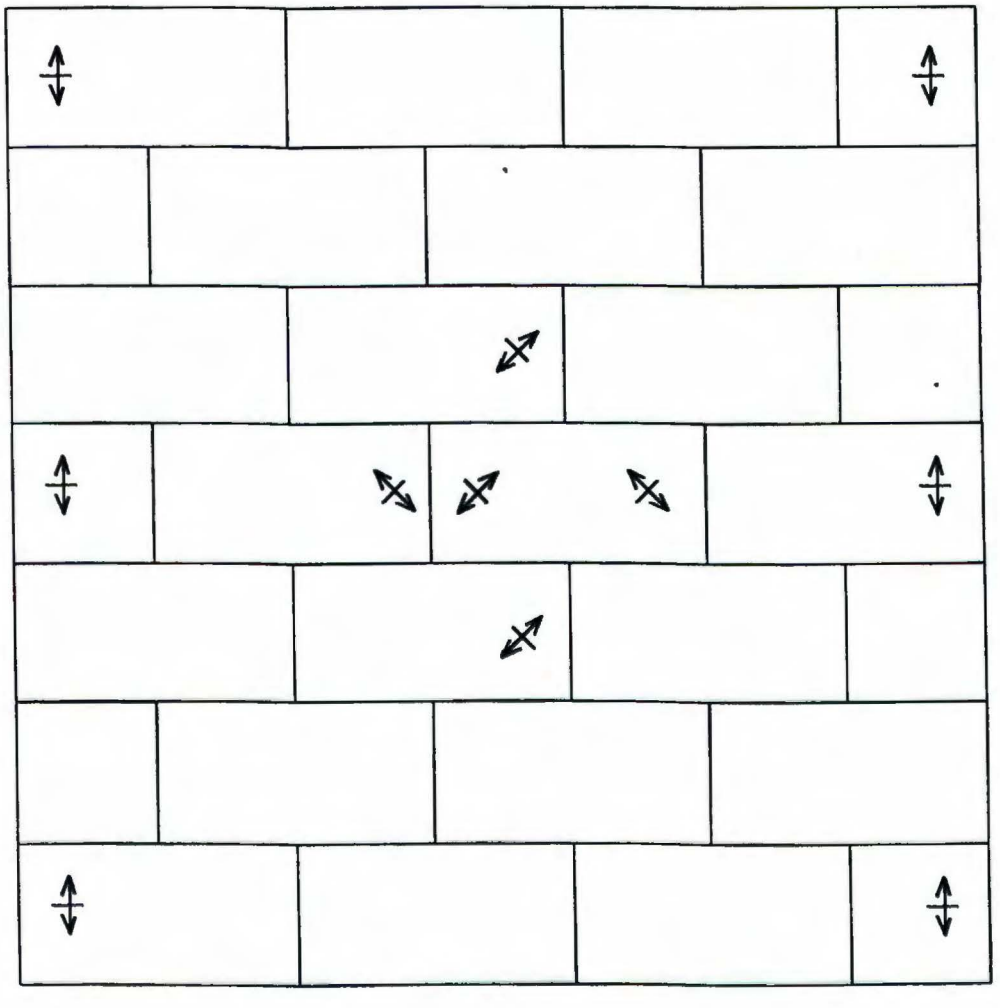
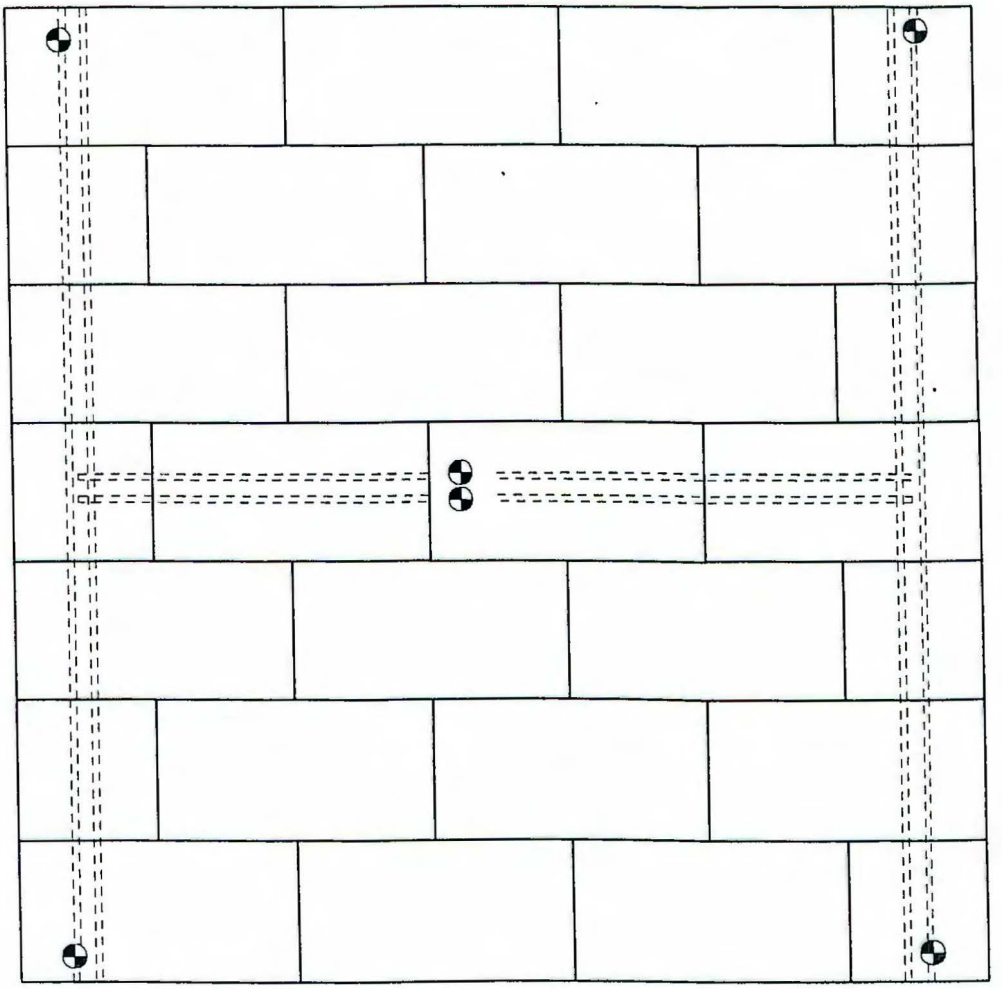


Figure 1.12 Displacement Transducer Locations on North Face of Masonry Specimens



Linear Strain Transducer (LST)

Figure 1.13 Strain Transducer Locations on South Face of Masonry Specimens



Electric Resistance Strain Gage (ERSG)

Figure 1.14 Strain Gage Locations on Shear Wall Reinforcement

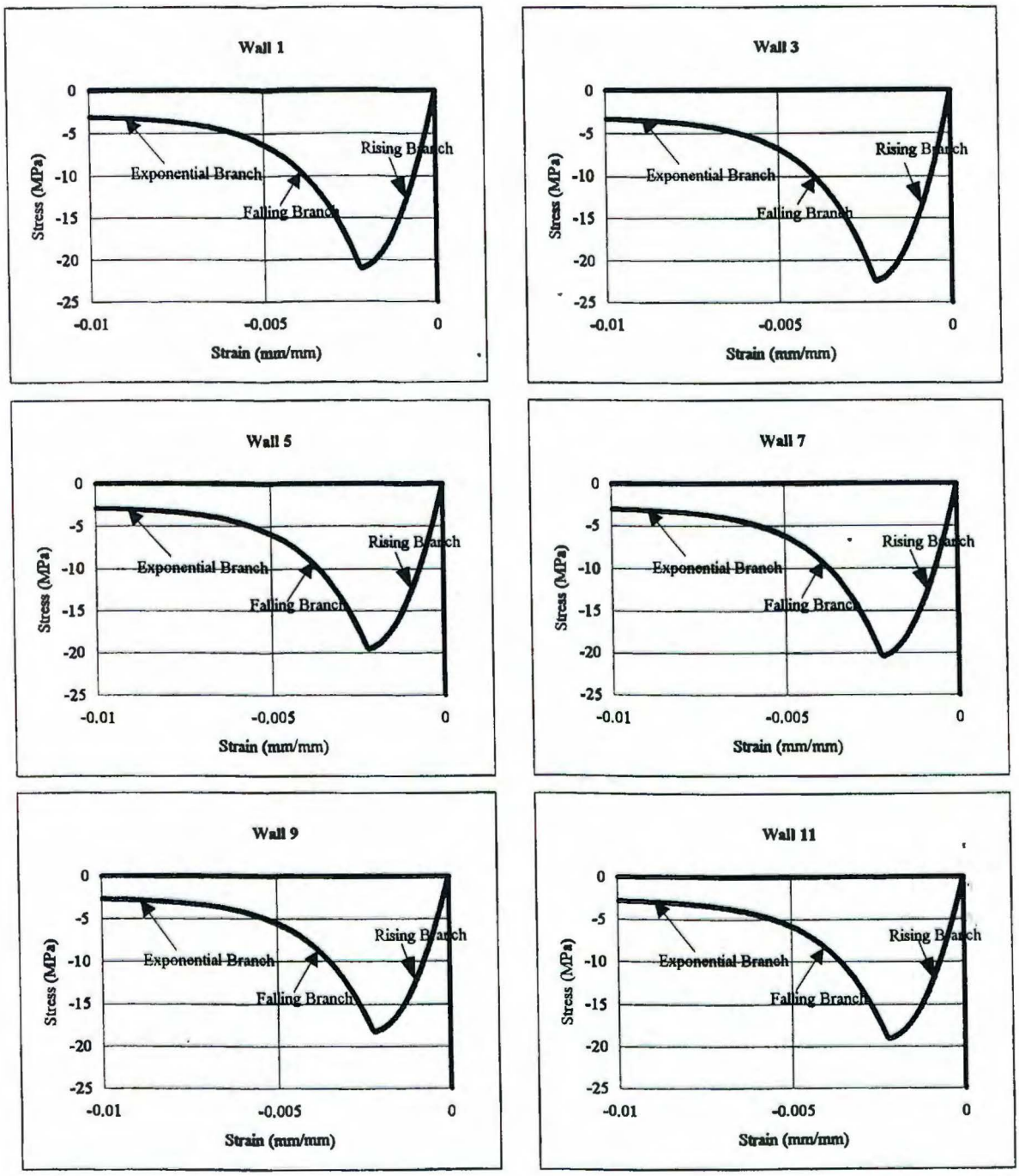


Figure 2.1 Compression Models for Grouted Masonry

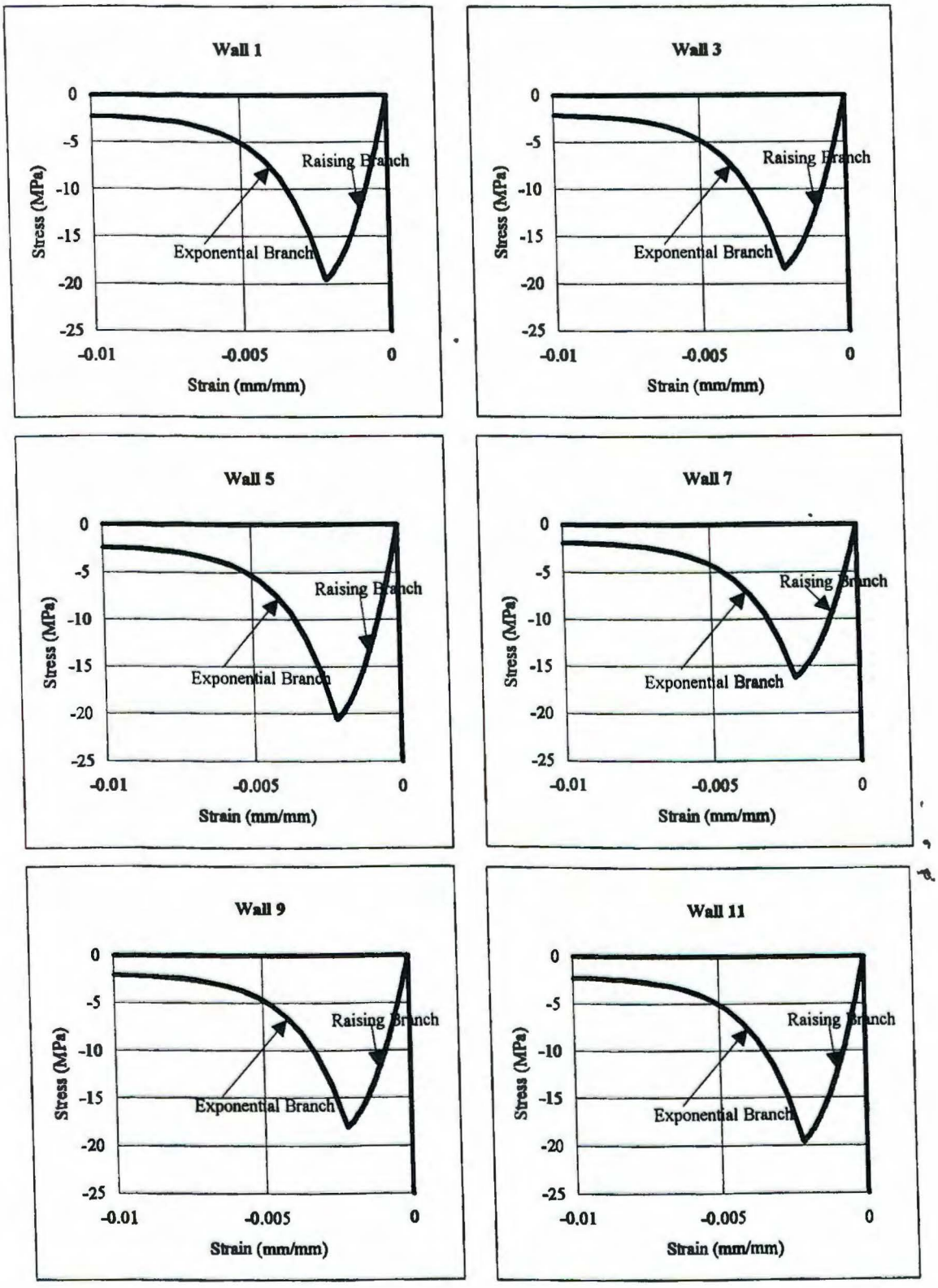
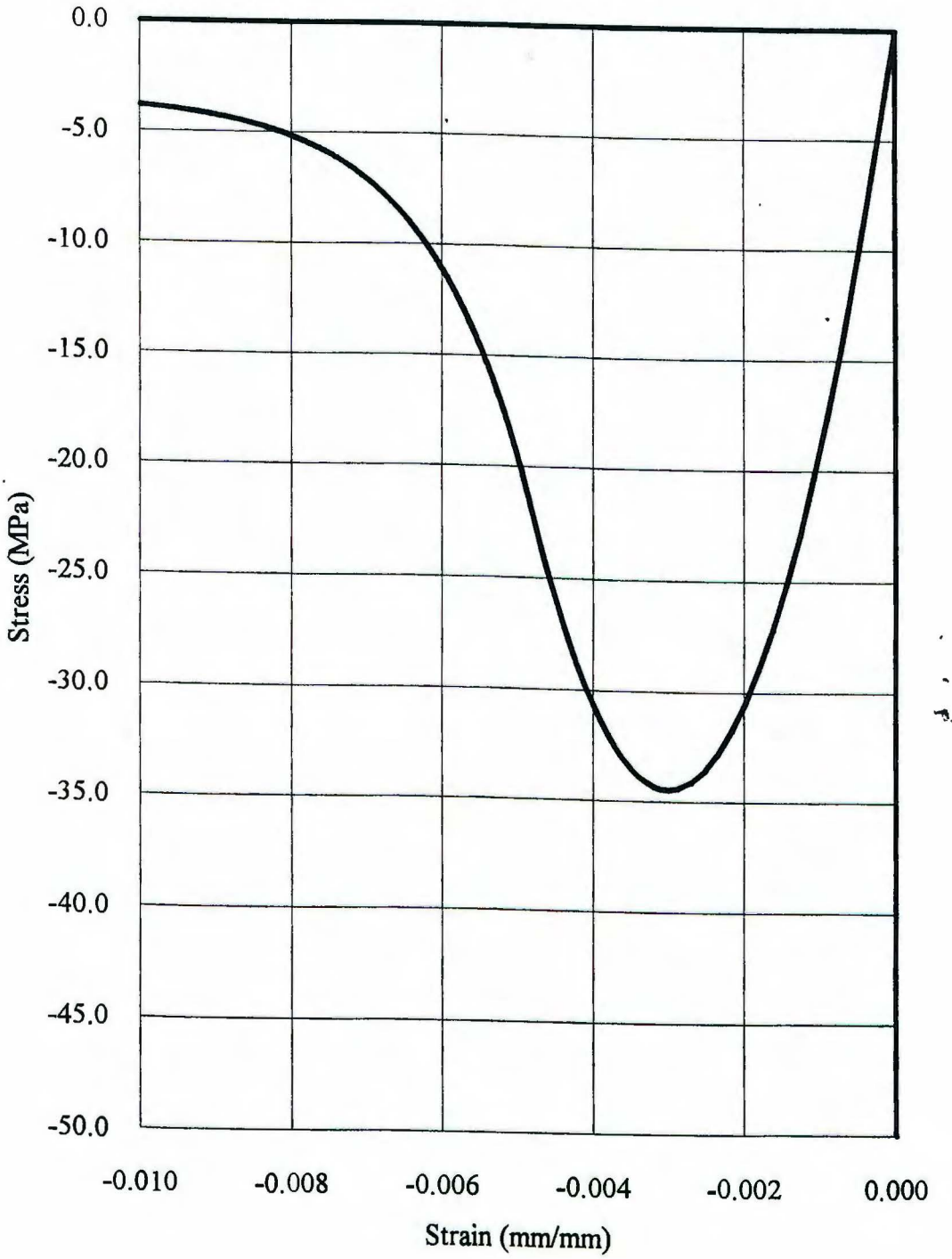


Figure 2.2 Compression Models for Ungrouted Masonry

Figure 2.3 Compression Model for Concrete Header and Footer



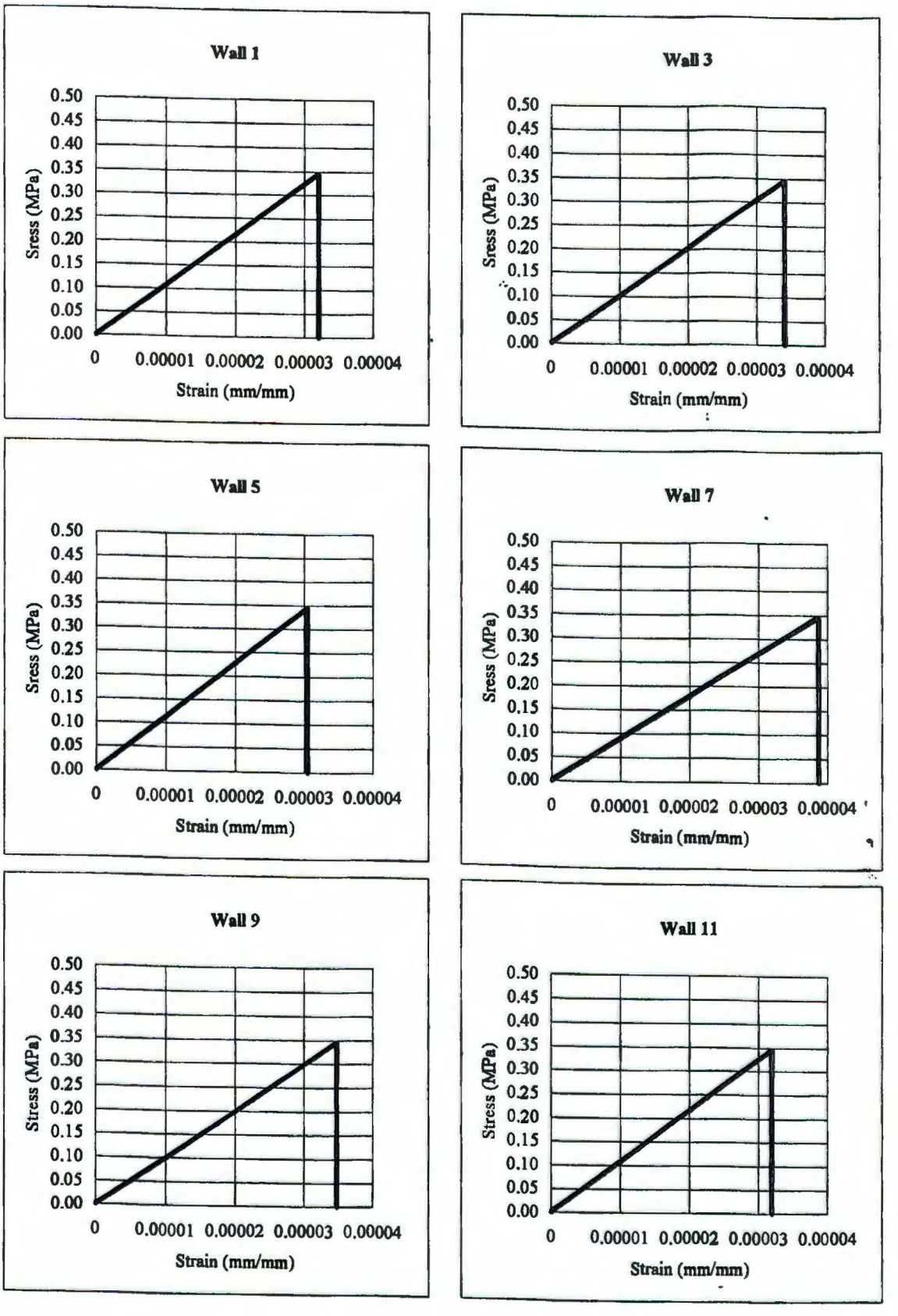


Figure 2.4 Tension Stiffening Models for Ungrouted Masonry

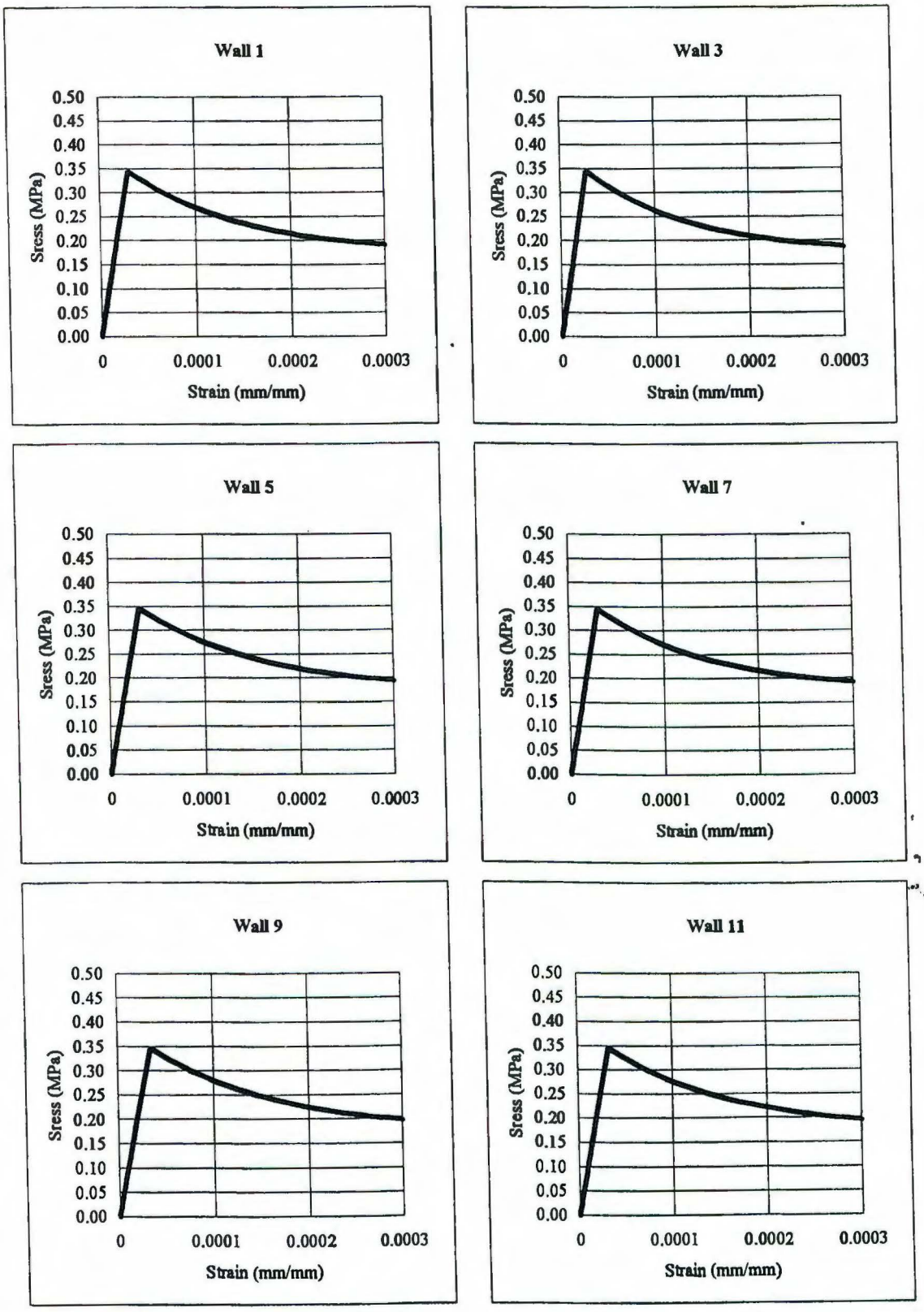
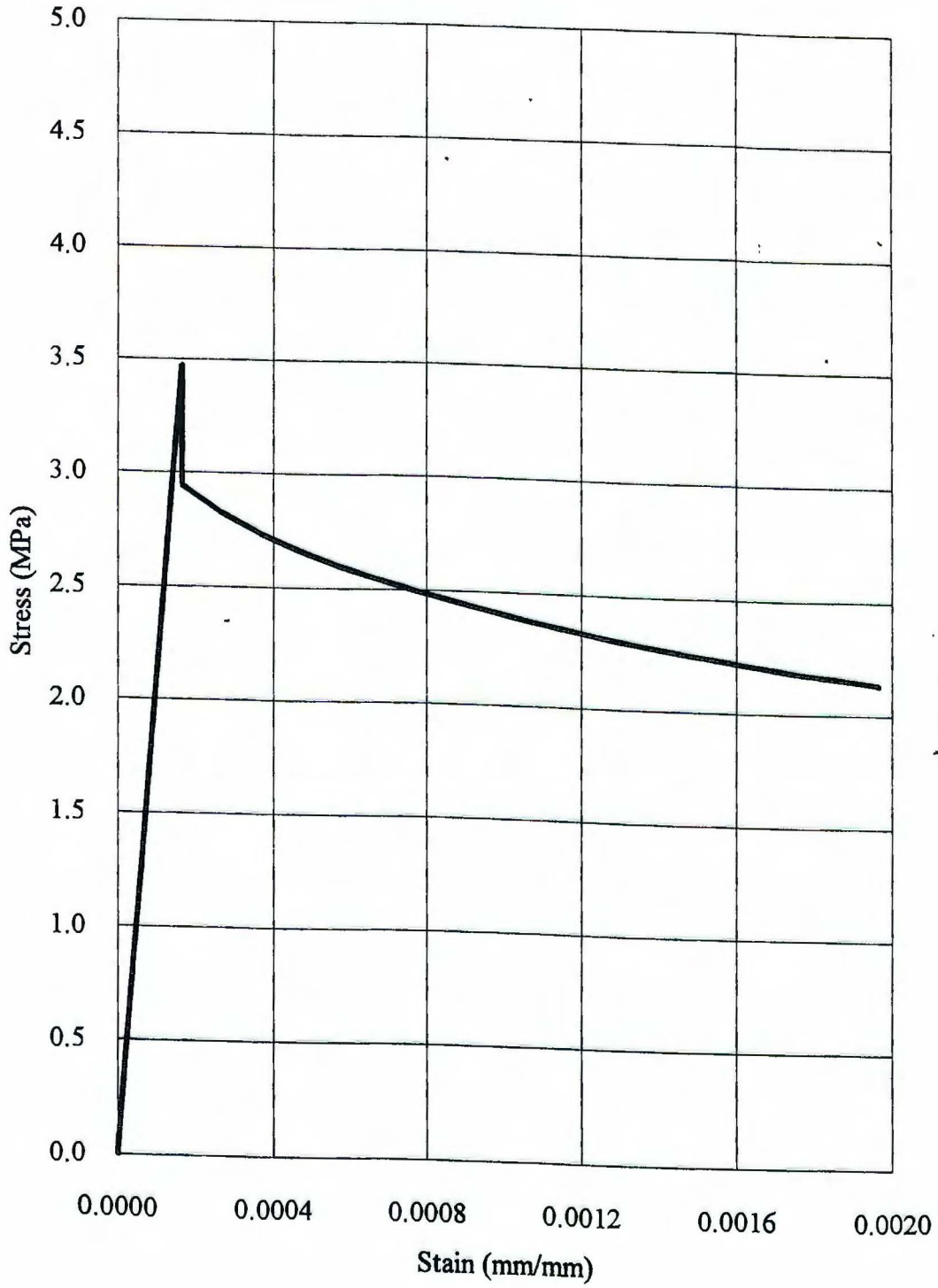


Figure 2.5 Tension Stiffening Model for Grouted Reinforced Masonry

Figure 2.6 Tension Stiffening Model for Reinforced Concrete



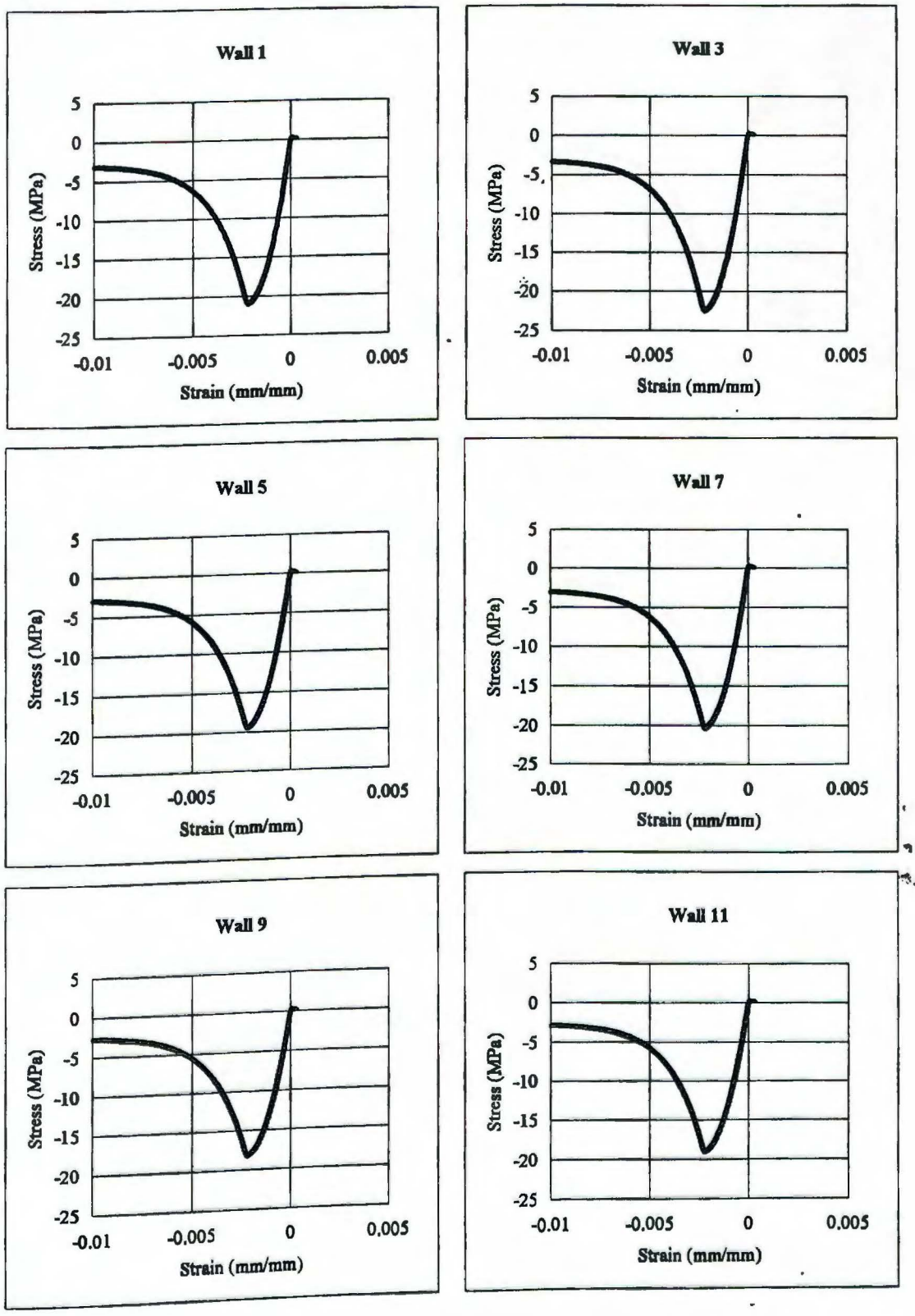


Figure 2.7 Grouted Masonry Models, Tension and Compression

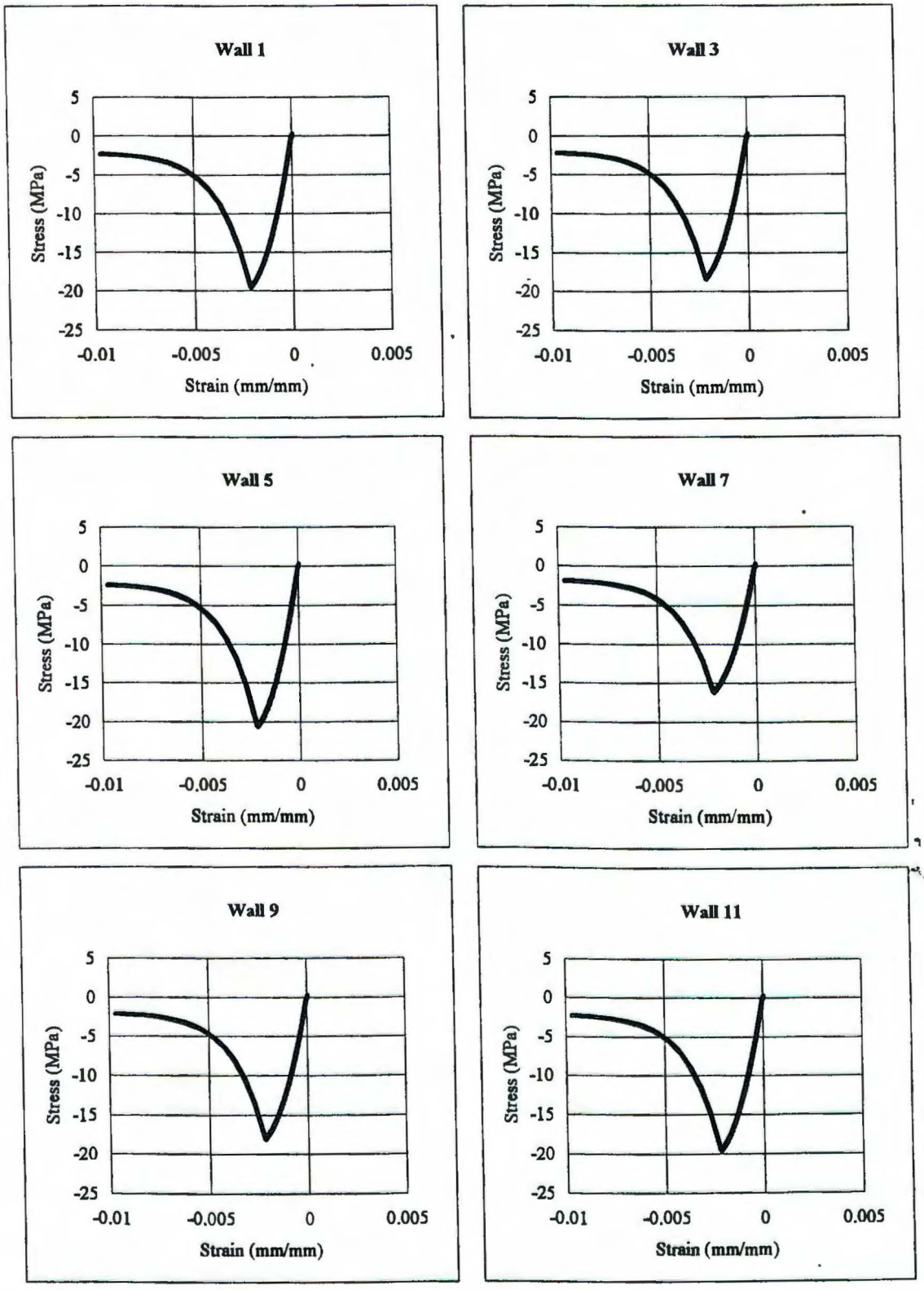


Figure 2.8 Ungrouted Masonry Models, Tension and Compression

Figure 2.9 Concrete Header and Footer Model, Tension and Compression

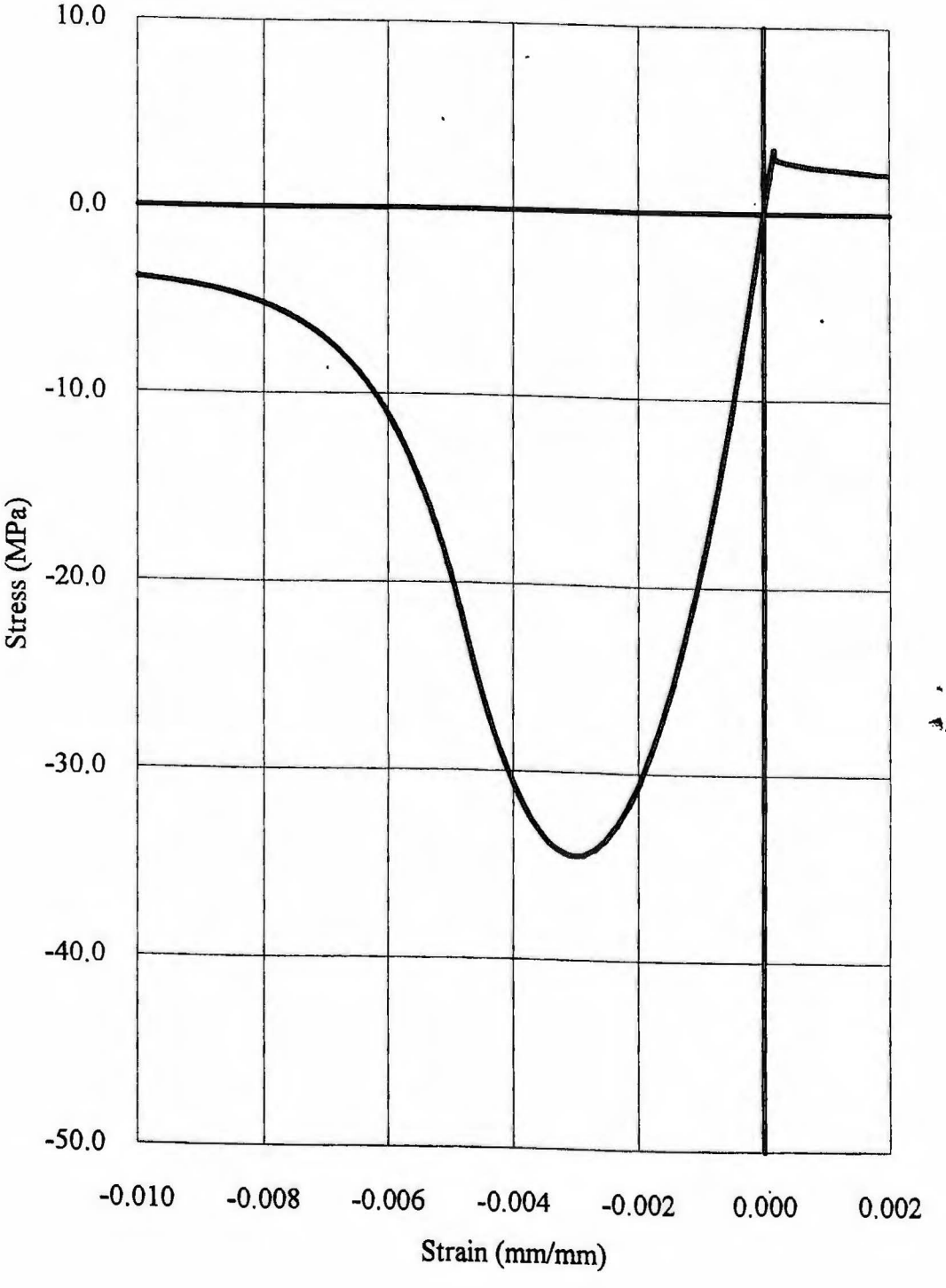
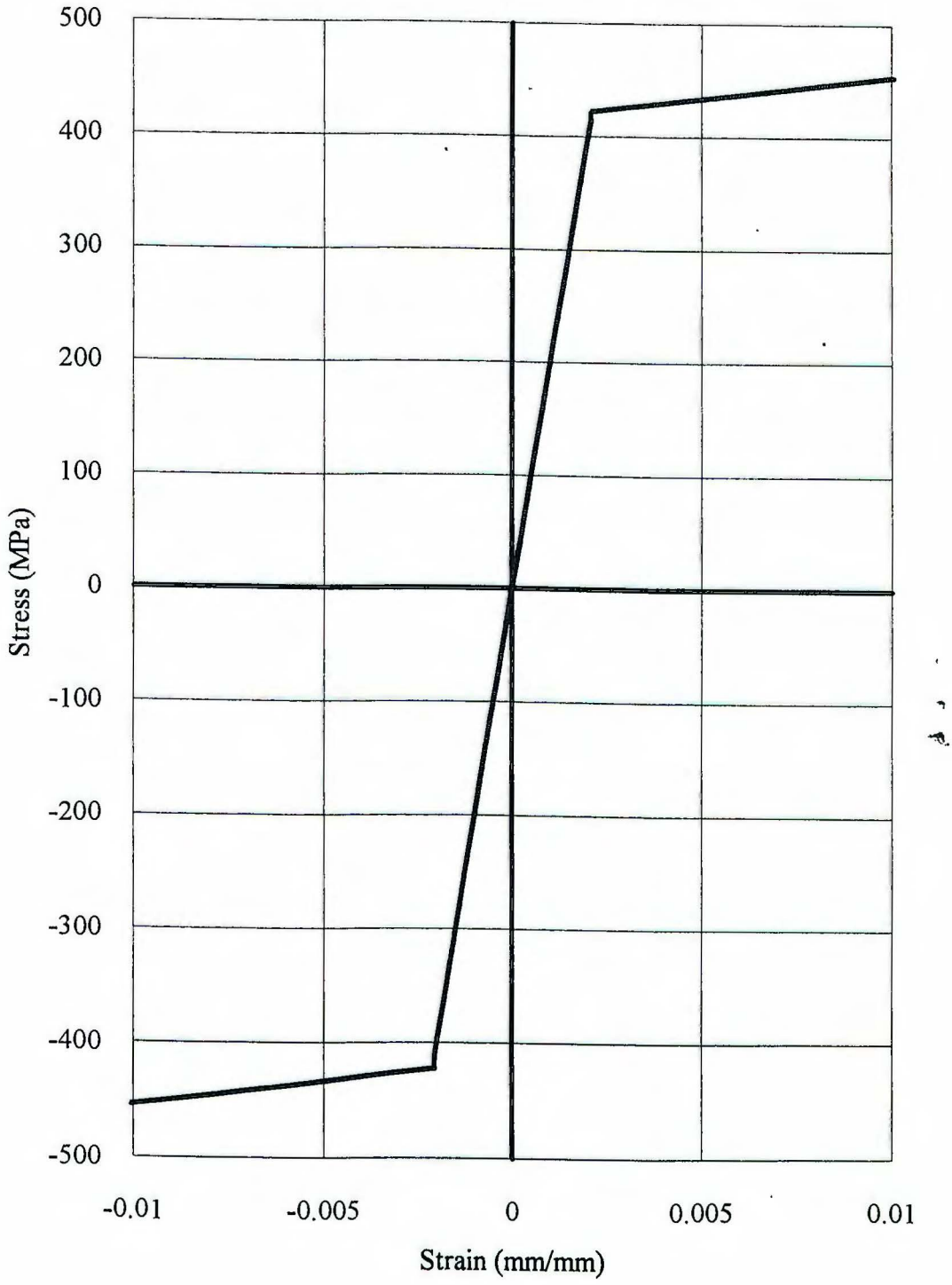


Figure 2.10 Reinforcement Model



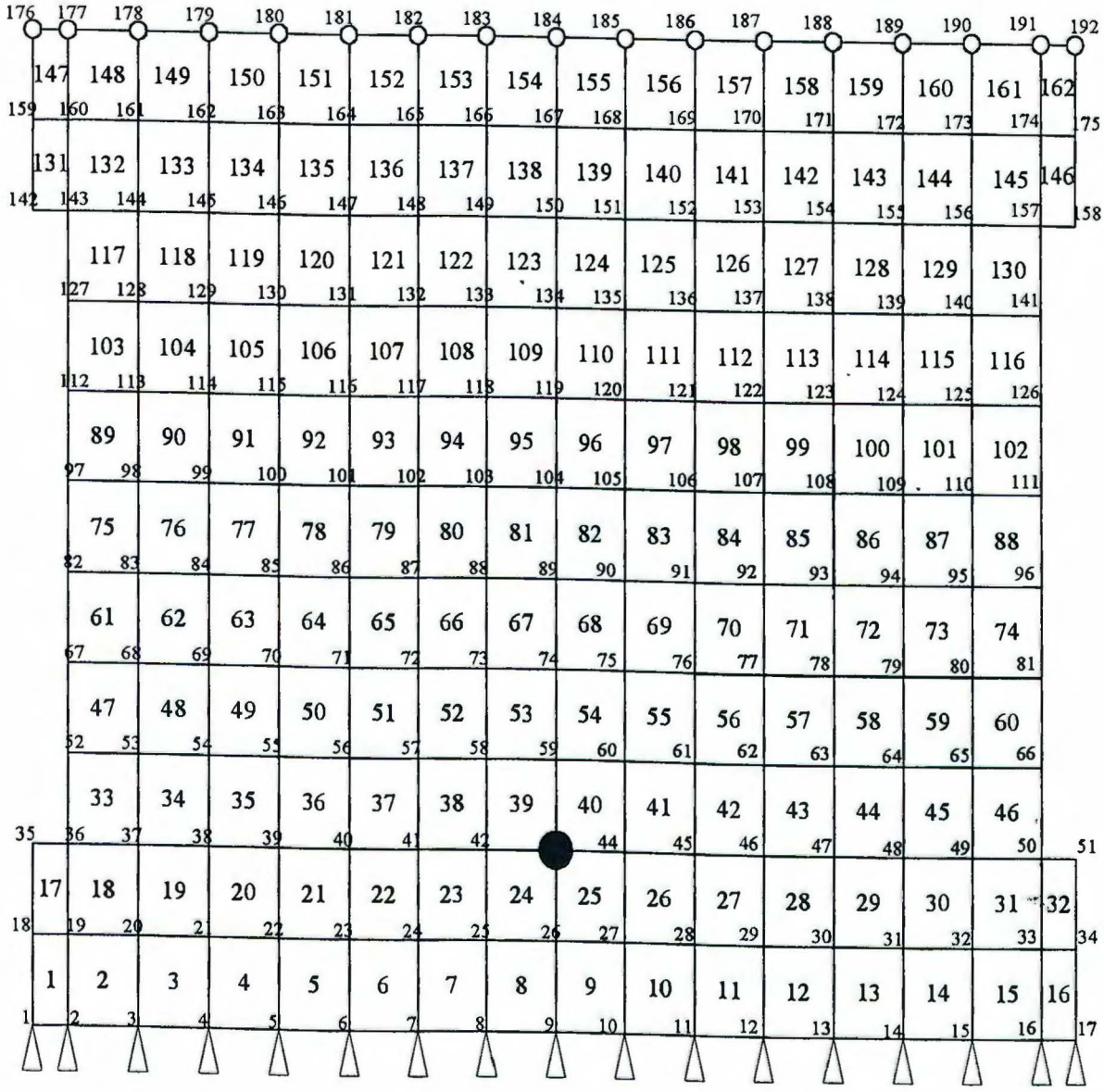


Figure 3.1 FEM/I Mesh for Wall 1 and Wall 7

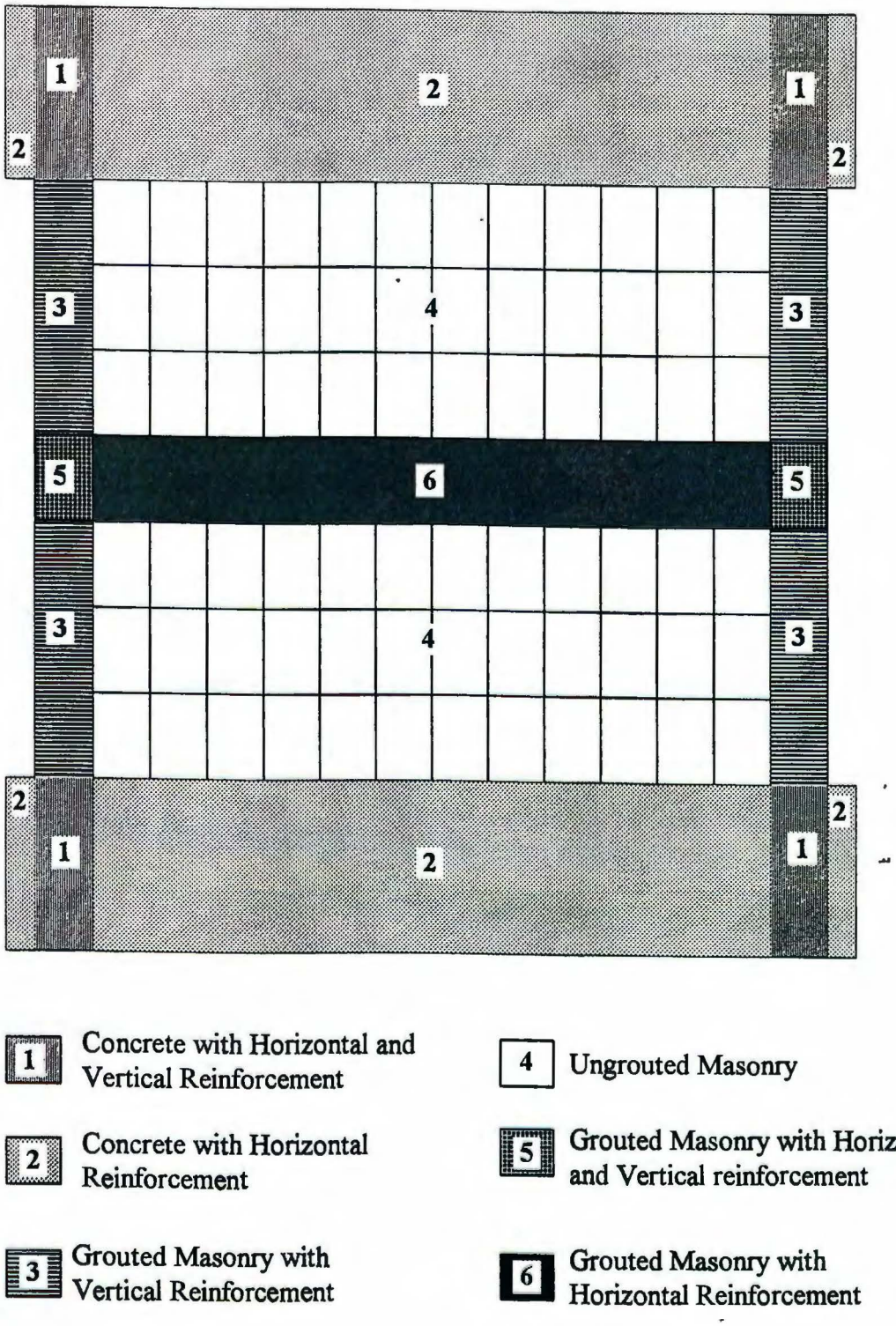


Figure 3.2 FEM/I Material Pattern for Wall 1 and Wall 7

Figure 3.3 FEM/I Displacement History for Wall 1

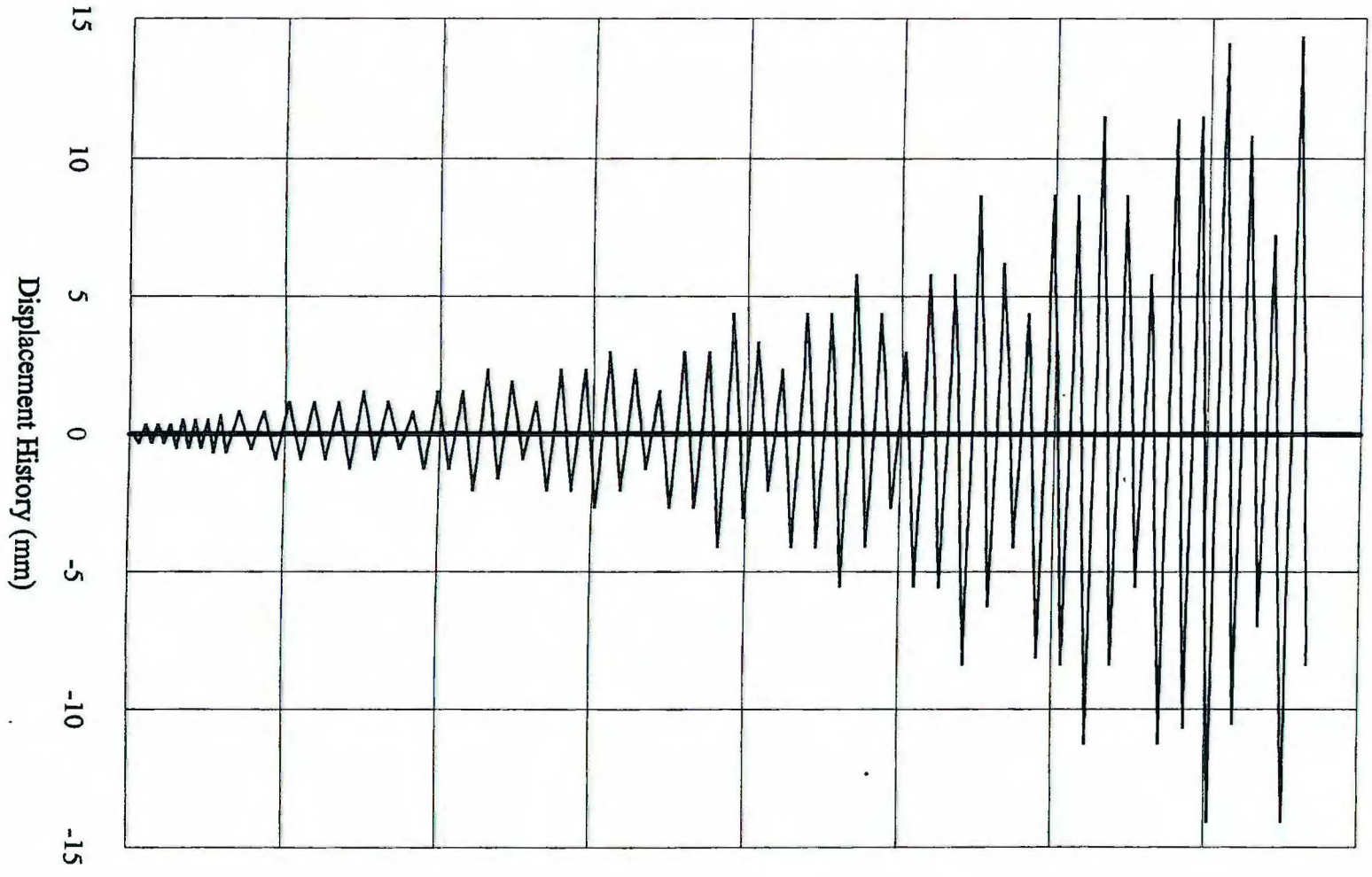
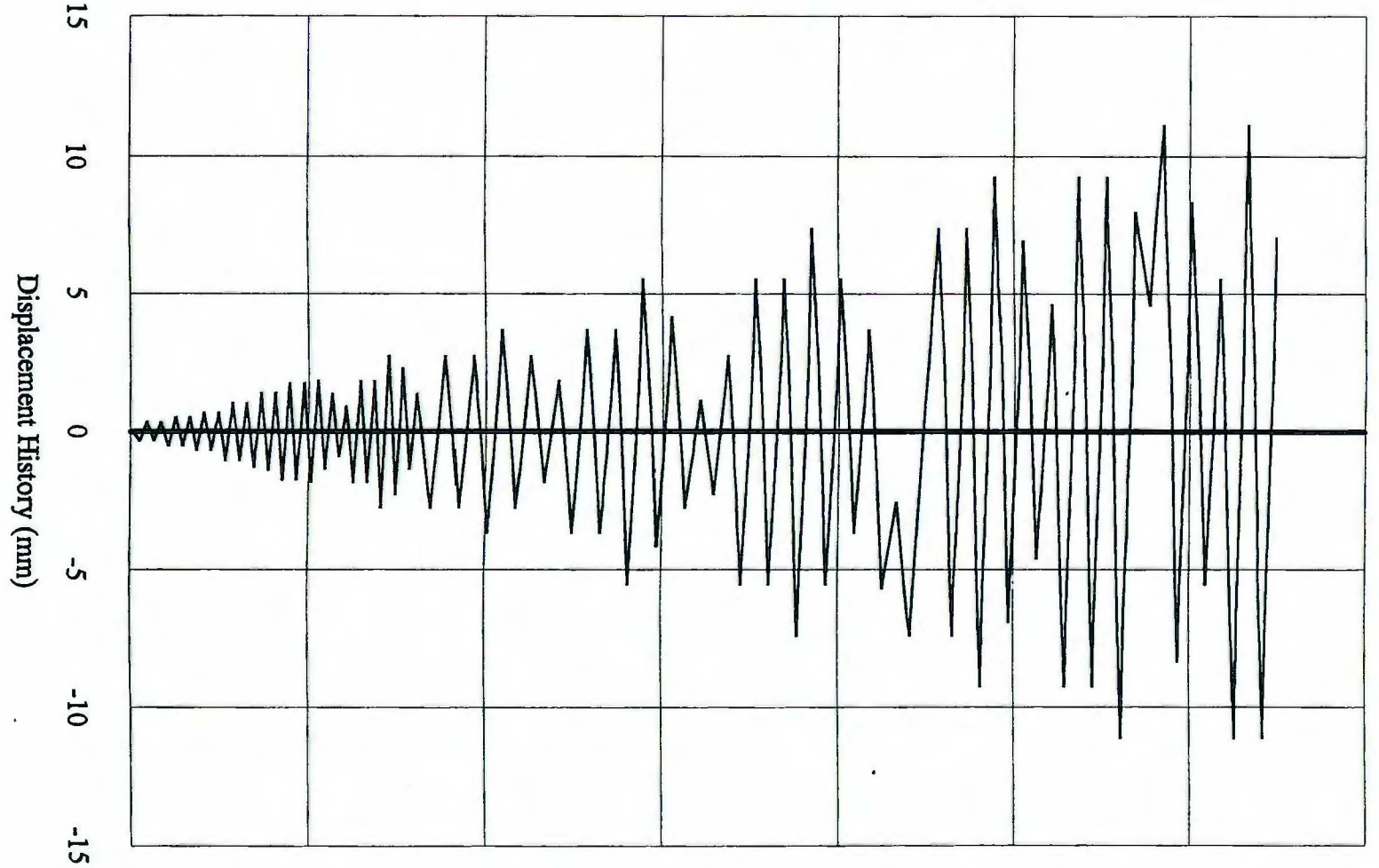


Figure 3.4 FEM/I Displacement History for Wall 7



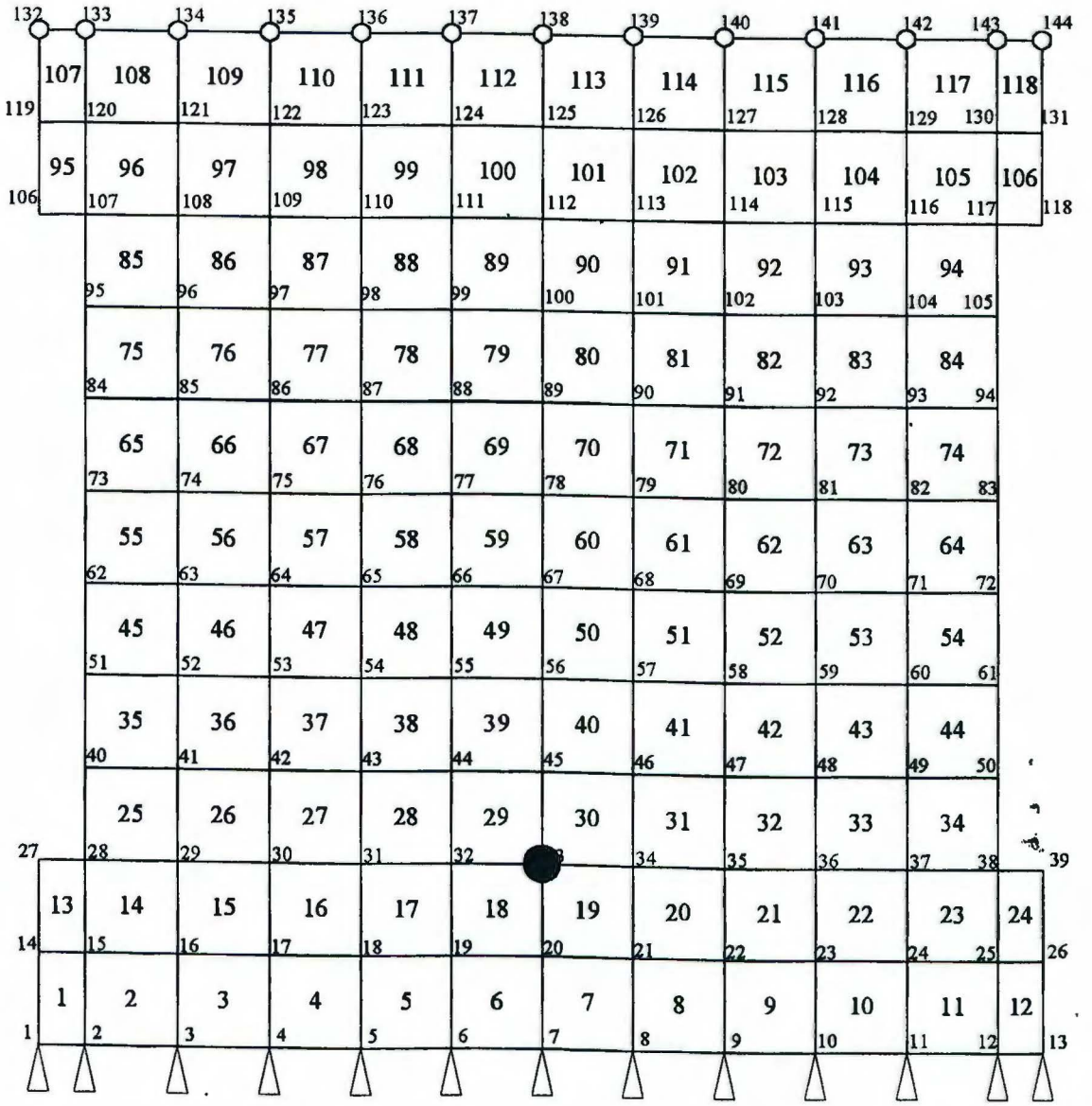


Figure 3.5 FEM/I Mesh for Wall 3 and Wall 9

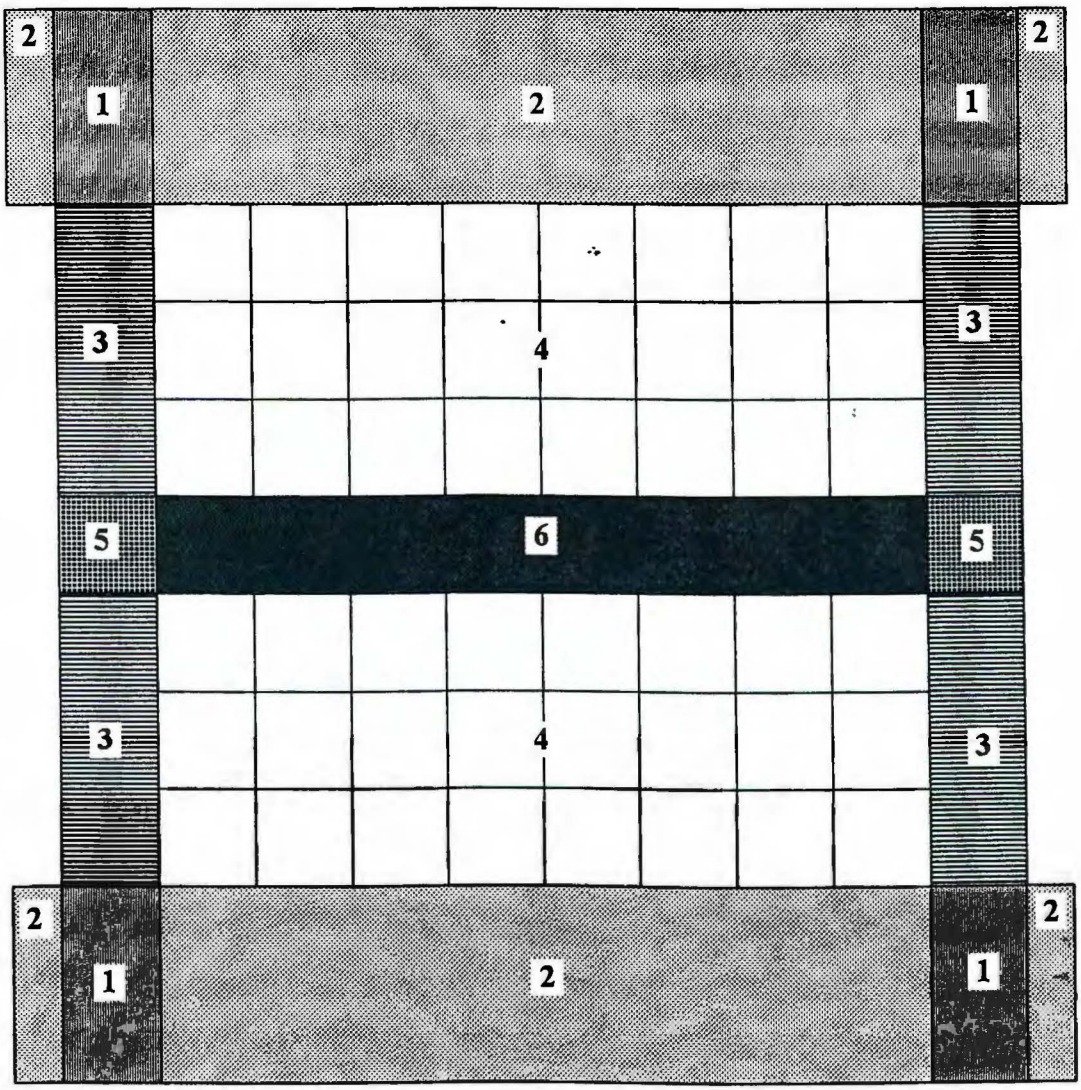


Figure 3.6 FEM/I Material Pattern for Wall 3 and Wall 9

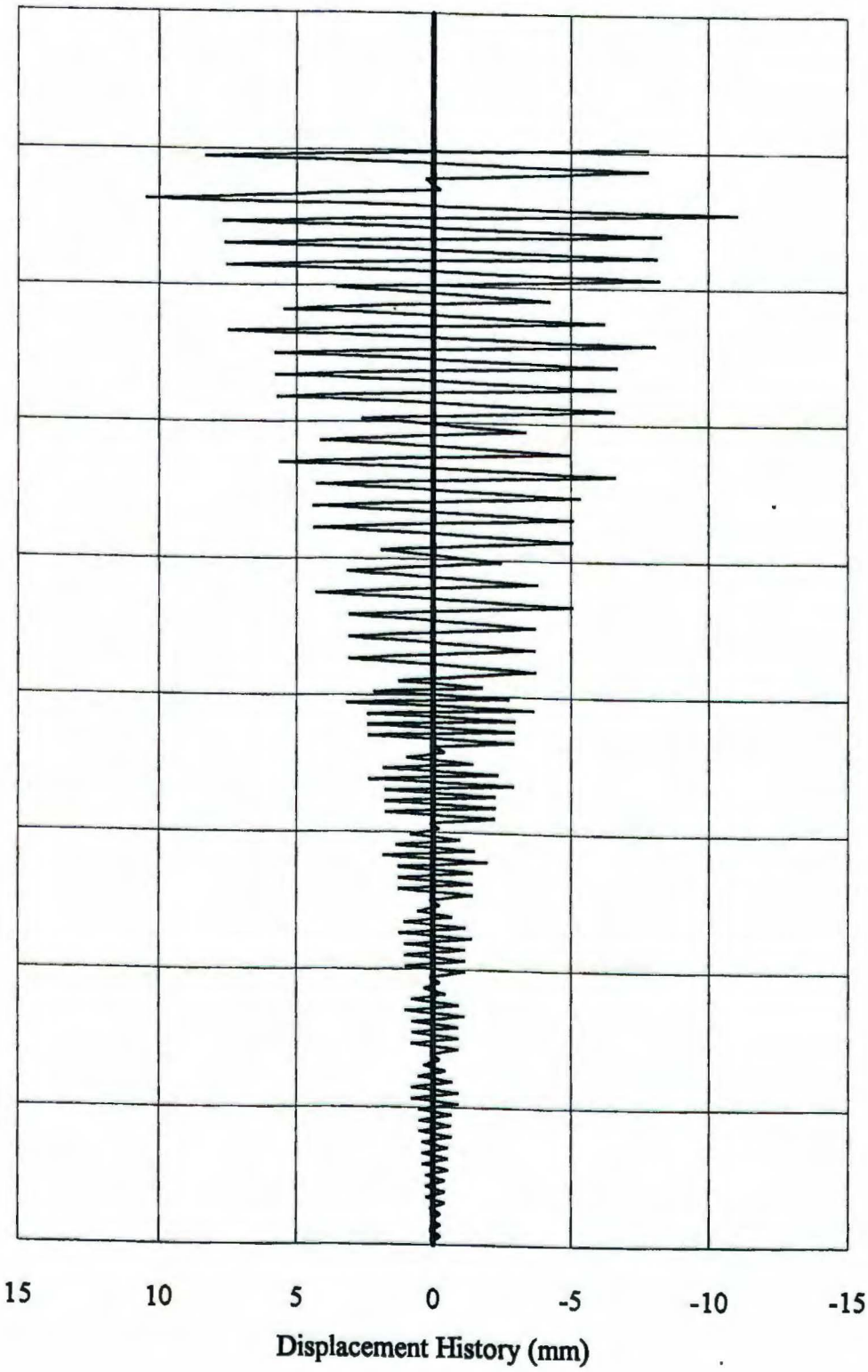
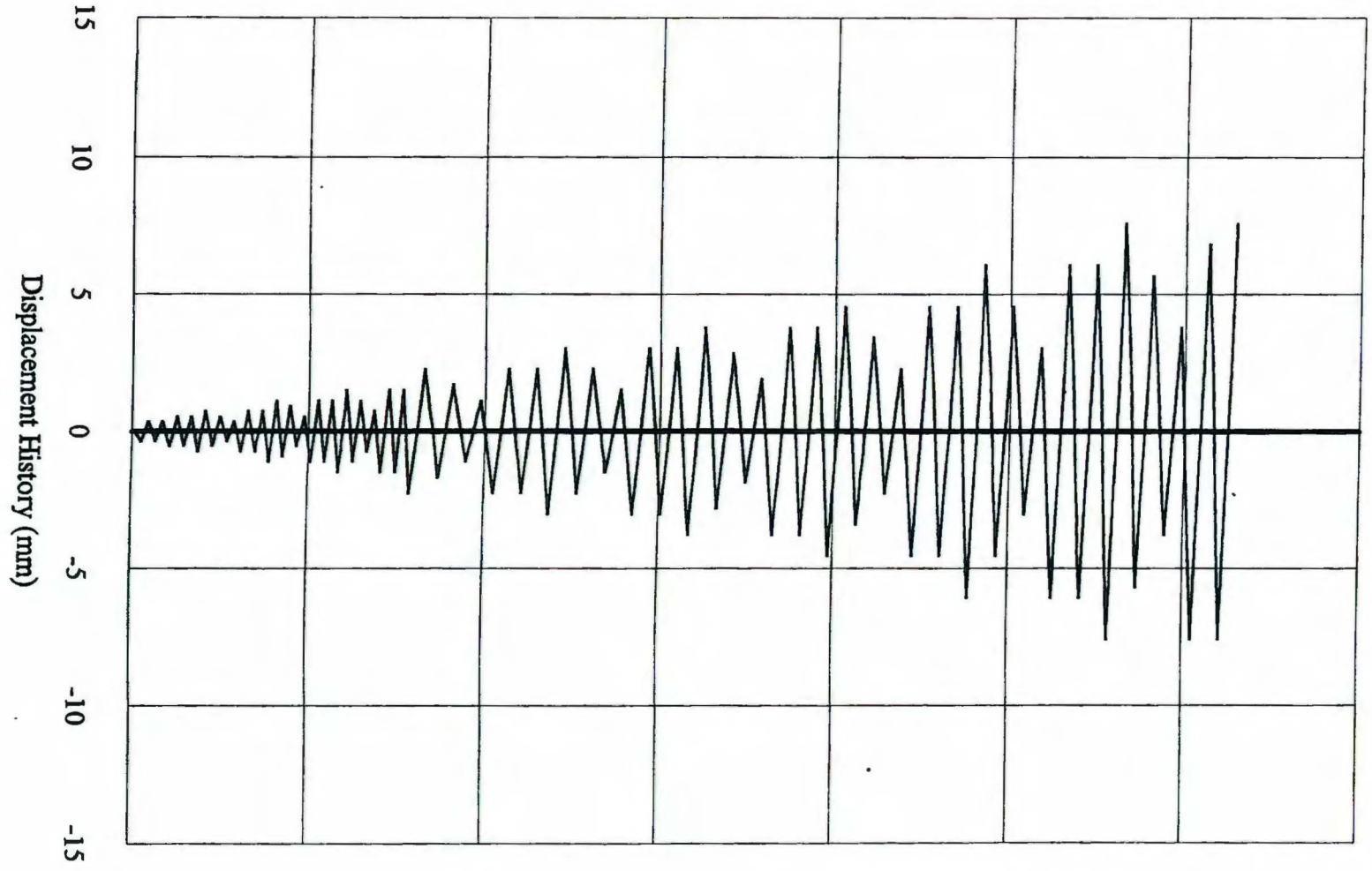


Figure 3.7 FEM/I Displacement History for Wall 3

Figure 3.8 FEM/I Displacement History for Wall 9



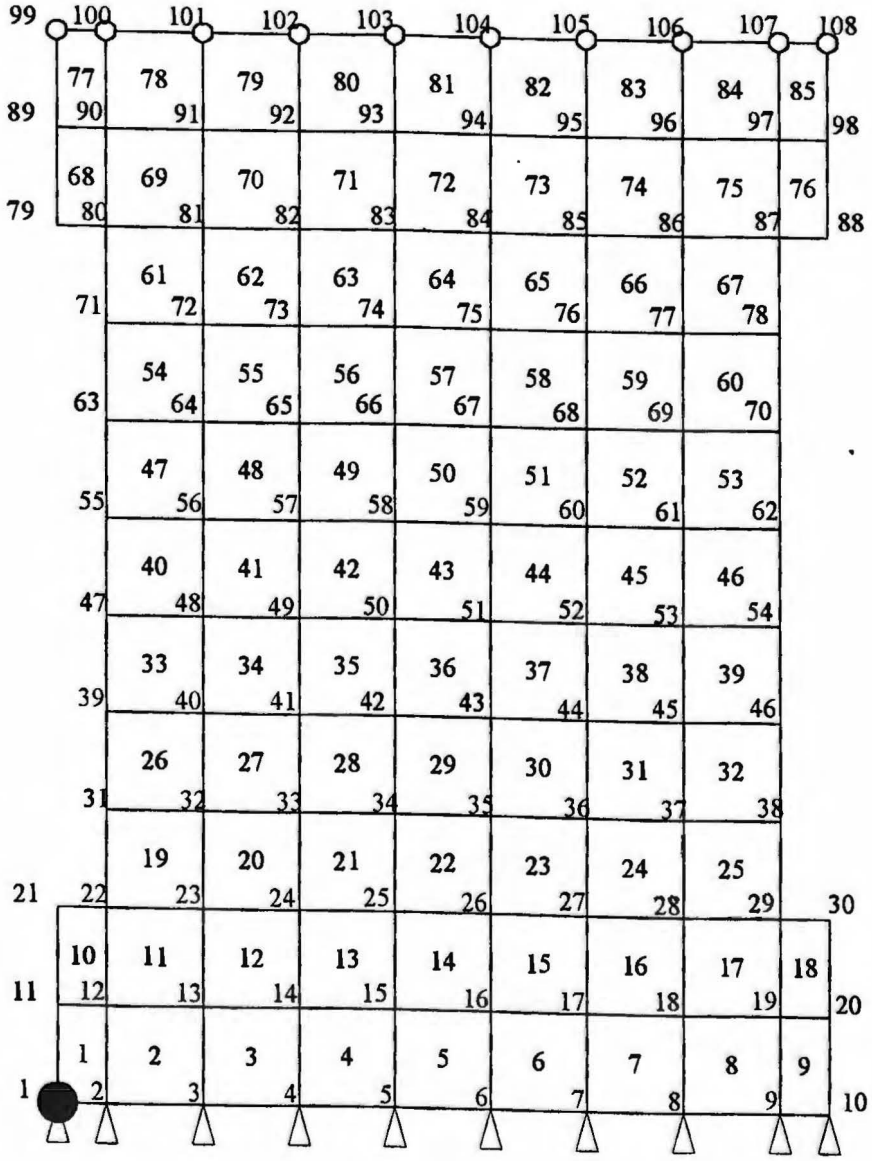


Figure 3.9 FEM/I Mesh for Wall 5 and Wall 11

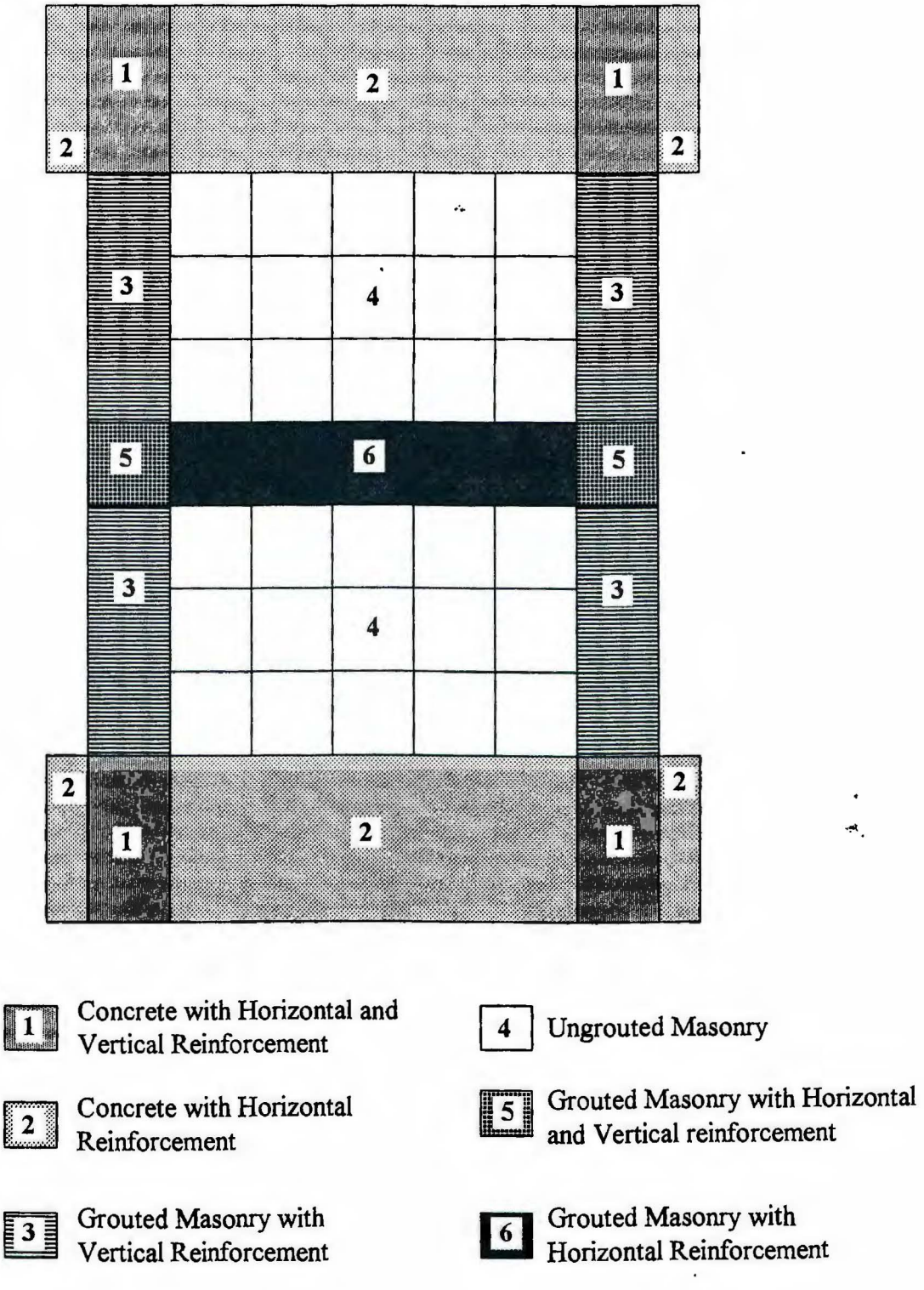


Figure 3.10 FEM/I Material Pattern for Wall 5 and Wall 11

Figure 3.11 FEM/I Displacement History for Wall 5

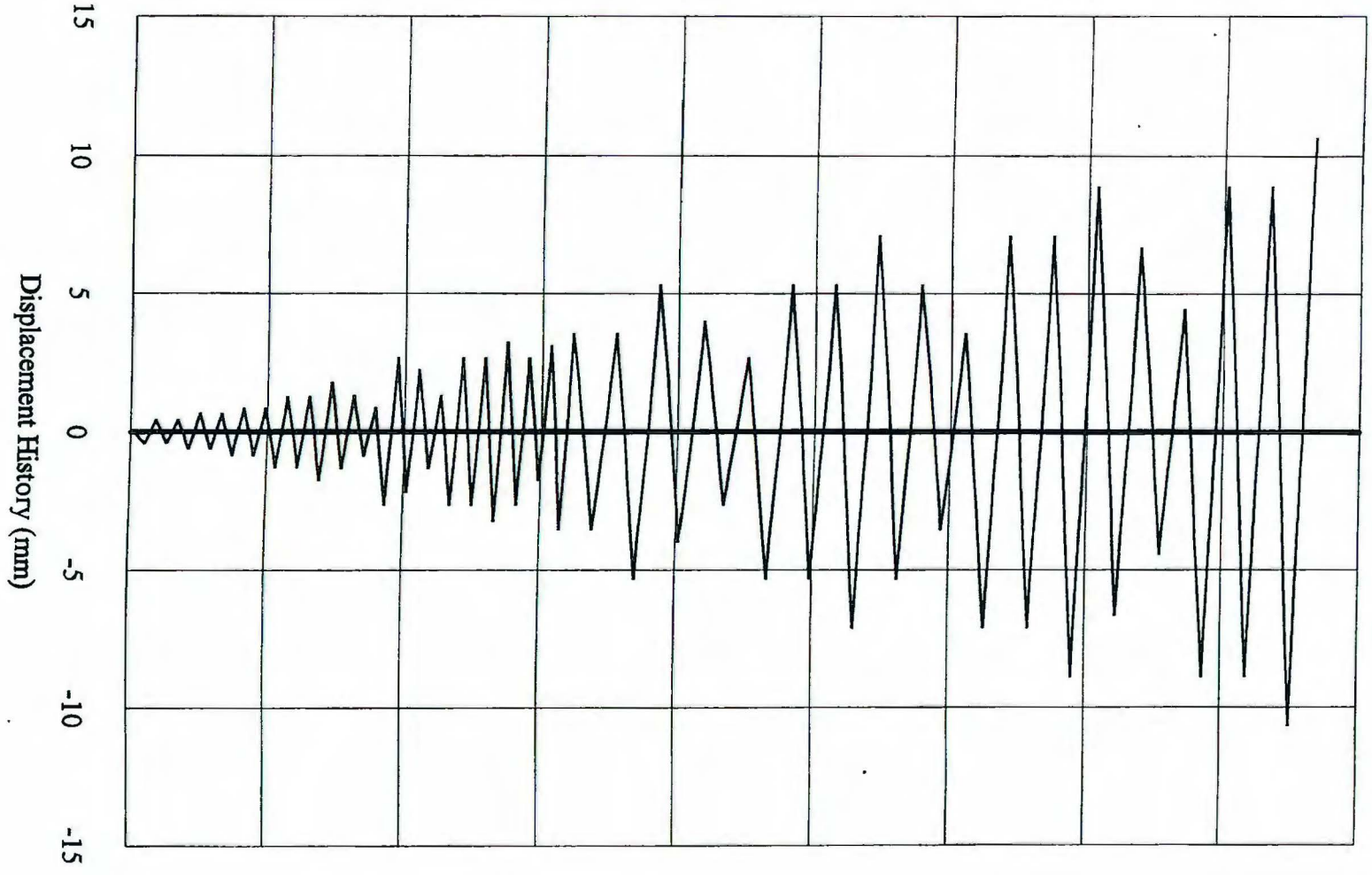
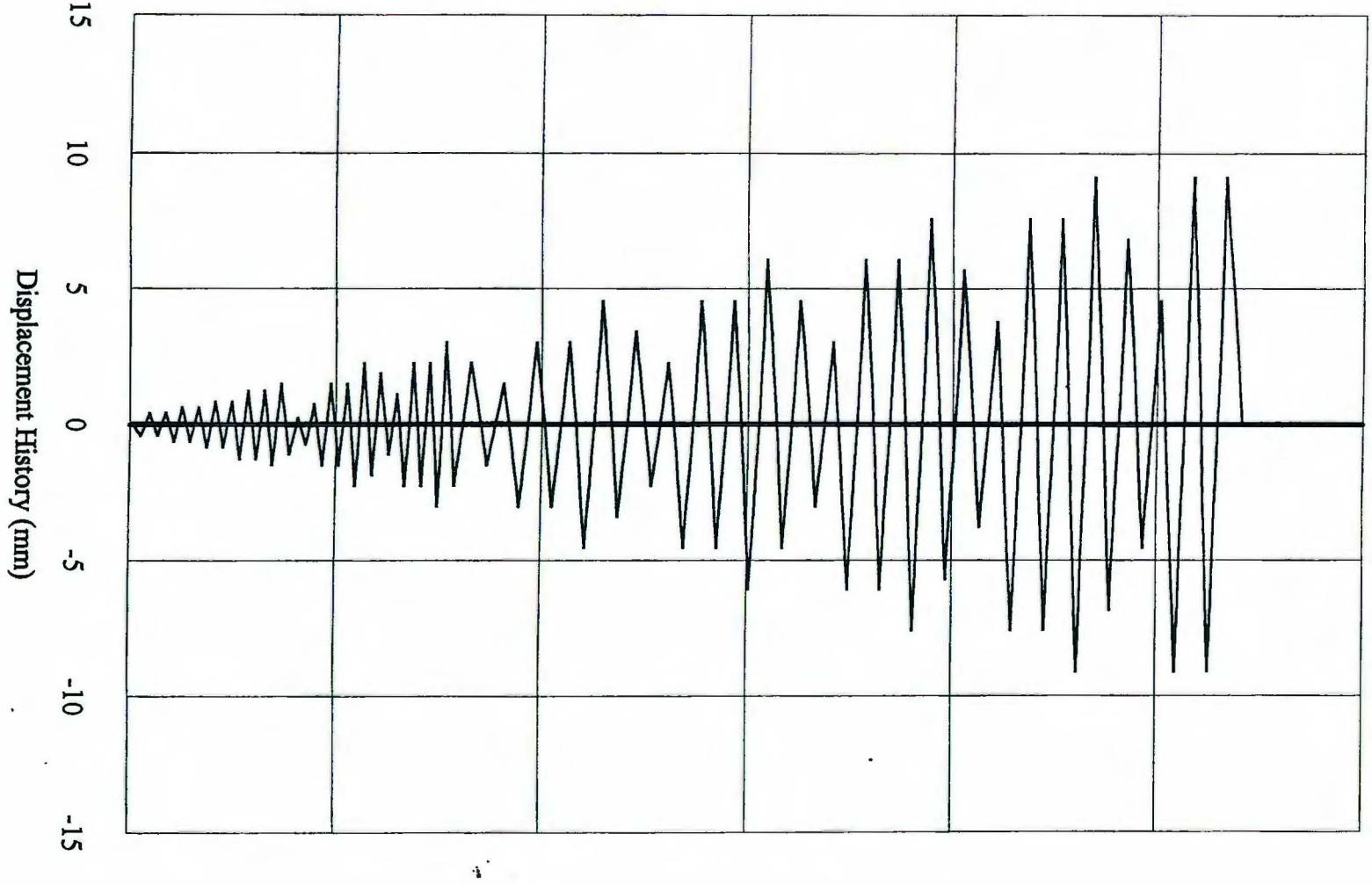
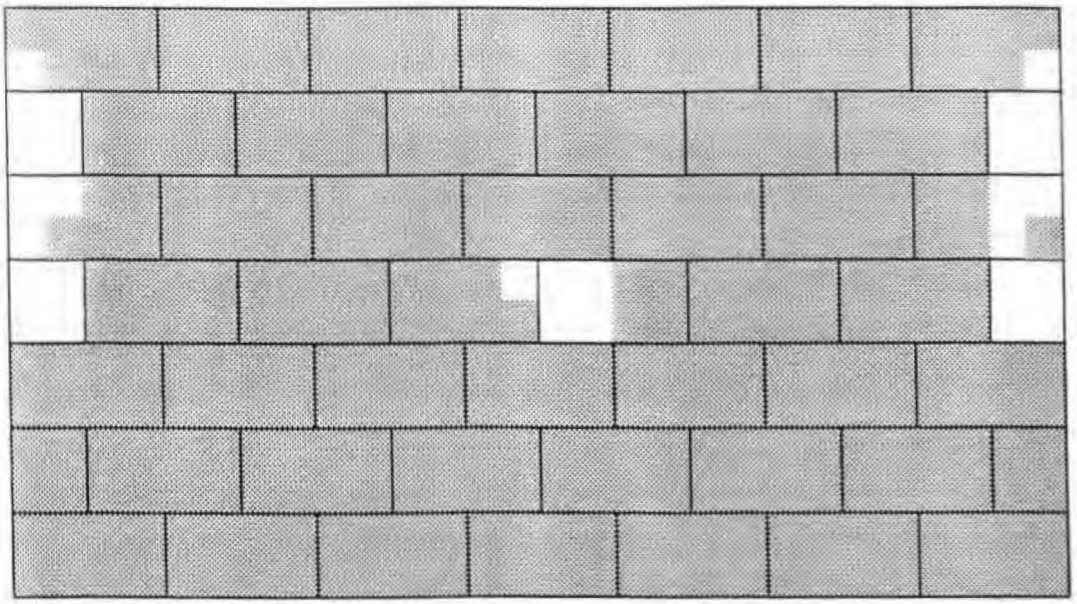
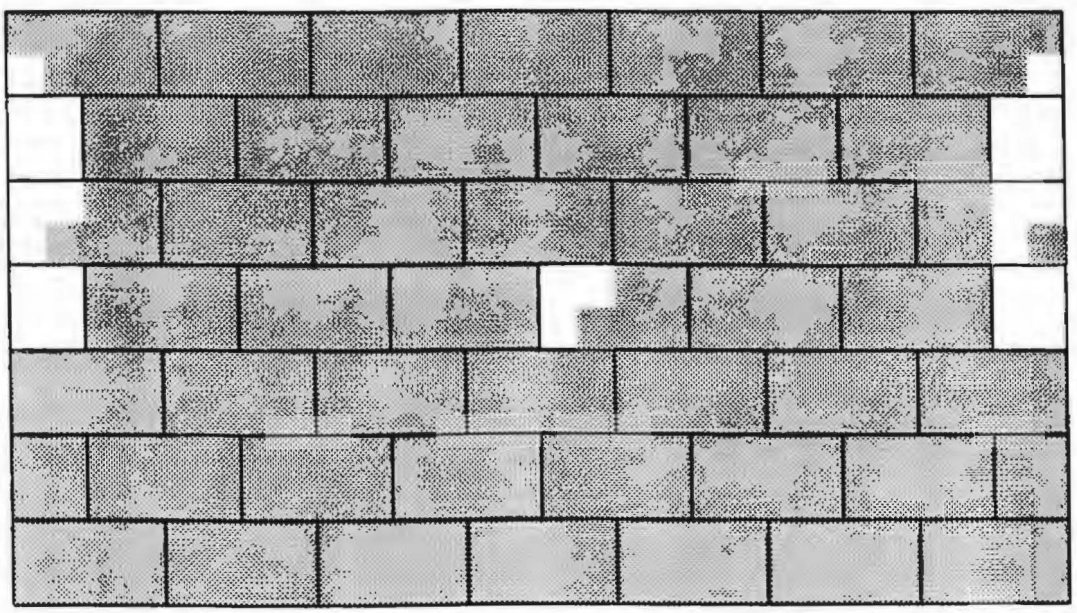


Figure 3.12 FEM/I Displacement History for Wall 11





Cycle 1



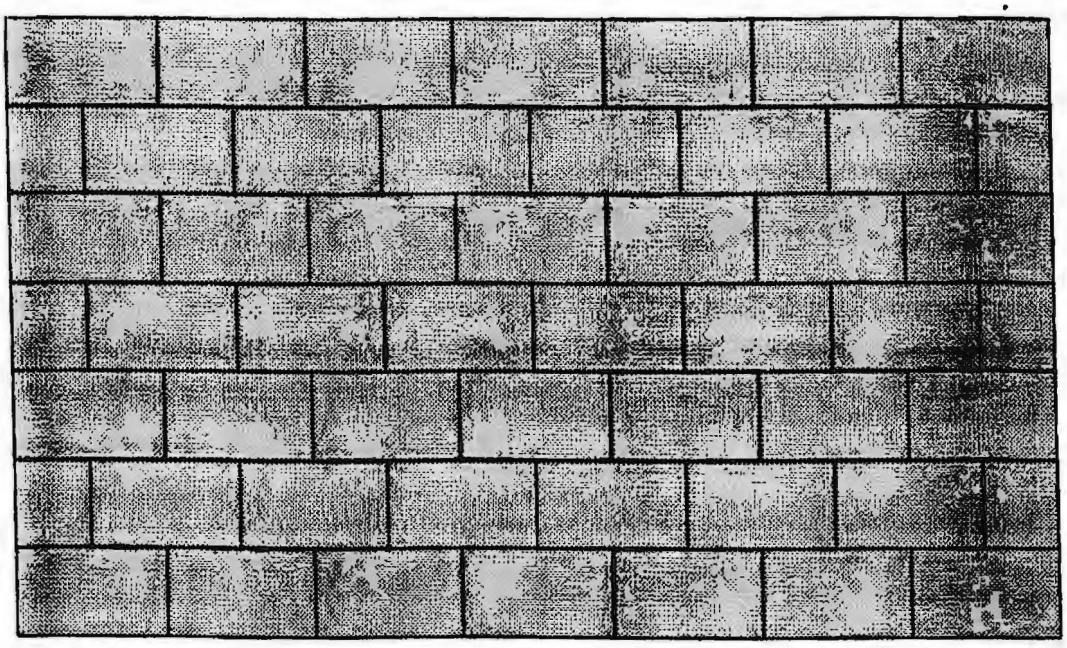
Cycle 2

FEM/I Crack Pattern

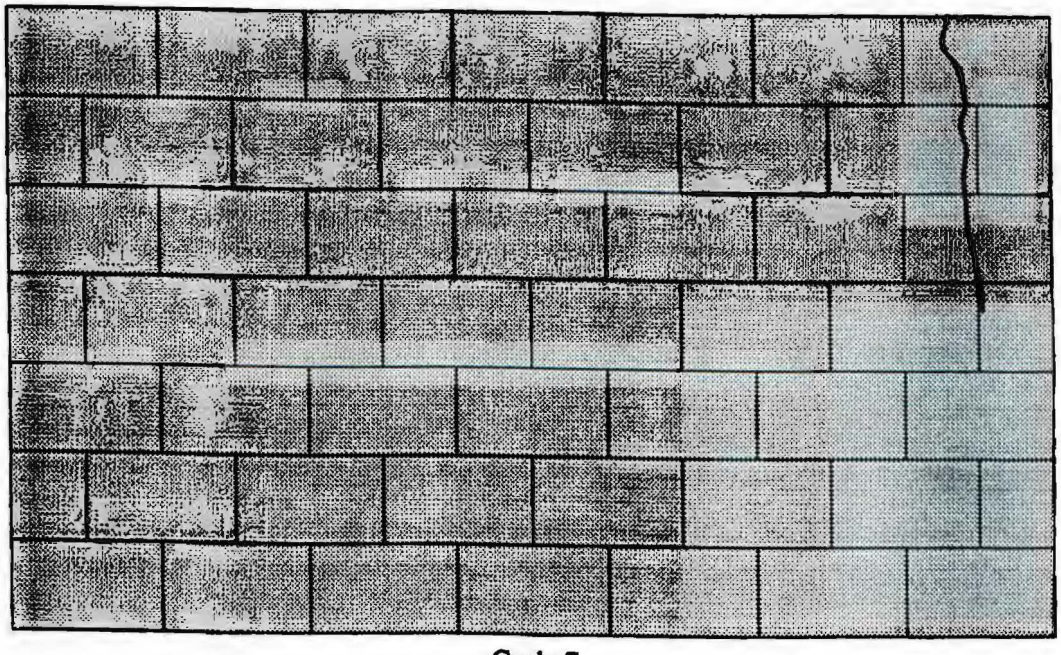
FEM/I Masonry Crushing Pattern

Experimental Study Crack Pattern

Figure 4.1 Crack Pattern for Wall 1

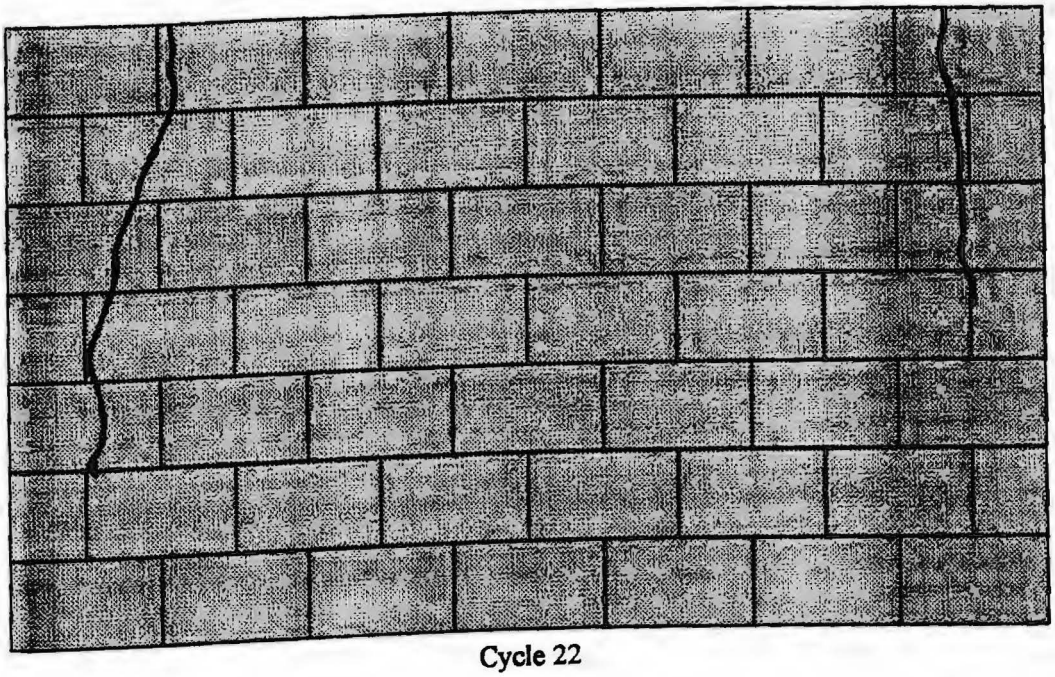


Cycle 4

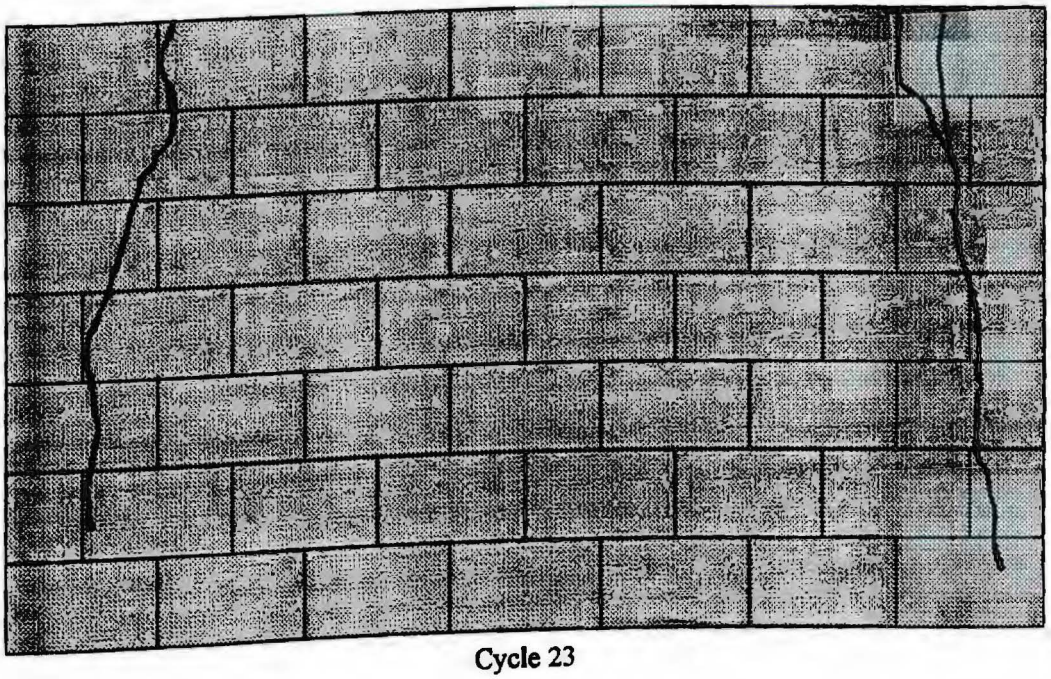


Cycle 7

Figure 4.1 Crack Pattern for Wall 1 (cont.)

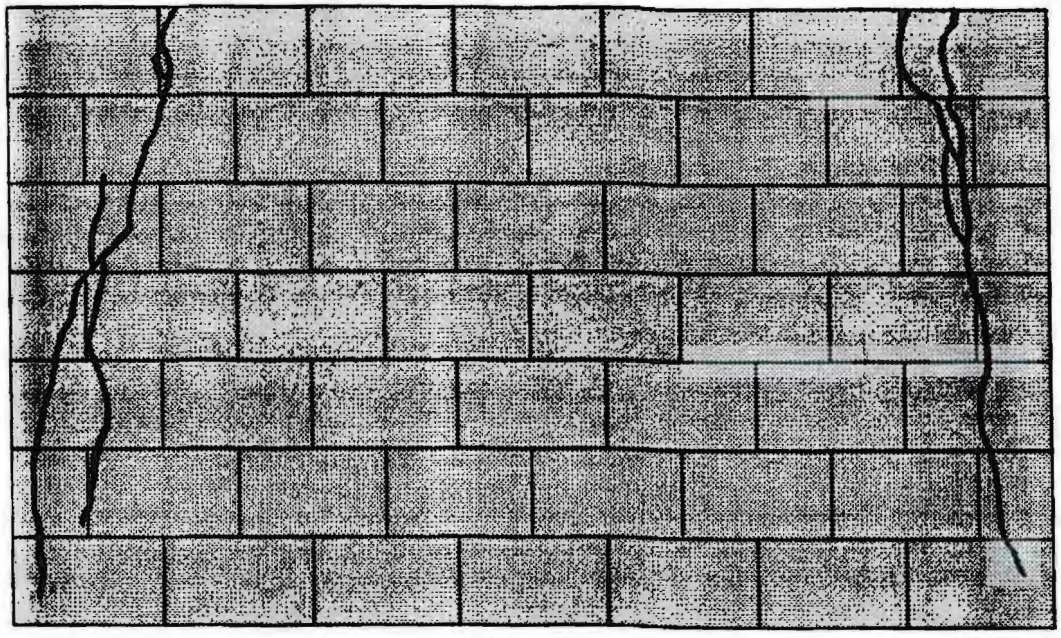


Cycle 22

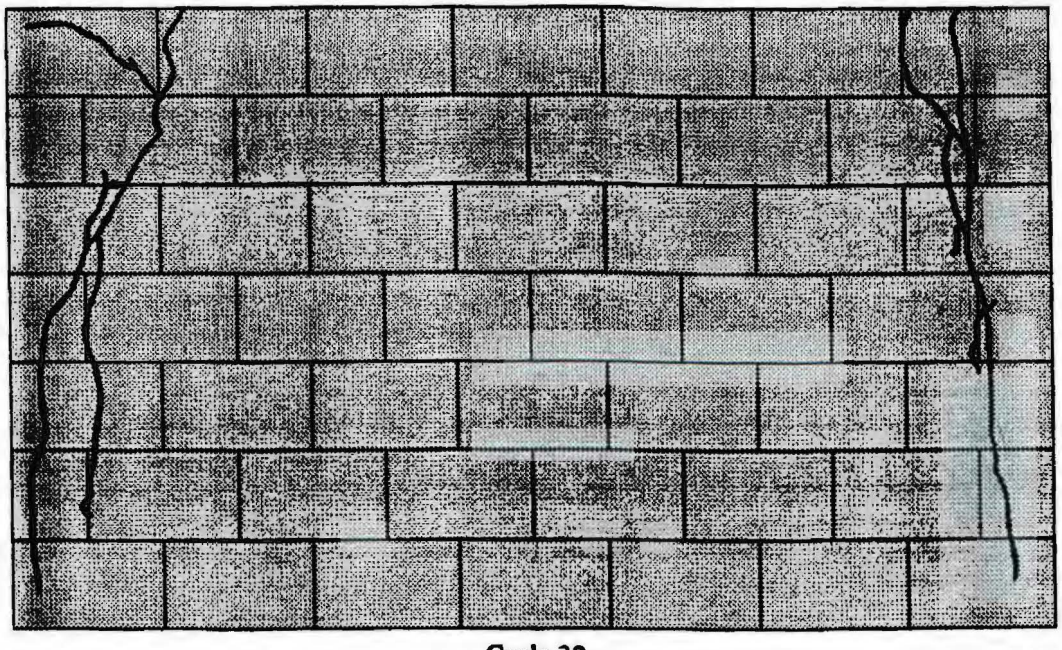


Cycle 23

Figure 4.1 Crack Pattern for Wall 1 (cont.)

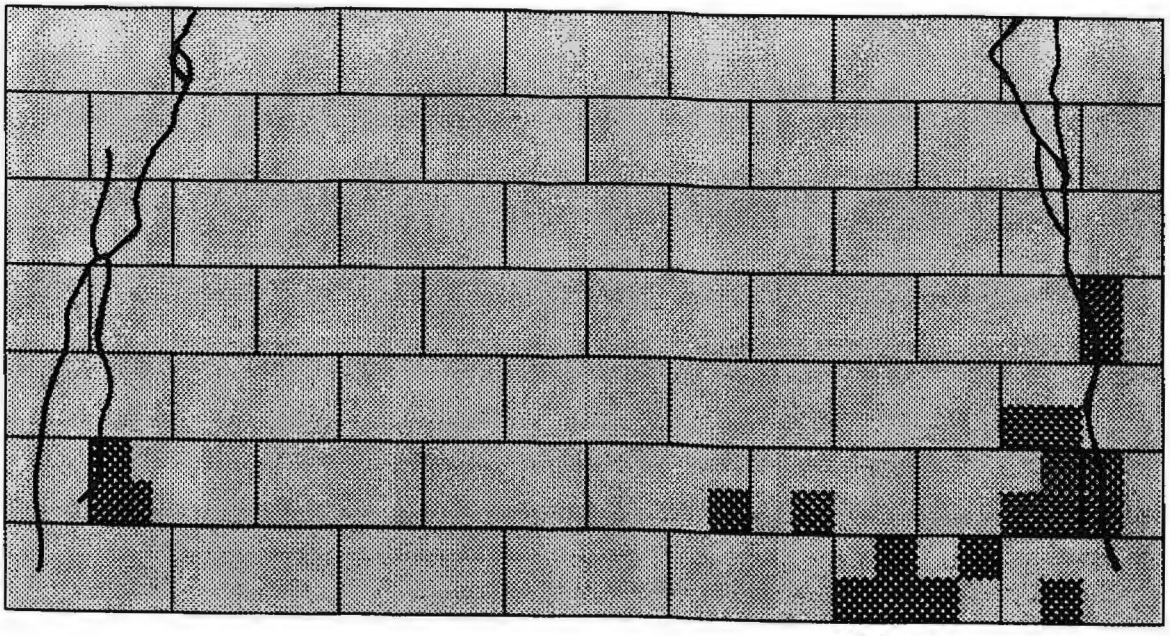


Cycle 27

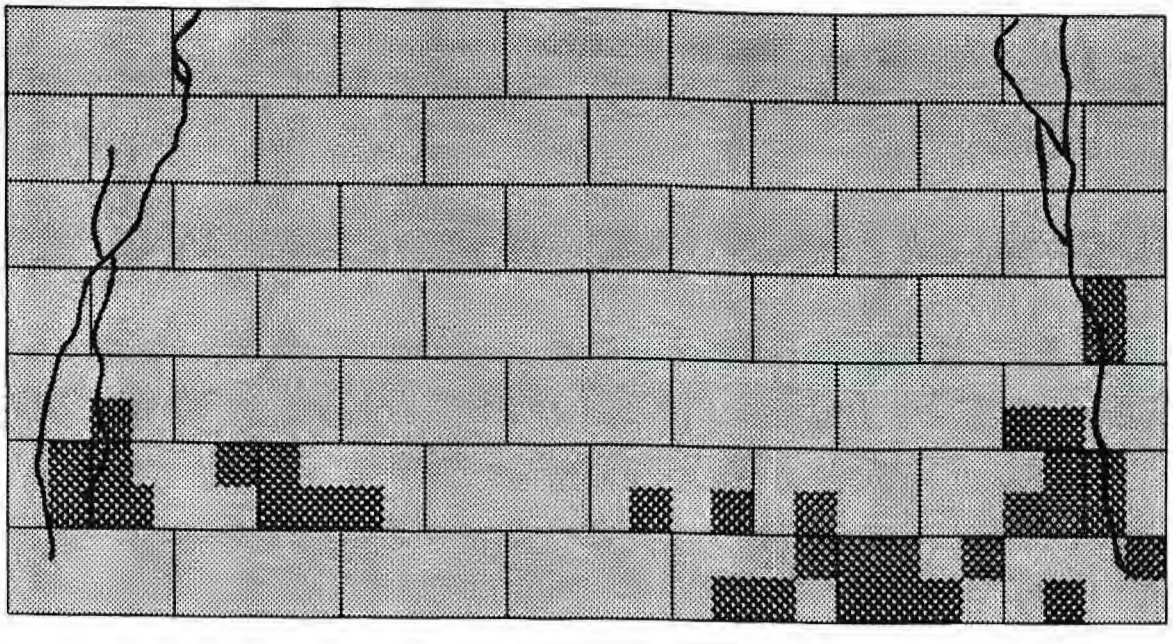


Cycle 32

Figure 4.1 Crack Pattern for Wall 1 (cont.)

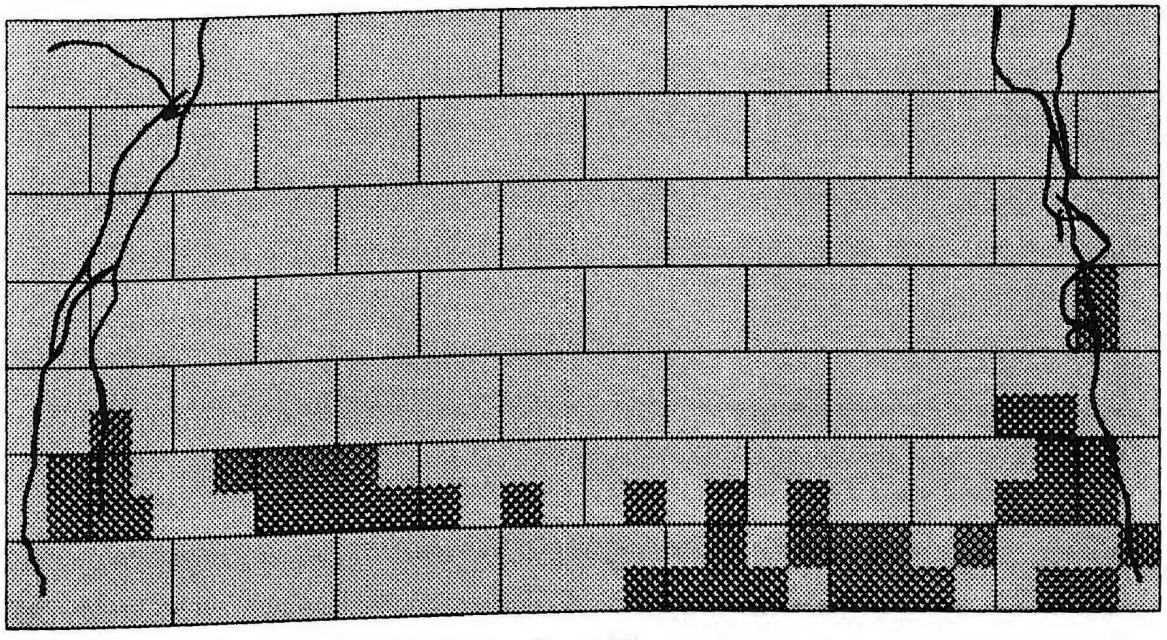


Cycle 33

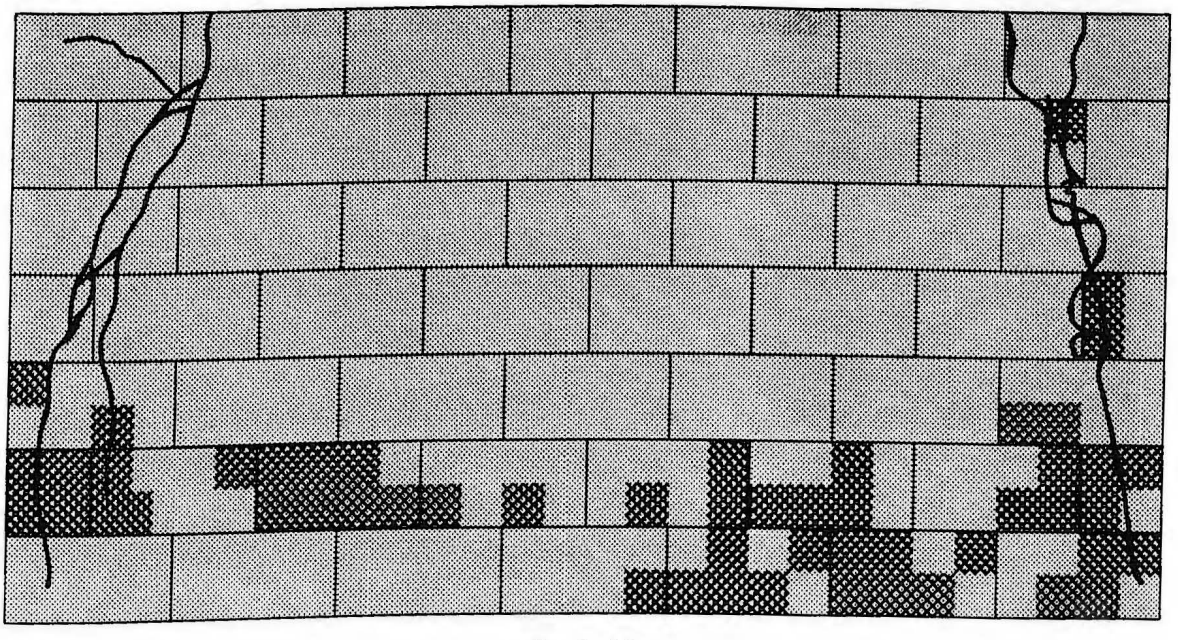


Cycle 36

Figure 4.1 Crack Pattern for Wall 1 (cont.)

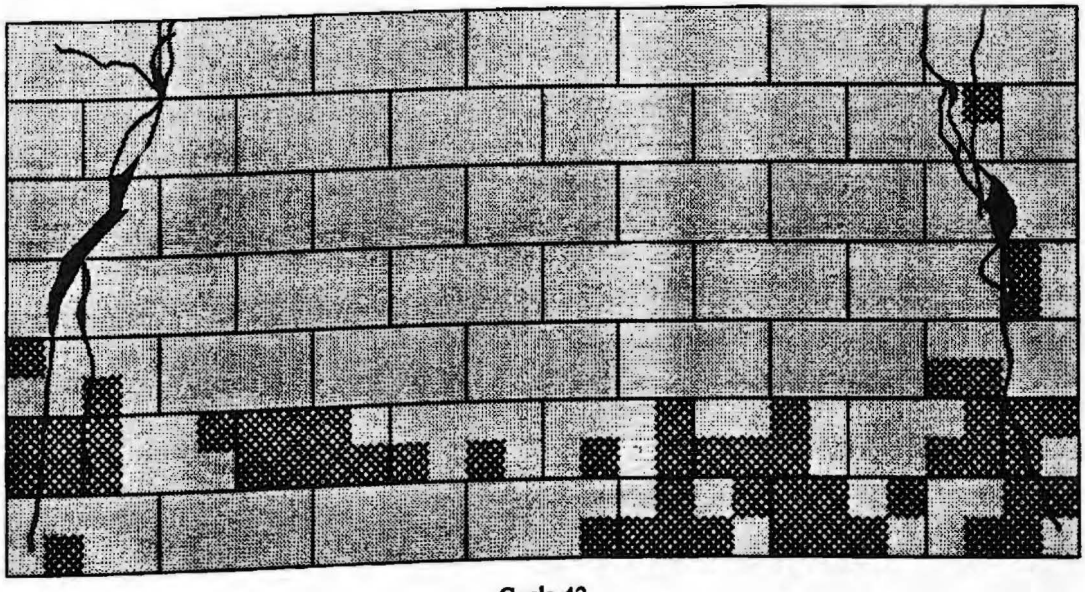


Cycle 37

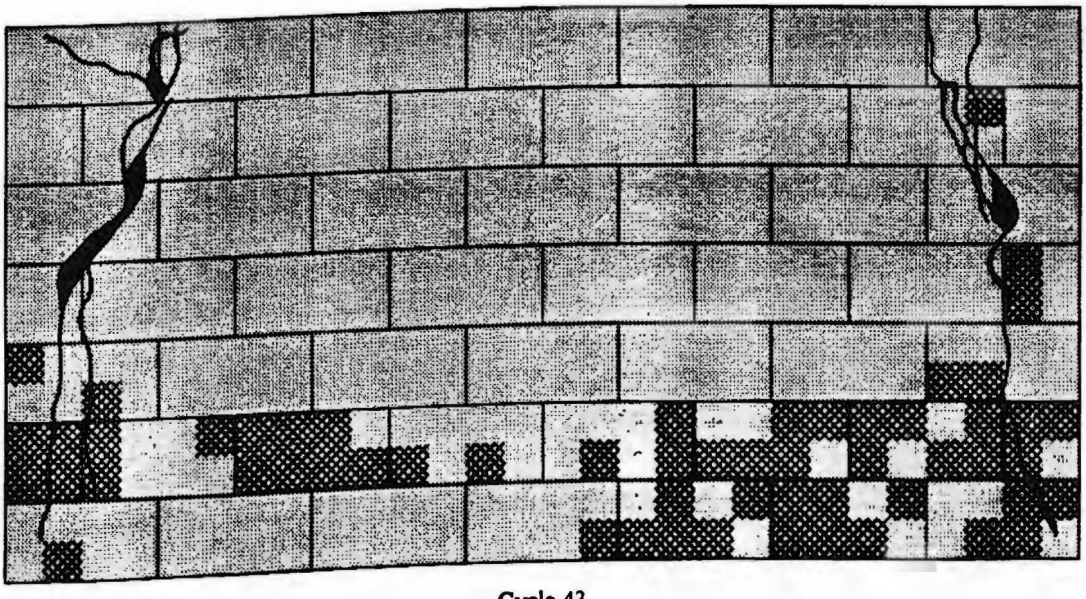


Cycle 38

Figure 4.1 Crack Pattern for Wall 1 (cont.)

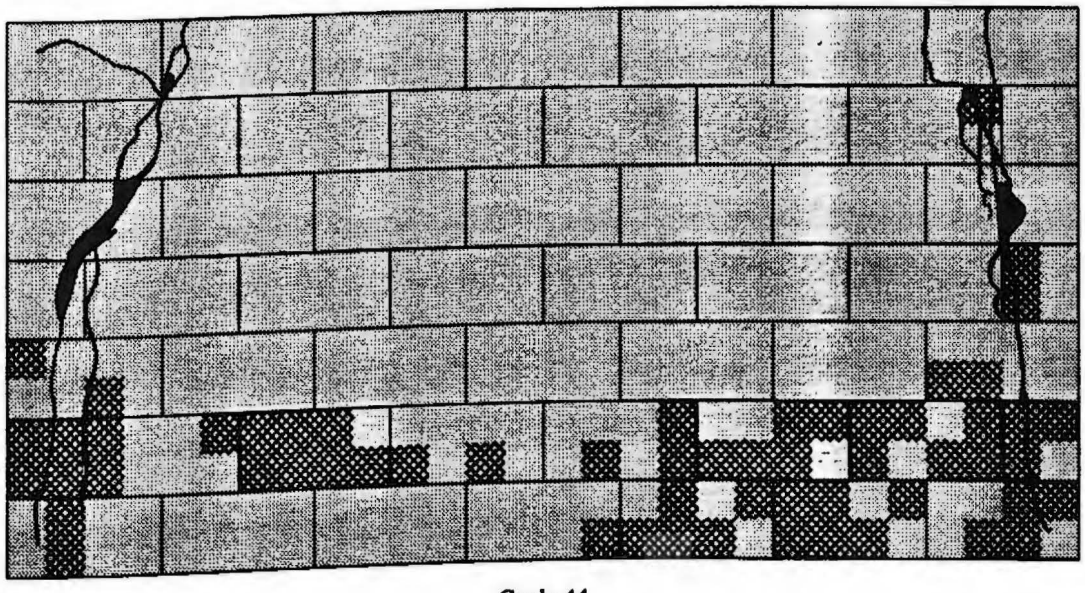


Cycle 42

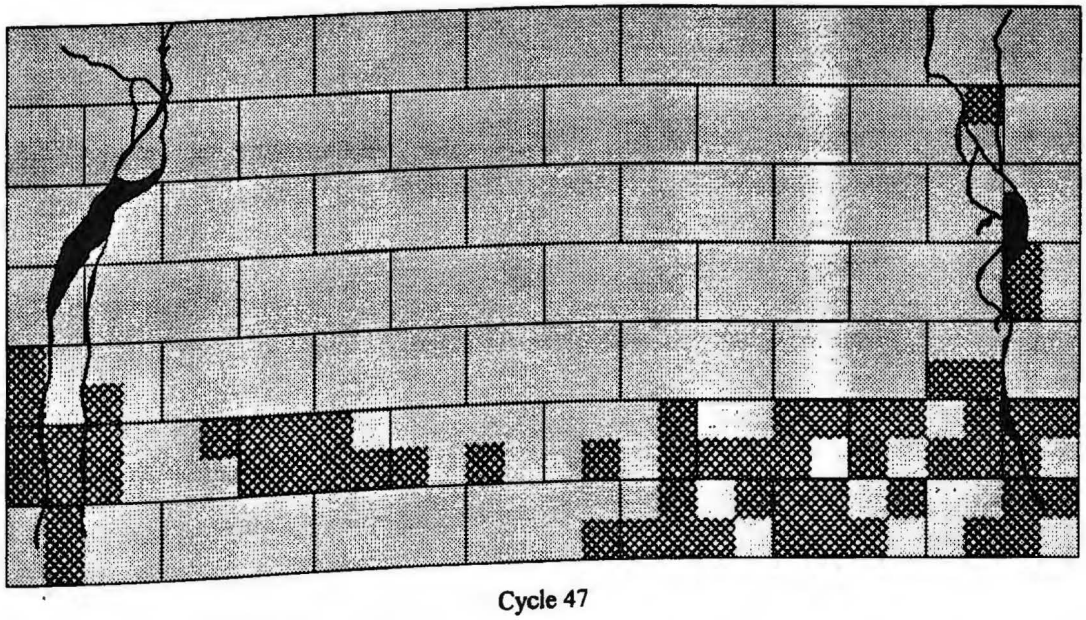


Cycle 43

Figure 4.1 Crack Pattern for Wall 1 (cont.)

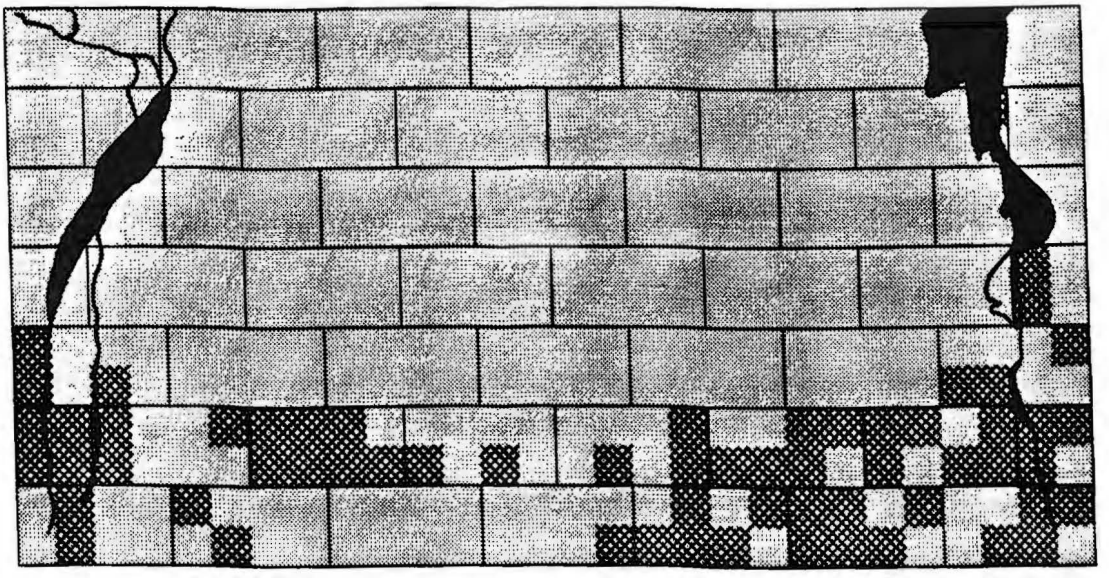


Cycle 44



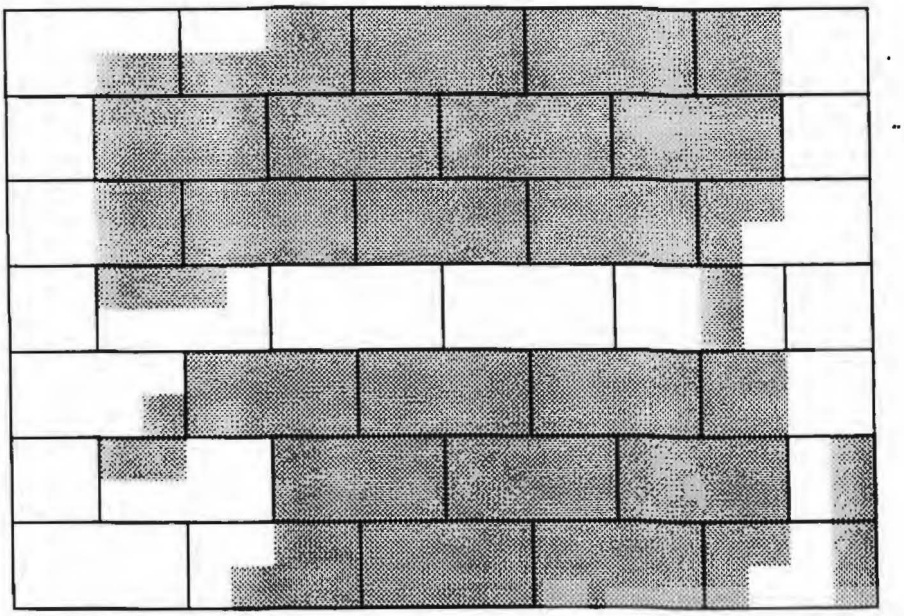
Cycle 47

Figure 4.1 Crack Pattern for Wall 1 (cont.)

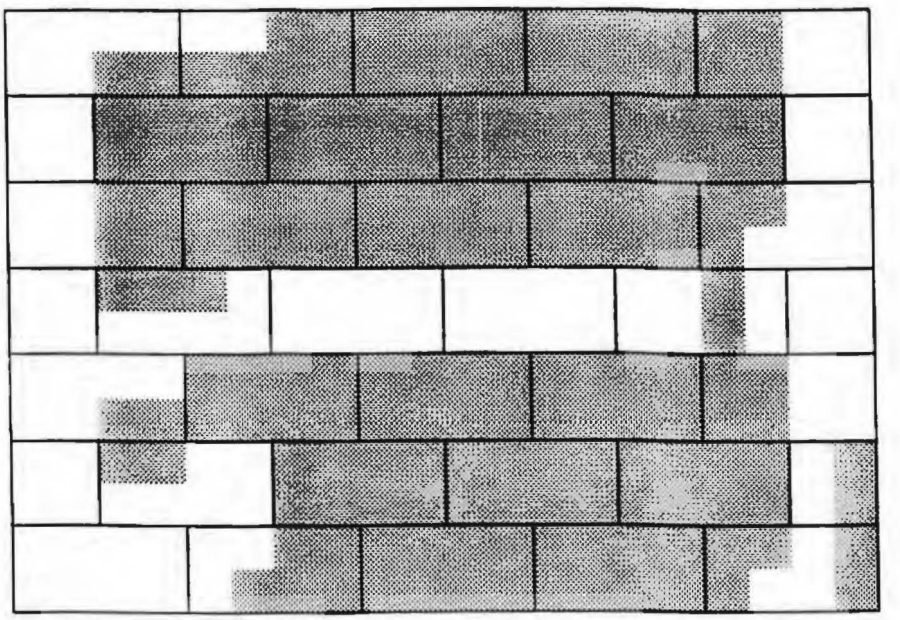


Cycle 51

Figure 4.1 Crack Pattern for Wall 1 (cont.)



Cycle 1



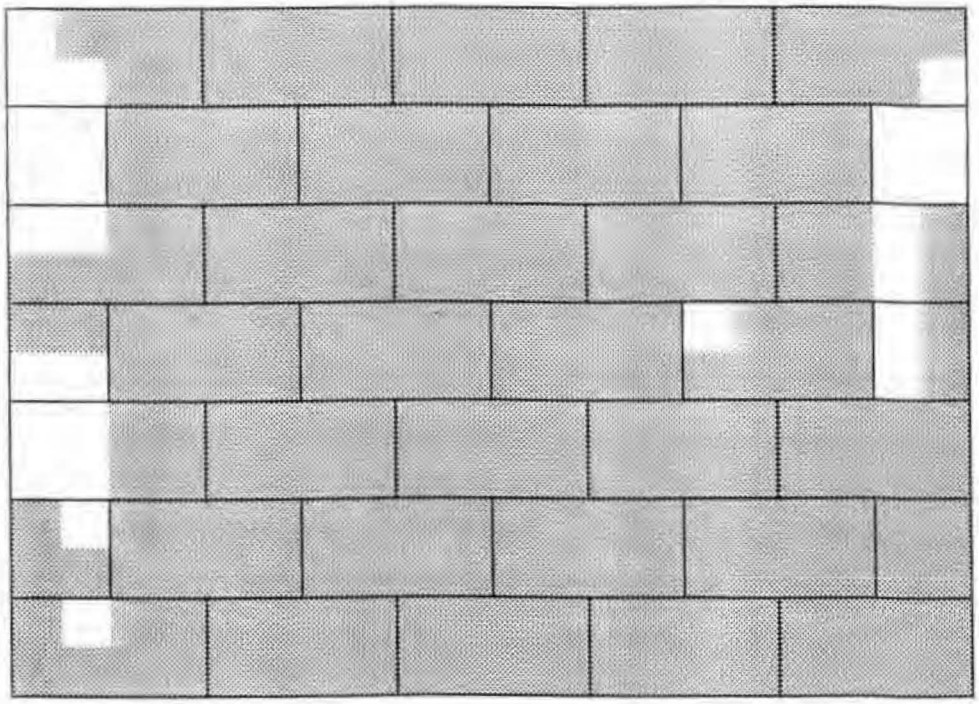
Cycle 2

FEM/I Crack Pattern

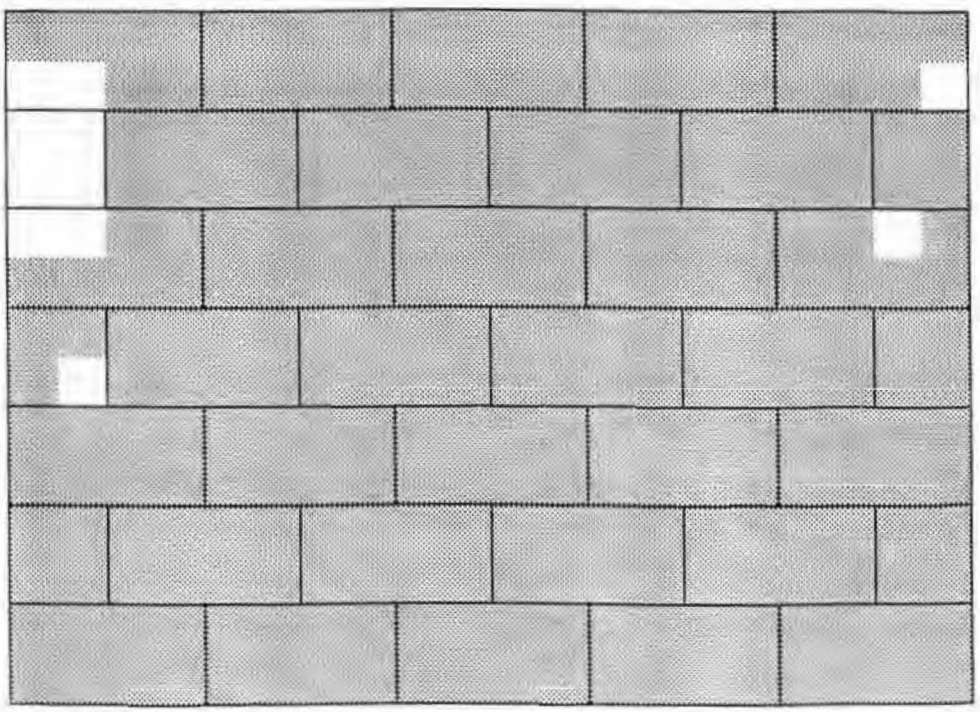
FEM/I Masonry Crushing Pattern

Experimental Study Crack Pattern

Figure 4.2 Crack Pattern for Wall 3

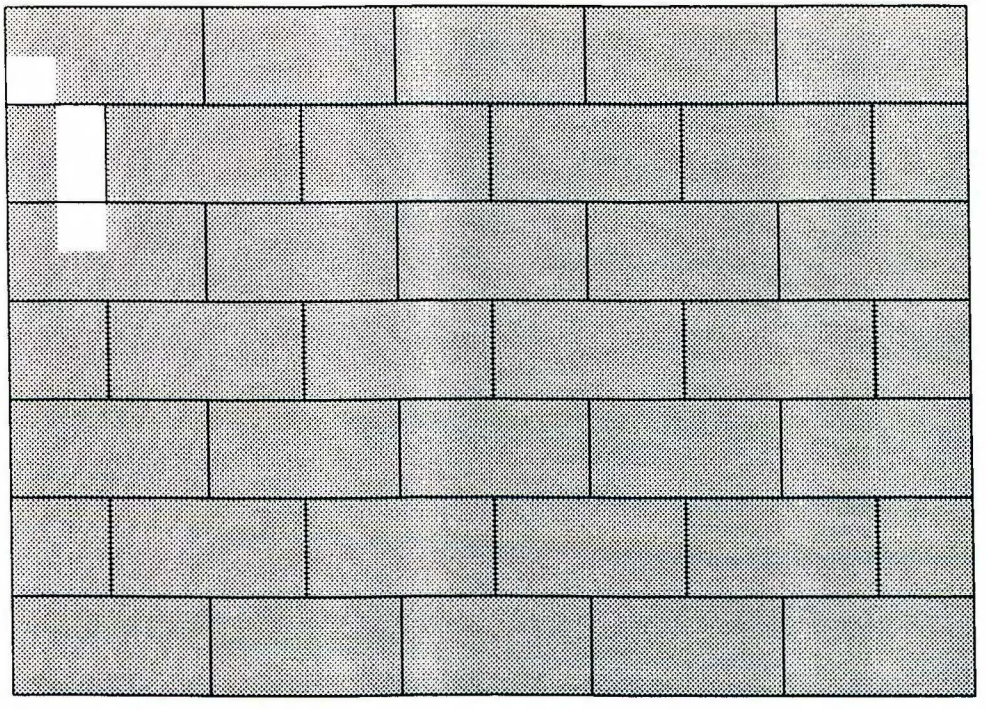


Cycle 4

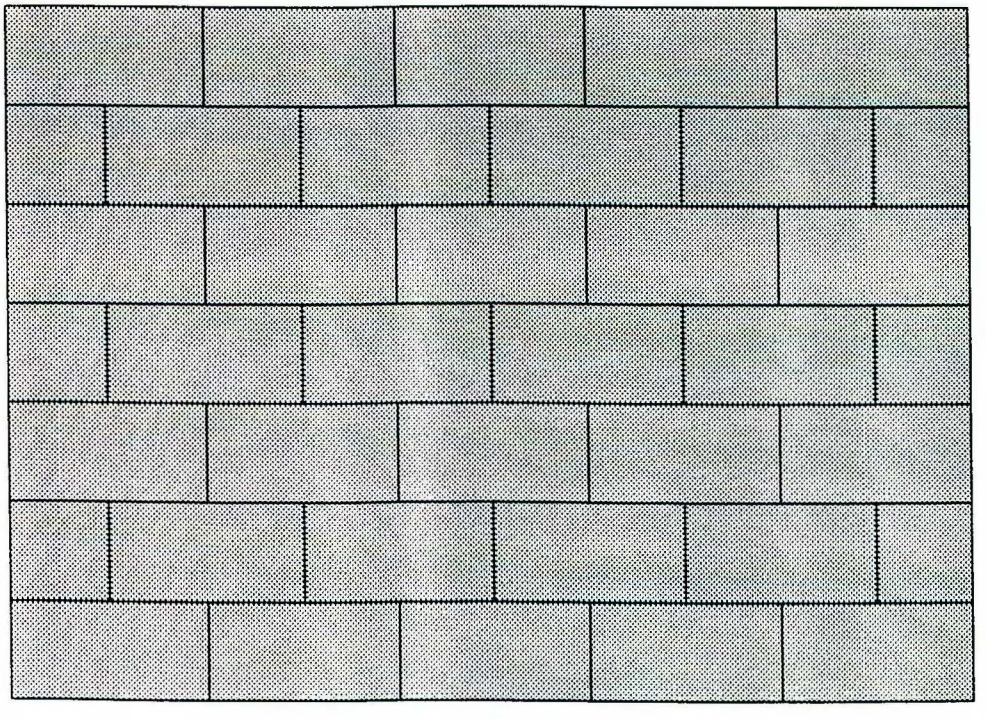


Cycle 7

Figure 4.2 Crack Pattern for Wall 3 (cont.)

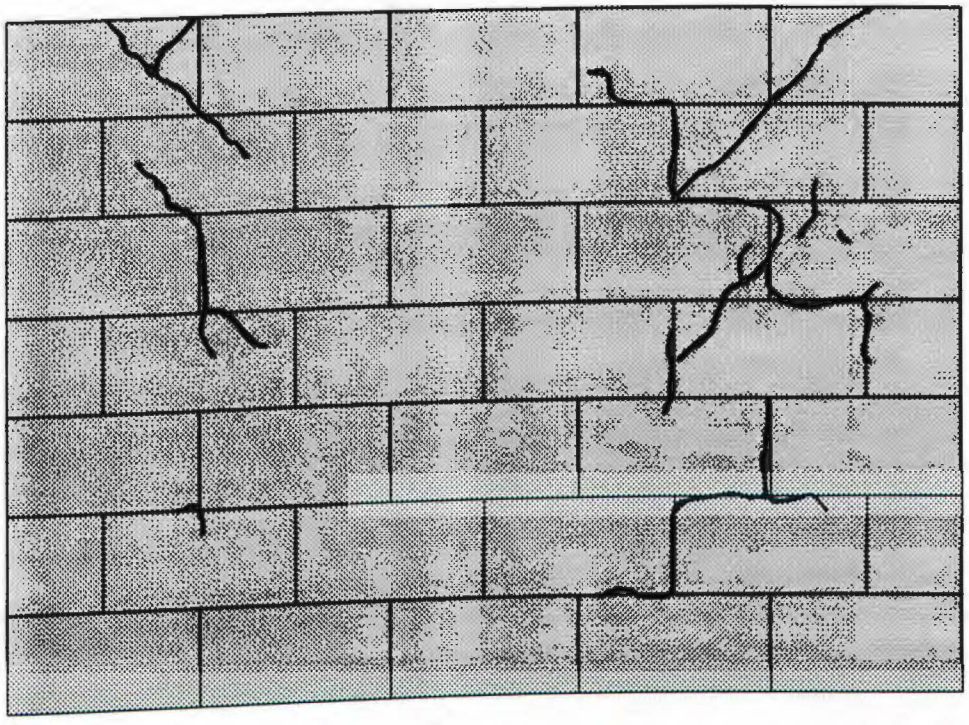


Cycle 10

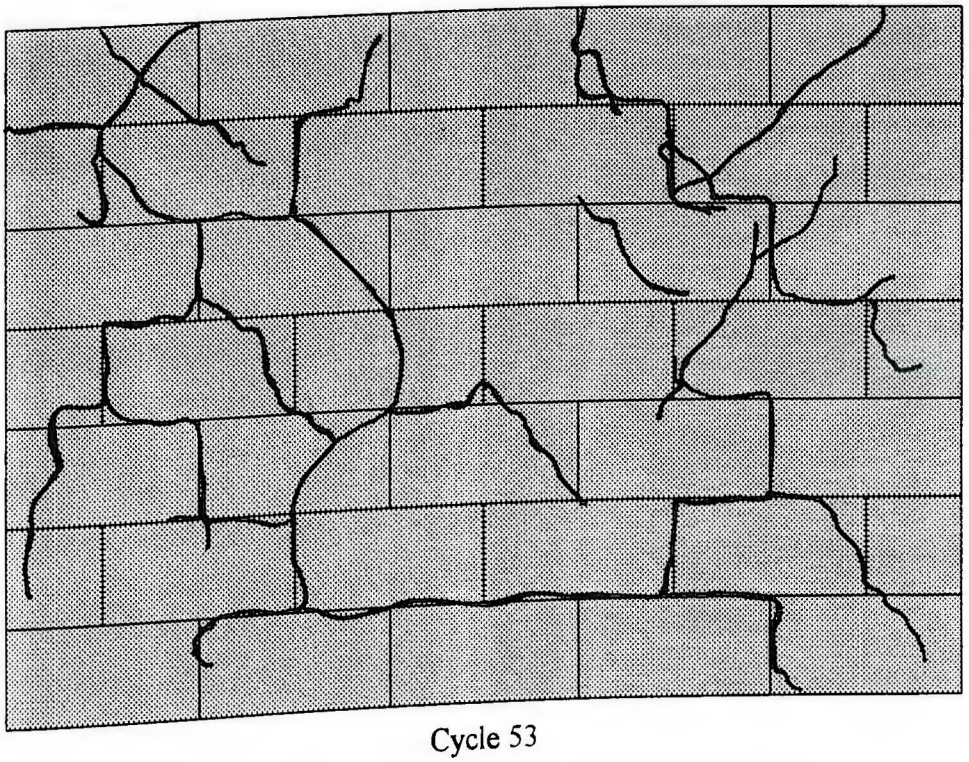


Cycle 13

Figure 4.2 Crack Pattern for Wall 3 (cont.)

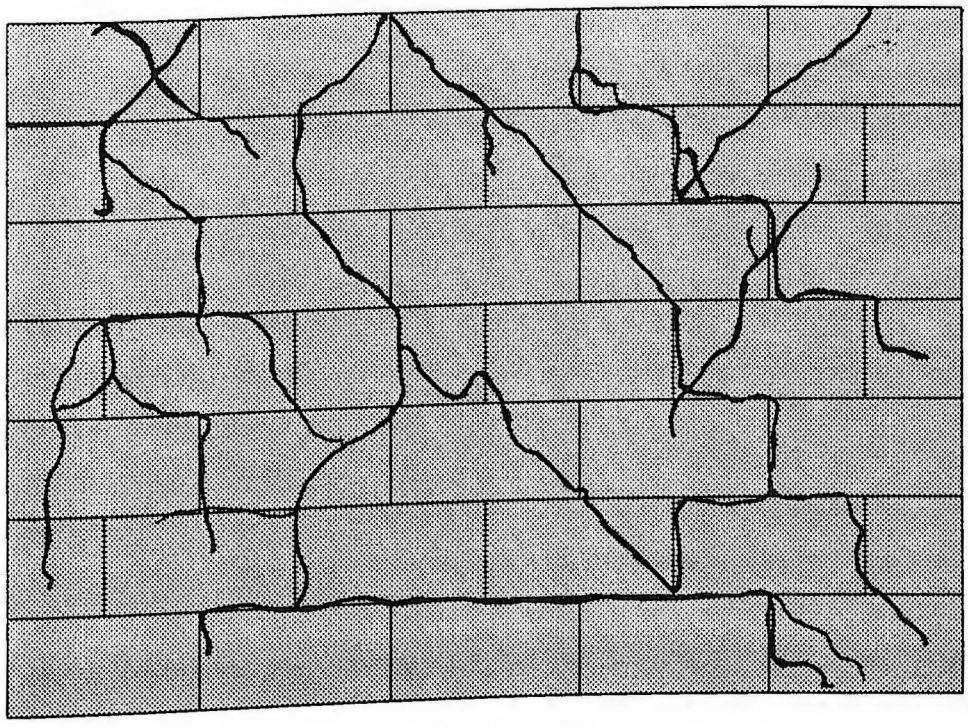


Cycle 39

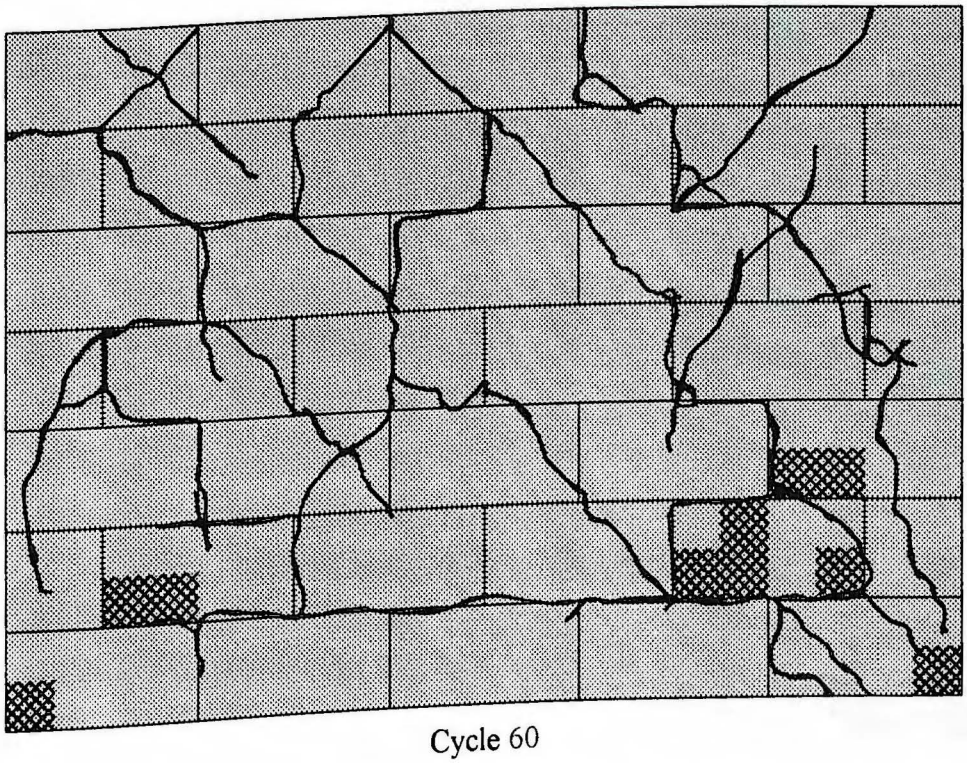


Cycle 53

Figure 4.2 Crack Pattern for Wall 3 (cont.)

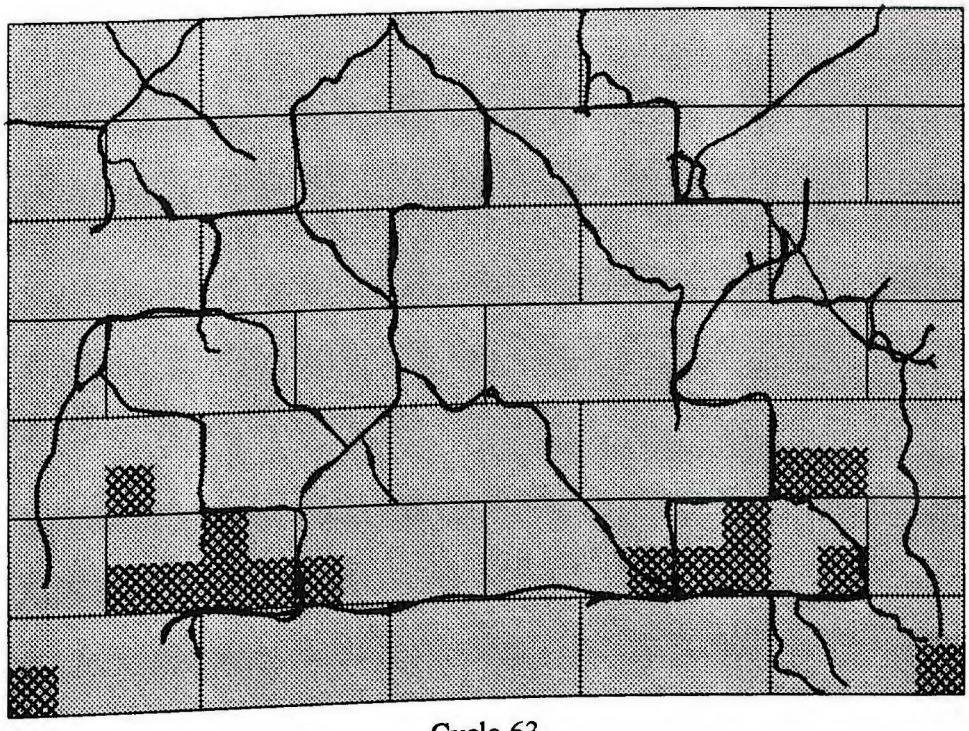


Cycle 54

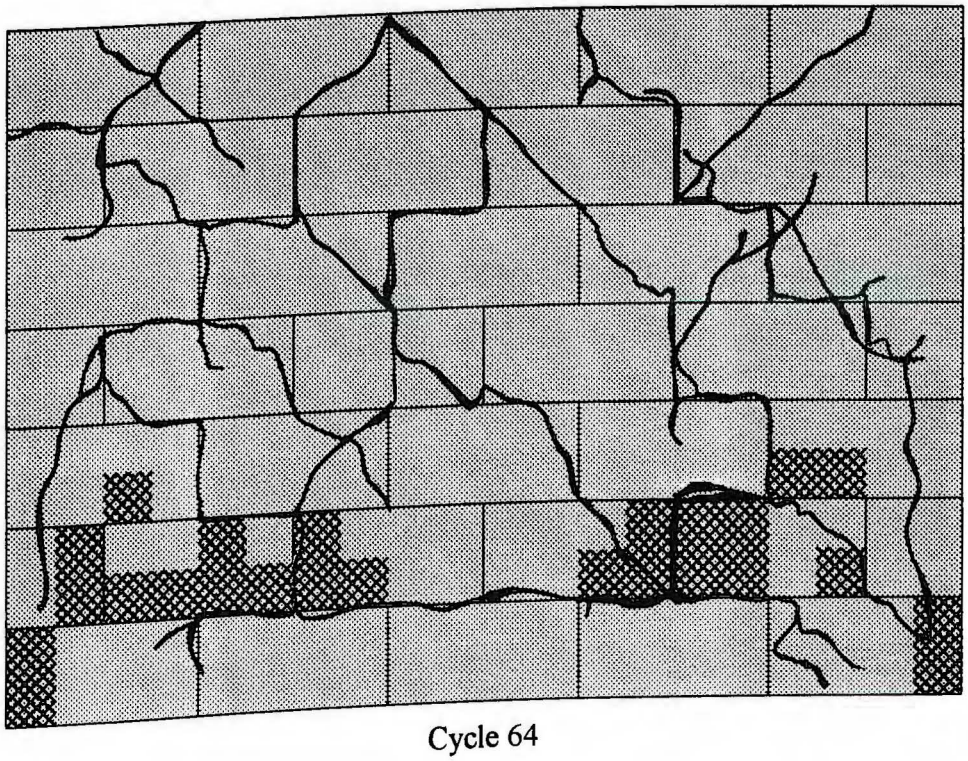


Cycle 60

Figure 4.2 Crack Pattern for Wall 3 (cont.)

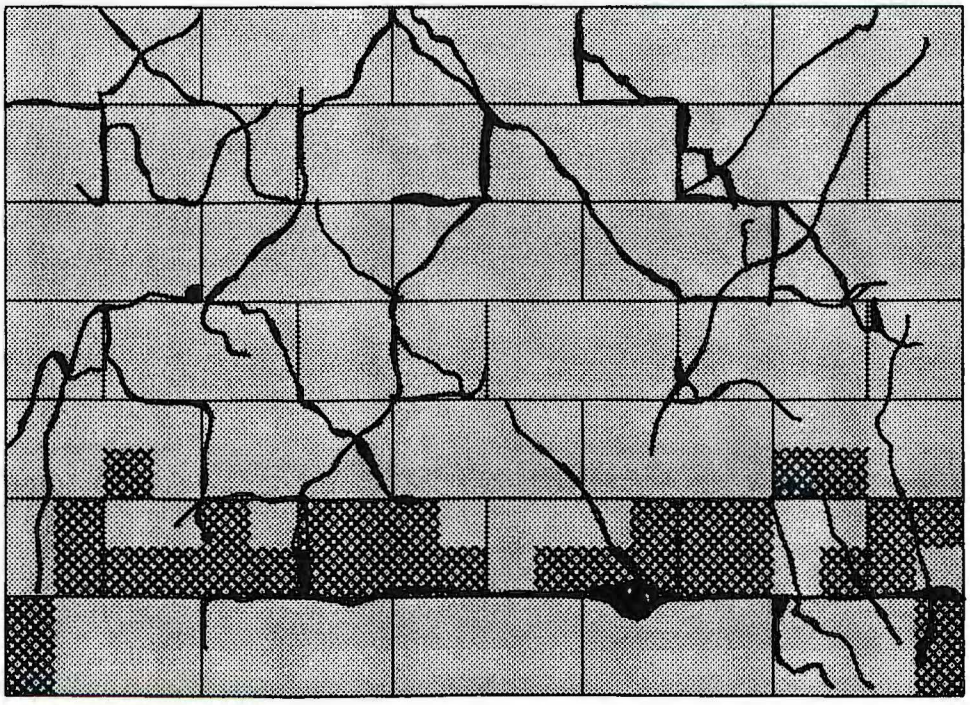


Cycle 63

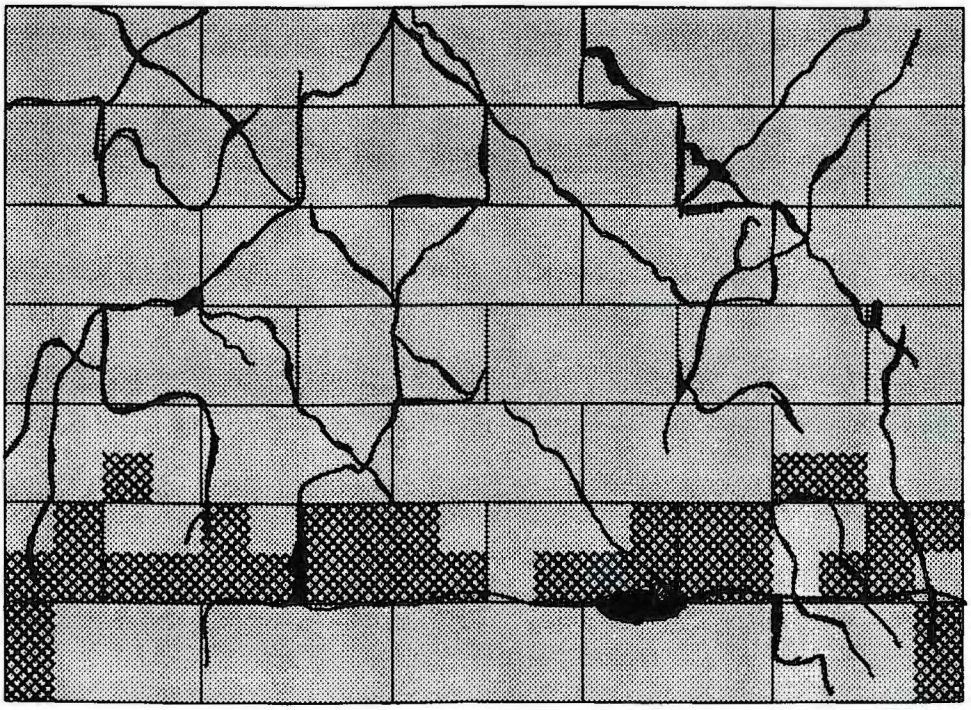


Cycle 64

Figure 4.2 Crack Pattern for Wall 3 (cont.)

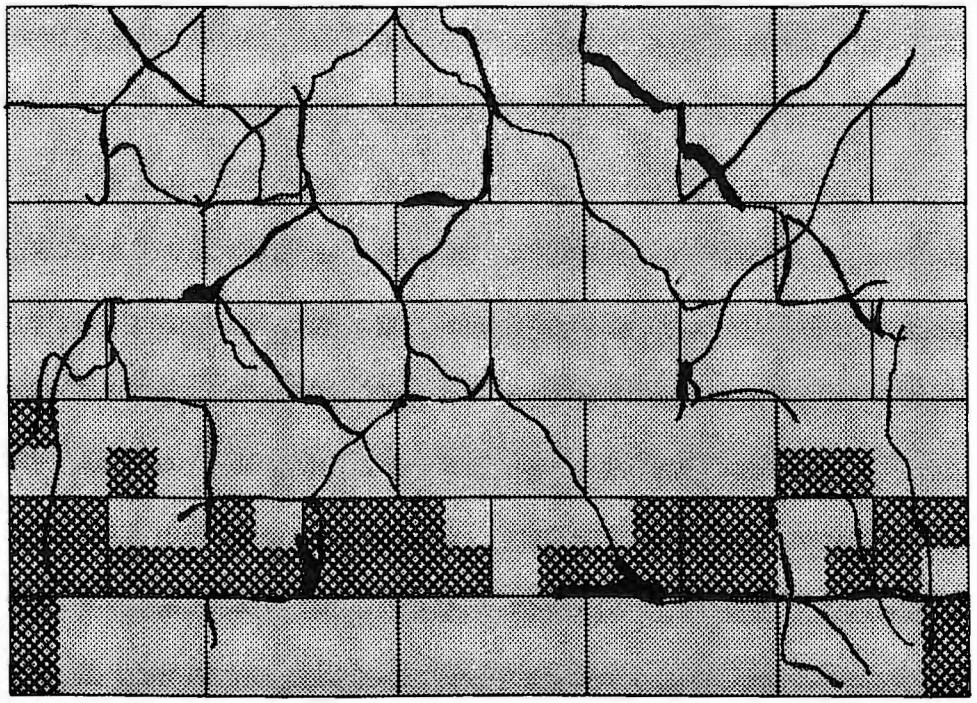


Cycle 65

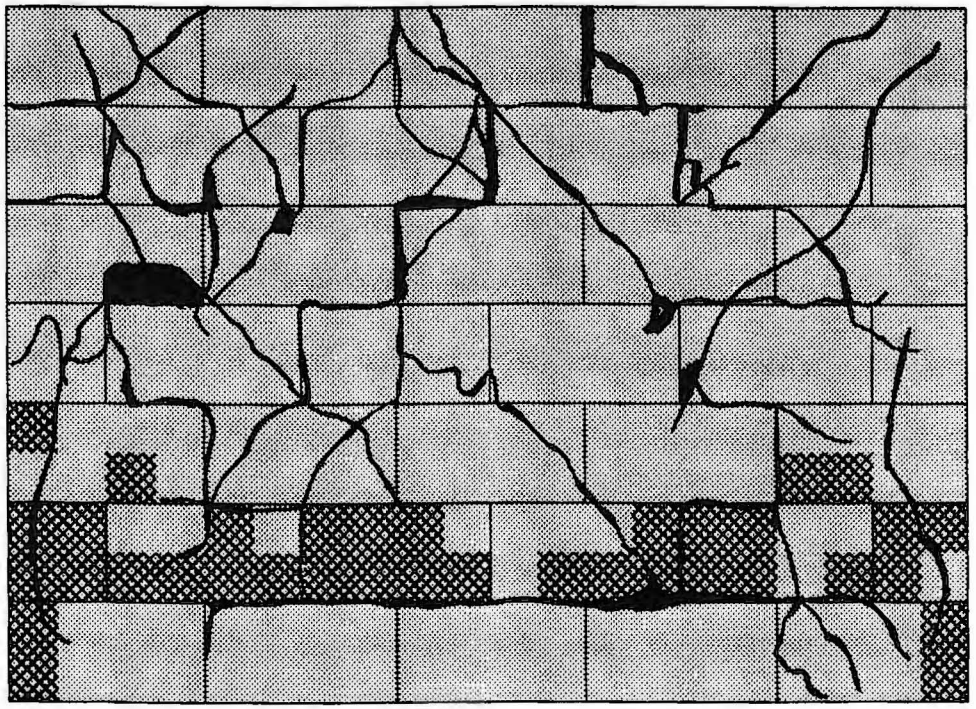


Cycle 66

Figure 4.2 Crack Pattern for Wall 3 (cont.)

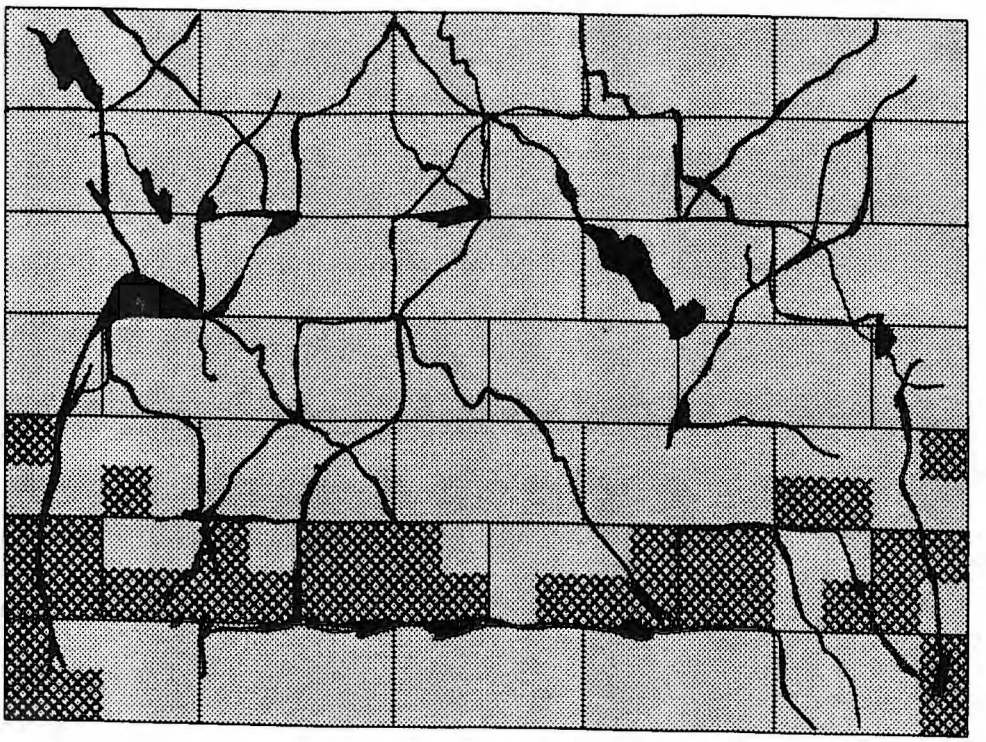


Cycle 69



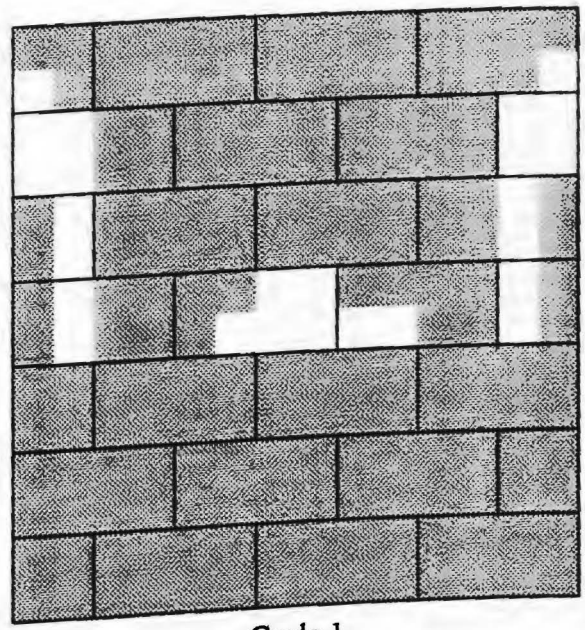
Cycle 71

Figure 4.2 Crack Pattern for Wall 3 (cont.)

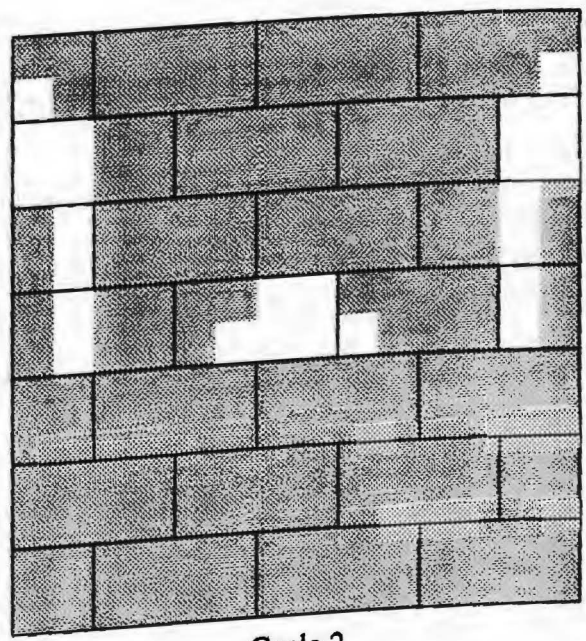


Cycle 72

Figure 4.2 Crack Pattern for Wall 3 (cont.)



Cycle 1



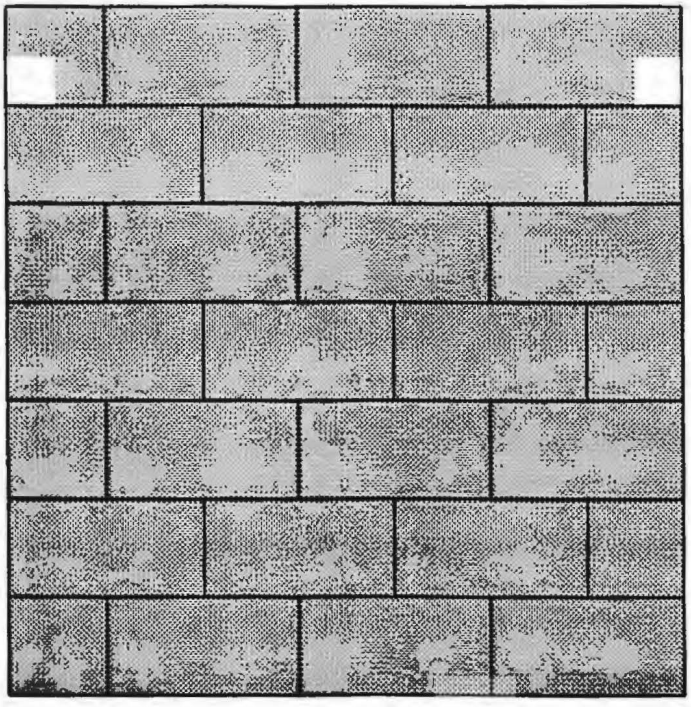
Cycle 2

FEM/I Crack Pattern

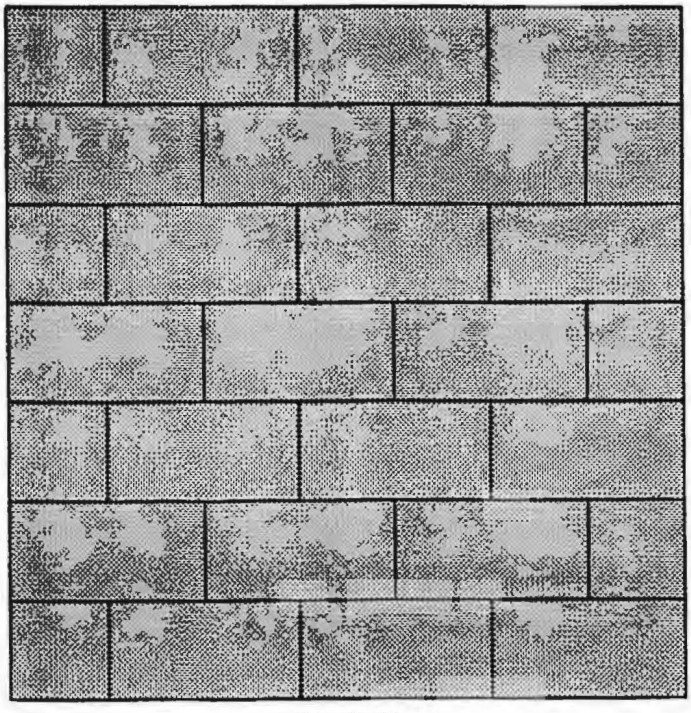
FEM/I Masonry Crushing Pattern

Experimental Study Crack Pattern

Figure 4.3 Crack Pattern for Wall 5

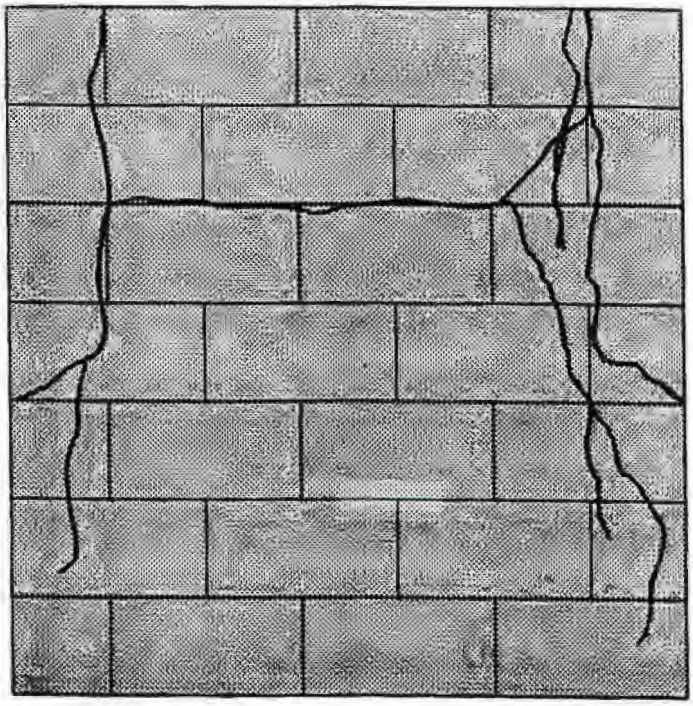


Cycle 3

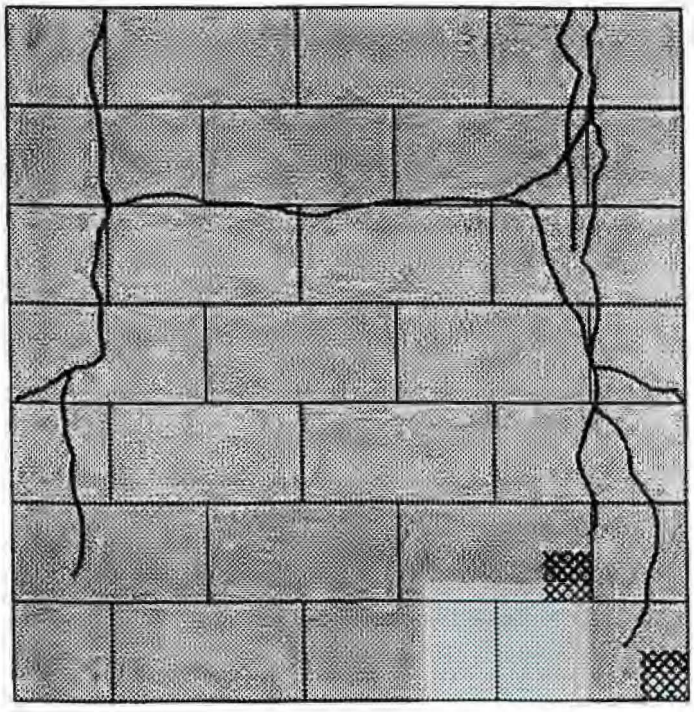


Cycle 5

Figure 4.3 Crack Pattern for Wall 5 (cont.)

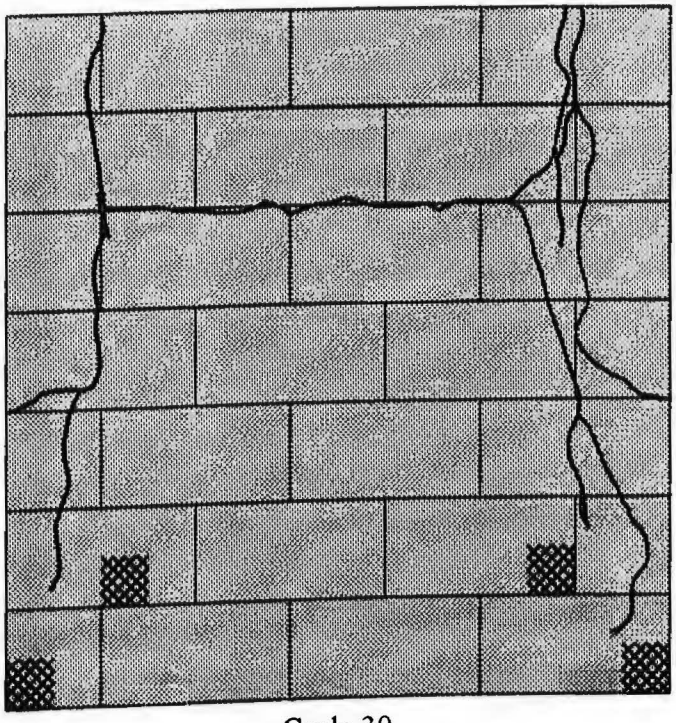


Cycle 26

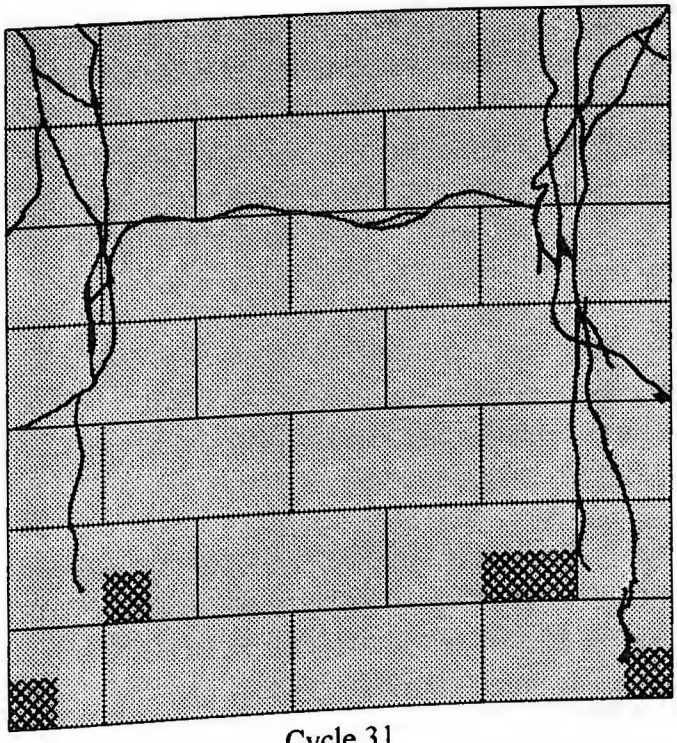


Cycle 27

Figure 4.3 Crack Pattern for Wall 5 (cont.)

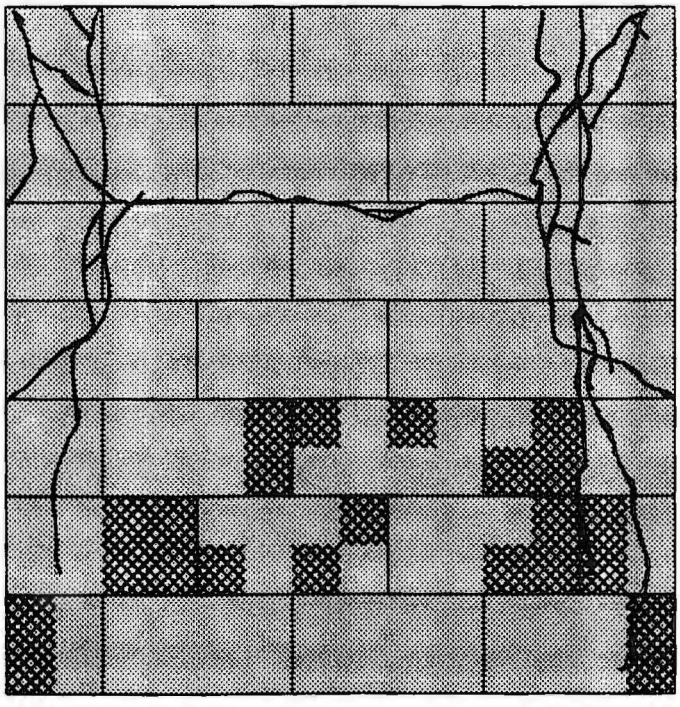


Cycle 30

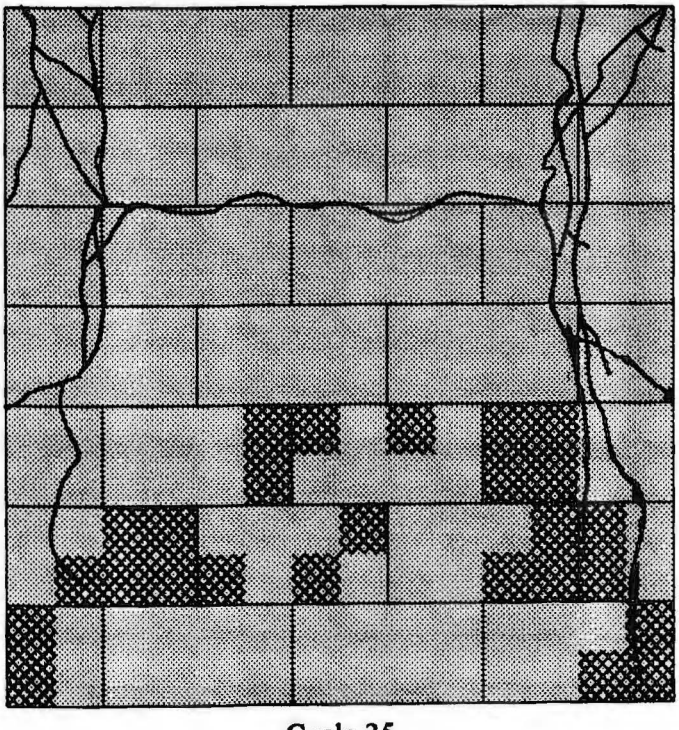


Cycle 31

Figure 4.3 Crack Pattern for Wall 5 (cont.)

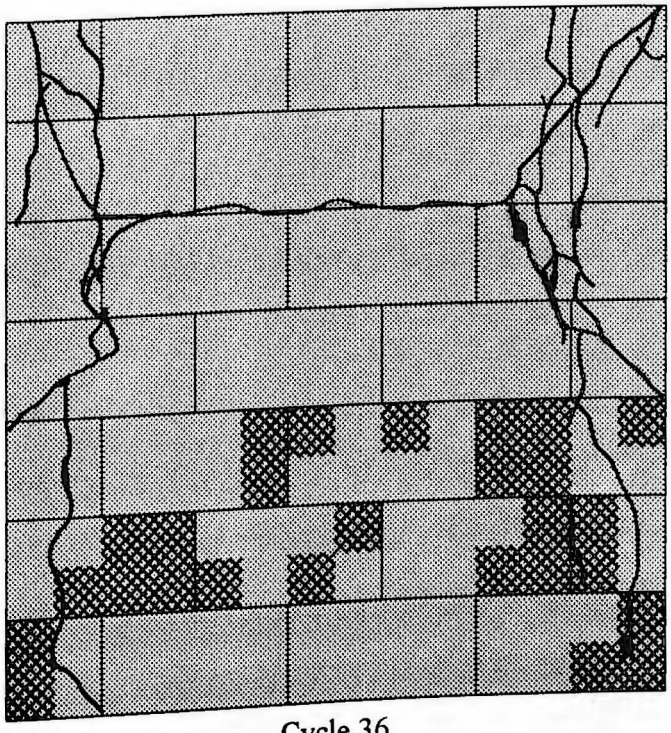


Cycle 32

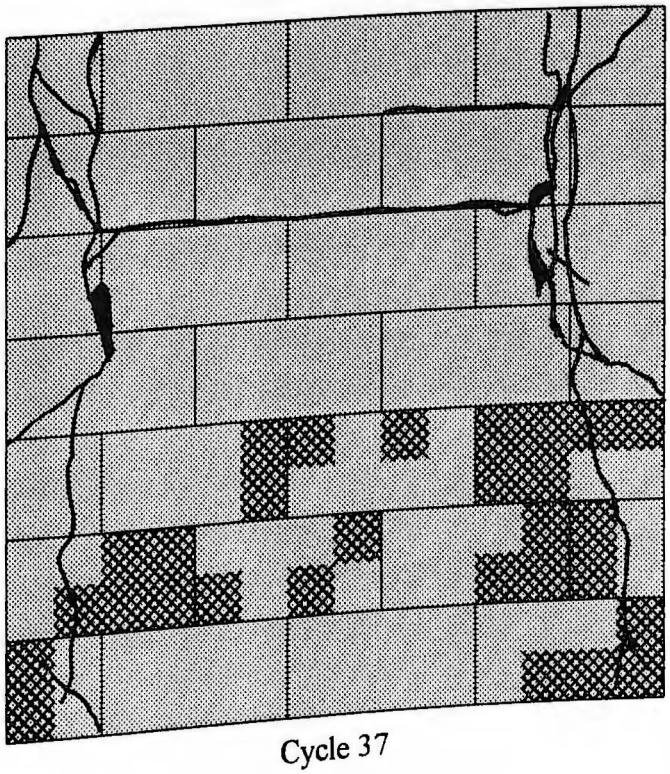


Cycle 35

Figure 4.3 Crack Pattern for Wall 5 (cont.)

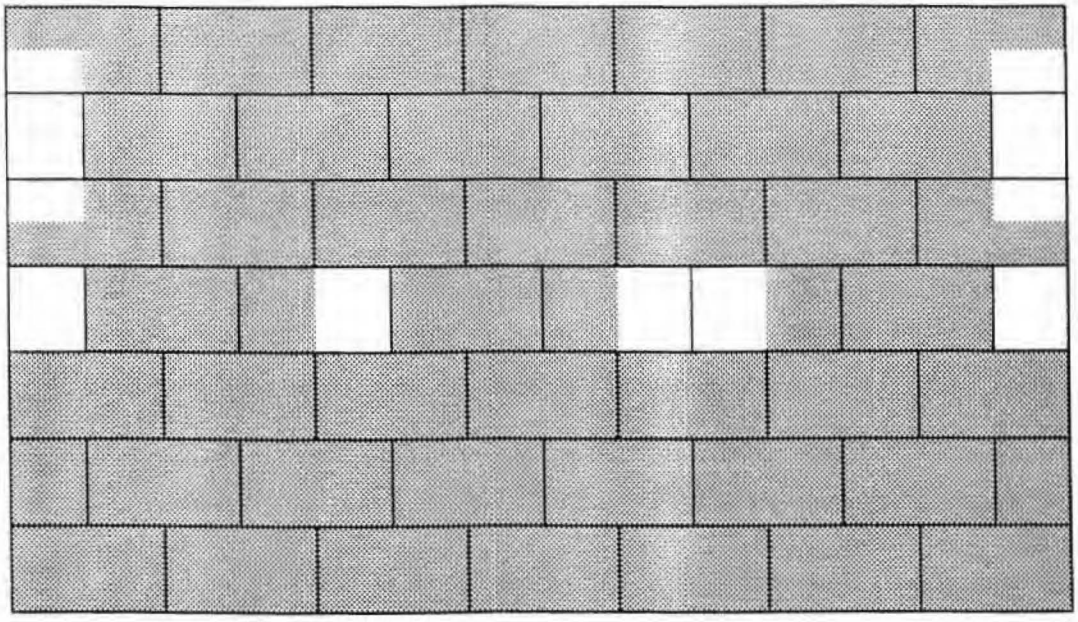


Cycle 36

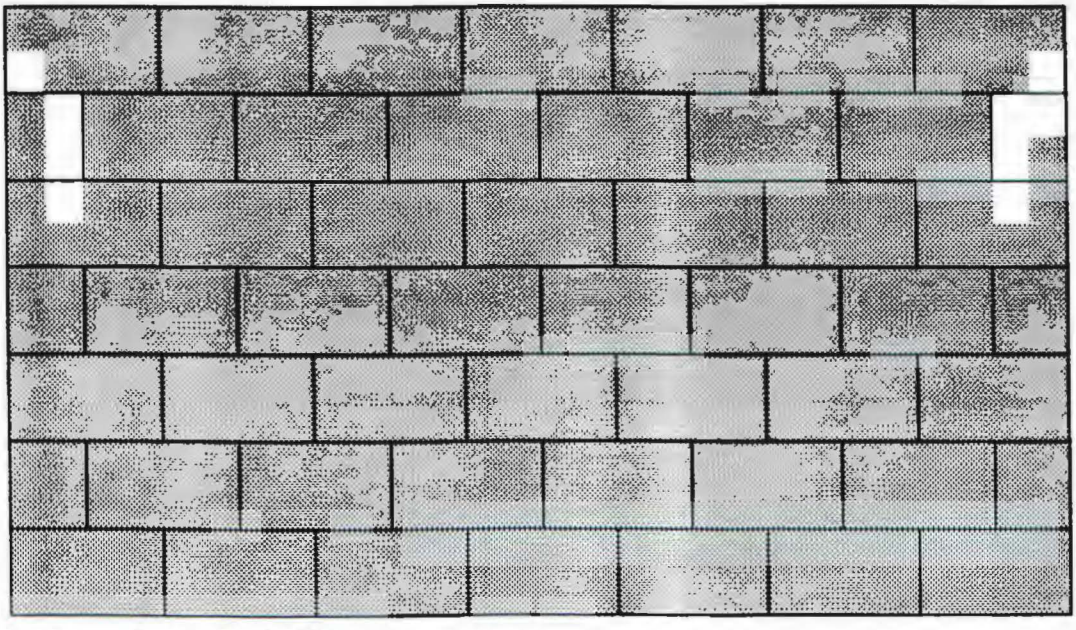


Cycle 37

Figure 4.3 Crack Pattern for Wall 5 (cont.)



Cycle 1



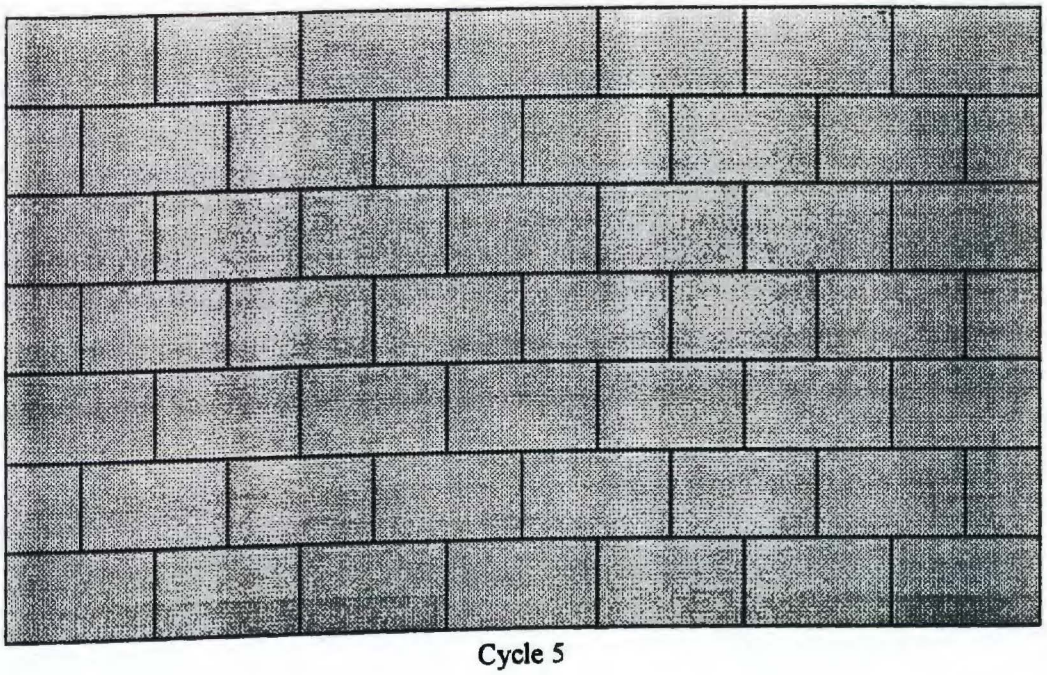
Cycle 3

FEM/I Crack Pattern

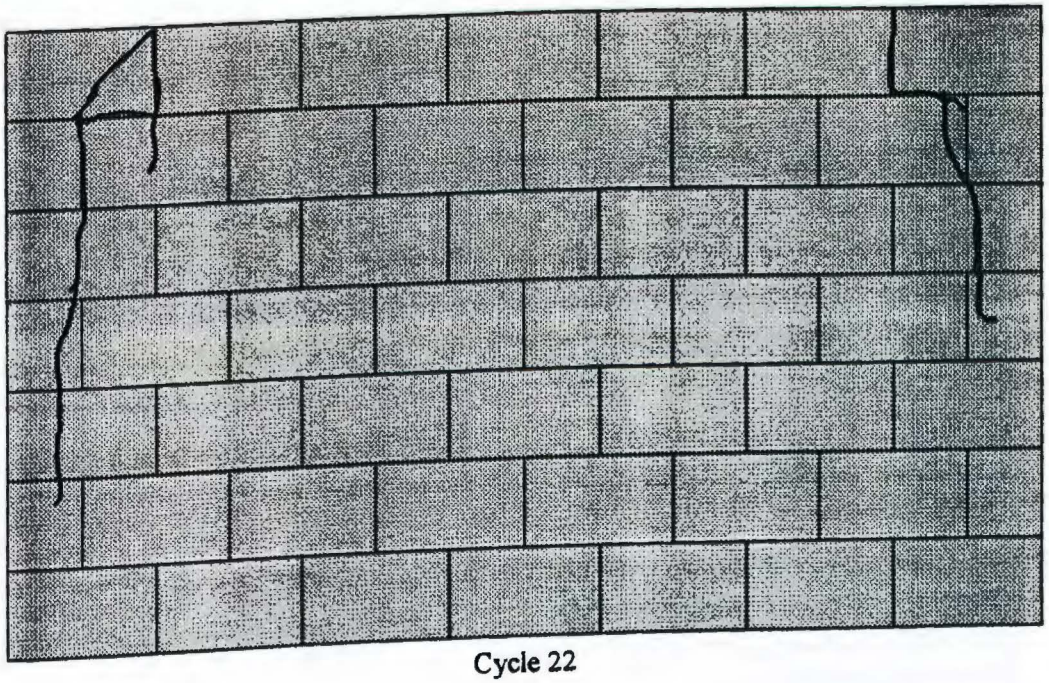
FEM/I Masonry Crushing Pattern

Experimental Study Crack Pattern

Figure 4.4 Crack Pattern for Wall 7

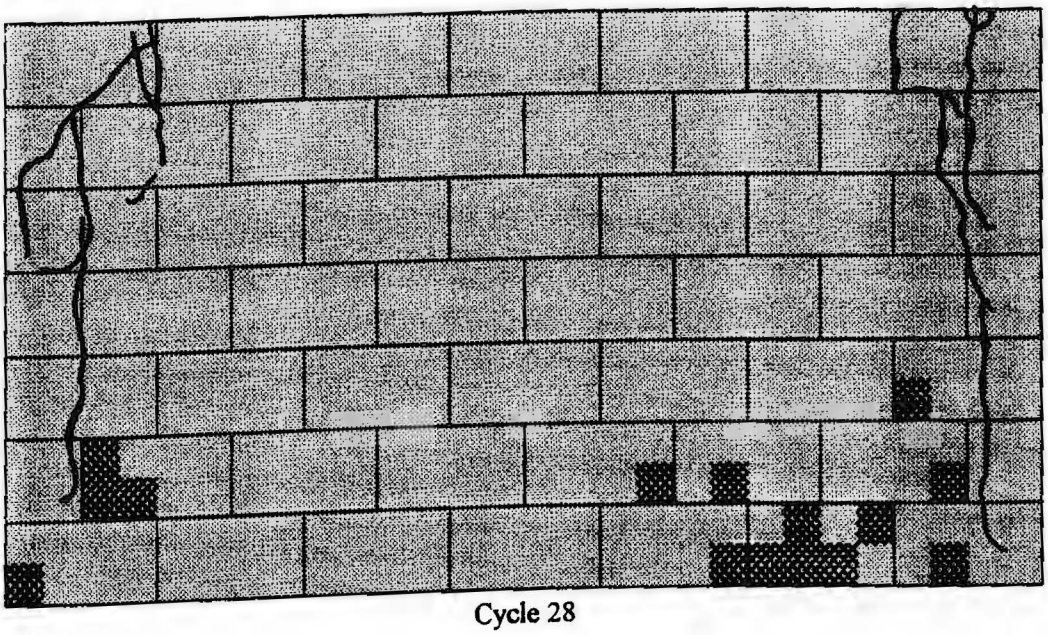


Cycle 5

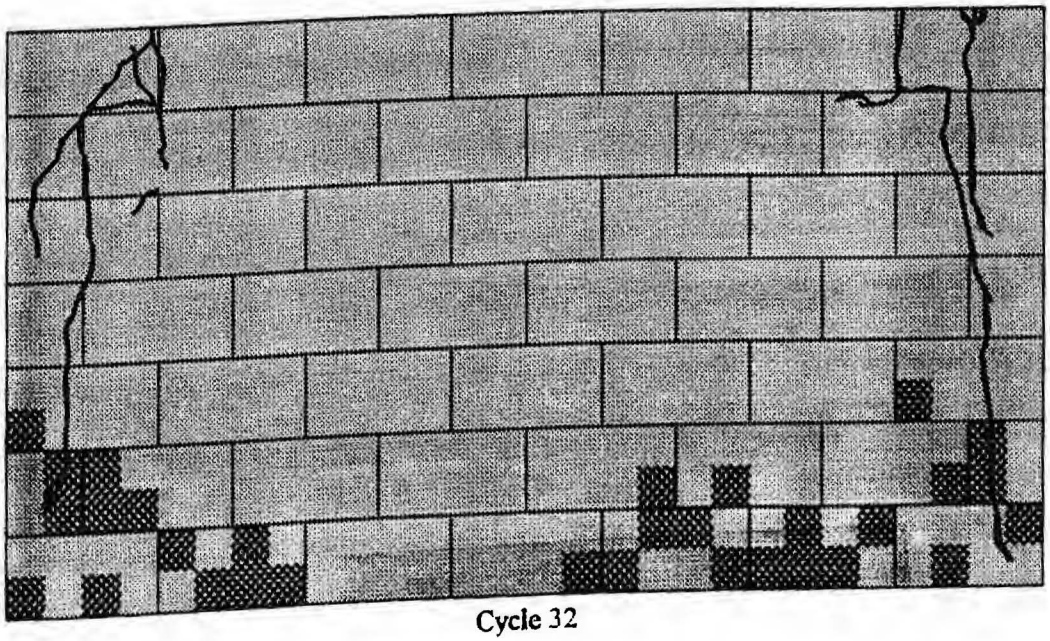


Cycle 22

Figure 4.4 Crack Pattern for Wall 7 (cont.)

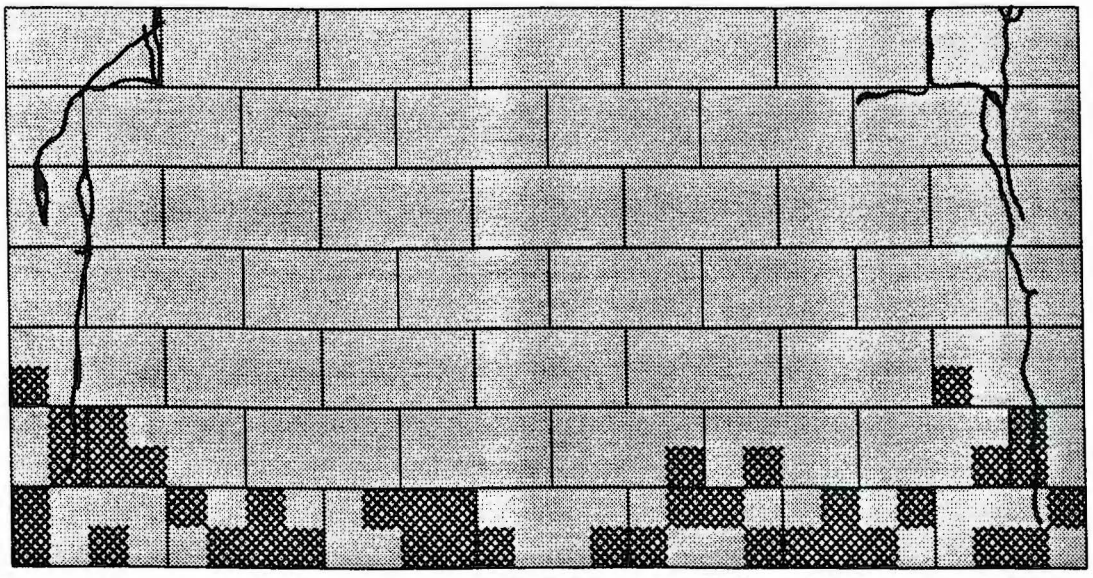


Cycle 28

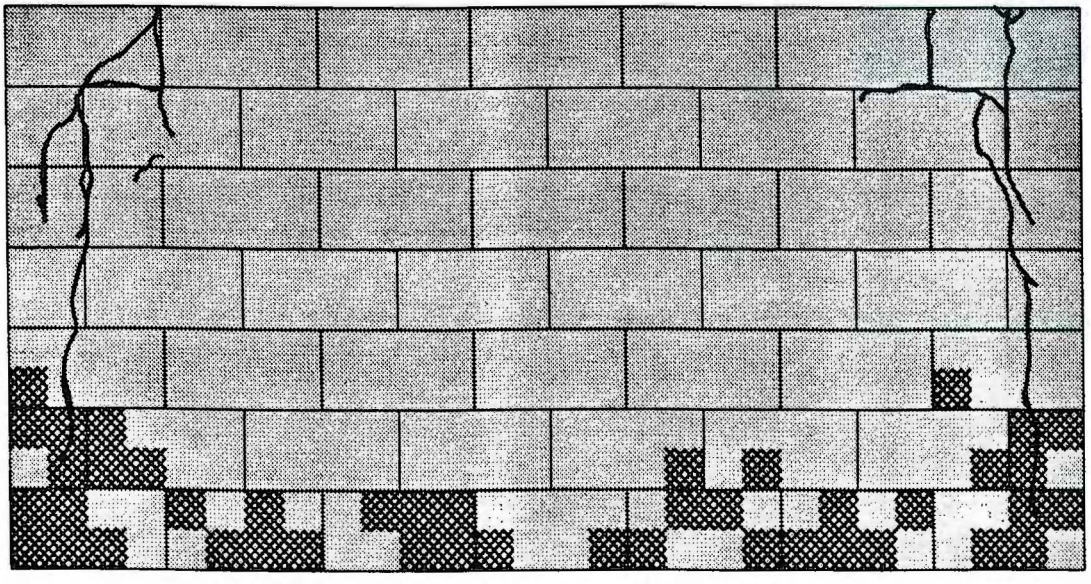


Cycle 32

Figure 4.4 Crack Pattern for Wall 7 (cont.)

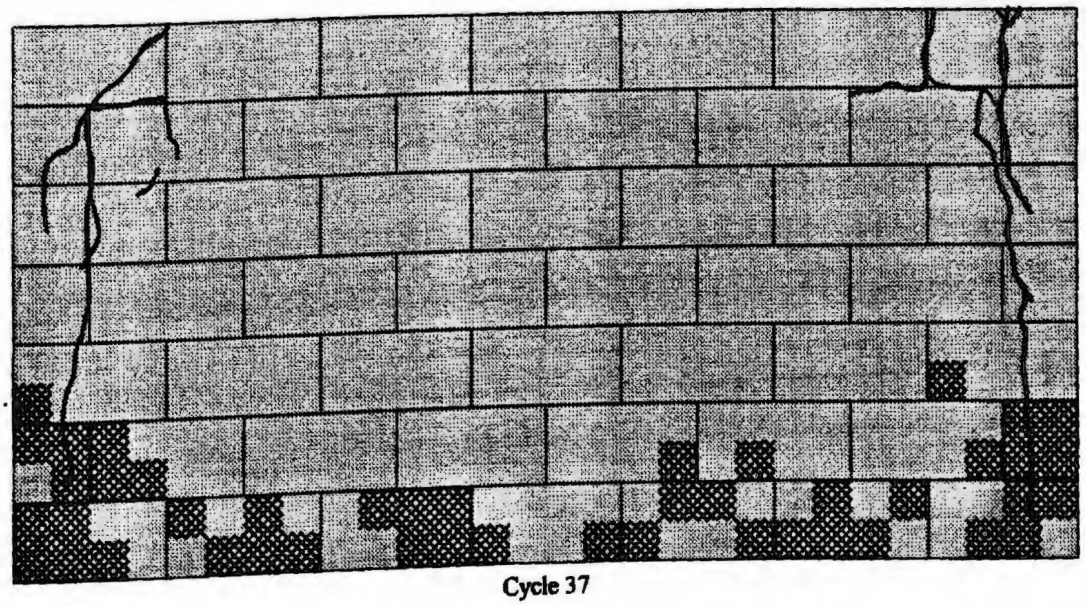


Cycle 33

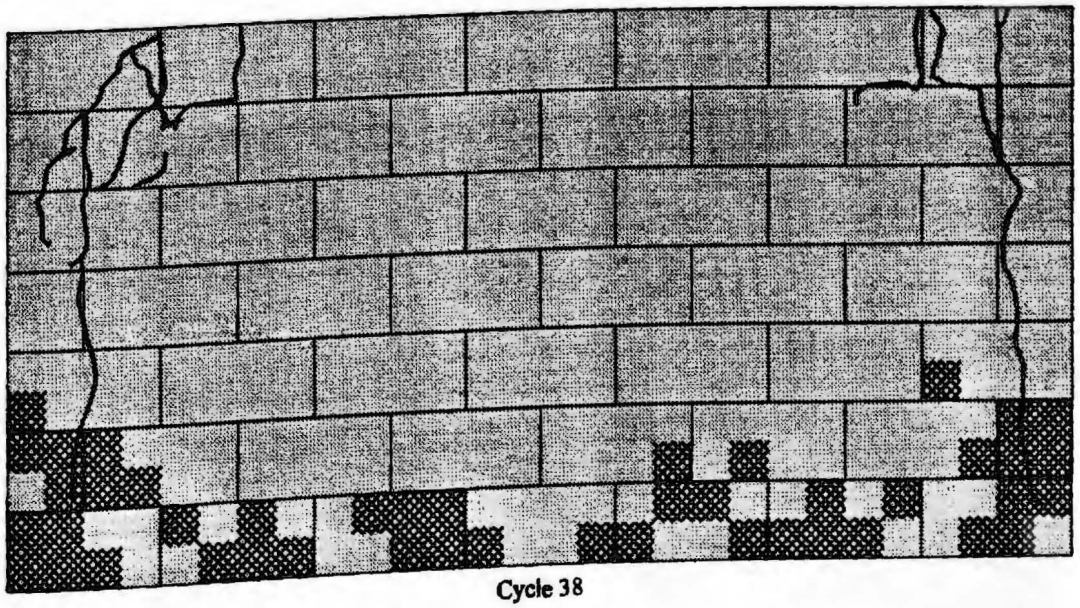


Cycle 34

Figure 4.4 Crack Pattern for Wall 7 (cont.)

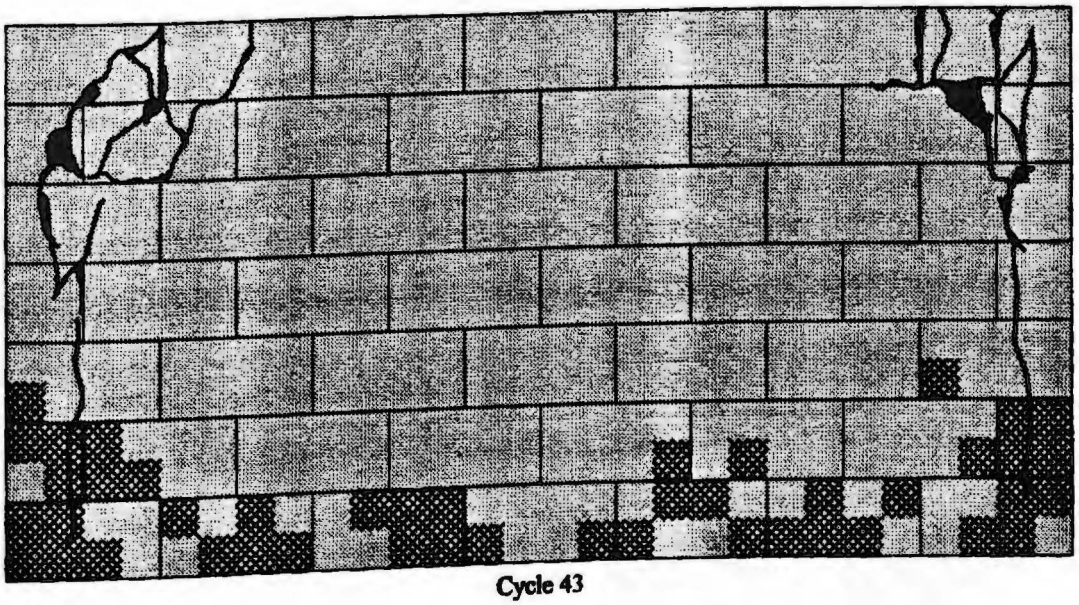


Cycle 37

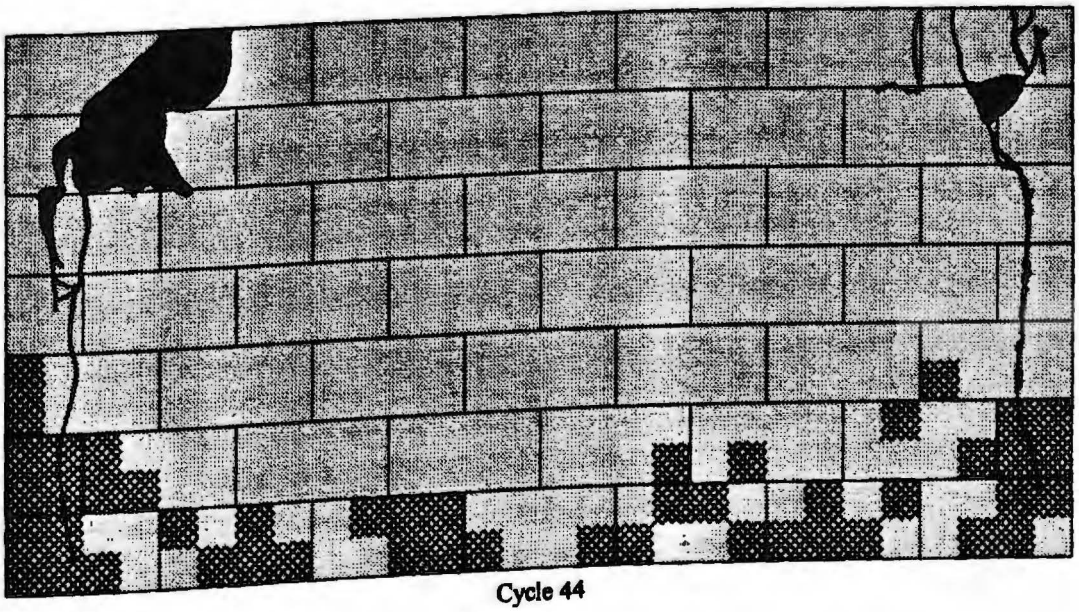


Cycle 38

Figure 4.4 Crack Pattern for Wall 7 (cont.)

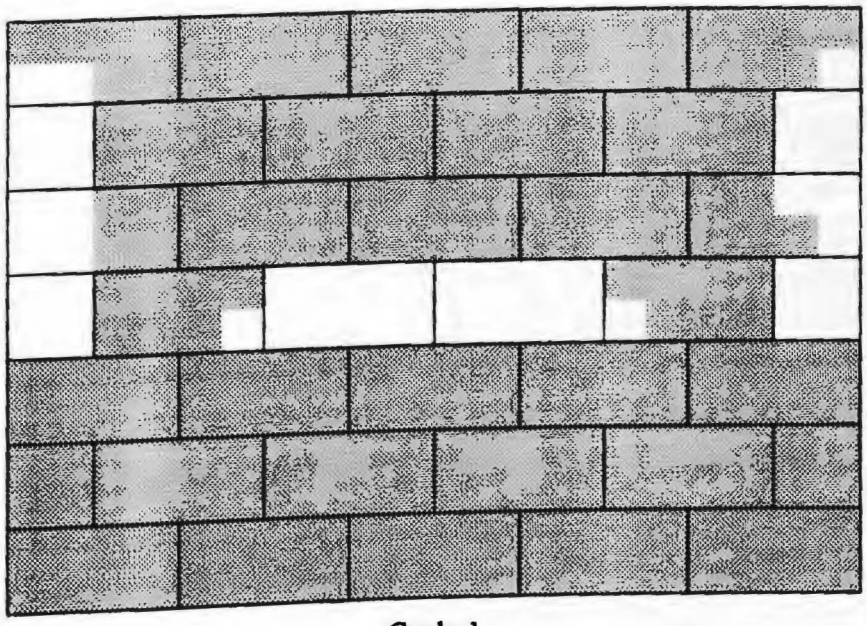


Cycle 43

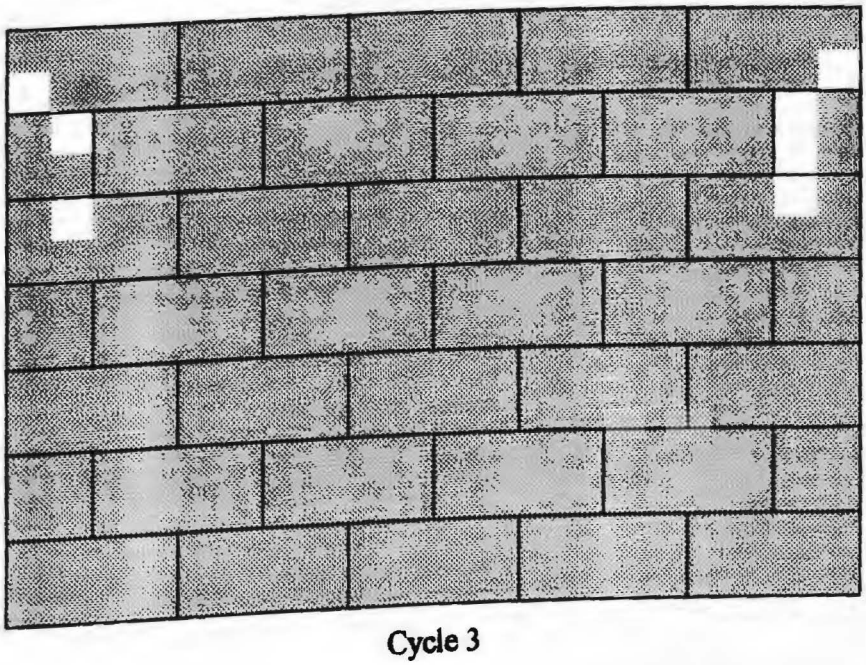


Cycle 44

Figure 4.4 Crack Pattern for Wall 7 (cont.)



Cycle 1



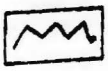
Cycle 3



FEM/I Crack Pattern

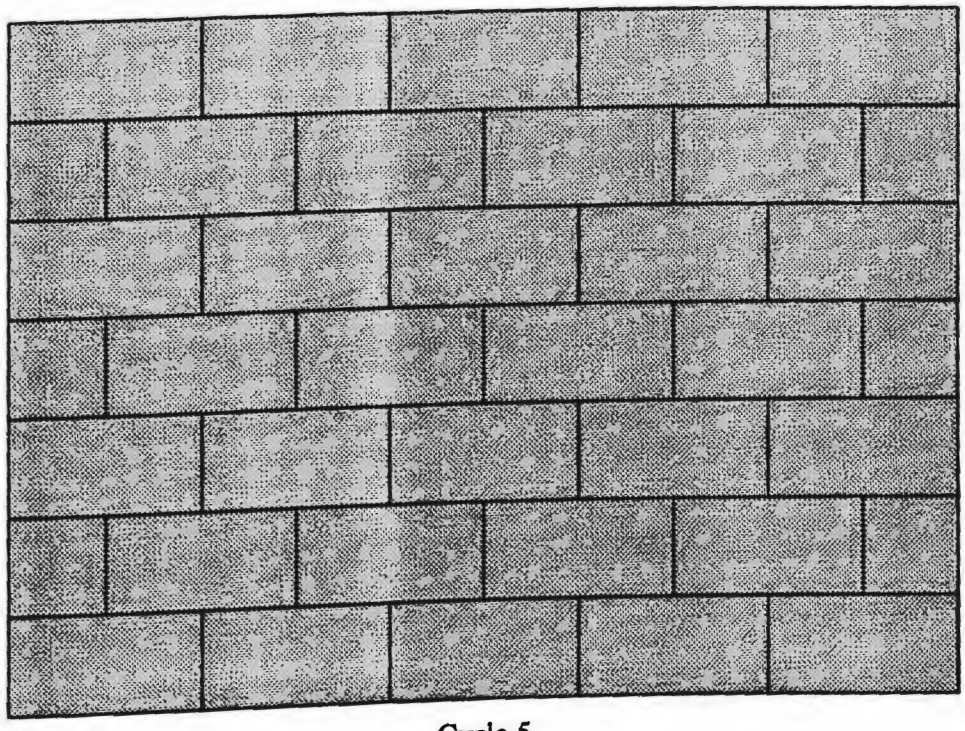


FEM/I Masonry Crushing Pattern

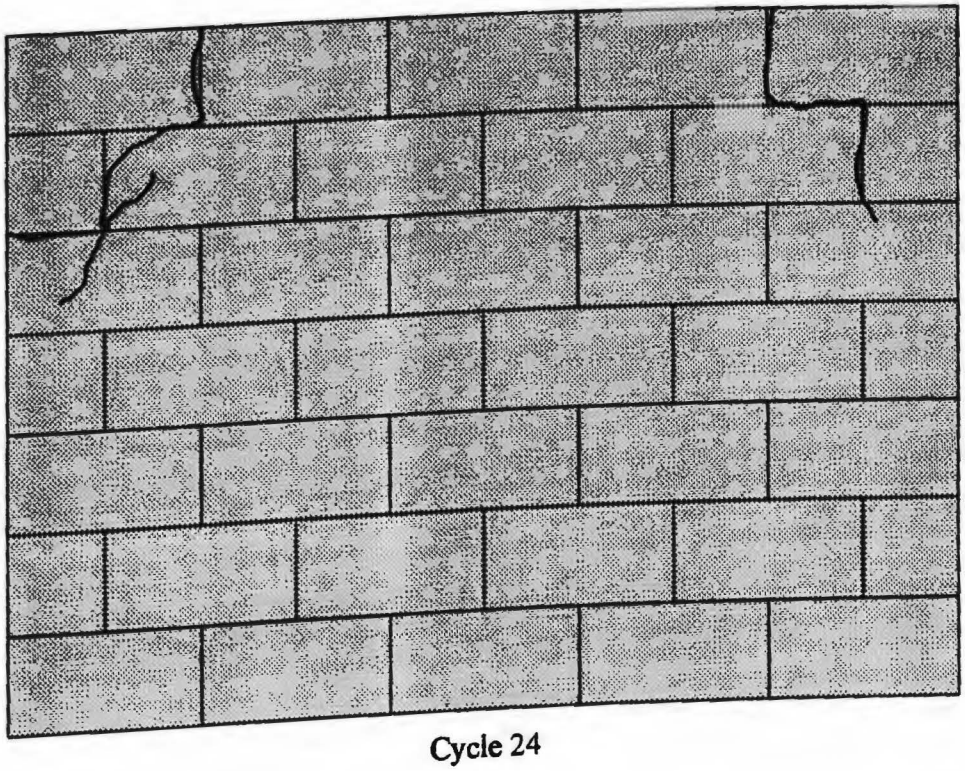


Experimental Study Crack Pattern

Figure 4.5 Crack Pattern for Wall 9

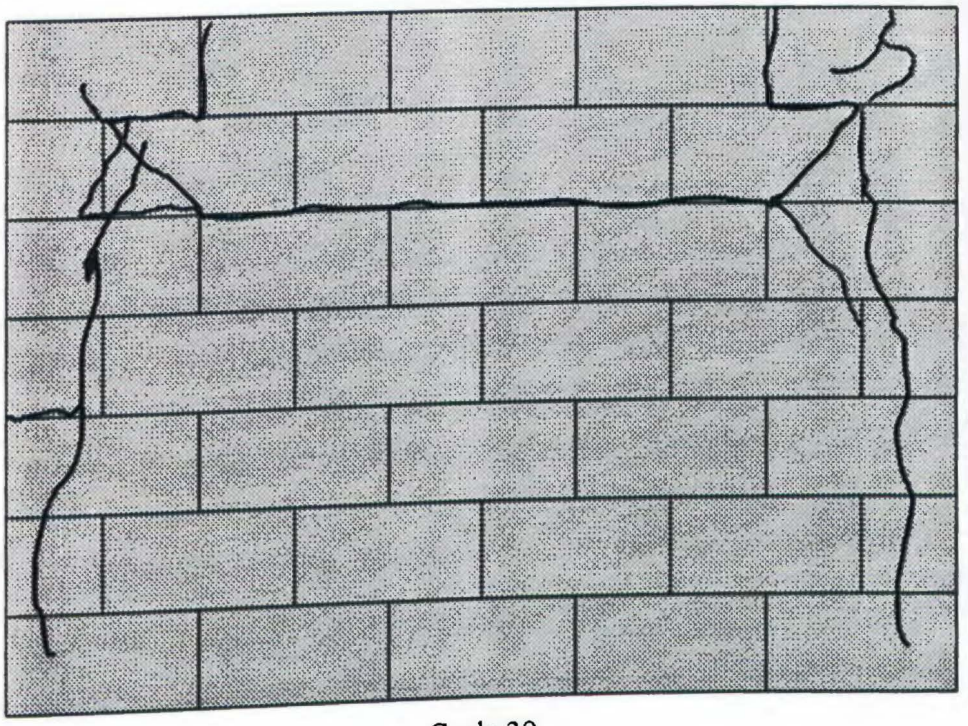


Cycle 5

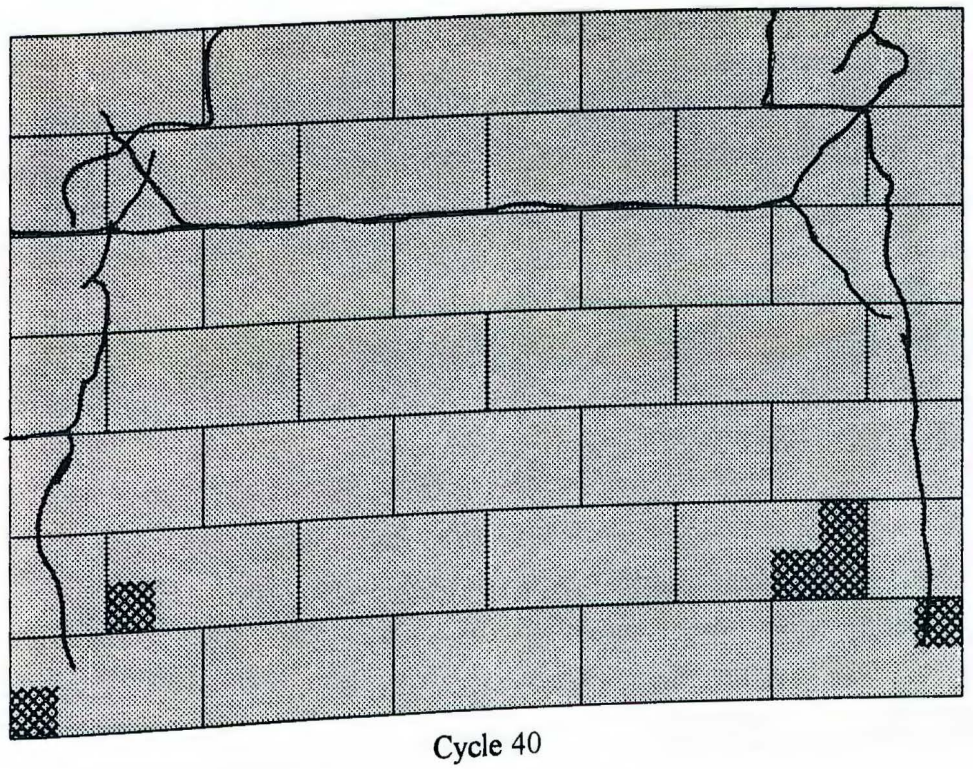


Cycle 24

Figure 4.5 Crack Pattern for Wall 9 (cont.)

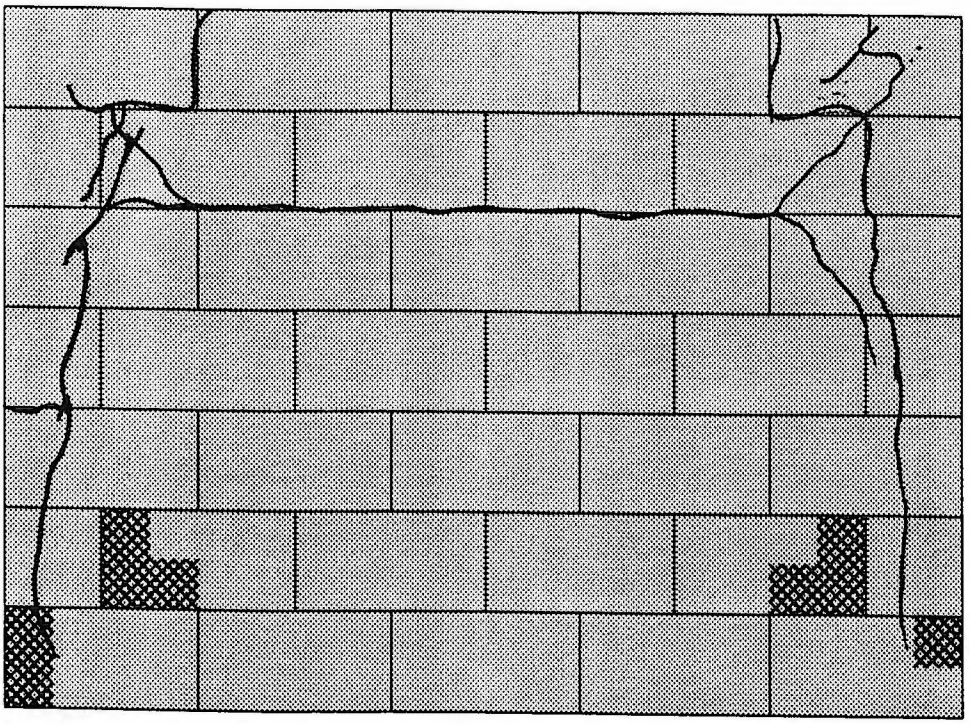


Cycle 39

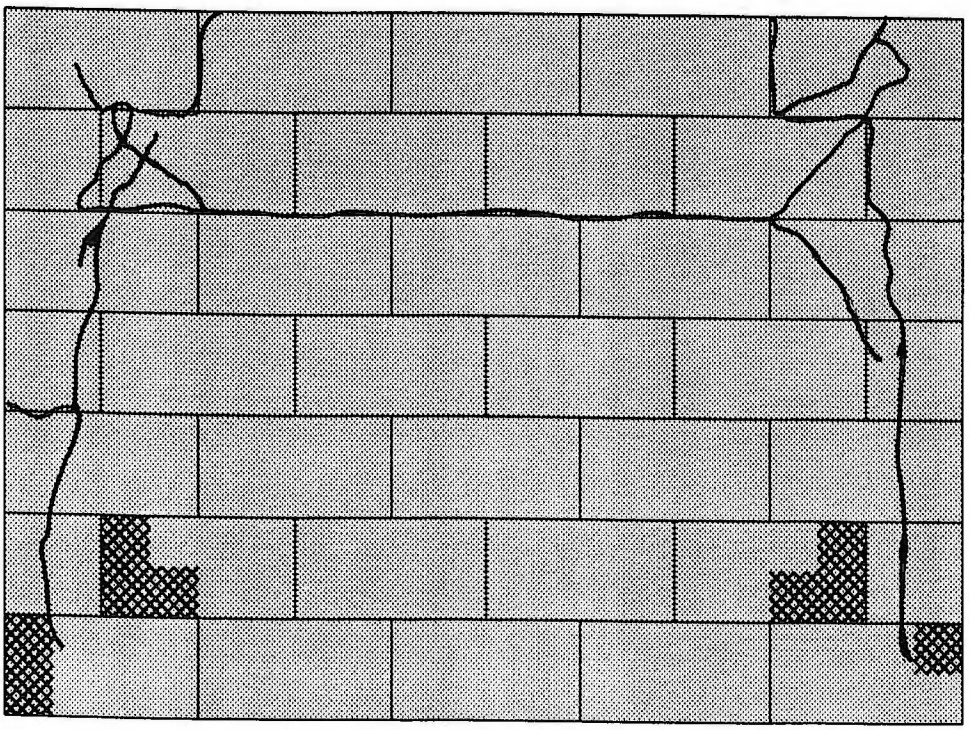


Cycle 40

Figure 4.5 Crack Pattern for Wall 9 (cont.)

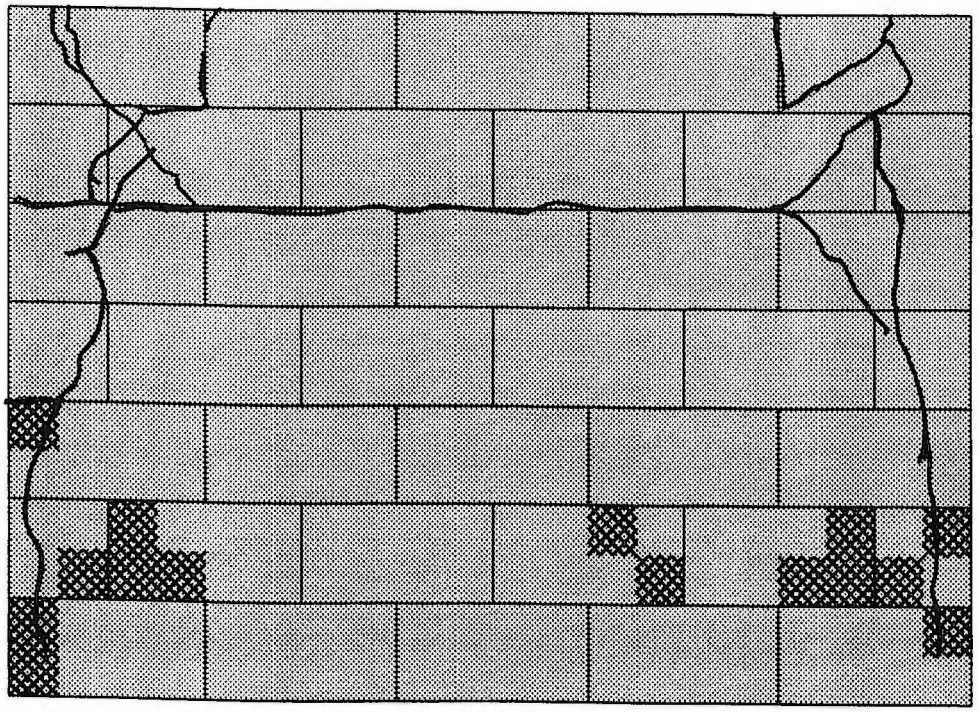


Cycle 43

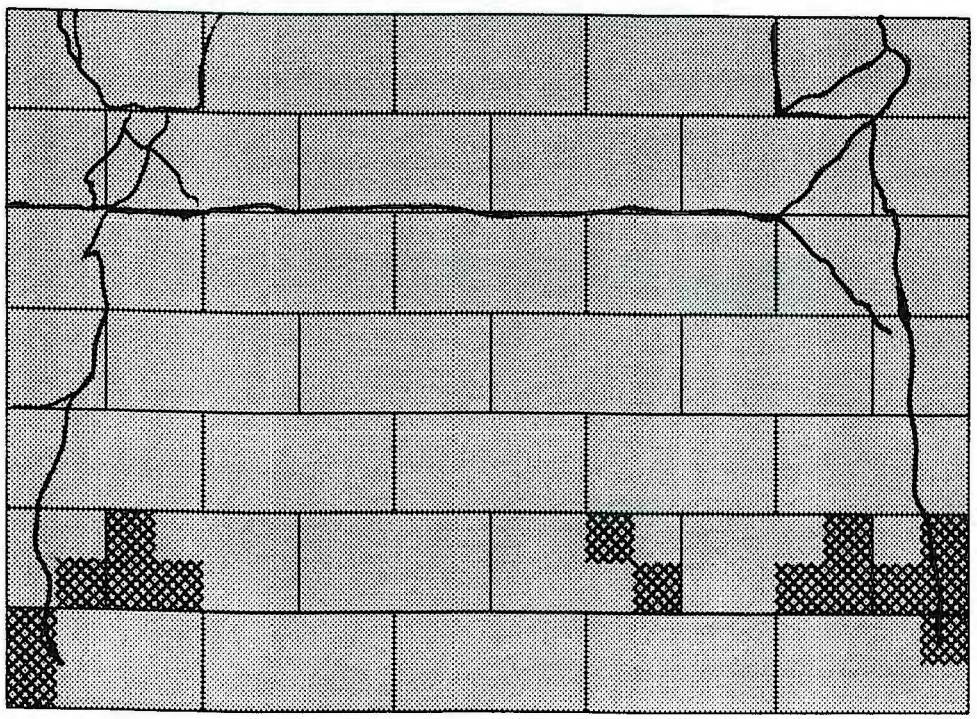


Cycle 44

Figure 4.5 Crack Pattern for Wall 9 (cont.)

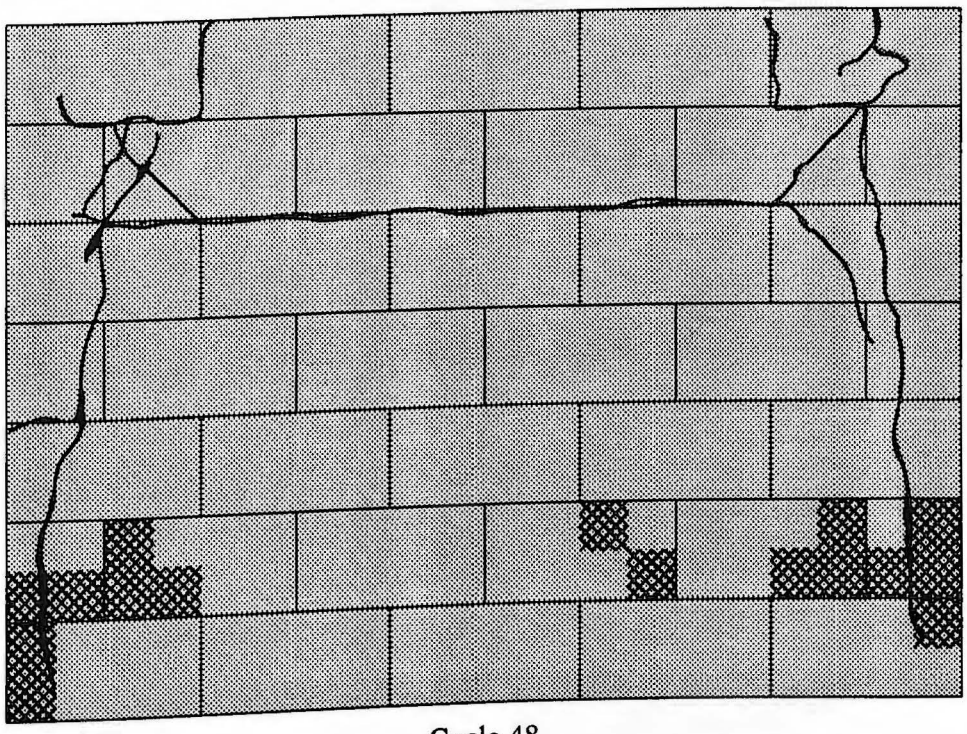


Cycle 45

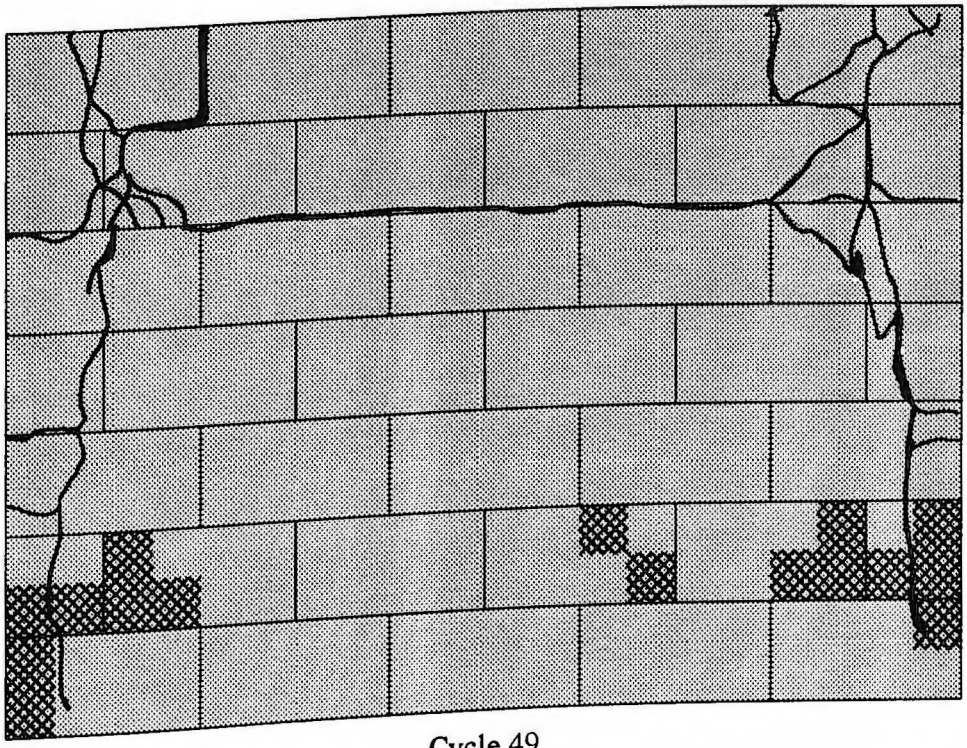


Cycle 46

Figure 4.5 Crack Pattern for Wall 9 (cont.)

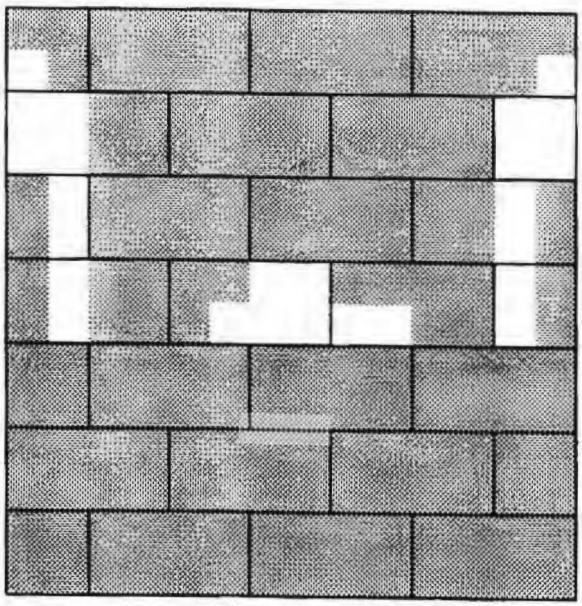


Cycle 48



Cycle 49

Figure 4.5 Crack Pattern for Wall 9 (cont.)



Cycle 1



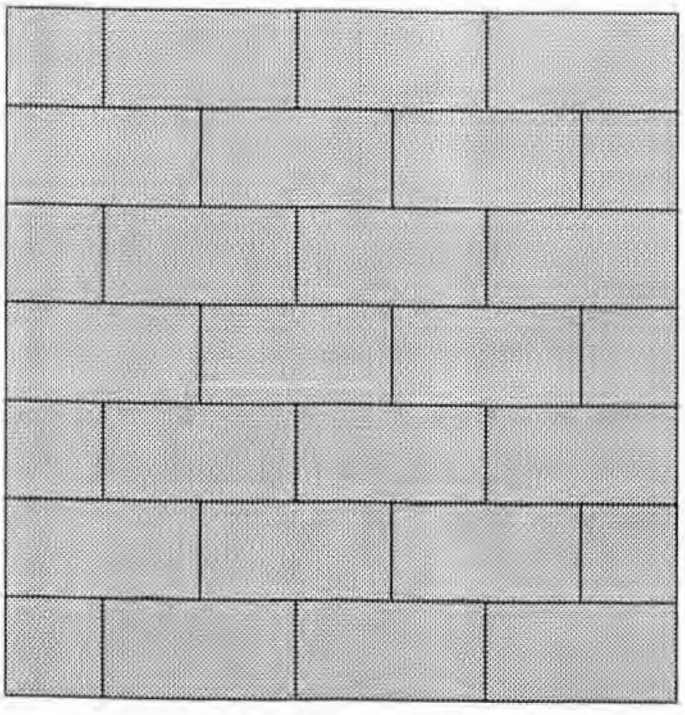
Cycle 3

FEM/I Crack Pattern

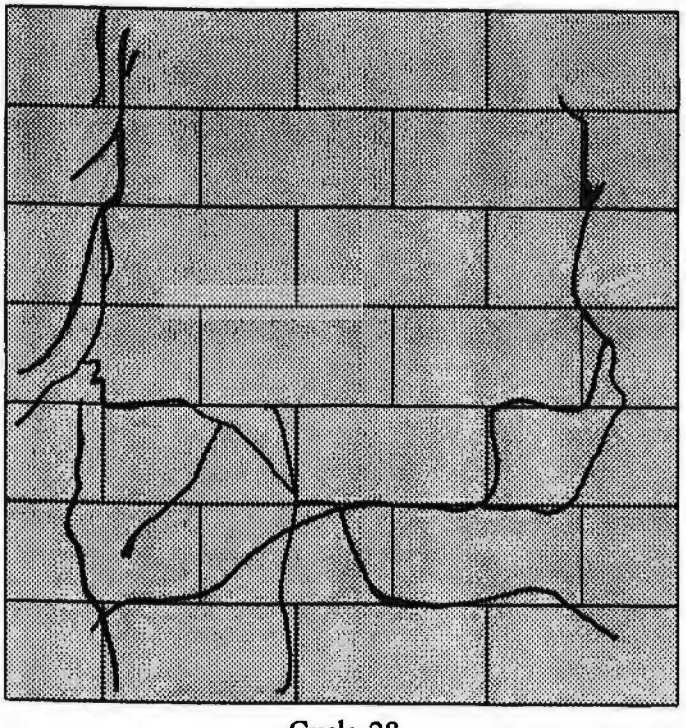
FEM/I Masonry Crushing Pattern

Experimental Study Crack Pattern

Figure 4.6 Crack Pattern for Wall 11

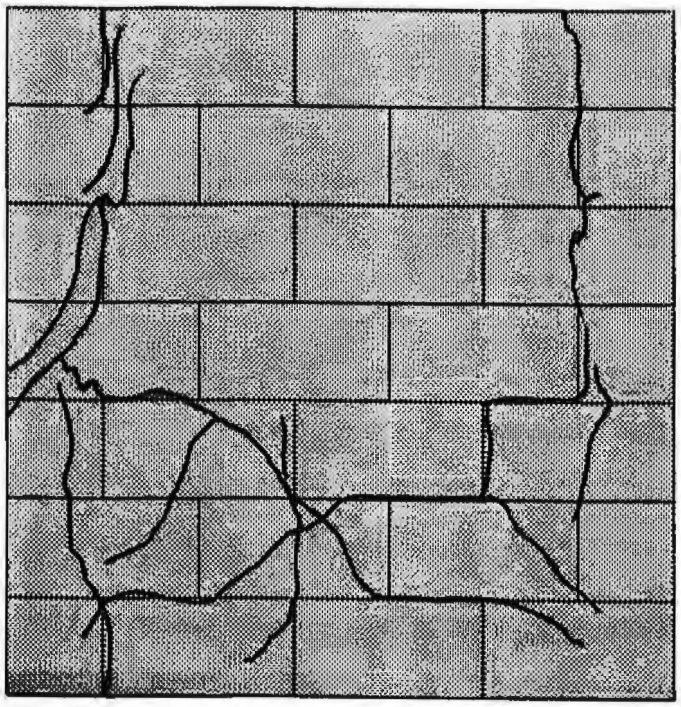


Cycle 5

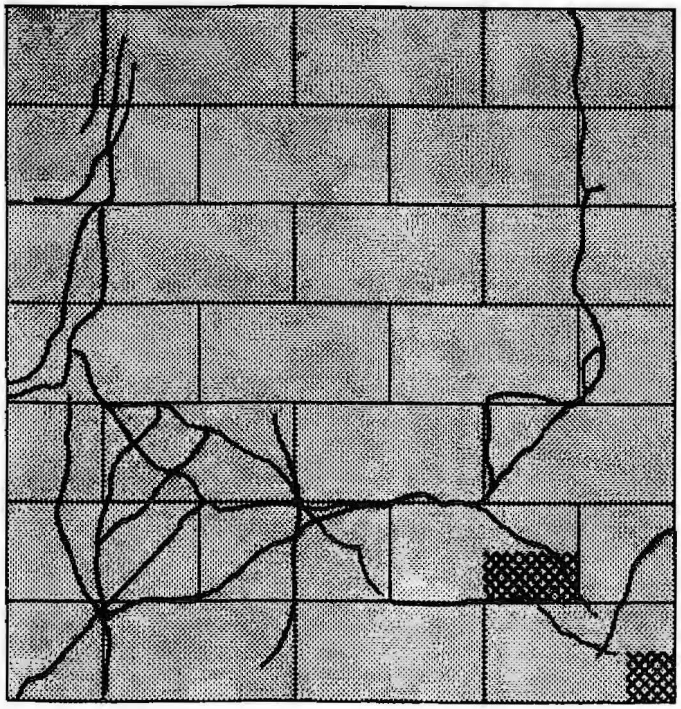


Cycle 28

Figure 4.6 Crack Pattern for Wall 11 (cont.)

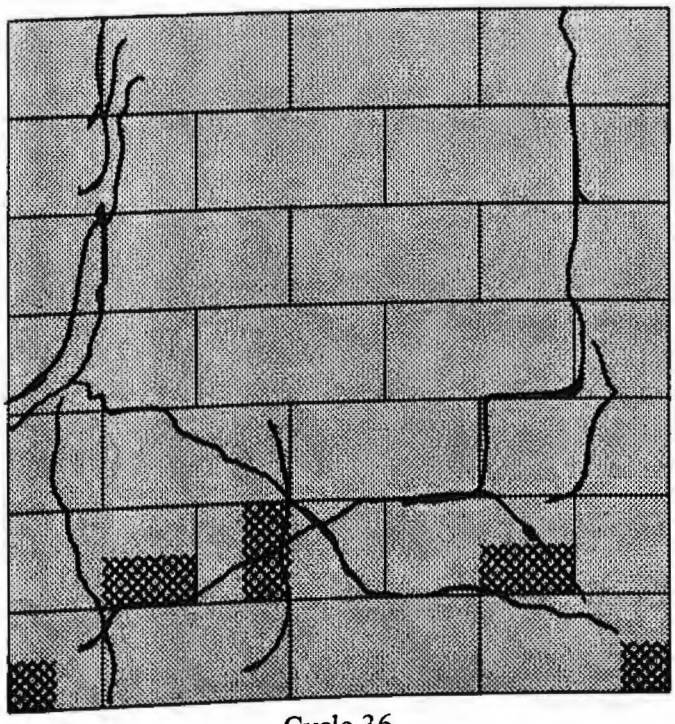


Cycle 32

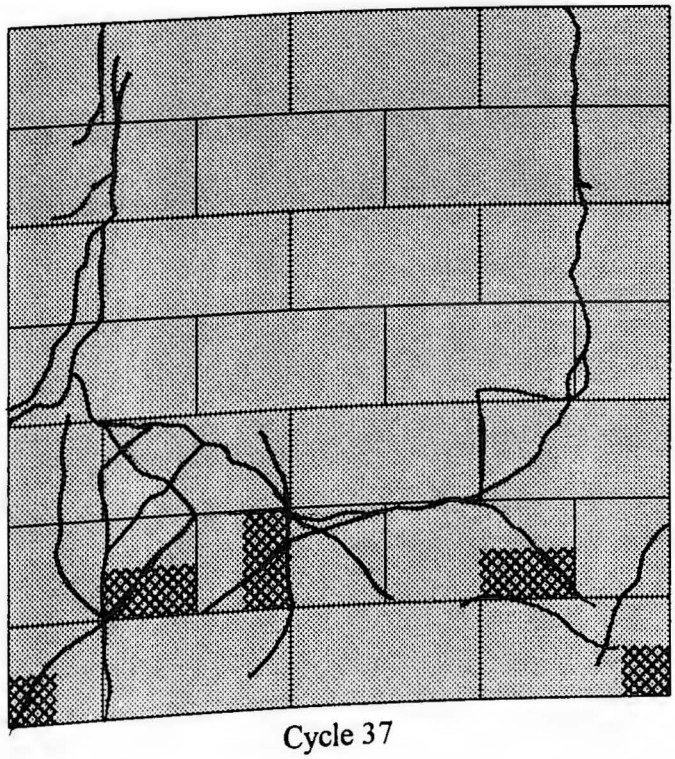


Cycle 33

Figure 4.6 Crack Pattern for Wall 11 (cont.)

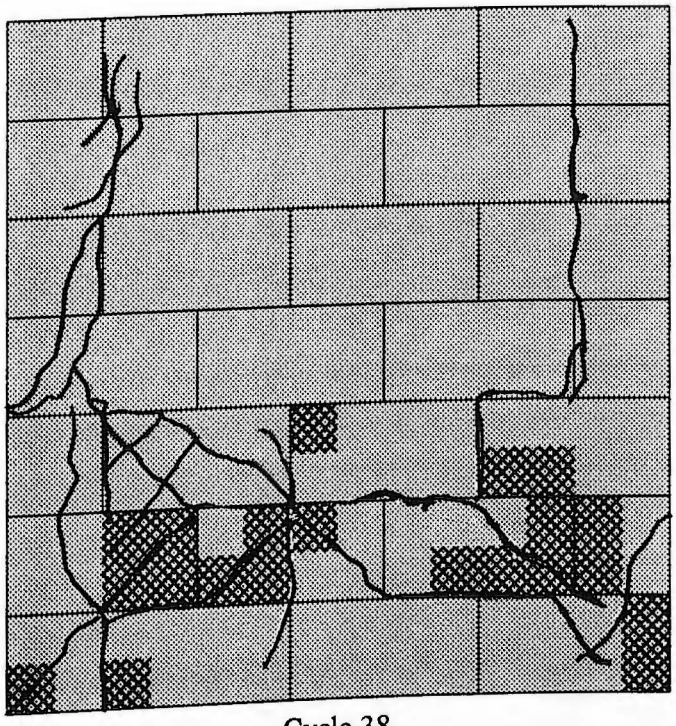


Cycle 36

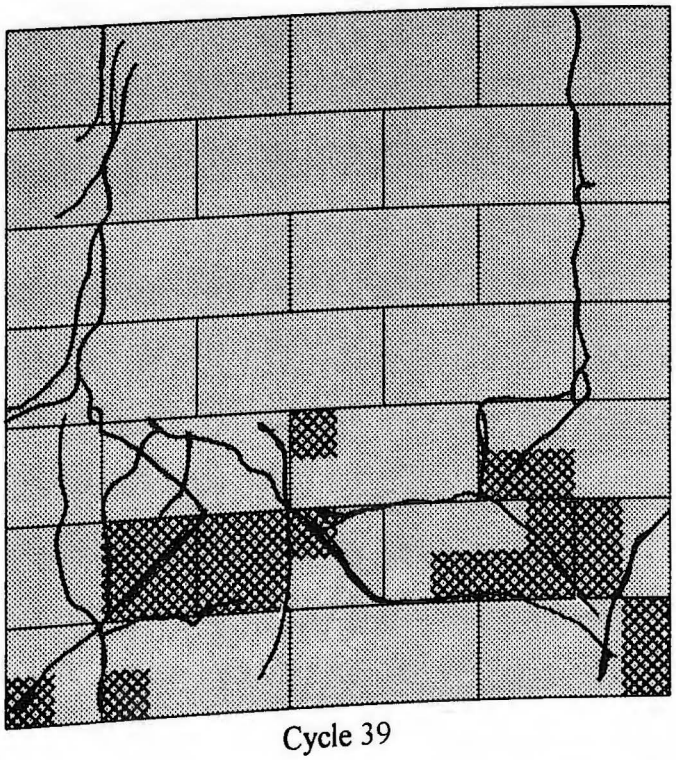


Cycle 37

Figure 4.6 Crack Pattern for Wall 11 (cont.)

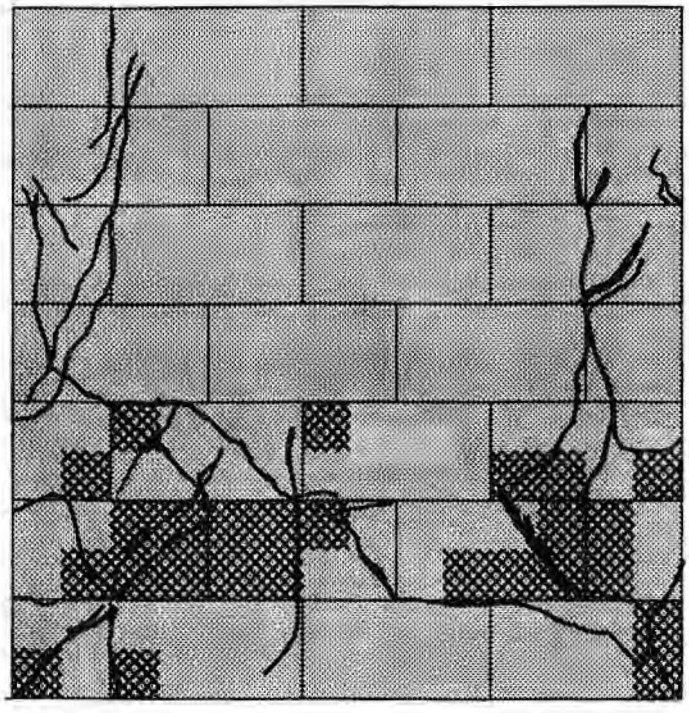


Cycle 38



Cycle 39

Figure 4.6 Crack Pattern for Wall 11 (cont.)



Cycle 41

Figure 4.6 Crack Pattern for Wall 11 (cont.)

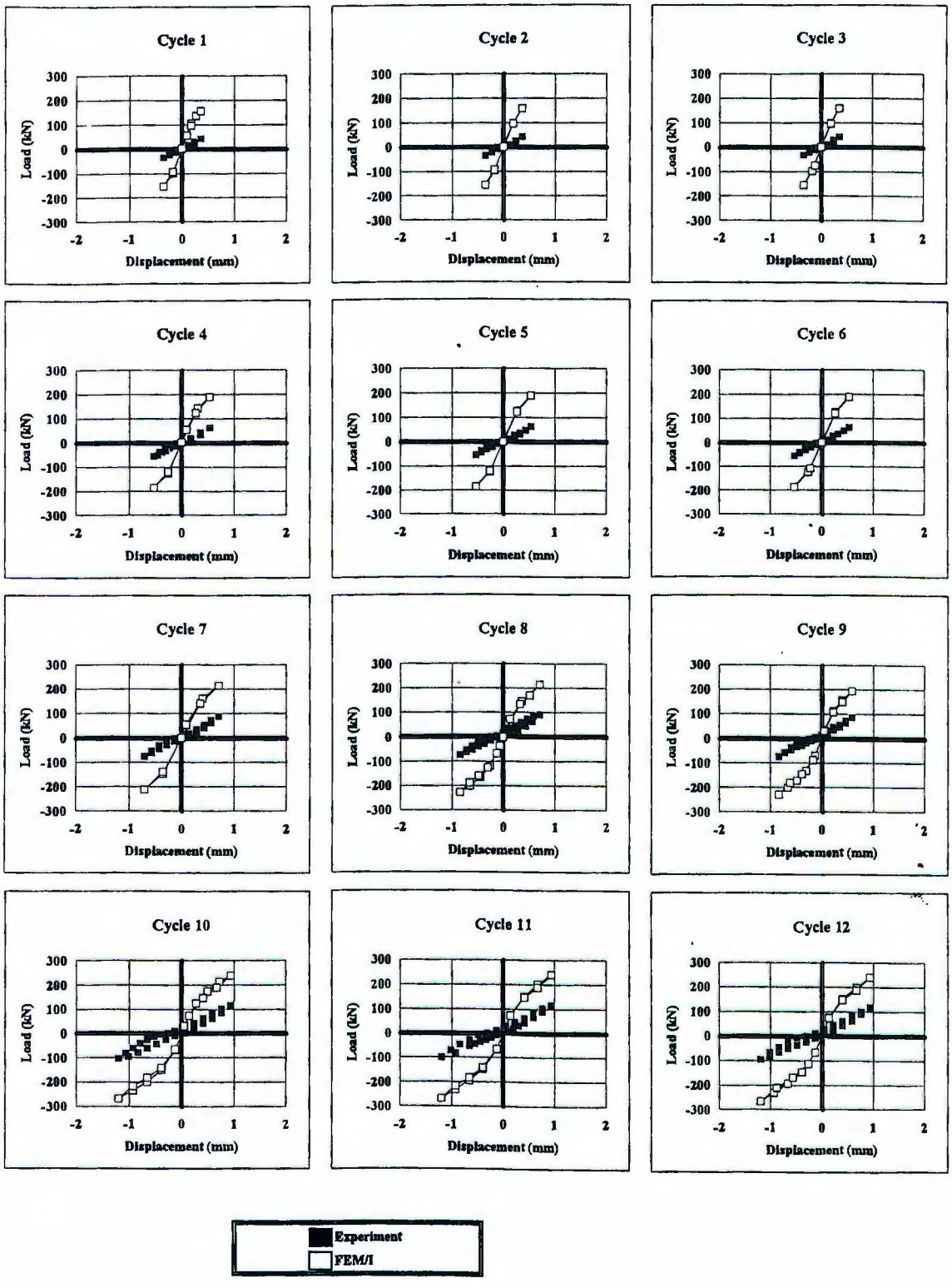


Figure 4.7 Force Displacement Cycles for Wall 1

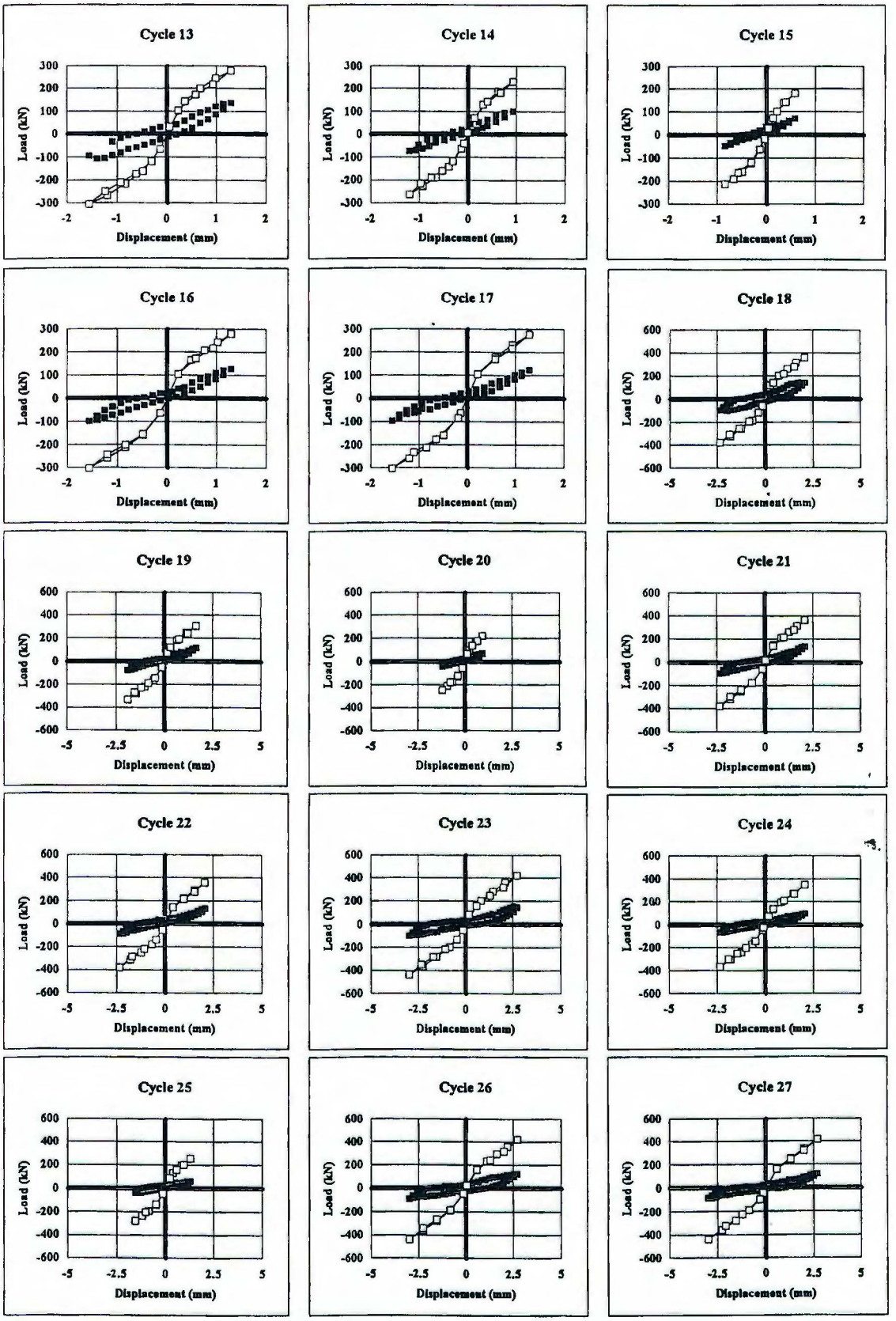


Figure 4.7 Force Displacement Cycles for Wall 1 (cont.)

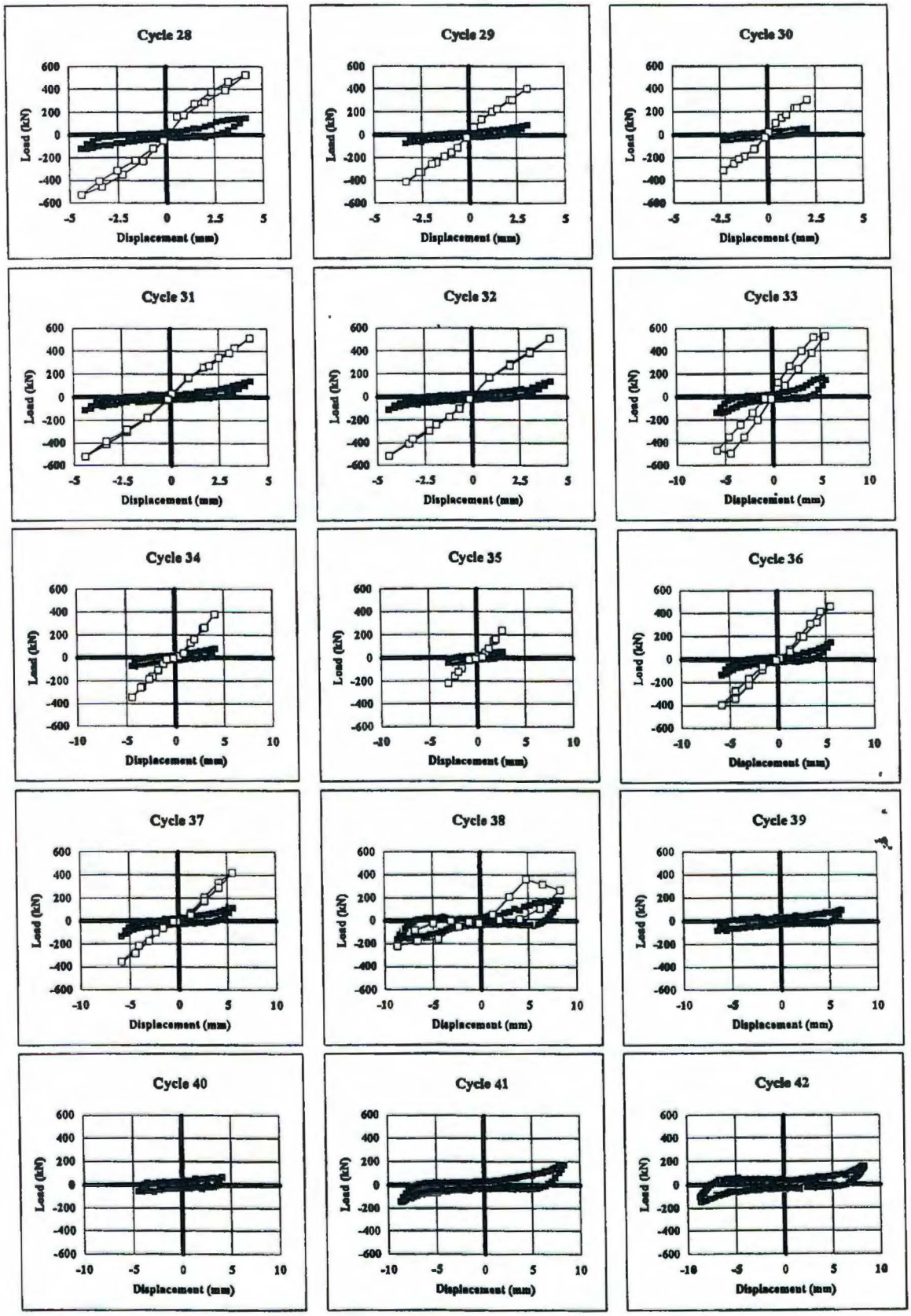


Figure 4.7 Force Displacement Cycles for Wall 1 (cont.)

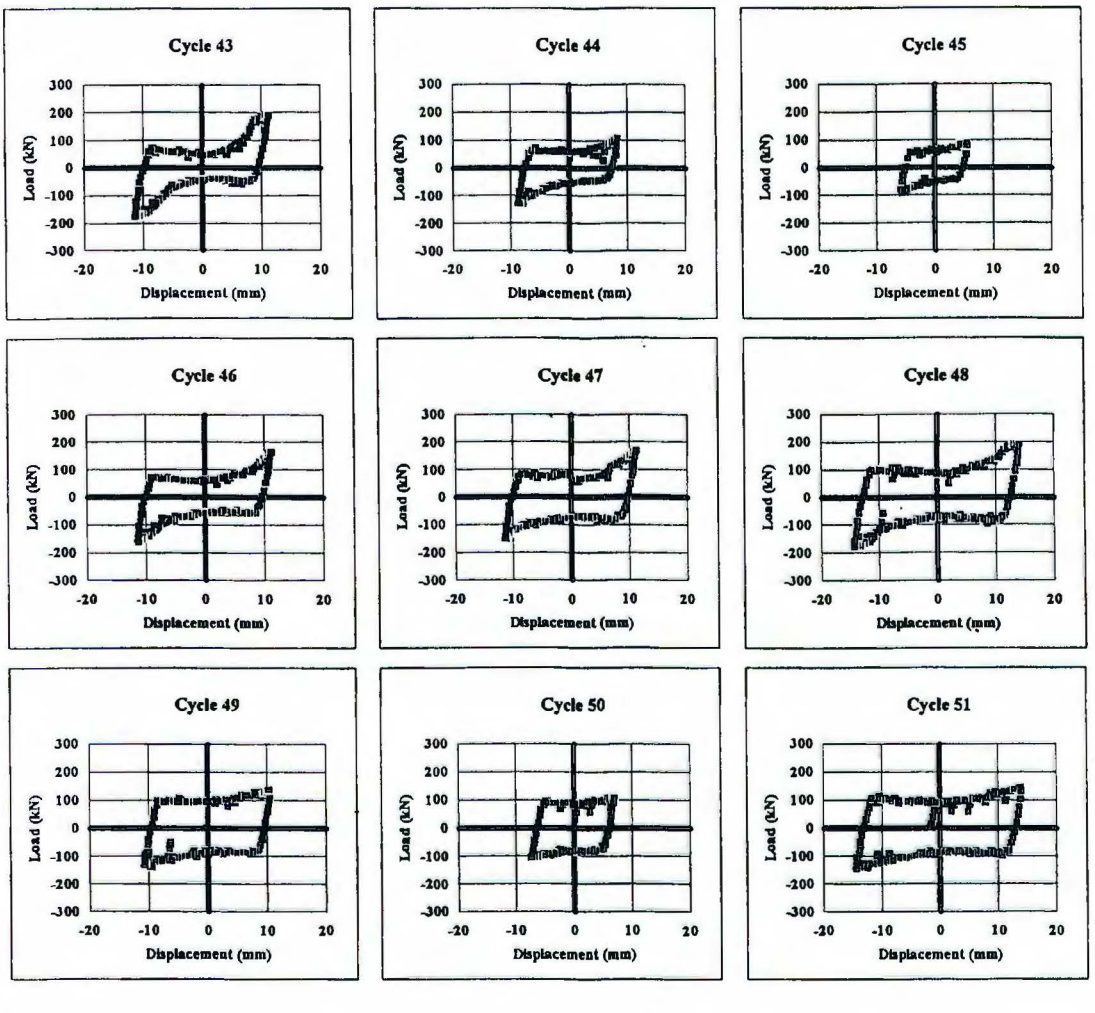


Figure 4.7 Force Displacement Cycles for Wall 1 (cont.)

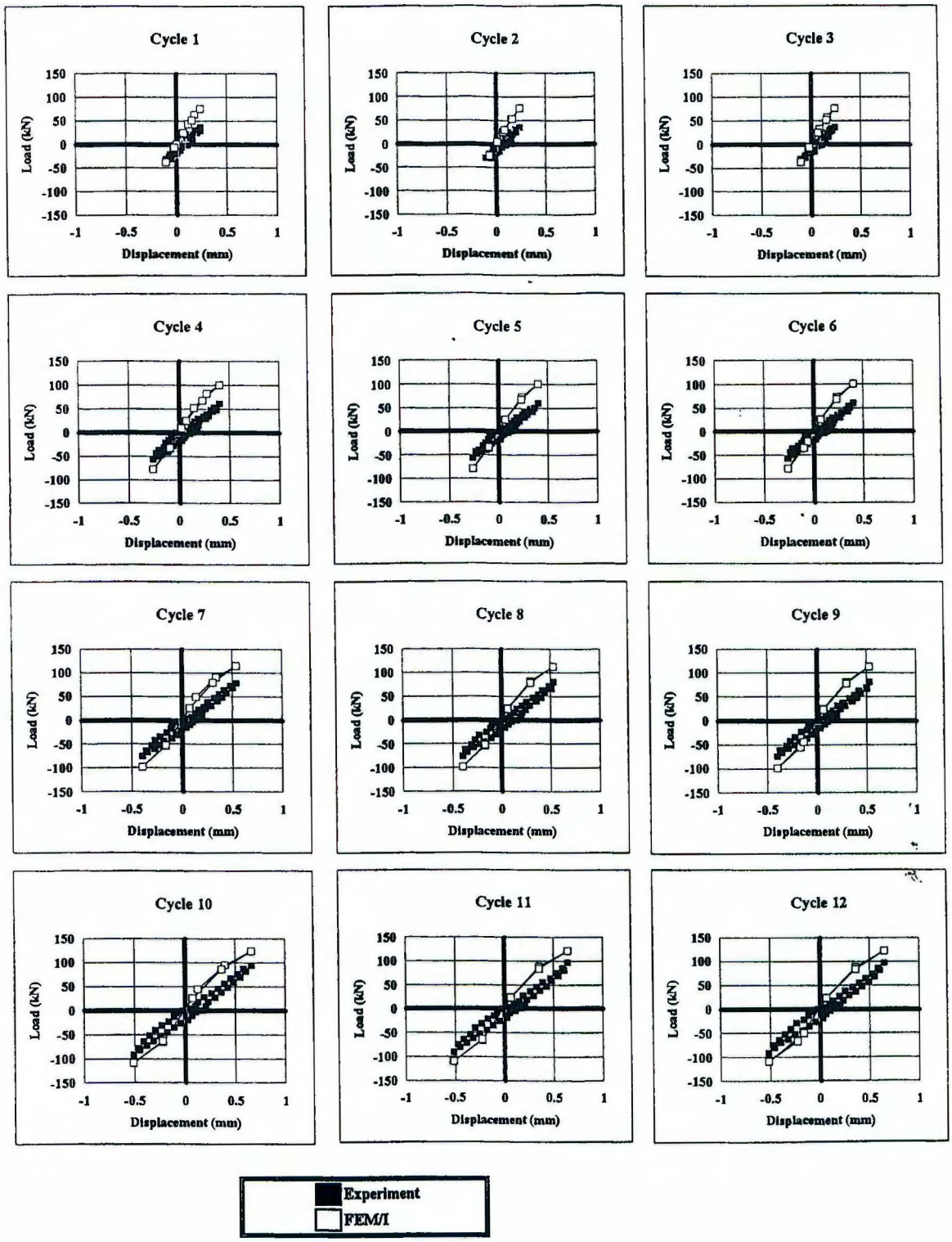


Figure 4.8 Force Displacement Cycles for Wall 3

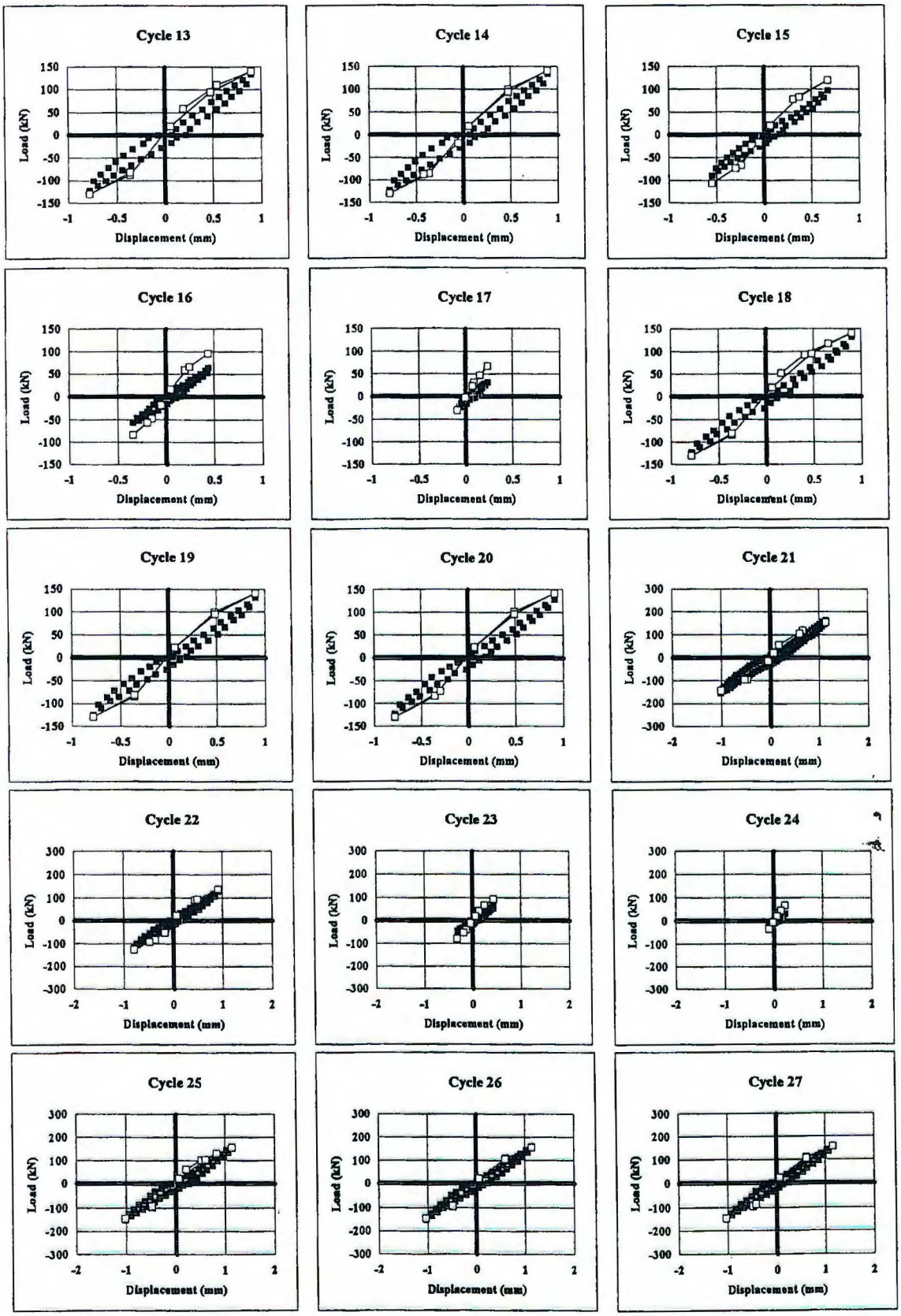


Figure 4.8 Force Displacement Cycles for Wall 3 (cont.)

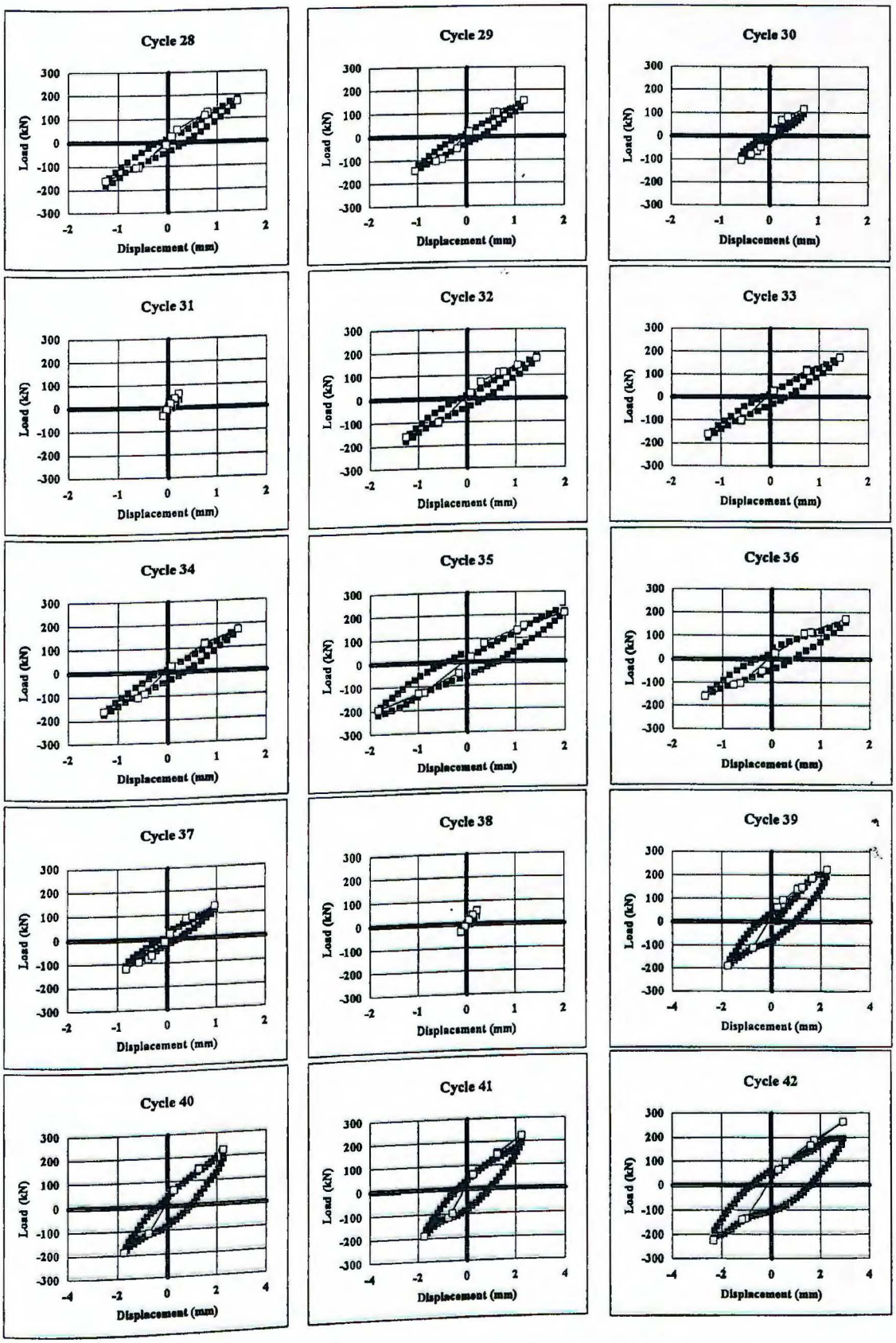


Figure 4.8 Force Displacement Cycles for Wall 3 (cont.)

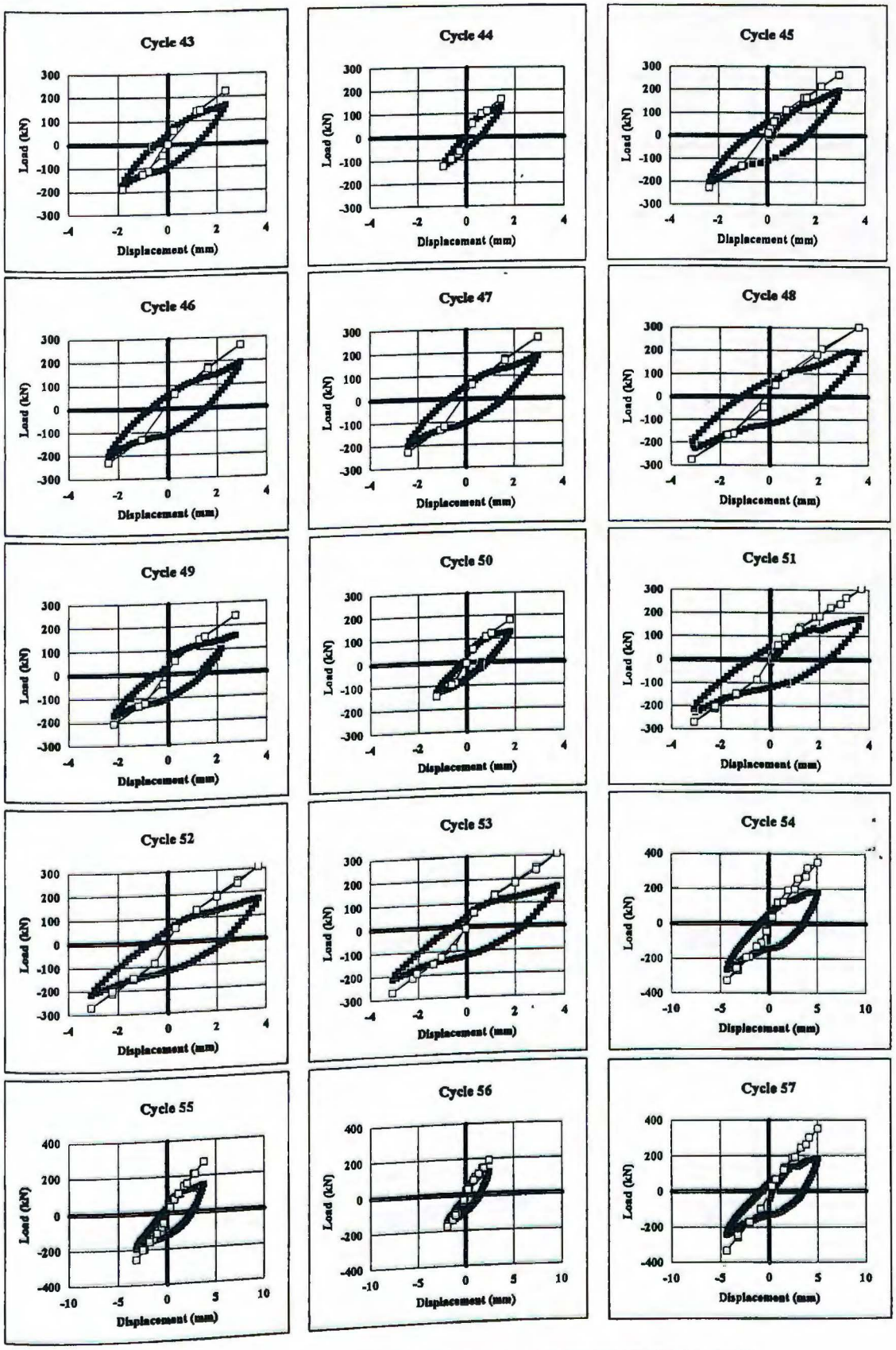


Figure 4.8 Force Displacement Cycles for Wall 3 (cont.)

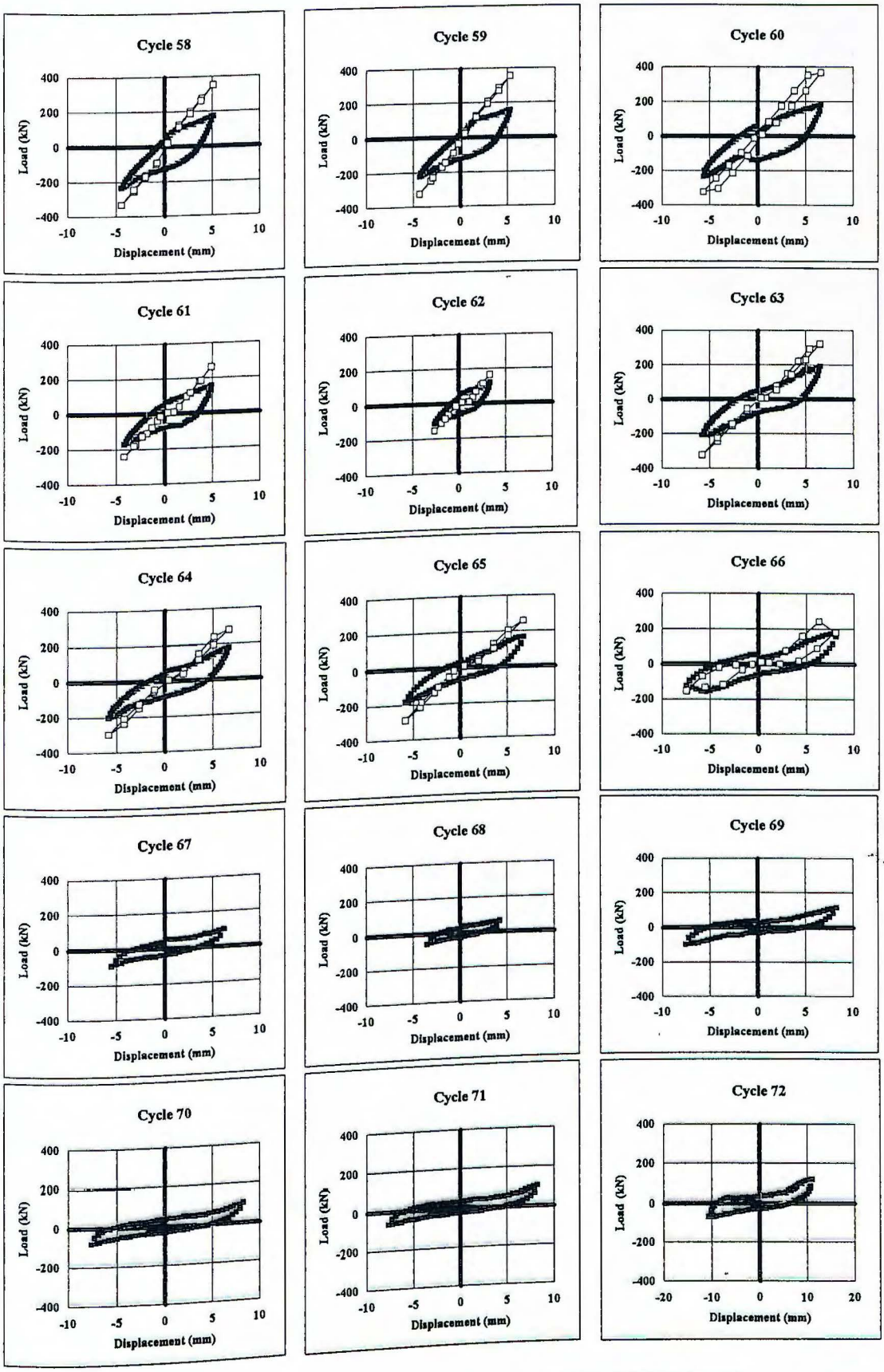


Figure 4.8 Force Displacement Cycles for Wall 3 (cont.)

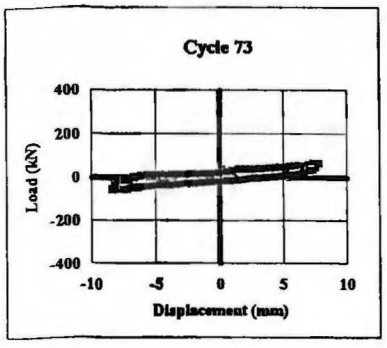


Figure 4.8 Force Displacement Cycles for Wall 3 (cont.)

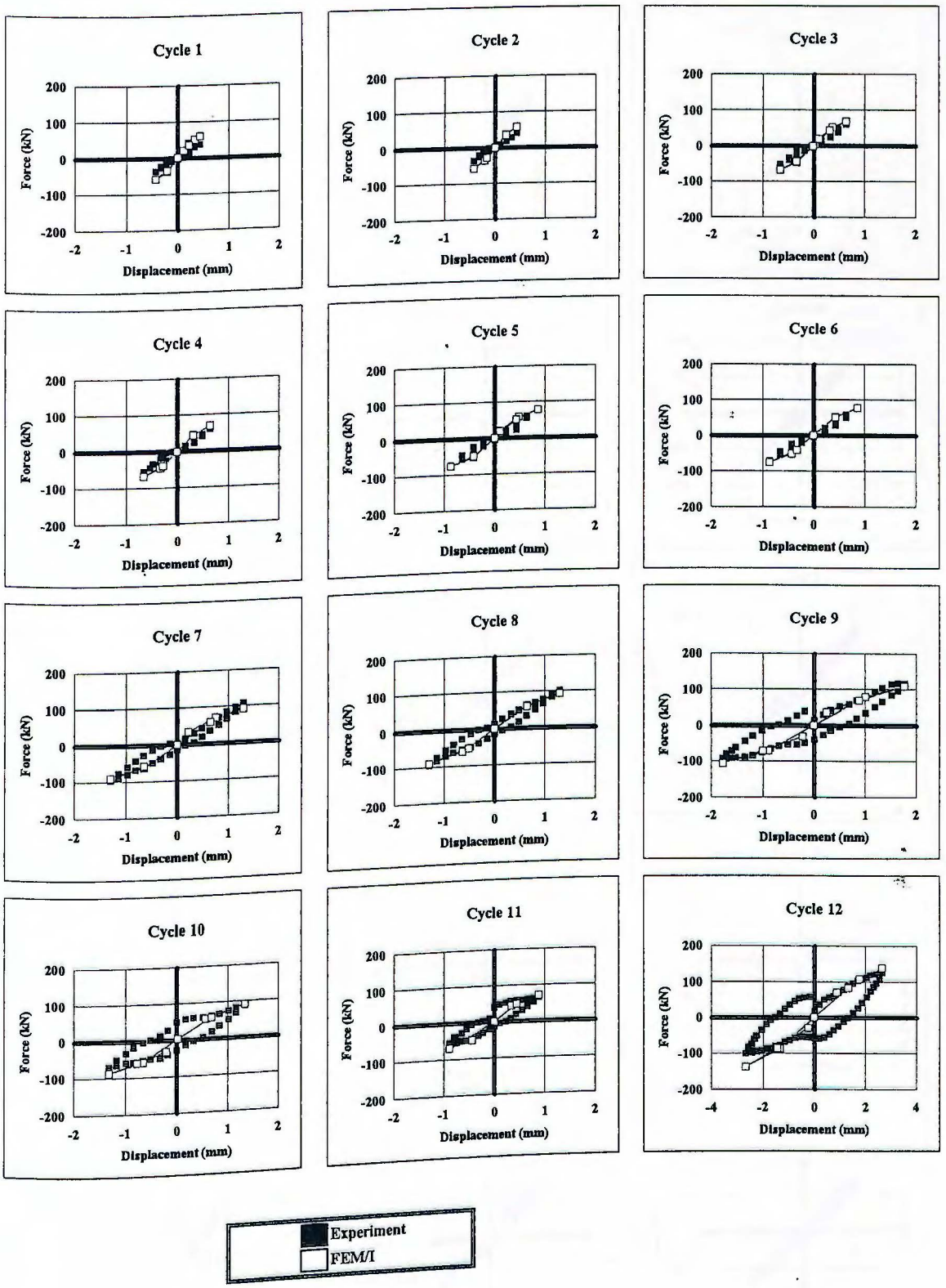


Figure 4.9 Force Displacement Cycles for Wall 5

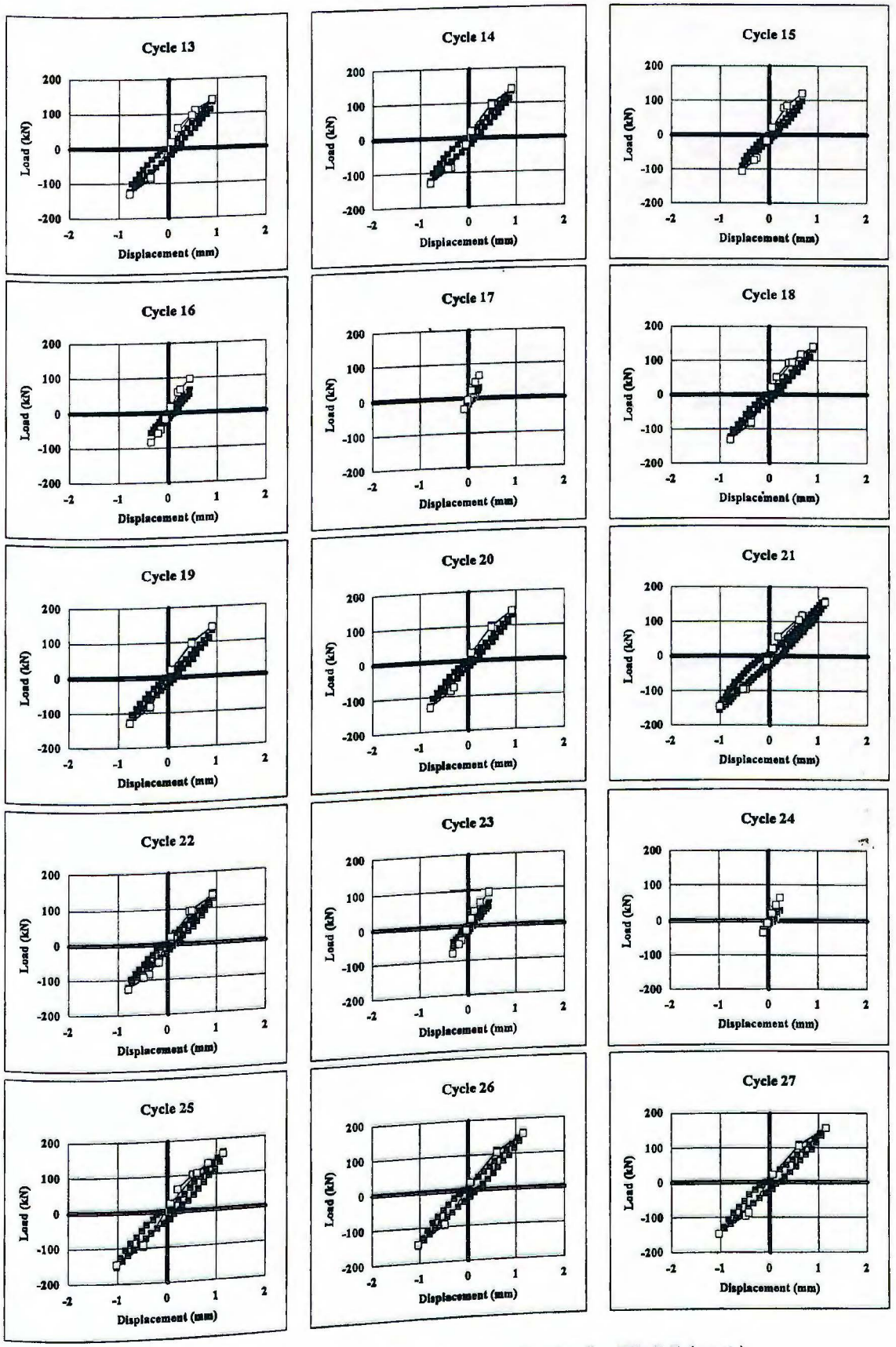


Figure 4.9 Force Displacement Cycles for Wall 5 (cont.)

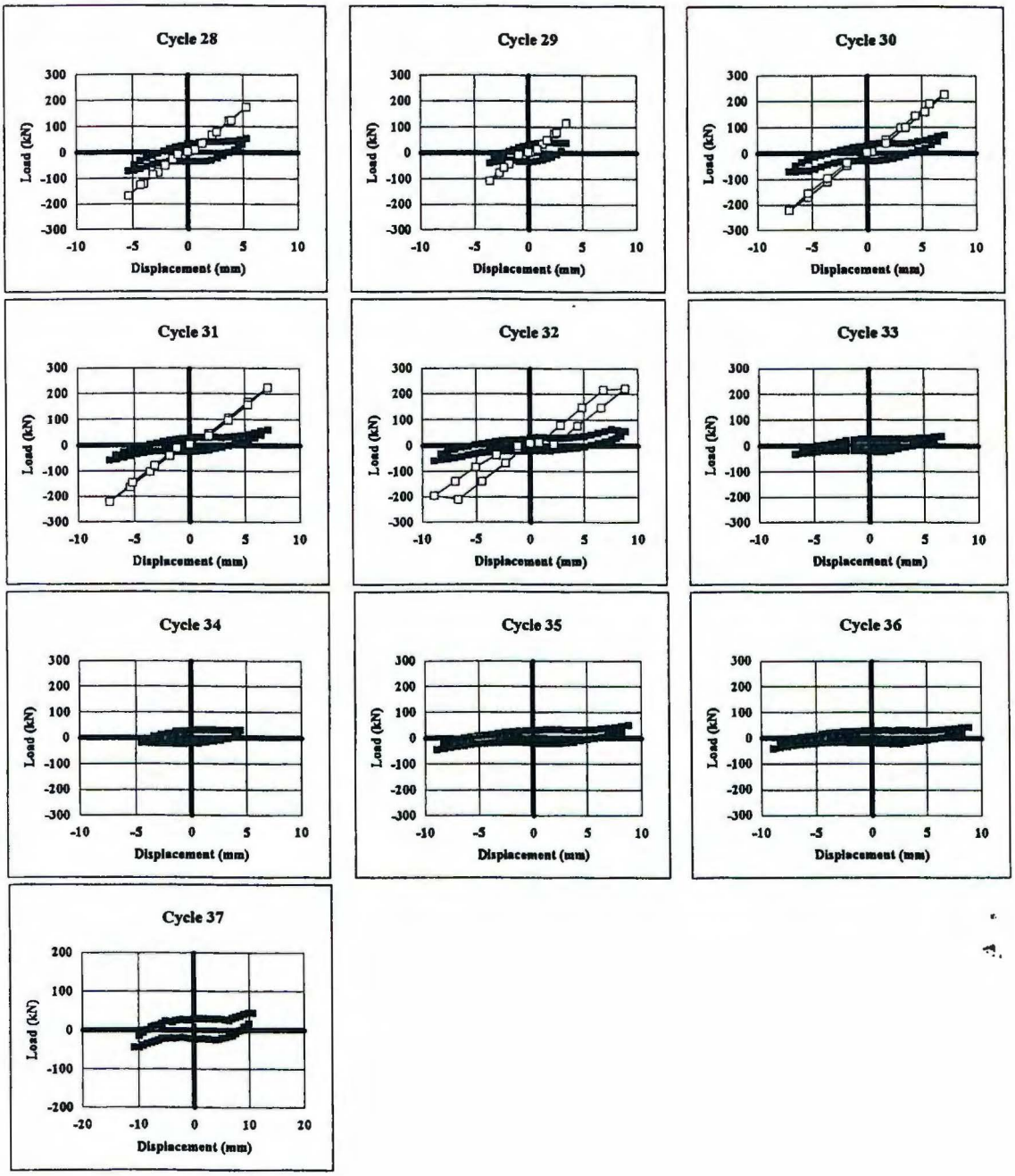


Figure 4.9 Force Displacement Cycles for Wall 5 (cont.)

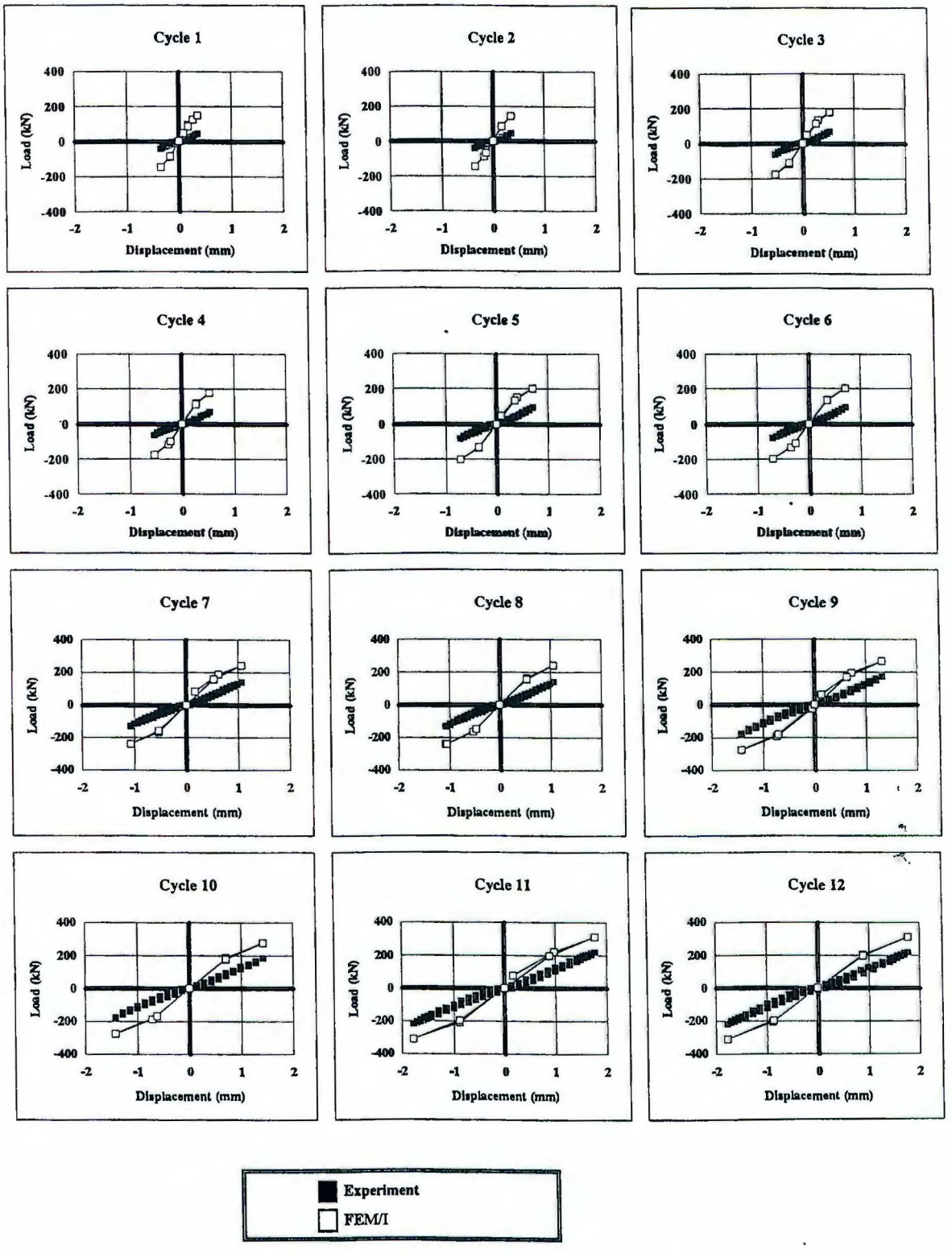


Figure 4.10 Force Displacement Cycles for Wall 7

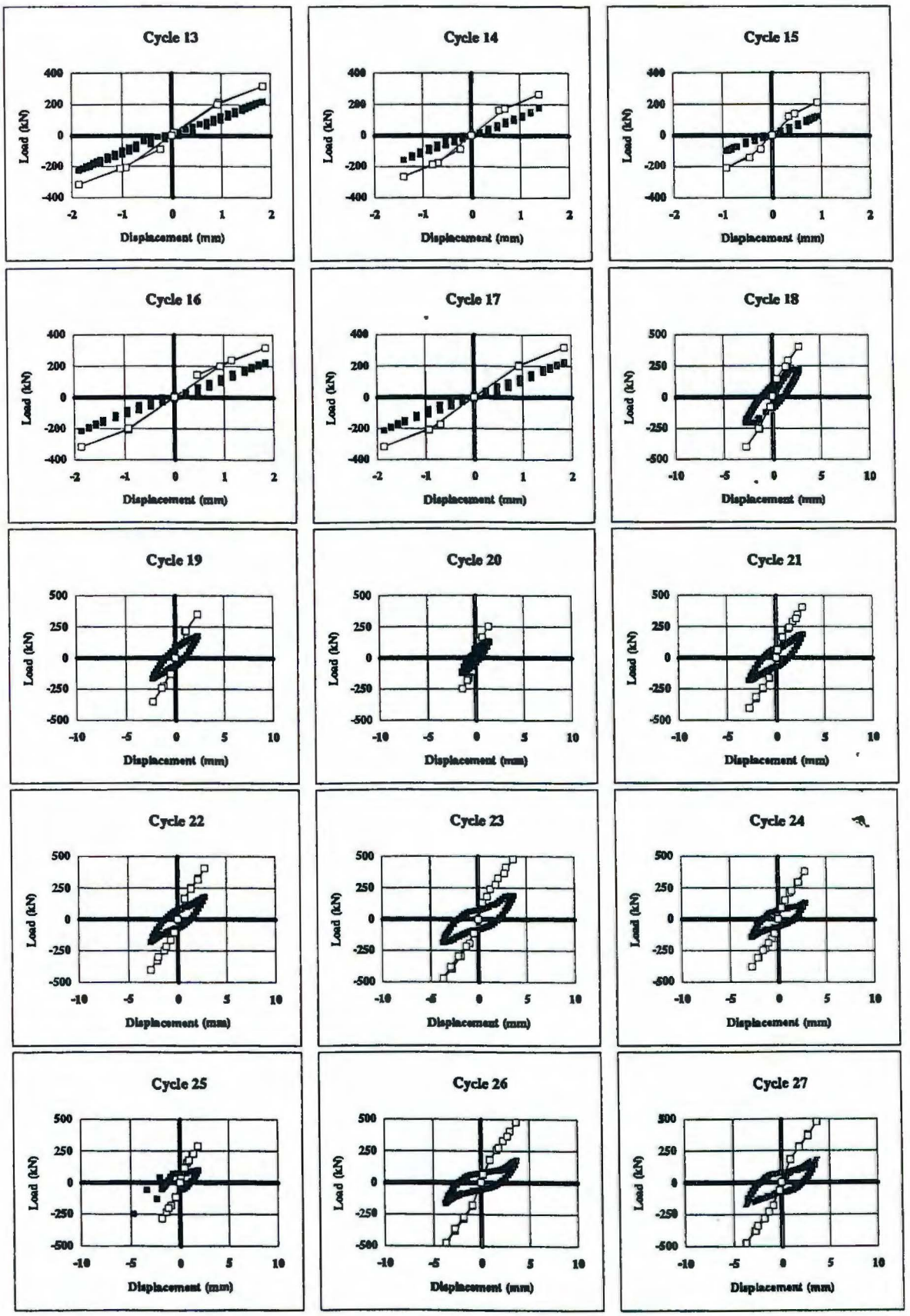


Figure 4.10 Force Displacement Cycles for Wall 7 (cont.)

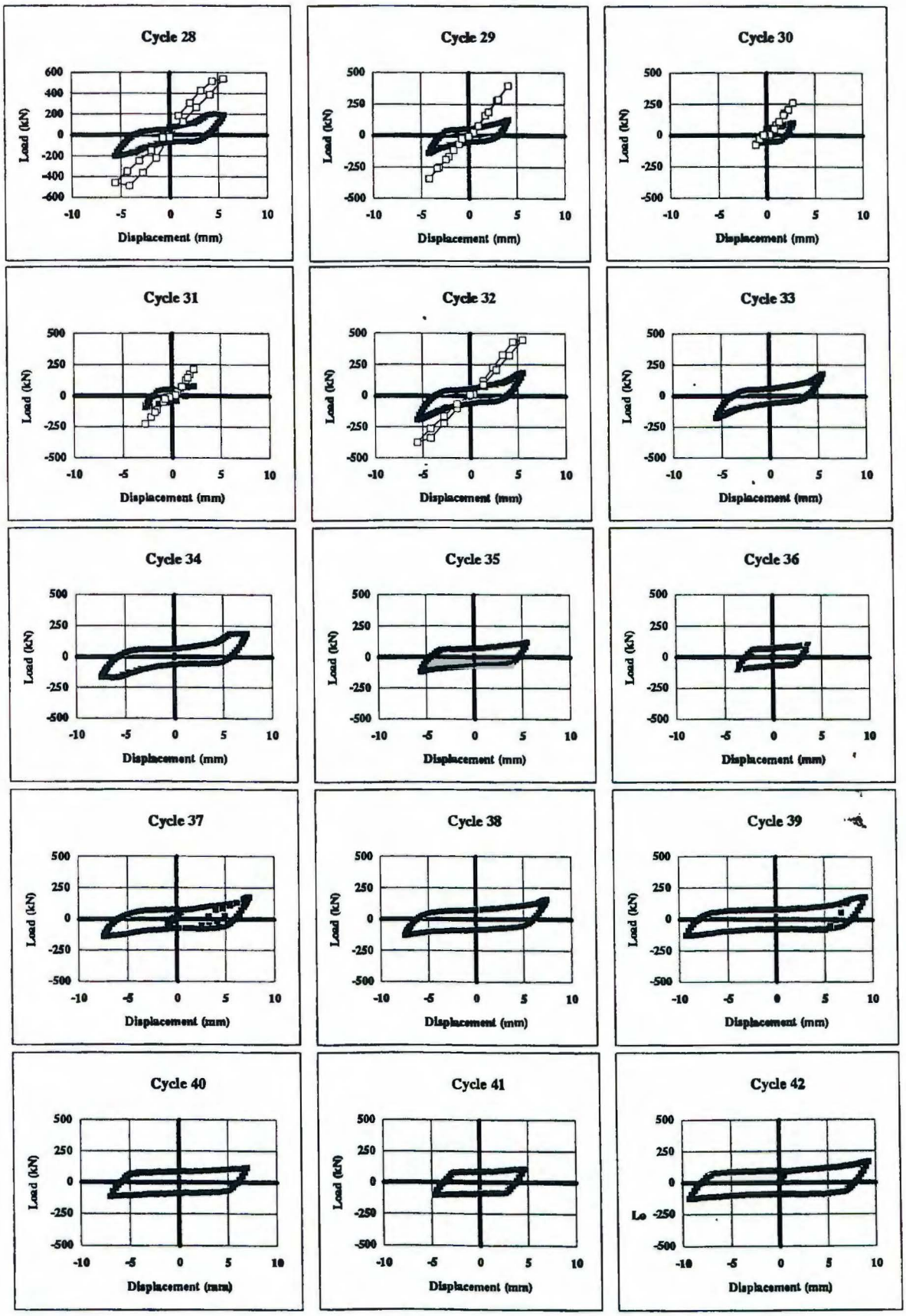


Figure 4.10 Force Displacement Cycles for Wall 7 (cont.)

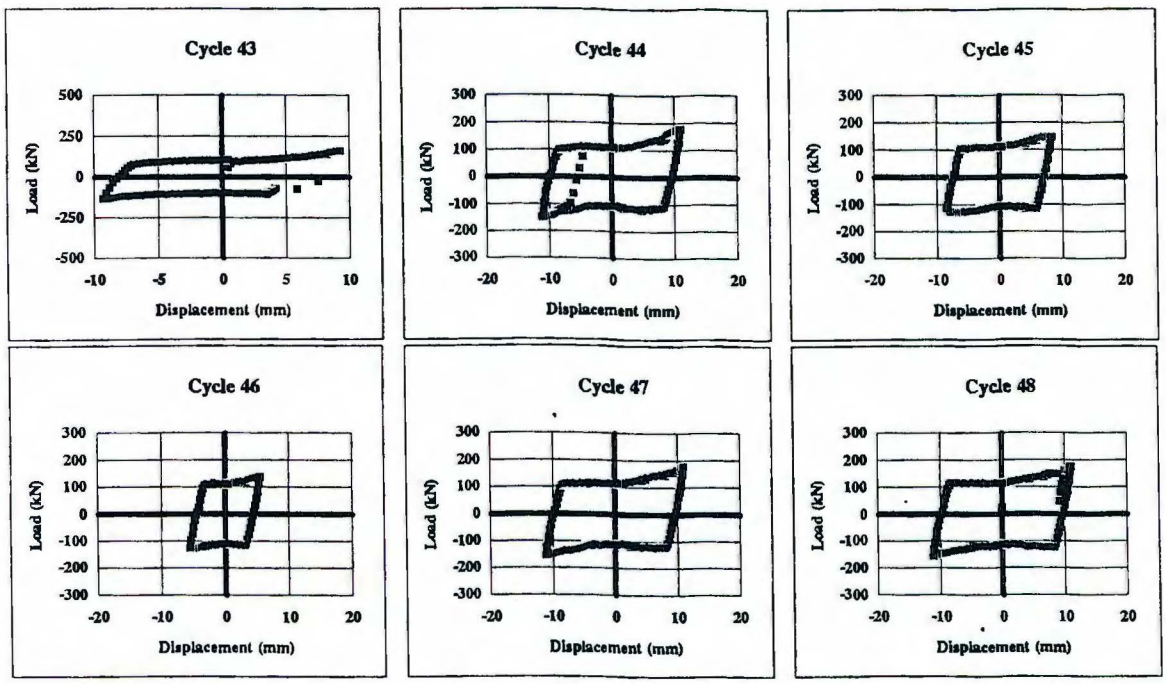


Figure 4.10 Force Displacement Cycles for Wall 7 (cont.)

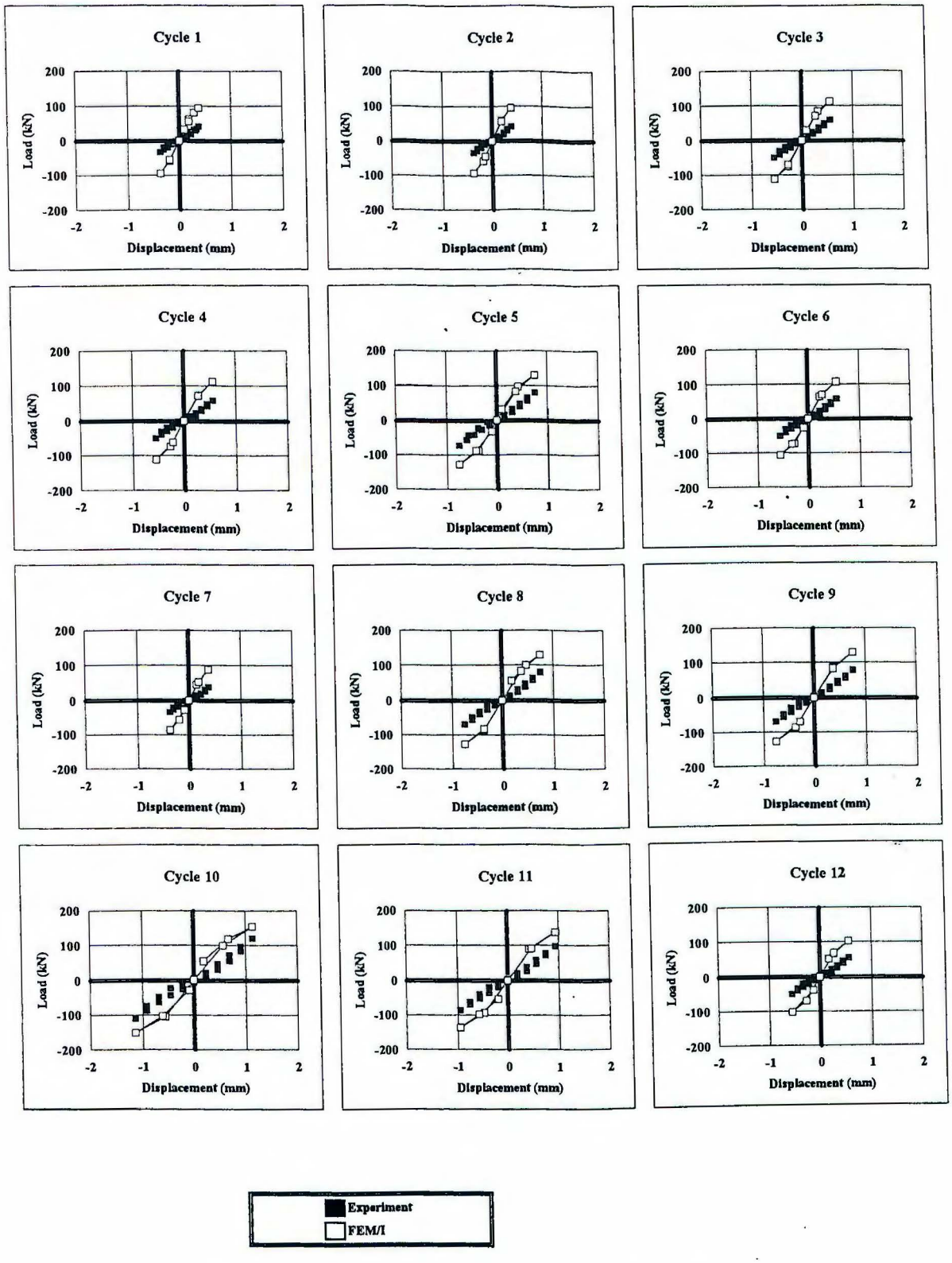


Figure 4.11 Force Displacement Cycles for Wall 9

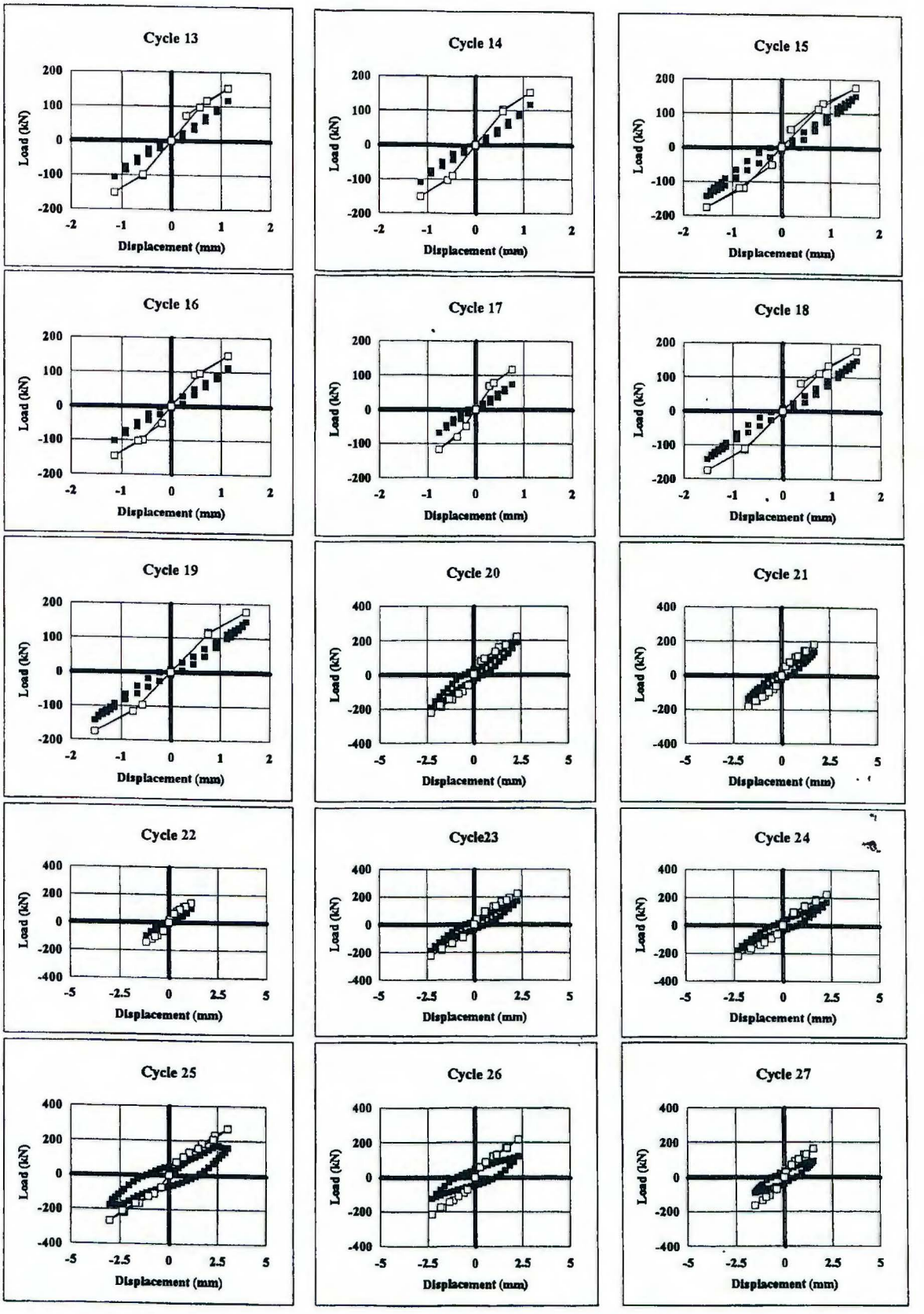


Figure 4.11 Force Displacement Cycles for Wall 9 (cont.)

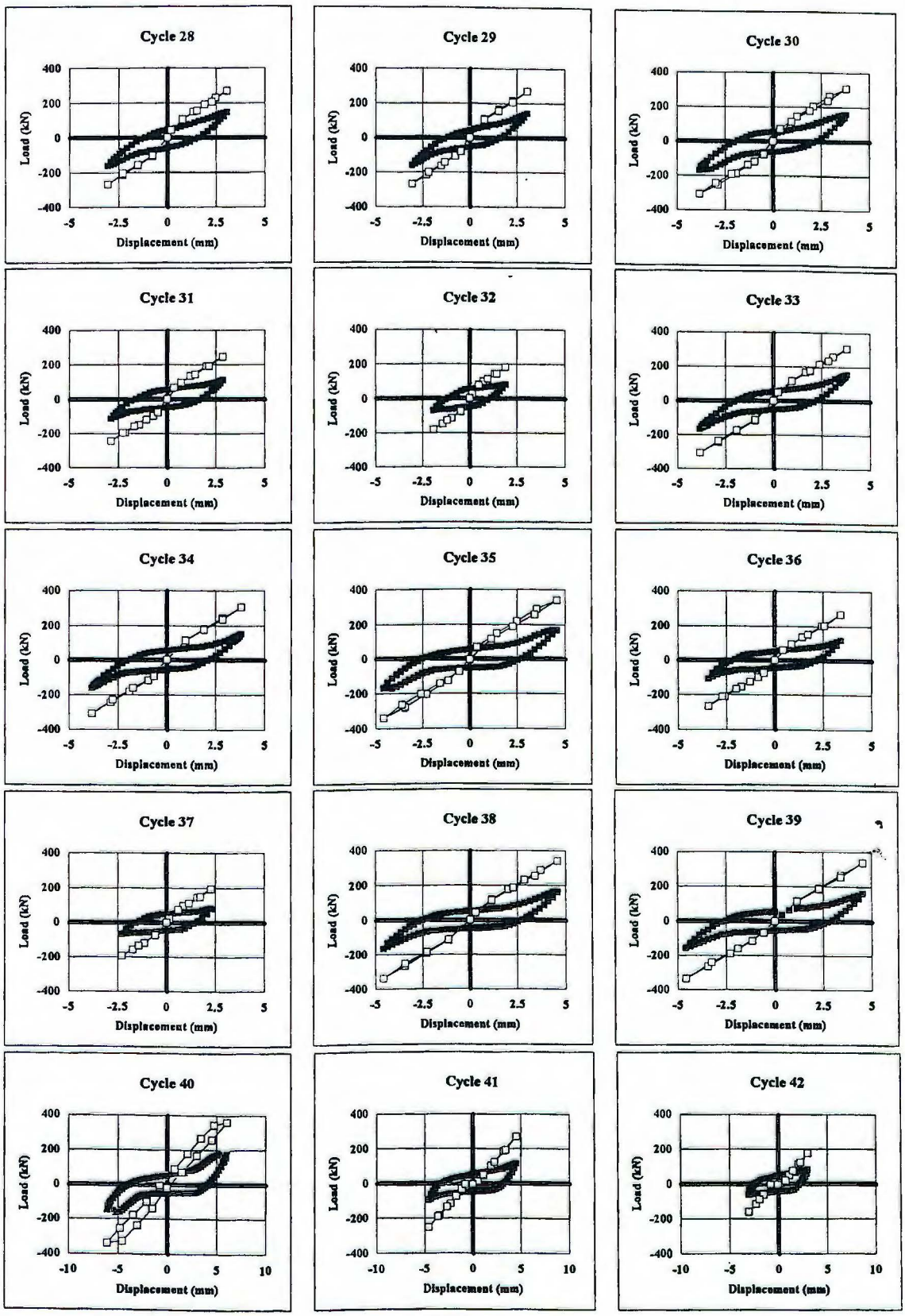


Figure 4.11 Force Displacement Cycles for Wall 9 (cont.)

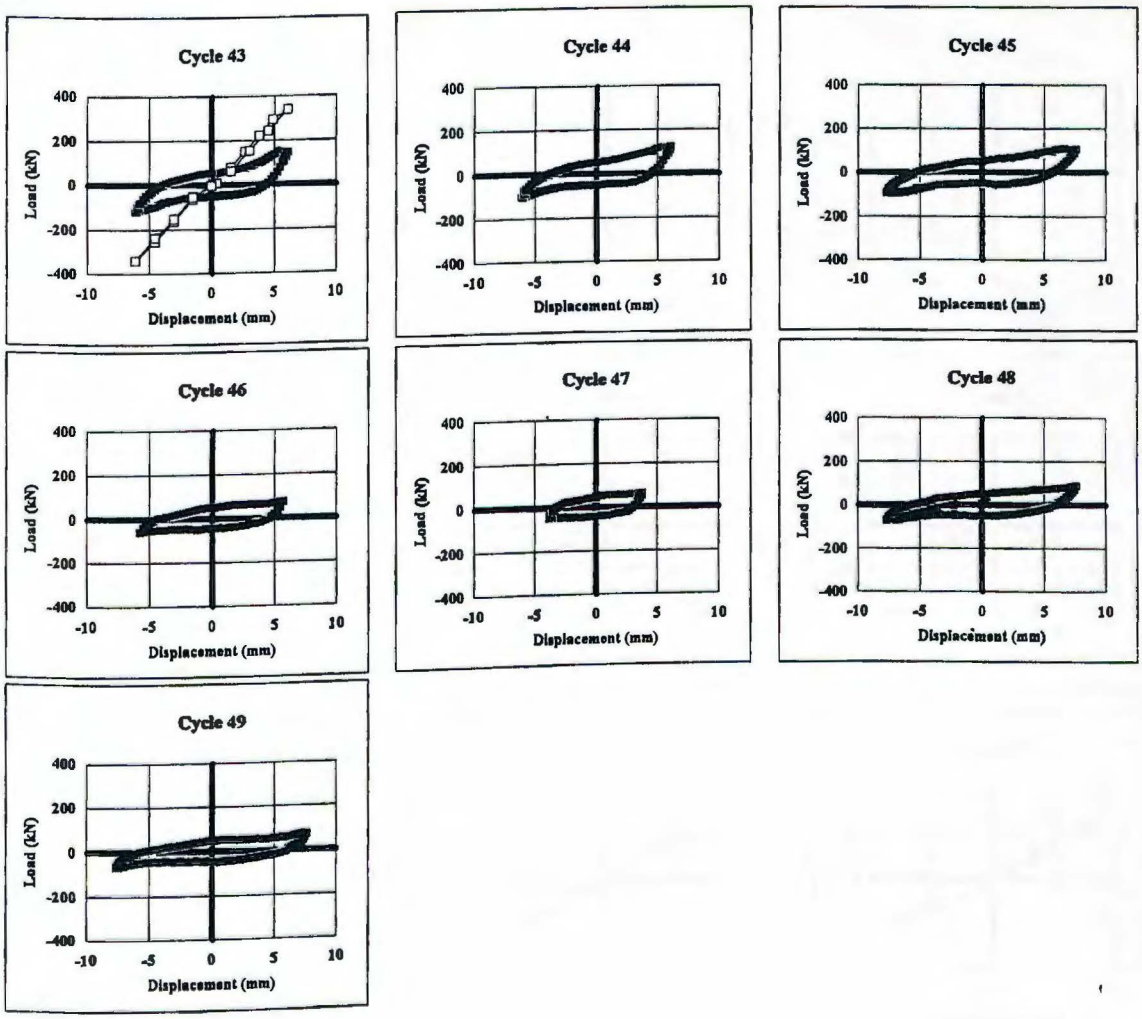


Figure 4.11 Force Displacement Cycles for Wall 9 (cont.)

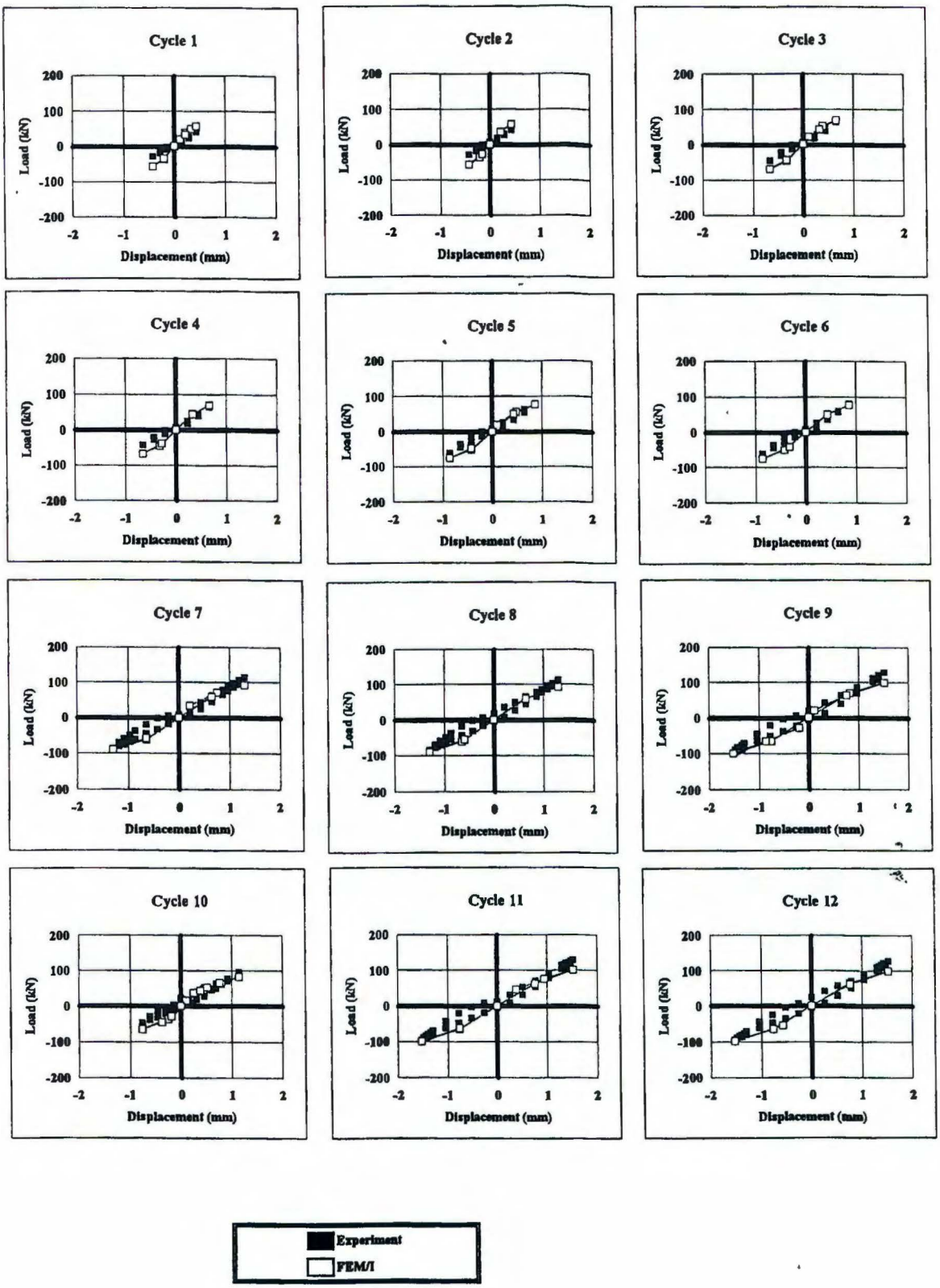


Figure 4.12 Force Displacement Cycles for Wall 11

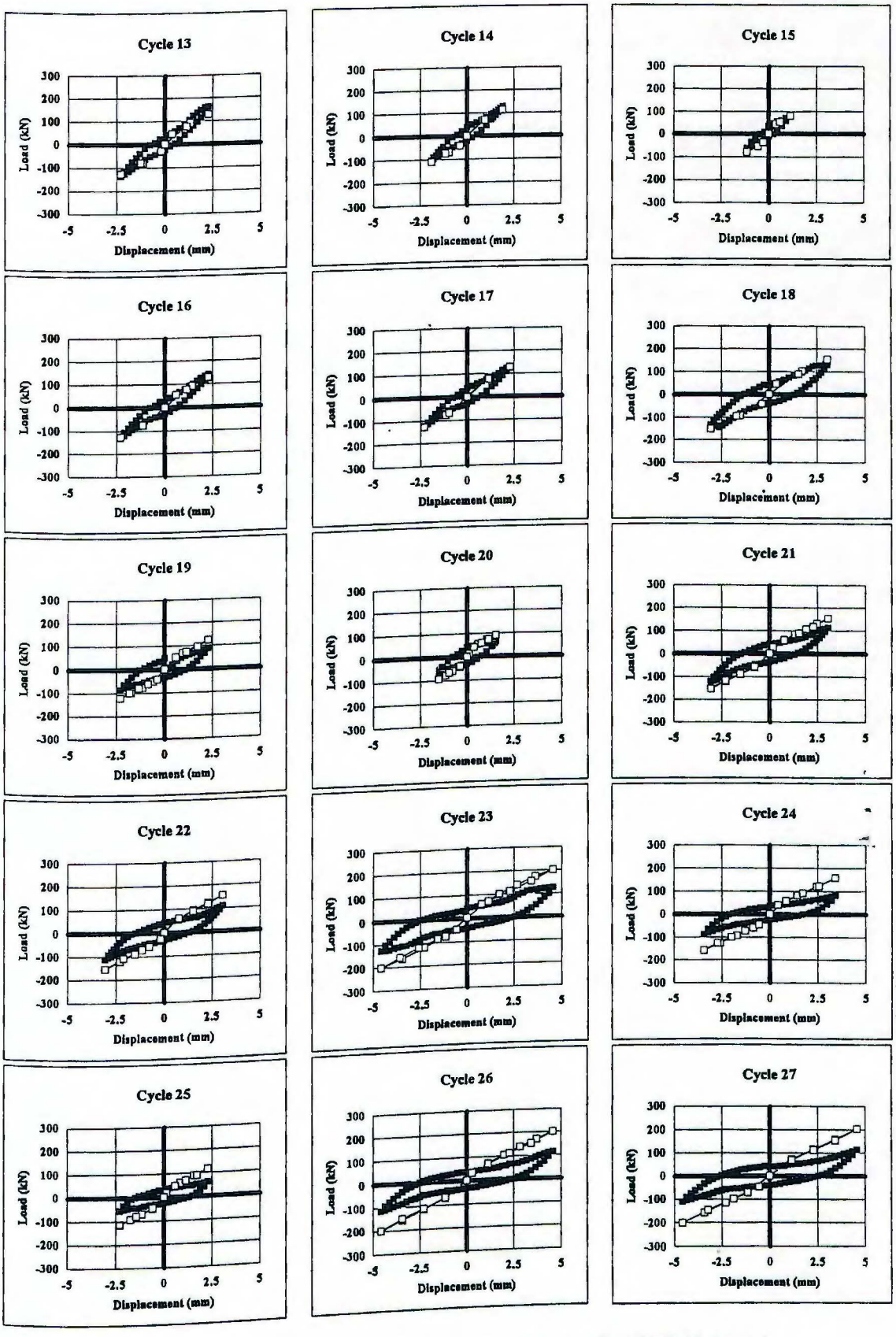


Figure 4.12 Force Displacement Cycles for Wall 11 (cont.)

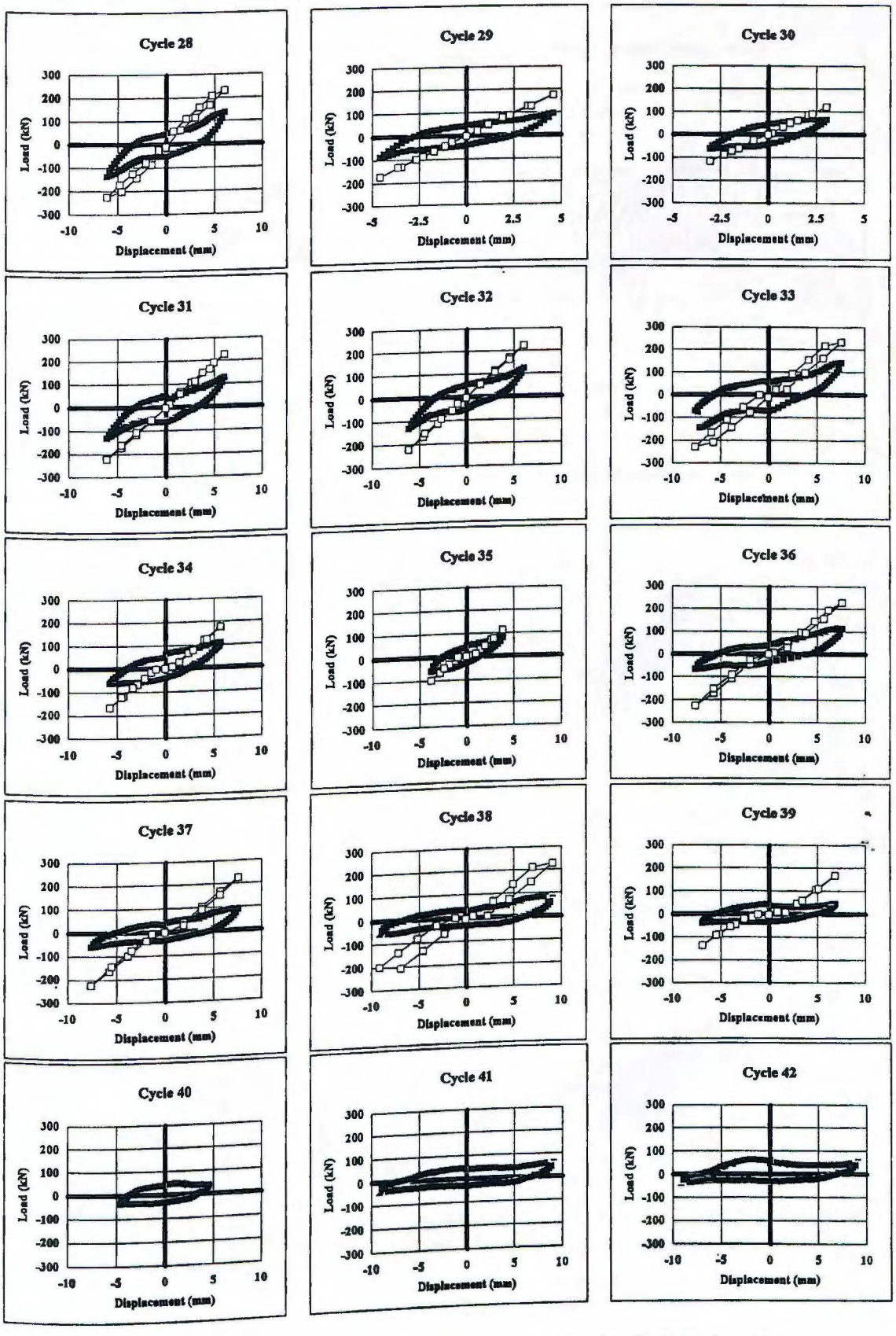


Figure 4.12 Force Displacement Cycles for Wall 11 (cont.)

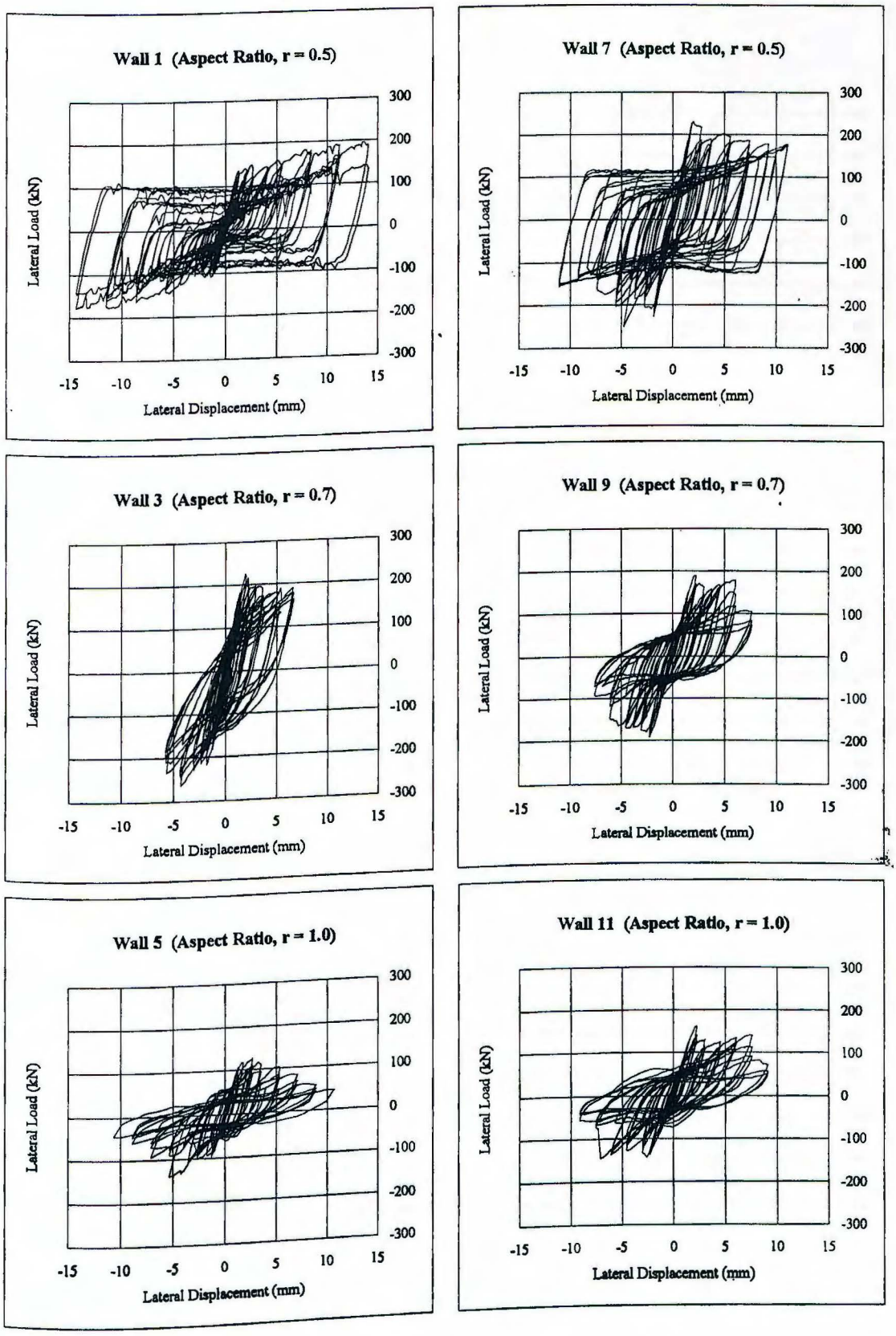


Figure 4.13 Experimental Study Force-Displacement Response for Masonry Specimens

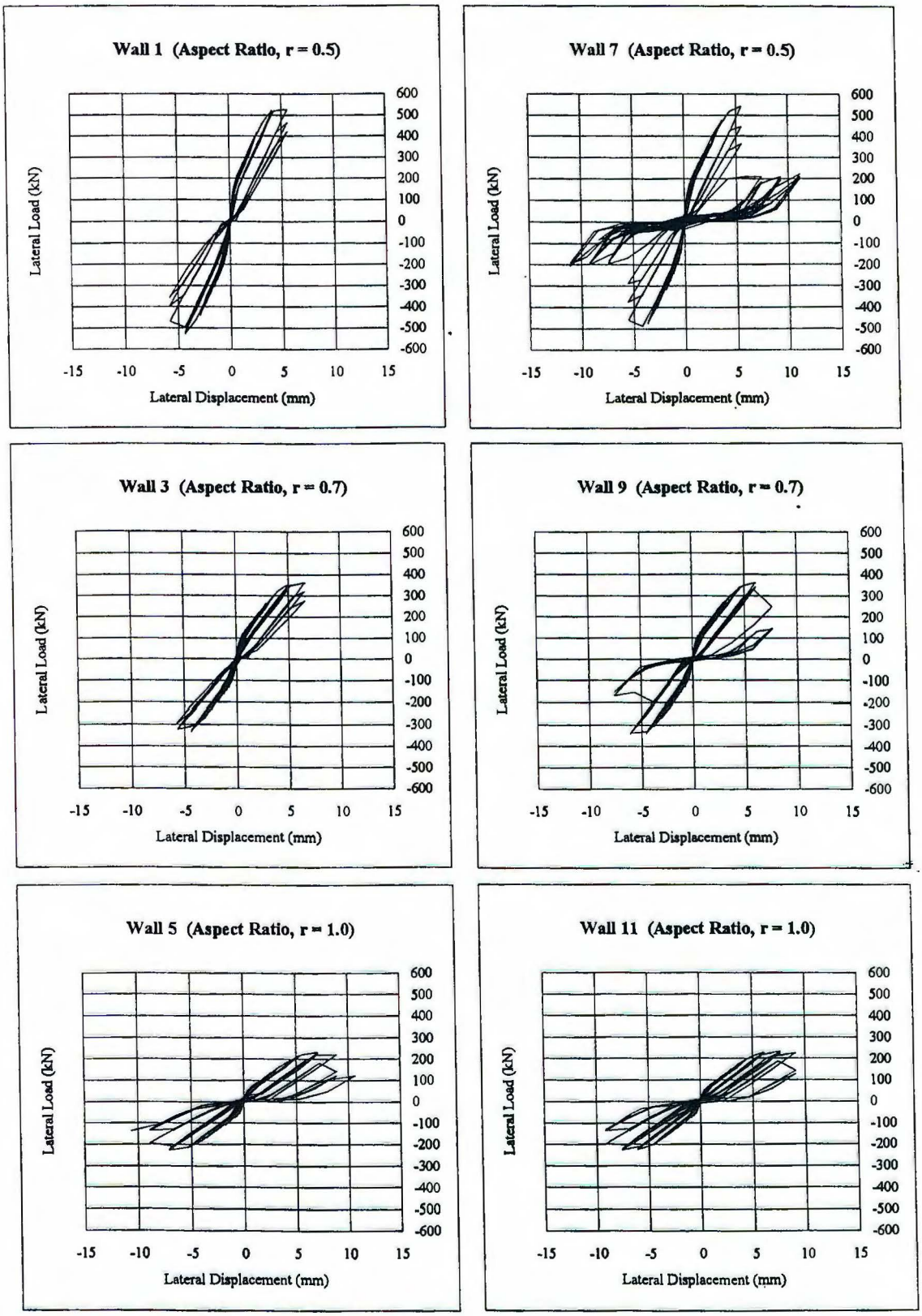


Figure 4.14 FEM/I Force-Displacement Response for Masonry Specimens

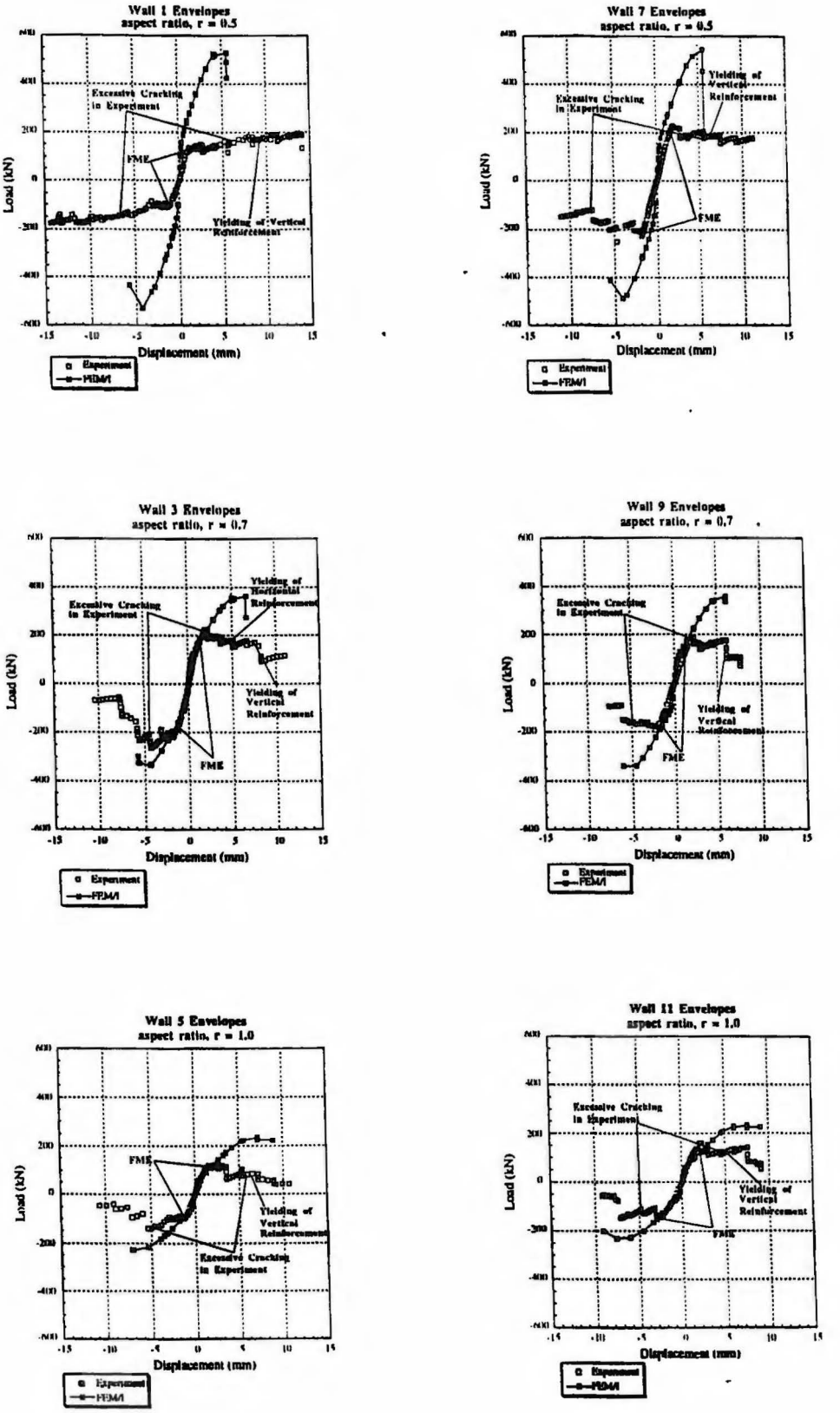


Figure 4.15 Force-Displacement Envelopes

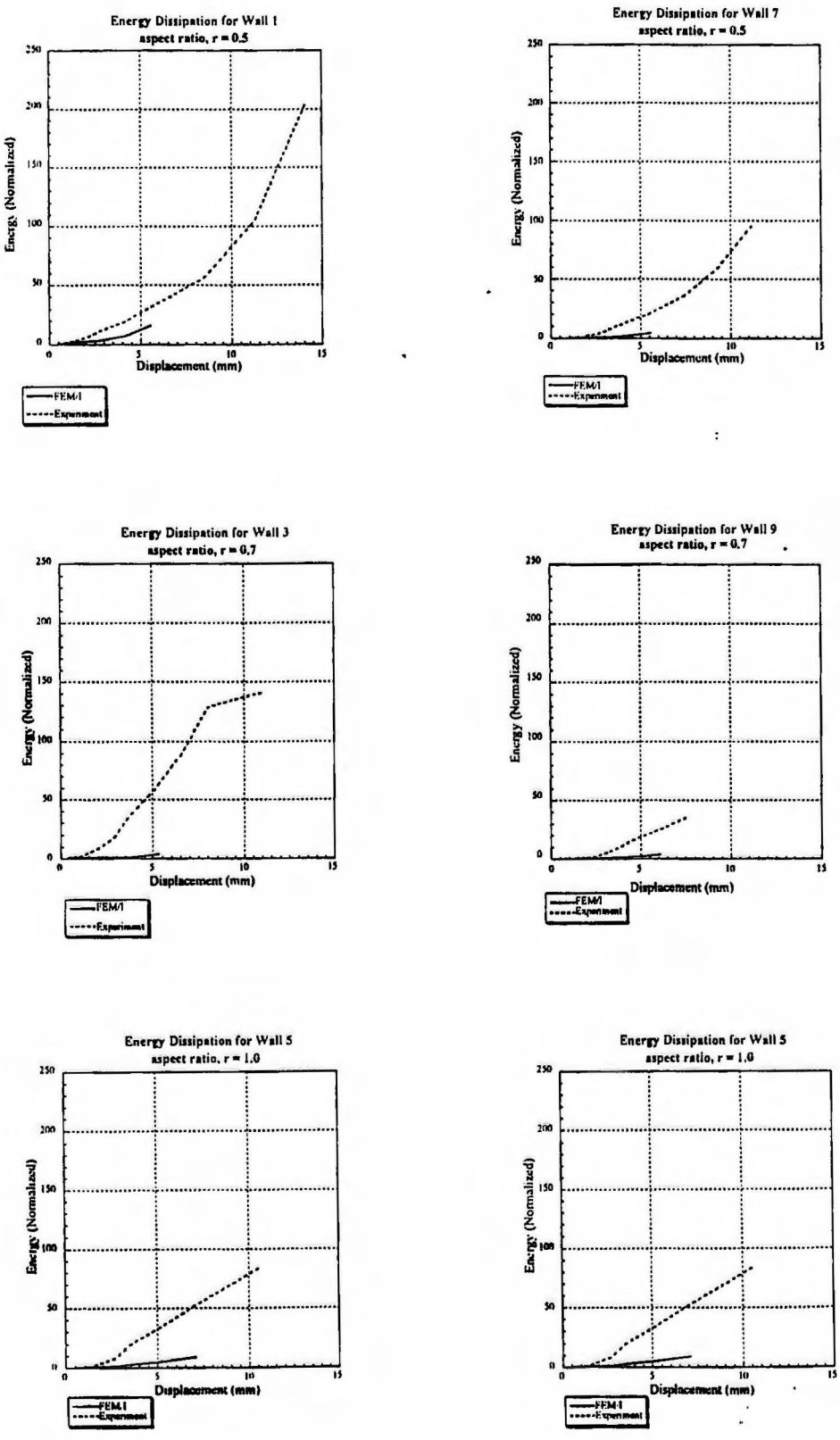


Figure 4.16 Cumulative Energy Dissipation

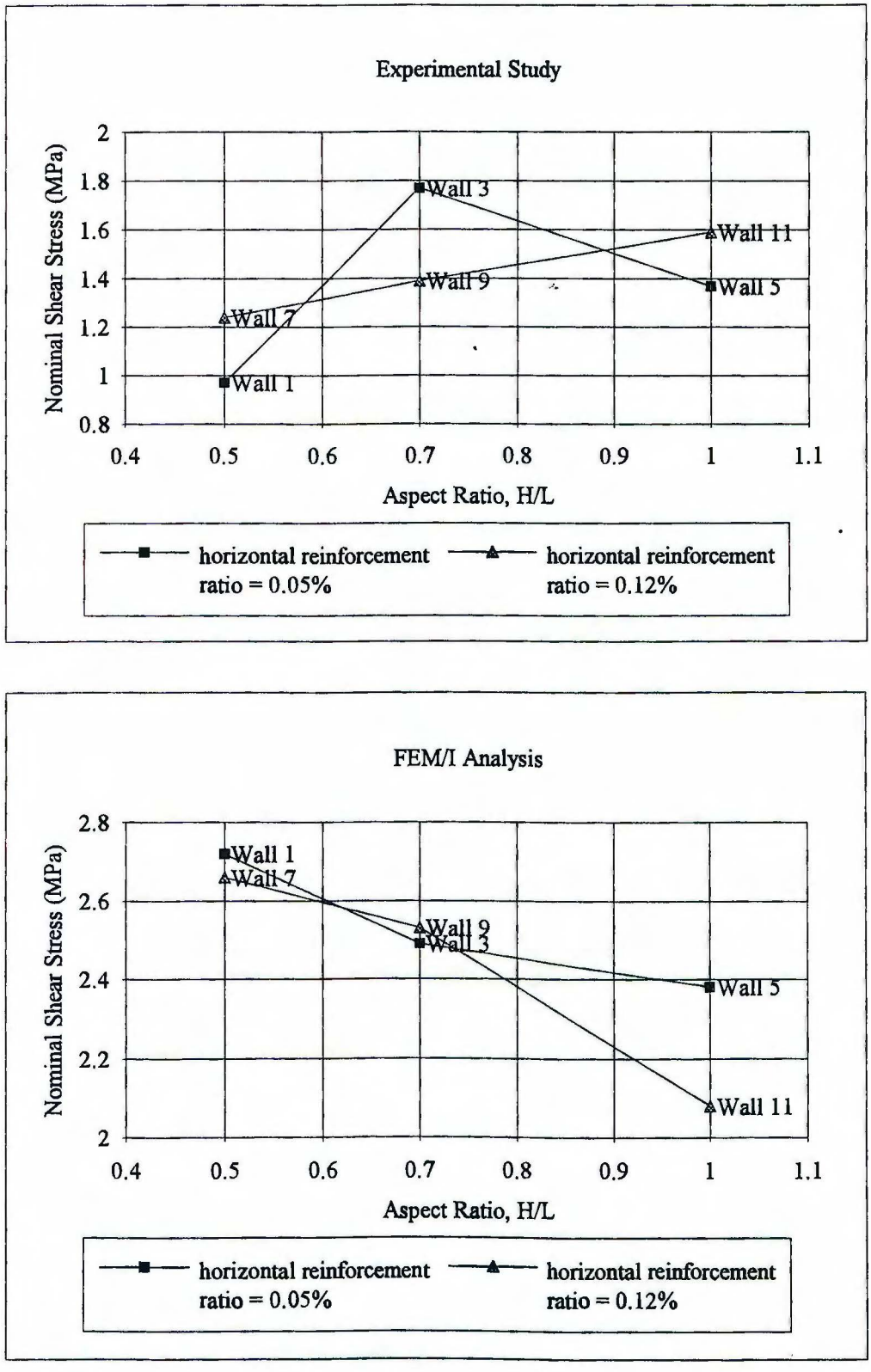
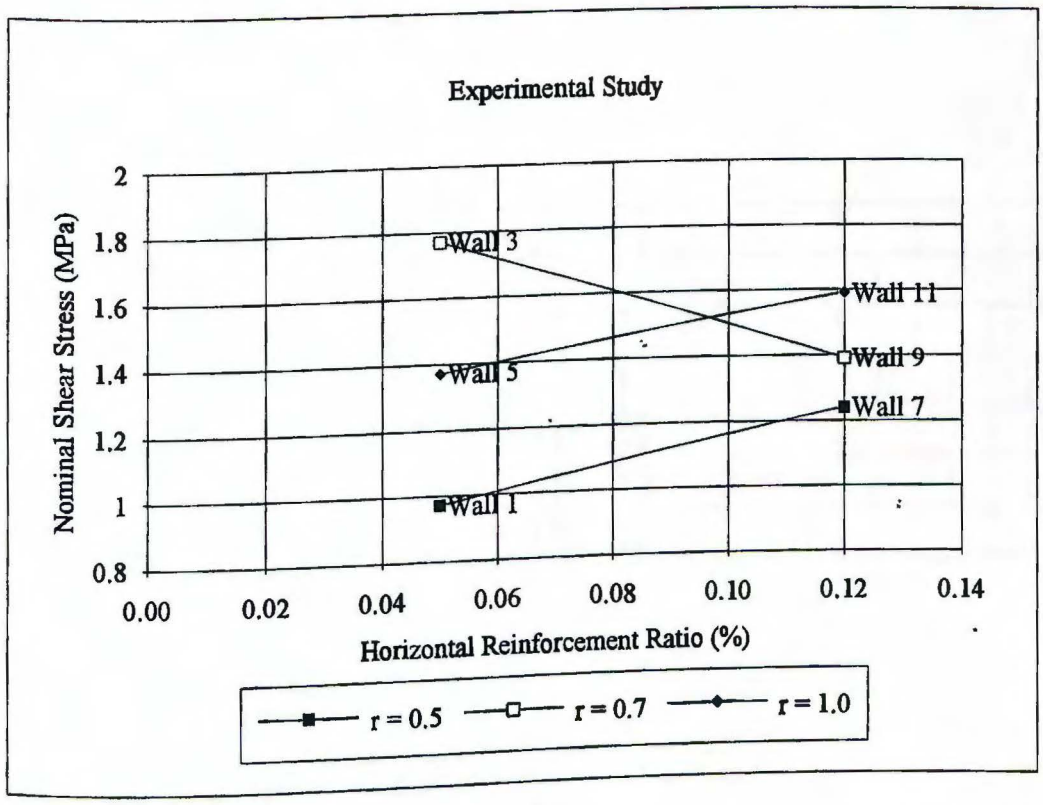


Figure 4.17 Influence of Aspect Ratio on Ultimate Shear Stress



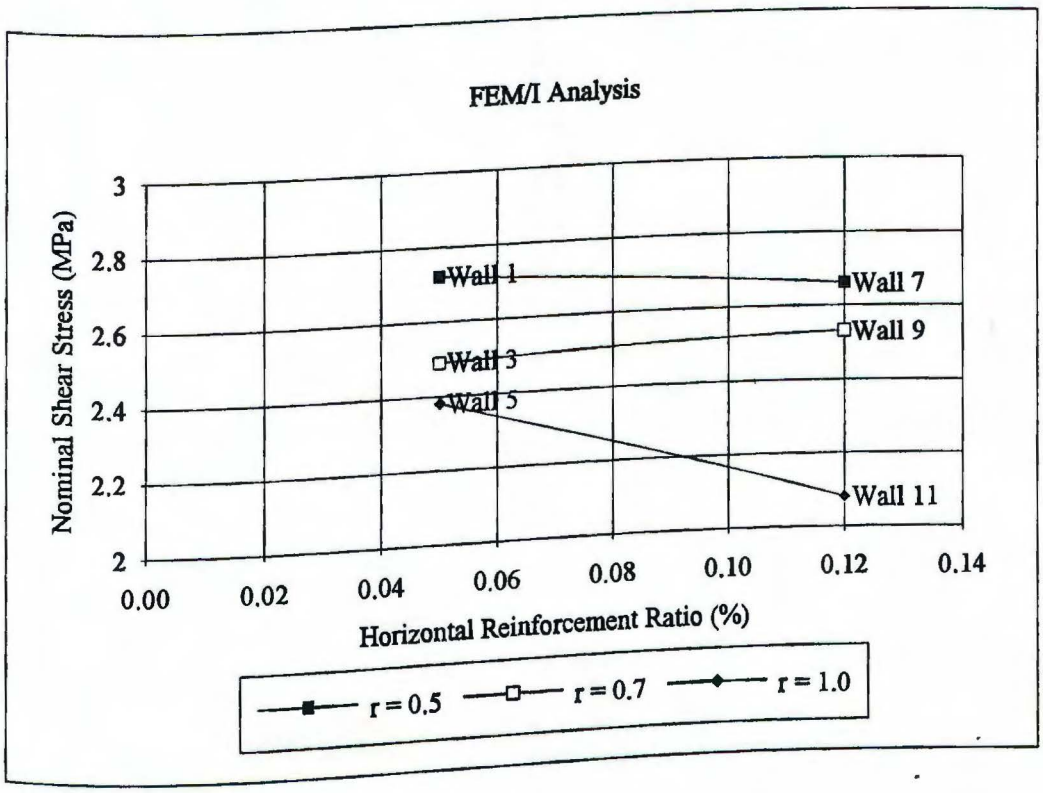
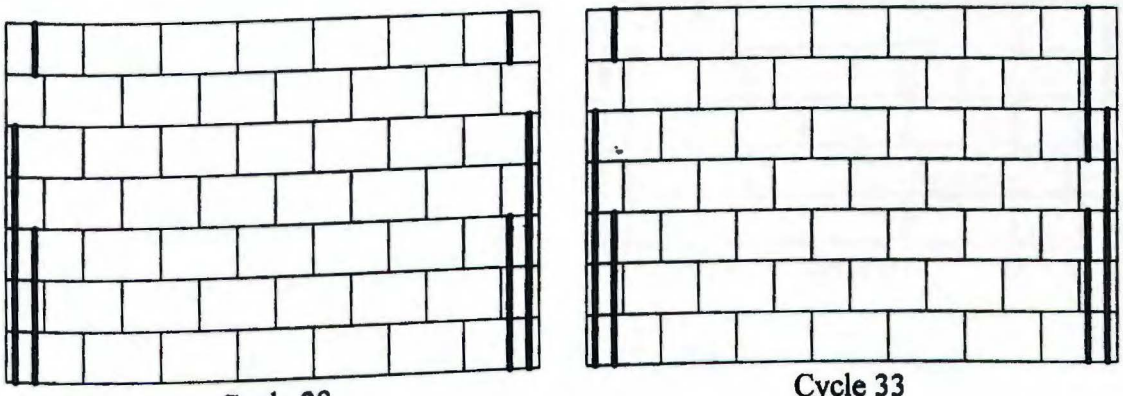
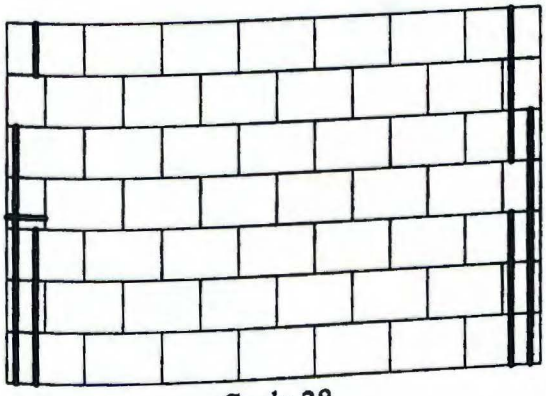


Figure 4.18 Influence of Horizontal Reinforcement Ratio on Ultimate Shear Stress





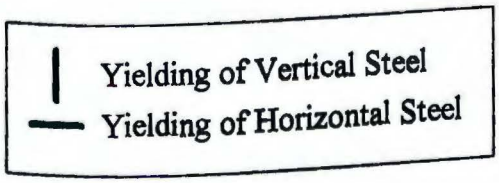


Figure 4.19 FEM/I Steel Reinforcement Yield Pattern for Wall 1

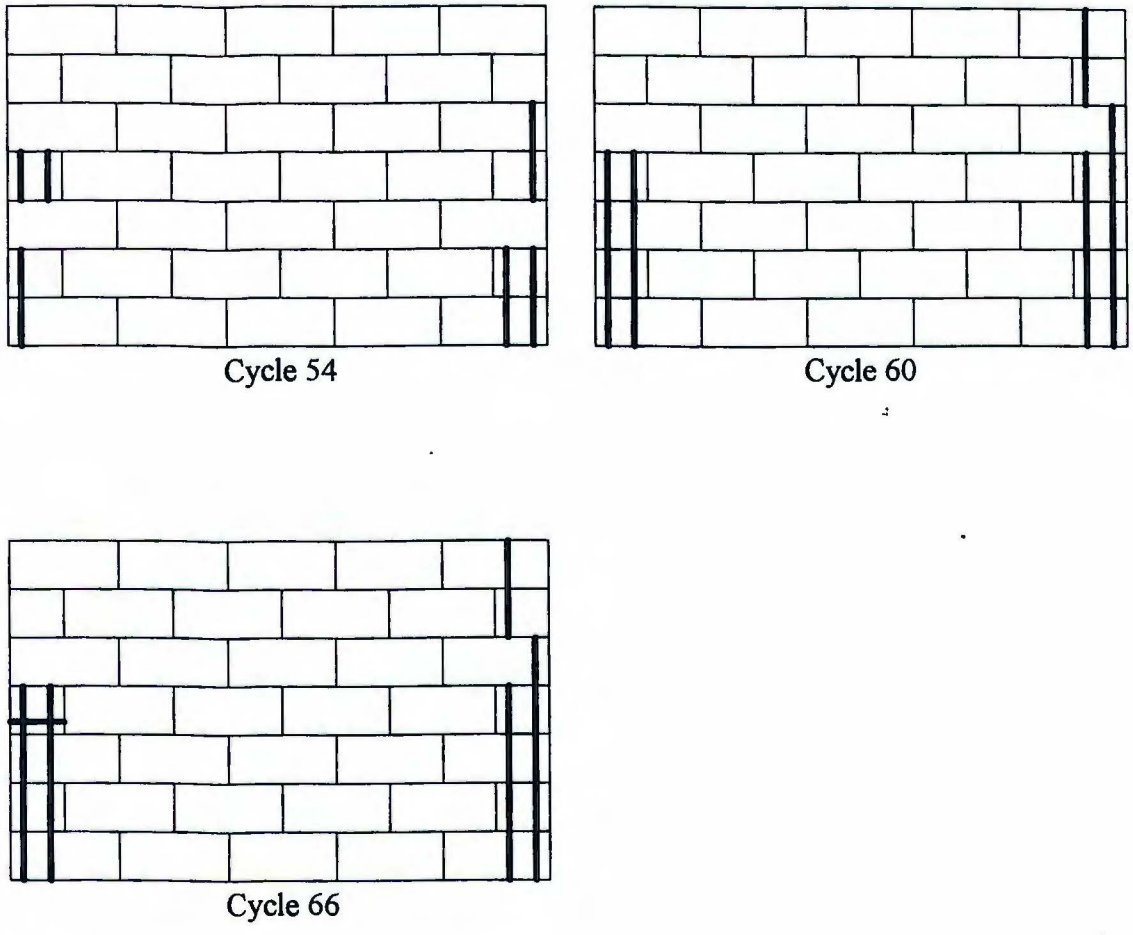
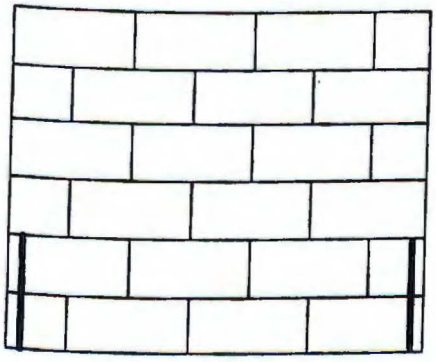
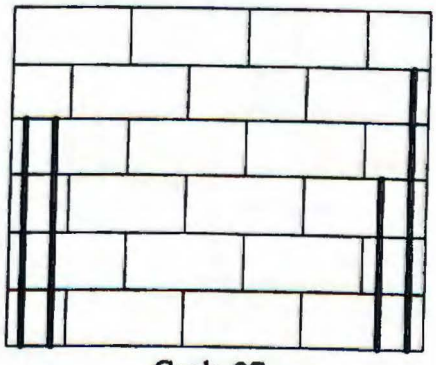


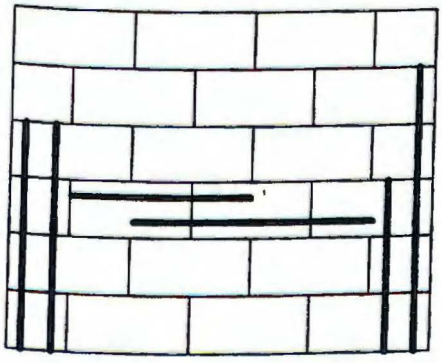
Figure 4.20 FEM/I Steel Reinforcement Yield Pattern for Wall 3



Cycle 22



Cycle 27



Cycle 32

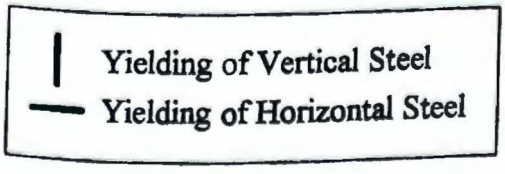
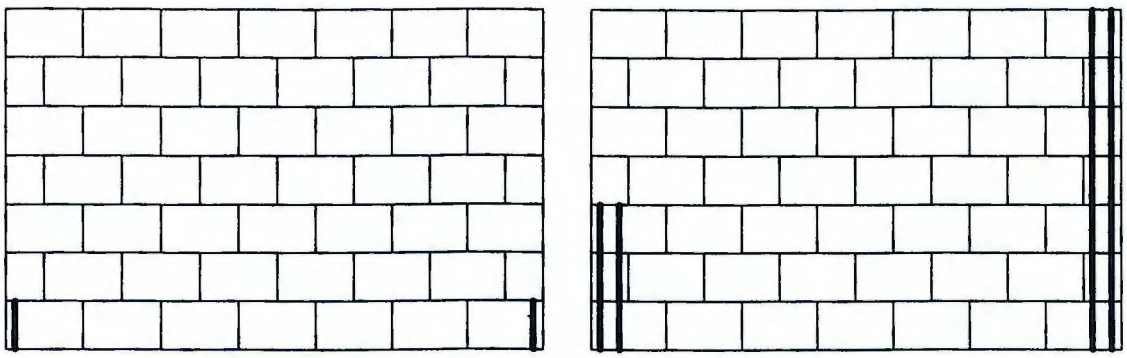


Figure 4.21 FEM/I Steel Reinforcement Yield Pattern for Wall 5



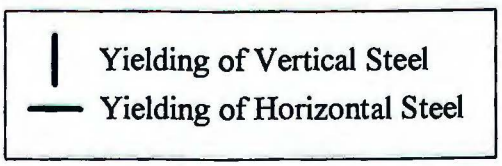
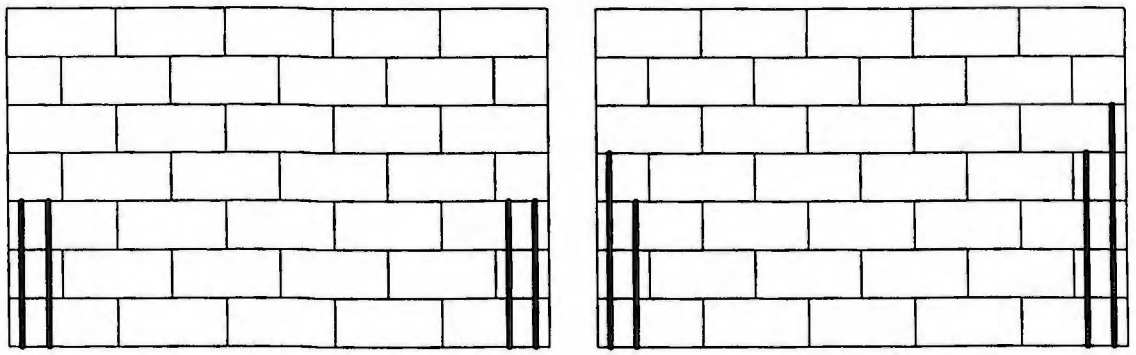


Figure 4.22 FEM/I Steel Reinforcement Yield Pattern for Wall 7



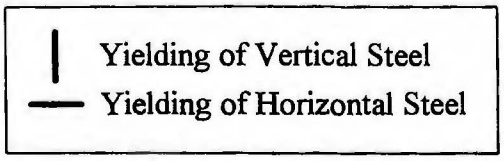
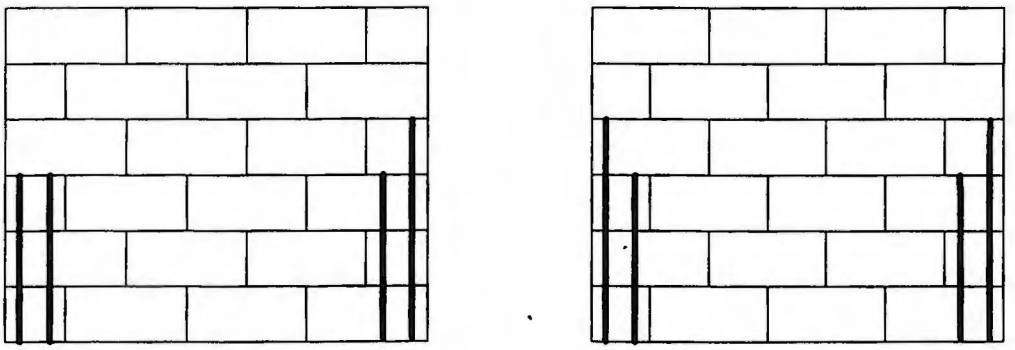


Figure 4.23 FEM/I Steel Reinforcement Yield Pattern for Wall 9



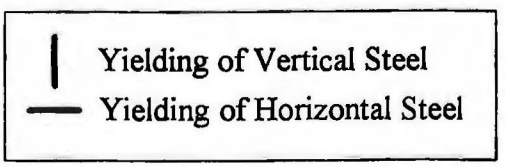


Figure 4.24 FEM/I Steel Reinforcement Yield Pattern for Wall 11

Figure 4.25 Vertical Strain for Wall 3 (West-Bottom Location)

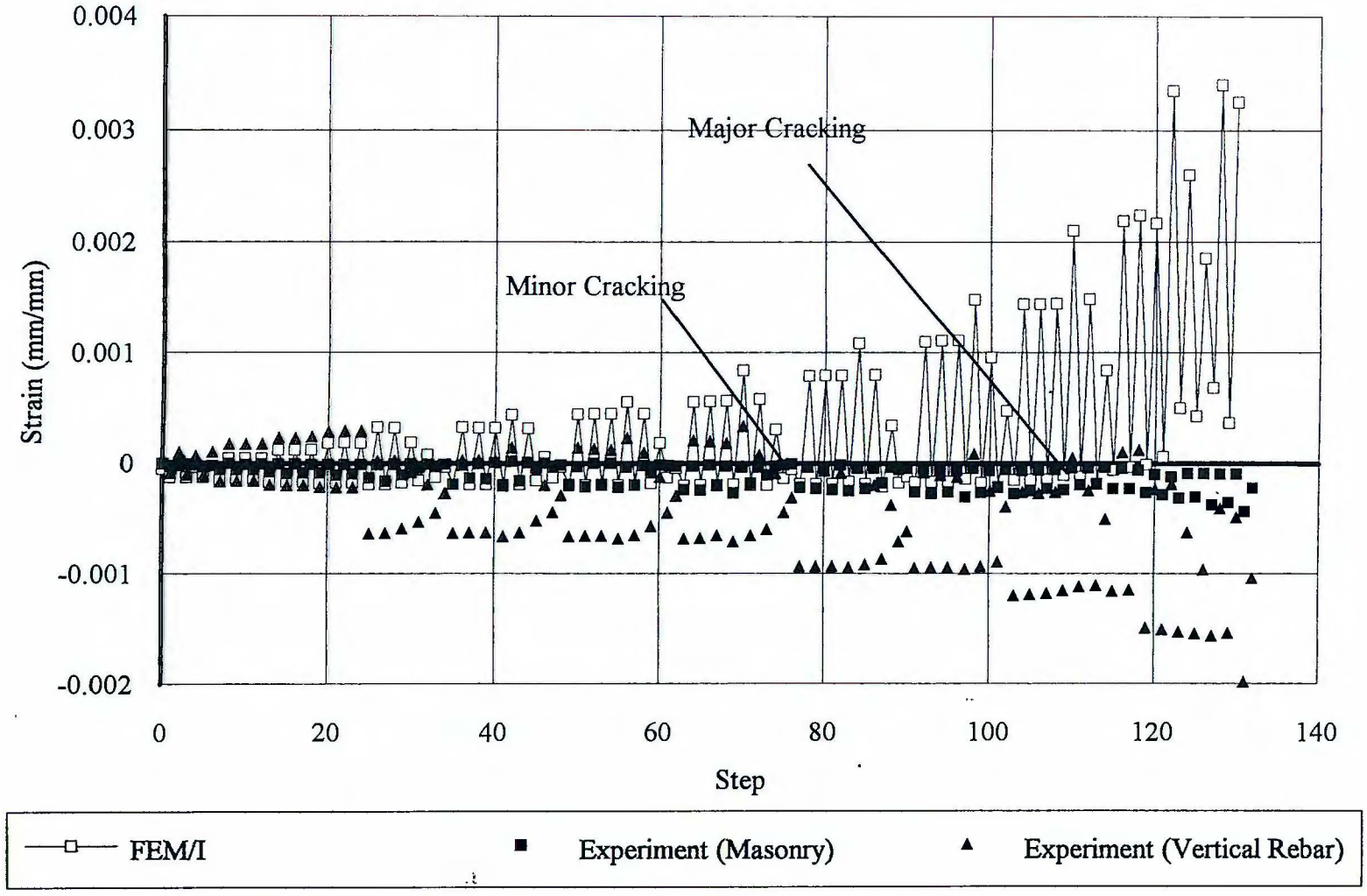


Figure 4.26 Vertical Strain for Wall 3 (West-Top Location)

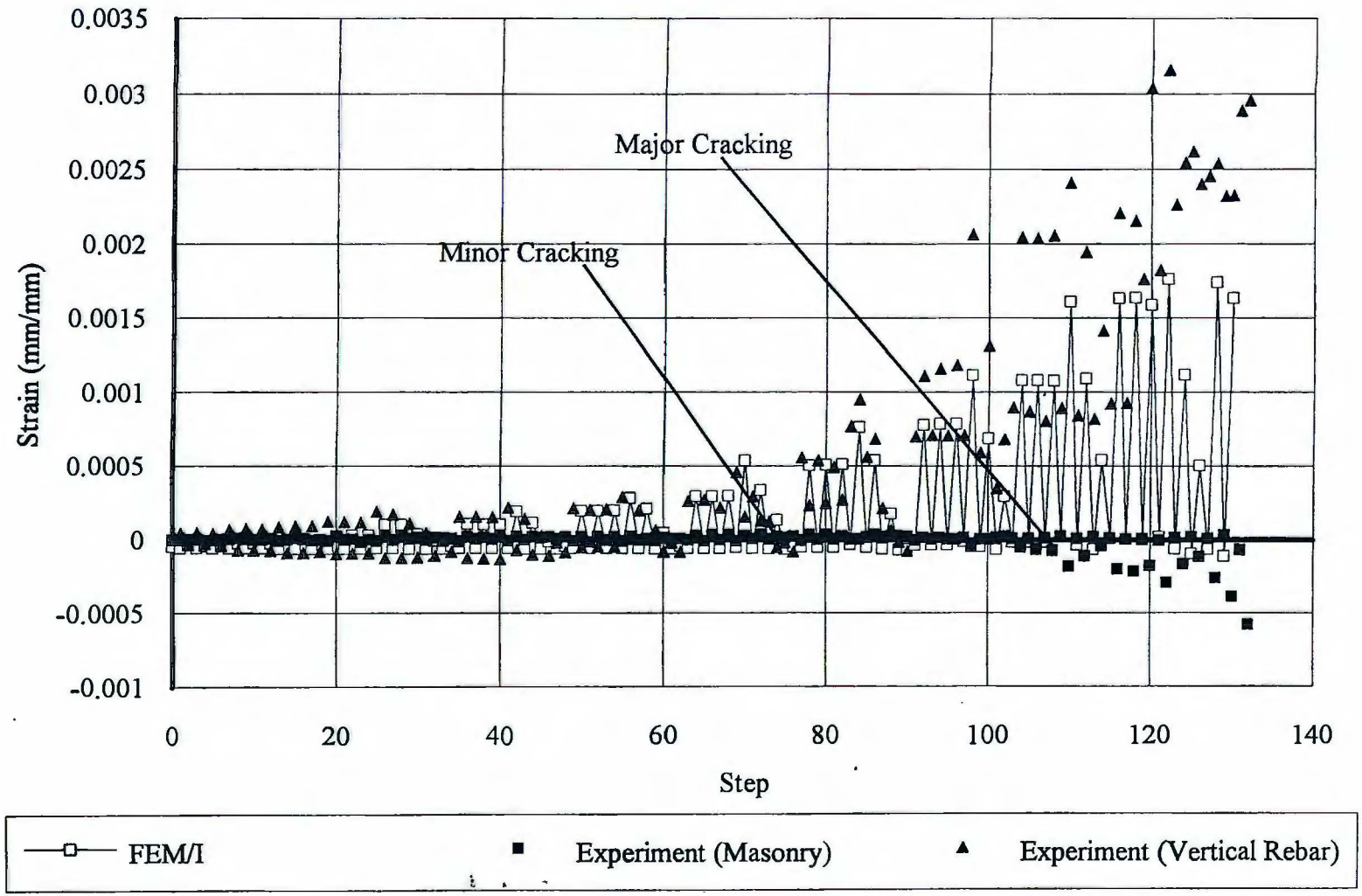


Figure 4.27 Horizontal Rebar Strain for Wall 3 (Middle Location)

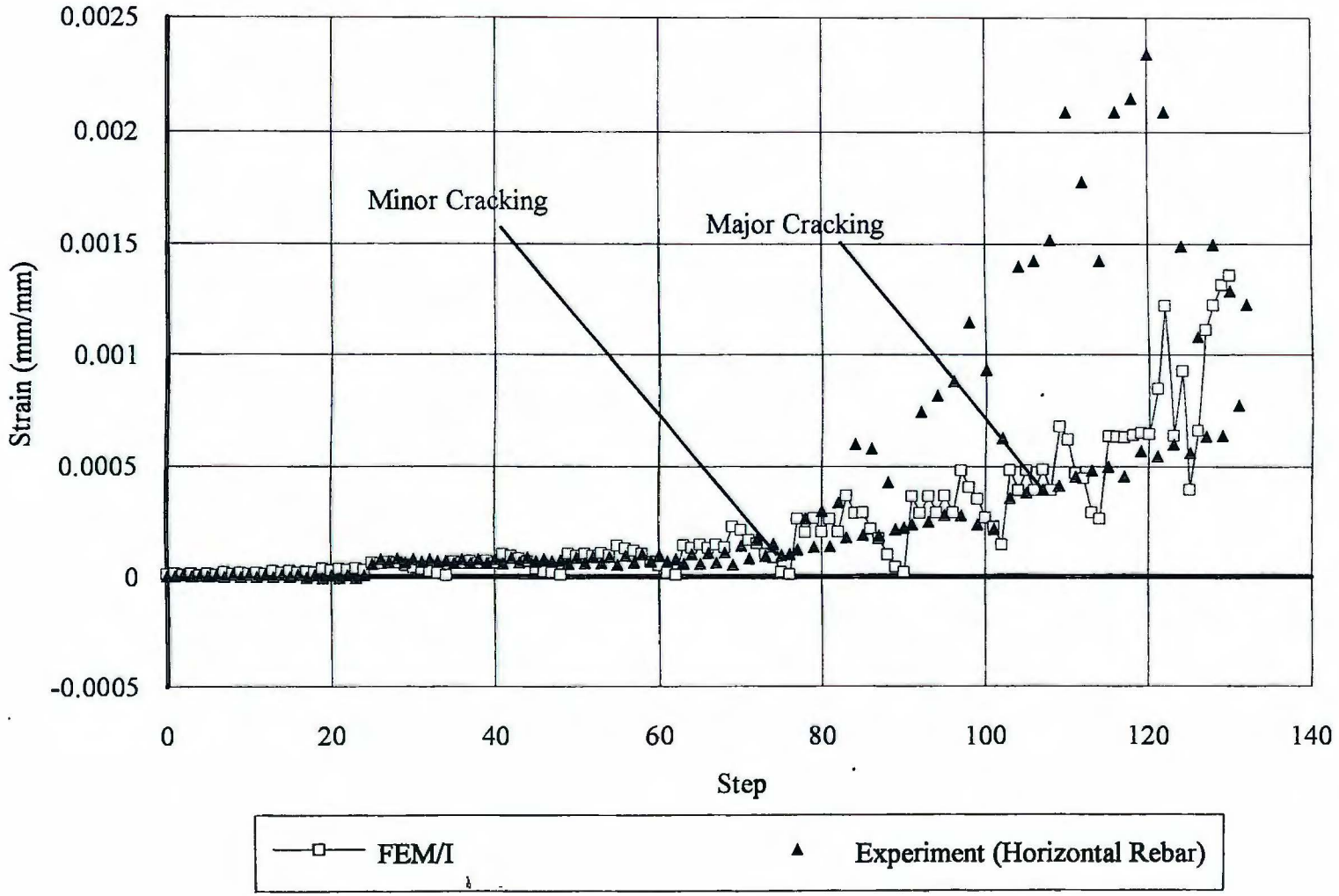


Figure 4.28 Vertical Strain Wall 9 (West-Bottom Location)

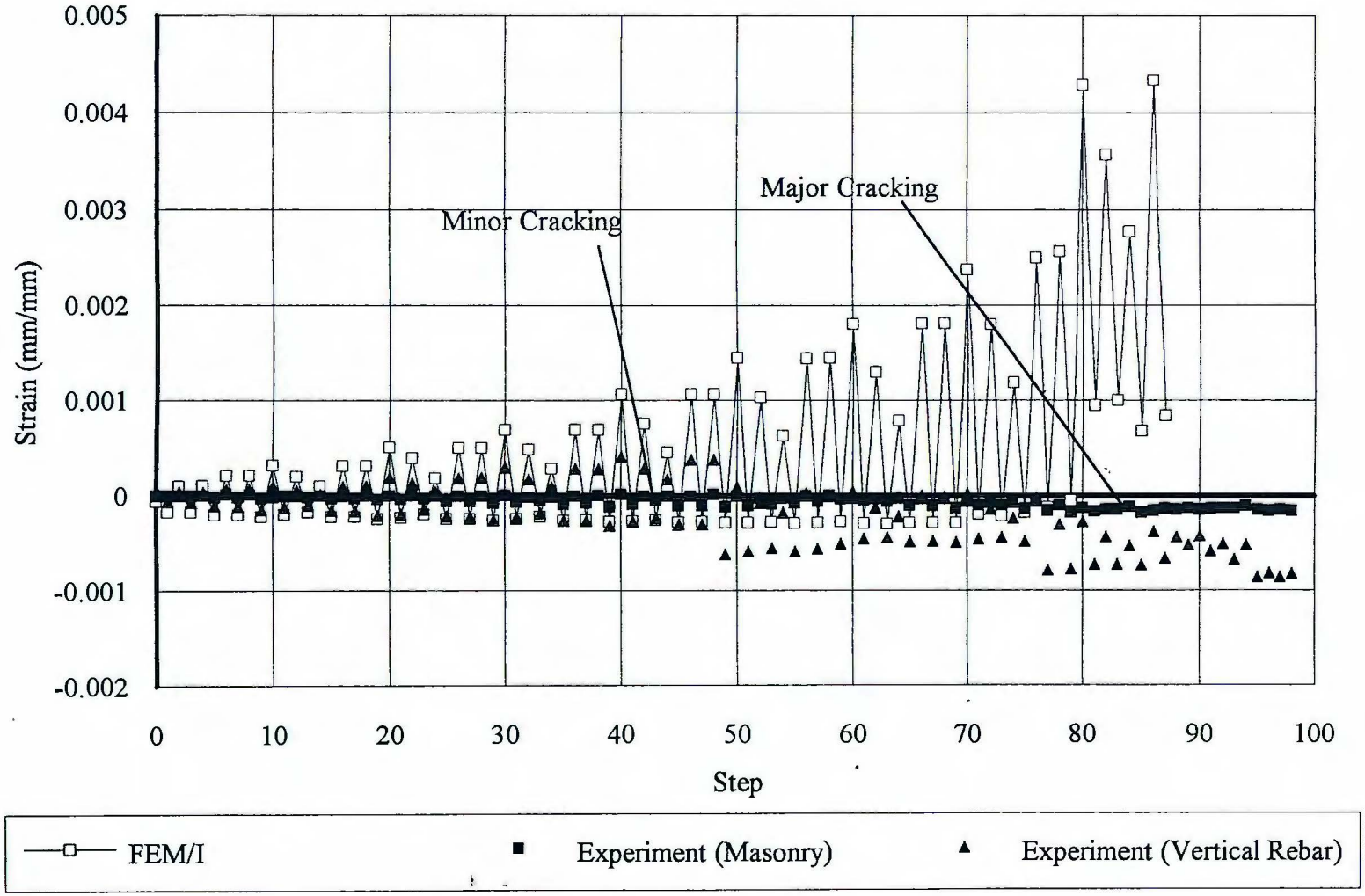


Figure 4.29 Vertical Strain for Wall 9 (West-Top Location)

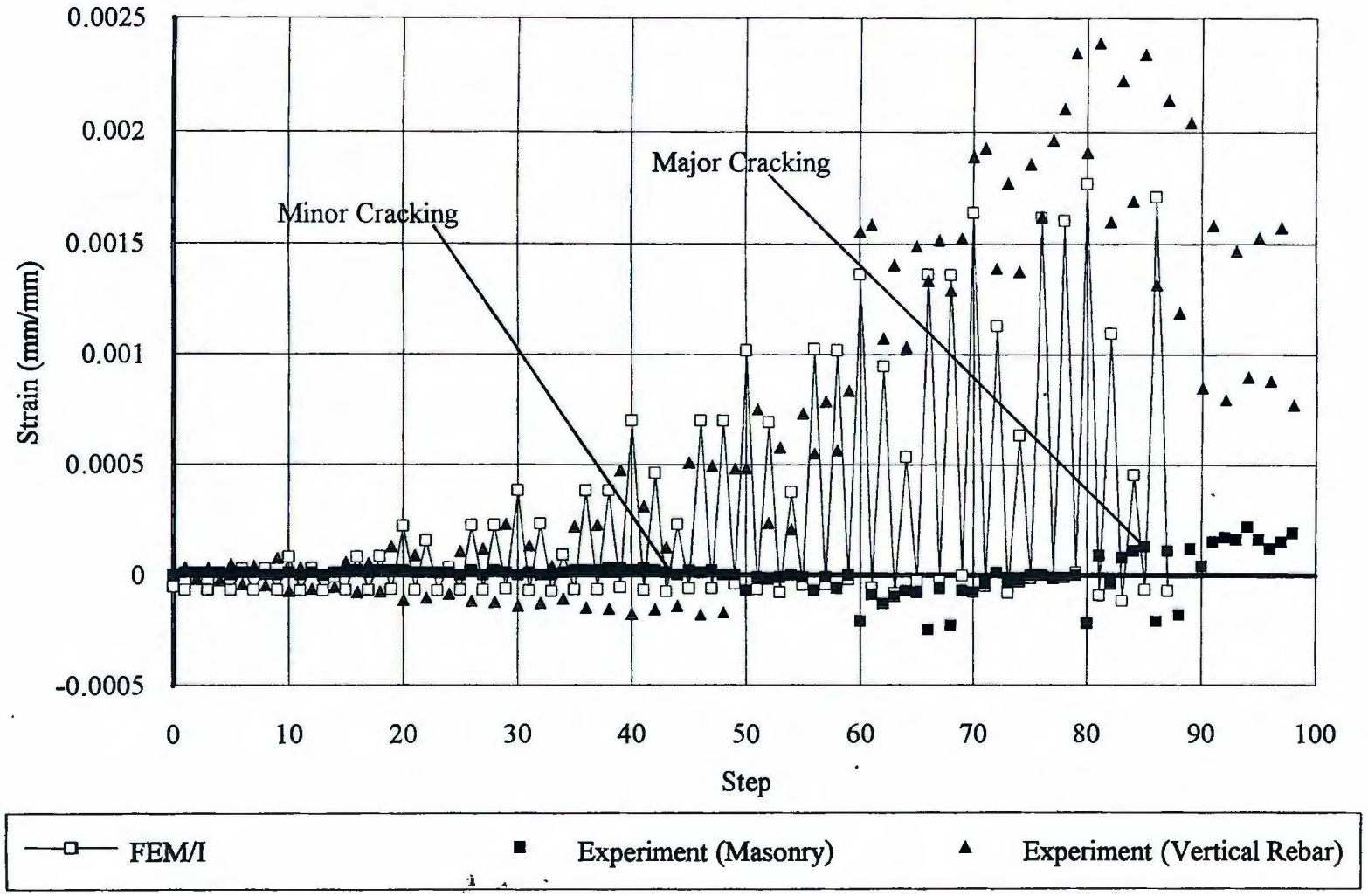


Figure 4.30 Horizontal Rebar Strain for Wall 9 (Middle Location)

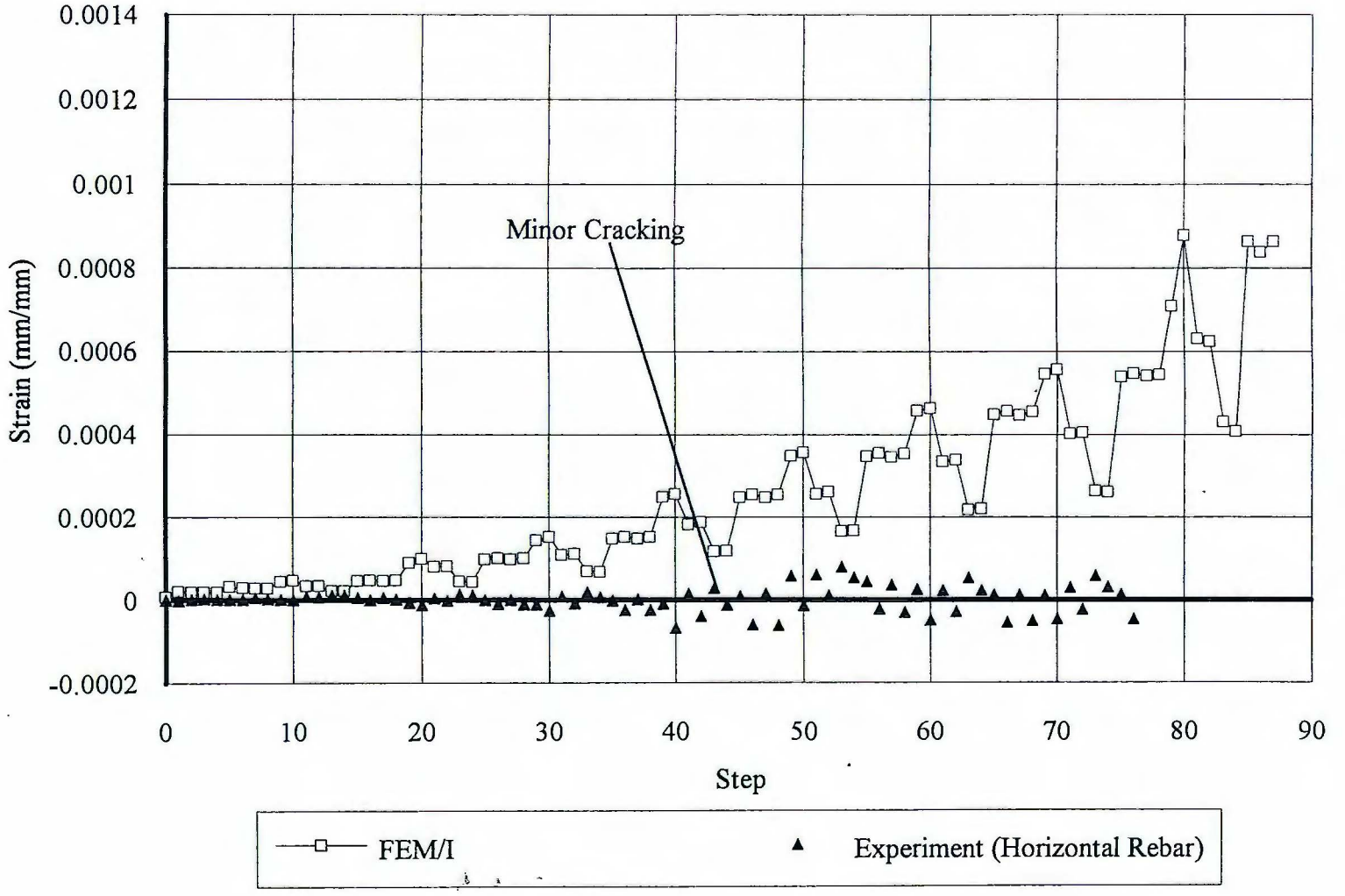


Table 1.1

Masonry Wall Specimen Details

Specimen		Aspect Ratio	Vertical Reinforcement		Horizontal Reinforcement	
Wall #	**Dimensions mm (inches)**	**(H/L)**	**Bar Combination**	**Ratio (%)**	**Bar Combination**	**Ratio (%)**
1	2845 x 1422 (112 x 56)	r_1= 0.5	4-#6	ρ_{v1}= 0.21	2-#3	ρ_{h1}= 0.05
3	2032 x 1422 (80 x 56)	r_2= 0.7	4-#6	ρ_{v2}= 0.29	2-#3	ρ_{h1}= 0.05
5	1422 x 1422 (56 x 56)	r_3= 1.0	4-#6	ρ_{v3}= 0.41	2-#3	ρ_{h1}= 0.05
7	2845 x 1422 (112 x 56)	r_1= 0.5	4-#6	ρ_{v1}= 0.21	1-#4 & 1-#5	ρ_{h2}= 0.12
9	2032 x 1422 (80 x 56)	r_2= 0.7	4-#6	ρ_{v2}= 0.29	1-#4 & 1-#5	ρ_{h2}= 0.12
11	1422 x 1422 (56 x 56)	r_3= 1.0	4-#6	ρ_{v3}= 0.41	1-#4 & 1-#5	ρ_{h2}= 0.12

Table 1.2

Material Test Results for Masonry Shear Wall Specimens

Type of Prism	Wall No.	Date Tested	Compression Strength MPa (psi)	
			individual	average
grouted	1	3/1/95	18.70 (2710)	21.04 (3050)
		3/1/95	23.39 (3390)	
	3	1/26/95	20.63 (2990)	22.49 (3260)
		1/27/95	24.36 (3530)	
	5	3/20/95	19.18 (2780)	19.53 (2830)
		3/20/95	19.87 (2880)	
	7	4/11/95	16.08 (2330)	20.42 (2960)
		4/11/95	24.77 (3590)	
	9	5/12/95	17.66 (2560)	18.28 (2650)
		5/12/95	18.84 (2730)	
	11	4/27/95	16.63 (2410)	19.11 (2770)
		4/27/95	21.60 (3130)	
ungrouted	1	3/1/95	19.73 (2860)	19.60 (2840)
		3/1/95	19.39 (2810)	
	3	1/27/95	18.35 (2660)	18.42 (2670)
		1/27/95	18.49 (2680)	
	5	3/20/95	22.08 (3200)	20.63 (2990)
		3/20/95	19.11 (2770)	
	7	4/11/95	16.49 (2390)	16.22 (2350)
		4/11/95	16.01 (2320)	
	9	5/12/95	19.25 (2790)	18.07 (2620)
		5/12/95	16.84 (2440)	
	11	4/27/95	20.84 (3020)	19.66 (2850)
		4/27/95	18.56 (2690)	

Table 1.3

Vertical Stress on Masonry Shear Wall Specimens

Wall No.	Vertical Stress (MPa)	
	Mean (MPa)	Standard Deviation (MPa)
1	1.38	0.07
3	1.38	0.06
5	1.38	0.05
7	1.38	0.03
9	1.28	0.04
11	1.36	0.06

Table 4.1
Summary of Experimental and FEM/I Analysis

Wall #	Lateral Load of FEM/I @ FME of Experiment / Lateral Load of Experiment @ FME of Experiment	Peak Lateral Load of FEM/I / Peak Lateral Load of Experiment
1	1.8	2.8
3	1.0	1.4
5	1.0	1.7
7	1.3	2.1
9	1.1	1.8
11	0.9	1.2

Lateral load values are the average of both loading directions

Wall #	Accumulated Energy from FEM/I up to FME / Accumulated Energy from Experiment up to FME	Total Energy from FEM/I / Total Energy from Experiment	Deformation Capacity of Experiment (mm)	Deformation Capacity of FEM/I (mm)
1	0.45	0.51	13.61[1]	5.84
3	0.21	0.06	5.46	6.46
5	0.33	0.15	5.00	9.25
7	0.64	0.19	9.98	5.66
9	0.62	0.16	4.70	6.10[2]
11	0.44	0.21	5.21	4.57[2]

[1]Deformation capacity was not reached, peak displacement shown
[2]Deformation capacity was not reached due to convergence criteria not met, peak displacement is shown

Wall #	Occurrence of Vertical Rebar Yielding in Experiment	Occurrence of Vertical Rebar Yielding in FEM/I	Occurrence of Horizontal Rebar Yielding in Experiment	Occurrence of Horizontal Rebar Yielding in FEM/I
1	Cycle 28	Cycle 28	No Yielding	Cycle 38
3	Cycle 60	Cycle 54	Cycle 54	Cycle 66
5	Cycle 24	Cycle 22	No Yielding	Cycle 32
7	Cycle 33	Cycle 23	No Yielding	No Yielding
9	Cycle 30	Cycle 35	No Yielding	No Yielding
11	Cycle 23	Cycle 28	No Yielding	No Yielding

Appendix B
Input Description for Wall 1

Card Group 1

Program Execution

Card Group 2

Problem Title

Card Group 3

NVFIX = 34 17 nodes have pinned boundary conditions and 17 nodes have prescribed displacements.

NNODE = 4 The nonlinear element have 4 nodes

NMATS = 1 - Concrete with horizontal and vertical reinforcement
2 - Concrete with horizontal reinforcement
3 - Grouted masonry with vertical reinforcement
4 - Ungrouted masonry
5 - Grouted masonry with horizontal and vertical reinforcement
6 - Grouted masonry with horizontal reinforcement

Card Group 4

Elements 2, 16, 18, 32, 132, 145, 147 and 191 have material property 1. Elements 1, 3 - 14, 16, 17, 19-30, 32, 131, 133 - 144, 146, 147, 149 - 160 and 162 have material property 2. Elements 33, 46, 47, 60, 61, 88, 89, 102, 103, 116, 117 and 130 have material property 3. Elements 34 - 45, 49 - 59, 52 - 73, 90 - 101, 104 - 115 and 118 - 129 have material property 4. Elements 75 and 98 have material property 5. Elements 76 - 97 have material property 6.

Specifying the element nodal connectivity numbers by starting at the same corner of each element (lower left hand corner in this case) guarantees that the Gauss points of all of the elements will be located in the same relative position. This is invaluable in the interpretation of the element stresses and strains.

Card Group 6

Nodal points 176 through 192 have prescribed displacement in the x direction and are free to translate in the y-direction. Therefore, the constraint code IFPRE is 10. Although any value of the x-component of the prescribed displacement PRESC(1) has been arbitrarily set to 1.0 so that the values given for FACTD in Card Group 18 are the actual displacements to be attained in the given load step. A positive displacement indicates that the displacement acts to the right.

Card Group 7

Material Properties

Concrete with Horizontal and Vertical Reinforcement		
ν	0.20	
f_c	5	ksi
ε_o	0.003	
A_1	2	
A_2	2	
A_3	0.1	
A_4	0.6	
MCD	1	
f_{cr}	0.504	ksi
E_t	3067	ksi
MTS	3	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	3.16	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.00423	
$^{**}\rho_h$	0.00760	
f_{yv}	60	ksi
f_{yh}	60	ksi

Concrete with Horizontal Reinforcement		
ν	0.20	
f_c	5	ksi
ε_o	0.003	
A_1	2	
A_2	2	
A_3	0.1	
A_4	0.6	
MCD	1	
f_{cr}	0.504	ksi
E_t	3067	ksi
MTS	3	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	3.16	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0.00760	
f_{yv}	0	ksi
f_{yh}	60	ksi

Grouted Masonry with Vertical Reinforcement		
ν	0.16	
f_m	3.05	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1678	ksi
MTS	2	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.01443	
$^{**}\rho_h$	0	
f_{yv}	60	ksi
f_{yh}	0	ksi

Ungrouted Masonry Unreinforced		
ν	0.16	
f_m	2.84	ksi
ε_o	0.0022	
A_1	1.7	
A_2	1.35	
A_3	0.11	
A_4	1.4	
MCD	1	
f_{cr}	0.05	ksi
E_t	1562	ksi
MTS	1	
B_1	0.5	
α	0.25	
E_s	0	ksi
ξ	0 %	
A_{sh}	0	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0	
f_{yv}	0	ksi
f_{yh}	0	ksi

Grouted Masonry with Horizontal and Vertical Reinforcement		
ν	0.16	
f_m	3.05	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1678	ksi
MTS	2	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0.22	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.01443	
$^{**}\rho_h$	0.00361	
f_{yv}	60	ksi
f_{yh}	60	ksi

Grouted Masonry with Horizontal Reinforcement		
ν	0.16	
f_m	3.05	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1678	ksi
MTS	1	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0.22	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0.00361	
f_{yv}	0	ksi
f_{yh}	60	ksi

* Vertical reinforcement ratios are calculated using the following equation:

$$\frac{\text{Area of vertical reinforcement}}{(\text{width of cell containing reinforcement})(\text{thickness of masonry wall})}$$

** Horizontal reinforcement ratios are calculated using the following equation:

$$\frac{\text{Area of horizontal reinforcement}}{(\text{width of cell containing reinforcement})(\text{thickness of masonry wall})}$$

Card Group 8

Not required - no initial stress

Card Group 9

NUMFDF = 17 To facilitate the interpretation off the output the sum of the reactions at 17 nodal points (NODE 1 = 176, NODE 2 = 177, NODE 3 = 178, ... NODE

17 = 192), i.e. the nodes with prescribed displacement will be directed to the Force-Deflection file along with the prescribed displacements at 1 nodal point (NODE1 = 176).

KOMPNT = 1 The x-component of the 17 reaction and the 1 displacement are to be output to the Force-Deflection file generated by FEM/I.

Card Group 10
Element Output Data

Card Group 11
Node Output Data

Card Group 12
Load Title

Card Group 13
Load Control Data

Card Group 14
Not required - no nodal point loading

Card Group 15
Not required - no gravity loading

Card Group 16
NEDGE = 14 Vertical axial pressure load applied to the top edge of elements 117 through 130.

Card Group 17
NOPRS(1) and NOPRS(2) - Specify the nodal points for each loaded element in a counterclockwise sequence. PRES(1,1) and PRES(2,1) - The normal load on an element is specified as a force per unit length (200 psi x 2.68 inch thickness = 0.536 kips per inch). A positive value indicates that the load acts downward (i.e. into the element).

Card Group 18
The load increment controls will generate 765 load/displacements increments. The convergence tolerance TOLER and maximum number of iterations MITER are set to 5% and 150, respectively, for all increments.

The first card (FACTE = 1.0, FACTD = 0.0, and NDIV = 1) will generate 1 increment where all of the vertical axial load is applied in the 1st increment (FACTE = 1.0) before any horizontal prescribed displacements are applied (FACTD = 0.0). In the remaining increments the vertical axial load is held constant (FACT = 1.0) and the horizontal prescribed displacements are applied in variable increments

The second card (FACTD = -0.014 and NDIV = 4) will generate 4 increments to move from the previous displacement of 0.0 inches to -0.014 inches with dx = -0.014/4 = -0.0035 inches.

The third card (FACTD = 0.014 and NDIV = 4) will generate 4 increments to move from the previous displacement of -0.014 to 0.014 inches with dx = (0.014 - (-0.0140)) /4 = 0.007 inches.

The remaining cards generate increments in a similar manner. The load increment control data is terminated when NDIV = -1.

Input Data File for Wall 1

START ---------- Card 1
"Wall #1 - W1.Inp, Mesh 1,Entire Cycle, Nominal Properties, in-kips" ---------- Card 2
192 162 34 1 4 6 0 0 0 ---------- Card 3
1 2 1 2 19 18 ---------- Card 4
2 1 2 3 20 19
3 2 3 4 21 20
4 2 4 5 22 21
5 2 5 6 23 22
6 2 6 7 24 23
7 2 7 8 25 24
8 2 8 9 26 25
9 2 9 10 27 26
10 2 10 11 28 27
11 2 11 12 29 28
12 2 12 13 30 29
13 2 13 14 31 30
14 2 14 15 32 31
15 1 15 16 33 32
16 2 16 17 34 33
17 2 18 19 36 35
18 1 19 20 37 36
19 2 20 21 38 37
20 2 21 22 39 38
21 2 22 23 40 39
22 2 23 24 41 40
23 2 24 25 42 41
24 2 25 26 43 42
25 2 26 27 44 43
26 2 27 28 45 44
27 2 28 29 46 45
28 2 29 30 47 46
29 2 30 31 48 47
30 2 31 32 49 48
31 1 32 33 50 49
32 2 33 34 51 50
33 3 36 37 53 52
34 4 37 38 54 53
35 4 38 39 55 54
36 4 39 40 56 55
37 4 40 41 57 56
38 4 41 42 58 57
39 4 42 43 59 58
40 4 43 44 60 59

41	4	44	45	61	60
42	4	45	46	62	61
43	4	46	47	63	62
44	4	47	48	64	63
45	4	48	49	65	64
46	3	49	50	66	65
47	3	52	53	68	67
48	4	53	54	69	68
49	4	54	55	70	69
50	4	55	56	71	70
51	4	56	57	72	71
52	4	57	58	73	72
53	4	58	59	74	73
54	4	59	60	75	74
55	4	60	61	76	75
56	4	61	62	77	76
57	4	62	63	78	77
58	4	63	64	79	78
59	4	64	65	80	79
60	3	65	66	81	80
61	3	67	68	83	82
62	4	68	69	84	83
63	4	69	70	85	84
64	4	70	71	86	85
65	4	71	72	87	86
66	4	72	73	88	87
67	4	73	74	89	88
68	4	74	75	90	89
69	4	75	76	91	90
70	4	76	77	92	91
71	4	77	78	93	92
72	4	78	79	94	93
73	4	79	80	95	94
74	3	80	81	96	95
75	5	82	83	98	97
76	6	83	84	99	98
77	6	84	85	100	99
78	6	85	86	101	100
79	6	86	87	102	101
80	6	87	88	103	102
81	6	88	89	104	103
82	6	89	90	105	104
83	6	90	91	106	105
84	6	91	92	107	106
85	6	92	93	108	107

86	6	93	94	109	108
87	6	94	95	110	109
88	5	95	96	111	110
89	3	97	98	113	112
90	4	98	99	114	113
91	4	99	100	115	114
92	4	100	101	116	115
93	4	101	102	117	116
94	4	102	103	118	117
95	4	103	104	119	118
96	4	104	105	120	119
97	4	105	106	121	120
98	4	106	107	122	121
99	4	107	108	123	122
100	4	108	109	124	123
101	4	109	110	125	124
102	3	110	111	126	125
103	3	112	113	128	127
104	4	113	114	129	128
105	4	114	115	130	129
106	4	115	116	131	130
107	4	116	117	132	131
108	4	117	118	133	132
109	4	118	119	134	133
110	4	119	120	135	134
111	4	120	121	136	135
112	4	121	122	137	136
113	4	122	123	138	137
114	4	123	124	139	138
115	4	124	125	140	139
116	3	125	126	141	140
117	3	127	128	144	143
118	4	128	129	145	144
119	4	129	130	146	145
120	4	130	131	147	146
121	4	131	132	148	147
122	4	132	133	149	148
123	4	133	134	150	149
124	4	134	135	151	150
125	4	135	136	152	151
126	4	136	137	153	152
127	4	137	138	154	153
128	4	138	139	155	154
129	4	139	140	156	155
130	3	140	141	157	156

131	2	142	143	160	159
132	1	143	144	161	160
133	2	144	145	162	161
134	2	145	146	163	162
135	2	146	147	164	163
136	2	147	148	165	164
137	2	148	149	166	165
138	2	149	150	167	166
139	2	150	151	168	167
140	2	151	152	169	168
141	2	152	153	170	169
142	2	153	154	171	170
143	2	154	155	172	171
144	2	155	156	173	172
145	1	156	157	174	173
146	2	157	158	175	174
147	2	159	160	177	176
148	1	160	161	178	177
149	2	161	162	179	178
150	2	162	163	180	179
151	2	163	164	181	180
152	2	164	165	182	181
153	2	165	166	183	182
154	2	166	167	184	183
155	2	167	168	185	184
156	2	168	169	186	185
157	2	169	170	187	186
158	2	170	171	188	187
159	2	171	172	189	188
160	2	172	173	190	189
161	1	173	174	191	190
162	2	174	175	192	191

1	-60	-16 ----------Card 5
2	-56	-16
3	-48	-16
4	-40	-16
5	-32	-16
6	-24	-16
7	-16	-16
8	-8	-16
9	0	-16
10	8	-16
11	16	-16
12	24	-16
13	32	-16

14	40	-16
15	48	-16
16	56	-16
17	60	-16
18	-60	-8
19	-56	-8
20	-48	-8
21	-40	-8
22	-32	-8
23	-24	-8
24	-16	-8
25	-8	-8
26	0	-8
27	8	-8
28	16	-8
29	24	-8
30	32	-8
31	40	-8
32	48	-8
33	56	-8
34	60	-8
35	-60	0
36	-56	0
37	-48	0
38	-40	0
39	-32	0
40	-24	0
41	-16	0
42	-8	0
43	0	0
44	8	0
45	16	0
46	24	0
47	32	0
48	40	0
49	48	0
50	56	0
51	60	0
52	-56	8
53	-48	8
54	-40	8
55	-32	8
56	-24	8
57	-16	8
58	-8	8

59	0	8
60	8	8
61	16	8
62	24	8
63	32	8
64	40	8
65	48	8
66	56	8
67	-56	16
68	-48	16
69	-40	16
70	-32	16
71	-24	16
72	-16	16
73	-8	16
74	0	16
75	8	16
76	16	16
77	24	16
78	32	16
79	40	16
80	48	16
81	56	16
82	-56	24
83	-48	24
84	-40	24
85	-32	24
86	-24	24
87	-16	24
88	-8	24
89	0	24
90	8	24
91	16	24
92	24	24
93	32	24
94	40	24
95	48	24
96	56	24
97	-56	32
98	-48	32
99	-40	32
100	-32	32
101	-24	32
102	-16	32
103	-8	32

104	0	32
105	8	32
106	16	32
107	24	32
108	32	32
109	40	32
110	48	32
111	56	32
112	-56	40
113	-48	40
114	-40	40
115	-32	40
116	-24	40
117	-16	40
118	-8	40
119	0	40
120	8	40
121	16	40
122	24	40
123	32	40
124	40	40
125	48	40
126	56	40
127	-56	48
128	-48	48
129	-40	48
130	-32	48
131	-24	48
132	-16	48
133	-8	48
134	0	48
135	8	48
136	16	48
137	24	48
138	32	48
139	40	48
140	48	48
141	56	48
142	-60	56
143	-56	56
144	-48	56
145	-40	56
146	-32	56
147	-24	56
148	-16	56

149	-8	56
150	0	56
151	8	56
152	16	56
153	24	56
154	32	56
155	40	56
156	48	56
157	56	56
158	60	56
159	-60	64
160	-56	64
161	-48	64
162	-40	64
163	-32	64
164	-24	64
165	-16	64
166	-8	64
167	0	64
168	8	64
169	16	64
170	24	64
171	32	64
172	40	64
173	48	64
174	56	64
175	60	64
176	-60	72
177	-56	72
178	-48	72
179	-40	72
180	-32	72
181	-24	72
182	-16	72
183	-8	72
184	0	72
185	8	72
186	16	72
187	24	72
188	32	72
189	40	72
190	48	72
191	56	72
192	60	72
1	11	0

0 ---------- Card 6

```
2       11      0       0
3       11      0       0
4       11      0       0
5       11      0       0
6       11      0       0
7       11      0       0
8       11      0       0
9       11      0       0
10      11      0       0
11      11      0       0
12      11      0       0
13      11      0       0
14      11      0       0
15      11      0       0
16      11      0       0
17      11      0       0
176     10      1       0
177     10      1       0
178     10      1       0
179     10      1       0
180     10      1       0
181     10      1       0
182     10      1       0
183     10      1       0
184     10      1       0
185     10      1       0
186     10      1       0
187     10      1       0
188     10      1       0
189     10      1       0
190     10      1       0
191     10      1       0
192     10      1       0
1       'Concrete with Horizontal and Vertical Reinforcement' ---------- Card 7
0.2     26      0       1
5       0.003   2       2       0.1     0.6     1
0.504   3067    3       0.5     0.25
29000   0.02    0.00423         0.0076  60      60
2       'Concrete with Horizontal Reinforcement'
0.2     26      0       1
5       0.003   2       2       0.1     0.6     1
0.504   3067    3       0.5     0.25
29000   0.02    0       0.0076  0       60
3       'Grouted Masonry with Vertical Reinforcement'
0.16    7.625   0       1
```

```
3.05    0.0022 1.9     1.3     0.14    0.165   1
0.05    1678   2       0.5     0.25
29000   0.02   0.01443         0       60      0
4       'Ungrouted Masonry'
0.16    2.68   0       1
2.84    0.0022 1.7     1.35    0.11    1.4     1
0.05    1562   1       0       0
0       0      0       0       0       0
5       'Grouted Masonry with Horizontal and Vertical Reinforcement'
0.16    7.625  0       1
3.05    0.0022 1.9     1.3     0.14    0.165   1
0.05    1678   2       0.5     0.25
29000   0.02   0.01443         0.00361         60      60
6       'Grouted Masonry with Horizontal Reinforcement'
0.16    7.625  0       1
3.05    0.0022 1.9     1.3     0.14    0.165   1
0.05    1678   2       0.5     0.25
29000   0.02   0       0.00361         0       60
162     17     17 ---------------------------------------------------------------------- Card 9
1       176    177     178     179     180     181
182     183    184     185     186     187     188
189     190    191     192
176     177    178     179     180     181     182 ---------------------------------- Card 11
183     184    185     186     187     188     189
190     191    192
"Wall #1 - W1.Inp, Mesh 1, Entire Cycle,Nominal Properties, in-kips" ---------- Card 12
0       0      1 ---------------------------------------------------------------------- Card 13
14 ---------------------------------------------------------------------------------- Card 16
117     144    143 -------------------------------------------------------------------- Card 17
0.536   0      0.536   0 ------------------------------------------------------------- Card 18
118     145    144
0.536   0      0.536   0
119     146    145
0.536   0      0.536   0
120     147    146
0.536   0      0.536   0
121     148    147
0.536   0      0.536   0
122     149    148
0.536   0      0.536   0
123     150    149
0.536   0      0.536   0
124     151    150
0.536   0      0.536   0
125     152    151
```

```
0.536  0      0.536  0
126    153    152
0.536  0      0.536  0
127    154    153
0.536  0      0.536  0
128    155    154
0.536  0      0.536  0
129    156    155
0.536  0      0.536  0
130    157    156
0.536  0      0.536  0
1      0      0      1      0
5      150    2      2      0      0
4      0      0      1      -0.014
5      150    2      2      0      0
4      0      0      1      0.014
5      150    2      2      0      0
4      0      0      1      -0.014
5      150    2      2      0      0
4      0      0      1      0.014
5      150    2      2      0      0
4      0      0      1      -0.014
5      150    2      2      0      0
4      0      0      1      0.014
5      150    2      2      0      0
4      0      0      1      -0.021
5      150    2      2      0      0
4      0      0      1      0.021
5      150    2      2      0      0
4      0      0      1      -0.021
5      150    2      2      0      0
4      0      0      1      0.021
5      150    2      2      0      0
4      0      0      1      -0.021
5      150    2      2      0      0
4      0      0      1      0.021
5      150    2      2      0      0
4      0      0      1      -0.028
5      150    2      2      0      0
4      0      0      1      0.028
5      150    2      2      0      0
4      0      0      1      -0.028
5      150    2      2      0      0
8      0      0      1      0.033
5      150    2      2      0      0
```

8	0	0	1	-0.023	
5	150	2	2	0	0
8	0	0	1	0.033	
5	150	2	2	0	0
8	0	0	1	-0.037	
5	150	2	2	0	0
8	0	0	1	0.047	
5	150	2	2	0	0
8	0	0	1	-0.037	
5	150	2	2	0	0
8	0	0	1	0.047	
5	150	2	2	0	0
8	0	0	1	-0.037	
5	150	2	2	0	0
8	0	0	1	0.047	
5	150	2	2	0	0
8	0	0	1	-0.051	
5	150	2	2	0	0
8	0	0	1	0.061	
5	150	2	2	0	0
8	0	0	1	-0.037	
5	150	2	2	0	0
8	0	0	1	0.047	
5	150	2	2	0	0
8	0	0	1	-0.023	
5	150	2	2	0	0
8	0	0	1	0.033	
5	150	2	2	0	0
8	0	0	1	-0.051	
5	150	2	2	0	0
8	0	0	1	0.061	
5	150	2	2	0	0
8	0	0	1	-0.051	
5	150	2	2	0	0
8	0	0	1	0.061	
5	150	2	2	0	0
8	0	0	1	-0.082	
5	150	2	2	0	0
8	0	0	1	0.092	
5	150	2	2	0	0
8	0	0	1	-0.065	
5	150	2	2	0	0
8	0	0	1	0.075	
5	150	2	2	0	0
8	0	0	1	-0.037	

5	150	2	2	0	0
8	0	0	1	0.047	
5	150	2	2	0	0
8	0	0	1	-0.082	
5	150	2	2	0	0
8	0	0	1	0.092	
5	150	2	2	0	0
8	0	0	1	-0.082	
5	150	2	2	0	0
8	0	0	1	0.092	
5	150	2	2	0	0
8	0	0	1	-0.107	
5	150	2	2	0	0
8	0	0	1	0.117	
5	150	2	2	0	0
8	0	0	1	-0.082	
5	150	2	2	0	0
8	0	0	1	0.092	
5	150	2	2	0	0
8	0	0	1	-0.051	
5	150	2	2	0	0
8	0	0	1	0.061	
5	150	2	2	0	0
8	0	0	1	-0.107	
5	150	2	2	0	0
8	0	0	1	0.117	
5	150	2	2	0	0
8	0	0	1	-0.107	
5	150	2	2	0	0
8	0	0	1	0.117	
5	150	2	2	0	0
8	0	0	1	-0.163	
5	150	2	2	0	0
8	0	0	1	0.173	
5	150	2	2	0	0
8	0	0	1	-0.121	
5	150	2	2	0	0
8	0	0	1	0.131	
5	150	2	2	0	0
8	0	0	1	-0.082	
5	150	2	2	0	0
8	0	0	1	0.092	
5	150	2	2	0	0
8	0	0	1	-0.163	
5	150	2	2	0	0

8	0	0	1	0.173	
5	150	2	2	0	0
8	0	0	1	-0.163	
5	150	2	2	0	0
8	0	0	1	0.173	
5	150	2	2	0	0
8	0	0	1	-0.219	
5	150	2	2	0	0
8	0	0	1	0.229	
5	150	2	2	0	0
8	0	0	1	-0.163	
5	150	2	2	0	0
8	0	0	1	0.173	
5	150	2	2	0	0
8	0	0	1	-0.107	
5	150	2	2	0	0
8	0	0	1	0.117	
5	150	2	2	0	0
8	0	0	1	-0.219	
5	150	2	2	0	0
8	0	0	1	0.229	
5	150	2	2	0	0
8	0	0	1	-0.22	
5	150	2	2	0	0
8	0	0	1	0.229	
5	150	2	2	0	0
8	0	0	1	-0.331	
5	150	2	2	0	0
8	0	0	1	0.341	
5	150	2	2	0	0
8	0	0	1	-0.247	
5	150	2	2	0	0
8	0	0	1	0.245	
5	150	2	2	0	0
8	0	0	1	-0.163	
5	150	2	2	0	0
8	0	0	1	0.173	
5	150	2	2	0	0
8	0	0	1	-0.32	
5	150	2	2	0	0
8	0	0	1	0.342	
5	150	2	2	0	0
8	0	0	1	-0.331	
5	150	2	2	0	0
8	0	0	1	0.341	

```
5     150   2     2     0     0
8     0     0     1     -0.443
5     150   2     2     0     0
8     0     0     1     0.453
5     150   2     2     0     0
8     0     0     1     -0.331
5     150   2     2     0     0
8     0     0     1     0.341
5     150   2     2     0     0
8     0     0     1     -0.219
5     150   2     2     0     0
8     0     0     1     0.229
5     150   2     2     0     0
8     0     0     1     -0.443
5     150   2     2     0     0
8     0     0     1     0.449
5     150   2     2     0     0
8     0     0     1     -0.42
5     150   2     2     0     0
8     0     0     1     0.453
5     150   2     2     0     0
8     0     0     1     -0.555
5     150   2     2     0     0
8     0     0     1     0.556
5     150   2     2     0     0
8     0     0     1     -0.415
5     150   2     2     0     0
8     0     0     1     0.425
5     150   2     2     0     0
8     0     0     1     -0.275
5     150   2     2     0     0
8     0     0     1     0.285
5     150   2     2     0     0
8     0     0     1     -0.555
5     150   2     2     0     0
8     0     0     1     0.565
5     150   2     2     0     0
8     0     0     1     -0.331
5     150   2     2     0     0
-1    0     0     0     0     0
0     0     0     0     0
```

Appendix C
Input Description for Wall 3

Card Group 1

Program Execution

Card Group 2

Problem Title

Card Group 3

NVFIX = 26 13 nodes have pinned boundary conditions and 13 nodes have prescribed displacements.

NNODE = 4 The nonlinear element having only 4 nodes.

NMATS = 1 - Concrete with horizontal and vertical reinforcement
2 - Concrete with horizontal reinforcement
3 - Grouted masonry with vertical reinforcement
4 - Ungrouted masonry
5 - Grouted masonry with horizontal and vertical reinforcement
6 - Grouted masonry with horizontal reinforcement

Card Group 4

Elements 2, 11, 14, 23, 96, 105, 108 and 117 have material property 1. Elements 1, 2-10, 12, 13, 15-22 and 24 have material property 2. Elements 25, 34, 35, 44, 45, 54, 65, 74, 75, 84, 85, and 94 have material property 3. Elements 26-33, 36-43, 46-53, 66-73, 76-83, 86-93 have material property 4. Elements 55 and 64 have material property 5 Elements 56 - 63 have material property 6.

Specifying the element nodal connectivity numbers by starting at the same corner of each element (lower left hand corner in this case) guarantees that the Gauss points of all of the elements will be located in the same relative position. This is invaluable in the interpretation of the element stresses and strains.

Card Group 6

Nodal points 132 through 144 have prescribed displacement in the x direction and are free to translate in the y-direction. Therefore, the constraint code IFPRE is 10. Although any value of the x-component of the prescribed displacement PRESC(1) has been arbitrarily set to 1.0 so that the values given for FACTD in Card Group 18 are the actual displacements to be attained in the given load step. A positive displacement indicates that the displacement acts to the right.

Card Group 7

Material Properties

Concrete with Horizontal and Vertical Reinforcement		
ν	0.20	
f_c	5	ksi
ε_o	0.003	
A_1	2	
A_2	2	
A_3	0.1	
A_4	0.6	
MCD	1	
f_{cr}	0.504	ksi
E_t	3067	ksi
MTS	3	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	3.16	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.00423	
$^{**}\rho_h$	0.00760	
f_{yv}	60	ksi
f_{yh}	60	ksi

Concrete with Horizontal Reinforcement		
ν	0.20	
f_c	5	ksi
ε_o	0.003	
A_1	2	
A_2	2	
A_3	0.1	
A_4	0.6	
MCD	1	
f_{cr}	0.504	ksi
E_t	3067	ksi
MTS	3	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	3.16	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0.00760	
f_{yv}	0	ksi
f_{yh}	60	ksi

Grouted Masonry with Vertical Reinforcement		
ν	0.16	
f_m	3.26	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1793	ksi
MTS	2	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.01443	
$^{**}\rho_h$	0	
f_{yv}	60	ksi
f_{yh}	0	ksi

Ungrouted Masonry Unreinforced		
ν	0.16	
f_m	2.67	ksi
ε_o	0.0022	
A_1	1.7	
A_2	1.35	
A_3	0.11	
A_4	1.4	
MCD	1	
f_{cr}	0.05	ksi
E_t	1793	ksi
MTS	1	
B_1	0.5	
α	0.25	
E_s	0	ksi
ξ	0 %	
A_{sh}	0	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0	
f_{yv}	0	ksi
f_{yh}	0	ksi

Grouted Masonry with Horizontal and Vertical Reinforcement		
ν	0.16	
f_m	3.26	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1793	ksi
MTS	2	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0.22	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.01443	
$^{**}\rho_h$	0.00361	
f_{yv}	60	ksi
f_{yh}	60	ksi

Grouted Masonry with Horizontal Reinforcement		
ν	0.16	
f_m	3.26	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1793	ksi
MTS	1	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0.22	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0.00361	
f_{yv}	0	ksi
f_{yh}	60	ksi

* Vertical reinforcement ratios are calculated using the following equation:

$$\frac{\text{Area of vertical reinforcement}}{(\text{width of cell containing reinforcement})(\text{thickness of masonry wall})}$$

** Horizontal reinforcement ratios are calculated using the following equation:

$$\frac{\text{Area of horizontal reinforcement}}{(\text{width of cell containing reinforcement})(\text{thickness of masonry wall})}$$

Card Group 8

Not required - no initial stress

Card Group 9

NUMFDF = 13 To facilitate the interpretation off the output the sum of the reactions at 13 nodal points (NODE 1 = 132, NODE 2 = 133, NODE 3 = 134, ... NODE

13 = 144), i.e. the nodes with prescribed displacement will be directed to the Force-Deflection file along with the prescribed displacements at 1 nodal point (NODE1 = 132).

KOMPNT = 1 The x-component of the 13 reaction and the 1 displacement are to be output to the Force-Deflection file.

Card Group 10

Element Output Data

Card Group 11

Node Output Data

Card Group 12

Load Title

Card Group 13

Load Control Data

Card Group 14

Not required - no nodal point loading

Card Group 15

Not required - no gravity loading

Card Group 16

NEDGE = 10 Vertical axial pressure load applied to the top edge of elements 85 through 94.

Card Group 17

NOPRS(1) and NOPRS(2) - Specify the nodal points for each loaded element in a counterclockwise sequence. PRES(1,1) and PRES(2,1) - The normal load on an element is specified as a force per unit length (200 psi x 2.68 inch thickness = 0.536 kips per inch). A positive value indicates that the load acts downward (i.e. into the element).

Card Group 18

The load increment controls will generate 629 load/displacements increments. The convergence tolerance TOLER and maximum number of iterations MITER are set to 5% and 250, respectively, for all increments.

The first card (FACTE = 1.0, FACTD = 0.0, and NDIV = 1) will generate 1 increment where all of the vertical axial load is applied in the 1st increment (FACTE = 1.0) before any horizontal prescribed displacements are applied (FACTD = 0.0). In the remaining increments the vertical axial load is held constant (FACT = 1.0) and the horizontal prescribed displacements are applied in variable increments.

The second card (FACTD = -0.0095 and NDIV = 4) will generate 4 increments to move from the previous displacement of 0.0 inches to -0.0095 inches with dx = -0.0095/4 = -0.00238 inches.

The third card (FACTD = 0.0041 and NDIV = 4) will generate 4 increments to move from the previous displacement of -0.0095 to 0.0041 inches with dx = (0.0041 - (-0.0095)) /4 = 0.0034 inches.

The remaining cards generate increments in a similar manner. The load increment control data is terminated when NDIV = -1.

Input Data File for Wall 3

START ---------- Card 1
"Wall #3 - W3.Inp, Mesh3, Nominal Properties, in-kips" ---------- Card 2
144 118 26 1 4 6 0 0 0 ---------- Card 3
1 2 1 2 15 14 ---------- Card 4
2 1 2 3 16 15
3 2 3 4 17 16
4 2 4 5 18 17
5 2 5 6 19 18
6 2 6 7 20 19
7 2 7 8 21 20
8 2 8 9 22 21
9 2 9 10 23 22
10 2 10 11 24 23
11 1 11 12 25 24
12 2 12 13 26 25
13 2 14 15 28 27
14 1 15 16 29 28
15 2 16 17 30 29
16 2 17 18 31 30
17 2 18 19 32 31
18 2 19 20 33 32
19 2 20 21 34 33
20 2 21 22 35 34
21 2 22 23 36 35
22 2 23 24 37 36
23 1 24 25 38 37
24 2 25 26 39 38
25 3 28 29 41 40
26 4 29 30 42 41
27 4 30 31 43 42
28 4 31 32 44 43
29 4 32 33 45 44
30 4 33 34 46 45
31 4 34 35 47 46
32 4 35 36 48 47
33 4 36 37 49 48
34 3 37 38 50 49
35 3 40 41 52 51
36 4 41 42 53 52
37 4 42 43 54 53
38 4 43 44 55 54
39 4 44 45 56 55
40 4 45 46 57 56

41	4	46	47	58	57
42	4	47	48	59	58
43	4	48	49	60	59
44	3	49	50	61	60
45	3	51	52	63	62
46	4	52	53	64	63
47	4	53	54	65	64
48	4	54	55	66	65
49	4	55	56	67	66
50	4	56	57	68	67
51	4	57	58	69	68
52	4	58	59	70	69
53	4	59	60	71	70
54	3	60	61	72	71
55	5	62	63	74	73
56	6	63	64	75	74
57	6	64	65	76	75
58	6	65	66	77	76
59	6	66	67	78	77
60	6	67	68	79	78
61	6	68	69	80	79
62	6	69	70	81	80
63	6	70	71	82	81
64	5	71	72	83	82
65	3	73	74	85	84
66	4	74	75	86	85
67	4	75	76	87	86
68	4	76	77	88	87
69	4	77	78	89	88
70	4	78	79	90	89
71	4	79	80	91	90
72	4	80	81	92	91
73	4	81	82	93	92
74	3	82	83	94	93
75	3	84	85	96	95
76	4	85	86	97	96
77	4	86	87	98	97
78	4	87	88	99	98
79	4	88	89	100	99
80	4	89	90	101	100
81	4	90	91	102	101
82	4	91	92	103	102
83	4	92	93	104	103
84	3	93	94	105	104
85	3	95	96	108	107

86	4	96	97	109	108
87	4	97	98	110	109
88	4	98	99	111	110
89	4	99	100	112	111
90	4	100	101	113	112
91	4	101	102	114	113
92	4	102	103	115	114
93	4	103	104	116	115
94	3	104	105	117	116
95	2	106	107	120	119
96	1	107	108	121	120
97	2	108	109	122	121
98	2	109	110	123	122
99	2	110	111	124	123
100	2	111	112	125	124
101	2	112	113	126	125
102	2	113	114	127	126
103	2	114	115	128	127
104	2	115	116	129	128
105	1	116	117	130	129
106	2	117	118	131	130
107	2	119	120	133	132
108	1	120	121	134	133
109	2	121	122	135	134
110	2	122	123	136	135
111	2	123	124	137	136
112	2	124	125	138	137
113	2	125	126	139	138
114	2	126	127	140	139
115	2	127	128	141	140
116	2	128	129	142	141
117	1	129	130	143	142
118	2	130	131	144	143

1	-45.375		-16 ----------Card 5
2	-40	-16	
3	-32	-16	
4	-24	-16	
5	-16	-16	
6	-8	-16	
7	0	-16	
8	8	-16	
9	16	-16	
10	24	-16	
11	32	-16	
12	40	-16	

13	45.375	-16
14	-45.375	-8
15	-40	-8
16	-32	-8
17	-24	-8
18	-16	-8
19	-8	-8
20	0	-8
21	8	-8
22	16	-8
23	24	-8
24	32	-8
25	40	-8
26	45.375	-8
27	-45.375	0
28	-40	0
29	-32	0
30	-24	0
31	-16	0
32	-8	0
33	0	0
34	8	0
35	16	0
36	24	0
37	32	0
38	40	0
39	45.375	0
40	-40	8
41	-32	8
42	-24	8
43	-16	8
44	-8	8
45	0	8
46	8	8
47	16	8
48	24	8
49	32	8
50	40	8
51	-40	16
52	-32	16
53	-24	16
54	-16	16
55	-8	16
56	0	16
57	8	16

58	16	16
59	24	16
60	32	16
61	40	16
62	-40	24
63	-32	24
64	-24	24
65	-16	24
66	-8	24
67	0	24
68	8	24
69	16	24
70	24	24
71	32	24
72	40	24
73	-40	32
74	-32	32
75	-24	32
76	-16	32
77	-8	32
78	0	32
79	8	32
80	16	32
81	24	32
82	32	32
83	40	32
84	-40	40
85	-32	40
86	-24	40
87	-16	40
88	-8	40
89	0	40
90	8	40
91	16	40
92	24	40
93	32	40
94	40	40
95	-40	48
96	-32	48
97	-24	48
98	-16	48
99	-8	48
100	0	48
101	8	48
102	16	48

103	24	48	
104	32	48	
105	40	48	
106	-45.375		56
107	-40	56	
108	-32	56	
109	-24	56	
110	-16	56	
111	-8	56	
112	0	56	
113	8	56	
114	16	56	
115	24	56	
116	32	56	
117	40	56	
118	45.375	56	
119	-45.375		64
120	-40	64	
121	-32	64	
122	-24	64	
123	-16	64	
124	-8	64	
125	0	64	
126	8	64	
127	16	64	
128	24	64	
129	32	64	
130	40	64	
131	45.375	64	
132	-45.375		72
133	-40	72	
134	-32	72	
135	-24	72	
136	-16	72	
137	-8	72	
138	0	72	
139	8	72	
140	16	72	
141	24	72	
142	32	72	
143	40	72	
144	45.375	72	
1	11	0	0 ----------Card 6
2	11	0	0
3	11	0	0

```
4       11      0       0
5       11      0       0
6       11      0       0
7       11      0       0
8       11      0       0
9       11      0       0
10      11      0       0
11      11      0       0
12      11      0       0
13      11      0       0
132     10      1       0
133     10      1       0
134     10      1       0
135     10      1       0
136     10      1       0
137     10      1       0
138     10      1       0
139     10      1       0
140     10      1       0
141     10      1       0
142     10      1       0
143     10      1       0
144     10      1       0
1       'Concrete with Horizontal and Vertical Reinforcement' ----------Card 7
0.2     26      0       1
5       0.003   2       2       0.1     0.6     1
0.504   3067    3       0.5     0.25
29000   0.02    0.00423         0.0076  60      60
2       'Concrete with Horizontal Reinforcement'
0.2     26      0       1
5       0.003   2       2       0.1     0.6     1
0.504   3067    3       0.5     0.25
29000   0.02    0       0.0076  0       60
3       'Grouted Masonry with Vertical Reinforcement'
0.16    7.625   0       1
3.26    0.0022  1.9     1.3     0.14    0.165   1
0.05    1793    2       0.5     0.25
29000   0.02    0.01443         0       60      0
4       'Ungrouted Masonry'
0.16    2.68    0       1
2.67    0.0022  1.7     1.35    0.11    1.4     1
0.05    1468    1       0       0
0       0       0       0       0       0
5       'Grouted Masonry with Horizontal and Vertical Reinforcement'
0.16    7.625   0       1
```

```
3.26    0.0022 1.9    1.3    0.14   0.165  1
0.05    1793   2      0.5    0.25
29000   0.02   0.01443       0.00361       60     60
6       'Grouted Masonry with Horizontal Reinforcement'
0.16    7.625  0      1
3.26    0.0022 1.9    1.3    0.14   0.165  1
0.05    1793   2      0.5    0.25
29000   0.02   0      0.00361       0      60
144     13     13 ----------------------------------------------------------------------Card 9
1       132    133    134    135    136    137
138     139    140    141    142    143    144
132     133    134    135    136    137
138     139    140    141    142    143    144 ----------------------------------Card 11
"Wall #3 - W3.Inp, Mesh 3 Nominal Properties, in-kips" ----------------------Card 12
0       0      1 ----------------------------------------------------------------Card 13
10 ---------------------------------------------------------------------------Card 16
85      108    107 --------------------------------------------------------------Card 17
0.536   0      0.536  0 ----------------------------------------------------------Card 18
86      109    108
0.536   0      0.536  0
87      110    109
0.536   0      0.536  0
88      111    110
0.536   0      0.536  0
89      112    111
0.536   0      0.536  0
90      113    112
0.536   0      0.536  0
91      114    113
0.536   0      0.536  0
92      115    114
0.536   0      0.536  0
93      116    115
0.536   0      0.536  0
94      117    116
0.536   0      0.536  0
1       0      0      1      0
5       250    2      2      0      0
4       0      0      1      -0.0095
5       250    2      2      0      0
4       0      0      1      0.0041
5       250    2      2      0      0
4       0      0      1      -0.0095
5       250    2      2      0      0
4       0      0      1      0.0026
```

5	250	2	2	0	0
4	0	0	1	-0.0095	
5	250	2	2	0	0
4	0	0	1	0.0041	
5	250	2	2	0	0
4	0	0	1	-0.0159	
5	250	2	2	0	0
4	0	0	1	0.0103	
5	250	2	2	0	0
4	0	0	1	-0.0159	
5	250	2	2	0	0
4	0	0	1	0.0104	
5	250	2	2	0	0
4	0	0	1	-0.0159	
5	250	2	2	0	0
4	0	0	1	0.0104	
5	250	2	2	0	0
4	0	0	1	-0.0214	
5	250	2	2	0	0
4	0	0	1	0.0156	
5	250	2	2	0	0
4	0	0	1	-0.021	
5	250	2	2	0	0
4	0	0	1	0.0157	
5	250	2	2	0	0
4	0	0	1	-0.021	
5	250	2	2	0	0
4	0	0	1	0.0159	
5	250	2	2	0	0
4	0	0	1	-0.0262	
5	250	2	2	0	0
4	0	0	1	0.0202	
5	250	2	2	0	0
4	0	0	1	-0.0256	
5	250	2	2	0	0
4	0	0	1	0.0204	
5	250	2	2	0	0
4	0	0	1	-0.0257	
5	250	2	2	0	0
4	0	0	1	0.0204	
5	250	2	2	0	0
4	0	0	1	-0.0354	
5	250	2	2	0	0
4	0	0	1	0.0308	
5	250	2	2	0	0

4	0	0	1	-0.0353
5	250	2	2	0 0
4	0	0	1	0.0308
5	250	2	2	0 0
4	0	0	1	-0.0265
5	250	2	2	0 0
4	0	0	1	0.0215
5	250	2	2	0 0
4	0	0	1	-0.0174
5	250	2	2	0 0
4	0	0	1	0.0135
5	250	2	2	0 0
4	0	0	1	-0.0092
5	250	2	2	0 0
4	0	0	1	0.0035
5	250	2	2	0 0
4	0	0	1	-0.0356
5	250	2	2	0 0
4	0	0	1	0.0309
5	250	2	2	0 0
4	0	0	1	-0.0357
5	250	2	2	0 0
4	0	0	1	0.0306
5	250	2	2	0 0
4	0	0	1	-0.0361
5	250	2	2	0 0
4	0	0	1	0.0307
5	250	2	2	0 0
4	0	0	1	-0.045
5	250	2	2	0 0
4	0	0	1	0.0399
5	250	2	2	0 0
4	0	0	1	-0.0363
5	250	2	2	0 0
4	0	0	1	0.0312
5	250	2	2	0 0
4	0	0	1	-0.0174
5	250	2	2	0 0
4	0	0	1	0.0125
5	250	2	2	0 0
4	0	0	1	-0.0093
5	250	2	2	0 0
4	0	0	1	0.0041
5	250	2	2	0 0
4	0	0	1	-0.0452

5	250	2	2	0	0
4	0	0	1	0.0403	
5	250	2	2	0	0
4	0	0	1	-0.0454	
5	250	2	2	0	0
4	0	0	1	0.0406	
5	250	2	2	0	0
4	0	0	1	-0.0457	
5	250	2	2	0	0
4	0	0	1	0.0407	
5	250	2	2	0	0
4	0	0	1	-0.0556	
5	250	2	2	0	0
4	0	0	1	0.0491	
5	250	2	2	0	0
4	0	0	1	-0.0466	
5	250	2	2	0	0
4	0	0	1	0.0413	
5	250	2	2	0	0
4	0	0	1	-0.0273	
5	250	2	2	0	0
4	0	0	1	0.0221	
5	250	2	2	0	0
4	0	0	1	-0.0087	
5	250	2	2	0	0
4	0	0	1	0.004	
5	250	2	2	0	0
4	0	0	1	-0.0558	
5	250	2	2	0	0
4	0	0	1	0.0495	
5	250	2	2	0	0
4	0	0	1	-0.0562	
5	250	2	2	0	0
4	0	0	1	0.0498	
5	250	2	2	0	0
4	0	0	1	-0.0564	
5	250	2	2	0	0
4	0	0	1	0.0502	
5	250	2	2	0	0
4	0	0	1	-0.0784	
5	250	2	2	0	0
4	0	0	1	0.072	
5	250	2	2	0	0
4	0	0	1	-0.0594	
5	250	2	2	0	0

4	0	0	1	0.0531
5	250	2	2	0 0
4	0	0	1	-0.0381
5	250	2	2	0 0
4	0	0	1	0.0327
5	250	2	2	0 0
4	0	0	1	-0.0086
5	250	2	2	0 0
4	0	0	1	0.0042
5	250	2	2	0 0
4	0	0	1	-0.089
5	250	2	2	0 0
4	0	0	1	0.0688
5	250	2	2	0 0
4	0	0	1	-0.0895
5	250	2	2	0 0
4	0	0	1	0.0692
5	250	2	2	0 0
4	0	0	1	-0.0888
5	250	2	2	0 0
4	0	0	1	0.0694
5	250	2	2	0 0
4	0	0	1	-0.1159
5	250	2	2	0 0
4	0	0	1	0.0925
5	250	2	2	0 0
4	0	0	1	-0.0927
5	250	2	2	0 0
4	0	0	1	0.0718
5	250	2	2	0 0
4	0	0	1	-0.057
5	250	2	2	0 0
4	0	0	1	0.0373
5	250	2	2	0 0
4	0	0	1	-0.0151
5	250	2	2	0 0
4	0	0	1	-0.002
5	250	2	2	0 0
4	0	0	1	-0.1156
5	250	2	2	0 0
4	0	0	1	0.0937
5	250	2	2	0 0
4	0	0	1	-0.1165
5	250	2	2	0 0
4	0	0	1	0.0944

5	*250*	*2*	*2*	*0*	*0*
4	0	0	1	-0.1171	
5	250	2	2	0	0
4	0	0	1	0.0944	
5	250	2	2	0	0
4	0	0	1	-0.144	
5	250	2	2	0	0
4	0	0	1	0.1244	
5	250	2	2	0	0
4	0	0	1	-0.1078	
5	250	2	2	0	0
4	0	0	1	0.0858	
5	250	2	2	0	0
4	0	0	1	-0.071	
5	250	2	2	0	0
4	0	0	1	0.0499	
5	250	2	2	0	0
8	0	0	1	-0.1465	
5	250	2	2	0	0
8	0	0	1	0.1214	
5	250	2	2	0	0
8	0	0	1	-0.1461	
5	250	2	2	0	0
8	0	0	1	0.1214	
5	250	2	2	0	0
8	0	0	1	-0.1465	
5	250	2	2	0	0
8	0	0	1	0.1215	
5	250	2	2	0	0
8	0	0	1	-0.1997	
5	250	2	2	0	0
8	0	0	1	0.1693	
5	250	2	2	0	0
8	0	0	1	-0.1494	
5	250	2	2	0	0
8	0	0	1	0.124	
5	250	2	2	0	0
8	0	0	1	-0.0979	
5	250	2	2	0	0
8	0	0	1	0.0754	
5	250	2	2	0	0
8	0	0	1	-0.1996	
5	250	2	2	0	0
8	0	0	1	0.1722	
5	250	2	2	0	0

8	0	0	1	-0.2006
5	250	2	2	0 0
8	0	0	1	0.1734
5	250	2	2	0 0
8	0	0	1	-0.2096
5	250	2	2	0 0
8	0	0	1	0.1688
5	250	2	2	0 0
8	0	0	1	-0.2609
5	250	2	2	0 0
8	0	0	1	0.2227
5	250	2	2	0 0
8	0	0	1	-0.1957
5	250	2	2	0 0
8	0	0	1	0.163
5	250	2	2	0 0
8	0	0	1	-0.1324
5	250	2	2	0 0
8	0	0	1	0.1031
5	250	2	2	0 0
8	0	0	1	-0.2592
5	250	2	2	0 0
8	0	0	1	0.2262
5	250	2	2	0 0
8	0	0	1	-0.261
5	250	2	2	0 0
8	0	0	1	0.2278
5	250	2	2	0 0
8	0	0	1	-0.263
5	250	2	2	0 0
8	0	0	1	0.2294
5	250	2	2	0 0
8	0	0	1	-0.3178
5	250	2	2	0 0
8	0	0	1	0.2948
5	250	2	2	0 0
8	0	0	1	-0.2449
5	250	2	2	0 0
8	0	0	1	0.2162
5	250	2	2	0 0
8	0	0	1	-0.1673
5	250	2	2	0 0
8	0	0	1	0.1391
5	250	2	2	0 0
8	0	0	1	-0.324

```
5     250   2     2     0     0
8     0     0     1     0.2984
5     250   2     2     0     0
8     0     0     1     -0.32
5     250   2     2     0     0
8     0     0     1     0.3009
5     250   2     2     0     0
8     0     0     1     -0.3263
5     250   2     2     0     0
8     0     0     1     0.3032
5     250   2     2     0     0
8     0     0     1     -0.4348
5     250   2     2     0     0
8     0     0     1     0.4119
5     250   2     2     0     0
8     0     0     1     -0.0094
5     250   2     2     0     0
8     0     0     1     0.0104
5     250   2     2     0     0
8     0     0     1     -0.3073
5     250   2     2     0     0
8     0     0     1     0.3283
5     250   2     2     0     0
8     0     0     1     -0.3074
5     250   2     2     0     0
-1    0     0     0     0
0     0     0     0     0     0
```

Appendix D
Input Description for Wall 5

Card Group 1

Program Execution

Card Group 2

Problem Title

Card Group 3

NVFIX = 20 10 nodes have pinned boundary conditions and 10 nodes have prescribed displacements.

NNODE = 4 The nonlinear element having only 4 nodes.

NMATS = 1 - Concrete with horizontal and vertical reinforcement
2 - Concrete with horizontal reinforcement
3 - Grouted masonry with vertical reinforcement
4 - Ungrouted masonry
5 - Grouted masonry with horizontal and vertical reinforcement
6 - Grouted masonry with horizontal reinforcement

Card Group 4

Elements 2, 8, 11, 17, 69, 75, 78 and 84 have material property 1. Elements 1, 3 - 7 ,9, 10, 12 - 16, 18, 88, 70 - 74, 76, 77, 79 - 83 and 85have material property 2. Elements 19, 25, 26, 32, 33, 39, 47, 53, 54, 60, 61 and 67, have material property 3. Elements 20 - 24, 27 - 31, 34 - 38, 48 - 52, 55 - 59, and 62 - 66have material property 4. Elements 40 and 46 have material property 5. Elements 41 - 45 have material property 6.

Specifying the element nodal connectivity numbers by starting at the same corner of each element (lower left hand corner in this case) guarantees that the Gauss points of all of the elements will be located in the same relative position. This is invaluable in the interpretation of the element stresses and strains.

Card Group 6

Nodal points 79 through 88 have prescribed displacement in the x direction and are free to translate in the y-direction. Therefore, the constraint code IFPRE is 10. Although any value of the x-component of the prescribed displacement PRESC(1) has been arbitrarily set to 1.0 so that the values given for FACTD in Card Group 18 are the actual displacements to be attained in the given load step. A positive displacement indicates that the displacement acts to the right.

Card Group 7

Material Properties

Concrete with Horizontal and Vertical Reinforcement		
ν	0.20	
f_c	5	ksi
ε_o	0.003	
A_1	2	
A_2	2	
A_3	0.1	
A_4	0.6	
MCD	1	
f_{cr}	0.504	ksi
E_t	3067	ksi
MTS	3	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	3.16	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.00423	
$^{**}\rho_h$	0.00760	
f_{yv}	60	ksi
f_{yh}	60	ksi

Concrete with Horizontal Reinforcement		
ν	0.20	
f_c	5	ksi
ε_o	0.003	
A_1	2	
A_2	2	
A_3	0.1	
A_4	0.6	
MCD	1	
f_{cr}	0.504	ksi
E_t	3067	ksi
MTS	3	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	3.16	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0.00760	
f_{yv}	0	ksi
f_{yh}	60	ksi

Grouted Masonry with Vertical Reinforcement		
ν	0.16	
f_m	2.83	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1556	ksi
MTS	2	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.01443	
$^{**}\rho_h$	0	
f_{yv}	60	ksi
f_{yh}	0	ksi

Ungrouted Masonry Unreinforced		
ν	0.16	
f_m	2.99	ksi
ε_o	0.0022	
A_1	1.7	
A_2	1.35	
A_3	0.11	
A_4	1.4	
MCD	1	
f_{cr}	0.05	ksi
E_t	1644	ksi
MTS	1	
B_1	0.5	
α	0.25	
E_s	0	ksi
ξ	0 %	
A_{sh}	0	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0	
f_{yv}	0	ksi
f_{yh}	0	ksi

Grouted Masonry with Horizontal and Vertical Reinforcement		
ν	0.16	
f_m	2.83	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1556	ksi
MTS	2	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0.22	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.01443	
$^{**}\rho_h$	0.00361	
f_{yv}	60	ksi
f_{yh}	60	ksi

Grouted Masonry with Horizontal Reinforcement		
ν	0.16	
f_m	2.83	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1556	ksi
MTS	1	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0.22	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0.00361	
f_{yv}	0	ksi
f_{yh}	60	ksi

* Vertical reinforcement ratios are calculated using the following equation:

$$\frac{\text{Area of vertical reinforcement}}{(\text{width of cell containing reinforcement})(\text{thickness of masonry wall})}$$

** Horizontal reinforcement ratios are calculated using the following equation:

$$\frac{\text{Area of horizontal reinforcement}}{(\text{width of cell containing reinforcement})(\text{thickness of masonry wall})}$$

Card Group 8

Not required - no initial stress

Card Group 9

NUMFDF = 13 To facilitate the interpretation off the output the sum of the reactions at 13 nodal points (NODE 1 = 132, NODE 2 = 133, NODE 3 = 134, ... NODE

13 = 144), i.e. the nodes with prescribed displacement will be directed to the Force-Deflection file along with the prescribed displacements at 1 nodal point (NODE1 = 132).

KOMPNT = 1 The x-component of the 13 reaction and the 1 displacement are to be output to the Force-Deflection file.

Card Group 10

Element Output Data

Card Group 11

Node Output Data

Card Group 12

Load Title

Card Group 13

Load Control Data

Card Group 14

Not required - no nodal point loading

Card Group 15

Not required - no gravity loading

Card Group 16

NEDGE = 10 Vertical axial pressure load applied to the top edge of elements 61 through 67

Card Group 17

NOPRS(1) and NOPRS(2) - Specify the nodal points for each loaded element in a counterclockwise sequence. PRES(1,1) and PRES(2,1) - The normal load on an element is specified as a force per unit length (200 psi x 2.68 inch thickness = 0.536 kips per inch). A positive value indicates that the load acts downward (i.e. into the element).

Card Group 18

The load increment controls will generate 801 load/displacements increments. The convergence tolerance TOLER and maximum number of iterations MITER are set to 5% and 250, respectively, for all increments.

The first card (FACTE = 1.0, FACTD = 0.0, and NDIV = 1) will generate 1 increment where all of the vertical axial load is applied in the 1st increment (FACTE = 1.0) before any horizontal prescribed displacements are applied (FACTD = 0.0). In the remaining increments the vertical axial load is held constant (FACT = 1.0) and the horizontal prescribed displacements are applied in variable increments

The second card (FACTD = -0.017 and NDIV = 4) will generate 4 increments to move from the previous displacement of 0.0 inches to -0.017 inches with dx = -0.017/4 = -0.00425 inches.

The third card (FACTD = 0.017 and NDIV = 4) will generate 4 increments to move from the previous displacement of -0.017 to 0.017 inches with dx = [0.017 - (-0.017)] /4 = 0.0085 inches.

The remaining cards generate increments in a similar manner. The load increment control data is terminated when NDIV = -1.

Input Data File for Wall 5

START ----------Card 1
"Wall #5 - W5.Inp, Mesh 5, Nominal Properties, in-kips" ----------Card 2
108 85 20 1 4 6 0 0 0 ----------Card 3
1 2 1 2 12 11 ----------Card 4
2 1 2 3 13 12
3 2 3 4 14 13
4 2 4 5 15 14
5 2 5 6 16 15
6 2 6 7 17 16
7 2 7 8 18 17
8 1 8 9 19 18
9 2 9 10 20 19
10 2 11 12 22 21
11 1 12 13 23 22
12 2 13 14 24 23
13 2 14 15 25 24
14 2 15 16 26 25
15 2 16 17 27 26
16 2 17 18 28 27
17 1 18 19 29 28
18 2 19 20 30 29
19 3 22 23 32 31
20 4 23 24 33 32
21 4 24 25 34 33
22 4 25 26 35 34
23 4 26 27 36 35
24 4 27 28 37 36
25 3 28 29 38 37
26 3 31 32 40 39
27 4 32 33 41 40
28 4 33 34 42 41
29 4 34 35 43 42
30 4 35 36 44 43
31 4 36 37 45 44
32 3 37 38 46 45
33 3 39 40 48 47
34 4 40 41 49 48
35 4 41 42 50 49
36 4 42 43 51 50
37 4 43 44 52 51
38 4 44 45 53 52
39 3 45 46 54 53
40 5 47 48 56 55

41	6	48	49	57	56
42	6	49	50	58	57
43	6	50	51	59	58
44	6	51	52	60	59
45	6	52	53	61	60
46	5	53	54	62	61
47	3	55	56	64	63
48	4	56	57	65	64
49	4	57	58	66	65
50	4	58	59	67	66
51	4	59	60	68	67
52	4	60	61	69	68
53	3	61	62	70	69
54	3	63	64	72	71
55	4	64	65	73	72
56	4	65	66	74	73
57	4	66	67	75	74
58	4	67	68	76	75
59	4	68	69	77	76
60	3	69	70	78	77
61	3	71	72	81	80
62	4	72	73	82	81
63	4	73	74	83	82
64	4	74	75	84	83
65	4	75	76	85	84
66	4	76	77	86	85
67	3	77	78	87	86
68	2	79	80	90	89
69	1	80	81	91	90
70	2	81	82	92	91
71	2	82	83	93	92
72	2	83	84	94	93
73	2	84	85	95	94
74	2	85	86	96	95
75	1	86	87	97	96
76	2	87	88	98	97
77	2	89	90	100	99
78	1	90	91	101	100
79	2	91	92	102	101
80	2	92	93	103	102
81	2	93	94	104	103
82	2	94	95	105	104
83	2	95	96	106	105
84	1	96	97	107	106
85	2	97	98	108	107

1	0	0	Card 5
2	5.375	0	
3	13.375	0	
4	21.375	0	
5	29.375	0	
6	37.375	0	
7	45.375	0	
8	53.375	0	
9	61.375	0	
10	66.75	0	
11	0	8	
12	5.375	8	
13	13.375	8	
14	21.375	8	
15	29.375	8	
16	37.375	8	
17	45.375	8	
18	53.375	8	
19	61.375	8	
20	66.75	8	
21	0	16	
22	5.375	16	
23	13.375	16	
24	21.375	16	
25	29.375	16	
26	37.375	16	
27	45.375	16	
28	53.375	16	
29	61.375	16	
30	66.75	16	
31	5.375	24	
32	13.375	24	
33	21.375	24	
34	29.375	24	
35	37.375	24	
36	45.375	24	
37	53.375	24	
38	61.375	24	
39	5.375	32	
40	13.375	32	
41	21.375	32	
42	29.375	32	
43	37.375	32	
44	45.375	32	
45	53.375	32	

46	61.375	32
47	5.375	40
48	13.375	40
49	21.375	40
50	29.375	40
51	37.375	40
52	45.375	40
53	53.375	40
54	61.375	40
55	5.375	48
56	13.375	48
57	21.375	48
58	29.375	48
59	37.375	48
60	45.375	48
61	53.375	48
62	61.375	48
63	5.375	56
64	13.375	56
65	21.375	56
66	29.375	56
67	37.375	56
68	45.375	56
69	53.375	56
70	61.375	56
71	5.375	64
72	13.375	64
73	21.375	64
74	29.375	64
75	37.375	64
76	45.375	64
77	53.375	64
78	61.375	64
79	0	72
80	5.375	72
81	13.375	72
82	21.375	72
83	29.375	72
84	37.375	72
85	45.375	72
86	53.375	72
87	61.375	72
88	66.75	72
89	0	80
90	5.375	80

```
91      13.375 80
92      21.375 80
93      29.375 80
94      37.375 80
95      45.375 80
96      53.375 80
97      61.375 80
98      66.75  80
99      0      88
100     5.375  88
101     13.375 88
102     21.375 88
103     29.375 88
104     37.375 88
105     45.375 88
106     53.375 88
107     61.375 88
108     66.75  88
1       11     0     0 ----------Card 6
2       11     0     0
3       11     0     0
4       11     0     0
5       11     0     0
6       11     0     0
7       11     0     0
8       11     0     0
9       11     0     0
10      11     0     0
99      10     1     0
100     10     1     0
101     10     1     0
102     10     1     0
103     10     1     0
104     10     1     0
105     10     1     0
106     10     1     0
107     10     1     0
108     10     1     0
1       'Concrete with Horizontal and Vertical Reinforcement' ----------Card 7
0.2     26     0     1
5       0.003  2     2     0.1    0.6    1
0.504   3067   3     0.5   0.25
29000   0.02   0.00423     0.0076 60     60
2       'Concrete with Horizontal Reinforcement'
0.2     26     0     1
```

```
5       0.003   2       2       0.1     0.6     1
0.504   3067    3       0.5     0.25
29000   0.02    0       0.0076  0       60
3       'Grouted Masonry with Vertical Reinforcement'
0.16    7.625   0       1
2.83    0.0022  1.9     1.3     0.14    0.165   1
0.05    1556    2       0.5     0.25
29000   0.02    0.01443         0       60      0
4       'Ungrouted Masonry'
0.16    2.68    0       1
2.99    0.0022  1.7     1.35    0.11    1.4     1
0.05    1644    1       0       0
0       0       0       0       0       0
5       'Grouted Masonry with Horizontal and Vertical Reinforcement'
0.16    7.625   0       1
2.83    0.0022  1.9     1.3     0.14    0.165   1
0.05    1556    2       0.5     0.25
29000   0.02    0.01443         0.00361         60      60
6       'Grouted Masonry with Horizontal Reinforcement'
0.16    7.625   0       1
2.83    0.0022  1.9     1.3     0.14    0.165   1
0.05    1556    2       0.5     0.25
29000   0.02    0       0.00361         0       60
108     10      10 ----------------------------------------------------------------------------Card 9
1       99      100     101     102     103     104
105     106     107     108
99      100     101     102     103     104 ----------------------------------------Card 11
105     106     107     108
"Wall #5 - W5.Inp, Mesh 5 Nominal Properties, in-kips" ----------------------Card 12
0       0       1 ----------------------------------------------------------------------------Card 13
7 ----------------------------------------------------------------------------Card 16
61      81      80 ----------------------------------------------------------------------------Card 17
0.536   0       0.536   0 ----------------------------------------------------------Card 18
62      82      81
0.536   0       0.536   0
63      83      82
0.536   0       0.536   0
64      84      83
0.536   0       0.536   0
65      85      84
0.536   0       0.536   0
66      86      85
0.536   0       0.536   0
67      87      86
0.536   0       0.536   0
```

1	0	0	1	0	
5	250	2	2	0	0
4	0	0	1	-0.017	
5	250	2	2	0	0
4	0	0	1	0.017	
5	250	2	2	0	0
4	0	0	1	-0.017	
5	250	2	2	0	0
4	0	0	1	0.017	
5	250	2	2	0	0
4	0	0	1	-0.025	
5	250	2	2	0	0
4	0	0	1	0.026	
5	250	2	2	0	0
4	0	0	1	-0.025	
5	250	2	2	0	0
4	0	0	1	0.026	
5	250	2	2	0	0
4	0	0	1	-0.034	
5	250	2	2	0	0
4	0	0	1	0.034	
5	250	2	2	0	0
4	0	0	1	-0.034	
5	250	2	2	0	0
4	0	0	1	0.034	
5	250	2	2	0	0
4	0	0	1	-0.051	
5	250	2	2	0	0
4	0	0	1	0.051	
5	250	2	2	0	0
4	0	0	1	-0.051	
5	250	2	2	0	0
4	0	0	1	0.051	
5	250	2	2	0	0
4	0	0	1	-0.07	
5	250	2	2	0	0
4	0	0	1	0.07	
5	250	2	2	0	0
4	0	0	1	-0.053	
5	250	2	2	0	0
4	0	0	1	0.052	
5	250	2	2	0	0
4	0	0	1	-0.035	
5	250	2	2	0	0
4	0	0	1	0.035	

5	250	2	2	0	0
4	0	0	1	-0.105	
5	250	2	2	0	0
4	0	0	1	0.105	
5	250	2	2	0	0
4	0	0	1	-0.087	
5	250	2	2	0	0
4	0	0	1	0.088	
5	250	2	2	0	0
4	0	0	1	-0.053	
5	250	2	2	0	0
4	0	0	1	0.052	
5	250	2	2	0	0
4	0	0	1	-0.105	
5	250	2	2	0	0
4	0	0	1	0.105	
5	250	2	2	0	0
4	0	0	1	-0.105	
5	250	2	2	0	0
4	0	0	1	0.105	
5	250	2	2	0	0
4	0	0	1	-0.128	
5	250	2	2	0	0
4	0	0	1	0.128	
5	250	2	2	0	0
4	0	0	1	-0.105	
5	250	2	2	0	0
4	0	0	1	0.105	
5	250	2	2	0	0
4	0	0	1	-0.07	
5	250	2	2	0	0
4	0	0	1	0.123	
5	250	2	2	0	0
4	0	0	1	-0.14	
5	250	2	2	0	0
4	0	0	1	0.14	
5	250	2	2	0	0
8	0	0	1	-0.14	
5	250	2	2	0	0
8	0	0	1	0.14	
5	250	2	2	0	0
8	0	0	1	-0.21	
5	250	2	2	0	0
8	0	0	1	0.21	
5	250	2	2	0	0

8	0	0	1	-0.157	
5	250	2	2	0	0
8	0	0	1	0.158	
5	250	2	2	0	0
8	0	0	1	-0.105	
5	250	2	2	0	0
8	0	0	1	0.105	
5	250	2	2	0	0
8	0	0	1	-0.21	
5	250	2	2	0	0
8	0	0	1	0.21	
5	250	2	2	0	0
8	0	0	1	-0.21	
5	250	2	2	0	0
8	0	0	1	0.21	
5	250	2	2	0	0
8	0	0	1	-0.28	
5	250	2	2	0	0
8	0	0	1	0.28	
5	250	2	2	0	0
8	0	0	1	-0.21	
5	250	2	2	0	0
8	0	0	1	0.21	
5	250	2	2	0	0
8	0	0	1	-0.14	
5	250	2	2	0	0
8	0	0	1	0.14	
5	250	2	2	0	0
8	0	0	1	-0.28	
5	250	2	2	0	0
8	0	0	1	0.28	
5	250	2	2	0	0
8	0	0	1	-0.28	
5	250	2	2	0	0
8	0	0	1	0.28	
5	250	2	2	0	0
8	0	0	1	-0.35	
5	250	2	2	0	0
8	0	0	1	0.35	
5	250	2	2	0	0
8	0	0	1	-0.262	
5	250	2	2	0	0
8	0	0	1	0.263	
5	250	2	2	0	0
8	0	0	1	-0.175	

```
5     250   2     2     0     0
8     0     0     1     0.175
5     250   2     2     0     0
8     0     0     1     -0.35
5     250   2     2     0     0
8     0     0     1     0.35
5     250   2     2     0     0
8     0     0     1     -0.35
5     250   2     2     0     0
8     0     0     1     0.35
5     250   2     2     0     0
8     0     0     1     -0.42
5     250   2     2     0     0
8     0     0     1     0.42
5     250   2     2     0     0
-1    0     0     0     0
0     0     0     0     0     0
```

Appendix E
Input Description for Wall 7

Card Group 1

Program Execution

Card Group 2

Problem Title

Card Group 3

NVFIX = 34 17 nodes have pinned boundary conditions and 17 nodes have prescribed displacements.

NNODE = 4 The nonlinear element have 4 nodes.

NMATS = 1 - Concrete with horizontal and vertical reinforcement
2 - Concrete with horizontal reinforcement
3 - Grouted masonry with vertical reinforcement
4 - Ungrouted masonry
5 - Grouted masonry with horizontal and vertical reinforcement
6 - Grouted masonry with horizontal reinforcement

Card Group 4

Elements 2, 16, 18, 32, 132, 145, 147 and 191 have material property 1. Elements 1, 3 - 14, 16, 17, 19-30, 32, 131, 133 - 144, 146, 147, 149 - 160 and 162 have material property 2. Elements 33, 46, 47, 60, 61, 88, 89, 102, 103, 116, 117 and 130 have material property 3. Elements 34 - 45, 49 - 59, 52 - 73, 90 - 101, 104 - 115 and 118 - 129 have material property 4. Elements 75 and 98 have material property 5. Elements 76 - 97 have material property 6.

Specifying the element nodal connectivity numbers by starting at the same corner of each element (lower left hand corner in this case) guarantees that the Gauss points of all of the elements will be located in the same relative position. This is invaluable in the interpretation of the element stresses and strains.

Card Group 6

Nodal points 176 through 192 have prescribed displacement in the x direction and are free to translate in the y-direction. Therefore, the constraint code IFPRE is 10. Although any value of the x-component of the prescribed displacement PRESC(1) has been arbitrarily set to 1.0 so that the values given for FACTD in Card Group 18 are the actual displacements to be attained in the given load step. A positive displacement indicates that the displacement acts to the right.

Card Group 7

Material Properties

Concrete with Horizontal and Vertical Reinforcement		
ν	0.20	
f_c	5	ksi
ε_o	0.003	
A_1	2	
A_2	2	
A_3	0.1	
A_4	0.6	
MCD	1	
f_{cr}	0.504	ksi
E_t	3067	ksi
MTS	3	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	3.16	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.00423	
$^{**}\rho_h$	0.00760	
f_{yv}	60	ksi
f_{yh}	60	ksi

Concrete with Horizontal Reinforcement		
ν	0.20	
f_c	5	ksi
ε_o	0.003	
A_1	2	
A_2	2	
A_3	0.1	
A_4	0.6	
MCD	1	
f_{cr}	0.504	ksi
E_t	3067	ksi
MTS	3	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	3.16	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0.00760	
f_{yv}	0	ksi
f_{yh}	60	ksi

Grouted Masonry with Vertical Reinforcement		
ν	0.16	
f_m	2.96	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1628	ksi
MTS	2	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.01443	
$^{**}\rho_h$	0	
f_{yv}	60	ksi
f_{yh}	0	ksi

Ungrouted Masonry Unreinforced		
ν	0.16	
f_m	2.35	ksi
ε_o	0.0022	
A_1	1.7	
A_2	1.35	
A_3	0.11	
A_4	1.4	
MCD	1	
f_{cr}	0.05	ksi
E_t	1292	ksi
MTS	1	
B_1	0.5	
α	0.25	
E_s	0	ksi
ξ	0 %	
A_{sh}	0	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0	
f_{yv}	0	ksi
f_{yh}	0	ksi

Grouted Masonry with Horizontal and Vertical Reinforcement		
ν	0.16	
f_m	2.96	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1628	ksi
MTS	2	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0.51	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.01443	
$^{**}\rho_h$	0.00361	
f_{yv}	60	ksi
f_{yh}	60	ksi

Grouted Masonry with Horizontal Reinforcement		
ν	0.16	
f_m	2.96	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1628	ksi
MTS	1	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0.51	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0.00361	
f_{yv}	0	ksi
f_{yh}	60	ksi

* Vertical reinforcement ratios are calculated using the following equation:

$$\frac{\text{Area of vertical reinforcement}}{(\text{width of cell containing reinforcement})(\text{thickness of masonry wall})}$$

** Horizontal reinforcement ratios are calculated using the following equation:

$$\frac{\text{Area of horizontal reinforcement}}{(\text{width of cell containing reinforcement})(\text{thickness of masonry wall})}$$

Card Group 8

Not required - no initial stress

Card Group 9

NUMFDF = 17 To facilitate the interpretation off the output the sum of the reactions at 17 nodal points (NODE 1 = 176, NODE 2 = 177, NODE 3 = 178, ... NODE

17 = 192), i.e. the nodes with prescribed displacement will be directed to the Force-Deflection file along with the prescribed displacements at 1 nodal point (NODE1 = 176).

KOMPNT = 1 The x-component of the 17 reaction and the 1 displacement are to be output to the Force-Deflection file generated by FEM/I.

Card Group 10

Element Output Data

Card Group 11

Node Output Data

Card Group 12

Load Title

Card Group 13

Load Control Data

Card Group 14

Not required - no nodal point loading

Card Group 15

Not required - no gravity loading

Card Group 16

NEDGE = 14 Vertical axial pressure load applied to the top edge of elements 117 through 130.

Card Group 17

NOPRS(1) and NOPRS(2) - Specify the nodal points for each loaded element in a counterclockwise sequence. PRES(1,1) and PRES(2,1) - The normal load on an element is specified as a force per unit length (200 psi x 2.68 inch thickness = 0.536 kips per inch). A positive value indicates that the load acts downward (i.e. into the element).

Card Group 18

The load increment controls will generate 649 load/displacements increments. The convergence tolerance TOLER and maximum number of iterations MITER are set to 5% and 150, respectively, for all increments.

The first card (FACTE = 1.0, FACTD = 0.0, and NDIV = 1) will generate 1 increment where all of the vertical axial load is applied in the 1st increment (FACTE = 1.0) before any horizontal prescribed displacements are applied (FACTD = 0.0). In the remaining increments the vertical axial load is held constant (FACT = 1.0) and the horizontal prescribed displacements are applied in variable increments

The second card (FACTD = -0.014 and NDIV = 4) will generate 4 increments to move from the previous displacement of 0.0 inches to -0.014 inches with dx = -0.014/4 = -0.0035 inches.

The third card (FACTD = 0.014 and NDIV = 4) will generate 4 increments to move from the previous displacement of -0.014 to 0.014 inches with dx = (0.014 - (-0.0140) /4 = 0.007 inches.

The remaining cards generate increments in a similar manner. The load increment control data is terminated when NDIV = -1.

Input Data File for Wall 7

START ---------- Card 1
"Wall #7 - W7.Inp, Mesh 7,Entire Cycle, Nominal Properties, in-kips" ---------- Card 2
192 162 34 1 4 6 0 0 0 ---------- Card 3
1 2 1 2 19 18 ---------- Card 4
2 1 2 3 20 19
3 2 3 4 21 20
4 2 4 5 22 21
5 2 5 6 23 22
6 2 6 7 24 23
7 2 7 8 25 24
8 2 8 9 26 25
9 2 9 10 27 26
10 2 10 11 28 27
11 2 11 12 29 28
12 2 12 13 30 29
13 2 13 14 31 30
14 2 14 15 32 31
15 1 15 16 33 32
16 2 16 17 34 33
17 2 18 19 36 35
18 1 19 20 37 36
19 2 20 21 38 37
20 2 21 22 39 38
21 2 22 23 40 39
22 2 23 24 41 40
23 2 24 25 42 41
24 2 25 26 43 42
25 2 26 27 44 43
26 2 27 28 45 44
27 2 28 29 46 45
28 2 29 30 47 46
29 2 30 31 48 47
30 2 31 32 49 48
31 1 32 33 50 49
32 2 33 34 51 50
33 3 36 37 53 52
34 4 37 38 54 53
35 4 38 39 55 54
36 4 39 40 56 55
37 4 40 41 57 56
38 4 41 42 58 57
39 4 42 43 59 58
40 4 43 44 60 59

41	4	44	45	61	60
42	4	45	46	62	61
43	4	46	47	63	62
44	4	47	48	64	63
45	4	48	49	65	64
46	3	49	50	66	65
47	3	52	53	68	67
48	4	53	54	69	68
49	4	54	55	70	69
50	4	55	56	71	70
51	4	56	57	72	71
52	4	57	58	73	72
53	4	58	59	74	73
54	4	59	60	75	74
55	4	60	61	76	75
56	4	61	62	77	76
57	4	62	63	78	77
58	4	63	64	79	78
59	4	64	65	80	79
60	3	65	66	81	80
61	3	67	68	83	82
62	4	68	69	84	83
63	4	69	70	85	84
64	4	70	71	86	85
65	4	71	72	87	86
66	4	72	73	88	87
67	4	73	74	89	88
68	4	74	75	90	89
69	4	75	76	91	90
70	4	76	77	92	91
71	4	77	78	93	92
72	4	78	79	94	93
73	4	79	80	95	94
74	3	80	81	96	95
75	5	82	83	98	97
76	6	83	84	99	98
77	6	84	85	100	99
78	6	85	86	101	100
79	6	86	87	102	101
80	6	87	88	103	102
81	6	88	89	104	103
82	6	89	90	105	104
83	6	90	91	106	105
84	6	91	92	107	106
85	6	92	93	108	107

86	6	93	94	109	108
87	6	94	95	110	109
88	5	95	96	111	110
89	3	97	98	113	112
90	4	98	99	114	113
91	4	99	100	115	114
92	4	100	101	116	115
93	4	101	102	117	116
94	4	102	103	118	117
95	4	103	104	119	118
96	4	104	105	120	119
97	4	105	106	121	120
98	4	106	107	122	121
99	4	107	108	123	122
100	4	108	109	124	123
101	4	109	110	125	124
102	3	110	111	126	125
103	3	112	113	128	127
104	4	113	114	129	128
105	4	114	115	130	129
106	4	115	116	131	130
107	4	116	117	132	131
108	4	117	118	133	132
109	4	118	119	134	133
110	4	119	120	135	134
111	4	120	121	136	135
112	4	121	122	137	136
113	4	122	123	138	137
114	4	123	124	139	138
115	4	124	125	140	139
116	3	125	126	141	140
117	3	127	128	144	143
118	4	128	129	145	144
119	4	129	130	146	145
120	4	130	131	147	146
121	4	131	132	148	147
122	4	132	133	149	148
123	4	133	134	150	149
124	4	134	135	151	150
125	4	135	136	152	151
126	4	136	137	153	152
127	4	137	138	154	153
128	4	138	139	155	154
129	4	139	140	156	155
130	3	140	141	157	156

131	2	142	143	160	159
132	1	143	144	161	160
133	2	144	145	162	161
134	2	145	146	163	162
135	2	146	147	164	163
136	2	147	148	165	164
137	2	148	149	166	165
138	2	149	150	167	166
139	2	150	151	168	167
140	2	151	152	169	168
141	2	152	153	170	169
142	2	153	154	171	170
143	2	154	155	172	171
144	2	155	156	173	172
145	1	156	157	174	173
146	2	157	158	175	174
147	2	159	160	177	176
148	1	160	161	178	177
149	2	161	162	179	178
150	2	162	163	180	179
151	2	163	164	181	180
152	2	164	165	182	181
153	2	165	166	183	182
154	2	166	167	184	183
155	2	167	168	185	184
156	2	168	169	186	185
157	2	169	170	187	186
158	2	170	171	188	187
159	2	171	172	189	188
160	2	172	173	190	189
161	1	173	174	191	190
162	2	174	175	192	191

1	-60	-16	----------Card 5
2	-56	-16	
3	-48	-16	
4	-40	-16	
5	-32	-16	
6	-24	-16	
7	-16	-16	
8	-8	-16	
9	0	-16	
10	8	-16	
11	16	-16	
12	24	-16	
13	32	-16	

14	40	-16
15	48	-16
16	56	-16
17	60	-16
18	-60	-8
19	-56	-8
20	-48	-8
21	-40	-8
22	-32	-8
23	-24	-8
24	-16	-8
25	-8	-8
26	0	-8
27	8	-8
28	16	-8
29	24	-8
30	32	-8
31	40	-8
32	48	-8
33	56	-8
34	60	-8
35	-60	0
36	-56	0
37	-48	0
38	-40	0
39	-32	0
40	-24	0
41	-16	0
42	-8	0
43	0	0
44	8	0
45	16	0
46	24	0
47	32	0
48	40	0
49	48	0
50	56	0
51	60	0
52	-56	8
53	-48	8
54	-40	8
55	-32	8
56	-24	8
57	-16	8
58	-8	8

59	0	8
60	8	8
61	16	8
62	24	8
63	32	8
64	40	8
65	48	8
66	56	8
67	-56	16
68	-48	16
69	-40	16
70	-32	16
71	-24	16
72	-16	16
73	-8	16
74	0	16
75	8	16
76	16	16
77	24	16
78	32	16
79	40	16
80	48	16
81	56	16
82	-56	24
83	-48	24
84	-40	24
85	-32	24
86	-24	24
87	-16	24
88	-8	24
89	0	24
90	8	24
91	16	24
92	24	24
93	32	24
94	40	24
95	48	24
96	56	24
97	-56	32
98	-48	32
99	-40	32
100	-32	32
101	-24	32
102	-16	32
103	-8	32

104	0	32
105	8	32
106	16	32
107	24	32
108	32	32
109	40	32
110	48	32
111	56	32
112	-56	40
113	-48	40
114	-40	40
115	-32	40
116	-24	40
117	-16	40
118	-8	40
119	0	40
120	8	40
121	16	40
122	24	40
123	32	40
124	40	40
125	48	40
126	56	40
127	-56	48
128	-48	48
129	-40	48
130	-32	48
131	-24	48
132	-16	48
133	-8	48
134	0	48
135	8	48
136	16	48
137	24	48
138	32	48
139	40	48
140	48	48
141	56	48
142	-60	56
143	-56	56
144	-48	56
145	-40	56
146	-32	56
147	-24	56
148	-16	56

149	-8	56
150	0	56
151	8	56
152	16	56
153	24	56
154	32	56
155	40	56
156	48	56
157	56	56
158	60	56
159	-60	64
160	-56	64
161	-48	64
162	-40	64
163	-32	64
164	-24	64
165	-16	64
166	-8	64
167	0	64
168	8	64
169	16	64
170	24	64
171	32	64
172	40	64
173	48	64
174	56	64
175	60	64
176	-60	72
177	-56	72
178	-48	72
179	-40	72
180	-32	72
181	-24	72
182	-16	72
183	-8	72
184	0	72
185	8	72
186	16	72
187	24	72
188	32	72
189	40	72
190	48	72
191	56	72
192	60	72
1	11	0

0 ---------- Card 6

```
2       11      0       0
3       11      0       0
4       11      0       0
5       11      0       0
6       11      0       0
7       11      0       0
8       11      0       0
9       11      0       0
10      11      0       0
11      11      0       0
12      11      0       0
13      11      0       0
14      11      0       0
15      11      0       0
16      11      0       0
17      11      0       0
176     10      1       0
177     10      1       0
178     10      1       0
179     10      1       0
180     10      1       0
181     10      1       0
182     10      1       0
183     10      1       0
184     10      1       0
185     10      1       0
186     10      1       0
187     10      1       0
188     10      1       0
189     10      1       0
190     10      1       0
191     10      1       0
192     10      1       0
1       'Concrete with Horizontal and Vertical Reinforcement' ---------- Card 7
0.2     26      0       1
5       0.003   2       2       0.1     0.6     1
0.504   3067    3       0.5     0.25
29000   0.02    0.00423         0.0076  60      60
2       'Concrete with Horizontal Reinforcement'
0.2     26      0       1
5       0.003   2       2       0.1     0.6     1
0.504   3067    3       0.5     0.25
29000   0.02    0       0.0076  0       60
3       'Grouted Masonry with Vertical Reinforcement'
0.16    7.625   0       1
```

```
2.96    0.0022 1.9     1.3     0.14    0.165   1
0.05    1628   2       0.5     0.25
29000   0.02   0.01443         0       60      0
4       'Ungrouted Masonry'
0.16    2.68   0       1
2.35    0.0022 1.7     1.35    0.11    1.4     1
0.05    1292   1       0       0
0       0      0       0       0       0
5       'Grouted Masonry with Horizontal and Vertical Reinforcement'
0.16    7.625  0       1
2.96    0.0022 1.9     1.3     0.14    0.165   1
0.05    1628   2       0.5     0.25
29000   0.02   0.01443         0.00836         60      60
6       'Grouted Masonry with Horizontal Reinforcement'
0.16    7.625  0       1
2.96    0.0022 1.9     1.3     0.14    0.165   1
0.05    1628   2       0.5     0.25
29000   0.02   0       0.00836         0       60
162     17     17 ---------------------------------------------------------------------- Card 9
1       176    177     178     179     180     181
182     183    184     185     186     187     188
189     190    191     192
176     177    178     179     180     181     182 ---------------------------------- Card 11
183     184    185     186     187     188     189
190     191    192
"Wall #7 - W7.Inp, Mesh 1, Entire Cycle,Nominal Properties, in-kips" ---------- Card 12
0       0      1 ---------------------------------------------------------------------- Card 13
14 ---------------------------------------------------------------------------------- Card 16
117     144    143 -------------------------------------------------------------------- Card 17
0.536   0      0.536   0 ------------------------------------------------------------- Card 18
118     145    144
0.536   0      0.536   0
119     146    145
0.536   0      0.536   0
120     147    146
0.536   0      0.536   0
121     148    147
0.536   0      0.536   0
122     149    148
0.536   0      0.536   0
123     150    149
0.536   0      0.536   0
124     151    150
0.536   0      0.536   0
125     152    151
```

```
0.536  0      0.536  0
126    153    152
0.536  0      0.536  0
127    154    153
0.536  0      0.536  0
128    155    154
0.536  0      0.536  0
129    156    155
0.536  0      0.536  0
130    157    156
0.536  0      0.536  0
1      0      0      1      0
5      150    3      2      1      0
4      0      0      1      -0.014
5      150    3      2      1      0
4      0      0      1      .0.014
5      150    3      2      1      0
4      0      0      1      -0.014
5      150    3      2      1      0
4      0      0      1      0.014
5      150    3      2      1      0
4      0      0      1      -0.021
5      150    3      2      1      0
4      0      0      1      0.021
5      150    3      2      1      0
4      0      0      1      -0.021
5      150    3      2      1      0
4      0      0      1      0.021
5      150    3      2      1      0
4      0      0      1      -0.028
5      150    3      2      1      0
4      0      0      1      0.028
5      150    3      2      1      0
4      0      0      1      -0.028
5      150    3      2      1      0
4      0      0      1      0.028
5      150    3      2      1      0
4      0      0      1      -0.042
5      150    3      2      1      0
4      0      0      1      0.042
5      150    3      2      1      0
4      0      0      1      -0.042
5      150    3      2      1      0
4      0      0      1      0.042
5      150    3      2      1      0
```

4	0	0	1	-0.052
5	150	3	2	1 0
4	0	0	1	0.056
5	150	3	2	1 0
4	0	0	1	-0.056
5	150	3	2	1 0
4	0	0	1	0.056
5	150	3	2	1 0
4	0	0	1	-0.07
5	150	3	2	1 0
4	0	0	1	0.07
5	150	3	2	1 0
4	0	0	1	-0.07
5	150	3	2	1 0
4	0	0	1	0.07
5	150	3	2	1 0
4	0	0	1	-0.073
5	150	3	2	1 0
4	0	0	1	0.073
5	150	3	2	1 0
4	0	0	1	-0.0548
5	150	3	2	1 0
4	0	0	1	0.0548
5	150	3	2	1 0
4	0	0	1	-0.0365
5	150	3	2	1 0
4	0	0	1	0.0365
5	150	3	2	1 0
4	0	0	1	-0.073
5	150	3	2	1 0
4	0	0	1	0.073
5	150	3	2	1 0
4	0	0	1	-0.073
5	150	3	2	1 0
4	0	0	1	0.073
5	150	3	2	1 0
4	0	0	1	-0.1095
5	150	3	2	1 0
4	0	0	1	0.1095
5	150	3	2	1 0
4	0	0	1	-0.0913
5	150	3	2	1 0
4	0	0	1	0.0913
5	150	3	2	1 0
4	0	0	1	-0.0548

```
5   150   3   2   1   0
4   0     0   1   0.0548
5   150   3   2   1   0
8   0     0   1   -0.1095
5   150   3   2   1   0
8   0     0   1   0.1095
5   150   3   2   1   0
8   0     0   1   -0.1095
5   150   3   2   1   0
8   0     0   1   0.1095
5   150   3   2   1   0
8   0     0   1   -0.146
5   150   3   2   1   0
8   0     0   1   0.146
5   150   3   2   1   0
8   0     0   1   -0.1095
5   150   3   2   1   0
8   0     0   1   0.1095
5   150   3   2   1   0
8   0     0   1   -0.073
5   150   3   2   1   0
8   0     0   1   0.073
5   150   3   2   1   0
8   0     0   1   -0.146
5   150   3   2   1   0
8   0     0   1   0.146
5   150   3   2   1   0
8   0     0   1   -0.146
5   150   3   2   1   0
8   0     0   1   0.146
5   150   3   2   1   0
8   0     0   1   -0.219
5   150   3   2   1   0
8   0     0   1   0.219
5   150   3   2   1   0
8   0     0   1   -0.1643
5   150   3   2   1   0
8   0     0   1   0.1643
5   150   3   2   1   0
8   0     0   1   -0.1095
5   150   3   2   1   0
8   0     0   1   0.045
5   150   3   2   1   0
8   0     0   1   -0.09
5   150   3   2   1   0
```

8	0	0	1	0.1095
5	150	3	2	1 0
8	0	0	1	-0.219
5	150	3	2	1 0
8	0	0	1	0.219
5	150	3	2	1 0
8	0	0	1	-0.219
5	150	3	2	1 0
8	0	0	1	0.219
5	150	3	2	1 0
8	0	0	1	-0.292
5	150	3	2	1 0
8	0	0	1	0.292
5	150	3	2	1 0
8	0	0	1	-0.219
5	150	3	2	1 0
8	0	0	1	0.219
5	150	3	2	1 0
8	0	0	1	-0.146
5	150	3	2	1 0
8	0	0	1	0.146
5	150	3	2	1 0
8	0	0	1	-0.225
5	150	3	2	1 0
8	0	0	1	-0.101
5	150	3	2	1 0
8	0	0	1	-0.292
5	150	3	2	1 0
8	0	0	1	0.045
5	150	3	2	1 0
8	0	0	1	0.292
5	150	3	2	1 0
8	0	0	1	-0.292
5	150	3	2	1 0
8	0	0	1	0.292
5	150	3	2	1 0
8	0	0	1	-0.365
5	150	3	2	1 0
8	0	0	1	0.365
5	150	3	2	1 0
8	0	0	1	-0.2738
5	150	3	2	1 0
8	0	0	1	0.2738
5	150	3	2	1 0
8	0	0	1	-0.1825

```
5     150   3     2     1     0
8     0     0     1     0.1825
5     150   3     2     1     0
8     0     0     1     -0.365
5     150   3     2     1     0
8     0     0     1     0.365
5     150   3     2     1     0
8     0     0     1     -0.365
5     150   3     2     1     0
8     0     0     1     0.365
5     150   3     2     1     0
8     0     0     1     -0.438
5     150   3     2     1     0
8     0     0     1     0.315
5     150   3     2     1     0
8     0     0     1     0.18
5     150   3     2     1     0
8     0     0     1     0.438
5     150   3     2     1     0
8     0     0     1     -0.329
5     150   3     2     1     0
8     0     0     1     0.329
5     150   3     2     1     0
8     0     0     1     -0.219
5     150   3     2     1     0
8     0     0     1     0.219
5     150   3     2     1     0
8     0     0     1     -0.438
5     150   3     2     1     0
8     0     0     1     0.438
5     150   3     2     1     0
8     0     0     1     -0.438
5     150   3     2     1     0
8     0     0     1     0.279
5     150   3     2     1     0
-1    0     0     0     0
0     0     0     0     1     0
```

Appendix F
Input Description for Wall 9

Card Group 1

Program Execution

Card Group 2

Problem Title

Card Group 3

NVFIX = 26 13 nodes have pinned boundary conditions and 13 nodes have prescribed displacements.

NNODE = 4 The nonlinear element having only 4 nodes.

NMATS = 1 - Concrete with horizontal and vertical reinforcement
2 - Concrete with horizontal reinforcement
3 - Grouted masonry with vertical reinforcement
4 - Ungrouted masonry
5 - Grouted masonry with horizontal and vertical reinforcement
6 - Grouted masonry with horizontal reinforcement

Card Group 4

Elements 2, 11, 14, 23, 96, 105, 108 and 117 have material property 1. Elements 1, 2-10, 12, 13, 15-22 and 24 have material property 2. Elements 25, 34, 35, 44, 45, 54, 65, 74, 75, 84, 85, and 94 have material property 3. Elements 26-33, 36-43, 46-53, 66-73, 76-83, 86-93 have material property 4. Elements 55 and 64 have material property 5 Elements 56 - 63 have material property 6.

Specifying the element nodal connectivity numbers by starting at the same corner of each element (lower left hand corner in this case) guarantees that the Gauss points of all of the elements will be located in the same relative position. This is invaluable in the interpretation of the element stresses and strains.

Card Group 6

Nodal points 132 through 144 have prescribed displacement in the x direction and are free to translate in the y-direction. Therefore, the constraint code IFPRE is 10. Although any value of the x-component of the prescribed displacement PRESC(1) has been arbitrarily set to 1.0 so that the values given for FACTD in Card Group 18 are the actual displacements to be attained in the given load step. A positive displacement indicates that the displacement acts to the right.

Card Group 7

Material Properties

Concrete with Horizontal and Vertical Reinforcement		
ν	0.20	
f_c	5	ksi
ε_o	0.003	
A_1	2	
A_2	2	
A_3	0.1	
A_4	0.6	
MCD	1	
f_{cr}	0.504	ksi
E_t	3067	ksi
MTS	3	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	3.16	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.00423	
$^{**}\rho_h$	0.00760	
f_{yv}	60	ksi
f_{yh}	60	ksi

Concrete with Horizontal Reinforcement		
ν	0.20	
f_c	5	ksi
ε_o	0.003	
A_1	2	
A_2	2	
A_3	0.1	
A_4	0.6	
MCD	1	
f_{cr}	0.504	ksi
E_t	3067	ksi
MTS	3	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	3.16	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0.00760	
f_{yv}	0	ksi
f_{yh}	60	ksi

Grouted Masonry with Vertical Reinforcement		
ν	0.16	
f_m	2.65	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1458	ksi
MTS	2	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.01443	
$^{**}\rho_h$	0	
f_{yv}	60	ksi
f_{yh}	0	ksi

Ungrouted Masonry Unreinforced		
ν	0.16	
f_m	2.62	ksi
ε_o	0.0022	
A_1	1.7	
A_2	1.35	
A_3	0.11	
A_4	1.4	
MCD	1	
f_{cr}	0.05	ksi
E_t	1441	ksi
MTS	1	
B_1	0.5	
α	0.25	
E_s	0	ksi
ξ	0 %	
A_{sh}	0	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0	
f_{yv}	0	ksi
f_{yh}	0	ksi

Grouted Masonry with Horizontal and Vertical Reinforcement		
ν	0.16	
f_m	2.65	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1458	ksi
MTS	2	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0.51	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.01443	
$^{**}\rho_h$	0.00361	
f_{yv}	60	ksi
f_{yh}	60	ksi

Grouted Masonry with Horizontal Reinforcement		
ν	0.16	
f_m	2.65	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1458	ksi
MTS	1	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0.51	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0.00361	
f_{yv}	0	ksi
f_{yh}	60	ksi

* Vertical reinforcement ratios are calculated using the following equation:

$$\frac{\text{Area of vertical reinforcement}}{(\text{width of cell containing reinforcement})(\text{thickness of masonry wall})}$$

** Horizontal reinforcement ratios are calculated using the following equation:

$$\frac{\text{Area of horizontal reinforcement}}{(\text{width of cell containing reinforcement})(\text{thickness of masonry wall})}$$

Card Group 8

Not required - no initial stress

Card Group 9

NUMFDF = 13 To facilitate the interpretation off the output the sum of the reactions at 13 nodal points (NODE 1 = 132, NODE 2 = 133, NODE 3 = 134, ... NODE

13 = 144), i.e. the nodes with prescribed displacement will be directed to the Force-Deflection file along with the prescribed displacements at 1 nodal point (NODE1 = 132).

KOMPNT = 1 The x-component of the 13 reaction and the 1 displacement are to be output to the Force-Deflection file.

Card Group 10
Element Output Data

Card Group 11
Node Output Data

Card Group 12
Load Title

Card Group 13
Load Control Data

Card Group 14
Not required - no nodal point loading

Card Group 15
Not required - no gravity loading

Card Group 16
NEDGE = 10 Vertical axial pressure load applied to the top edge of elements 85 through 94.

Card Group 17
NOPRS(1) and NOPRS(2) - Specify the nodal points for each loaded element in a counterclockwise sequence. PRES(1,1) and PRES(2,1) - The normal load on an element is specified as a force per unit length (200 psi x 2.68 inch thickness = 0.536 kips per inch). A positive value indicates that the load acts downward (i.e. into the element).

Card Group 18
The load increment controls will generate 629 load/displacements increments. The convergence tolerance TOLER and maximum number of iterations MITER are set to 5% and 250, respectively, for all increments.

The first card (FACTE = 1.0, FACTD = 0.0, and NDIV = 1) will generate 1 increment where all of the vertical axial load is applied in the 1st increment (FACTE = 1.0) before any horizontal prescribed displacements are applied (FACTD = 0.0). In the remaining increments the vertical axial load is held constant (FACT = 1.0) and the horizontal prescribed displacements are applied in variable increments

The second card (FACTD = -0.015 and NDIV = 4) will generate 4 increments to move form the previous displacement of 0.0 inches to -0.015 inches with dx = -0.015/4 = -0.00375 inches.

The third card (FACTD = 0.015 and NDIV = 4) will generate 4 increments to move from the previous displacement of -0.015 to 0.015 inches with dx = (0.015 - (-0.015)) /4 = 0.0075 inches.

The remaining cards generate increments in a similar manner. The load increment control data is terminated when NDIV = -1.

Input Data File for Wall 9

START ----------Card 1
"Wall #9 - W9.Inp, Mesh9, Nominal Properties, in-kips" ----------Card 2
144 118 26 1 4 6 0 0 0 ----------Card 3
----------Card 4

1	2	1	2	15	14
2	1	2	3	16	15
3	2	3	4	17	16
4	2	4	5	18	17
5	2	5	6	19	18
6	2	6	7	20	19
7	2	7	8	21	20
8	2	8	9	22	21
9	2	9	10	23	22
10	2	10	11	24	23
11	1	11	12	25	24
12	2	12	13	26	25
13	2	14	15	28	27
14	1	15	16	29	28
15	2	16	17	30	29
16	2	17	18	31	30
17	2	18	19	32	31
18	2	19	20	33	32
19	2	20	21	34	33
20	2	21	22	35	34
21	2	22	23	36	35
22	2	23	24	37	36
23	1	24	25	38	37
24	2	25	26	39	38
25	3	28	29	41	40
26	4	29	30	42	41
27	4	30	31	43	42
28	4	31	32	44	43
29	4	32	33	45	44
30	4	33	34	46	45
31	4	34	35	47	46
32	4	35	36	48	47
33	4	36	37	49	48
34	3	37	38	50	49
35	3	40	41	52	51
36	4	41	42	53	52
37	4	42	43	54	53
38	4	43	44	55	54
39	4	44	45	56	55
40	4	45	46	57	56

41	4	46	47	58	57
42	4	47	48	59	58
43	4	48	49	60	59
44	3	49	50	61	60
45	3	51	52	63	62
46	4	52	53	64	63
47	4	53	54	65	64
48	4	54	55	66	65
49	4	55	56	67	66
50	4	56	57	68	67
51	4	57	58	69	68
52	4	58	59	70	69
53	4	59	60	71	70
54	3	60	61	72	71
55	5	62	63	74	73
56	6	63	64	75	74
57	6	64	65	76	75
58	6	65	66	77	76
59	6	66	67	78	77
60	6	67	68	79	78
61	6	68	69	80	79
62	6	69	70	81	80
63	6	70	71	82	81
64	5	71	72	83	82
65	3	73	74	85	84
66	4	74	75	86	85
67	4	75	76	87	86
68	4	76	77	88	87
69	4	77	78	89	88
70	4	78	79	90	89
71	4	79	80	91	90
72	4	80	81	92	91
73	4	81	82	93	92
74	3	82	83	94	93
75	3	84	85	96	95
76	4	85	86	97	96
77	4	86	87	98	97
78	4	87	88	99	98
79	4	88	89	100	99
80	4	89	90	101	100
81	4	90	91	102	101
82	4	91	92	103	102
83	4	92	93	104	103
84	3	93	94	105	104
85	3	95	96	108	107

86	4	96	97	109	108
87	4	97	98	110	109
88	4	98	99	111	110
89	4	99	100	112	111
90	4	100	101	113	112
91	4	101	102	114	113
92	4	102	103	115	114
93	4	103	104	116	115
94	3	104	105	117	116
95	2	106	107	120	119
96	1	107	108	121	120
97	2	108	109	122	121
98	2	109	110	123	122
99	2	110	111	124	123
100	2	111	112	125	124
101	2	112	113	126	125
102	2	113	114	127	126
103	2	114	115	128	127
104	2	115	116	129	128
105	1	116	117	130	129
106	2	117	118	131	130
107	2	119	120	133	132
108	1	120	121	134	133
109	2	121	122	135	134
110	2	122	123	136	135
111	2	123	124	137	136
112	2	124	125	138	137
113	2	125	126	139	138
114	2	126	127	140	139
115	2	127	128	141	140
116	2	128	129	142	141
117	1	129	130	143	142
118	2	130	131	144	143

1	-45.375		-16 ----------Card 5
2	-40	-16	
3	-32	-16	
4	-24	-16	
5	-16	-16	
6	-8	-16	
7	0	-16	
8	8	-16	
9	16	-16	
10	24	-16	
11	32	-16	
12	40	-16	

13	45.375	-16	
14	-45.375		-8
15	-40	-8	
16	-32	-8	
17	-24	-8	
18	-16	-8	
19	-8	-8	
20	0	-8	
21	8	-8	
22	16	-8	
23	24	-8	
24	32	-8	
25	40	-8	
26	45.375	-8	
27	-45.375		0
28	-40	0	
29	-32	0	
30	-24	0	
31	-16	0	
32	-8	0	
33	0	0	
34	8	0	
35	16	0	
36	24	0	
37	32	0	
38	40	0	
39	45.375	0	
40	-40	8	
41	-32	8	
42	-24	8	
43	-16	8	
44	-8	8	
45	0	8	
46	8	8	
47	16	8	
48	24	8	
49	32	8	
50	40	8	
51	-40	16	
52	-32	16	
53	-24	16	
54	-16	16	
55	-8	16	
56	0	16	
57	8	16	

58	16	16
59	24	16
60	32	16
61	40	16
62	-40	24
63	-32	24
64	-24	24
65	-16	24
66	-8	24
67	0	24
68	8	24
69	16	24
70	24	24
71	32	24
72	40	24
73	-40	32
74	-32	32
75	-24	32
76	-16	32
77	-8	32
78	0	32
79	8	32
80	16	32
81	24	32
82	32	32
83	40	32
84	-40	40
85	-32	40
86	-24	40
87	-16	40
88	-8	40
89	0	40
90	8	40
91	16	40
92	24	40
93	32	40
94	40	40
95	-40	48
96	-32	48
97	-24	48
98	-16	48
99	-8	48
100	0	48
101	8	48
102	16	48

```
103     24      48
104     32      48
105     40      48
106     -45.375         56
107     -40     56
108     -32     56
109     -24     56
110     -16     56
111     -8      56
112     0       56
113     8       56
114     16      56
115     24      56
116     32      56
117     40      56
118     45.375  56
119     -45.375         64
120     -40     64
121     -32     64
122     -24     64
123     -16     64
124     -8      64
125     0       64
126     8       64
127     16      64
128     24      64
129     32      64
130     40      64
131     45.375  64
132     -45.375         72
133     -40     72
134     -32     72
135     -24     72
136     -16     72
137     -8      72
138     0       72
139     8       72
140     16      72
141     24      72
142     32      72
143     40      72
144     45.375  72
1       11      0       0 ----------Card 6
2       11      0       0
3       11      0       0
```

```
4       11      0       0
5       11      0       0
6       11      0       0
7       11      0       0
8       11      0       0
9       11      0       0
10      11      0       0
11      11      0       0
12      11      0       0
13      11      0       0
132     10      1       0
133     10      1       0
134     10      1       0
135     10      1       0
136     10      1       0
137     10      1       0
138     10      1       0
139     10      1       0
140     10      1       0
141     10      1       0
142     10      1       0
143     10      1       0
144     10      1       0
1       'Concrete with Horizontal and Vertical Reinforcement' ----------Card 7
0.2     26      0       1
5       0.003   2       2       0.1     0.6     1
0.504   3067    3       0.5     0.25
29000   0.02    0.00423         0.0076  60      60
2       'Concrete with Horizontal Reinforcement'
0.2     26      0       1
5       0.003   2       2       0.1     0.6     1
0.504   3067    3       0.5     0.25
29000   0.02    0       0.0076  0       60
3       'Grouted Masonry with Vertical Reinforcement'
0.16    7.625   0       1
2.65    0.0022  1.9     1.3     0.14    0.165   1
0.05    1458    2       0.5     0.25
29000   0.02    0.01443         0       60      0
4       'Ungrouted Masonry'
0.16    2.68    0       1
2.62    0.0022  1.7     1.35    0.11    1.4     1
0.05    1441    1       0       0
0       0       0       0       0       0
5       'Grouted Masonry with Horizontal and Vertical Reinforcement'
0.16    7.625   0       1
```

```
2.65    0.0022 1.9     1.3     0.14    0.165  1
0.05    1458   2       0.5     0.25
29000 0.02     0.01443         0.00836         60      60
6       'Grouted Masonry with Horizontal Reinforcement'
0.16    7.625  0       1
2.65    0.0022 1.9     1.3     0.14    0.165  1
0.05    1458   2       0.5     0.25
29000 0.02     0       0.00836         0       60
144     13      13 ----------------------------------------------------------------------Card 9
1       132     133     134     135     136     137
138     139     140     141     142     143     144
132     133     134     135     136     137
138     139     140     141     142     143     144 ----------------------------Card 11
"Wall #9 - W9.Inp, Mesh 9 Nominal Properties, in-kips" ----------------------Card 12
0       0       1 ----------------------------------------------------------------Card 13
10 ----------------------------------------------------------------------------Card 16
85      108     107 ---------------------------------------------------------Card 17
0.536   0       0.536   0 ----------------------------------------------------Card 18
86      109     108
0.536   0       0.536   0
87      110     109
0.536   0       0.536   0
88      111     110
0.536   0       0.536   0
89      112     111
0.536   0       0.536   0
90      113     112
0.536   0       0.536   0
91      114     113
0.536   0       0.536   0
92      115     114
0.536   0       0.536   0
93      116     115
0.536   0       0.536   0
94      117     116
0.536   0       0.536   0
1       0       0       1       0
5       250     2       2       0       0
4       0       0       1       -0.015
5       250     2       2       0       0
4       0       0       1       0.015
5       250     2       2       0       0
4       0       0       1       -0.015
5       250     2       2       0       0
4       0       0       1       0.015
```

5	250	2	2	0	0
4	0	0	1	-0.022	
5	250	2	2	0	0
4	0	0	1	0.022	
5	250	2	2	0	0
4	0	0	1	-0.022	
5	250	2	2	0	0
4	0	0	1	0.022	
5	250	2	2	0	0
4	0	0	1	-0.03	
5	250	2	2	0	0
4	0	0	1	0.03	
5	250	2	2	0	0
4	0	0	1	-0.022	
5	250	2	2	0	0
4	0	0	1	0.022	
5	250	2	2	0	0
4	0	0	1	-0.015	
5	250	2	2	0	0
4	0	0	1	0.015	
5	250	2	2	0	0
4	0	0	1	-0.03	
5	250	2	2	0	0
4	0	0	1	0.03	
5	250	2	2	0	0
4	0	0	1	-0.03	
5	250	2	2	0	0
4	0	0	1	0.03	
5	250	2	2	0	0
4	0	0	1	-0.045	
5	250	2	2	0	0
4	0	0	1	0.045	
5	250	2	2	0	0
4	0	0	1	-0.0375	
5	250	2	2	0	0
4	0	0	1	0.0375	
5	250	2	2	0	0
4	0	0	1	-0.022	
5	250	2	2	0	0
4	0	0	1	0.022	
5	250	2	2	0	0
4	0	0	1	-0.045	
5	250	2	2	0	0
4	0	0	1	0.045	
5	250	2	2	0	0

4	0	0	1	-0.045	
5	250	2	2	0	0
4	0	0	1	0.045	
5	250	2	2	0	0
4	0	0	1	-0.06	
5	250	2	2	0	0
4	0	0	1	0.06	
5	250	2	2	0	0
4	0	0	1	-0.045	
5	250	2	2	0	0
4	0	0	1	0.045	
5	250	2	2	0	0
4	0	0	1	-0.03	
5	250	2	2	0	0
4	0	0	1	0.03	
5	250	2	2	0	0
4	0	0	1	-0.06	
5	250	2	2	0	0
4	0	0	1	0.06	
5	250	2	2	0	0
4	0	0	1	-0.06	
5	250	2	2	0	0
4	0	0	1	0.06	
5	250	2	2	0	0
4	0	0	1	-0.09	
5	250	2	2	0	0
8	0	0	1	0.09	
5	250	2	2	0	0
8	0	0	1	-0.0675	
5	250	2	2	0	0
8	0	0	1	0.0675	
5	250	2	2	0	0
8	0	0	1	-0.045	
5	250	2	2	0	0
8	0	0	1	0.045	
5	250	2	2	0	0
8	0	0	1	-0.09	
5	250	2	2	0	0
8	0	0	1	0.09	
5	250	2	2	0	0
8	0	0	1	-0.09	
5	250	2	2	0	0
8	0	0	1	0.09	
5	250	2	2	0	0
8	0	0	1	-0.12	

```
5    250    2    2    0    0
8    0    0    1    0.12
5    250    2    2    0    0
8    0    0    1    -0.09
5    250    2    2    0    0
8    0    0    1    0.09
5    250    2    2    0    0
8    0    0    1    -0.06
5    250    2    2    0    0
8    0    0    1    0.06
5    250    2    2    0    0
8    0    0    1    -0.12
5    250    2    2    0    0
8    0    0    1    0.12
5    250    2    2    0    0
8    0    0    1    -0.12
5    250    2    2    0    0
8    0    0    1    0.12
5    250    2    2    0    0
8    0    0    1    -0.15
5    250    2    2    0    0
8    0    0    1    0.15
5    250    2    2    0    0
8    0    0    1    -0.1125
5    250    2    2    0    0
8    0    0    1    0.1125
5    250    2    2    0    0
8    0    0    1    -0.075
5    250    2    2    0    0
8    0    0    1    0.075
5    250    2    2    0    0
8    0    0    1    -0.15
5    250    2    2    0    0
8    0    0    1    0.15
5    250    2    2    0    0
8    0    0    1    -0.15
5    250    2    2    0    0
8    0    0    1    0.15
5    250    2    2    0    0
8    0    0    1    -0.18
5    250    2    2    0    0
8    0    0    1    0.18
5    250    2    2    0    0
8    0    0    1    -0.135
5    250    2    2    0    0
```

8	0	0	1	0.135	
5	250	2	2	0	0
8	0	0	1	-0.09	
5	250	2	2	0	0
8	0	0	1	0.09	
5	250	2	2	0	0
8	0	0	1	-0.18	
5	250	2	2	0	0
8	0	0	1	0.18	
5	250	2	2	0	0
8	0	0	1	-0.18	
5	250	2	2	0	0
8	0	0	1	0.18	
5	250	2	2	0	0
8	0	0	1	-0.24	
5	250	2	2	0	0
8	0	0	1	0.24	
5	250	2	2	0	0
8	0	0	1	-0.18	
5	250	2	2	0	0
8	0	0	1	0.18	
5	250	2	2	0	0
8	0	0	1	-0.12	
5	250	2	2	0	0
8	0	0	1	0.12	
5	250	2	2	0	0
8	0	0	1	-0.24	
5	250	2	2	0	0
8	0	0	1	0.24	
5	250	2	2	0	0
8	0	0	1	-0.24	
5	250	2	2	0	0
8	0	0	1	0.24	
5	250	2	2	0	0
8	0	0	1	-0.3	
5	250	2	2	0	0
8	0	0	1	0.3	
5	250	2	2	0	0
8	0	0	1	-0.225	
5	250	2	2	0	0
8	0	0	1	0.225	
5	250	2	2	0	0
8	0	0	1	-0.15	
5	250	2	2	0	0
8	0	0	1	0.15	

```
5     250   2     2     0     0
8     0     0     1     -0.3
5     250   2     2     0     0
8     0     0     1     0.27
5     250   2     2     0     0
8     0     0     1     -0.3
5     250   2     2     0     0
8     0     0     1     0.3
5     250   2     2     0     0
-1    0     0     0     0
0     0     0     0     0     0
```

Appendix G
Input Description for Wall 11

Card Group 1

Program Execution

Card Group 2

Problem Title

Card Group 3

NVFIX = 20 10 nodes have pinned boundary conditions and 10 nodes have prescribed displacements.

NNODE = 4 The nonlinear element having only 4 nodes

NMATS = 1 - Concrete with horizontal and vertical reinforcement
2 - Concrete with horizontal reinforcement
3 - Grouted masonry with vertical reinforcement
4 - Ungrouted masonry
5 - Grouted masonry with horizontal and vertical reinforcement
6 - Grouted masonry with horizontal reinforcement

Card Group 4

Elements 2, 8, 11, 17, 69, 75, 78 and 84 have material property 1. Elements 1, 3 - 7 ,9, 10, 12 - 16, 18, 88, 70 - 74, 76, 77, 79 - 83 and 85 have material property 2. Elements 19, 25, 26, 32, 33, 39, 47, 53, 54, 60, 61 and 67, have material property 3. Elements 20 - 24, 27 - 31, 34 - 38, 48 - 52, 55 - 59, and 62 - 66have material property 4. Elements 40 and 46 have material property 5. Elements 41 - 45 have material property 6

Specifying the element nodal connectivity numbers by starting at the same corner of each element (lower left hand corner in this case) guarantees that the Gauss points of all of the elements will be located in the same relative position. This is invaluable in the interpretation of the element stresses and strains.

Card Group 6

Nodal points 79 through 88 have prescribed displacement in the x direction and are free to translate in the y-direction. Therefore, the constraint code IFPRE is 10. Although any value of the x-component of the prescribed displacement PRESC(1) has been arbitrarily set to 1.0 so that the values given for FACTD in Card Group 18 are the actual displacements to be attained in the given load step. A positive displacement indicates that the displacement acts to the right.

Card Group 7

Material Properties

Concrete with Horizontal and Vertical Reinforcement		
ν	0.20	
f_c	5	ksi
ε_o	0.003	
A_1	2	
A_2	2	
A_3	0.1	
A_4	0.6	
MCD	1	
f_{cr}	0.504	ksi
E_t	3067	ksi
MTS	3	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	3.16	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.00423	
$^{**}\rho_h$	0.00760	
f_{yv}	60	ksi
f_{yh}	60	ksi

Concrete with Horizontal Reinforcement		
ν	0.20	
f_c	5	ksi
ε_o	0.003	
A_1	2	
A_2	2	
A_3	0.1	
A_4	0.6	
MCD	1	
f_{cr}	0.504	ksi
E_t	3067	ksi
MTS	3	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	3.16	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0.00760	
f_{yv}	0	ksi
f_{yh}	60	ksi

Grouted Masonry with Vertical Reinforcement		
ν	0.16	
f_m	2.77	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1524	ksi
MTS	2	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.01443	
$^{**}\rho_h$	0	
f_{yv}	60	ksi
f_{yh}	0	ksi

Ungrouted Masonry Unreinforced		
ν	0.16	
f_m	2.85	ksi
ε_o	0.0022	
A_1	1.7	
A_2	1.35	
A_3	0.11	
A_4	1.4	
MCD	1	
f_{cr}	0.05	ksi
E_t	1568	ksi
MTS	1	
B_1	0.5	
α	0.25	
E_s	0	ksi
ξ	0 %	
A_{sh}	0	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0	
f_{yv}	0	ksi
f_{yh}	0	ksi

Grouted Masonry with Horizontal and Vertical Reinforcement		
ν	0.16	
f_m	2.77	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1524	ksi
MTS	2	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0.51	in^2
A_{sv}	0.88	in^2
$^{*}\rho_v$	0.01443	
$^{**}\rho_h$	0.00361	
f_{yv}	60	ksi
f_{yh}	60	ksi

Grouted Masonry with Horizontal Reinforcement		
ν	0.16	
f_m	2.77	ksi
ε_o	0.0022	
A_1	1.9	
A_2	1.3	
A_3	0.14	
A_4	0.165	
MCD	1	
f_{cr}	0.05	ksi
E_t	1524	ksi
MTS	1	
B_1	0.5	
α	0.25	
E_s	29000	ksi
ξ	2 %	
A_{sh}	0.51	in^2
A_{sv}	0	in^2
$^{*}\rho_v$	0	
$^{**}\rho_h$	0.00361	
f_{yv}	0	ksi
f_{yh}	60	ksi

* Vertical reinforcement ratios are calculated using the following equation:

$$\frac{\text{Area of vertical reinforcement}}{(\text{width of cell containing reinforcement})(\text{thickness of masonry wall})}$$

** Horizontal reinforcement ratios are calculated using the following equation:

$$\frac{\text{Area of horizontal reinforcement}}{(\text{width of cell containing reinforcement})(\text{thickness of masonry wall})}$$

Card Group 8

Not required - no initial stress

Card Group 9

NUMFDF = 13 To facilitate the interpretation off the output the sum of the reactions at 13 nodal points (NODE 1 = 132, NODE 2 = 133, NODE 3 = 134, ... NODE

13 = 144), i.e. the nodes with prescribed displacement will be directed to the Force-Deflection file along with the prescribed displacements at 1 nodal point (NODE1 = 132).

KOMPNT = 1 The x-component of the 13 reaction and the 1 displacement are to be output to the Force-Deflection file.

Card Group 10
Element Output Data

Card Group 11
Node Output Data

Card Group 12
Load Title

Card Group 13
Load Control Data

Card Group 14
Not required - no nodal point loading

Card Group 15
Not required - no gravity loading

Card Group 16
NEDGE = 10 Vertical axial pressure load applied to the top edge of elements 61 through 67.

Card Group 17
NOPRS(1) and NOPRS(2) - Specify the nodal points for each loaded element in a counterclockwise sequence. PRES(1,1) and PRES(2,1) - The normal load on an element is specified as a force per unit length (200 psi x 2.68 inch thickness = 0.536 kips per inch). A positive value indicates that the load acts downward (i.e. into the element).

Card Group 18
The load increment controls will generate 541 load/displacements increments. The convergence tolerance TOLER and maximum number of iterations MITER are set to 5% and 250, respectively, for all increments.

The first card (FACTE = 1.0, FACTD = 0.0, and NDIV = 1) will generate 1 increment where all of the vertical axial load is applied in the 1st increment (FACTE = 1.0) before any horizontal prescribed displacements are applied (FACTD = 0.0). In the remaining increments the vertical axial load is held constant (FACT = 1.0) and the horizontal prescribed displacements are applied in variable increments

The second card (FACTD = -0.017 and NDIV = 4) will generate 4 increments to move from the previous displacement of 0.0 inches to -0.017 inches with dx = -0.017/4 = -0.00425 inches.

The third card (FACTD = 0.017 and NDIV = 4) will generate 4 increments to move from the previous displacement of -0.017 to 0.017 inches with dx = [0.017 - (-0.017)] /4 = 0.0085 inches.

The remaining cards generate increments in a similar manner. The load increment control data is terminated when NDIV = -1.

Input Data File for Wall 11

START ----------Card 1
"Wall #11 - W11.Inp, Mesh 11, Nominal Properties, in-kips" ----------Card 2

108	85	20	1	4	6	0	0	0	----------Card 3
1	2	1	2	12	11	----------			Card 4
2	1	2	3	13	12				
3	2	3	4	14	13				
4	2	4	5	15	14				
5	2	5	6	16	15				
6	2	6	7	17	16				
7	2	7	8	18	17				
8	1	8	9	19	18				
9	2	9	10	20	19				
10	2	11	12	22	21				
11	1	12	13	23	22				
12	2	13	14	24	23				
13	2	14	15	25	24				
14	2	15	16	26	25				
15	2	16	17	27	26				
16	2	17	18	28	27				
17	1	18	19	29	28				
18	2	19	20	30	29				
19	3	22	23	32	31				
20	4	23	24	33	32				
21	4	24	25	34	33				
22	4	25	26	35	34				
23	4	26	27	36	35				
24	4	27	28	37	36				
25	3	28	29	38	37				
26	3	31	32	40	39				
27	4	32	33	41	40				
28	4	33	34	42	41				
29	4	34	35	43	42				
30	4	35	36	44	43				
31	4	36	37	45	44				
32	3	37	38	46	45				
33	3	39	40	48	47				
34	4	40	41	49	48				
35	4	41	42	50	49				
36	4	42	43	51	50				
37	4	43	44	52	51				
38	4	44	45	53	52				
39	3	45	46	54	53				
40	5	47	48	56	55				

41	6	48	49	57	56
42	6	49	50	58	57
43	6	50	51	59	58
44	6	51	52	60	59
45	6	52	53	61	60
46	5	53	54	62	61
47	3	55	56	64	63
48	4	56	57	65	64
49	4	57	58	66	65
50	4	58	59	67	66
51	4	59	60	68	67
52	4	60	61	69	68
53	3	61	62	70	69
54	3	63	64	72	71
55	4	64	65	73	72
56	4	65	66	74	73
57	4	66	67	75	74
58	4	67	68	76	75
59	4	68	69	77	76
60	3	69	70	78	77
61	3	71	72	81	80
62	4	72	73	82	81
63	4	73	74	83	82
64	4	74	75	84	83
65	4	75	76	85	84
66	4	76	77	86	85
67	3	77	78	87	86
68	2	79	80	90	89
69	1	80	81	91	90
70	2	81	82	92	91
71	2	82	83	93	92
72	2	83	84	94	93
73	2	84	85	95	94
74	2	85	86	96	95
75	1	86	87	97	96
76	2	87	88	98	97
77	2	89	90	100	99
78	1	90	91	101	100
79	2	91	92	102	101
80	2	92	93	103	102
81	2	93	94	104	103
82	2	94	95	105	104
83	2	95	96	106	105
84	1	96	97	107	106
85	2	97	98	108	107

1	0	0	----------Card 5
2	5.375	0	
3	13.375	0	
4	21.375	0	
5	29.375	0	
6	37.375	0	
7	45.375	0	
8	53.375	0	
9	61.375	0	
10	66.75	0	
11	0	8	
12	5.375	8	
13	13.375	8	
14	21.375	8	
15	29.375	8	
16	37.375	8	
17	45.375	8	
18	53.375	8	
19	61.375	8	
20	66.75	8	
21	0	16	
22	5.375	16	
23	13.375	16	
24	21.375	16	
25	29.375	16	
26	37.375	16	
27	45.375	16	
28	53.375	16	
29	61.375	16	
30	66.75	16	
31	5.375	24	
32	13.375	24	
33	21.375	24	
34	29.375	24	
35	37.375	24	
36	45.375	24	
37	53.375	24	
38	61.375	24	
39	5.375	32	
40	13.375	32	
41	21.375	32	
42	29.375	32	
43	37.375	32	
44	45.375	32	
45	53.375	32	

46	61.375	32
47	5.375	40
48	13.375	40
49	21.375	40
50	29.375	40
51	37.375	40
52	45.375	40
53	53.375	40
54	61.375	40
55	5.375	48
56	13.375	48
57	21.375	48
58	29.375	48
59	37.375	48
60	45.375	48
61	53.375	48
62	61.375	48
63	5.375	56
64	13.375	56
65	21.375	56
66	29.375	56
67	37.375	56
68	45.375	56
69	53.375	56
70	61.375	56
71	5.375	64
72	13.375	64
73	21.375	64
74	29.375	64
75	37.375	64
76	45.375	64
77	53.375	64
78	61.375	64
79	0	72
80	5.375	72
81	13.375	72
82	21.375	72
83	29.375	72
84	37.375	72
85	45.375	72
86	53.375	72
87	61.375	72
88	66.75	72
89	0	80
90	5.375	80

```
91      13.375 80
92      21.375 80
93      29.375 80
94      37.375 80
95      45.375 80
96      53.375 80
97      61.375 80
98      66.75  80
99      0      88
100     5.375  88
101     13.375 88
102     21.375 88
103     29.375 88
104     37.375 88
105     45.375 88
106     53.375 88
107     61.375 88
108     66.75  88
1       11     0     0 ----------------------------------------------------------Card 6
2       11     0     0
3       11     0     0
4       11     0     0
5       11     0     0
6       11     0     0
7       11     0     0
8       11     0     0
9       11     0     0
10      11     0     0
99      10     1     0
100     10     1     0
101     10     1     0
102     10     1     0
103     10     1     0
104     10     1     0
105     10     1     0
106     10     1     0
107     10     1     0
108     10     1     0
1       'Concrete with Horizontal and Vertical Reinforcement' ----------Card 7
0.2     26     0     1
5       0.003  2     2     0.1    0.6    1
0.504   3067   3     0.5   0.25
29000   0.02   0.00423     0.0076 60     60
2       'Concrete with Horizontal Reinforcement'
0.2     26     0     1
```

```
5       0.003  2       2       0.1     0.6     1
0.504   3067   3       0.5     0.25
29000   0.02   0       0.0076  0       60
3       'Grouted Masonry with Vertical Reinforcement'
0.16    7.625  0       1
2.77    0.0022 1.9     1.3     0.14    0.165   1
0.05    1524   2       0.5     0.25
29000   0.02   0.01443         0       60      0
4       'Ungrouted Masonry'
0.16    2.68   0       1
2.85    0.0022 1.7     1.35    0.11    1.4     1
0.05    1568   1       0       0
0       0      0       0       0       0
5       'Grouted Masonry with Horizontal and Vertical Reinforcement'
0.16    7.625  0       1
2.77    0.0022 1.9     1.3     0.14    0.165   1
0.05    1524   2       0.5     0.25
29000   0.02   0.01443         0.00836         60      60
6       'Grouted Masonry with Horizontal Reinforcement'
0.16    7.625  0       1
2.77    0.0022 1.9     1.3     0.14    0.165   1
0.05    1524   2       0.5     0.25
29000   0.02   0       0.00836         0       60
108     10     10 ----------------------------------------------------------------------Card 9
1       99     100     101     102     103     104
105     106    107     108
99      100    101     102     103     104 ----------------------------------------Card 11
105     106    107     108
"Wall #11 - W11.Inp, Mesh 11 Nominal Properties, in-kips" ----------------------Card 12
0       0      1 ----------------------------------------------------------------------Card 13
7 ----------------------------------------------------------------------------------Card 16
61      81     80 ----------------------------------------------------------------------Card 17
0.536   0      0.536   0 ----------------------------------------------------------Card 18
62      82     81
0.536   0      0.536   0
63      83     82
0.536   0      0.536   0
64      84     83
0.536   0      0.536   0
65      85     84
0.536   0      0.536   0
66      86     85
0.536   0      0.536   0
67      87     86
0.536   0      0.536   0
```

1	0	0	1	0	
5	250	2	2	0	0
4	0	0	1	-0.017	
5	250	2	2	0	0
4	0	0	1	0.017	
5	250	2	2	0	0
4	0	0	1	-0.017	
5	250	2	2	0	0
4	0	0	1	0.017	
5	250	2	2	0	0
4	0	0	1	-0.026	
5	250	2	2	0	0
4	0	0	1	0.026	
5	250	2	2	0	0
4	0	0	1	-0.026	
5	250	2	2	0	0
4	0	0	1	0.026	
5	250	2	2	0	0
4	0	0	1	-0.034	
5	250	2	2	0	0
4	0	0	1	0.034	
5	250	2	2	0	0
4	0	0	1	-0.034	
5	250	2	2	0	0
4	0	0	1	0.034	
5	250	2	2	0	0
4	0	0	1	-0.051	
5	250	2	2	0	0
4	0	0	1	0.051	
5	250	2	2	0	0
4	0	0	1	-0.051	
5	250	2	2	0	0
4	0	0	1	0.051	
5	250	2	2	0	0
4	0	0	1	-0.06	
5	250	2	2	0	0
4	0	0	1	0.06	
5	250	2	2	0	0
4	0	0	1	-0.045	
5	250	2	2	0	0
4	0	0	1	0.01	
5	250	2	2	0	0
4	0	0	1	-0.03	
5	250	2	2	0	0
4	0	0	1	0.03	

5	250	2	2	0	0
4	0	0	1	-0.06	
5	250	2	2	0	0
4	0	0	1	0.06	
5	250	2	2	0	0
4	0	0	1	-0.06	
5	250	2	2	0	0
4	0	0	1	0.06	
5	250	2	2	0	0
4	0	0	1	-0.09	
5	250	2	2	0	0
4	0	0	1	0.09	
5	250	2	2	0	0
4	0	0	1	-0.075	
5	250	2	2	0	0
4	0	0	1	0.075	
5	250	2	2	0	0
4	0	0	1	-0.045	
5	250	2	2	0	0
4	0	0	1	0.045	
5	250	2	2	0	0
4	0	0	1	-0.09	
5	250	2	2	0	0
4	0	0	1	0.09	
5	250	2	2	0	0
4	0	0	1	-0.09	
5	250	2	2	0	0
4	0	0	1	0.09	
5	250	2	2	0	0
4	0	0	1	-0.12	
5	250	2	2	0	0
4	0	0	1	0.12	
5	250	2	2	0	0
4	0	0	1	-0.09	
5	250	2	2	0	0
8	0	0	1	0.09	
5	250	2	2	0	0
8	0	0	1	-0.06	
5	250	2	2	0	0
8	0	0	1	0.06	
5	250	2	2	0	0
8	0	0	1	-0.12	
5	250	2	2	0	0
8	0	0	1	0.12	
5	250	2	2	0	0

8	0	0	1	-0.12	
5	250	2	2	0	0
8	0	0	1	0.12	
5	250	2	2	0	0
8	0	0	1	-0.18	
5	250	2	2	0	0
8	0	0	1	0.18	
5	250	2	2	0	0
8	0	0	1	-0.135	
5	250	2	2	0	0
8	0	0	1	0.135	
5	250	2	2	0	0
8	0	0	1	-0.09	
5	250	2	2	0	0
8	0	0	1	0.09	
5	250	2	2	0	0
8	0	0	1	-0.18	
5	250	2	2	0	0
8	0	0	1	0.18	
5	250	2	2	0	0
8	0	0	1	-0.18	
5	250	2	2	0	0
8	0	0	1	0.18	
5	250	2	2	0	0
8	0	0	1	-0.24	
5	250	2	2	0	0
8	0	0	1	0.24	
5	250	2	2	0	0
8	0	0	1	-0.18	
5	250	2	2	0	0
8	0	0	1	0.18	
5	250	2	2	0	0
8	0	0	1	-0.12	
5	250	2	2	0	0
8	0	0	1	0.12	
5	250	2	2	0	0
8	0	0	1	-0.24	
5	250	2	2	0	0
8	0	0	1	0.24	
5	250	2	2	0	0
8	0	0	1	-0.24	
5	250	2	2	0	0
8	0	0	1	0.24	
5	250	2	2	0	0
8	0	0	1	-0.3	

```
5     250   2     2     0     0
8     0     0     1     0.3
5     250   2     2     0     0
8     0     0     1     -0.225
5     250   2     2     0     0
8     0     0     1     0.225
5     250   2     2     0     0
8     0     0     1     -0.15
5     250   2     2     0     0
8     0     0     1     0.15
5     250   2     2     0     0
8     0     0     1     -0.3
5     250   2     2     0     0
8     0     0     1     0.3
5     250   2     2     0     0
8     0     0     1     -0.3
5     250   2     2     0     0
8     0     0     1     0.3
5     250   2     2     0     0
8     0     0     1     -0.36
5     250   2     2     0     0
8     0     0     1     0.36
5     250   2     2     0     0
8     0     0     1     -0.27
5     250   2     2     0     0
8     0     0     1     0.27
5     250   2     2     0     0
8     0     0     1     -0.18
5     250   2     2     0     0
8     0     0     1     0.18
5     250   2     2     0     0
8     0     0     1     -0.36
5     250   2     2     0     0
8     0     0     1     0.36
5     250   2     2     0     0
8     0     0     1     -0.36
5     250   2     2     0     0
8     0     0     1     0.36
5     250   2     2     0     0
8     0     0     1     0
5     250   2     2     0     0
-1    0     0     0     0
0     0     0     0     0     0
```

Glossary

ξ = Bilinear factor

γ = Exponential parameter

ε = Principal compressive strain in the masonry

λ = Strength modification factor

ε_{cr} = Tensile cracking strain of the masonry

ε_e = Point of tangency between Equations 2.2 and 2.3

ε_o = Strain at uniaxial compressive strength, f_m

ε_p = Strain at peak uniaxial compressive strength, f_p

ε_t = Tensile strain in the masonry

A'_3 = Shape factor for the exponential falling branch

A_1 = Shape factor for the rising branch

A_2 = Shape factor for the initial falling branch

A_3 = Shape factor for the exponential falling branch

A_4 = Shape factor for the attachment point of the exponential tail

E_s = Modulus of elasticity of the reinforcement

E_{sp} = Plastic modulus of the reinforcement

E_t = Modules of elasticity of the masonry in tension

$f(\varepsilon)$ = Principal compressive stress in the masonry

$f(\varepsilon)$ = Stress in the masonry due to tension stiffening

f_e = Compressive stress at point of tangency, ε_e

f_m = Uniaxial compressive strength of the masonry

f_p = Peak uniaxial compressive strength

f_p = Peak uniaxial compressive strength of the masonry

H' = Strain-hardening parameter

r = aspect ratio of wall

ρ_h = horizontal reinforcement ratio

ρ_v = vertical reinforcement ratio

ν = Poisson's ratio of masonry

MCD = Compression Damage Parameter Model Number

f_{cr} = Tensile cracking strength of masonry

MTS = Tension Stiffening Model Number

B_1 = Lower limit of the exponential branch for Tension Stiffening Model Number 2

α = Exponential parameter for Tension Stiffening Model Number 2

A_{sh} = Area of horizontal reinforcement steel

A_{sv} = Area of vertical reinforcement steel

ρ_v = Vertical reinforcement ratio

ρ_h = Horizontal reinforcement ratio

f_{yv} = Yield stress of the vertical reinforcement

f_{yh} = Yield stress of the horizontal reinforcement

H = Height of masonry specimen

L = Length of masonry specimen

For clarity, the terms designating the type of masonry construction are defined as follows:

Plain: masonry which contains no grout or reinforcing bars

Partially-grouted: masonry in which all the hollow cores are grouted

Fully-grouted: masonry in which all the hollow cores are solidly grouted

Reinforcement: masonry in which reinforcing bars are used

Unreinforced: masonry which contains no reinforcement

Additional terms:

Area, gross cross-sectional: The area delineated by the out-to-out dimensions of masonry in the plane under consideration.

Area, net cross-sectional: The area of masonry units, grout and mortar crossed by the plane under consideration based on out-to-out dimensions.

Running bond: The placement of masonry units such that head joints in successive courses are horizontally offset at least one-quarter the unit length.

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