SHEAR CONNECTORS IN CAVITY WALLS DUE TO CLIMATIC CONDITIONS AND MATERIAL PROPERTIES

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STRESSES ON SHEAR CONNECTORS IN CAVITY WALLS DUE TO CLIMATIC CONDITIONS AND MATERIAL PROPERTIES.

ABSTRACT

The relative deformations between two wythes of a cavity wall. due to environmental factors such as humidity, temperature change. and due to material properties. induce significant internal forces on the masonry components and connectors.

An experimental study and· a theoretical analysis were conducted in order to investigate the. behavior of a shear connected cavity wall under deformations induced by the above noted factors.

A simplified method is proposed to calculate the internal forces and deformations on the masonry components and the critical shear connectors.

INTRODUCTION

A knowledge of deformations that can take place in cavity masonry walls during its life is essential to .an understanding of its structural behavior. The most significant deformations that can occur are those due to the loading and those due to environmental factors (humidity and temperature changes). Deformations due to loading can be divided funher into elastic and creep deformations. Deformations due to environmental humidity include shrinkage of concrete block masonry and expansion of brick veneer wall.

It is important to account for these deformations, especially, when the two masonry materials (brickwork and blockwork) are used in close proximity. In the case were the two wythes are bounded together using shear connectors the opposite vertical movements between the two wythes induce significant forces at the connectors. On the other hand, the connectors restrain these movements and generate internal forces to the masonry components.

In addition, as it is common for other materials masonry, will expand when heated and contract when cooled. This will lead to differential deformations between interior walls in a building, which are at a relative constant temperature. and exterior walls exposed to the weather temperature. Again in the case of a shear connected cavity walJ these deformations due to temperature effect will generate internal forces at the connectors.

In order to investigate the behavior of shear connected cavity walls under imposed defonnations due to environmental factors (such as humidity and temperature changes), an experimental and theoretical study was conducted at the University of Albena.

A simplified method is proposed for hand calculation of the critical internal forces induced in the masonry components and critical shear connectors.

EXPERIMENTAL PROGRAM.

The experimental study consisted of a full scale cavity wall (3.0 m high and 1.2 m wide) with a brick veneer curtain wythe and a concrete block backup wythe. The cavity between the two wythes <:onsisted of *50* mm insulation and 25 mm air space. The two masonry walls were connected together using connectors with shear resisting capability. The connectors were placed at 800 mm in both directions. Figure 1 shows a typical shear connector. It consists of a galvanized steel plate with holes and slots, cross legs and bend-rod tie. The cross rods are embedded into the mortar joint of the block wall and are used to provide rotational restraint between block wythe and connector. The bend-rod tie is embedded within the mortar bed of the brick wythe and allows rotation between connectors and bricks. The cross-section of the connector was 70 mm by 1.8 mm and its lenght 258 mm(see also Figure 3).

In terms of design of the support typical support conditions were reproduced by supporting the specimen in a frame consisted of upper and lower concrete slabs separated by four steel columns. A 12 mm shelf angle was attached to each concrete slab with the bottom angle used to support the brick veneer. Figure 2 shows the dimensions and ·support conditions of the specimen.

The free face of the concrete wan was isolated and maintained at temperatures between 15 and 30 'C. The cavity wall specimen was placed outside the laboratory and was exposed to the climatological conditions for a period of 10 months.

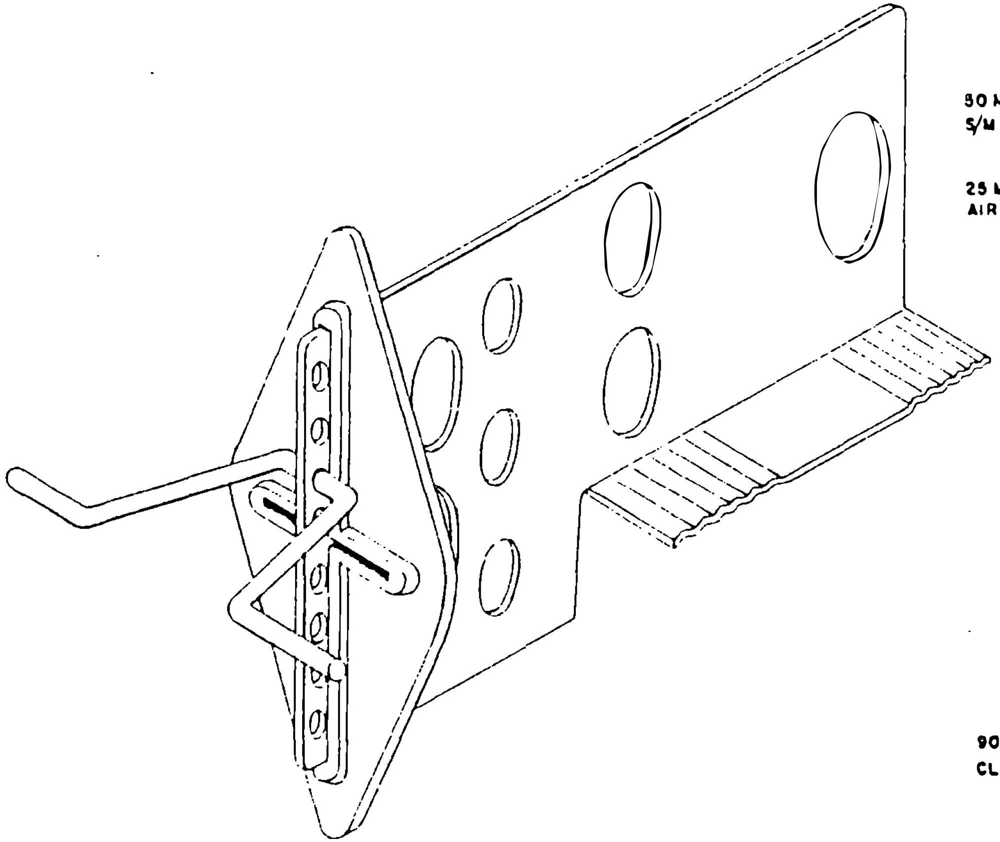


FIGURE 1. Shear Connector Prototype.

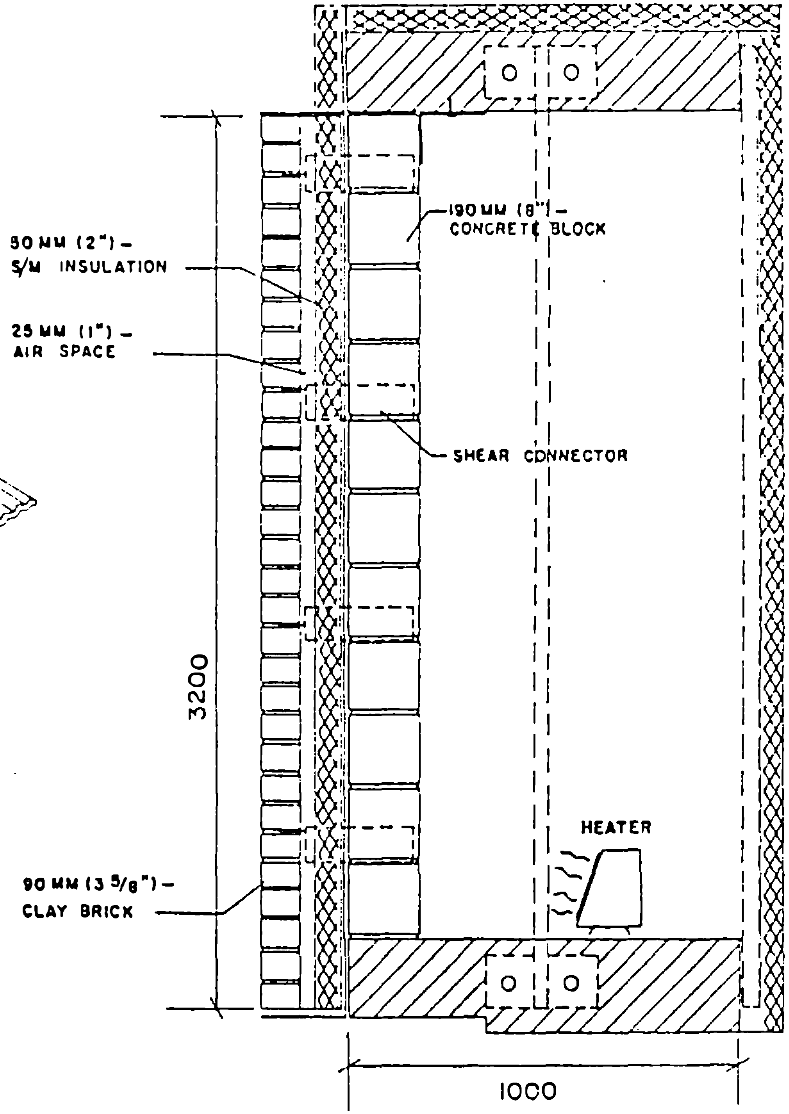


FIGURE 2. Cross- Section of Test Chamber and Wall Section,

No specific external load was applied to the specimen although from the readings it was observed that the wind load sometimes acted as an externally applied lateral load.

The shear connectors were instrumented by means of strain gauges located as shown in Figure 3. Measurements recorded during a period of 10 months included average daily humidities, external temperatures, internal temperatures and readings from the strain gauges.

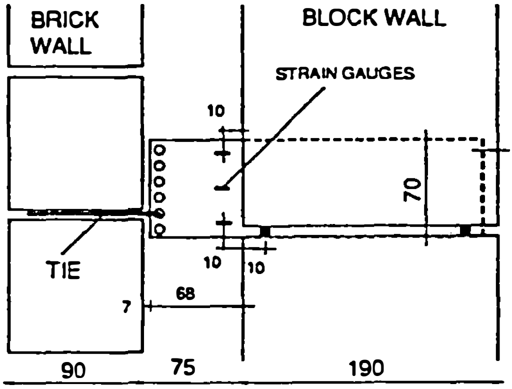


FIGURE 3. Shear Connector and Location of Strain Gauges.

Test Results

The deformations that were induced in the composite wall system were as follows:

- The concrete block wythe having water as an essential ingredient and being moist cured underwent a period of drying after construction. This loss of moisture results in shrinkage, the amount of which depends upon the composition of the materials and upon environmental humidities.
- The brick veneer, on the other hand, consisting of bricks that have been fired in a kiln, experienced expansion over an extended period of time. The amount of expansion depends on the composition of the bricks, on environmental humidity and on time.
- Thermal deformations were also introduced due to difference of temperature between the two wythes. These deformations had a beneficial effect since they were opposite to the previous ones.

These relative deformations between the two wythes are partially restrained by the shear connectors.

As indicated previously, it was difficult to isolate one parameter and investigate its effect to the internal forces of the shear connected cavity wall. Another difficulty was noted when computing the internal forces based on the strain gauges readings. After the data were reduced to allow for the thermally induced strains on the connectors a linear strain distribution was assumed for the deformation of the connectors. By using linear regression a best linear stain distribution that can fits the three stain gage readings was found. Based on this strain distribution, on Hooke's law (with E=200 GPa) and on the equilibrium equation, the corresponding internal forces and moment were calculated. Figure 4 shows the method used to reduce the data. Although the calculated internal forces were not that accurate since the real strain distribution is not exactly linear, a good estimate of their magnitude was obtained.

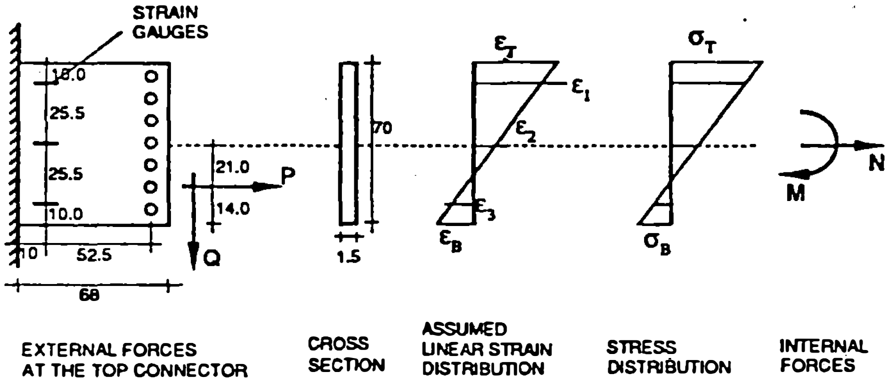


FIGURE 4. Method Used to Calculate Internal Forces from Strain Gages Readings.

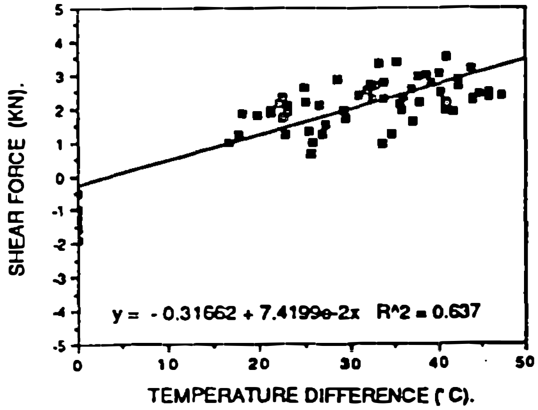


FIGURE 5. Temperature Difference vs. Shear Forces (KN) for the Critical Connector.

The maximum internal forces were recorded at the top connector. Figure 5 shows a typical diagram of the difference of temperature (internal minus external) versus the shear forces at the critical top connector. The maximum recorded shear force was 3.50 KN and was recorded at a temperature difference of 40'C. Although, other parameters affected these values Figure 5 shows that as the temperature difference increases the shear force is also increases. This shear force represents the magnitude of the axial force on the masonry components. It was also found from the results that the brick wall was subjected to compressive forces, while tensile forces were generated to the backup wall. Therefore, such a system has the advantage of generating tensile forces in the block wall, which can be taken care of by suitable reinforcement.

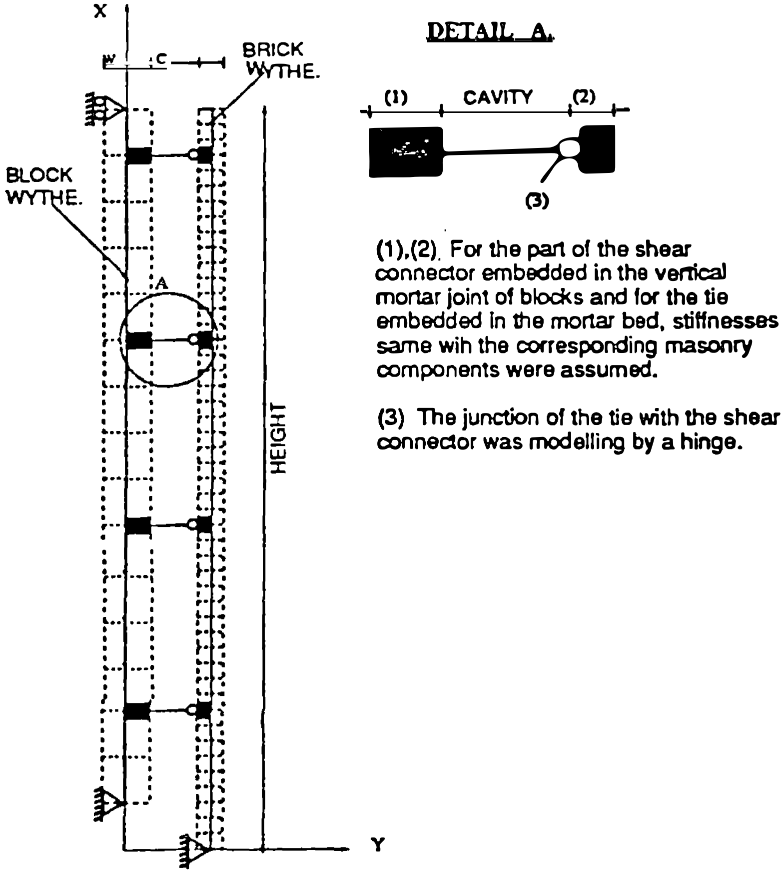
No damage has been observed to the shear connectors or wall components of the tested specimen.

3./ ANALYTICAL STUDY.

3.1./ Finite Element Model.

For the analytical study an elastic finite element model (F.E.M.) was developed and the general purpose finite element program SFRAME was used. Figure 6 shows the two-dimensional model for the cavity wall. Beam elements were used to model all the components. The parts of the shear connectors embedded within the masonry walls were assumed to have the same stiffnesses with the corresponding masonry materials (see detail A of Figure 6). The junction of the tie with the shear connector was modeled by a hinge.

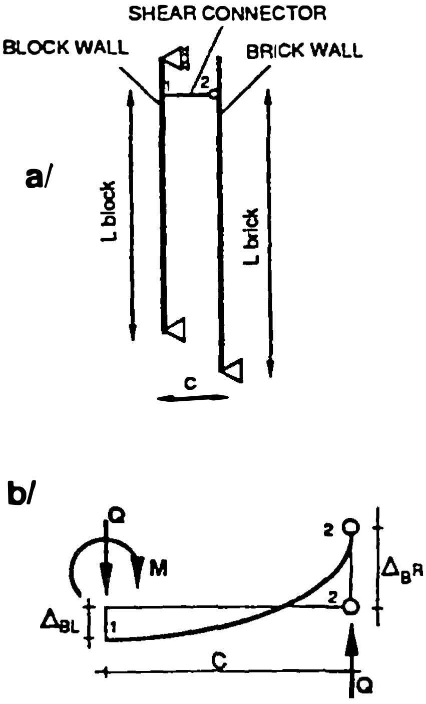
The imposed deformations (due to shrinkage or expansion) are applied at each element (in mm). In addition, the SFRAME program gives the option to impose the necessary relatives temperatures at each element. The self weight of the masonry components can also be included.



(1),(2). For the part of the shear connector embedded in the vertical mortar joint of blocks and for the tie embedded in the mortar bed, stiffnesses same wih the corresponding masonry components were assumed.

(3) The junction of the tie with the shear connector was modelling by a hinge.

FIGURE 6. Finite Element Model.



FJGURE 7. Model for the Approximate Method.

3.2./ Approximate Method.

The critical shear connector is the one at the top and a conservative approximate approach will be to neglect all the others shear connectors and assume that the restraint to the imposed deformations is provided by the top connector. It is also assumed that no moment capacity exist at the junction of the connector and the brick wythe. These conditions are shown schematically in Figure 7. The problem, now, becomes statically determinate and by using compatibility, equilibrium and Hooke's law, a close form solution for the final deformations ABL and ABR at nodes 1 and 2 (sec Figure 7) could be derived. The proposed expression is:

$$\begin{vmatrix} (\alpha+1) & -\alpha \\ -\beta & (\beta+1) \end{vmatrix} . \begin{Bmatrix} \Delta_{BL} \\ \Delta_{BR} \end{Bmatrix} = \begin{Bmatrix} \delta_{BL} \\ \delta_{BR} \end{Bmatrix} \qquad (1)$$

where

$$\alpha = \frac{3.E_{SC}.I_{SC}}{C^3} . \frac{L_{BL}}{A_{BL}E_{BL}} \qquad \beta = \frac{3.E_{SC}.I_{SC}}{C^3} . \frac{L_{BR}}{A_{BR}E_{BR}} \qquad (2)$$

δ_{BL} and δ_{BR} are imposed deformations at nodes 1 and 2 due to material properties and temperature changes. These deformations correspond to unrestrained movements of the wall and can be expressed as follows

$$\delta_{BL} = (\varepsilon_{SH,BL} + \alpha_{BL} . \Delta T_{BL}).L_{BL}$$

$$\delta_{BR} = (\varepsilon_{EXP,BR} + \alpha_{BR} . \Delta T_{BR}).L_{BR} \qquad (3)$$

By solving equation (1) the unknown final deformations Δ_{BL} and Δ_{BR} can be found. Finally, the internal forces arc given by the slope - deflection formula for the connector:

$$Q = \frac{3.E_{SC}.I_{SC}}{C^3}.(\Delta_{BR} - \Delta_{BL}) \quad \text{and} \quad M = \frac{3.E_{SC}.I_{SC}}{C^2}.(\Delta_{BR} - \Delta_{BL}) \qquad (4)$$

Example: As a demonstration of the approximate method, case No 9 of Table 1 is analyzed. Sec also Figure 7. The geometric and material properties for a strip of a wall section 800 mm wide and 3000 mm high containing connectors spaced at 800 mm are:

Block Wall: E_{BL}=10 GPa A_{BL}=60.32x10^3 mm^2

	L_{BL}=2800 mm	I_{BL}=353.4x10^6 mm^4
Brick Wall:	E_{BR}=10 GPa	A_{BR}=72x10^3 mm^2
	L_{BR}=3000 mm	I_{BR}=48.6x10^6 mm^4
Connectors	E_{SC}=200 GPa	A_{SC}=90 mm^2
	C=75 mm	I_{SC}=27x10^3 mm^4

Solution:

-From equ. (2): α=0.17825 and β=0.16

-From equ. (3): δ_{BL}= (-0.025% + 5.0x10^{-6}x22)x2800=-0.392 mm
δ_{BR}= (+0.045% - 3.6x10^{-6}x18)x3000=1.1556 mm

- Substituting these values into expression (1) :

$$\begin{vmatrix} 1.17825 & -0.17825 \\ -0.16 & 1.16 \end{vmatrix} \cdot \begin{Bmatrix} \Delta_{BL} \\ \Delta_{BR} \end{Bmatrix} = \begin{Bmatrix} -0.392 \\ 1.1556 \end{Bmatrix}$$

- Solving that system of equations the final deformations can be found:

Δ_{BL}= -0.19 mm
Δ_{BR}= +0.97 mm

- The internal force and moment are then given by equations (4):

Q = 44.5 KN M = 3.34 KN.M

- Conclusion: the brick wall has to resist a compressive stress of

$$\frac{44.5x10^3}{72x10^3} = 0.62\ \text{MPa}$$

the block wall has to resist a tensile stress of:

$$\frac{44.5x10^3}{60.32x10^3} + \frac{3.34x10^6 x95}{353.4x10^6} = 1.63\ \text{MPa}$$

- Stresses due to the weight of the masonry components and other external loads must be added *to* previous obtained values.

3.3./ Comparison of F.E.M. with Approximate Method

The approximate method was compared with the F.E.M. through a parametric analysis. Note that the approximate method models only the top connector and as such it is expected to give larger internal forces, since in reality.the restrains provided by all the other connectors along the wall reduce the internal forces.

Using the parametric analysis the effects of the differential deformations due to material properties and temperatures changes were investigated. In addition, the effect of the cavity width was also examined.

Table I shows the values of the different parameters that were used. For all the cases, the wall was assumed to have the same dimensions and shear connector arrangement as the testing specimen. The coefficients of thermal expansion for the block wall and the veneer brick were assumed to be $5.0x10^{-6}$ and $3.6x10^{-6}$ respectively.

TABLE 1. Parameters.

	$\varepsilon_{SH,BL}$ (%)	$\varepsilon_{EXP,BR}$: (%)	ΔT_{BL} (°C)	Δ_{BR} (°C)	CAVITY (mm)
1	-0.015	+0.020	0	0	75
2	-0.025	+0.045	0	0	75
3	-0.040	+0.060	0		75
4	-0.025	+0.020	0	0	25
5	-0.025	+0.045	0	0	50
6	-0.025	+0.045	0	0	75
7	-0.025	+0.045	0	0	100
8	-0.025	+0.045	+10	-15	75
9	-0.025	+0.045	+22	-18	75
10	-0.025	+0.045	+20	-30	75
11	-0.025	+0.045	+25	-25	75

The maximum shear forces versus the different parameters are plotted in Figures Ba, 8b, 8c. These Figures show that the approximate method gives always conservative results for both final deformations and internal forces. For cavities smaller than 50 mm the shear forces calculated by the approximate method deviate from the values obtained by the F.E.M..

From a comparison of Figures 8a and 8b the effect of shrinkage and expansion of the masonry components is more critical than the effect of temperature changes.

Both analyses gave compressive forces to the brick wythe and tensile forces to the block wythe and showed that internal forces increase with decreasing cavity. Figure 8c shows this reduction.

4./ CONCLUSIONS AND RECOMMENDATIONS.

From the investigation presented in this paper the following conclusions can be made:

1- Both the experimental and analytical study showed that the effects of thermal and moisture deformations on shear connected cavity walls cannot be neglected. The forces induced to the masonry components due to the restraints provided by the connectors should be calculated using a rational approach arid the adequacy of the materials in resisting these forces must be checked.

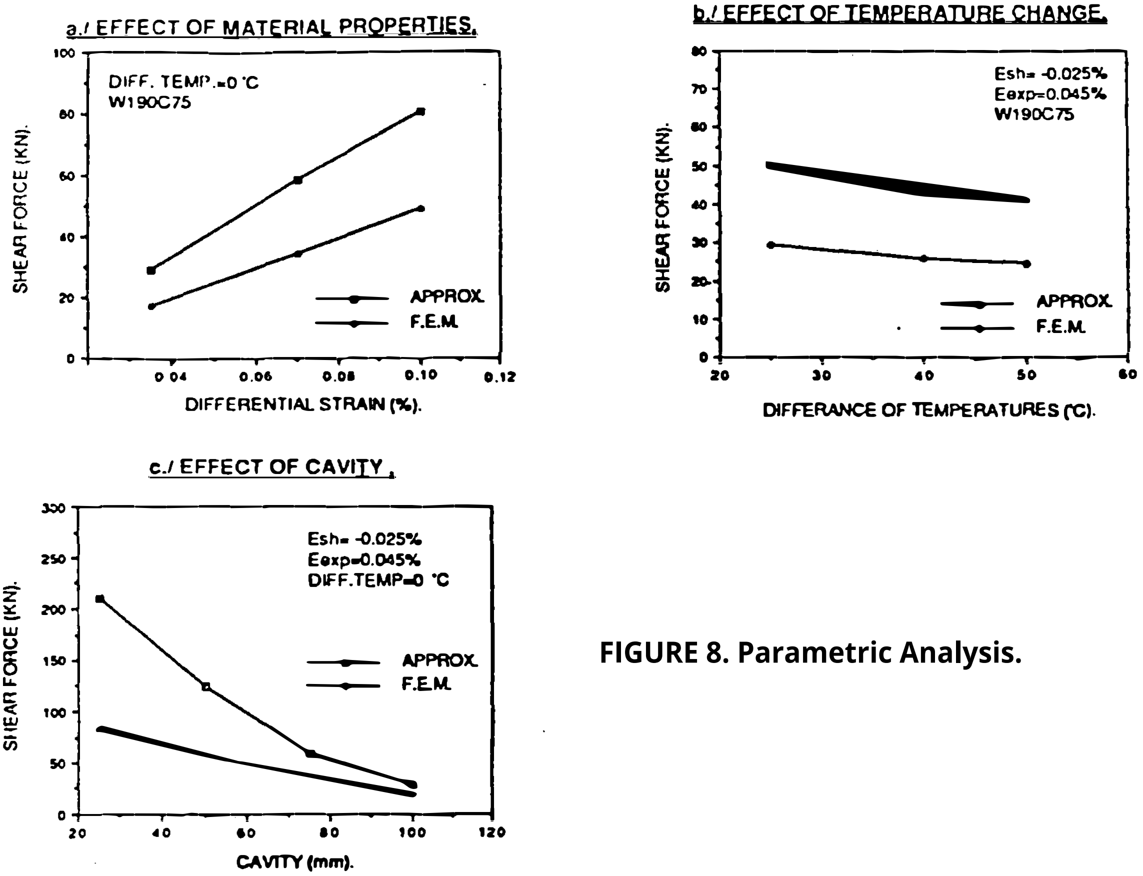


FIGURE 8. Parametric Analysis.

2 - Placing connectors at 800 mm in both directions will facilitate construction and placement of accessories such as insulation, air-vapor seals etc.. Since no adverse effects were found in this study for such connector arrangement, this spacing of connectors (every 800 mm vertically and horizontally) is recommended for consideration.

3 - For all cases investigated and for this type of load conditions it was found that the critical shear connectors arc those locat d at the top. The analysis also confirmed that the brick is always subjected to compressive forces and the block wall to tensile forces. Shear connected non load bearing walls must be reinforced to resist these internal tensile forces.

4 - The approximate method proposed to calculate the internal forces and deformations on the masonry components due to environmental conditions appears to provide adequate results. The simplified method was compared with a finite element analysis and was found to give conservative results for bolh the final deformations and the internal forces. For cavities smaller than 5O mm the internal forces calculated using the simplified method were approximately twice the values obtained from the finite element analysis.

5 - From the parametric analysis it was found that the internally generated forces on walls with cavity less than 50 mm arc very large. It is therefore recommended that shear connected cavity walls incorporate cavities no less than 50 mm.

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NOTATION.

A_{BL}:	Net Cross-Section of Block Wall.
A_{BR}:	Cross Section of Brick Wall.
C	Cavity of the Wall or Unsupported Length of Shear Connector.
E_{BL}, E_{BR}, E_{SC}:	Modulus of Elasticity of the Block Wall, Veneer Brick and Shear Connector.
Q	Shear Force at the Shear Connector or Axial Force Applied at the Masonry Components.
M:	Moment at the Fixed End of the Shear Connector.
L_{BL}, L_{BR}:	Distance of the Uppermost Connector from the Bottom of the Block and Brick Walls.
α_{BL}, α_{BR}:	Coefficients of Linear Thermal Expansion for Block and Brick Walls
δ_{BL}, δ_{BR}:	Unrestrained Deformations at the Junction of the Top Connector with the Block Wall and Brick Veneer.
Δ_{BL}, Δ_{BR}:	Final Deformations at the Junction of the Top Connector with the Block Wall and Brick Veneer.
$\Delta T_{BL}, \Delta T_{BR}$:	Relative Temperatures of the Walls.
$\varepsilon_{SH,BL}$:	Linear Shrinkage Strain of the Concrete Block Wall.
$\varepsilon_{EXP,BR}$:	Linear Expansion Strain of the Brick Wall.

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