POST-TENSIONED CONCRETE BRICK MASONRY WITHOUT MORTAR JOINT

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ABSTRACT :

Masonry is commonly used to build housing with technical as well as economical advantages. Nevertheless, there are some difficulties in guaranteeing a good performance in serviceability limit state due to the control of the quality of the mortar joints and the grouting. In this paper, a structural system of post-tensioned concrete brick masonry is presented. The system eliminates the bed and head mortar joints, it uses unbounded post-tensioned tendons and it does not consider conventional reinforcement. In the first phase of this research, the system has been used to build and test a full scale model of beams and two-way slabs. In a next phase, the structural system will be used to build both to walls as slabs. The obtained results permit to identify the following characteristics: 1) The post-tensioned panels, built with blocks, to be used as walls and slab, have an isotropic behavior; 2) it lets the immediate use after finishing the tensioning of the tendons; 3) it reduces the construction time and 4) It provides lean construction.

KEYWORDS: Concrete brick masonry; post-tensioned; walls, two-way slab; unbounded tendons; tests.

1. INTRODUCTION

Masonry has a relatively large compressive strength but only a low tensile strength. Therefore, so far, masonry has been used as a construction material for vertical members subjected essentially to gravity loads. Apart from this main action, however, in-plane shear and out-of-plane lateral loads as well as imposed deformations caused by deflections and volume changes of floor slabs may be applied to masonry walls. Small lateral loads and deformations may be resisted due to the weight of the walls. However, for larger lateral loads, walls with low axial loads exhibit a poor cracking behavior and a low strength. To overcome these disadvantages, masonry may be post-tensioned. Post-tensioning offers the possibility to actively introduce any desired level of axial load in a wall to enhance strength, performance, and durability of masonry structures. The prestressing steel helps to avoid brittle tensile failure modes of masonry walls and offers major advantages for the connection of vertical and horizontal members in precast construction. Existing structures may be strengthened by prestressing to comply with recent code requirements for lateral loading; particularly, in seismic areas. Therefore, possttensioning of masonry is most beneficial in situations where axial loads are low and transverse loads, such as wind load, earth pressure, and inertia forces from seismic excitation, are significant.

The mayority of post-tensioned masonry systems use mortar joints and bonded tendons. However, it is recognized that it is very difficult to guarantee a good quality of the mortar and that the bed joints are the plane of weakness in masonry. Additionally, the use of unbounded tendons may show a low energy dissipation capacity as unreinforced masonry under reversal load. In the first phase of this work, the mortar joint and grouting were eliminated in order to confirm the good behavior of the system inside the elastic interval. In the nonlinear range, the behavior of the systems is poor because it is not ductile. Therefore, a second phase has been defined. The necessaries requirements for the system have an elasto-plastic behavior, especially when it is necessary to resist moderate and high level of seismic demand, which will be developed. One of these requirements corresponds to the design of special bricks in order to guarantee a fixed distance between the tendon and the upper and bottom extreme. These bricks can be used to dissipate energy and will have a similar effect to deviators elements considered in the external post tensioned concrete elements.

2. LITERATURE REVIEW

The first instance of post-tensioned masonry in the literature is from F.J.Samuely in the United Kingdom who noted in 1953 that it was used to construct brickwork piers in a school (Shrive, 1988). Since then, post-tensioned masonry has been researched and used for out-plane designs such as basement and retaining walls (Rosenboom, 2002). In the 1980´s, various experimental research were carried out in order to evaluate the behavior under gravitational loads of post-tensioned masonry elements such as beams, walls and panels. Different types of reinforcement and structural configurations were tested (Pedreschi and Sinha, 1982; AI-Manaseer and Neis, 1987; Uduehi and Sinha, 1988; Page and Huizer; 1988). Bean et. al. (2007) presents an overview of the state-of-the-art on the behavior of post-tensioned masonry walls under transverse loading. The variables such as the tension strength, masonry type, section geometry, amount of reinforcement, tendon restraint condition, prestress magnitude have been analyzed on walls behavior. However, most of the systems that have been proposed use mortar joints and grouting. In this work, both elements are removed and a post-tensioned masonry system using high steel unbounded tendons is proposed. This system can be used to build one and two-way slabs and structural walls.

3. STRUCTURAL TIPOLOGY

The proposed system is composed by ordinary hand made bricks of low compressive strength, high tensile steel tendons and an anchoring system. In this phase of the research, a normal concrete brick has been used; however, the proposed system can be used for other blocks, such as clay bricks. In the case of beams, a precast reinforced concrete end blocks have been designed and constructed in order to anchor the tendons. These end blocks eliminate any unwanted local failure in masonry in the vicinity of the anchorages and reduce cost and time. Figure 1 shows a detail of the precast concrete reinforced end block and a beam of 2.5 m. For the two-way slab, a reinforced concrete edge beam was cast monolithically and was used to anchor the tendons. Nevertheless, in next phase of this research, a precast reinforced concrete anchorage system will be implemented similar as used in beams.

a) Normal concrete brick   b) Anchorage block   c) Post tensioned beam

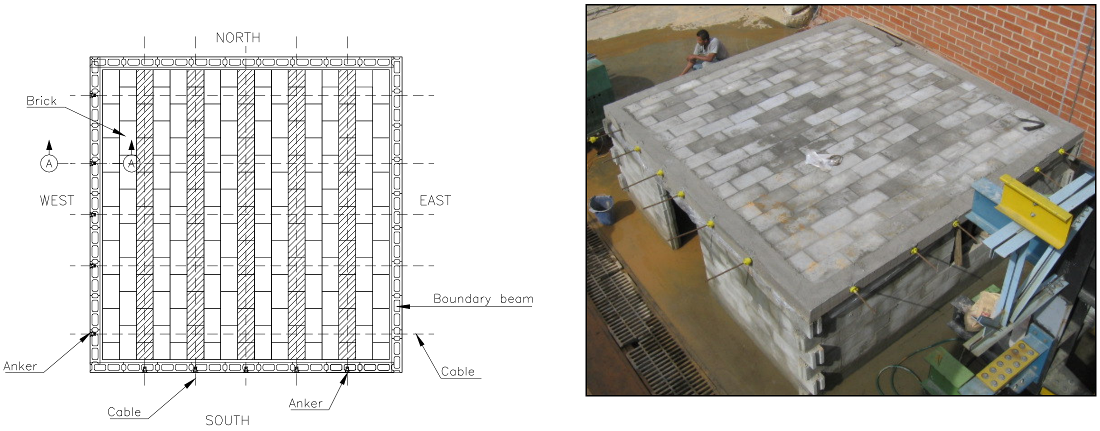
Figure 1. Anchorage system and post-tensioned masonry beam.

The system uses the basic principle of interlock between the blocks to build panels. This provision is highly advantageous because it offers very good capacity of the panels subjected to in-plane and out-of-plane loads, which represents an additional advantage over the traditional masonry. Hence, the system can be used to build walls, beams and one or two-way slab with a substantial decrease the construction time and a reduction of losses due to the absence of mortars and paste grouting.

The shape in the masonry cavities direction has advantages in terms of its resistance, because its behavior is similar to an *I* profile section. However, in the other direction, in which it was necessary to make a hollow to place the tendons, the section presents a low shear resistant due to the fact that a surface in contact has no web. Nevertheless, the shear capacity of the system is guaranteed by compression in both directions.

4. CONSTRUCTION OF THE SPECIMEN

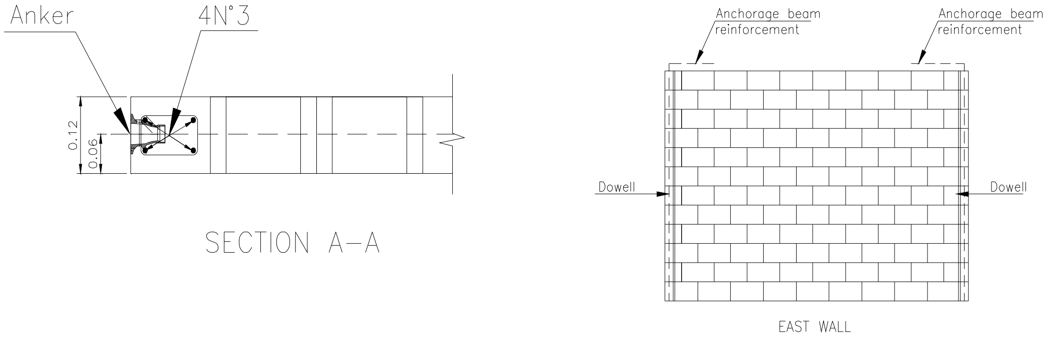
A full-scale two-way slab specimen was constructed by an experience mason using 400 mm x 200 mm x 120 mm hollow concrete blocks and was post-tensioned by six strands of 12.7-mm-diameter placed at 0.60 m in each direction. The specimen corresponds to a square fixed-edge two-way slab with 3.315 m of size (see Figure 2a). The slab construction proceeded as follows: A concrete masonry wall of 1.50 m in height was built to support the slab. In the corners, four confinement vertical elements were built to prevent the lifting of the slab and reduce the torsion effect. False work was installed and a sand bag with 10 mm of thickness was distributed on the entire surface. This element allows obtaining of a perfect contact between the surfaces of the blocks in both orthogonal directions, eliminating any kind of roughness. The concrete blocks were placed on the sand bag in a same manner as the traditionally walls are done. This improves the contact surface as possible weak areas. After that, the tendons were distributed in both directions. A reinforced concrete beam of 0.15m x 0.20m x 0.20m was built on the perimeter wall was built with a compressive strength of 35 MPa. This beam was used to: 1) allow the installation of the anchors for the tendons by installing strips as shown in Figure 3a, 2) connect the walls with the slab in order to simulate a fixed condition in the four ends of the slab (see Figure 3b), which is considered representative of a two-way slab of a building. Once the strength of the beam was reached, the tendons were prestressed in both directions with 150 kN each one. Figure 2b shows a photograph of the finished specimen.



a) Plan View

b) Photograph of two-way slab

Figure 2. Details of the specimen.



a) Detail of anchorage system

b) Wall and beam connection.

Figure 3. Anchorage and connection systems.

5. NUMERICAL MODEL

The behavior of the two-way slab can be expressed by mean of a similar differential equation proposed by Timoshenko and Woinowsky-Krieger (1972):

$$Dx \cdot \frac{\partial^4 \delta}{\partial x^4} + 2H \cdot \frac{\partial^4 \delta}{\partial x^2 \partial y^2} + Dy \cdot \frac{\partial 4\delta}{\partial y4} = q \tag{1}$$

$$Dx = I_y E_m \quad ; \quad Dy = I_x E_m \quad ; \quad H = E_m \sqrt{Dx.Dy}\left(\frac{1-\nu+\nu^3}{1-\nu^2}\right) \tag{2}$$

Where *Ix* and *Iy* are the second moment of area around x and y axis, respectively, *E* is the modulus of elasticity and ν is the Poisson´s ratio.

In both directions, the resistant moment capacity can be obtained by means of the following equations:

$$Mx\cdot = \left(\beta_1 + \beta_2.\nu.\sqrt{\frac{Dx}{Dy}}\right).\frac{q.a^2}{\varepsilon} \tag{3}$$

$$My = \left(\beta_2 + \beta_1.\nu.\sqrt{\frac{Dx}{Dy}}\right).q.b^2 \tag{4}$$

$$\varepsilon = \frac{a}{b}\sqrt[4]{\frac{Dy}{Dx}}^{2} \tag{5}$$

Where M_x and M_y are the bending moment about X and Y axis, respectively, β_1 and β_2 are given in terms of ε parameter, *a* and *b* are the dimensions of the slab.

Table 1. Specimen material properties.

Parameter	Unit	Value
Compressive strength of masonry, f_b'	MPa	8.0
Modulus of elasticity of masonry, E_m	MPa	8000
Effective force in prestressing tendon after all prestress losses have occurred, F_{se}	kN	116

Considering the specimen materials properties given in table 1, the following values are calculated: A_x = 0.060 m^2, A_y = 0.085 m^2, Dx = 1.024 x 10^{-4} E_m m^4/m and Dy = 1.000 x 10^{-4} E_m m^4/m. Note that *Dx* and *Dy* are given in terms of modulus of elasticity, E_m. It is assumed $\nu = 0$ and then equations (4) and (5) can be expressed as:

$$Mx = My = \beta_1 \cdot q \cdot a^2 \tag{6}$$

$$Mx = My = 0.0368 \cdot q \cdot 3.445^2 = 0.436 \cdot q \tag{7}$$

The maximum load q is obtained when the bottom fiber losses the compression stress due to bending, $\sigma_c = 0$.

$$\sigma_c = -\frac{116}{0.6 \cdot 0.069} + \frac{0.436 \cdot q \cdot 0.11}{2 \cdot 1.025x10^{-4}} = 0 \tag{8}$$

Then q = 11.97 kN/m^2. For this value, a deflection δ = 8 mm is obtained from equation (1).

6. EXPERIMENTAL PROGRAM

An experimental program was developed to investigate and validate the conceptual model of the response of post-tensioned masonry two-way slab to vertical load. The program comprised the design, fabrication, instrumentation, and testing of one two-way slab.

6.1 *Material properties*

A low strength brick, manufactured by a mechanized process was chosen for casting the test specimen. The brick size and compressive strength were found to be 400 mm x 200 mm x 120 mm and 8.0 MPa for the low strength bricks. High tensile steel tendons of 12.7-mm-diameter were selected in order to prestress the slab specimen. The modulus of elasticity, E_s, stress at 1% of elongation and the ultimate strength have been determined as 200 GPa, 1500 MPa and 1900 MPa, respectively.

6.2 *Test setup and loading system*

The specimen was subjected to monotonically increasing vertical load. This load was applied to 0.5 lts/s flow rate and uniformly distributed on the surface of the wall using a plastic swimming pool of 16.60 m^3 (3.45 m x 3.45 m x 1.40 m). A steel frame was built in order to support the swimming pool and it was placed on the beam edge (see figure 4). Four LVDT´s were placed at different locations under the slab to measure vertical deflections. The sample rate was divided in three phases: 0.03 samples per second up to 30 kN, 0.1 samples per second between 30 kN and 60 kN and finally, 1 sample per second to failure.

Figure 4. Loading system and specimen ready for testing.

7. RESULTS AND DISCUSSION

Figure 5 shows load versus deflection in the four points indicated (C1, C2, C3 and C4). The comparison presented in this figure, indicated that there is a good agreement between C1 and C3 channel. Therefore, it is seen that the behavior correspond to an isotropic slab despite the geometrical differences between the blocks in the two orthogonal directions. The difference between analytical (8 mm) and experimental (5.96 mm) deflection of midspan slab is 34%. In the case of the maximum load capacity, the difference is 4%. The capacity of this system is bigger than traditional masonry systems that use mortar joints in-plane as well as out-of-plane loads. In the linear elastic range before the slab cracks, the system can be characterized only using the properties of the bricks. It is not necessary to take into account the reduction for the aspect ratio (length/thickness), but having in mind that the prestressing force must be taken into account. The unbounded post-tensioned tendons will be considered as the reinforcement of the slab and its efficiency will depend of the way like these are placed and the position of the deviator tendons.

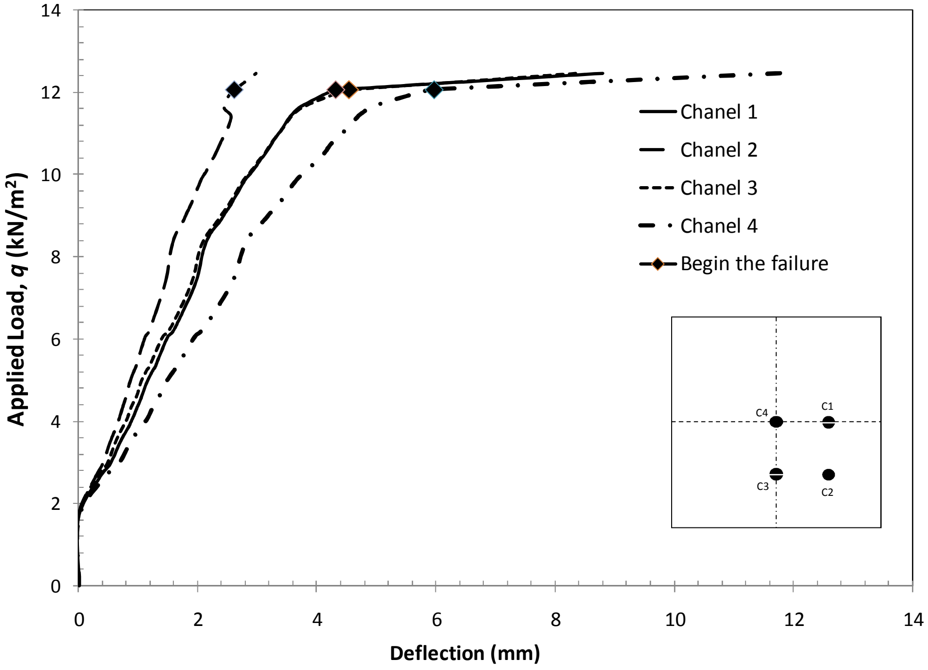


Figure 5. Experimental load-deflection curve for the two-way slab.

8. FUTURE RESEARCH

In subsequent stages of this research, the possibilities of the system provide a certain level of ductility to attend seismic loads associated with moderate and high levels of seismic hazard will be studied. In order to reduce time and minimize the losses, a new anchorage modular system will be proposed.

The final objective of this project is to formulate a conceptual frame for this system, in order to define the limits corresponding to the elastic behavior and the necessary requirements to obtain a ductile response to attend seismic loads in moderate and high seismic hazard zones.

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