EXPERIMENTAL AND ANALYTICAL RESULTS FOR SHEAR CONNECTED CAVITY WALLS

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ABSTRACT

Experimental and analytical studies were conducted to evaluate the performance of shear connectors in cavity walls consisting of brick veneer and concrete block backup wythe.

The experimental work consisted of fifteen full scale masonry cavity walls subjected to positive lateral loads.

A two-dimensional finite element model (F.E.M) was developed to compute internal forces in cavity walls subjected to uniform lateral loads. Comparison of the F.E.M. results with experimental data indicates that the analytical model was valid and could be used for parametric studies. The analytical model was therefore used to determine the effect that certain geometric parameters have on the internal forces developed at the connectors of a cavity wall subjected to uniform lateral load.

Based on the theoretical and experimental results the adequacy of the current design approach was evaluated. A recommendation for optimum spacing of 800 mm for connectors with consideration for ease of construction is given.

1. INTRODUCTION

Masonry cavity wall construction is one in which a 25 to 100 mm thick continuous air space is provided inside the wall- The cavity walls that were investigated in this study are the ones that have an external brick veneer wythe and an inner wythe of concrete block and were subjected to uniformly lateral load. Traditionally, the veneer has served to provide for architectural appearance, weathering, and moisture control. By providing a connection capable of transferring the lateral pressure from the facing wythe to the backup wall the overall behavior of the system is improved. The connector that was

used in this study is shown in Fig. 1. Part A is the shear connector plate, part B is a bent rod which is embedded in the brick wythe. Rotation is allowed between the plate and the brick wythe. Parts C are cross legs embedded in the block wythe and provide rotational restraint between the plate and block wythe. Part D fixes the position of the insulation.

This paper describes the results of the analytical and experimental studies of such a cavity wall, and relevant recommendations based on the results are also presented.

2. EXPERIMENTAL PROGRAM

The test apparatus was designed to accommodate testing of full scale walls 3 m high and 1.2 m wide. Figure 2 presents a typical wall test specimen and its dimensions. Standard concrete blocks of
H/15/C/M and mortar type S were used for all the specimens. For the reinforced cavity walls the grout that was used had a minimum strength of 20 MPa. The shear connectors ·that were used consisted of 14 gage galvanized metal plate with a cross sectio of 60 x 1.5 mm^2 and its length, L, varied with cavity width and block width. The uniform lateral pressure was applied at the facing wall (brick veneer) using an air bag.

Fifteen walls were fabricated and tested in four series. The first series consisting of four walls was conducted to compare the performance of cavity walls with conventional wire truss reinforcement to shear connected cavity walls. The other three series investigated the following geometric parameters: concrete block width (140 mm, 190 mm), cavity width (25 mm, SO mm, 75 mm, 100 mm) and five shear connector arrangements which are shown in Fig. 4.

Table 1 summarizes the important variables of the specimens and the test results (maximum lateral load and corresponding maximtnn lateral deflection).

3. TEST RESULTS

Based on the test results shown in Table 1, the following observations are made:

- From series 1 it is concluded that wall strength increases substantially by replacing the conventional wire truss reinforcement

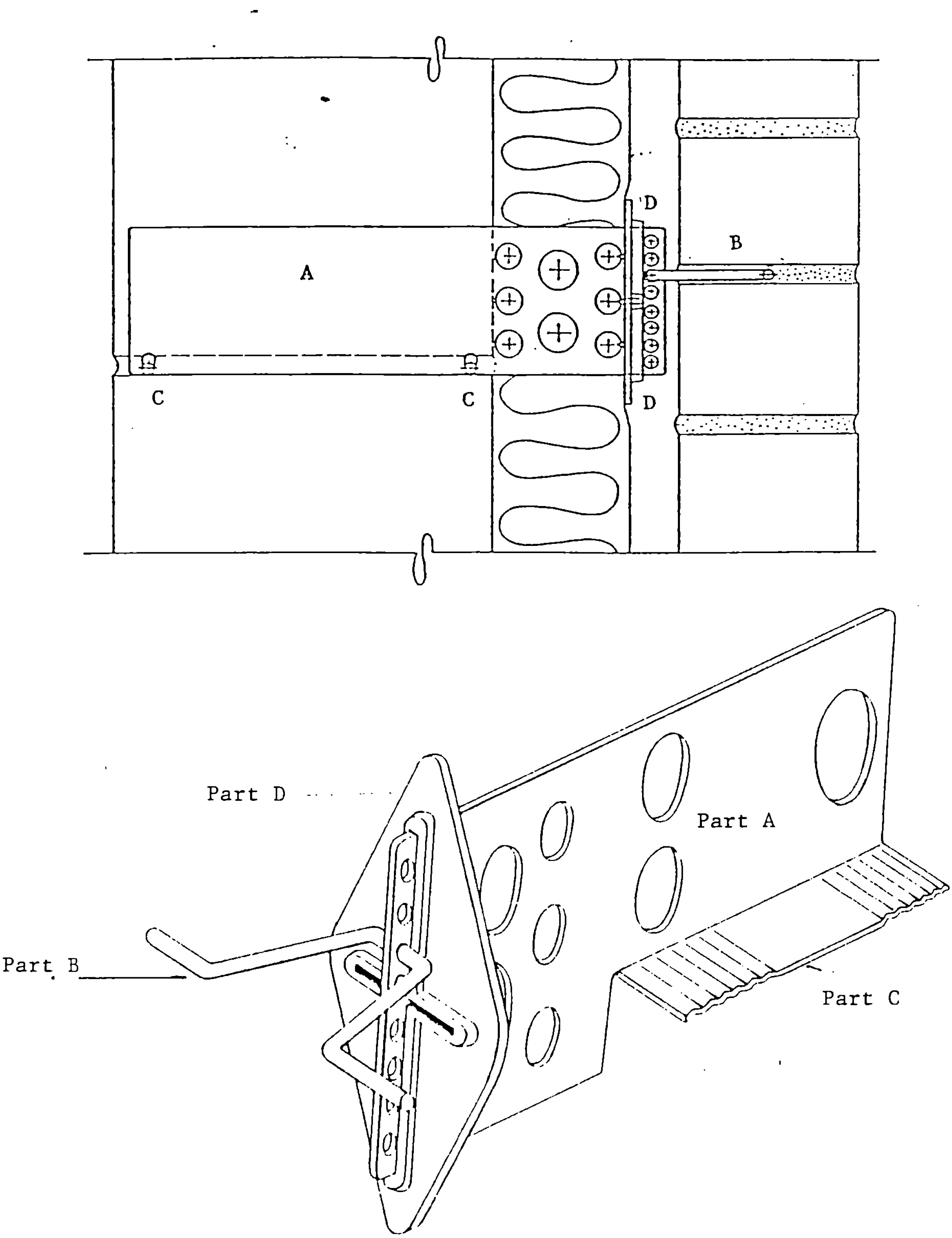

Figure 1. Shear Connector

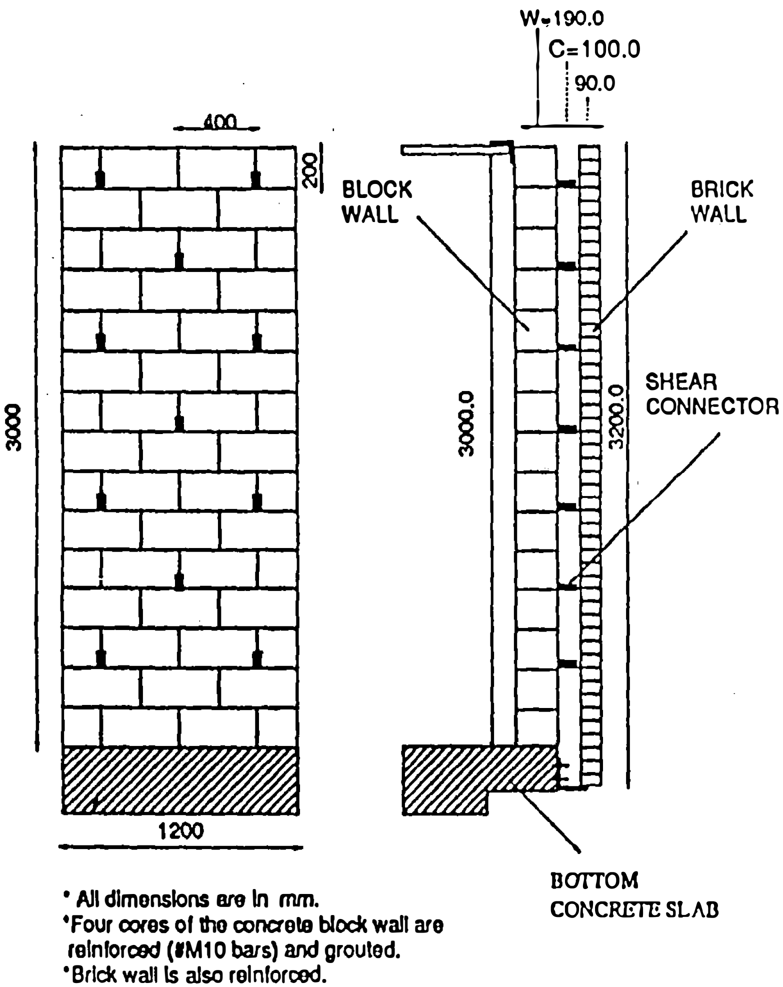

FIGURE 2. Typical Full Scale Wall Specimen (S4W3).

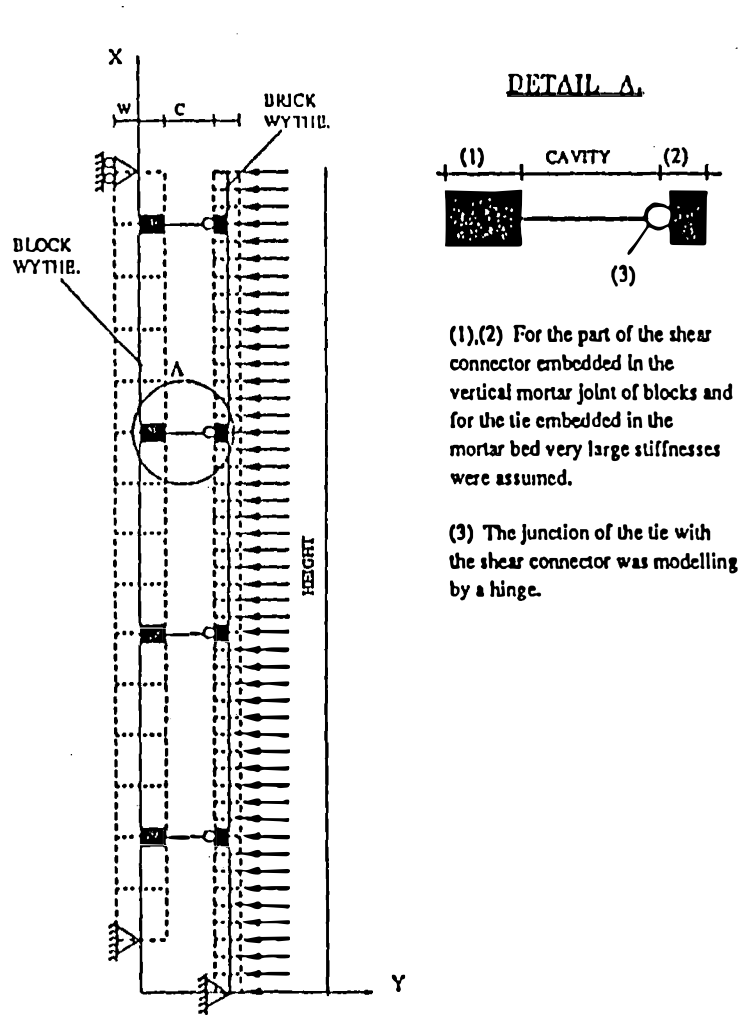

FIGURE 3. Finite Element Model.

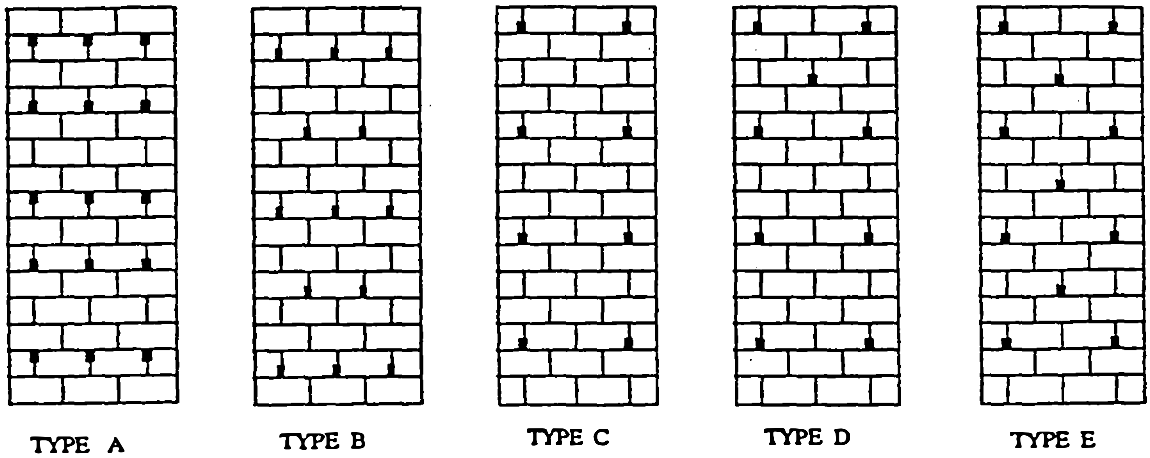

Figure 4. Shear Connector Arrangements

with shear connectors. In addition, the lateral deflection of a cavity wall using shear connectors is consistently less than that for conventional wire truss reinforcement.

- Comparing series 1 and 2, increasing the width of the concrete block wythe results in an increase in the load carrying capacity of the wall system.

- Series 3 demonstrates that vertical reinforcement in the block backup wall results in a composite wall system with a load carrying capacity at least twice that of a hollow block backup system.

- By increasing the width of the cavity the load carrying capacity of the system increases since a more stable wall system with increased resisting moment capacity is achieved.

- In all the specimens except S3W2 and S4W3 the failure mode was by tension failure in the block wall at the mortar bed close to midspan.

- Failure of specimen S3W2 occurred in the brick wall when the tensile stresses (due to secondary moments) exceeded the tensile bond strength of the mortar. This specimen was able to resist a pressure of 3.6 kPa with a maximum centerline deflection of 10 mm. It is important to note that this. specimen was repaired and strengthened by an additional connector at the failed mortar bed and was re-tested as specimen S4WI. Failure of S4WI occurred at a pressure of 4.7 k.Pa and maximum deflection of 17 mm. The mode of failure was sliding of the concrete wythe at the junction of the wall with the bottom slab.

- In specimen S4W3 both wythes were reinforced to force the connectors to fail and to find the pressure at which this failure will occur. The specimen was able to resist a pressure of 6.2 kPa before the two uppermost shear connectors buckled. These connectors were instrumented by means of strain gauges in order to evaluate the failure (buckling) load which was calculated from the measured strains to be S.2 kN. The corresponding maximum deflection just before failure was 16.3 mm.

Table 1. Variables and Test Results of the Full Scale Specimens

SERIES NO.	WALL NO.	BLOCK (1) WIDTH (mm)	BRICK VENEER (mm)	CAVITY WIDTH (mm)	TYPE OF WALL TIE UTILIZED	TIE ARRANGEMENT (2)	MAXIMUM LATERAL LOAD (kPa)	MAXIMUM DEFLECTION (mm)
1	S1W1	140 H (1)	90	75	Truss (d=3.66 mm)	B	1.2	4.8
	S1W2	140 H	90	75	Truss (d=4.76 mm)	B	0.75	2.0
	S1W3	140 H	90	75	Shear Connector	B	1.23	1.28
	S1W4	140 H	90	100	Shear Connector	B	1.68	1.92
2	S2W1	190 H	90	75	Truss (d=3.66 mm)	A	1.25	3.2
	S2W2	140 R (1)	90	75	Shear Connector	B	2.85 (3) 3.2	3.4 6.4
	S2W3	190 H	90	75	Shear Connector	B	1.4	2.9
	S2W4	190 H	90	100	Shear Connector	B	1.85	1.76
3	S3W1	190 H	90	25	Shear Connector	C	0.91	12
	S3W2	190 R	90	100	Shear Connector	C	1.75 3.6	1.0 10.0
	S3W3	140 H	90	25	Shear Connector	C	1.0	9.9
	S3W4	140 R	90	100	Shear Connector	C	1.7 2.4	10.3 49
4	S4W1 (4)	190 R	90	100	Shear Connector	D	4.7	17
	S4W2	140 R	90	50	Shear Connector	C	3.0	33
	S4W3	190 R	90 R (5)	100	Shear Connector	E	6.2	17

(1) B•Hollow blocks R•Reinforced and grouted blocks
(2) See Figure 4.
(3) First value correspond before 1st crack occurred. Second values correspond at failure.
(4) Restoration of specimen S3W2.
(5) Brick veneer wall vu reinforced.

– In general, from the deflected shapes of the two wythes we can conclude that the brick veneer and the concrete block backup wall act compositely when shear connectors are utilized (see Fig. 5).

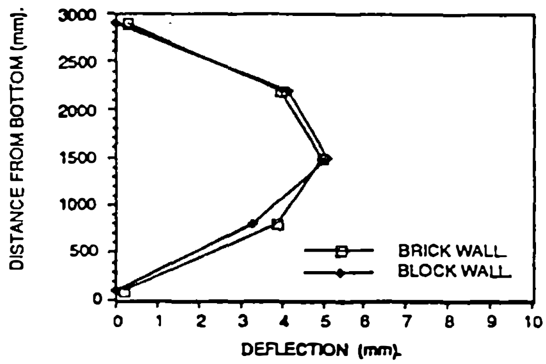

Figure 5. Deflected Shapes of Specimen S3W2 at 3.0 k.Pa

4. ANALYTICAL STUDY

4.1 Finite Element Model

An elastic finite element (F.E.) model was developed and the general purpose F.E. program SFRAME was used. The two-dimensional model used to model a cavity wall is shown in Fig. S. In order to describe the behavior of the masonry components a mesh with beam elements of 67 mm is used. This dimension of 67 mm was found to be the most appropriate when comparing the analytical results to the experimental.

Particular attention was given in modelling the shear connector. Detail A in Fig. 3 shows that the part of the shear connector embedded in the vertical mortar joint of blocks was assumed to have a large stiffness. The part of the tie embedded in the mortar bed of bricks was also assumed to have a large stiffness. The junction of the tie with the shear connector was model by a hinge. The boundary conditions which better describe the experimental setup and the typical support conditions is also shown in Fig. 3.

The validity of the F.E. model in computing the internal forces transferred by the shear connectors, was also confirmed by the agreement of the model with the experimental results. Table 2 shows that agreement for the force transferred by the top shear connector (critical location) for specimens S3W2 and S2W4 at different lateral pressures. The deflections obtained by the F.E. model (in the elastic range) were about half of those measured experimentally. This difference is due to the difficulty of measuring small displacements (less than 1 mm) with the available measuring devices.

4.2 Parametric Study

. The geometric parameters that were investigated using the analytical model are cavity, height of the wall and concrete block width.

Table 2. Axial Compressive Force in Top Shear Connector

PRESSURE (kPa)	S3W2		S3W4	
	F.E.M.	TEST	F.E.M.	TEST
0.5	0.285	0.19	0.315	0.27
1.0	0.575	0.51	0.63	0.64
1.5	0.86	0.82		

Table 3. Variables Used in the Parametric Study

WALL HEIGHT (mm)	CAVITY (mm)	BLOCK WIDTH (mm)
3000 3800 4600 5400 6200 7000	25 50 75 100	190 240 290

The last two parameters reflect the effect of the relative stiffness between the two wythes. Table 3 shows the values of the different parameters used in the parametric study.

The horizontal and vertical spacing of the connectors was constant for all the cases and equal with 800 mm. Uniform lateral load of 1.0 kPa (nominal wind load) was applied for the 72 different cases analyzed. The material properties used in the model were: Em = 7.5 GPa for the masonry components and Es = 200 GPa for the shear connectors. The cross-section of the shear connector was 1.5 x 60 mm.

4.2.1 Axial Force in the Connectors. The maximum axial force occurs at the endmost shear connectors as it will be discussed in section 4.2.3. From Fig. 6 it is concluded that the larger the cavity and the taller the wall the higher the axial compression transferred by the connectors. Graphs a, b, c of Fig. 6 indicate that as the concrete block width increases, the axial force on the connectors decreases since more load can be attracted by the backup wall.

4.2.2 Shear Force in the Connectors. Maximum shear force again occurs at the endmost shear connectors. As can be shown in Fig. 7 the shear force on the connectors descreases as the cavity increases. Fig. 7 also indicates that the shear force increases with the height of the wall. The effect of concrete block width is the same as described in section 3.2.1.

4.2.3 Variation of Connector Forces Along the Wall. Figures Sa and 8b show the variation of connector forces (axial and shear) along the wall height. These indicate that the connector forces are not uniform particularly for tall walls (more flexible backup wythe). The maximum values for both axial and shear forces appeared at the endmost shear connectors. Therefore, the critical location for the connectors is the region adjacent to the supports. The behavior of a cavity wall subjected to uniform lateral load is similar to that of a beam under uniform load where it is known that the maximum shear forces occur close to the supports.

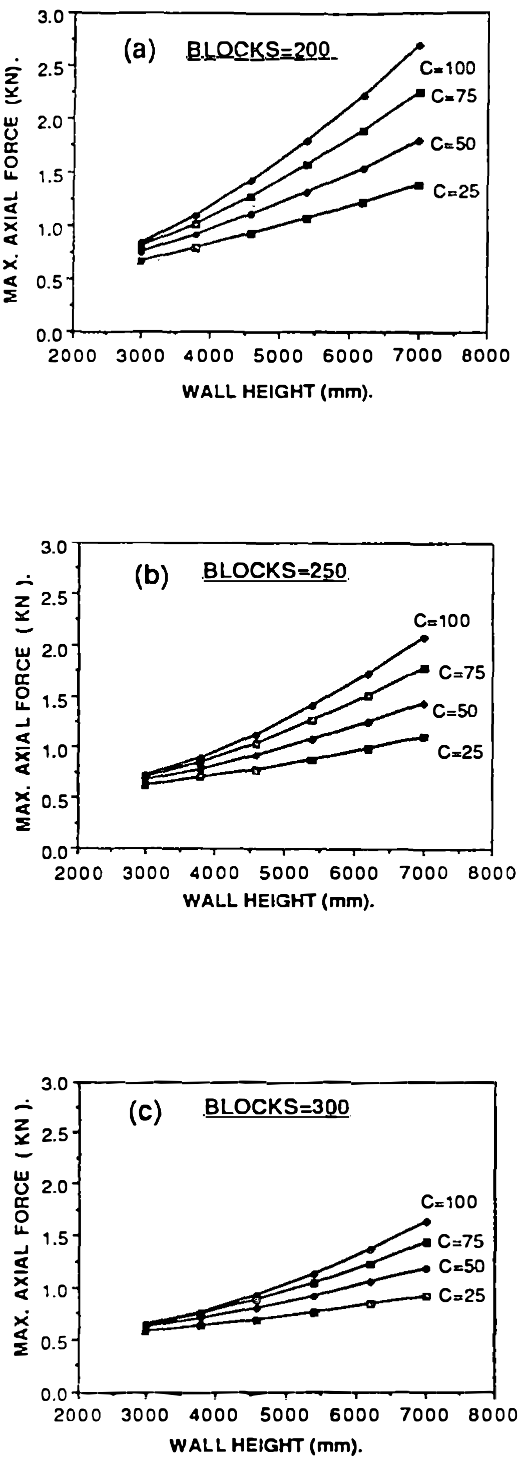

FIGURE 6. Maximum Axial Forces In Shear Connectors

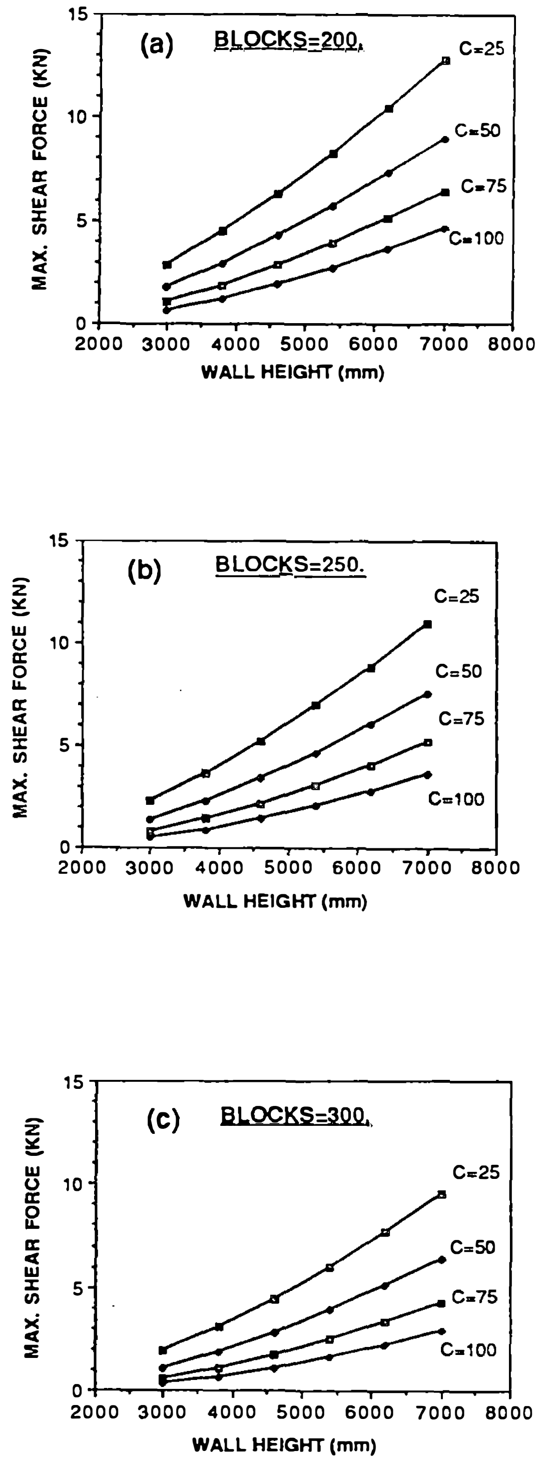

FIGURE 7. Maximum Shear Forces In Shear Connectors.

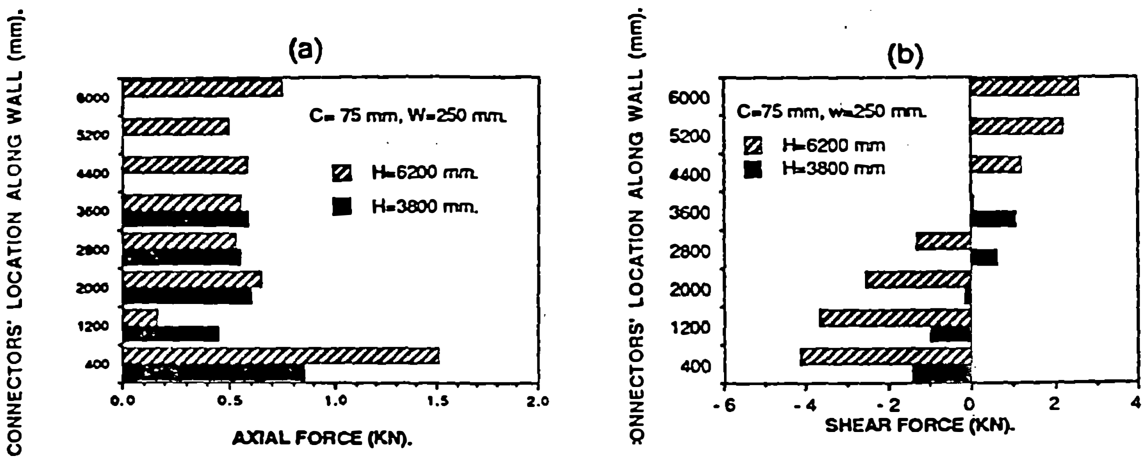

Figure 8. Variation of Forces on Shear Connectors Along the Wall

5. CONCLUSIONS

Based on both analytical and experimental studies presented in this paper the following conclusions can be drawn:

- The shear connectors are capable of transferring shear and axial load from the brick veneer to backup wall.

- From the deflected shapes of the two walls we can conclude that the brick veneer and the concrete backup wall act compositely if shear connectors are utilized.

- Under comparable loads, the lateral deflection of a wall system using shear connectors is consistently less than that for conventional wire truss tie reinforcement; such reduction in deflections will minimize crack width and moisture penetration in actual structures.

- Load transferred between the two wythes through the shear connectors are not uniform along the height of the wall as commonly assumed in the simplified design approach. The more the flexibility of the backup wythe (smaller concrete block width, taller wall) the higher the nonuniformity of the connector forces. High forces are attracted by the connectors near the supports which are the critical locations for the connectors.

- Better performance is observed for greater cavity widths.

6. RECOMMENDATIONS

With due consideration given to ease of construction and placing of both the connectors and the accessories (i.e. air-vapor etc.) a shear connector arrangement with horizontal and vertical spacing of 800 mm is suggested. In order to improve the behavior of the assembly it is recommended that the concrete block wall be reinforced since it is subjected to tensile stresses. Providing minimum vertical reinforcement will not affect the cost of the assemblies drastically, however the behavior and performance will be superior to that of a plain wall.

7. REFERENCES

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