# CONTROL OF RAIN PENETRATION OF MASONRY WITH SPECIAL REFERENCE TO SRI LANKAN CONDITIONS

by

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## Abstract

Rain penetration resistance is one of the most important functions of a building envelope. Higher buildings, exposures of increasing severity, abandonment of conventional treatments and lack of understanding of the rain penetration mechanism, make a study of rain penetration important. This study consisted of a review of previous research and current design practices together with an assessment of impact of local conditions on rain penetration. It resulted in recommendation of suitable wall types for Sri Lankan conditions as well as appreciation of the mechanism of rain penetration, its influential factors, means of effective control and what further research is necessary.

## 1.0 Introduction

The masonry wall continues to be the most preferred building envelope in Sri Lanka. In the climatic conditions here, rain penetration resistance is one of the most important functions of a building envelope and hence control of rain penetration resistance of masonry walls is of considerable relevance.

Attention to control of rain penetration during design can be very rewarding as damage caused by rain penetration may include dimensional change, decay or other deterioration including growth of mould and fungi, deterioration of interior finishes and building contents, occupant inconvenience, corrosion of metal components (if any) and increased heat transmission.

Single storey masonry walls with roof overhangs have shown satisfactory rain penetration resistance. On the top portion of the wall, where wind speed is high, rain reaching the wall is cut off by the roof overhang while on the lower portion, where rain reaches the wall, wind speed is low with both conditions improving rain penetration resistance. Wall constructions successful in these low sheltered buildings cannot be applied directly to buildings that are high which are also more severely exposed to the weather. Thus rain penetration is often a problem in tall buildings.

Abandonment of ornament and protruding details of old multistorey buildings, which were originally developed as a means of controlling movement of water across the wall surface and of providing protection to the wall itself, and evolution of plain multistorey buildings also cause increased likelihood of rain penetration in masonry.

There is an inverse relationship between needs of structural design and rain penetration resistance. Structural design requires greater mass of material at the lower levels of a building with reduction of mass towards the top of the building. For resistance to rain penetration reverse is true. Paying attention to only the structural design needs also leads to greater risk of rain penetration in loadbearing masonry structures.

Attachment of air conditioning and mechanical ventilation equipment, pumps, motors, fans and lifts to relatively flexible reinforced concrete framed buildings induces vibrations that contribute to cracking of brittle masonry joints which also increases the likelihood of rain penetration.

Nowadays, building users expect a higher standard of comfort than the users of a generation ago and minor inconveniences of the past are considered intolerable today. Thus effective control of rain penetration cannot be ignored.

Trend towards building in very exposed locations for specific requirements such as those of the tourist industry and preference of more convenient mortar mixtures than lime mortars, also increase the likelihood of rain penetration in masonry.

Concrete blockwork is in demand for multistorey buildings in Sri Lanka due to lesser breakages of units during

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lifting and faster construction rate. However, one block thick concrete block wall has a poor record of rain water penetration resistance (1). Its use in multistorey buildings where likelihood of rain penetration is severe, requires a sound appreciation of the mechanism of rain penetration and latest information on it will be valuable to designers.

Rain penetration of masonry has been well researched (2). Despite the existence of a solid foundation of information, the results are neither freely available to design engineers to use them effectively nor applied to study the specific conditions in Sri Lanka. This paper is directed to fulfill these dual objectives.

## 2.0 Review of Literature

### 2.1 General

Rain penetration of masonry is a well researched area with work commencing as early as 1930(3) and still continuing. Many factors such as material selection (masonry units, mortar, flashing, coping, coatings), design details (mortar joints, flashing details, control joints) and workmanship (mortar, cavities and weep holes, flashing, protection) contribute to successful performance against rain penetration and hence problem is complex. Succeeding sections summarise the state of the art at present.

### 2.2 Mechanism of Rain Penetration

Rain penetration is defined (2) as the penetration of water into a wall either through the surface of the wall or through leakage at openings such as windows and doors. It takes place when water, entry paths and driving forces are present simultaneously in an exterior wall (4).

When rainwater strikes a wall the water is at first absorbed(2). As the rain continues and exceeds the rate of suction, water flows down the face of the wall producing a film of water and the first condition necessary for rain penetration is established.

Common entry paths are through pores in the face of masonry units and mortar, through cracks in masonry units or mortar, through cracks between masonry units and mortar, and through improperly sealed cracks between masonry and other building elements. Greatest rain penetration occurs through the two latter types of entry paths(3). Water penetration occurs through cracks wider than 0.1mm and capillary suction is important for openings smaller than 0.5mm. It should be noted that pores in bricks generally have a diameter of about 0.01mm while those of blocks are larger with hairline cracks ranging from 0.1 to 1.0mm in width(3).

The driving forces that assist rain penetration are gravity, capillary action, kinetic energy and air pressure(5). Of these, the kinetic energy of rain actually hitting a crack is not the main source of rain leakage. Water running down the face of the wall can be drawn into the wall by capillary action and eventually leaks through the wall by gravity. However, when air pressure differences exist on either side of the leaf or wall, rain penetration through it will be substantially increased.

Rain penetration resistant walls are designed by eliminating one or more of the above three conditions. In the open screen concept (in the cavity wall) (Figure 1) sufficient openings are intentionally left in the outer leaf to allow for pressure equalization, so that when the air pressure in the cavity is equal to the external air pressure, the main driving force causing rain penetration is removed. Another way to reduce the influence of driving forces is to use a thicker wall, but this solution is not very economical now. Entry paths can be substantially cut off in walls when external finishes such as renderings are applied. Formation of a thick layer of water on the wall can be minimized by roof overhangs, drips and other details.

### 2.4 Rain Penetration Resistant Wall Systems

The most effective of all the wall systems is the cavity wall(4). The pressure from wind forces on the outer leaf is canceled by using equal pressure in the cavity with openings provided in the exterior leaf (Figure 1). The pressure being equalized, water in cracks and pores will not be forced inside. The inner leaf provides an adequate degree of airtightness to keep the equalization system working. Any moisture penetrating the outer leaf will not be in contact with the inner leaf and can drain through the cavity to exit at flashings and weepholes. The success of this wall system will depend(5) on the following: (a) Cavities must be sufficiently compartmentalized to allow pressure equalization. Otherwise pressure differences across the face of the wall and around corners of the structure will prevent equalization of pressure and air drawn into the wall may carry extra water directly into the cavity; (b) The inner leaf must be sufficiently air tight to allow pressure equalization to occur without requiring movement of large quantities of air which may carry too much water into the cavity. Further, localized leakage paths in the inner leaf will cause water to jet across the cavity on the inner leaf; and (c) The cavity must be sufficiently clear of mortar or other materials to allow water to drain freely out of the wall, and flashing and weep holes must be adequate to handle anticipated moisture.

Another wall system which is very successful is the barrier wall (Figure 2) which consists of a solid brick-wall of thickness 1 1/2 brick or more. This is not very popular now due to higher cost and heavier weight. In a barrier wall(6), water which passes through the outer face of the wall is usually absorbed by the wall before it reaches the inner wall surface. When the rain ceases, absorbed water gradually evaporates out of the wall without passing to interior spaces. Efficient performance of the wall will depend on (a) full, well compacted mortar joints; (b) good contact and adhesion between the mortar and brick as provided by a lime based mortar; (c) when high absorption bricks are used, provision of wall plaster or other coating of water shedding but breathing material; and (d) restricted flow of water over the wall surface by provisions of overhangs, drips or ornamental mouldings.

Fully grouted reinforced concrete block wall (Figure 3) is also used (4) particularly in seismic areas. This relies on concrete grout to prevent water leakage through mortar joints and high strength block to minimize water penetration through webs of blocks. Reinforcement embedded in the wall also reduces incidence of cracking through which water may penetrate. Efficient performance depends largely on use of well consolidated, defect free, strong grout.

Partially grouted reinforced concrete masonry wall (Figure 4) performs adequately in moderate exposures. In this wall, weepholes in mortar bed joints make cavity pressure same as that outside, thus minimizing water penetration. Reduced cracking by embedded reinforcement also helps to minimize passage of water. Its efficient performance depends on following requirements:- (a) Pressure equalization of the cavity, in each area bounded by grouted cores (horizontal spacing not greater than 2.4m) and bond beams (vertical spacing not greater than 2.4m), by weep holes placed immediately above bond beams and D.P.C. at 600mm centre to centre. Weep holes also provide drainage to the cavity; (b) The internal pressure of the building is sealed by providing an air barrier on the inside surface; and (c) Water absorption by units and mortar is prevented by appropriate coatings, applied to the exterior surface, which can shed water while being able to breathe.

## 2.5 Factors that Affect Rain Penetration

### 2.5.1 Materials

Use of masonry unit that is cracked, nonuniform in shape or size, or dirty, increases water penetration. The structural strength of the masonry unit has been shown (2) to be of less concern than its absorptivity as regards rain penetration. Lower the absorption of the unit at the time of laying the less permeable the wall. High absorption unit performs poorly while low absorption brick when cored was found to be highly impermeable. Unless in very severe exposures or when high absorption units are used, rain penetration through the unit is insignificant. However, when it is significant, some external protection such as a plaster or coating, which sheds water but breathes, is necessary.

As regards rain penetration, bond strength of mortar is more important than its compressive strength. Use of lime is preferred as it improves workability and water retentivity of mortar, which are essential for maximum bond. Walls with mortars (3) 1:1/2:4 1/4 and 1:1:6 (Portland cement : lime : sand by volume) are found to be less permeable than 1:1/4:3 mortar. As sand fineness increases water requirement also increases, causing reduction in water retentivity and strength. It is important to use a creamy plastic mortar (2) made by paying close attention to grain size of sand, with very fine sand fractions absent. Lack of fines should be made up with addition of lime and not by plasticisers or densifiers.

The properties of mortar should be matched to the properties of the units and poor bond may result by certain combinations of brick and mortar simply because the two materials are not well suited to one another and not because of any defect in either. The combination of mortar having low water retentivity and high suction units or mortar having high water retentivity and low suction units increases water permeance. A mortar mix of 1:1/2:4 1/2 (Portland cement : lime : sand by volume) is recommended (3) for units of water absorption less than 5%; 1:1:6 for units of water absorption between 5% and 10%; and 1:2:9 for units of absorption greater than 10%.

Flashing is a sheet built into a structure to prevent moisture penetration or to direct moisture to the outside. Flashing materials have to be impervious to moisture penetration, durable in the environment, resistant to puncture and tearing, easy to form into the desired shape, and capable of retaining this shape throughout service. Popular materials are Copper combinations, Aluminium, Galvanized iron and certain plastics.

The coping or covering at the top of the wall, should possess impermeability or good surface run off, continuity and drainage. Impermeable copings of Aluminium or Steel are rapidly replacing conventional construction because they are lighter, easy to install, impermeable and available in many colours. Permeable copings are specially shaped to improve surface run-off. Continuity of metal copings is ensured by properly crimped joints with provision for thermal movement of the metal. Continuity in stone or precast concrete copings is achieved by caulking while that at brick or block copings is achieved at the flashing layer below, as numerous joints between units make continuity of top surface difficult to achieve. With impermeable copings, drainage occurs at the top surface which should be sloped away from the face of the wall at a recommended minimum of 1 in 10. Permeable copings require two drainage paths with top surface run-off via overhangs and drips and the other path at the flashing for water that may penetrate the coping. This flashing should be sloped away from the wall face.

### 2.5.2 Design Details

For unplastered masonry walls exposed to wind driven rain, only concave and weathered joints (Figure 5) should be used. Concave tooling of mortar joint compacts the mortar properly and helps to close capillary cracks. Weathered joint is not as good but adequate (4).

Flashings are built into a cavity wall at the bottom of cavities (Figure 1), sills, heads, wall-roof junctures and at parapets under pervious copings, while flashings are required for solid walls for latter two cases only. Flashing (except at wall-roof junctions) should be carried beyond the wall face and turned down at 45 degrees to form a drip projecting from the wall no less than 19mm(3). One edge of the flashing (except under pervious copings) should be turned up 150 to 225 mm and embedded in a mortar joint in the inner leaf or the solid wall.

Adequate control joints should be provided to control movement of masonry due to various effects such as shrinkage, creep, moisture and temperature. This reduces incidence of cracking and thereby improves rain penetration resistance. The control joints must be sealed to exclude the effects of the weather and generally this consists of placement of a compressible filler covered with a flexible sealant.

On all projecting cornices, sills, copings, caps and other surfaces projecting from a wall, drips at least 16mm wide by 10mm deep should be provided. The drips should be located at least 50mm from the wall(3).

In cavity walls every other head joint above a flashing should be left unfilled to function as weep holes. In other instances, weep holes at least 6mm in diameter extending into the masonry at least 75mm, should be located not greater than 60mm on centres horizontally in brick masonry and 800mm on centres horizontally in concrete masonry(3).

In cavity walls, a clear air space in the cavity of 40 to 50mm should be provided(5) to allow for construction tolerances and to minimize mortar bridging across the cavity.

### 2.5.3 Workmanship

Special care must be taken in gauging constituents and mixing of mortar. Excessive mixing, which causes air to be entrained, can reduce both compressive strength and bond, thus increasing risk of rain penetration.

The length of mortar bed placed during construction prior to laying the masonry units should be limited to ensure that units can be adjusted while mortar is still soft and plastic. However, mason should be encouraged to improve his technique to involve minimum movement of the masonry unit after it has been placed in contact with fresh mortar. As the time interval between spreading of mortar and laying of the unit increases, water permeance increases and an interval longer than 1 minute is excessive(3).

Complete filling of the head joint is essential as this joint does not benefit from compaction by compression which naturally occurs in horizontal mortar beds. Greater care is necessary with concrete masonry as larger the vertical height of the masonry unit the greater the problem of adequately filling the vertical joint becomes. Every effort should be made to have full and well tooled mortar joints.

### 2.5.4 Other factors

Walls should be protected from high concentrations of water flowing on wall surface due to defective gutters and downspouts.

Cleaning up of masonry walls should be carried out regularly as masonry walls accumulate air-borne pollutants (7) in the form of dust and dirt which are composed mainly of carbon and sulphur. These deposits form a film or think-skinned build-up to accumulate on the horizontal and vertical surfaces and it acts as a barrier that prevents the egress of vapours to occur at a normal rate. This prevents breathing of the masonry wall, and moisture locked in the wall can accelerate decay of the wall.

## 2.6 Repairs to Defective Walls

Determination of the location of water entry should be done before commencing any repairs. Water seldom passes directly through walls and water which enters may travel a long distance inside the wall before emerging into interior spaces. Once the general leak area is found, a direct "mask and spray" method can be used to further isolate the leak origination point. This may indicate whether the leak is over a large area of the wall or a specific region such as the perimeter of a door or window.

When leakage is caused by absence of weep holes or clogged weep holes, new weep holes should be drilled without puncturing flashing. All defective sealant joints and flashings should be replaced.

When wall itself is leaking, methods of repair possible are: tuckpointing (for unplastered walls); clear coating application; water cement paint application; external plaster application; and replacement of leaking wall. Tuckpointing involves grinding or chiseling out the existing mortar joints to a depth of about 13mm and packing fresh mortar into the joints. Clear coatings (such as silicone) can seal tiny cracks but they do not bridge openings wider than 0.5mm (3) and obstructs breathing of the wall. Water cement paints can seal bigger cracks and allow wall to breathe. When leakage is substantial external plaster application or replacement of existing plaster is suitable. The last resort will be the replacement of the leaking wall.

### 2.7 Research

Experimental research on rain penetration resistance so far consisted of (i) testing (9,10,11,12) in accordance with ASTM E 514 (8); (ii) testing using modified methods based on ASTM test (13); and (iii) field studies (2,14). Theoretical research is also developing rapidly based on numerical modelling of capillary flow of water (15).

## 3.0 Sri Lankan conditions that influence rain penetration and ways to control them

### 3.1 Climatic Conditions

Temperature can magnify after effects of rain penetration. However, its influence is less severe here as absence of low temperatures makes walls free from detrimental effects of freezing and thawing, but presence of moderately high temperatures encourages mould and green moss growth.

The combination of relative humidity and temperature in various parts of the country does not inhibit evaporation of water and faster evaporation is beneficial. Further, in some regions evaporation is very rapid and a wet wall can dry very rapidly.

The combination of rain and wind in various parts of Sri Lanka does not contribute to severe exposures as experienced in other countries, but parts of some structures may be under severe exposure due to conditions of the local terrain. Further studies are needed to classify Sri Lanka into various exposure zones.

## 3.2 Materials

Ordinary bricks have high water absorption, surface cracks, non-uniform shapes and dusty surfaces, all of which increase rain penetration. Hence good quality control, and external and internal plasters are very necessary. Wirecut bricks have low water absorption and perform excellently.

Blocks are of moderate absorption, but this advantage is offset by other factors. Face shell thickness of hollow blocks are insufficient and weep holes and external plaster should be provided. Head joints of solid blocks may not get adequate compaction due to greater height and require careful supervision.

Coarse sand used locally in masonry construction increases rain penetration and hence addition of lime to the mortar mix is very important. In rain penetration resistant wall design, mortar should be selected to ensure compatibility with units rather than attaining higher structural strength or ease of construction as in mortar without lime.

### 3.3 Design Considerations

Attention to spacing and location of control joints can minimize wall cracking and thereby rain penetration. Careful detailing of copings can minimize flow of water down the wall, thus resulting in reduced rain penetration. Common practice of providing door and window overhangs should not be discouraged. Where that cannot be done, flaring the wall jamb and sloping the window sill around openings to improve drainage and direct water away from opening/wall interface should be carried out rather than relying solely on achieving a watertight joint at the opening/wall interface. Walls in severely exposed locations should be detailed as cavity or barrier walls. In specifying plaster or paints to an exterior face of a wall exposed to rain penetration, the water shedding as well as breathing qualities should be considered.

### 3.4 Construction Practices

Both bricklaying and blocklaying techniques used in Sri Lanka reduce rain penetration as head joints are compacted by trowel rather than by pressing a unit buttered with mortar. However, mason's skills should be continuously improved to prevent undue disturbance of the unit after placement and particularly after elapse of about a minute as bond will be adversely affected.

Incorrect proportioning of mortar mix, excessive addition of water and inadequate wetting of bricks can reduce bond significantly and should be prevented by careful supervision. Attention to proper construction of drips in copings or overhangs will reduce flow of water on the wall face leading to reduced rain penetration.

In walls which should be plastered, bed joints should be grooved before hardening by rubbing and pressing with a mason's timber straight edge. This compacts the mortar solidly as well as providing grooves for plaster to hold on by bonding on a larger surface area as well as by physical interlock. In the case of blockwork even the head joints should be grooved similarly with a short timber straight edge as grooved bed joints are few and far apart.

Attention to timely maintenance cannot be ignored. Repair to defective gutters and downspouts cut off concentration of water flow on wall face. Cleaning the wall face by removal of mould, green moss, or peeling plaster or paint film prevents higher flow of water in certain areas of wall face. Mould and green moss can increase risk of cracking. Peeling plaster or paint film exposes absorbent layers of wall to moisture thus increasing rain penetration. Cleaning up of dust and dirt removes a thin skin which prevents evaporation of water vapour freely. Repair of cracks in caulking of control joints will also reduce ingress of water into the wall.

### 3.5 Wall systems suitable for local conditions

Study of current trends in rain penetration resistant wall design and local conditions in Sri Lanka resulted in the following recommended wall systems (Figure 6). For severe exposure either a cavity wall or a 338mm barrier wall in brickwork is suitable. For moderate exposure, a 225mm brickwall, a 200mm block wall with cavities filled or a 200mm hollow blockwork with weep holes is suitable.

## 4.0 Conclusions

The following conclusions can be made from this study:

a) Considerable research on rain penetration of masonry has resulted in understanding the mechanism of rain penetration, factors that influence it and how it can be effectively controlled. However, the wall systems available in the literature cannot be directly applied to Sri Lanka due to differences in prevalent local conditions.

b) The wall systems recommended for Sri Lanka were based on the assessment of impact of local conditions on rain penetration as well as information generated by reviewing previous research;

c) Further research on rainfall and wind patterns in Sri Lanka is necessary to identify regions in the country where various exposure conditions are likely to exist.

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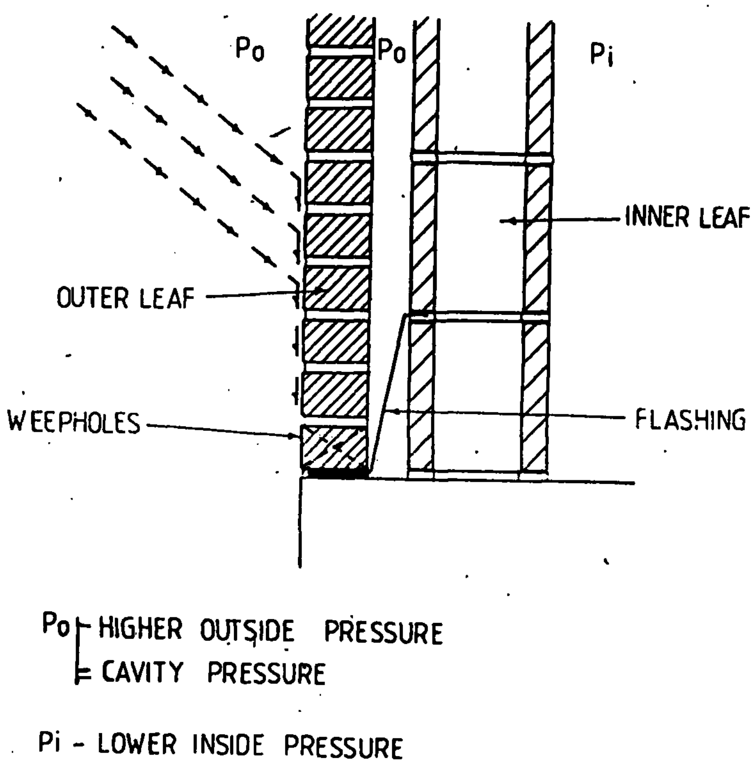



FIGURE 1 - CAVITY WALL

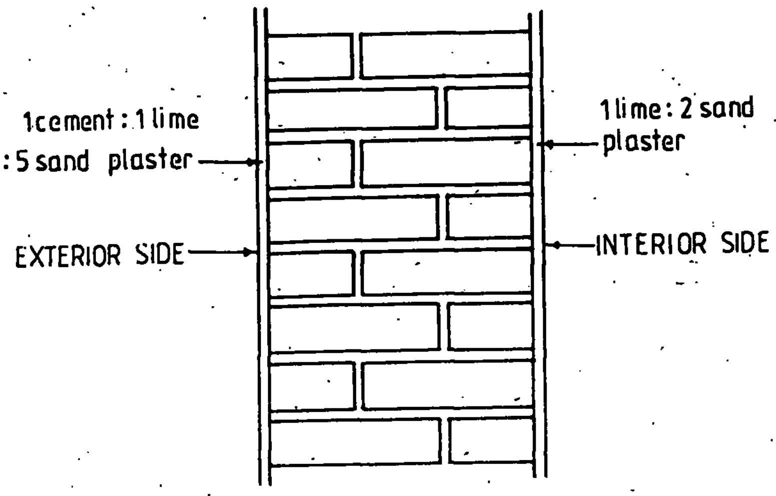



FIGURE 2 - BARRIER WALL

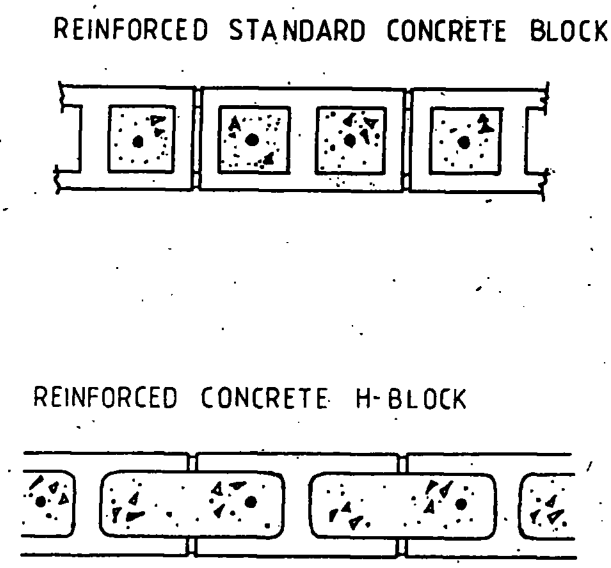
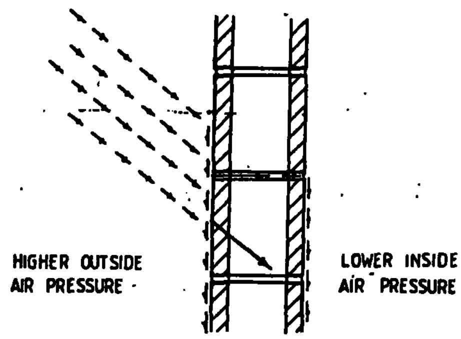
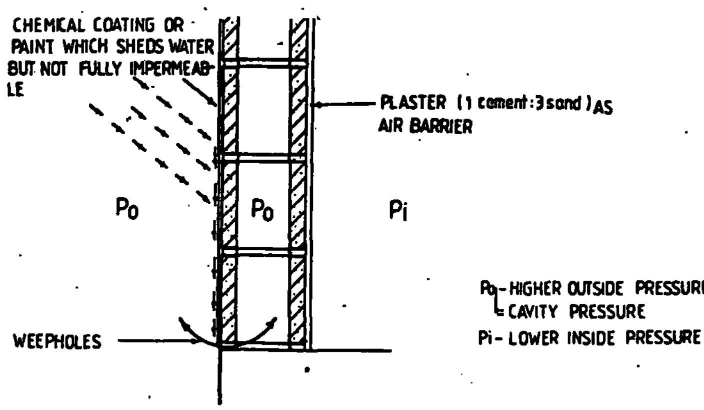



FIGURE 3 -REINFORCED CONCRETE MASONRY WALL

PLAN VIEW OF A PARTIALLY REINFORCED CONCRETE MASONRY WALL

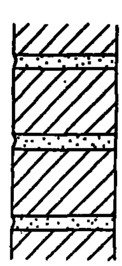



ELEVATION OF UNSUITABLE CONSTRUCTION

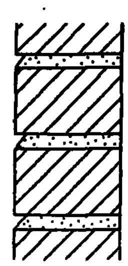



ELEVATION OF SUITABLE CONSTRUCTION

FIGURE 4 - PARTIALLY REINFORCED CONCRETE MASONRY WALL

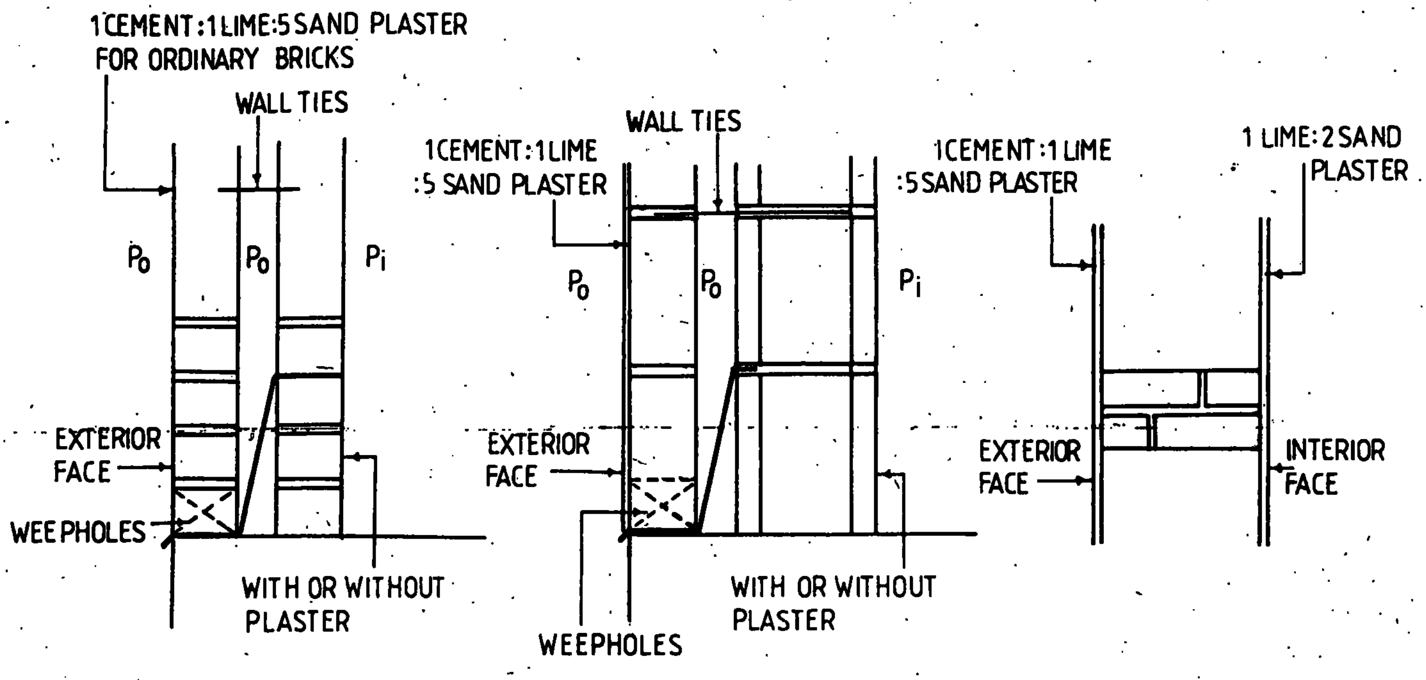


1. CONCAVE



2. WEATHERED

FIGURE 5 - RECOMMENDED MORTAR JOINTS

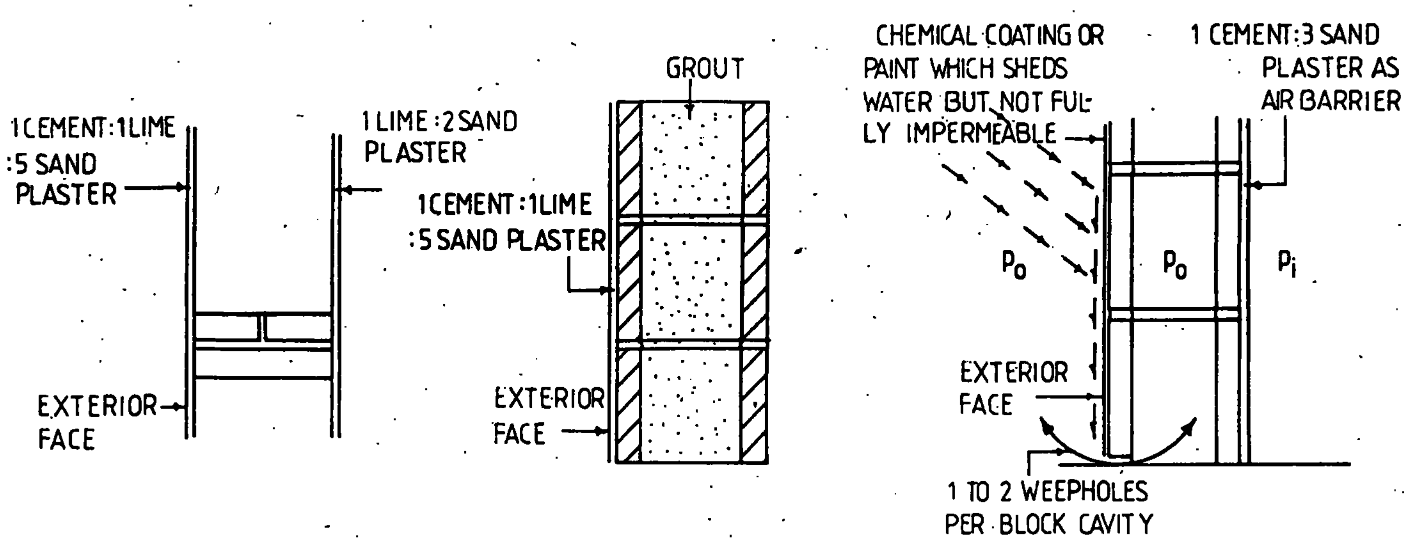



(a) CAVITY WALL WITH BRICKS

(b) CAVITY WALL WITH BLOCKS

(c) 300mm BARRIER WALL IN BRICKWORK

## WALLS FOR SEVERE EXPOSURE




(a) 225mm BRICK WALL

(b) CAVITY FILLED 200mm BLOCK WALL

(c) 200 mm HOLLOW BLOCK WALL

## WALLS FOR MODERATE EXPOSURE

KEY - $P_o$ - OUTSIDE PRESSURE

$P_i$ - INSIDE PRESSURE

## FIGURE 6 - WALL SYSTEMS SUITABLE FOR SRI LANKAN CONDITIONS