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Behavior of ungrouted and unbonded post-tensioned masonry beams and slabs

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ABSTRACT

The paper shows and discusses the results of an experimental program aimed at assessing the flexural behavior of ungrouted and unbonded post-tensioned masonry (UUPTM) elements such a beams or two-way slabs. In this structural system, the bed and head mortar joints are excluded and the concrete blocks are post-tensioned with unbonded tendons. A special tendon restraint block has been added to provide nonlinear displacement capacity of the specimens. The global performance is assessed in terms of cracking patterns, failure modes and load-deflection curves. Results from the experimental program indicate that the tendon restraints blocks improve the flexural behavior in terms of strength and nonlinear displacement capacity. Comparison between measured and predicted strength demonstrated that the equations of out-of-plane or in-plane flexural capacity of walls or solid masonry beams provided by building codes for masonry structures, may be used to estimate the maximum flexural capacity of the UUPTM beams having tendon restraint block.

1. Introduction

In the last four decades, the behavior of post-tensioned masonry elements such as beams and walls under static and dynamic loads has been assessed experimentally and numerically. Wight [1] performed a literature review on the behavior of post-tensioned masonry walls and reported the main applications and the progress on patents using this structural system. Measured performance in beams is much more limited than that in walls. In the 80's, some research programs were carried out on the behavior of prestressed masonry beams [2–7]. Experimental and numerical results allowed identifying the effect on deflection, cracking and maximum load of parameters such as brick and mortar compressive strength, cross-sectional dimensions and coursing pattern, prestressing cable's profile, bond between the prestressing steel and the surrounding masonry, diameter and number of strands, prestress force and the shear-span ratio [3,6,7]. Moreover, the mid-span deflection of beams was remarkably influenced by the tendon stress, reinforcement ratio and compressive strength of bricks [4]. The cracking and maximum load capacities of the beams were controlled by the coursing pattern and the eccentricity of the prestress force [7]. According to the experimental investigation conducted by Baqi [6], maximum load increases with the change in cable's profile from straight to parabolic. Additionally, the use of bond and parabolic shape of the cable increase the ductility of prestressed masonry beams. Neis et al. [8] identified that prestressed masonry beams are economically competitive when compared with reinforced concrete beams because the lower requirements of construction time and materials.

Currently, post-tensioned masonry systems include structural mortar joints and grouting. However, the use of mortar and grouting increases construction costs due to the amount of materials and the time required. This paper is aimed at developing and validating experimentally an improved Unbonded and Ungrouting Post-tensioned Masonry system (UUPTM). This structural system has been planned to fulfill three basic conditions; firstly, to assure a good performance under gravity and dynamic loads in terms of security and integrity; secondly, to reduce the construction-time by eliminating the use of mortar joints and grouting, and in third place, to reduce the debris and construction waste for providing a clean construction. Roumani and Phipps [9] identified drawbacks associated to strength and nonlinear capacity of UUPTM elements. To overcome these limitations, an improved UUPTM system has been developed herein incorporating tendon restraint blocks allowing to obtain similar strength and nonlinear displacement capacity values as those corresponding to grouted and bonded

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post-tensioned masonry systems. The improved UUPTM system developed in this work can be used to build beams, walls and slabs elements. Fig. 1 shows two full-scale housing prototypes built in Medellin city (Colombia). In these prototypes, all structural components such as foundation, walls and slab, were built using UUPTM system.

In this paper, the global behavior of flexural-controlled UUPTM structural elements is evaluated. Two types of structural elements, beams and two-way slabs, were experimentally analyzed. The experimental program consisted of testing four full-scale specimens under monotonic loads up to damage states close to failure. The measured structural responses of the UUPTM specimens are evaluated in terms of cracking patterns, failure modes and load-deflection curves. The capability of tendon restraints blocks to increase the nonlinear displacement and the energy dissipation capacity of the proposed ungrouted and unbonded post-tensioned masonry system is also discussed.

a) Single-family house

b) Two-story building

Fig. 1. Full-scale prototypes of Ungrouted and Unbonded Post-tensioned Masonry in Colombia.

2. Description of the UUPTM system

The UUPTM system is based on interlocking between the blocks for building panels. The system can be used to increase both the strength and nonlinear displacement capacity of beams and one-way or two-way slabs, and to reduce construction time and environmental impact due to the elimination of grouting [10,11]. Mortar joint and grouting are unnecessary in the proposed system. A mixture of cement, sand and water is used as contact material between blocks. A 5-mm thick mixture is used only to smooth the contact surface and to avoid cracking of blocks during the tensioning of the strands due to stress concentration. As shown in Fig. 2, the proposed UUPTM system includes the following structural components: a) hollow concrete masonry units (conventional blocks), b) hollow concrete masonry units with an additional cavity in the transversal direction (special block), c) high strength steel tendons, d) precast reinforced concrete end-blocks used as an anchoring system, and e) precast tendon restraints blocks used to keep constant the distance between the centroid of the strands and the extreme fiber in compression of the concrete blocks.

2.1. Hollow concrete blocks

Table 1 shows the average brick dimensions and measured compressive strength of concrete bricks used for construction of specimens. The test was carried out according to ASTM Standards C140-2015 [12]. The average-strength concrete blocks (f'_b) was 11.3 MPa. As shown in Fig. 2b, layout of conventional units was modified for two-way slab specimens. The modification consisted in making an additional cavity in the transversal direction for using tendons in both orthogonal directions. This new unit is called "*special block*".

Garcia et al. [13] evaluated the compression behavior of hollow concrete blocks that were identical as those used in this study. From a database of 90 samples, Eq. (1) was proposed to calculate the compressive strain ε_c corresponding to maximum compressive strength f'_b of these hollow concrete blocks. Substituting the average-compressive strength $f'_b = 11.3$ MPa in Eq. (1), a compressive strain of 0.0042 was obtained.

$$\varepsilon_c = 0.0078(f'_b)^{-1/4} f'_b \; in \; \mathrm{MPa} \qquad (1)$$

2.2. High strength tendons

All the specimens were post-tensioned using high-tensile-strength steel tendons. Table 2 shows the main mechanical properties of one of the two different types of tendons used in the study. At a previous experimental program, 6.3-mm diameter prestressing strands were used to build beam-type specimens. This diameter is not commonly used for construction in Latin American countries. Therefore, the commonly used 12.5-mm diameter prestressing strands were used and validated in this study.

2.3. Tendon restraint block

A key element of the proposed system is the tendon restraint block. This block was used to keep constant the distance between the centroid of the strand and the extreme fiber in compression in the concrete blocks when the structural element deflects under gravity loads. The dimensions of the tendon restraint blocks depend on the type of specimen. For beams, tendon restraint blocks have the same dimension to conventional blocks (390 × 190 × 190 mm) as show in Fig 2d. For slabs, however, restraint blocks having a half of the length of conventional blocks (190 × 190 × 140 mm) are required (Fig. 2e). The specified com-