Differential Movement in Cavity Walls and Veneer Walls Due to Material and Environmental Effects

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DIFFERENTIAL MOVEMENT IN CAVITY WALLS AND VENEER WALLS DUE TO MATERIAL AND ENVIRONMENTAL EFFECTS

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Introduction

The transfer of loads acting on a masonry veneer to the backup system is carried out by ties spaced at intervals not greater than 600 mm in the vertical direction and 800 mm in the horizontal direction. The configuration and design of these ties has evolved over the years into two distinct categories; ties which allow and ties which restrict vertical movement. Cavities have increased to accommodate increasing amounts of insulation. This has made it necessary to examine the influence of the ties on the behaviour of these walls as it relates to material and environmental effects.

Two types of backup systems are evaluated, namely: concrete block and steel stud, with both connected to the veneer by ties which provide resistance to vertical movement.

Due to climatic effects and material properties the brick veneer may expand and the backup wythe may shrink or remain dimensionally stable. The brick veneer is also subjected to a variation in temperature while the backup wythe is under relatively constant temperature. These temperature differences may lead to differential movement between the two wythes, which in turn may cause stresses within the assembly.

Determining the level of stress which may be attributed to differential movement and its effect on the assembly will contribute to better understanding of the behaviour of these walls, leading to better designs.

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The restraint to differential movement provided by the ties causes induces in both wythes. These stresses are generally in the form of compression in the brick veneer and tension in the backup system. By designing the ties for stiffness, the differential movement can be of benefit to the structural performance of the assembly and can improve serviceability performance by reducing cracking of the veneer.

Cavity walls have traditionally been designed on the assumption that all lateral loads acting on the exterior wythe are transferred and resisted by a backup interior wythe portion of the assembly. The need for higher wall insulation requirements has increased the width of the cavities and it is possible for cavities to be 100 mm or larger. The rigidity of the connectors and the spacing in the horizontal and vertical direction is governed by the ability of masonry to span between connectors and the ability of the connector to resist the load acting on them.

Two common cavity walls used in buildings are assemblies consisting of an exterior weathering veneer (usually 90 mm thick burned clay or concrete brick masonry), a 25 mm air space, 25 to 75 mm or more insulation, and an interior backup wall of either 140 mm or thicker concrete masonry wall or 140 mm steel stud wall. Additional insulation can be provided either as loose fill in the cores of the masonry, or in the form of batt insulation between the studs.

An air/vapour barrier is normally positioned between the cavity insulation and the backup wall. The main consideration for choosing the position of the insulation and the air/vapour barrier is the location of the dew point and the continuity of the insulation and membrane. Where steel studs form the backup wall, placing the insulation in the cavity will shift the dew point outside the metal studs, reducing the risk of condensation and possible subsequent corrosion of the steel stud backup wall.

This paper examines the effect of connecting the veneer and backup wythes with connectors capable of providing resistance to differential movement in the vertical direction. Theoretical analyses were verified by experimental work carried out over the last 5 years. It is concluded that restraint to differential movement can be beneficial to the serviceability performance of cavity and veneer wall assemblies.

Ties

There are two distinct types of ties for connecting cavity or veneer walls. Ties that permit differential vertical movement and ties which provide restraint to differential vertical movement.

Figure 1 shows a typical adjustable tie for masonry veneer and metal stud backup wall systems. The tie shown in Figure 1 allows for differential vertical movement between the veneer and the backup only if the assembly remains vertical; i.e. the veneer and backup remain parallel. Deflection or deformation of the backup and/or the veneer may cause the adjustibility of the tie to become ineffective.

The connector shown in Figure 2 allows for construction adjustability while providing partial restraint to differential vertical movement after completion of construction.
The connector shown in Figure 2 is manufactured from mild steel plate, 1.6 mm thick and which has a yield strength of 240 MPa. The end holes on the plate are 5.8 mm in diameter and the V-Tie is manufactured from 4.8 mm diameter wire. The moment of inertia of the wire is 25.2 mm^4 (50.4 mm^4 for the V-Tie with two legs) and that of the main plate at the weakest location is 16,800 mm^4.

The V-Tie is placed into the appropriate 5.8 mm diameter end hole corresponding to the location of the mortar joint in the veneer. For utilization with modular brick veneer, the 75 mm height of the connector plate makes the connector assembly position independent of the location of the mortar joint of the concrete block or other backup system.
In developing the connector, the rigidity of the wire and that of the plate were designed to allow for initial movement (such as moisture expansion of the bricks) to be accommodated by the V-Tie and structural or external loads to be resisted by the action of the wall assembly (veneer, tie, backup).

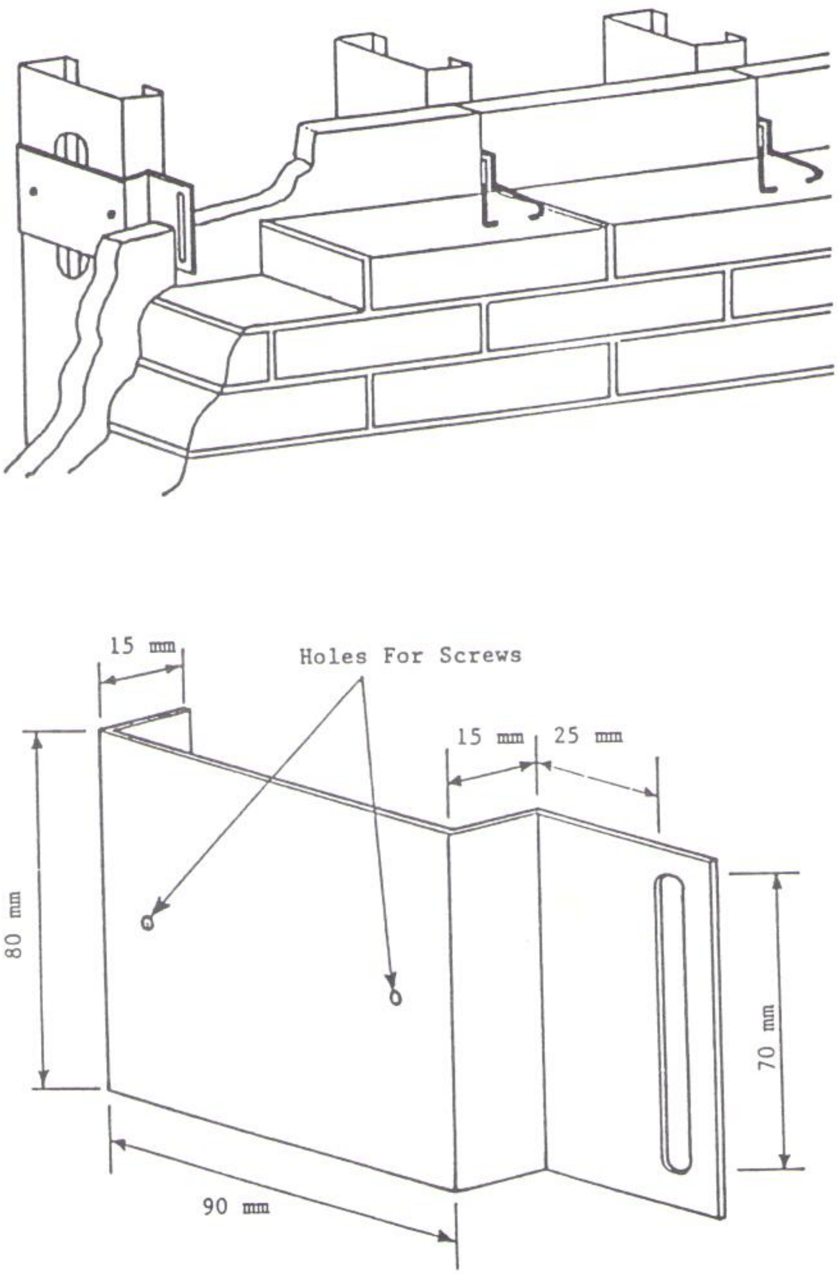
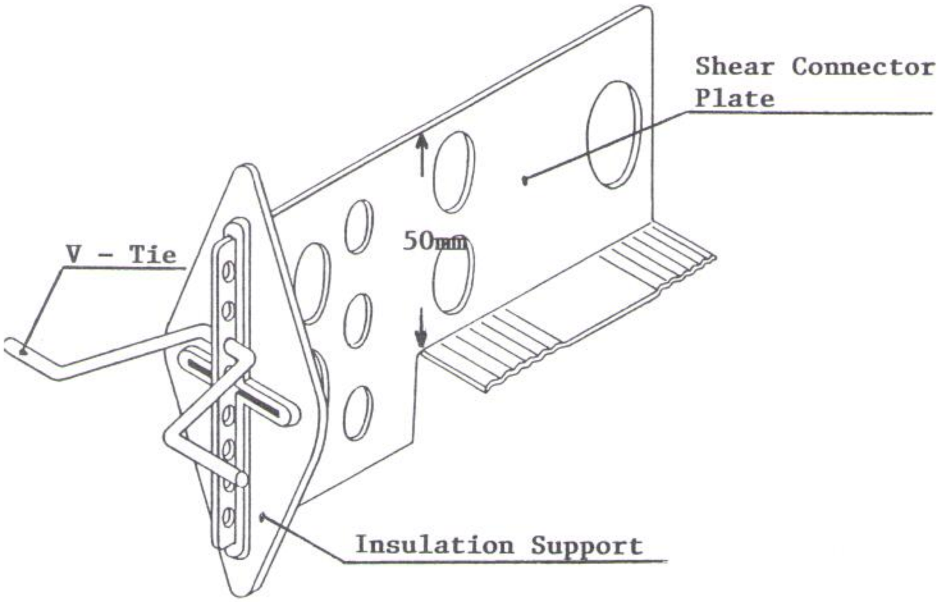
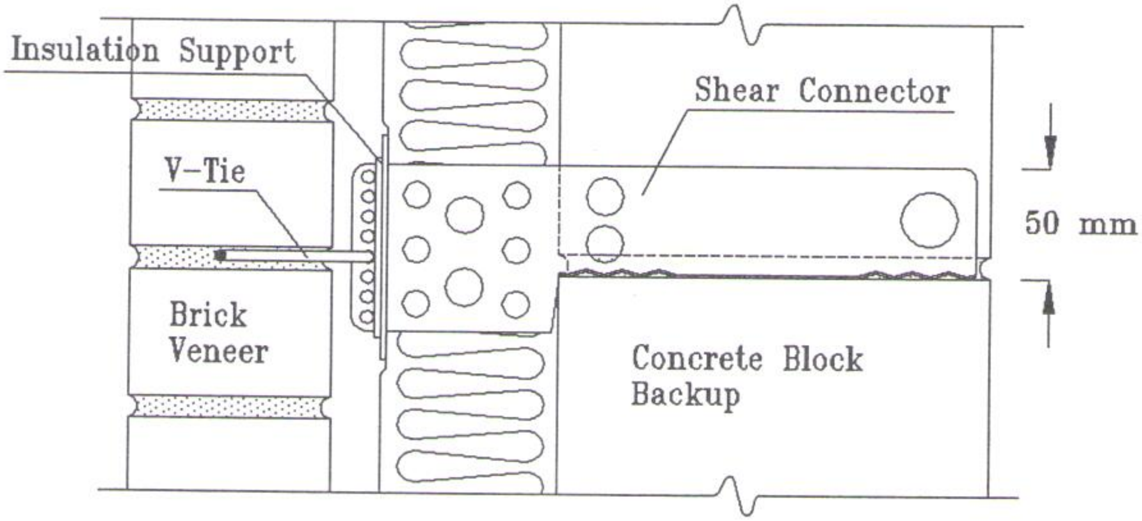


Figure 1. Adjustable Connector.



(A) Shear Connector Components.



(B) Cavity Wall Shear Connector Installation.

Figure 2. Shear Connected Cavity Wall.

Differential Movement And Material Physical Properties.

Concrete block masonry can be expected to undergo a linear shrinkage after construction in the order of 0.01% to 0.02%. Subsequent wetting and drying of the concrete blocks results in lesser amounts of expansion and contraction. In this paper the average of 0.015% was assumed in evaluating the effects of shrinkage of the concrete block backup wythe.

Bricks on the other hand, having been fired in a kiln, experience irreversible moisture expansion over an extended period of time. This is due to the hydration of amorphous materials that are formed during burning of the bricks being exposed to environmental humidity over time. Although there is shrinkage taking place in the mortar at the same time, there is generally a small resultant expansion of the clay brick veneer. A typical value of brick masonry linear expansion after two years would be of the order of 0.005% to 0.015%. Most of this expansion takes place at the early life of the unit. At 30 days after production, 40% of the total expected expansion of the clay brick has taken place. It is for this reason, combined with the fact that the cement based mortar joints will shrink over time, that a conservative value of 0.010% was assumed in the evaluation of the moisture expansion of the burned clay units on the assembly.

As is common for other structural materials, masonry will expand when heated and contract when cooled. This will lead to differential deformations between interior walls in a building, which are maintained at a relatively constant temperature, and exterior walls which are exposed to variations in climatic conditions. The coefficients of linear thermal expansions are of the order of 0.000,008 mm/mm per degree Celsius for normal concrete masonry and 0.000,006 mm/mm per degree Celsius for clay brick and stone masonry. These values are approximate and will vary with materials available locally. The coefficient for thermal movement of the steel stud was assumed to be 0.000,011,3 mm/mm per degree Celcius.

Theoretical Evaluation Of Forces Resulting From Shear Connecting The Veneer To The Backup System.

A typical cavity wall is presented in Figure 3, identifying the most important features of the assembly. Figure 4 illustrates the important features of a veneered wall for which the backup consists of steel studs. The ties are spaced closer at the top and bottom of the walls to reflect the increased load resulting from the action of external lateral loads. The first and last connectors are placed at 200 mm vertically from the supports, the second connector from the top and bottom at 600 mm from the supports (400mm from the first and last connector), and the remaining connectors are spaced at 600 mm o.c. vertically. Horizontal spacing of the connectors was assumed to be 800 mm o.c.

Consider differential movement between the veneer and the backup for the walls shown in Figures 3 and 4. As the wire is much more flexible than the plate, it is safe to assume that most of the movement will be accommodated by the more flexible wire.

There are two wires per V-Tie crossing the air space with a combined moment of inertia of 50.4 mm^4. The horizontal portion of the wire which is placed through the end hole of the plate will further reduce the rigidity of the assembly as it relates to differential movement. Note that the plate has a moment of inertia 333 times larger than the two wires of the V-Tie. The effect of the differential movement will induce an axial force and a moment in the veneer, and an axial force in the back-up, the direction of which will depend on the relative movement. Expansion in the brick and shrinkage in the block will cause compression in the brick and tension in the block.

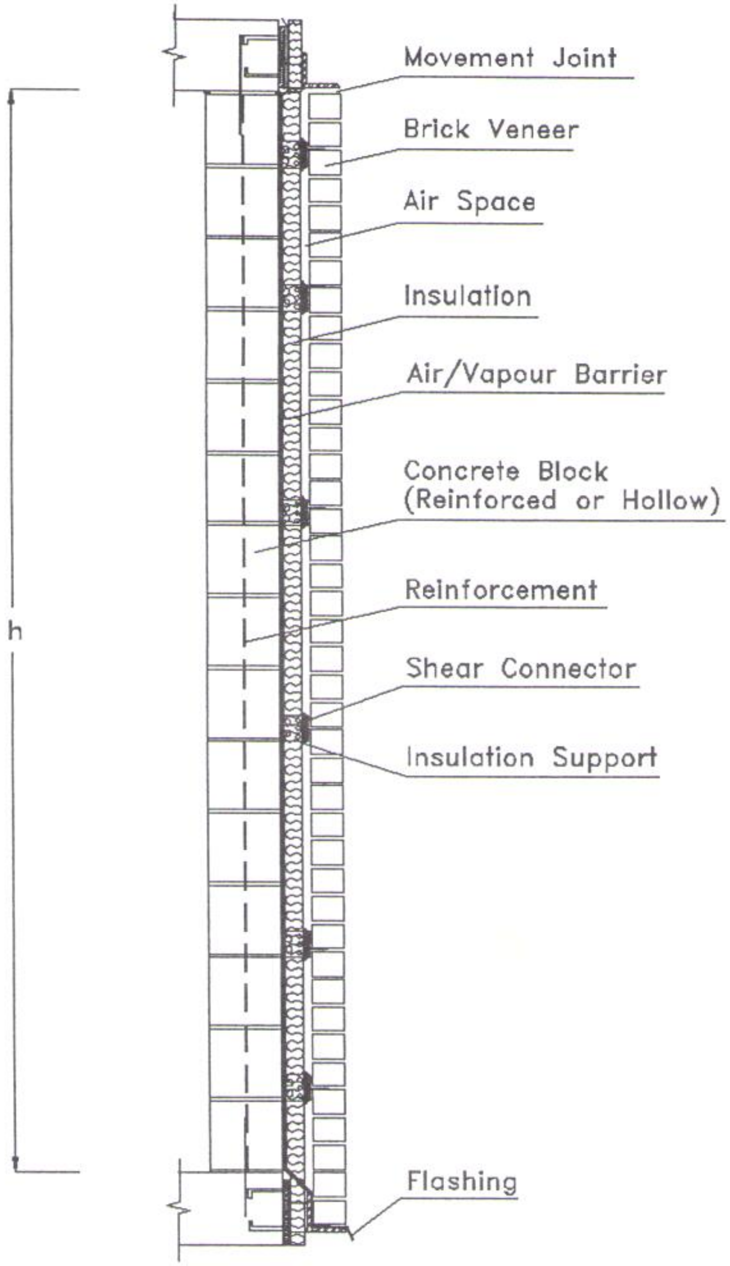


Figure 3. Typical Cavity Wall.

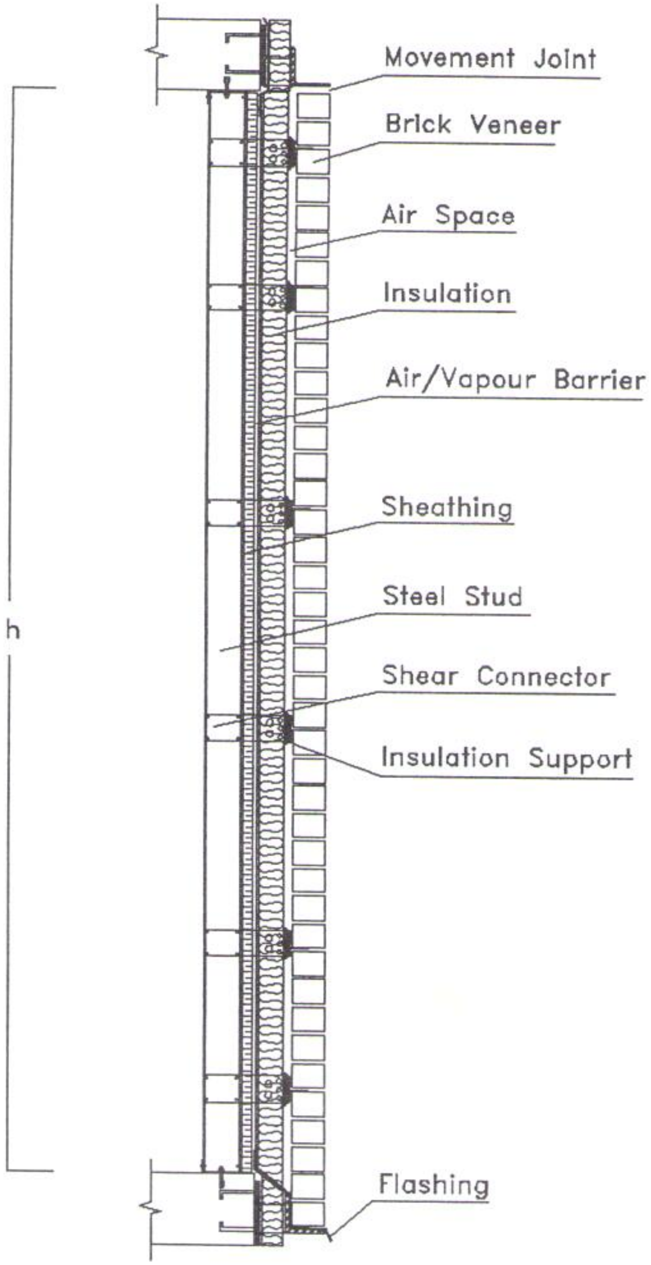


Figure 4. Typical Masonry Veneered Wall.

Consider further a section of the assembly idealized as shown in Figure 5. The V-Tie is fixed into the brick and pin connected to the shear connector plate. Figure 6 shows the forces acting on the connector model of Figure 5 resulting from relative movement between the two wythes.

By using compatibility equations and Hooke's law, a close form solution for the final deformations Δ_{BL} and Δ_{BR} at nodes 1 and 2 (see Figure 5) is derived as follows:

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

where

$$\alpha = \frac{3E_{SC}I_{SC}}{C^3} \cdot \frac{L_{BL}}{A_{BL}E_{BL}}$$

and (2)

$$\beta = \frac{3E_{SC}I_{SC}}{C^3} \cdot \frac{L_{BR}}{A_{BR}E_{BR}}$$

Deformations 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 :

$$\delta_{BL} = (\varepsilon_{SH,BL} + \alpha_{BL} \cdot \Delta T_{BL}) \cdot L_{BL} + \frac{(H_{BL} \cdot W_{BL}) \cdot L_{BL}}{A_{BL} \cdot E_{BL}} + \Delta_{1BL}$$

and (3)

$$\delta_{BR} = (\varepsilon_{EXP,BR} + \alpha_{BR} \cdot \Delta T_{BR}) \cdot L_{BR} + \frac{(H_{BR} \cdot W_{BR}) \cdot L_{BR}}{A_{BR} \cdot E_{BR}} + \Delta_{1BR}$$

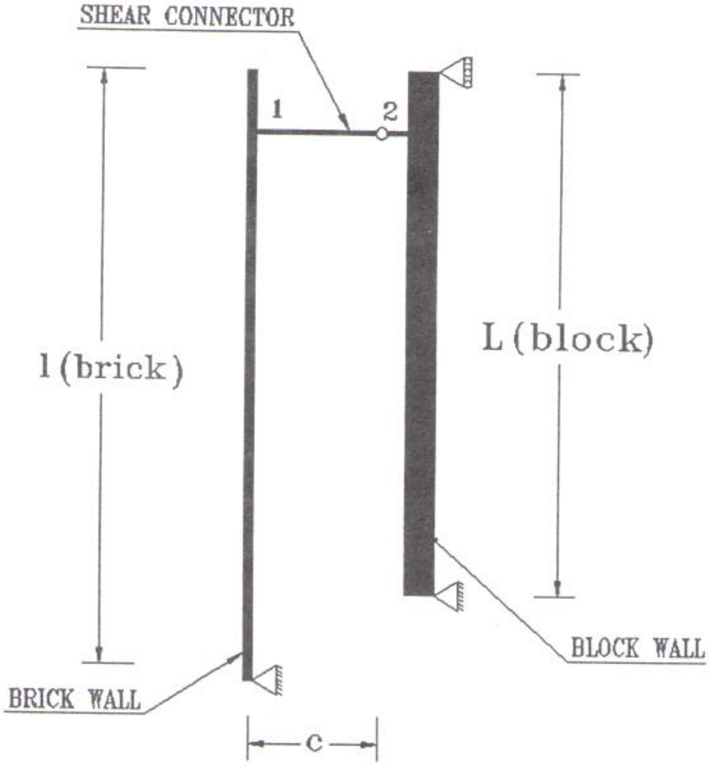


Figure 5. Idealized Brick-Connector Backup Assembly.

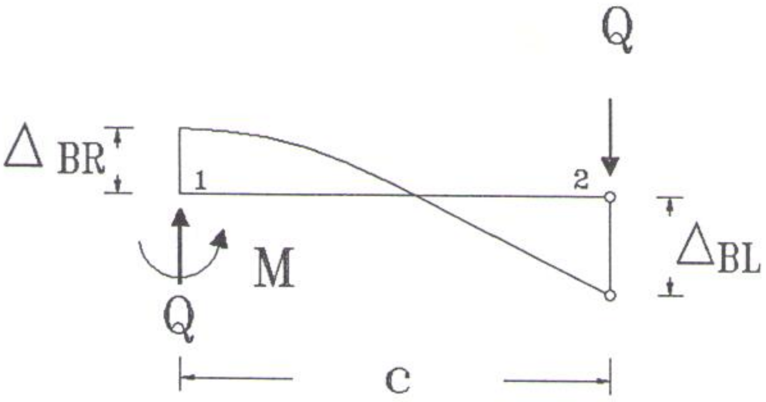


Figure 6. Forces Acting On The Connector Caused By Differential Movement.

Where Δ_{1BL} and Δ_{1BR} are the deformations of the block wythe and the brick wythe below the segment under consideration respectively and Δ_{BL} and Δ_{BR} are the deformations of the block wythe and the brick wythe of the segment. Solving equation (1), (2) and (3) the unknown final deformations for each segment of the block wythe and the brick wythe can be calculated. Finally, the internal forces are given by the slope deflection formula for the shear connector:

$$Q=\frac{3E_{SC}I_{SC}}{C^3}.\left(\Delta_{1BR}-\Delta_{1BL}\right)$$

and (4)

$$M=\frac{3E_{SC}I_{SC}}{C^2}.\left(\Delta_{1BR}-\Delta_{1BL}\right)$$

Where :

A_{BL}:	Net cross sectional area of block wall.
A_{BR}:	Net cross sectional area of brick veneer.
C :	Air space between the brick veneer and the insulation.
E_{BL}, E_{BR}, E_{SC} :	Modulus of Elasticity of the block masonry, brick masonry and shear connector respectively.
H_{BL}, H_{BR} :	Height of the wall above the segment under consideration.
W_{BL}, W_{BR} :	Self weight of the block wythe and the brick wythe.
L_{BL}, L_{BR} :	Distance of the uppermost connector from the bottom of the block wythe and the brick wythe, respectively.
α_{BL}, α_{BR} :	Coefficients of linear thermal expansion for block masonry and brick masonry, respectively.
δ_{BL}, δ_{BR} :	Unrestrained deformations at the segment of block or brick wythe under consideration.
ΔT_{BL}, ΔT_{BR} :	Relative temperatures of the wythes.
$\varepsilon_{SH,BL}$, $\varepsilon_{EXP,BR}$:	Linear shrinkage strain of the block wythe and linear expansion strain of the brick wythe, respectively.

Theoretical Results

Consider the two walls shown in Figures 3 and 4. It is assumed that the cavity wall is constructed using 190 mm concrete block for the 5,000 mm high wall and 240 mm concrete block for the 8,000 mm high wall. In both cases the air space is 25 mm and the assembly includes 50 mm cavity insulation for a total cavity width of 75 mm. The wall is reinforced with 1-15M vertical steel reinforcing bar spaced at 1,600 mm centres. The walls are connected with shear connector as shown in Figure 2. The veneered wall of Figure 3 is assumed to be backed by 140 mm wide, 1.2 mm thick (18 gauge) steel studs for the 3,000 mm high wall. For 800 mm horizontal spacing of the connectors and 90 mm thick solid brick veneer, and assuming that the walls are constructed with Type S mortar, the relations derived earlier are used to evaluate the forces acting on the assembly caused by the effects of differential vertical movement.

Figure 7 shows the results obtained by solving relation (1), (2), (3) and (4) using a 50 degree Celcius thermal fluctuation of the veneer, 25 mm wide airspace and the previously reported average moisture expansion coefficient for the brick of 0.010 % and shrinkage coefficient for the concrete blocks of 0.015 %. The other properties used in the analysis were :

E_{BL} = 7,350 MPa, A_{BL} = 81,190 mm^2/800mm
E_{BR} = 9,750 MPa, A_{BR} = 72,000 mm^2/800mm.

In evaluating the stresses in the block wythe, the force acting on the plate was assumed to be transferred to the block without introducing a moment. This assumption is considered justified because the flexibility of the plate was neglected in the analysis. The deformations of the shear connector plate combined with the action of the shear force within the V-tie will reduce the stresses transferred to the walls.

The difference in the stresses shown in Figure 7 between the 5,000 and 8,000 mm high walls are the result of self-weight which was assumed to be 155 kg/m^2 for the burned clay brick and 225 kg/m^2 for the 190 mm concrete block and 250 kg/m^2 for the 240 mm concrete block. Figures 8 and 9 present similar results for the cases where the wires span an air space equal to 13 mm and 35 mm, respectively. The effect of air space on the tensile stress in the concrete block wythe is shown in Figure 10 for the 5,000 mm and 8,000 mm high cavity walls.

A decrease in the temperature of the brick veneer will result in contraction of the brick veneer. Applying a temperature fluctuation of -50°C to the brick veneer in combination with shrinkage in the block wall results in the solution of the relations developed earlier yielding a maximum tensile stress in the order of 0.000,6 MPa in the brick veneer and a maximum compressive stress in the concrete block in the order of 0.000,26 MPa.

For the veneered wall system, Figure 11 shows the results of applying an increased temperature fluctuations of 50°C to the brick veneer, and assuming the steel stud wall remains at a constant temperature and that the air space is 25 mm wide. All other factors remain the same in the analysis.

If an axial load is applied on the backup wythe of a cavity wall, it will cause a strain which can be incorporated in the analysis in the form of an additional shrinkage on the concrete block wythe. For example, the worst case axial load would be equal to the maximum allowable stress on a concrete block wall of 0.30 f'_m. For $f'_m = 8.1$ MPa, the maximum allowable stress is 2.45 MPa. For a 5,000 mm high wall, this load will cause a strain equal to approximately 1.7 mm. Incorporating this strain into the relations derived earlier and solving using $C = 25$ mm, with all other parameters as per the non-load bearing 5,000 mm high analysis, the results obtained are shown in Figure 12.

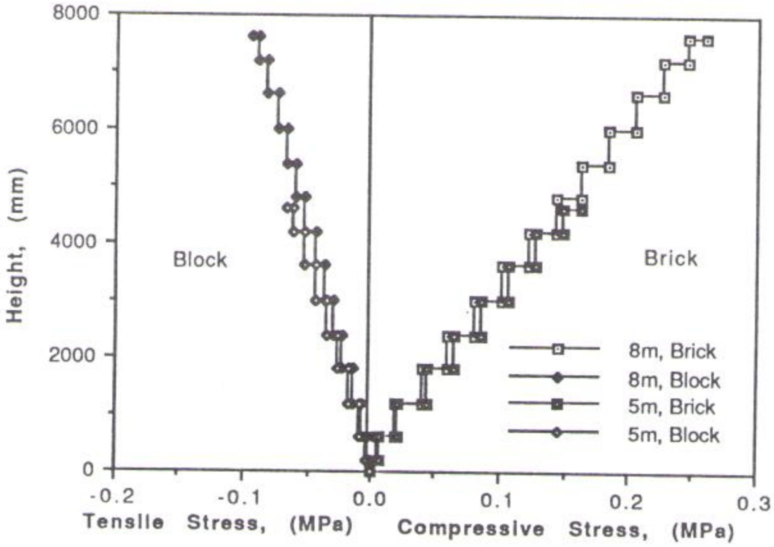


Figure 7. Cavity Wall Stresses Due To Differential Vertical Movement, 25 mm Air Space.

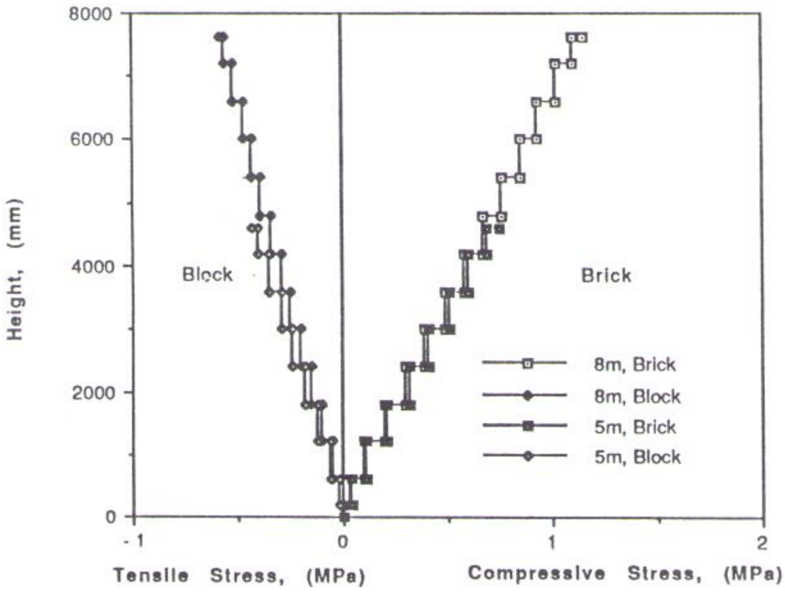


Figure 8. Cavity Wall Stresses Due To Differential Vertical Movement, 13 mm Air Space.

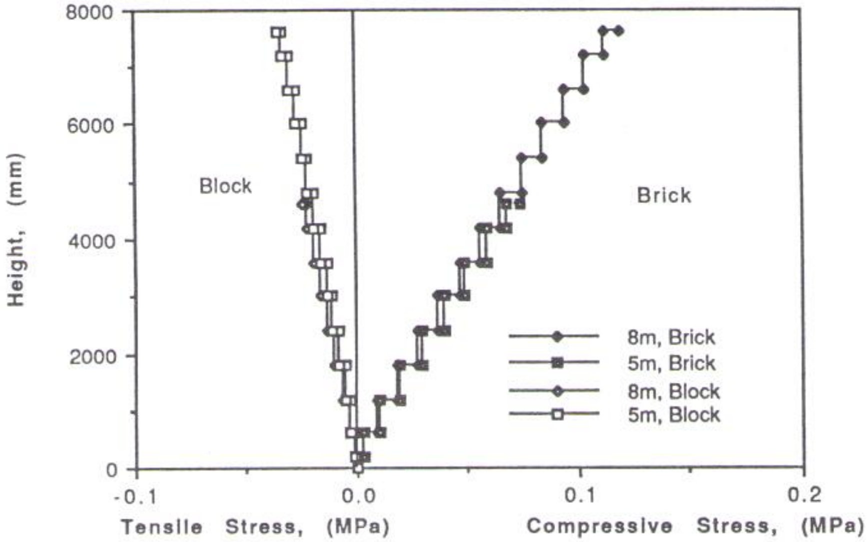


Figure 9. Cavity Wall Stresses Due To Differential Vertical Movement, 35 mm Air Space.

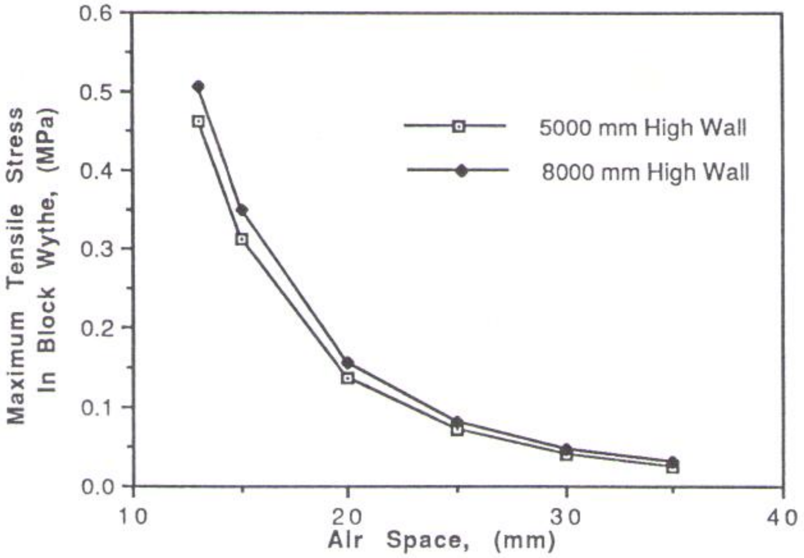


Figure 10. Effect Of Air Space On The Tensile Stress In Concrete Block Wythe.

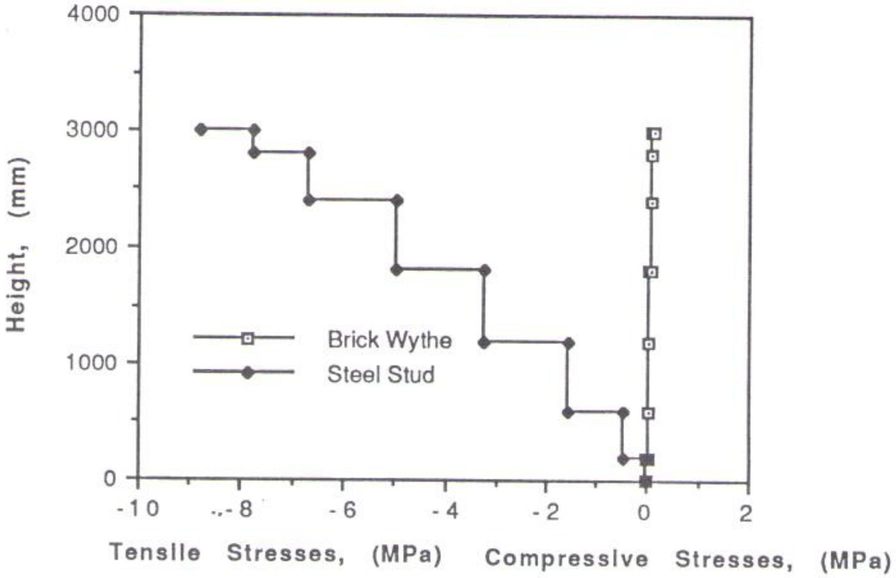


Figure 11. Stresses In 3,000 mm High Steel Stud Backup Wall With 25 mm Air Space.

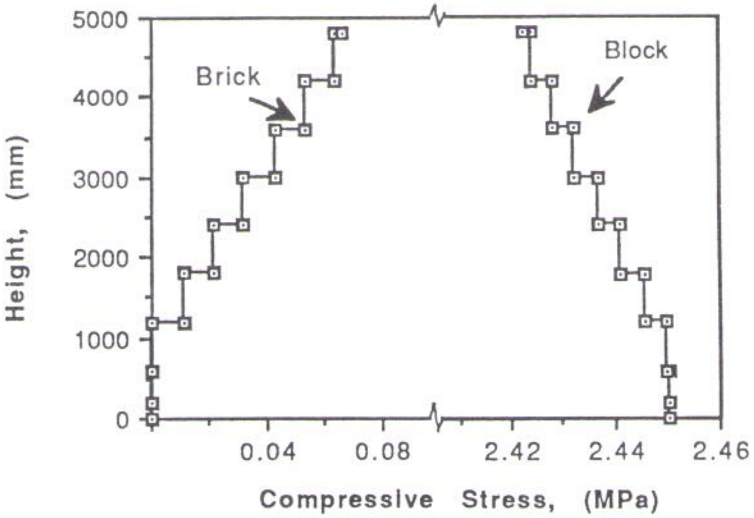


Figure 12. Stresses In 5,000 mm High Cavity Wall Subjected To Axial Load And Thermal and Material Effects, 25 mm Air Space.

Discussion of theoretical results

The results obtained from the analysis show that walls connected to backup systems with ties capable of transferring shear forces across the cavity are subjected to stresses when differential vertical movement occurs. The stiffness of the tie system and the amount of movement control the stress levels within these walls. For burned clay and concrete block cavity wall assemblies, the influence of the ties studied in this paper introduced a compressive stress in the veneer and a tensile stress in the concrete block. The flexible V-Tie portion of the connector acts as a link between the veneer and the Shear Connector Plate and thus the system is capable of resisting external lateral loads in composite action. In all cases the stress levels remained within the allowable, and it is shown that by varying the width of the air space the stress level can be further controlled.

For veneered walls with steel stud backup, the veneer is in compression at a very low stress level, with the steel studs carrying a tensile stress (in the order of 9 MPa for 3,000 mm high walls). Although this stud tensile stress is not very high, placing the connectors at 400 mm on center in the horizontal direction will reduce the tension in the studs. The results obtained from this analysis are verified by full-scale experimental work. The wall shown in Photo 1, consisting of an assembly as shown in Figure 13, has been monitored over a period of 5 years, during which time no signs of distress have been observed. The wall was exposed to climatic conditions of Edmonton, Alberta, with the veneer facing east in a wind sheltered location. The wall has been exposed to severe temperature fluctuations, with the interior portion of the chamber kept at 20°C during the winter month.

The wall shown in Photo 2 was constructed in 1967 and is part of a school gymnasium in Wetaskiwin, Alberta. It consists of 190 mm concrete block and 90 mm burned clay brick connected with a row of brick header courses at 400 mm centres vertically and a 25 mm air space. The wall was opened during renovations to the facility in 1991 and no signs of distress were observed. The wall presented in Photo 3, showing the shear connector plate installation, was completed with 50 mm insulation, 25 mm air space and 90 mm burned clay veneer in 1988, in Wainright, Alberta. Todate it is performing as expected.

Walls with both wythes constructed using materials with similar physical properties will only be subjected to the effects of temperature variations, and thus the differential movement effects will not be as severe as for walls where the veneer and backup are of different materials.

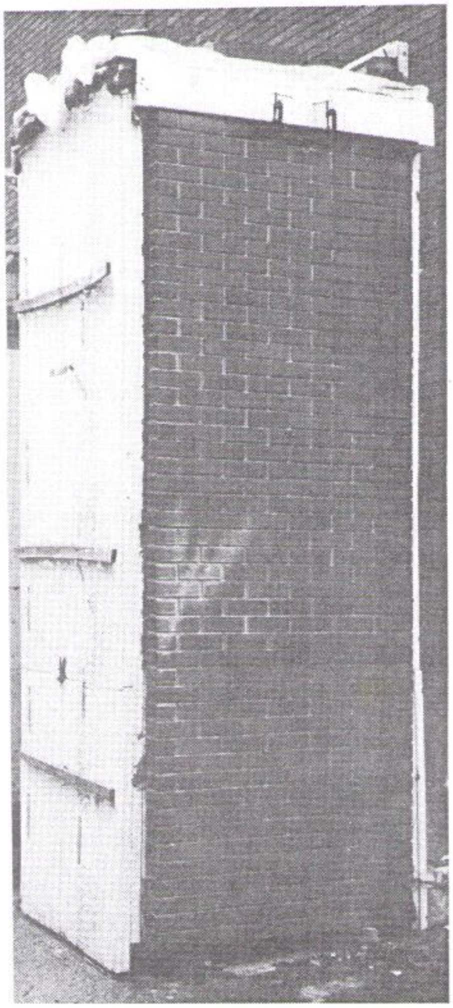


Photo 1. Experimental Shear Connected Cavity Wall.

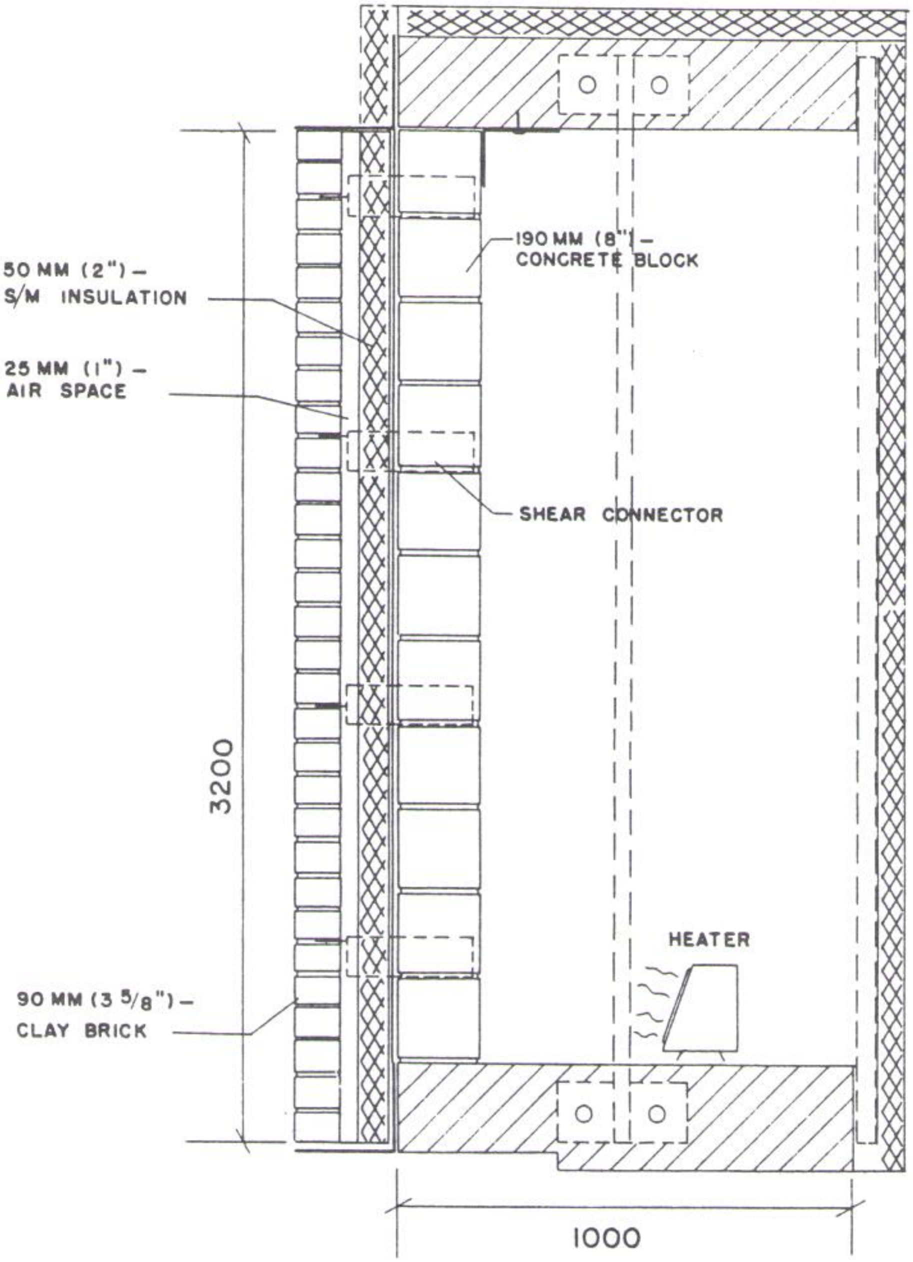


Figure 13. Cross Section Of Test Chamber And Cavity Wall Section.

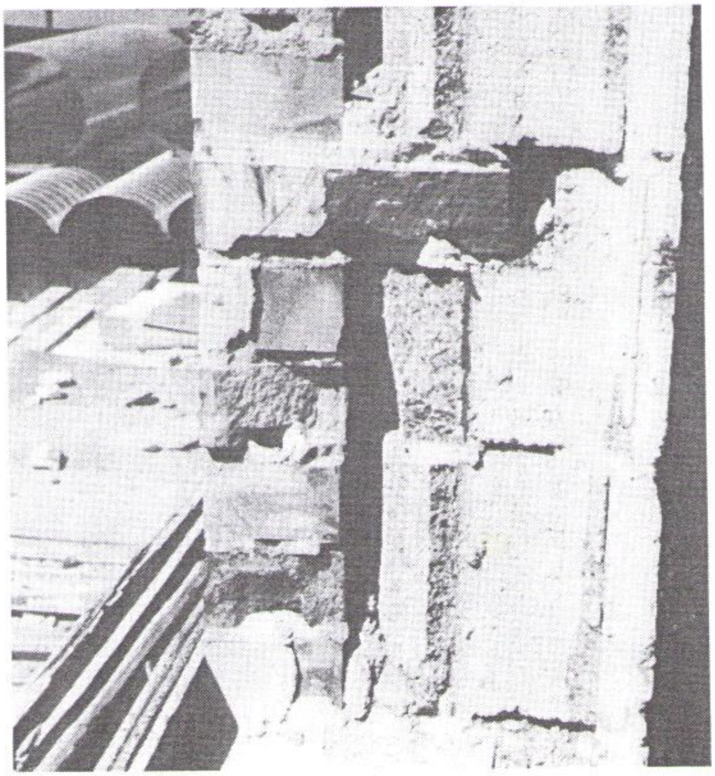


Photo 2. Uncracked Header Course Of Composite Wall After 25 Years Of Service.

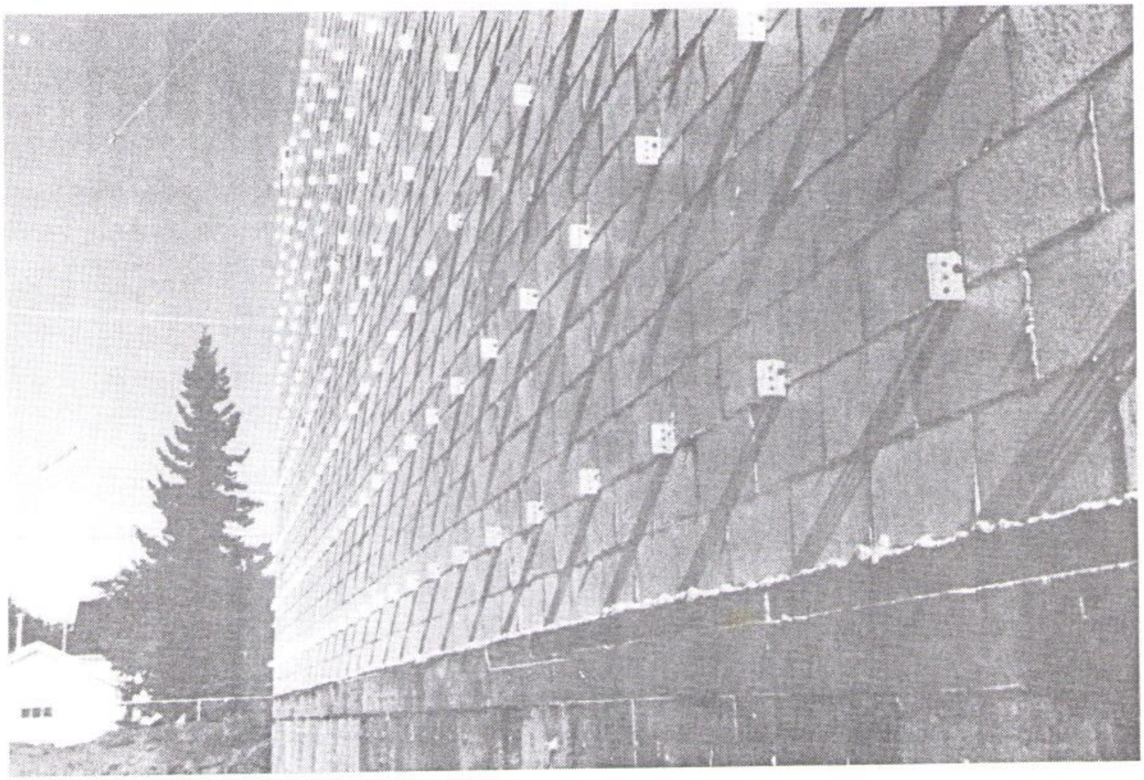


Photo 3. Shear Connector Plates Installed In Partially Completed Cavity Wall.

Conclusions

Connectors capable of providing for shear transfer between the veneer and the backup can be of benefit to the performance of the assembly. For walls where the air space is bridged with 4.8 mm diameter wire, the stresses caused by differential movement are within the allowable levels of CSA Standard CAN3-S304-M84 "Masonry Design for Building".

Expansion of the veneer will cause a compressive stress in the veneer and a tensile stress in the back-up assembly. The level of stress is a function of the rigidity of the tie, the distance over which the tie is spanning, and the amount of movement to be accommodated.

For cavity walls higher than 8,000 mm, the air space should be increased to 35 mm minimum. Where steel studs are used as the backup for veneered walls, placing the shear connectors at 400 mm centres in the horizontal direction will reduce the differential movement induced tensile stress within the studs.

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