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XXX IAHS – CONTROL OF THERMAL AND MOISTURE DEFORMATIONS IN BUILDING MASONRY WALLS AND CONFINING REINFORCED CONCRETE ELEMENTS

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Abstract
Daily or seasonal changes in temperature and moisture can be related with volume changes, mass variation and cracking of masonry walls and confining reinforced concrete elements. Generally, cracking of building elements can be often a result of thermal stresses, due to the change of temperature, which exceeds the tensile strength of the respective material. It is possible to reduce or even avoid the possibility of cracking in masonry walls minimizing the temperature differential that exists between elements in contact or relieving the stress generated in the masonry walls. Moreover, when changes in temperature and moisture occur, the restriction of the overall expansion or contraction of roof slabs and beams due to the presence of adjoining walls is inconvenient, because it will generate significant stresses and cracks in these building elements, mainly in the masonry walls. Then, it is important that the building envelope design must try to control temperature deformations and moisture accumulation during all the year, and over service life. So, the purpose of this paper is to discuss the main factors related with the control of temperature and moisture movements in walls and confining reinforced concrete elements.

1 Deformation and cracking of masonry constituent materials due to temperature and moisture changes

Daily or seasonal changes in temperature and moisture, corrosion of concrete elements that are confining with masonry and water salt crystallization are usually related with volume changes and mass variation of masonry material. Movements of structural frames (excessive deflections), foundations (settlements), shelf angles, and roof slabs are frequently associated with the imposition of loads to masonry walls, [1] to [4]. The restraint of volume changes in masonry materials or the imposition of loads can, generally, induce significant strains, which result in cracks in the masonry, [5], [6].

It must be stressed that it is not possible, from technical and economical point of view, to avoid completely the formation of cracks in masonry, but it is desirable to minimize them and to assure acceptable levels of aesthetic aspect [1], [2].

The wall movements occurring after construction depends not only on the range of temperature (extreme values of temperature variation associated, generally, with volume and mass variation) but also on the initial temperature of the constituents units and on their initial moisture content as well as to the effect of the wall restraints, [5].

It is important to get a better understanding of volume changes in masonry walls and confining elements due to temperature and moisture changes and to know how to control the corresponding deformations in those elements. So, the purpose of this paper is to discuss the main factors related with the control of temperature and moisture movements in walls and confining reinforced concrete elements.

2 Characteristic behaviour of masonry unit’s

Due to wetting and drying, brickwork is subjected to reversible expansion and shrinkage, [7] to [9]. But superimposed on that movement there is also irreversible expansion that takes place over a long period of time. This expansion depends on the combined effect of expansion in the individual bricks accompanied by shrinkage in the mortar joints. Clay bricks after production expand due to the absorption of water from the air. This expansion is wholly irreversible and a large part of it takes place within a few days (near two weeks) and the rest takes place over a period of about six months. The net expansion of brick masonry due to moisture, heat, freezing, and mortar shrinkage, is estimated to have a mean value of about 0,3 mm/m (0,03%), but can reach exceptionally a value of 0,7 mm/m (0,07%), [8]. If the bricks are linked to a concrete element, the differential vertical movement (contractions of concrete columns due to shrinkage, creep and elastic deformation) may average 1,4 mm/m. Due to wetting or drying, bricks also suffer partly or wholly reversible expansion or contraction, but not very significant, except in case of the calcium silicate bricks.

Concrete masonry units (CMU) behaviour is different compared with those of the bricks, as they are generally subjected to shrinkage during the process of drying. Usually, they show some increase of shrinkage as water absorption of the unit is increased and the density is reduced.

3 Mass variation associated to volume changes of masonry block material due to temperature changes (blocks of aerated autoclaved concrete)

As referred above, it can be expected, when temperature changes occur, a mass variation of masonry constituent materials together with the increase of deformations in that materials. So a test was done to access the behaviour, in terms of mass variation of block material, when there is a step variation of temperature. Six cubic (dimension of 100 mm) specimens of autoclaved aerated concrete were subjected to a period of drying (total of 105 hours) at a variable temperature regime. The mean net dry density of blocks of aerated autoclaved concrete was 560 kg/m^3.

The specimens were taken from laboratory conditions (closed room) and set in an oven with initial temperature of 30ºC. The temperature were varied by steps of 10ºC and remained in a given temperature during a period of 24 hours. The results of the test show a mass relative variation (reported to the initial value) of approximate linear type, and a range of maximum value between 1,4% (positive value: loss of mass) and 1,6 %. If we compute the mass relative variation in each period of 24 hours (reported to the last period of a determined temperature) it can be noticed a constant increase of that value of mass in the first 48 hours (less than 0,20% in the first period of 24 hours and less than 0,50 % in the second period). After that limit of time (48 hours) the evolution of the values showed little scatter among the specimens with cases of decrease or constancy in the subsequent periods (exception of specimen X1 where there was first a reduction in the 3rd period, and then a increase in 4th period). These results suggest that the most significant increase in mass and possibly deformation variation in the material occurred in the second period (24 h - 48 h) corresponding to a temperature of 40 ºC, temperature that is easily achieved when the walls are exposed to sun radiation in summer time.

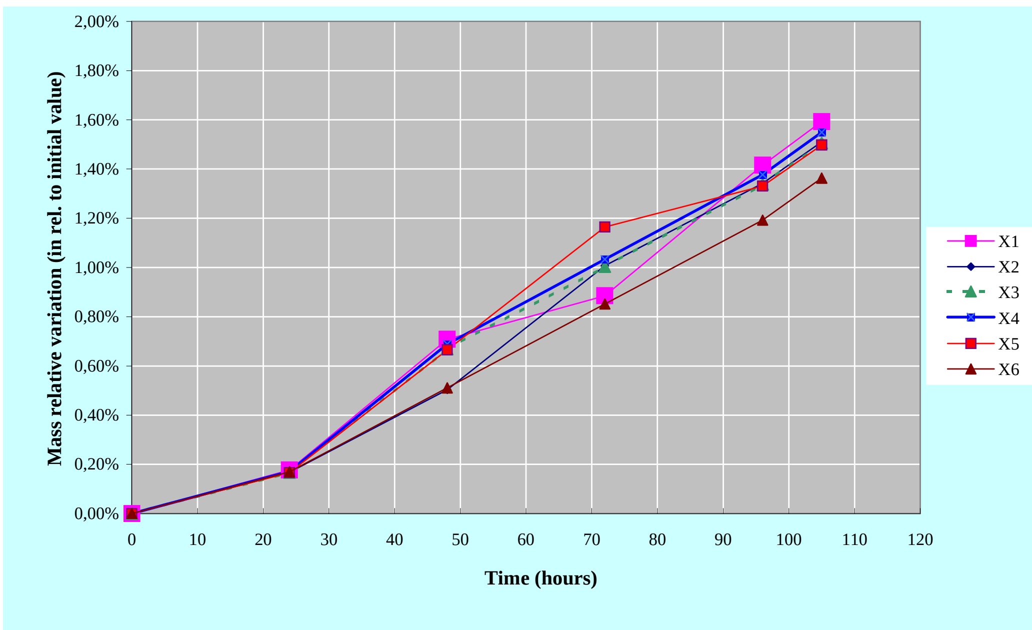

Figure 1: Mass relative variation with a step change of temperature (relatively to the initial value)

Table 1 - Test of drying at a variable temperature regime

Temp. (ºC)	Mass value at end of each interval of time						Relative variation of mass (related to the initial mass)					
	22ºC	30ºC	40ºC	50ºC	60ºC	70ºC	22º	30º	40º	50º	60º	70º
Time	0 h	24 h	48 h	72 h	96 h	105 h	0 h	24 h	48 h	72 h	96 h	105 h
X1	565	564	561	560	557	556	0	0,00177	0,00708	0,00885	0,01416	0,01592
X2	596	595	593	590	588	587	0	0,00168	0,00503	0,01007	0,01342	0,01510
X3	598	597	594	592	590	589	0	0,00168	0,00669	0,01003	0,01338	0,01505
X4	581	580	577	575	573	572	0	0,00172	0,00689	0,01033	0,01377	0,01549
X5	601	600	597	594	593	592	0	0,00166	0,00666	0,01165	0,01331	0,01498
X6	587	586	584	582	580	579	0	0,00170	0,00511	0,00851	0,01193	0,01364

4 Main characteristics of masonry walls deformation behaviour and type of cracking

Brick masonry and concrete masonry, generally, show after construction different characteristics of behaviour in terms of deformation. Brick masonry has a long-term net volume increase due to moisture expansion. That reveals a considerable distinction in deformation behaviour when compared with concrete masonry, which is subjected to shrinkage during the period of drying. Both materials are subjected to reversible thermal expansion and contraction, elastic contraction, and creep, but at considerable different rates. The expansion of both types of masonry may be caused by heat and moisture.

Cracking patterns can be different regarding the type of masonry (concrete masonry or brickwork). Cracks in perforated brick, that are perpendicular to the face, are usually located inside the brick, at a core, and are usually related with deficient quality of the bricks, [8]. If the cracks are parallel to the face generally they are related with the lamination of ceramic material and are not visible on the surface. Usually this kind of cracks does not affect considerably brick performance.

The expected mortar shrinkage transverse to the plane of a mortar head joint is usually much less than brick initial moisture expansion (irreversible). So, the shrinkage crack (due to initial shrinkage of mortar and mortar/brick differential strain) in the mortar head joint is not likely to occur in brick masonry when the temperature and moisture movements are not significant [8].

On the other joint (bed joint) mortar shrinkage and brick expansion are additive, so the differential strain must be limited in order that the corresponding stress be lesser than the shear strength of brick. Vertical cracks may occur in horizontal bed joints due to the differential movement between brick and mortar (coefficient of thermal expansion of brick is greater than that of mortar). The bond strength and the extensibility of mortar can be important factors to avoid cracks in the case of high shrinkage mortar combined with low moisture expansion brick.

Frequently facial separation cracks can occur due to inadequate tooling of mortar joints during construction or thermal contraction of masonry units and mortar and at less extent to mortar shrinkage. These cracks are openings in the face between brick and mortar, generally with 1 mm or less of width, [8].

Due to the fact that the bond strength between bricks and mortar is lower than the tensile strength of mortar, the cracks are likely to occur at the brick-mortar interface rather than in mortar. Also, at the brick-mortar interface, horizontal cracks can be induced by shear or flexure.

In concrete masonry, due to the fact that wall shrinkage is restrained at the wall base by bond and friction, but is not usually restrained at the top of the wall, for a high ratio of wall length to height a vertical crack can occur near the center of the wall (crack wider at the top).

The probability of cracks formation in walls is higher at changes in wall dimension; openings, corners, or other wall stiffener; and in areas of greater exposure as in parapets and wing walls.

5 Control of thermal and moisture deformations in masonry walls and confining elements

5.1 General

When changes in temperature and moisture occur, the restriction of the overall expansion and contraction of roof slabs and beams due to the presence of adjoining walls is inconvenient, because it will generate significant stresses. The free movement of the slab over the wall must be prevented. Cracking of the wall at the top and damage to the rendering can occur when the connection of the slab and the wall is made by an interface of mortar. Probably cracking will first occur along this interface of mortar and then in the top of the wall (sometimes in a step way).

Cracking of building elements can be a result of thermal stresses, due to the change of temperature, which exceeds the tensile strength of the respective material. To reduce or even avoid the possibility of cracking in walls there are two approaches: minimize the temperature differential that exists between elements in contact through the use of insulating material; relief of stress generated in the walls by the provision of movements joints. Regarding this last solution, three types of sealants joints are used for crack control in masonry: control joints open to accommodate shrinkage of concrete masonry; expansion joints close to accommodate expansion of brick masonry; construction joints that seal the interface gap between masonry and other materials, such as windows and doors, [10].

It is important to choose carefully the method of waterproofing the movement joints and in particular the choice of adequate sealants and backing fillers. The movement accommodated in the sealants reflected by their elasticity is, generally, expressed in terms of a percentage of the joint width. The backing materials for sealants are supposed to have an adequate elasticity and accommodate these movements without inducing inconvenient stress (in general polyethylene or polyurethane strips are good examples of joint fillers).

5.2 Contraction and expansion of the elements

Vertical thermal movements (expansion) in brickwork exposed to direct sunlight are usually reversible, meanwhile horizontal movements may only be reversible if the wall does not crack as a result of the expansion or contraction. It must be referred that the coefficient of expansion of brickwork is greater in vertical direction than in the horizontal one.

It is recommended the location of movement joints (contraction and expansion) at: junctions of walls; ends of long walls and at suitable distances along the wall (it is convenient to be less than 10 m for brickwork walls and 30 m for concrete walls).

To avoid cracking, movement joints (contraction and expansion) in brickwork may be provided at intervals that depend upon the moisture content of bricks at the time of laying (it is convenient to be less than 6 m). The age of the bricks and the type of mortar can influence the spacing of the joints. The spacing of joints should be reduced in cases of large temperature variations and in uninsulated walls.

Because shrinkage normally exceeds expansion in concrete masonry walls, expansion joints are generally not required. There is some technical solutions to control cracks due to movements in concrete masonry walls, [5], [8], such as: designing the building to use discrete panels of masonry; keeping masonry units and wall protected during construction; location of control joints at points of stress concentration; limitations on horizontal distance between vertical control joints; limitation on length to height ratio of walls (it is recommended that this ratio should not be greater than 2);

installation of bed joint reinforcement in situations of high stress concentration (near windows and doors); control of moisture content in CMU; installation of slip joints (this joints are formed by breaking the bond of mortar bed joints with the CMU and are placed at the top exterior corners of walls that support cast-in-place concrete roofs or floor slabs and at CMU lintel bearings); use of flexible wall ties to prevent differential movement and cracking in cavity walls where the outer and inner leaves are made of different block material (example: bricks and CMU); finally, care should be taken about bonding pattern (bond broken) and wall bonding (intersecting walls).

In case of concrete masonry, the use of strong mortars is not recommended (unless for durability or stability reasons) due to fact that these mortars accommodate movements (example: unit's shrinkage) to a lesser extent than weaker mortars due to their greater modulus of elasticity and lower creep in tension, [5], [8].

The control joint spacing can be increased with reduction of the spacing of bed joint reinforcement and of average annual relative humidity. Besides that, control joints are necessary at critical points of high stress concentration: changes in wall height or thickness, above joints in floors or foundations and below joints in slab roofs bearing on the wall, at one or both sides of wall openings.

6 Final considerations

Finally, it is also essential to define, in integrated form, moisture control, thermal insulation and energetic management strategies for building walls compatible with the different types of use, bearing in mind long-term performance and durability for the all types of climate zones of a country. Besides, it is also important to characterize the capacity of buildings walls to manage thermal effects and moisture sources, including construction moisture, soil humidity in contact with walls, indoor humidity and outdoor air, indoor human activities, and precipitation. The envelope design strategy must take in account all these aspects, and must try to control thermal deformations and moisture accumulation during all the year, and over service life.

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