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Common Causes of Cracking in Masonry Walls Diagnosis and Remedy

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Abstract

Masonry: concrete block, lime stone and recently oven dried clay hollow bricks are widely used in most of the underdeveloped countries in the construction industry either as a wall bearing construction or as part of the structure skeleton for walls. Yet little is known about the deformations encountered once these units are in service due to the lack of research and information employed in the design. When it comes to the collective behavior the knowledge gap is worse, wall cracking is the typical drawbacks noticed in most of the low rise masonry buildings. These cracks are attributed to various effects ranging from unit properties, climatic boundaries, poor construction, and bad design: collectively leads to cracking and at ultimate can result in failure. This paper is thoroughly pin points the wide varieties of cracks in walls and summarizes their causes and how they can be avoided contributing to good masonry design through insuring aesthetic as well as safety provision at lowest possible cost.

Emphasis is been pointing to huge information available about unit properties whilst few research has been devoted to collective behavior of walls thus concluding that full scale studies, extensive field surveys and numerical or mathematical simulation model(s) must be carried out and verify each other, with good knowledge of soil conditions and climatic changes throughout the life of the wall, therefore, leading to desired improvements in masonry design.

Keywords: Causes of masonry cracking, control joints, masonry wall cracking

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1. Introduction

Cracking is the failure which probably occurs most often. It is necessary to understand the causes of stress in order to carry out a design which will accommodate the anticipated movements. Cracks develop in many different ways but there are typical modes and characteristics; often the type and magnitude of cracking indicate the cause of cracks.

This paper reviews different crack modes in masonry walls and their probable reason and how these cracks can be avoided or treated as reported in the concerned literature. An emphasis had been made on main drawbacks leading to knowledge gap in terms of more studies concerning wall behavior are required as well as emphasizing block units properties which are well researched. Knowledge gap can only be bridged through a comprehensive structural model employing numerical means and done through proper simulation of all variables involved.

2. Causes of Deformations

2.1 Slab (Roof) Deflections

When a roof resting on a wall is loaded, the end rotation of the slab can develop cracks at the wall slab interface. This type of cracking is more visible in the external walls although it may occur at internal walls as well. This crack is setup by the upward left tensile force in the roof slab due to the rotation of the end of the slab.
Cracking risk decreases as the force in the wall (and the restraining moment on the slab end) increases. Theoretically, cracks will be formed if the induced tensile forces at the outer face of the masonry wall exceed the permissible tensile stress of the wall. This type of crack can only be accommodated by providing tensile reinforcement sufficient to handle the tensile stress or by separating the slab from the wall. Another way is to reduce the slab deflection by increasing its stiffness, but zero deflection may not be practically possible.

2.2 Differential Strain From Stress and Temperature Changes

The differential strains can occur as a result of different expansion characteristics of two walls, or a wall and a column with different Young’s modulus or might be due to the difference in stress level for the same material walls. Moreover external walls are subjected to fluctuations of temperature and hence they tend to deform differently than internal walls, causing cracks in the connecting walls. This action may also happen in cavity walls connected by metal ties bridging between the two withes. To avoid this type of cracking caution should be exercised when choosing materials and stress levels for wall in higher buildings at least.

2.3 Roof Expansion and Construction

Generally the foundation of a building is considered to be at a fixed temperature while the roof is exposed to daily and seasonal temperature fluctuations. Due to geometrical features and orientation of the building some walls will receive more direct sun rays than the other and hence deform to different amounts. The outcome of the differential movement is to induce stresses in the wall section due to relative movements of the roof and the wall. Long horizontal cracks tend to form when these stresses exceed the permissible strength of the blockwork. This of course will occur only if no provisions were made for an independent movement to take place.

2.4 Creep and Shrinkage Cracking

A masonry wall is normally restrained to some extent along its edge or at certain points. Differential shrinkage between the masonry and the restraining media will therefore build up stresses in the masonry. Due to creep such stresses are relieved to some extent in certain cases. In other cases the creep can be a source of differential movements and accompanying stresses.

As soon as the bond strength between the vertical mortar joint and the block is exceeded, cracks will open in these joints. The cracks are typically 0.025 to 0.076 mm wide prior to failure[1]. The wall is divided into two or more parts by continuous cracks of the wall. The restraint can be reduced by the introduction of control joints. Cracking may develop in shear through the vertical and horizontal joints or by bond tension failure in the vertical joints and tensile failure in the blocks along the line of the vertical joints. According to [1]; two core block could provide somewhat higher resistance to the later type of cracking.

2.5 Poor Details and Improper Construction

Poor construction as well as insufficient details are other common reasons for cracking development and may include:

a. Wrong location of control joint(s).
b. Design of the drain.
c. Alignment of windows.
d. Placing of steel plates above an opening.
e. Location of splices.

Usually control joints are laid up in mortar first, and once the mortar has hardened it is raked out to a depth of about 20 mm. The remaining mortar then provides a packing of the caulking. Quite frequently it appeared as though the mortar was not racked out of the control joint, thus eliminating benefits derived from the joint.

To avoid spalling that may occur as a result of the freeze-thaw action care should be taken when selecting the run-off drain for the roof. If the water from the drain is allowed to fall back into the wall, the freeze-thaw effect will cause spalling.

A window opening(s) has two vertical planes of weakness on either side of the opening. For a window opening above another opening, the sides of the openings should be aligned.

To avoid spalling due to an eccentricity of the load, caution should be exercised when placing the steel plate above an opening. If the mortar between the plate and the block is not deep enough the load may be applied to one portion of the block. The stresses caused by the eccentricity of the load may cause cracking of the supporting blocks below the steel plate.

Some designers will utilize part of the opening for a movement joint, but this procedure will lead to problems in practice. Above the opening lintel beams or soldier courses carry the load from the blocks above the supporting block for it to act properly. Since the soldier course bears on the supporting block it is hard to establish a gap between the beam and the block.

Joint reinforcement is used so that there will be many fine cracks as opposed to one large crack. Proper splicing of the joint reinforcement should be insured so that a potential crack does not form.

2.6 Running Bond versus Staked Bond

This type of bond used will determine the strength of a concrete block wall. This was reflected in design codes for non-reinforced block walls. The tension parallel to bed joint is twice that normal to the bed joints. Typically, joint reinforcement at 400 mm intervals gives the same strength for two bonding patterns which is an increase of 20% for the running bond and 120% for the stacked bond[2].Joint reinforcement at 200 mm intervals shows an increase of 60% for running bond and a four-fold increase for stacked bond[2].

2.7 Load Bearing Versus Non-Load Bearing

The designer must make a choice, whether to use loadbearing masonry walls or not. A loadbearing wall will tend to have a clamping action making it harder for a crack to form in the bed joint by increasing the shear friction between the unit and the mortar joint.

2.8 Foundations

When masonry walls are built on concrete foundations that extend above the grade, thermal expansion of the wall (masonry) may work against the drying shrinkage of the concrete causing extension of the masonry wall beyond the foundation. When the masonry wall contracts with lowering of temperature the tensile strength of masonry is not sufficient to move the masonry wall back with it thereby causing cracking in the masonry near corners.

2.9 Settlement

Foundation settlement is one of the common reasons for cracking, especially in soft soils such as silty clay. Very often detrimental settlement occurs in smaller buildings where foundations are designed by guess. Settlement cracks are usually larger at the top diminishing to a hairline crack at the bottom or vice versa, depending upon the relative direction of the settlement and its location with respect to wall length. It should be noted that it is the differential settlement rather than the total settlement which is the trouble maker.

[3] Is a useful document in which a practice oriented study of cracking problem is presented. The report summarizes different modes of cracking and their expected reasoning as well as suggested remedies to overcome such cracking. The reasoning as well as the remedies seems to be based on practical experience and engineering judgment rather than analytical or experimental evidence. The report was written for the Australian conditions and hence, it may not be directly applicable to other practice.

3. Control of Horizontal Movement

As has already been discussed in the previous section, walls and all materials that make up a building are in a constant state of movement due to elastic, creep, shrinkage, and thermal deformations, acting together or individually. There are generally two techniques reported in the literature for accommodating such movements and controlling cracks. These techniques are:

1. To provide reinforcement, and
2. To provide control joints

4. Horizontal Reinforcement

This was developed to help control cracking in walls, and all it does is distribute the stresses so that there will be a number of fine cracks instead as opposed to one or two large ones. It may be in the form of reinforced collar joints or bond beams. The joint reinforcement is placed at vertical distances from 200 to 600 mm; having a minimum cover of 10 mm and the bars should overlap at the ends by at least 150 mm. one should note that the use of minimum reinforcement in masonry may not insure crack control under moisture changes and thermal deformations.

5. Control Joints

Control joints are vertical joints built into a wall to relieve stresses that may be either tensile or compressive in nature, by reducing restraint and permitting movement to take place.

In clay brick walls the dominant movement is slight expansion which, in long walls, can create excessive stresses and cracking in the brickwork. Hence the expansion in the long wall should be controlled. A common method of control is the inclusion in the walls of expansion joints which providespace intowhich the expanding masonry can move. Vertical expansion joints are used toaccommodate horizontalmovements in masonry walls, and horizontal expansion joints are used to absorb vertical movements between walls and frames of buildings.

In walls of concrete and sand-lime masonry the dominant movement is a slight contraction which, if not controlled, can result in excessive stresses and cracking even in short walls. A common way of control is the provision of joints in walls, such joints are able to open when the adjoining masonry contracts. The usual types of expansion joints can open as well as close, and thus function also as contracting joints.

There have been many attempts to come up with a specific answer to the question of where the control joint(s) should be located, question that is further complicated by the nature of the thermal and moisture stresses in masonry walls which involves many separate phases, and variable factors and it does not lend itself to a neat mathematical solution.

[4] is based on simplified assumptions and a limited number of experimental data, proposed two methods of locating control joints in blank walls which in general tend to be conservative solutions [2] proposed a

theoretical solution to the problem of locating the control joints. Based on the assumption that the roof temperature is higher than the wall temperature, they arrived at theoretical curves by solving the compatibility and equilibrium equations at the roof-wall interface. The theoretical nature of the method and the lack of the analytical and experimental support limit the use of the method to serve as a guide only.

The recommendations provided by the American Concrete Institute [2], are useful guidelines and probably the most widely used to deal with concrete masonry crack control procedures.

Control joints should be incorporated into a wall in locations at which stress concentrations might occur: at locations where there are abrupt changes in wall height or in wall cross-section. Joints may also be located at pilasters and at the pipe or duct chases, above joints in the foundation or floor, below joints in the roof or floors bearing on the wall, at a distance not over one half the allowable joint spacing from bonded intersections or corner, and at one or both sides of all door or window openings depending on its size. Next tableshows a typical spacing of control joints [2].

Joint reinforcing spacing mm	Maximum Spacing of control joints	
	panel H/L	Panel length m
non	0.5	12
600	0.4	13.5
400	0.33	15
2000	0.25	18

6. Design Considerations for Horizontal Movement

Due to the wide variety of the involved factors in the generation of horizontal movements in masonry walls; namely elastic, creep, shrinkage, and thermal effects, it became almost impossible to write down general rules or specifications that are universally true and applicable. The reported literature describes a set of rules and cautions that are based more on art than science, in which experience was the dominating factor. These considerations are summarized herein as reported in [2], [5] and [6].

6.1 General Design

It is important that dimensional change characteristics of the materials to be used be considered at the same time as the general design of the building. The designer may approach this in two ways, one being to modify design to suite the materials, the other to select materials carefully to fit the design. In practice however, it is usually necessary because of economic considerations and other factors to compromise between these two approaches and to use those materials which produce minimum movement, or to design the masonry wall to accommodate movement.

6.2 Locations and Frequency of Movement Joints

The positioning and frequency of vertical movement joints must generally be a compromise between the technical need to reduce the possibility of cracking to the minimum on the one hand and the cost and the aesthetic considerations on the other. It is not possible to lay down strict rules or write a specification for the spacing and location of joints to suite structures but some general guidance is possible:

(1) Clay brickwork should have movement joints at about 12 meter centers. In a cavity wall, having clay on one wythe and concrete units in the other, this interval should be reduced to between 6 and 7.5 meters.

(2) Plain concrete block masonry walls should have movement joints at not more than 6 meter intervals. While the frequency of movement joints suggested afford useful guidance, the following modifying factors need to be taken into consideration in locating movement joints in particular circumstances.

i. In thin walls less than 200 mm thick with no openings, connected to supporting piers or columns at intervals, movement joints may need to be at shorter intervals than in thick walls, but this will depend on the frequency of the piers and the bonding. It may be convenient to form a movement joint at the side of each pier or at alternate piers.

ii. In thicker walls, since the tensile failing load is higher, it is possible to lengthen distances between joints. Similarly, high walls will tolerate greater lengths than short walls.

iii. When openings are present the frequency of such openings and the heights of brick or blockwork above and below them, in relation to the total height, will influence the need for joints. Where the total section of wall is much reduced by the openings, the stress concentration will be great and movement joints need to be more frequent.

iv. Where linear and outer wythes of cavity walls consist of materials of different dimensional change characteristics (e.g. clay brick and concrete block), and are rigidly connected at the end or at the bottom of then the frequency of movement joint needed is determined by the algebraic sum of the maximum probable movement. Thus if one is likely to expand slightly and the other to shrink slightly, the movement joint will need to be more frequent than if both were of the same material. Where possible, rigid connections of two different materials in this way should be avoided.

v. Where there are features which can be used to conceal movement joints, the positioning should be adjusted to take advantage of this possibility even if this necessitates closer intervals than would be otherwise be required.

vi. Where brick or block work is returned about steel or reinforced concrete frame members and there is no clearance left between the brickwork and the frame member, it may impose restraint or may transmit movements of the frame to the brickwork. It is preferable to isolate the brickwork from columns either by a space or by resilient membrane such as bitumen, bituminous silt or joint filler. Where this is not done, provision made for movement should take the imposed restraint into account.

vii. Restraint at top and bottom edges of brick or blockwork is reduced by the presence dam-proof coursing, which reduces shear resistance. This fact may reduce the need for vertical movement joints or modify the desirable positioning of them.

7. Concluding Remarks

- The precautions to be taken in design should be related to the properties of the specific materials being used. Thus where there are in clay bricks it may be in some instances desirable to make provision against expansion, with concrete and calcium silicate materials some provision is usually required against shrinkage. With all types of bricks and blocks, provision must be made against thermal movement either increase or decrease.
- The precautions in design which may be useful in preventing cracking include the provision of movement joints, use of reinforcement to assist in distribution of stresses, and location of openings and features so that movement does not lead to accumulation of stresses at points of weakness that could lead to conspicuous crack formation.
- A significant amount of research has been carried out with most of it being devoted to deformations of clay brick and concrete block units.
- The importance of the various effects varies greatly in different countries and indeed even in different parts of countries. Climatic factors and building- techniques locally give greater importance to one of the effects; also the raw materials available may make one type of block or brick suffer from a given defect very much in one area and very little in another.
- There seem to be insufficient data available for the calculation of the amount of the unrestrained movement that can be accommodated without risk of cracking. Whilst the elasticity and the tensile and the compressive strength of masonry panels may be determined, bond and shear strength, creep effects and the distribution of stresses induced by shrinkage and expansion cannot be easily assessed and applied qualitatively to actual structural design.
- One of the major drawbacks of the available literature is the absence of extensively carried out case studies and surveys that relates the cracking problem to the local climatic conditions. The importance of including climatic conditions as a factor in studying deformations arise from the fact that excluding settlement, moisture and thermal deformations are the common reason for cracking. There is no evidence, about neither the probability of the occurrence of the different types of the deformations, nor how the thermal and moisture variation along wall height might be.
- A rational model(s) needs to be developed and analyzed by means numerical means, and available software might be useful to check and or support full scale laboratory tests, field surveys or practical case study.

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