

# Connecting Cavity Walls

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### ABSTRACT

Recent developments in cavity wall construction include increased cavity widths, different ties ranging from flexible to rigid, and different types of back-up wall. These changes have resulted from the need to provide space for thermal insulation, to recognize new developments in wall construction utilizing steel studs, and shear transfer type wall connectors. Details of performance and design recommendations for cavity walls are presented and discussed.

### INTRODUCTION

Cavity walls in current construction include an exterior wythe usually brick and not load bearing, and a back-up wythe of concrete masonry or steel studs which resist lateral load. These wythes are separated by a cavity, which includes an air space and insulation, and are connected with ties. The incorporation of 75 mm or more of insulation in the cavities and the interaction of the exterior wall assembly with the main structural elements requires better understanding of the behaviour and function of the ties connecting the two wythes of the cavity walls and of the fastening of the back-up walls to the main structural elements.

This paper examines the performance of several types of cavity walls as they relate to two types of connectors; namely flexible, capable of transferring only tension and compression, and rigid, capable of transferring shear, tension and compression. Recommendations are made as to the type of connectors best suited for constructing walls with relatively large cavities.

## TYPES OF CAVITY WALLS

Cavity walls have traditionally been designed on the assumption that all lateral loads acting on the exterior wythe are transferred and resisted by a back-up portion or interior wythe 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. 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 back-up 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 barrier is normally positioned between the insulation placed in the cavity and the back-up wall. The main consideration for choosing the position of the insulation and the air barrier is the location of the dew point and the continuity of the thermal barrier. Where steel studs form the back-up wall, placing the insulation in the cavity so that the dew point is outside the studs will reduce the risk of condensation and possible subsequent corrosion of the steel stud back-up wall.

In addition to the main components of the wall assembly, flashing is incorporated at the bottom portion of the assembly to intercept any water which may enter the assembly from the exterior and divert it outwards through weep holes (vents) constructed in the exterior walls at regular intervals, usually at 600 mm center to center. Figure 1 shows the main components of the two wall assemblies described above.

The two wythes of the cavity walls are connected by ties spaced at intervals usually obtained from traditional guidelines codified in standards such as CSA A370, (1).

The guidelines provided by standards as they relate to fastening cavity walls to the main structural elements (slabs, beams, columns, etc.) are at present not very clear. Ref. 1 requires that the top of concrete masonry back-up walls be supported at 1200mm centers on each side in a staggered configuration. The interaction of these walls with the structure and the influence of the type of connectors used to transfer the load to the main structural elements has been left to chance over the years. For steel stud back-up walls, the studs are supported by steel tracks which are usually fastened to concrete slabs by means of power activated fasteners with varying and at times questionable results.



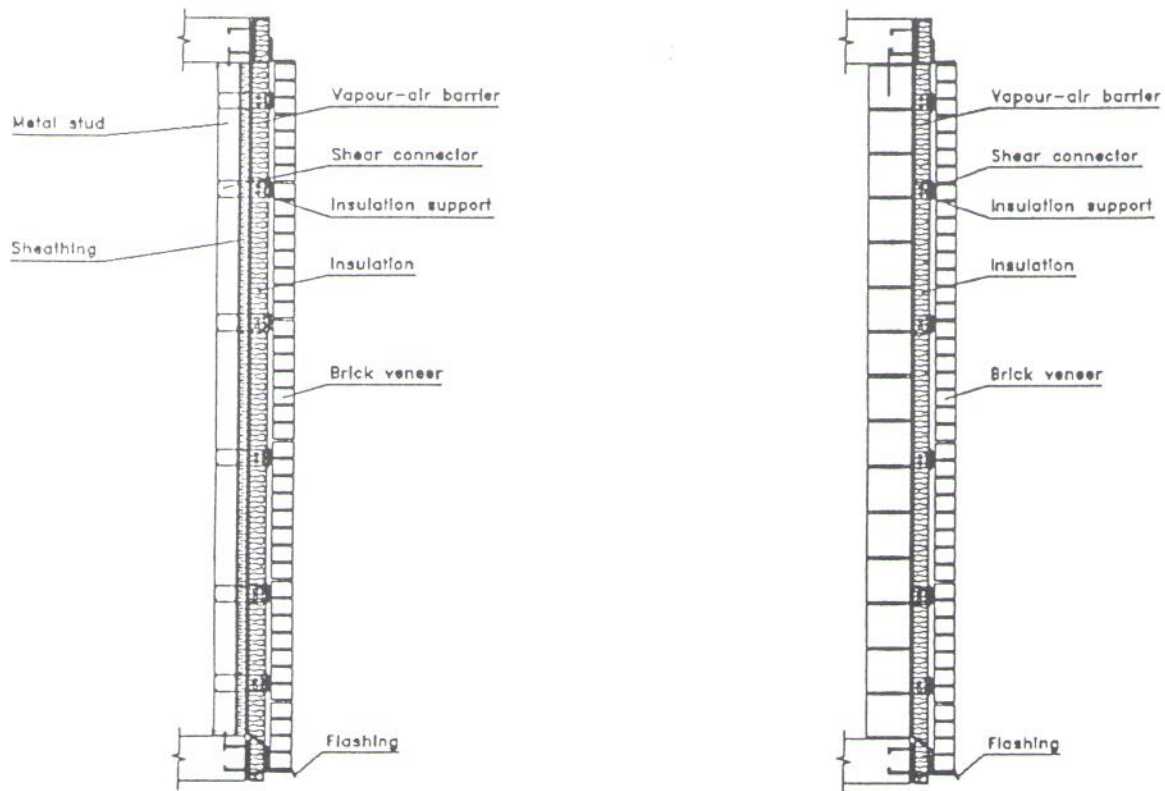


Fig. 1 Cavity Walls

### TIE FUNCTIONS AND THEIR EFFECT ON THE BEHAVIOR OF THE WALL ASSEMBLY

The traditional function of ties is to transfer the loads acting on the veneer to the back-up wall. Furthermore, considerable emphasis is placed on provisions to allow the differential movement between the veneer and the back-up wall resulting from both moisture expansion of the veneer, shrinkage of the back-up wythe and deformation caused by thermal movements.

Concrete block masonry can be expected to undergo, after construction, a linear shrinkage of the order of 0.01% to 0.02%. This value will be greater for lightweight concrete blocks made with expanded shale aggregates and less for concrete blocks that have been autoclaved or steam cured at high pressure. Subsequent wetting and drying of the concrete blocks results in lesser amounts of expansion and contraction. 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 resultant expansion of the clay brick veneer. A typical value of brick masonry linear expansion after two years would be 0.005% to 0.015%. The shrinkage of concrete block masonry and the expansion of clay brick masonry should be borne in mind, especially when the two materials are used in close proximity. Stone masonry is relatively unaffected by changes in humidity.

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 at a relatively constant temperature, and exterior walls, which are exposed to variations in climatic conditions. The coefficients of linear thermal expansion are in the order of 0.000008 mm/mm per degree Celsius for normal concrete masonry and 0.000006 mm/mm per degree Celsius for clay brick and stone masonry. These values are approximate and will vary with materials available locally.

In order to accommodate these deformations ties called adjustable anchors have been developed permitting free movement in the vertical direction. A typical adjustable connector is shown in Fig. 2. Figure 3 shows a connector capable of developing a shear transfer between the two wythes of a cavity wall.

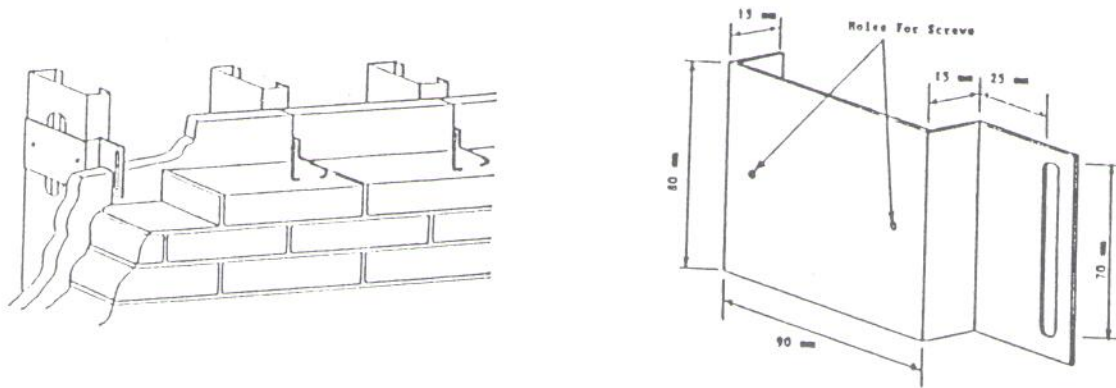


Fig. 2 Adjustable Connectors

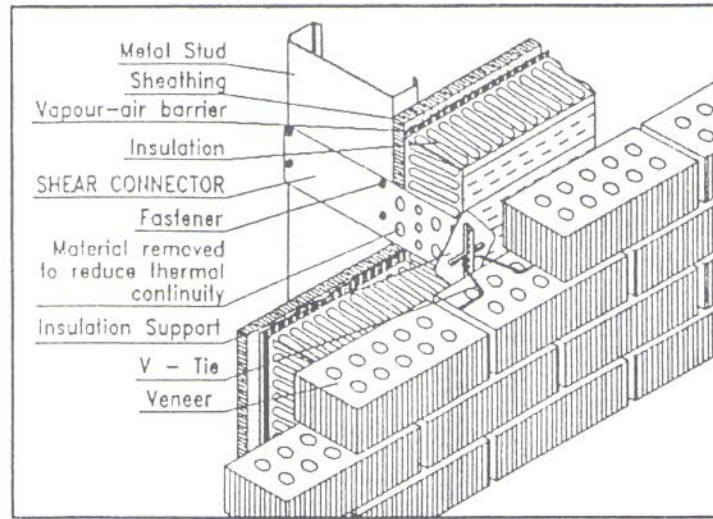


Fig. 3 Shear Transfer Connector

For a steel stud wall assembly similar to the one shown in Fig. 1, the assumption that the loads acting on the ties are determined by the tributary area for each tie is incorrect. Because of the flexibility of the steel stud back-up wall, ties located at the middle third of the height of the wall, will carry substantially less load than ties at the upper and lower portion of the wall. However, the loads will redistribute once the veneer cracks. A recent study (2) commissioned by the Canadian Mortgage and Housing Corporation, has found adjustable ties inadequate. Similar conclusions were reached by the authors in an earlier study (3). Adjustable connectors do not function as designed when the wall assembly deflects either due to loads applied or due to thermally induced movements. Figure 4 shows a typical load distribution on ties prior to cracking, obtained from Ref. (2), which takes into account the support conditions.

Since the distribution of loads on the ties can be predicted, providing additional ties at the ends of the wall assembly is desirable for serviceability requirements. With the increasing size of the cavity and based on field observations of the effects of rigidly connecting the veneer to the back-up wall, the use of adjustable connectors is not justified.

Photo 1 shows a brick veneer connected to a block wall by means of a row of burned clay units set into the back-up wall. The wall was constructed in 1969 and no signs of distress due to thermal and moisture movements were observed when sections of the wall were removed recently for renovations. In addition to being load bearing, the concrete back-up block wall was also subjected to shrinkage strains.



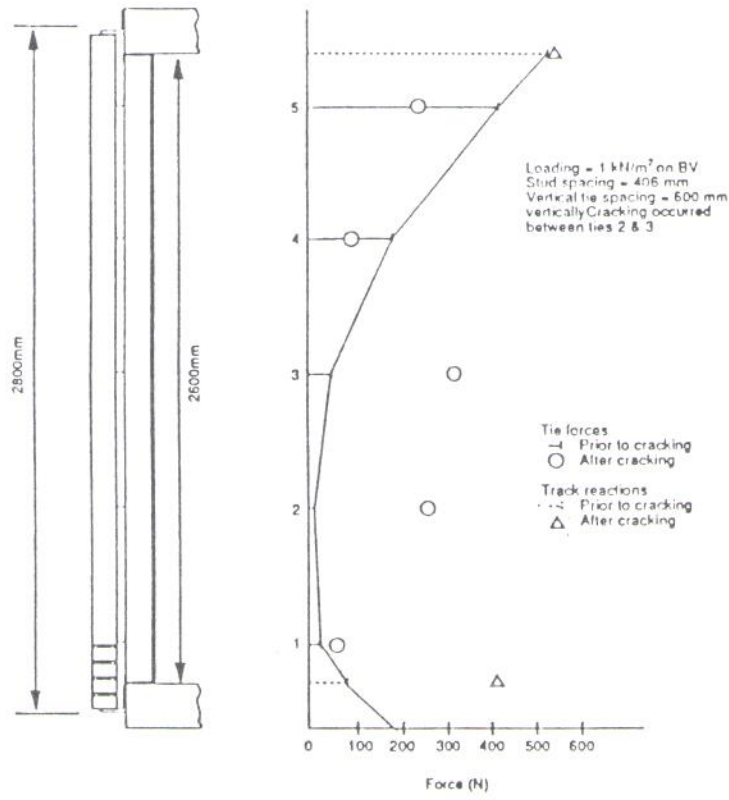


Fig 4 Tie Force Distribution

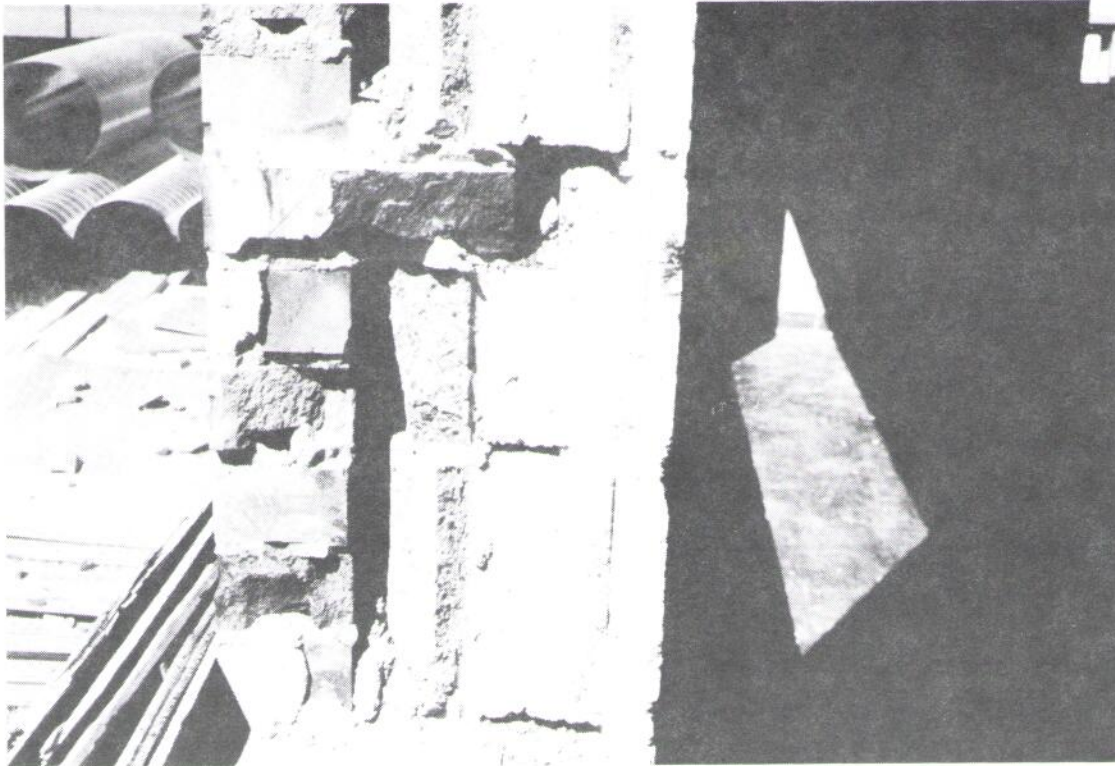


Photo 1 Masonry Cavity Wall

## APPROXIMATE EVALUATION OF FORCES INDUCED TO A SHEAR CONNECTOR CAVITY WALL BY DIFFERENTIAL MOVEMENT

The top shear connector is the critical connector and a conservative approximate approach would be to neglect all other shear connectors and assume that the restraint to imposed deformations is provided solely by the top connector. It is also assumed that no moment capacity exists at the junction of the connector and the brick wythe. These conditions are shown schematically in Fig. 5.

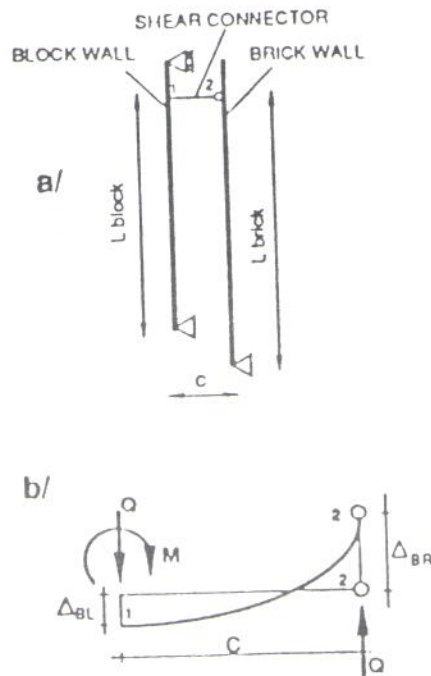


Fig. 5 Model for Approximate Analysis Method

By using compatibility, equilibrium and Hooke's law, a close form solution for the final deformations  $\Delta_{BL}$  and  $\Delta_{BR}$  at nodes 1 and 2 (see Fig 5) can be derived. The proposed expression is:

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



Where

$$\alpha = \frac{3E_{SC}I_{SC}}{C^3} \cdot \frac{L_{BL}}{A_{BL}E_{BL}} \quad (2)$$

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

Deformations  $\delta_{BL}$  and  $\delta_{BR}$  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 :

$$\delta_{BL} = (\epsilon_{SH,BL} + \alpha_{BL} \cdot \Delta T_{BL}) \cdot L_{BL} \quad (3)$$

and

$$\delta_{BR} = (\epsilon_{SH,BR} + \alpha_{BR} \cdot \Delta T_{BR}) \cdot L_{BR}$$

By solving equation (1) the unknown final deformations  $\Delta_{BL}$  and  $\Delta_{BR}$  can be found. Finally, the internal forces are obtained by the slope deflection relations for the shear connector:

$$Q = \frac{3E_{SC}I_{SC}}{C^3} \cdot (\Delta_{BR} - \Delta_{BL}) \quad (4)$$

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

#### MATERIAL AND ENVIRONMENTAL EFFECTS ON RIGIDLY CONNECTED CAVITY WALLS

The moisture expansion of burned clay units and the possible shrinkage of a concrete back-up wall will cause a load to be induced on the assembly if movement is restrained. This load will be in the form of compression in the bricks, tension in the concrete block wall and shear in the connectors. The presence of this load, provided that it is small in magnitude, will reduce cracking of the veneer and will have negligible effect on the back-up block wall especially if it contains vertical reinforcement to resist the induced tension if the allowable is exceeded. The induced loads are small in magnitude and can be easily evaluated using a suitable computer program or estimated using simple techniques. One such simple technique is illustrated here as follows:

Consider a wall 8000 mm high consisting of a 90 mm wide burned clay veneer shear connected to a 240 mm concrete block back-up wythe and reinforced with a 15M bars at 1600 mm centers, with a 75 mm cavity as shown in Figure 6.

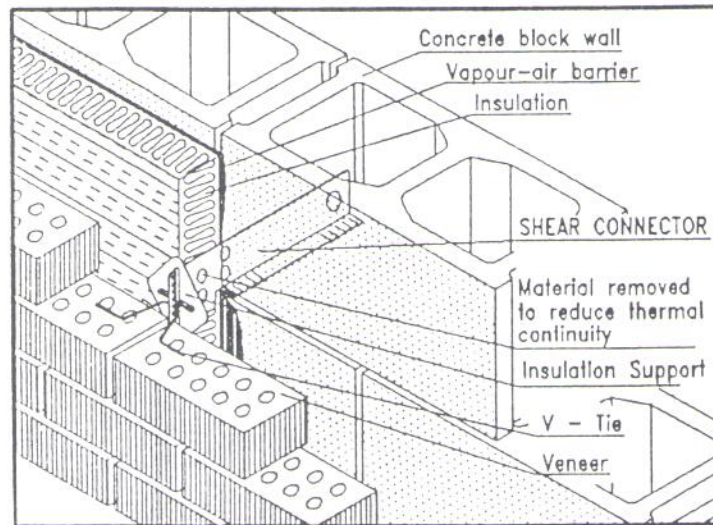


Fig. 6 Shear Transfer Connector

The spacing of the connectors is assumed to be 800 mm on center horizontally and there are a total of 15 connectors in the vertical direction. Assuming that the veneer will be exposed to a 50 degree Celsius thermal fluctuation and using the average values for moisture and shrinkage movement reported earlier, the most severe unrestrained movement between the wythes will be:

$$8,000 (0.0001 + 50 \times 0.000006) + 0.00015 \times 7,800 = 3.20 \text{ mm} + 1.17 \text{ mm} \\ = 4.37 \text{ mm}$$

Where 3.20 mm is the expansion of the clay brick veneer and 1.17 mm is the shrinkage of the concrete block back-up wythe. The elastic modulus of the block wall  $E_{BL}$  is 7,350 MPa and its area  $81,190 \text{ mm}^2 / 800 \text{ mm}$ . The corresponding values for the brick veneer are  $E_{BR} = 9,750 \text{ MPa}$  and its area of cross section is  $72,000 \text{ mm}^2 / 800 \text{ mm}$ . For the 75 mm cavity, which is commonly used in actual construction by incorporating 50mm insulation and 25mm air space, and shear connectors with an elastic modulus  $E_{sc} = 200 \text{ GPa}$  and effective moment of inertia,  $I_{sc} = 1,000 \text{ mm}^4$ , obtained from testing of V-ties (Ref 6) and by taking into consideration the influence of the shear connector plate, an approximate conservative evaluation of the induced forces of the assembly can be performed. Note that the moment of inertia of the V-tie is approximately  $55 \text{ mm}^4$  and there are a total of 15 V-

ties along the height of the 8,000 mm wall ( $15 \times 55 = 825, 1000 \text{ mm}^4$  is used for simplicity).

As a demonstration of the approximate analysis method consider the wall discussed earlier and refer to Fig. 5. From equation (3):  $\delta_{BL} = -1.17 \text{ mm}$  and  $\delta_{BR} = 3.20 \text{ mm}$ .

From equation (2):  $\alpha = 0.0186$  and  $\beta = 0.0162$

Substituting these values into equation (1) yields:

$$\Delta_{BL} = -1.9015 \text{ mm}$$

$$\Delta_{BR} = 3.1315 \text{ mm}$$

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

$$Q = 6.006 \text{ kN} \text{ and } M = 0.45 \text{ kN-m}$$

The brick wall has to resist a compressive stress of:

$$\frac{6.006 \times 10^3}{7.2 \times 10^3} = 0.083 \text{ MPa}$$

and the block wall a tensile stress of:

$$\frac{-6.006 \times 10^3}{81190} - \frac{0.45 \times 10^6}{5.752 \times 10^6} = -0.1523 \text{ MPa}$$

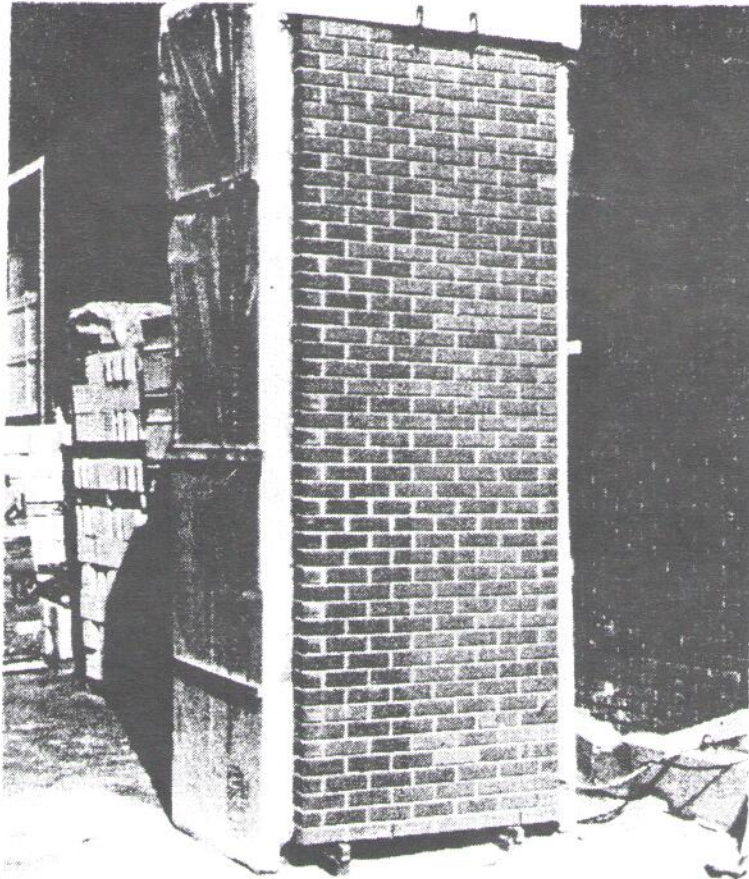


Photo 2 : Cavity wall exposed to climatic conditions



The forces obtained are relatively small and they can be resisted by the wall assemblies without causing distress. A small amount of vertical reinforcement is recommended for the back-up concrete block wall to resist the tensile stresses.

The results obtained reinforce the observations and instrumentations of wall assemblies such as the one shown in photo 2 monitored for a total of 5 years, which showed no sign of distress.

The distribution of connectors along the entire height of the wall will further decrease the induced stresses. Dead load stresses will further reduce the induced tensile stress in the block wythe.

Similar conclusions were reached by reference (2) after monitoring a tall structure in Ottawa. It should be noted also that walls constructed with adjustable connector are only free to move in the vertical direction if the wythes remain perfectly straight and parallel, a condition that never occurs in practice.

#### CONNECTING THE BACK-UP WALL TO THE MAIN STRUCTURAL ELEMENTS

Connecting the back-up wall to the structure requires that the effects of frame shortening and flexural deflections of the floor or roof system are evaluated. The performance of the assembly is influenced by this connection to such a degree that failure to properly detail and construct this connection may result in severe distress and expensive repairs.

For a typical concrete frame structure constructed with 30 MPa concrete, assuming that the elastic modulus is 27,500 MPa and that the effect of loads causes a stress in the order of 10 MPa, for a 3 metre high column the elastic deformation would be 1.1 mm. Creep deformation will be between 1.1 and 2.5 mm. Furthermore, long term shrinkage causes a deformation between 0.6 to 2.4 mm. Thus the total deformation of the column will range from about 2.8 to 6.0 mm.

Fastening the back-up wall to the slab or beam must be carried out in such a way as to account for the effects of slab deflection. For a 5,000 mm span between columns, the most commonly accepted value for deflection is in the order of 14 mm ( $L/360$ ). If no provisions are made to accommodate such deflections, connecting the back-up wall to slabs will result in load transfer from the main structural elements to the back-up wall.

For infill walls designed to resist only lateral loads, the connection at one end (usually at the top of the back-up wall), must allow for a minimum movement in the order of 20 mm

if the wall is not designed to carry the imposed load. For back-up walls designed to carry the load from frame shortening and slab or beam deflection, the effects of such loadings must be considered especially as resulting deformations may affect the integrity of the air barrier. To allow for vertical movement between back-up steel studs and floor slabs or beams where the wall is connected, Fig. 5 shows an arrangement utilizing the upper steel track to form a deflection accommodating connection. To ensure that the veneer and the air barriers are not affected by lateral deflections under service loads, the lateral deflection of the veneer must be limited to less than or equal to  $H/720$ , where  $H$  is the height of the back-up wall.

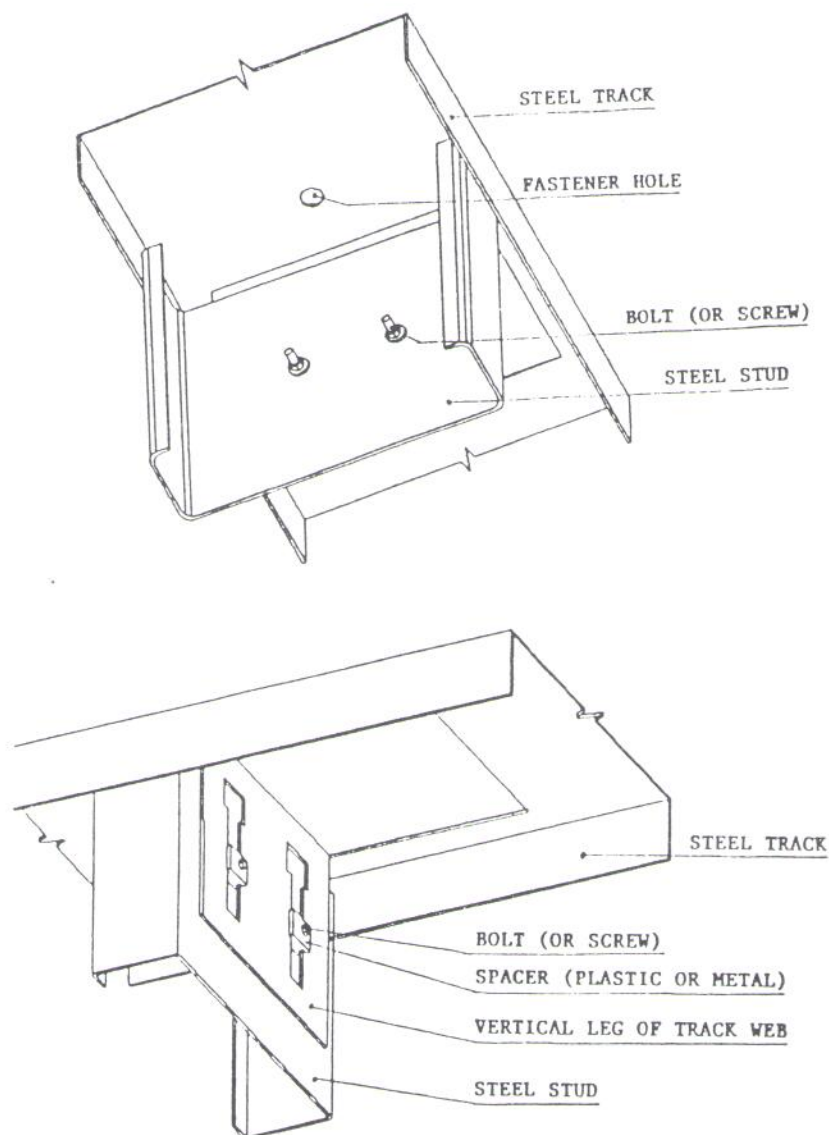


Fig. 5 Deflection Accommodating Connection

## RECOMMENDED TIES AND CONNECTIONS

In order to reduce the thermal effects of metal connectors bridging the cavity, their numbers and thermal conductivity must be minimized. The maximum permissible spacing in Ref (1) is 800 mm in the horizontal and 600 in the vertical directions but no guidelines exist relating to the thermal properties of connectors.

For back-up walls other than masonry, more than one subtrade is involved in the exterior wall construction and the fastening of connectors to the back-up wall is carried out prior to erecting the veneer. The type of connector to be used should facilitate the construction of the veneer by allowing the placing of the units to be independent of the locations of the connectors. Such is achieved using connectors shown in Fig. 3, used in conjunction with a steel stud back-up wall. This connector provides for a positive connection with the metal stud and the fastening is not susceptible to corrosion. Thermal conductivity is reduced by removing material not needed for strength. A plastic friction fit insert is placed over the connector plate and further locked in position by the V-shaped component which ensures that the insulation is held tightly against the back-up wall. A similar type of connector for use in conjunction with a concrete block masonry back-up wall is shown in Fig. 6. The performance of such connectors which additionally provide for transferring shear and thus utilizing the structural properties of the veneer is documented in Refs. (4) and (5). The use of stick clips or other accessories commonly available to fasten the insulation on the back-up wall is not recommended since their connection may be adversely affected by deformation of the wall and dimensional instability of some insulation materials.

## CONCLUSIONS AND RECOMMENDATIONS

The assumption that the only contributing factor to the distress of brick veneer walls is the moisture and thermal movement of the burned clay units needs to be re-examined. Cavity wall assemblies are very susceptible to the effects of frame shortening and deflections of the elements to which the walls are fastened.

Walls utilizing connectors permitting free vertical movement do not eliminate load transfer to the exterior wythe from the effects of frame shortening and deflections of slabs and beams. Cavity walls utilizing such connectors exhibit larger deflections of the veneer thus causing cracking to occur at lower load levels. To minimize such effects, the use of rigid connectors is recommended. In designing exterior wall assemblies, frame shortening and deflections of main structural elements must be accounted for.



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