BEHAVIOUR OF CONCRETE MASONRY WALLS WITH MORTAR STRONGER THAN BLOCK SUBJECTED TO COMPRESSIVE LOADING

ATMAN MOLOUD MOHAMED ALI PZABEZ

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by

ATMAN MOLOUD MOHAMED ALI PZABEZ

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ABSTRAK

Penyelidikan ini mengkaji keberkesanan beban mampat menegak dalam dinding kerja batu tidak bertetulang. Empat spesimen dinding bersaiz (1228 mm x 685mm x 100 mm) dengan sifat sambungan mortal atau lepa yang berlainan digunakan. Penyelidikan ini dijalankan berdasarkan standard Bs dan ASTM. Ciri kekuatan mampat pada bongkah konkrit serta dengan bahan lain diperoleh bagi kekuatan mampat. Keputusan penyelidikan menunjukkan bahawa kekuatan mampat sambungan lepa / mortal adalah tinggi bagi bongkah konkrit. Kegagalan yang berlaku pada bongkah konkrit semasa proses pemampatan adalah retakan menegak sepanjang pusat bongkah. Di samping itu, keputusan yang diperoleh dibandingkan juga dengan nilai kaedah teori, iaitu yang dikira berdasarkan rumusan analisis anjal. Keadah yang digunakan adalah berkaitan dengan (HANDRY-1981) dan (HILSDORF-1969).

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ABSTRACT

This research experiment presents an investigation of the behavior of vertical compressive loading in un-reinforced masonry walls. A total of four specimen walls sized 1228mm x 685mm x 100mm (height x length x width) were investigated, when the compressive strength properties of the mortar joints is higher than that of the concrete block. The experiment was evaluated by both the British Standard (BS) and the American Standard (ASTM). The characteristic compressive strength properties of the concrete block, together with the properties of other materials were obtained to determine the total compressive strength of the masonry wall built from them. The experimental results obtained for the materials of the wall showed that the compressive strength of mortar joints was higher than the compressive strength of the concrete blocks (as was in the experimental design). With progressive vertical loading up to the maximum compressive load which the wall can bear, the concrete block which are weaker in tensile strength showed failure as splitting cracks. Consequently, loading the wall beyond the maximum load capacity, the mortar began to spread outwards leading to more severe cracks, which will make the wall to collapse when the maximum load is exceeded. The failure in the wall specimens occurred principally in the concrete block during compression as a consequence of the general failure which occurred in the specimens, as shown by vertical cracking along the center of concrete blocks. The

result obtained from the present experiment was compared with the values of the theoretical method calculated with the formula for elastic analysis. The results obtained are in conformity to that stated in the literature, especially the method of Hendry and Hilsdorf.

CHAPTER 1

INTRODUCTION

1.1 Background

Since ancient times, masonry has been used to build all sorts of structures, to provide excellent resistance in the presence of different natural phenomena. In recent times around the world however, a large variety of masonry units have been adopted for many structural and architectural forms in extensive varieties of construction such as buildings, bridges, dams, walls and others (Tomazevic 2000). Masonry units, solid or hollow are made with different materials: sand-cement, lime-cement, concrete or clay. The mechanical properties governing their behavior are the compressive strengths and the initial rate of absorption (IRA). Masonry walls are used in almost all types of building construction in many parts of the world because of its low cost materials, good sound and heat insulation properties, easy availability, and locally available material and skilled labour (Kaushik et al., 2007)

Masonry is an excellent structural system when compressive stress controls the ultimate response. On the other hand, it is also well established that the low tensile strength of masonry could lead to inadequate response when lateral forces reach high values. Reinforcement appears to be a solution adopted to increase the tensile strength and thus, improve the mechanical behavior of masonry under lateral loading (Haach et al., 2011). The nature of masonry is such that its construction could be achieved without very heavy and expensive plants. Although it depends to a large extent on skilled labour for a high standard of construction, productivity could be maintained by the use of larger units, improved materials handling and off-site preparation of mortar (Hendry 2001).

However, masonry shear walls have been reported to exhibit complex structural behaviors since masonry is a composite material with anisotropic behavior and shear walls are subjected to a bi-axial stress state. Several experimental studies on masonry shear walls have been carried out in order to evaluate and better understand their behavior (Kaushik et al., 2007; Hendry 2001).

Existing un-reinforced masonry structures are vulnerable to seismic, wind, and other dynamic out-of-plane loads and as such, the emphasis on the demand for strengthening of such structures have recently gained much attention. Specifically, the tendency of out-of-plane dynamically loaded masonry walls to collapse in a brittle manner and to cause severe damage or even injury to the occupants has been emphasized.

In some cases, failures of masonry walls have been identified as the main cause of loss of lives under seismic events (Ehsani et al., 1999). In order to avoid this, an improvement in the structural performance of masonry wall is required. This could be achieved by a broad range of strengthening and upgrade techniques, among which is the use of reinforcements (Triantafillou 1998) and the examination of the right combination of composite materials used in the construction of masonry walls; especially the strength of the mortar and concrete blocks as it affects the dynamics of the wall stability and construction (Hilborn 1994).

In many practical cases, masonry walls (Plates 1.1; 1.2) are built within a surrounding frame that restrains their longitudinal deformations (McDowell et al., 1956; Hamed and Rabinovitch 2007). To that effect, cracking at the joints and the out-of-plane displacement may yield eccentric longitudinal reactions of the supporting frame. Under dynamic loads, the magnitude of the arching force and the location of its line of action vary in time. Dynamic cracking may also give rise to the rocking phenomenon, where the point of contact between adjacent masonry units shifts from one side of the joint to another. This effect gives rise to longitudinal inertial forces and couples the in-plane and the out-of-plane response (McDonald 1991). All the unique phenomena mentioned above critically affect the design and the performance of the reinforcement strengthening system and highlight the difficulties and the challenges associated with the modeling and the dynamic analysis of the reinforcement strengthened masonry walls.

The bearing capacity of a masonry element subject to compression is generally determined by elastic calculations which take into account the different mechanical properties of the constituents (Venanzi and Materazzi 1991). From damages observed after earthquakes and test results of confined masonry walls, several mechanisms of failure have been identified under in-plane lateral loads. Among many other variables, the resistance of masonry (combination of masonry units and joints), the resistance of the concrete columns, the quality of workmanship and steel reinforcement ratio define the failure pattern (Paulay and Priestley 1992; Tomazevic 2000). Four main failure modes have been identified as follows;

1. Flexion failure; This failure mode appears on slender walls, where the tension is

Plate 1.1: A sample of concrete block masonry wall

Plate 1.2: Concrete block masonry wall under construction

high and causes the yield of the longitudinal steel and the compression failure on the wall corners

2. Sliding shear failure; Sliding of a portion of the wall along the horizontal joint occurs when the shear stress is greater than the shear strength. Sliding produces the short column effect on the concrete elements which generates plastic hinges

3. Diagonal tension failure; This failure mode occurs because the diagonal stress along the wall exceeds the masonry tensile strength, causing diagonal cracking (Plate 1.3)

4. Splitting failure by diagonal compression; This happens when there is separation between masonry and concrete columns on discharged corners (Plate 1.4). A compression strut is then formed. This generates compression at the loaded corners and causes crushing of the masonry units (Plate 1.5) (Tomazevic 2000).

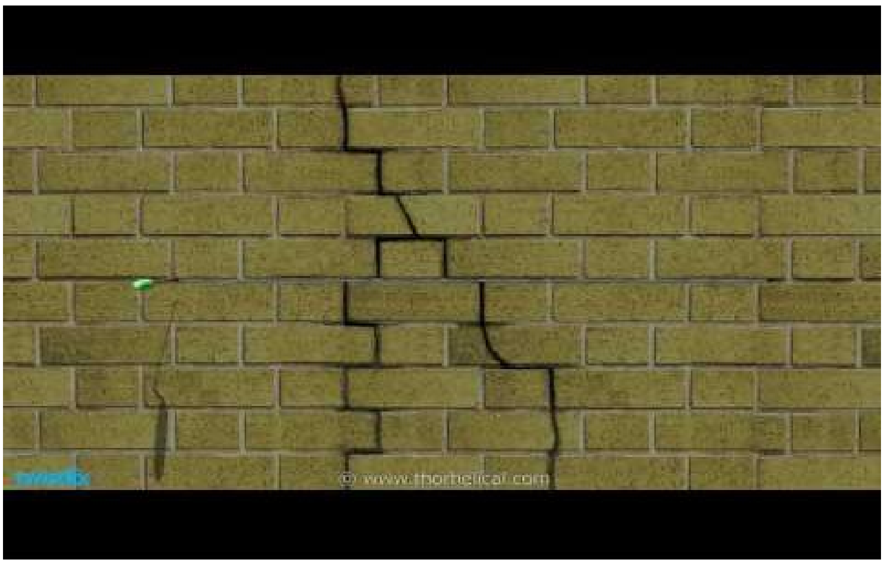

Plate 1.3: Failure along mortar joints in a concrete block masonry wall

Plate 1.4: Cracks due to failure in mortar of concrete block masonry wall

The dynamic behavior of masonry walls strengthened with composite materials could be characterized by a variety of nonlinear and unique physical phenomena, many of which result from the cracking of the mortar joints. In many cases, the tensile strength of the mortar or that of the masonry-mortar interface is relatively low or even null. In the event of dynamic or cyclic loadings, the response of the wall involves a cyclic opening and closure of the cracks (crack breathing) and correspondingly, a non-periodic or even chaotic nonlinear dynamic response (Dimarogonas 1996; Carpinteri and Pugno 2005). The cracking at mortar joints could trigger the formation of debonded regions in their vicinity, which may reduce the efficiency of the strengthening system, resulting in a local buckling/wrinkling of the compressed reinforcements and amplify the shear and the out-of-plane normal (peeling) stresses in the adhesive

Plate 1.5: A example of structural failures in Concrete block masonry wall

layers near the joints (Hamed and Rabinovitch 2007).

Consequently however, in preliminary tests performed to study some characteristics of the masonry blocks and the mortar, tension tests showed that the mortar bed joint failures occur at the contact interface between the mortar and the block (Yagust and Yankelevsky 2009). The test data provided the following relationships;

1. a relationship between the maximum shear stress and the tension bonding strength of mortar bed joint, subjected to the normal compression stress
2. relationship between the shear stress and the shear displacement
3. relationship between the maximum dilatation displacement
4. relationship between the dilatation displacements

These relationships are necessary for any numerical simulation of the masonry in filled wall.

The tensile strength of masonry units both direct and flexural influences the resistance of masonry under various stress conditions, but is not normally specified except in relation to concrete blocks used in partition walls, where typically a breaking strength of 0.05 N/mm^2 is required (Hendry 2001).

Although mortar accounts for as little as 7% of the total volume of masonry, it influences the performance far more than this proportion has indicated. Mortar requires to have certain properties prior to setting, particularly workability. Hardened mortar has to be sufficiently strong and to develop adequate adhesion to the units and also to set without excessive shrinkage, which would reduce the resistance of the masonry to rain penetration or even cause cracking of the units. It should also be capable of accommodating some degree of movement in the masonry resulting from creep or thermal effects without cracking (Hendry 2001).

Conventionally, mortar mixes are based on Portland cement, lime or plasticiser and sand, graded according to compressive strength. The stronger the mortar is, the less able it is to accommodate movement so that it is not advisable to use a stronger mix than is necessary, to meet structural requirements. A compressive strength of 2-5 N/mm^2 is considered adequate for most low-rise structures. For special purposes a type of cement other than ordinary Portland cement could be used, e.g. a sulfate resisting variety for blockwork below damp-proof course level where ground water is contaminated by sulfates (Watford 1991).

A workable mortar is that with a smooth, plastic consistency which is easily spread with a trowel and readily which adheres to a vertical surface. Well graded, smooth aggregates enhance workability as also do lime, air entrainment agents (plasticisers) and proper amounts of mixing water. Lime imparts plasticity and ability to retain water in the mix whilst plasticisers improve frost resistance. Thin bed mortars with a 1:2 cement/sand mix together with water retaining and workability admixtures are increasingly used with accurately dimensioned units (Watford 1998).

On the other hand, absorption and pore structure of blocks and blocks varies widely and is important in a number of ways. Thus certain clay blocks which absorb between 4.5 and 7.0% of their weight can be used as a dampproof course material. Highly absorptive clay blocks, on the other hand, may remove water from the mortar preventing complete hydration of the cement. Absorption is of less relevance in the case of calcium silicate and concrete units but pore structure affects resistance to frost damage (Hendry 2001).

In addition to units and mortar, masonry wall construction requires the use of a number of subsidiary components including damp-proof course material, cavity trays, wall ties and fixings. Each of these must be as durable as the masonry itself as well as meeting its particular function.

It is therefore important that thermal and moisture movements in masonry walls need to be taken into account in the design of walls, depending on the characteristics of the units. This becomes better appreciated considering that clay units tend to expand in service whereas concrete and calcium silicate units shrink (Watford 1979)

Masonry wall construction has a number of advantages; the first is the fact that a single element can fulfil several functions including structure, fire protection, thermal and sound insulation, weather protection and sub-division of space. Masonry materials exist, with properties capable of meeting most of these functions, requiring only to be supplemented in some cases by other materials for thermal insulation, damp-proof courses and other considerations (Hendry 2001). The second major advantage of masonry wall construction relates to the durability of the materials which, when appropriately selected, could be expected to remain serviceable for many decades, if not centuries, with relatively little maintenance. From the architectural point of view, masonry offers advantages in terms of great flexibility of plan form, spatial composition and appearance of external walls for which materials are readily available in a wide variety of colors and textures. Complex wall arrangements, including curved walls could be readily built without the need for expensive and wasteful formwork.

The advantages of masonry wall construction are therefore considerable but, as with all materials, appropriateness to the application has to be considered, assuming acceptability from the architectural viewpoint. If for instance, the masonry is not to be load bearing it will be necessary to consider the implications of the weight of the masonry as it affects the supporting structure. If the walls are to be load bearing, it will be important to ensure that their layout is consistent with overall stability and with avoidance of failure in the event of accidental damage (Hendry 2001).

These advantages are only beneficial when masonry materials are used in the proportions described according to the various standards. Where the use of masonry materials (especially mortar and blocks) are not according to standard specifications (as is the case when the mortar has more compressive strength than blocks), it is very likely that these advantages of masonry may not be attained.

1.2 Problem statement

Structural designs of masonry walls are carried out in accordance with national codes of practice. These codes are based on the limits of national principles, with safety being assured by the use of characteristic values of loads or actions and material strengths, together with partial safety factors and applied as a multiplier to loads and as a divisor to strengths. Characteristic values are intended to represent a 95% confidence limit of not being exceeded in the case of loads and of being attained in the case of strengths (Hendry 2001).

For every nation, the standard codes of practice as it applies to the specifications for mortar and block types depends on the strength of mortar or block needed for an application. Under normal circumstances, the block is usually stronger than the mortar. However, there is no assurance that these codes of practices as it applies to mortars will be followed strictly by all masons. It is therefore important to investigate the behavior of a masonry wall built when the mortar is stronger than the block.

Primary variables in the calculation of the compressive strength of a masonry wall, in addition to the unit strength includes the eccentricity of loading and the slenderness ratio of the wall. Both of these are difficult to assess on a theoretical basis depending as they do on interaction between walls and floors. Creep effects may be significant in some walls. In some cases, this may increase the eccentricity at mid-height of a wall but where there are interacting floor slabs, the eccentricity may reduce with time.

Compressive strength of masonry walls is thus a complex problem and a considerable amount of research work is still being carried out on it over many years (Hendry 1998). Since it is very presumable that masons (or owners of masonry buildings for that matter) may want to construct masonry walls with mortars of higher compressive strength than blocks, this phenomenon needs to be investigated under laboratory conditions and therefore the need of the present experiment.

The principal focus of the present study as therefore as follows;

1. The behavior of a concrete block-masonry wall when subjected to vertical, compressive loading and the effects on the wall

2. The maximum compressive load bearing capacity which a concrete block-masonry wall could tolerate without cracking, when the mortar has higher compressive strength than the concrete blocks and the safety of masonry construction

3. The characteristics of the ideal mortar to be used in the construction of concrete block-masonry walls

4. The relationship between the strength of the mortar and that for concrete blocks in the resistance of concrete walls to compressive loading

5. The effects of compressive loading on masonry walls when the mortar strength exceeds the required level and the types of failure which happen as a result of this loading of the walls

The proper understanding of behavior of a concrete block-masonry wall when subjected to compressive loading is necessary for safety of the walls being assured by the