MASONRY CLADDING: A REPORT ON CAUSES AND EFFECTS OF FAILURES

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ABSTRACT Many times masonry claddings have failed to function as intended or desired. Cladding failures generally mar the appearance of the building, frequently cost a lot of money to repair and occasionally pose a hazard to the public. This paper is a report on types of masonry cladding failures, their causes, symptoms and effects.

The basic causes of masonry cladding failures have been identified as improper design of buildings (through ignorance or negligence), poor choice of materials and poor workmanship during construction. Sometimes problems have been generated by failure to properly allocate responsibilities between the different professions and trades involved in the design and construction of the cladding and back-up and support systems. Cracking of cladding is often due to shrinkage of concrete masonry walls, creep and shrinkage of reinforced concrete frames and moisture expansion of clay brickwork. The paper also examines distress due to thermal movements, deflection of cladding supports and movement of foundations. The important role played by ties and anchors is considered. The effects of infiltration, exfiltration and corrosion are also covered.

1. INTRODUCTION

A masonry cladding on a building has tremendous aesthetic appeal, and enjoys great popularity. However, there is danger that in future designers will shy of masonry cladding because of incidents of masonry cladding failures. The failures are a problem because they are unsightly, expensive to repair and can threaten public safety. Failure may take the form of cracks, spalling, infiltration and exfiltration, efflorescence, and even complete collapse of the veneer, and is caused by improper design of buildings, poor choice of materials and substandard workmanship in installation. The use of more slender and more flexible frames in modern buildings means that frame deformations and differential movements between frames and cladding are larger and should be investigated in design. Unfortunately, the cladding seldom receives the same level of attention that goes into the design of the frame. Involvement of many professions and trades in the design and installation of cladding systems can result in a detrimental lack of coordination, mis-allocation of responsibility, and improper execution.

In Canada, many complaints about failures in exterior walls have been received by Canada Mortgage and Housing Corporation from owners of high-rise buildings. On reinforced concrete buildings, damage has occurred in the form of spalling, cracking and bulging of brick and stone veneers. Failures have also been reported in the USA, Britain and other countries.

This paper reviews previous publications on different types of cladding failures, their causes, symptoms and effects, and is condensed from a larger annotated report (1) prepared for the Canadian Masonry Research Council.

2. CAUSES AND SYMPTOMS

Masonry cladding failures are caused by one or a combination of several factors, but the real causes may be said to be ignorance, carelessness, negligence and

greed on the part of designers, constructors and owners; and a campaign to limit or eliminate cladding failures should be directed at educating all parties concerned on the causes and mechanisms of failure (2).

Masonry claddings on high-rise buildings are more susceptible to problems (3) because in the high-rise structure (a) deformations caused by moisture and thermal changes are magnified in the vertical direction, (b) there is more exposure to high-speed winds and driving rain, causing more air and moisture leakage at higher floors, as well as greater lateral load stresses and deflections, and (c) inspection during and after construction is more difficult, as is repair.

Cracking is the most common and dramatic symptom of cladding failure. Sometimes the location, orientation and form of the crack gives an indication of the cause of the failure (4). For example, vertical cracks close to the corner of a brick masonry veneer are usually associated with clay brick expansion. In general, however, many causative factors interact and it is much more difficult to pinpoint a specific cause. The relative strengths of the mortar and the unit, the location of openings and points of weakness, presence of lintels, floors and roofs all affect the form of the crack.

Spalling may be due to stresses generated by differential movement, or be caused by freeze-thaw action. Efflorescence is usually an indication of exfiltration in cold weather, and problems with air and vapour barriers, flashings and weepholes (5).

3. EFFECTS OF SHRINKAGE OF CONCRETE MASONRY WALLS

Mortar, concrete blocks and concrete or sand-lime bricks shrink with time as they dry out. If the wall is restrained, tensile stresses are set up in the wall and may be of sufficient magnitude to crack the wall.

Shrinkage-induced cracks are normally of even width and occur at the weakest parts of the walls, for example under or over openings (6). On long blank walls a vertical crack will normally appear at about mid-length, and if the wall is very long several vertical cracks will be spaced at approximately equal intervals. The vertical cracks may pass through perpend joints and units, be cogged through vertical and bed joints, or more rarely, be stepped. Figure 1 shows typical shrinkage-induced cracks.

Cracks will also occur at the ends of long lintels and hoods, and at stepped damp-proof courses if very strong mortars are used. With weaker mortars shrinkage will induce horizontal cracking in a bed joint under the lintel. If two perpendicular concrete walls are joined with a butt joint, the slightest amount of shrinkage will cause an ugly opening up of the joint. In construction using concrete or sand-lime bricks cracking is more likely to be caused by the shrinkage of the units, which is more serious than shrinkage of the mortar. Drying shrinkage (and wetting expansion) are reversible, but carbonation shrinkage is not. Shrinkage of concrete units have been reported to be 0.02 - 0.09% for blocks and 0.01 - 0.05% for concrete bricks (7).

By following certain guidelines it is possible to design and construct walls in which cracking, if it occurs at all, will be distributed in the form of finer less noticeable cracks. Problems will results only if the following recommendations and guidelines are not followed:

(i) Provide shrinkage or control joints to permit movement in the horizontal direction.

(ii) The units should be properly cured and stored (that is protected from moisture) before being built into the wall; and they should be wetted only sparingly, if at all.

(iii) The characteristics of the mortar can be chosen to reduce shrinkage cracking.

(iv) Use of bed-joint reinforcement, or ladder type ties is beneficial in reducing shrinkage cracking.

(v) Rendering of high-shrinkage units and repair of cracks should be done only after the wall is thoroughly dry.

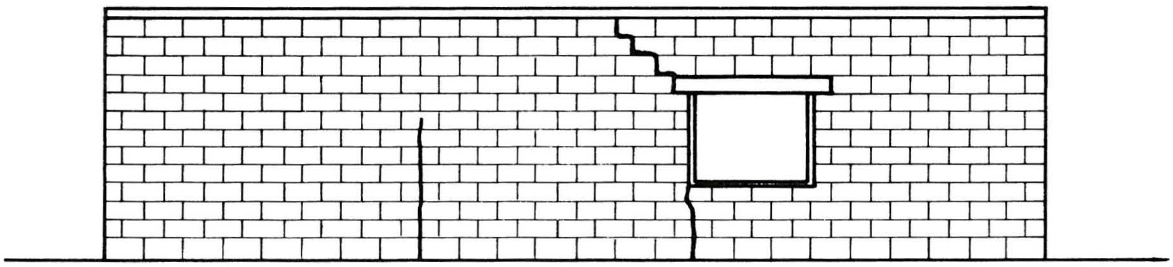


Figure 1 Cracks Due to Shrinkage of Long Concrete Masonry Wall

4. DISTRESS CAUSED BY DEFORMATION OF REINFORCED CONCRETE FRAMES

Cracking of masonry may be caused by shrinkage of large concrete members such as beams and roof or floor slabs on which the masonry walls sit or which are attached to the top of the walls (8). Usually the cracks are located towards the ends of the concrete beam or slab, and are horizontal or diagonal. However, a vertical crack may occur in a wall which runs parallel to the direction of major shrinkage of a concrete slab. Cracking induced by shrinkage of concrete members may resemble cracks due to thermal movement. A distinguishing feature is the fact that the slab will tend to tilt the wall inwards so that cracks will usually be wider at the outside face of the wall. In addition, the highest rate of shrinkage exists immediately following placing of the slab, so that cracking will normally be induced within a few months of casting the slab.

Load-induced elastic and creep deformations of frames can cause stressing of masonry cladding. In reinforced concrete frames the combination of creep and shrinkage may produce vertical movement of more than 15mm in a modest 18m high building. The stresses induced in any rigidly attached cladding will be increased by the effect of surface temperature variations. If brickwork cladding is built tight to the underside of shelf angles attached to slab or beam edges, contraction of the frame will cause transfer of part of the building weight to the cladding, and the resulting compressive force in the cladding can reach several tonnes per metre of length. The result normally is buckling spalling, and/or lateral displacement of the cladding.

5. DISTRESS DUE TO MOISTURE EXPANSION OF CLAY BRICK MASONRY

Burnt clay units undergo an irreversible expansion when they leave the kiln and absorb moisture from the atmosphere. The rate of expansion is highest in the kiln-fresh bricks, and decreases progressively with time. Reversible expansion and contraction also occur when the brick is alternately wetted and dried. The permanent moisture expansion of brickwork is principally affected by the following factors: time of exposure, time of laying, temperature of the moisture, relative humidity, cyclic wetting and drying, mortar joints, clay composition, manufacturing process and firing temperature. Free expansion of brickwork may reach 0.02 - 0.05% (7); if this expansion is restrained stresses are developed in masonry which are sufficient to rupture the veneer. Almost all damage caused by brickwork expansion occurs in external walls and occurs in the following forms: (a) cracking, (b) oversailing of upper portions of walls over lower parts, (c) bowing and arching of walls and parapets, (d) distortion of built-in frames, and (e) damage to adjoining buildings or components (8). Damage is most serious when a brickwork cladding is used in a reinforced concrete building and the design does not take into account differential movements. The magnitude of long-time contraction of reinforced concrete will normally approach or even exceed the expansion of clay brickwork.

The most usual and characteristic type of cracking will be vertical cracks close to the corners of long walls, in most cases located at a distance from the corner equal to the thickness of the intersecting wythe (Figure 2a). The crack originates at at a damp-proof course or flashing level, and follows a line of perpends. Crack widths vary from the barely perceptible hair-lines to a dramatic .25mm or more. Use of offsets without properly located expansion joints is another frequent cause of cracking (Figure 2b). Diagonal cracks occur mainly in balcony and garden walls, or in the vicinity of parapets and footings, because parapets have two exposed faces and normally expand more than the supporting walls, and footings usually tend to restrain wall movement. Diagonal cracks may also occur in piers between window or door openings. Lateral bowing of walls and parapets occur when vertical or horizontal ends of expanding walls or vertical ends of parapets are heavily restrained.

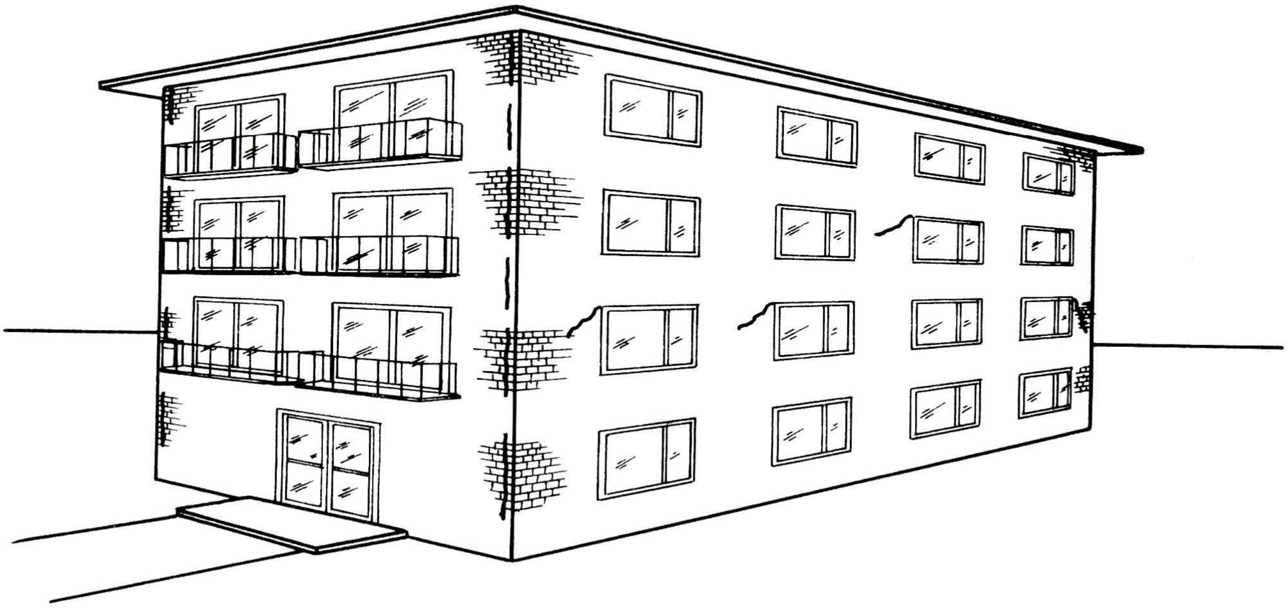
6. EFFECTS OF THERMAL MOVEMENT OF MASONRY AND ASSOCIATED BUILDING ELEMENTS

Thermal strains induced in the cladding and the structural frame may be sufficient to cause distress, although temperature deformations of masonry are usually much less than moisture movements (5, 6, 9). Temperature-induced strains may relieve or increase the stresses in masonry due to other movements (3).

Cracking of cladding may result if a flexible joint is not installed between the steel frame and the masonry, or if a sliding joint is not provided between a roof slab and the masonry parapet. If a steel truss or beam is parallel to the wall the cracking is usually diagonal, whereas the crack is normally horizontal when the steelwork is perpendicular to the wall.

Horizontal cracking may be observed between a large concrete roof slab and a masonry wall, and additional cracks may occur a few courses below the base of the slab. Diagonal stepped cracking may develop at the corners of the building and at partition walls, and slab movement may also induce lateral displacement and cracking in parapets. These cracks will be observed to open and close with temperature changes.

(a) Typical Crack Patterns



(b) Cracking at an Offset (3)

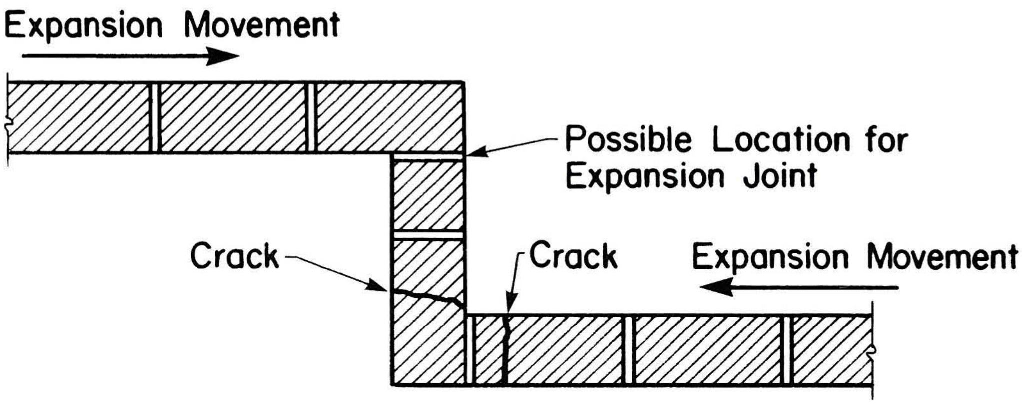


Figure 2 Effects of Brick Expansion

7. SAGGING OF SUPPORTS

Shallow concrete sections, such flat-slab or flat-plate floors which support masonry walls can undergo significant deflection increases with time due to shrinkage and creep of concrete. Creep deflections of beams and slabs due to sustained loading can amount to or even exceed 2.5 - 3 times the elastic deflections. Long-time deflections are even larger if loads are placed on the concrete members when the concrete is still young. The deflection is frequently sufficient to crack the supported masonry, and if very small or no horizontal control joints are used the cladding under the slab or beam may also be cracked. Cracks have also been caused by the deflection of shelf angles and beams. Typically, vertical cracks due to sagging of supports will be wider at their lower ends than at the top, and the cracks will be widest towards the midspan of the slab (10).

8. TIES, ANCHORS AND THE SHELF ANGLE DETAIL

Cladding failures may be due to erroneous design of connectors or improper installation of them. Buckling of cladding under loads induced by frame contraction is facilitated by omission of ties. Often problems result because an insufficient number of ties are used generally and at openings. Instability and rain penetration may results because (a) ties have inadequate embedment in the mortar, (b) they were pushed into green mortar instead of being built in, (c) ties are sloped towards the inside of the building instead of being sloped towards the outside, (d) mortar was allowed to drop and stick on the ties, and (e) moisture drips in ties are not positioned in the centre of the cavity.

Corrosion of metal ties has been identified in Britain as the cause of distress in a number of cavity walls, involving bulging, cracking, leaking and in a few cases, actual collapse of the wall under high wind loads (11). Originally corrosion was supposed to be confined to cases of poorly made ties, aggressive mortars and conditions of very severe exposure, but studies have indicated that the problem is probably more widespread than that.

Corrosion occurs only in the presence of moisture, and therefore corrosion can be virtually eliminated if metal components are kept dry. Tie corrosion is usually induced by rain water penetrating from the outside or condensation of the water vapour in exfiltrating air. If a tie is coated but then kept damp, corrosion may initiate at pin holes in the tie coating.

Corrosion of strip ties will cause a pattern of cracking at bed joints at wall tie levels, because corrosion products occupy about six times the volume of the original metal. However, volume changes from corrosion of wire ties are normally not sufficient to cause wall cracks. Corrosion of ties should also be suspected if the outer leaf has bulged locally; and it should be anticipated if it is known that the ties were substandard or if black ash mortar was used.

It is common for the masonry veneer to be supported on a steel angle which is attached to the structural frame. Improper design and/or construction of the shelf angle detail has been the cause of many instances of distress. Failure in the form of cracking, spalling or even complete collapse of portions of the veneer is often caused by lack of provisions for the following deformations: (a) elastic and thermal strains in steel frames and angles, (b) elastic, shrinkage, creep and thermal deformations of reinforced concrete frames, and (c) elastic, creep, thermal and shrinkage/expansion movements in masonry (12).

High stress can be induced in a masonry cladding if shelf angles are not properly anchored and shimmed to prevent rotation; spalling may result (13). Excessive deflection of the shelf angle can occur if the shelf angle is too

slender of the cracking anchor bolts are too widely spaced, and will in turn cause cracking of the veneer. Shelf angles should be provided with expansion gaps at corners, but should not be terminated too far from the corners. Figure 3 shows a typical shelf angle detail.

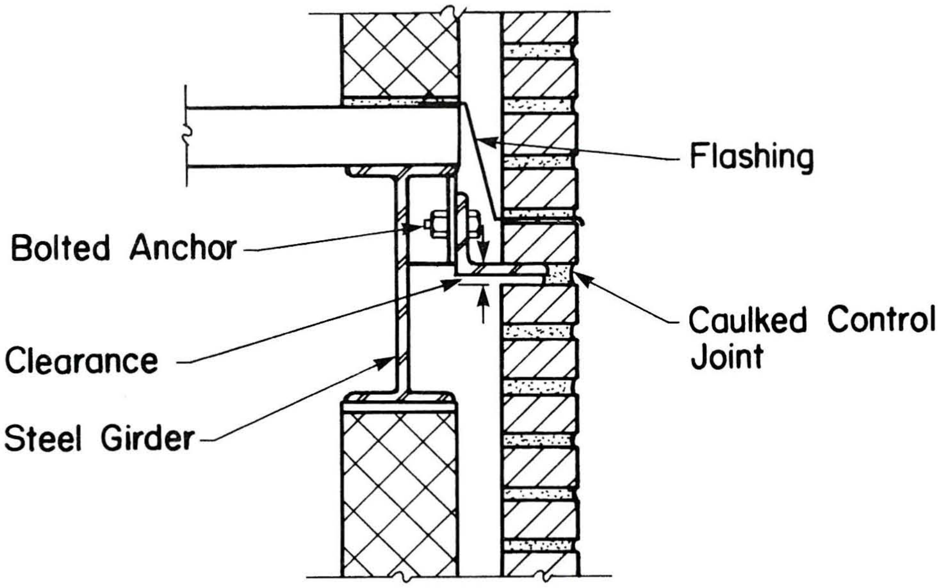


Figure 3 A Typical Shelf Angle Detail (12)

The following are some of the other important points in determining whether or not failure occurs.

(i) If a caulked movement joint is not provided between the brick and the underside of the shelf angle, or if the joint thickness is inadequate, significant vertical loads will be carried by the cladding.

(ii) Problems generated by freezing of water will develop if weepholes and flashing are not provided at the shelf angle, to collect water from the cavity behind the outer wythe and discharge it to the outside.

(iii) The displacement of the outer wythe is facilitated by the fact that the mason often finds it convenient to omit ties in the courses closest to the shelf angle.

(iv) Flashing may be ruptured by the bolts anchoring the shelf angle.

Suter and Hall (12) examined a two-year old 20-storey brickwork-clad reinforced concrete building in which the brickwork cladding had cracked severely, and concluded that the type of failure occurring depended on the width of the mortar joint at the toe of the shelf angle. It was deduced that very small and very large overhangs should be avoided.

9. OTHER CAUSES OF DISTRESS

9.1 Movement of Foundations

Uniform settlement of foundations do not present any problems; it is the differential movements which can generate stresses and cause cracking (6, 10).

Cracks which result from uneven settlement of foundations can take any form but are normally diagonal or vertical, and are usually wider at one end than at the other - an indication of bending failure. In exterior cavity walls cracks of approximately the same configuration appear in both leaves.

9.2 Chemical Attack

Building stones which contain carbonates are attacked by atmospheric sulphur dioxide, which reacts with the carbonates to form sulphates. Damage may manifest itself as blistering and scaling of the surfaces.

Sulphate attack on mortar results in vertical and horizontal cracks which affect all joints (11) and therefore can be distinguished from vertically spaced cracks due to corrosion-expansion of ties. In rendered or plastered brickwork the cracks induced by sulphate attack will generate a network of horizontal and vertical cracks.

9.3 Problems Associated with Metal Stud Backup

The use of metal stud backup for masonry veneers is currently being viewed with a great deal of caution because of potential structural and serviceability failures of the system. According to Heslip (14) several failures of metal stud/masonry veneer buildings have been reported in the United States. The system has been labelled as likely to crack, leak and become life-threatening if designed and built according to present practice.

The principal problem has been the low flexural stiffness of the steel studs relative to the veneer, which results in the masonry carrying a large portion of the lateral wind load, which in turn leads to large deflections and severe cracking. The problem may be overcome by including the flexural stiffness of the veneer in design and by use of more stringent deflection limits. The Brick Institute of America suggests limiting the maximum veneer deflection to 1/600 - 1/720 of the span. Use of a deflection limit of 1/240 - 1/360 of the span as recommended by metal design tables will likely result in distress.

Leaky walls due to poor detailing of flashing and weepholes, and spalling of bricks due to freeze/thaw phenomena have been reported but these problems are by no means unique to the metal stud/masonry veneer system. However, the system is very vulnerable to corrosion and the effects of corrosion are severe. The use of self-tapping screws results in a situation in which the tie is attached to the steel stud by only one turn of the threads (Figure 4). In addition, about one half of the galvanizing on the screw may be lost when the screw is inserted into the stud (14). It has been argued that in the presence of moisture and chlorides the expected life of the system is in fact not the intended 25-50 years but rather only 5-7 years.

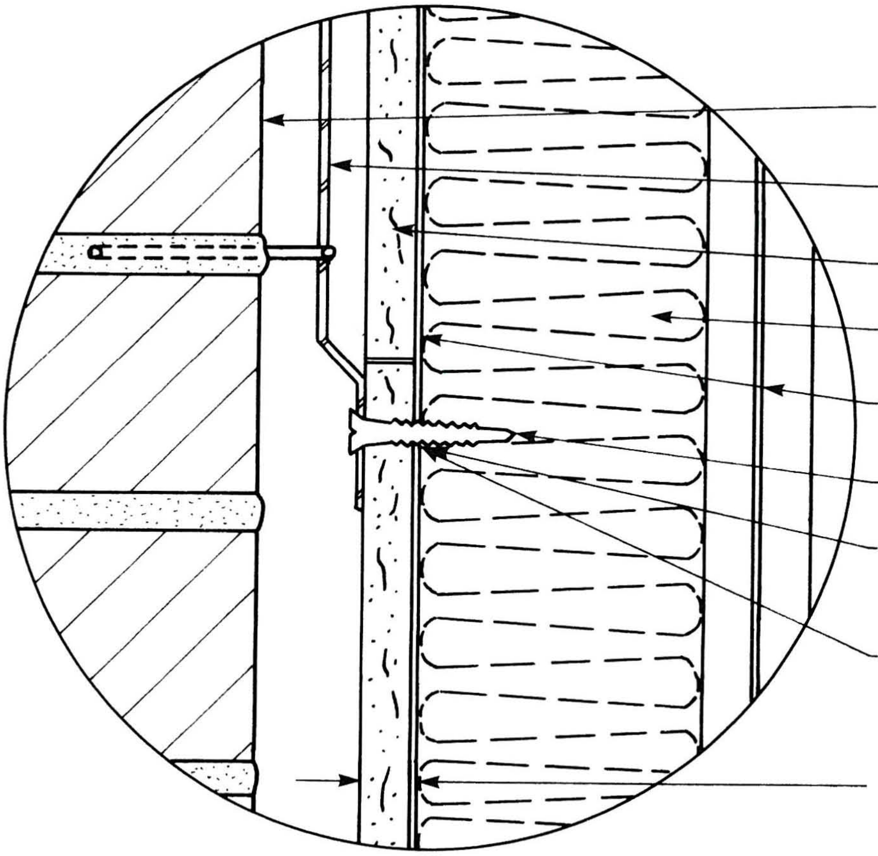


Figure 4 Detail of a Metal Stud/Masonry Veneer Attachment (14)

10. WATER PENETRATION AND AIR LEAKAGE

Water penetration of external masonry walls is a common problem. Water which penetrates a wall usually does so through fine capillary passages at the mortar/unit interface (where there is a lack of bond) and through cracks. Rainwater running down the outer face of a wall is drawn into capillary passages at the joints, with possible assistance from wind pressure. Water can be moved through larger cracks by gravity force and wind pressure. Flashing should be used to collect any water that penetrates the veneer or the outer wythe. The masonry materials are by themselves normally too dense for water to pass through quickly.

A line of damp observed at each floor level at certain times of the year is a sign that the weepholes are not operating properly. This might be because (a) weepholes have been plugged, (b) weepholes were not provided, (c) they are too far apart, or (d) they are too small.

Placing any type of insulation in the cavity of a cavity wall makes it so much easier to accidently bridge the remaining cavity width with mortar droppings or other materials and leaking of the outer wythe will result with the following negative effects: (a) drastic reduction of insulation value, (b) high incidence of efflorescence, (c) excessive brick spalling due to freeze-thaw cycles, and (d) displacement of the outer wythe through ice-formation in the cavity (2, 5).

Wind pressure can cause water to accumulate on flashings to a hydrostatic head of 50-75mm. This water may seep into the interior surface of the wall if the flashing is not raised high enough at the inside wall, or freeze on the flashing or in the brick or block pores. Spalling of units and heaving of the veneer could result.

In cold winter weather exfiltration of moisture-laden warm room air in places where vapour barriers are omitted or poorly installed usually results in condensation and formation of ice in the colder outer wall. The ice formation can cause spalling of units, and in the spring when the ice melts some parts of the wall may appear visibly damp and drying of the walls can result in efflorescence, which is a symptom of moisture barrier problems.

Vapour barriers are recommended for use where there are prolonged subzero winter conditions, and are intended to provide the major resistance to water vapour movement through the wall, so that the harmful levels of moisture do not develop in other materials on the outward side of the vapour barrier. If a vapour barrier is also designated as an air barrier it should be free of tears and gaps and should be sealed at all edges and joints.

11. STONE CLADDING

Stone cladding used on multi-storey buildings have failed in a number of instances (15). The failures take many different forms, but the most common have been: (a) cracks across slabs without significant movement or failure of fixings, (b) spalling and fractures at joints, (c) bulging, displacement and falling off of some slabs, and (e) more minor defects, like staining of stones and efflorescence.

The first four types of failure are caused by excesssive stresses in the cladding or its anchorage system. The most important causes of the stresses are: (a) elastic and creep deformation of the building under imposed loads, and drying shrinkage of concrete, (b) differential movement between the cladding and other building elements due to shrinkage of blockwork walls, expansion of brickwork, changes in temperature and foundation settlement, (c) distortion of stone slabs due to drying and shrinkage of the stone, exposure to the sun, reaction with mortar or release of stresses when the slab is cut from a massive block, (d) in-adequate support or anchorage of the veneer, including inaccurate location of fixings and the use of corrodible metal fixings, and (e) other less common faults like use of slabs that are too thin, or stones which are too susceptible to splitting, and attachment of heavy objects to the cladding.

12. CLOSING REMARKS

This paper has reviewed types of cladding distress, examined possible causes and effects, and suggested some solutions. A more detailed report with an extensive bibliography and annotations of key publications has been produced by the Centre for Research and Development in Masonry (1). It is intended that this work be developed further, and the next phase of the study should result in a set of design and repair guidelines which will eventually be produced as a handbook.

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