INCREASE OF THE STRUCTURAL RESISTANCE IN MASONRY PARAPETS WITH THE POST-TENSIONING TECHNIQUE

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Abstract

The study shows the comparison of the structural behavior of conventional parapets built with clay and concrete masonry units, to others incorporating the post-tensioning technique used for reinforced concrete elements. The purpose is to provide stability during seismic events that occur with a certain frequency in Peru. Masonry parapets are non-structural elements located in buildings, which pose a threat to people. The testing program consisted of 8 specimens between conventional and post-tensioned systems with a total length of 1.20 m and 2.40 m. respectively, a height of 1.20 m. and thickness of 0.12 m. that were provided by the company DINO - Pacasmayo (Piura, Peru) and tested in the structures laboratory of UDEP (University of Piura) with monotonic static loads perpendicular to the plane of the parapet. One of the main properties of masonry is to resist high compressive stresses and low tensile stresses. To overcome this disadvantage, it was proposed to incorporate an internal reinforcement to the wall with a technique known as post-tensioning in reinforced concrete. Based on the principle of incorporating constant compression through continuous tension in its cables or tendons aiming to find similar deformations in both elements. The tests allowed us to compare the increase in resistance of its material capacity of the walls, deflection, moments, shear forces, and forces at the base for the parapets with conventional and post-stressed clay and concrete masonry units. It was shown that the structural resistance of the conventional parapet is lower compared with the post-tensioned since there was an increase of 4 times its resistance in its load capacity, 5 times the shear forces, and 2 times in bending, which indicates that the post-tensioning technique in the parapets significantly improved the adhesion and capacity between the mortar and the brick.

Keywords: Post-tensioned, walls, reinforcement, anchors, stability.

1. Introduction

Parapets are masonry walls that, by their location in buildings, make them a hazard risking people who walk or escape from buildings during earthquakes [9]. Based on this problem, it was proposed to incorporate a reinforcement element using the technique known as post-tensioning in concrete reinforcement, which acts under the principle of incorporating constant compression through continuous tension in its cables [15].

The post-tensioning achieves results that offer advantages in the reduction of lateral displacements produced by the applied monotonic load allowing the parapet to acquire strength and stability [12] and in consequence also acquire resistance to tensile forces at its base and shear resistance between its parapet units [10]. As a hypothesis of the study, it was proposed that post-tensioning increase the resistance capacity in the walls and reduces the lateral displacements compared with conventional parapets.

2. Methodology

2.1. Masonry parapets

The parapets are non-bearing or secondary masonry walls for not providing seismic resistance [6] to the structure, they usually have an average height of 1.20 m. and are located below windows and the perimeter of the entire roof as shown in Fig. 1. Its importance would go unnoticed, nevertheless based on its location in buildings and considering that its instability and subsequent collapse can make them fall and based on its weight can cause heavy damage to people who live or transit in buildings, this problem occurred in the earthquake of Pisco in 2007, which caused the collapse of parapets at households [5].
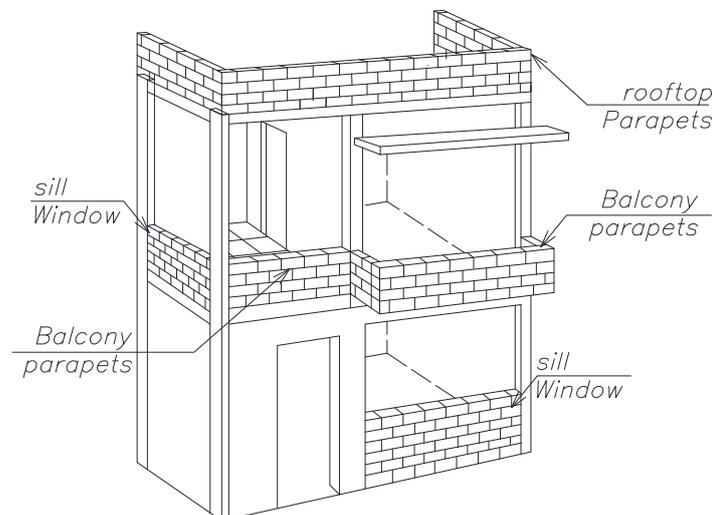

Fig. 1 - Location of masonry parapets in buildings

2.2. Parapet post-tensioning technique

Post-tensioning is a technique that offers a solution in the use of flexural elements such as parapets, as they help to compensate for the low tensile strength of this type of wall and reduce their lateral displacements [5]. With this technique, the wall would acquire resistance to perpendicular forces in its plane before seismic events, something that by natural conditions is not possible [13]. Post-tensioning is a pressure-relief technique in which a set of cables are inserted into concrete structural elements after construction and subsequently stretched by equipment (hydraulic jacks) to obtain parabolic trajectories [3]. The procedure was performed sequentially as shown in Fig. 2 (a) to obtain the effects shown in the same Fig. 2 (b) and (c) respectively.
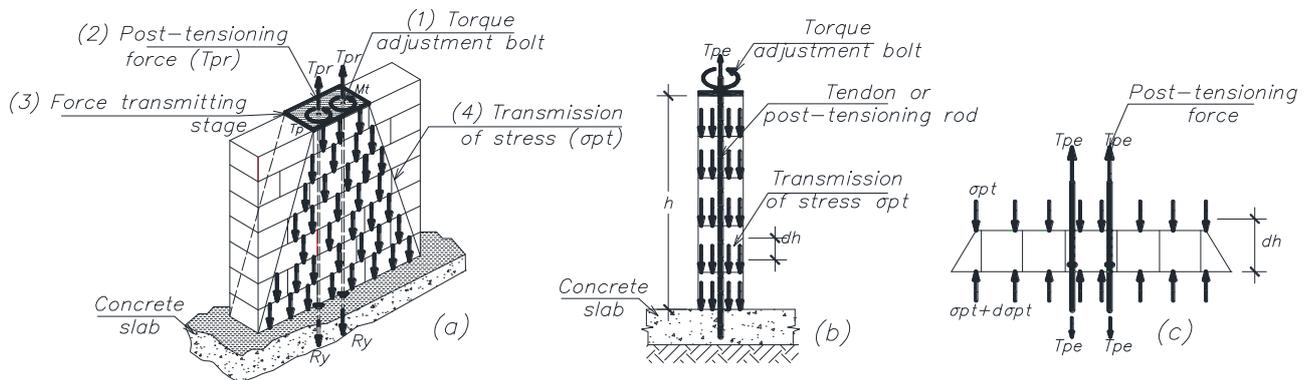
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Fig. 2 - Outline of the post-tensioning technique in masonry parapets

The research and standardization of this post-tensioned technique in masonry were originated in Switzerland and in the UK and in the last two decades, not much research has been carried out and its development has stalled, leading to multiple drafts because of the lack of a design code [7]. In New Zealand the design procedures for seismic reinforcement in walls for post-construction structural purposes were very successful, attributing the credit to the post-tensioning [2]. Tests carried out with concrete masonry walls have shown a reduction in the lateral displacements produced by seismic load [11]. This statement makes it possible to conclude in advance that they acquire resistance to traction at the base and shear resistance between the parapet units. Guidelines were exposed in the seismic engineering society of New Zealand regarding the comparison with conventional walls, which were tested with loads outside their plane, determining that the conventional ones resistless percentage of force [4].

2.3. Prototype of the post-tensioned parapet

To apply the same post-tensioning criteria and look for a similar result reinforced concrete, two reinforcements were incorporated into the alveoli of the masonry units (concrete and clay) and limits were placed at the bottom with nuts and washers and the top a steel plate with its bolt as shown in Fig. 3. The alveoli of the units through which the cables pass was filled with cementitious grout to guarantee the transmission of compression between units, protecting the reinforcement with a PVC tube to avoid adhesion stresses as shown in Fig. 3 (A-A). Its construction was performed with clay and concrete masonry units shown in Fig. 3, and its geometrical characteristics are shown in Table 1; where it is the specific weight (Υ_b), bending stress (f_b) and net area of each element (A_{nb}), it also shows the characteristics of the steel as the yield stress (f_y) and ultimate stress (f_u), the diameter of the bars (d_t) and weight of each element (W_e).
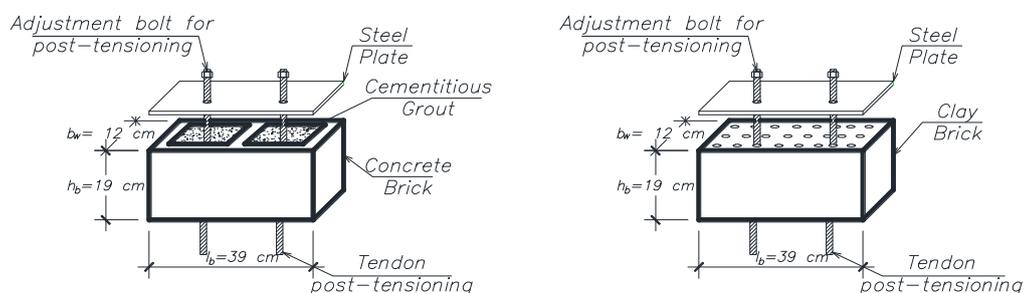

Fig. 3 – Reinforcement of parapet masonry units with post-tensioning technique

Table 1: Technical properties of the elements composing the post-tensioned parapets

Element	Clay brick	Concrete brick	Steel plate	Steel Reinforcement	Steel Bolt
Υ_b (kN/m³)	17.652	22.552	77.080	77.080	77.080
f_b (N/cm²)	1701.454	490.332	0	0	0
f_y (N/cm²)	0	0	25301.16	41972.46	41972.46
f_u (N/cm²)	0	0	40011.13	61978.03	61978.03
A_{nb} (cm²)	242.2	283.2	468	0.317	1.27
d_t (in)	0	0	0	1/4 - 1/2	1/4 - 1/2
W_e (kg)	8	10.6	1.1	0,293	1,20

Table 2 describes the properties of both conventional and post-tensioned walls for clay and concrete units: The tests were coded as follows: MCA for conventional parapets built with clay bricks and MPA post-tensioned, these acronyms are accompanied by a number, 12 for parapets of 1.20 m. and 24 for those of 2.40 m in length. The same sequence for parapets with concrete units, MCC for conventional and MPC for post-tensioned, their number code is like the previous one. The dimensions of length (l), height (h), and thickness (e) for each type of wall are described, its theoretical total post-tensioning forces (T_{py}), applied actual post-tensioning force (T_{pr}), and the percentage of the theoretical total post-tensioning force (T_{yr}) are indicated. It should be noticed that the calculation of the number of turns considered a deformation every 1/4" of turn-taking into consideration that the tendon did not flow, and part of the analysis would be the evaluation of the shear stress in the wall block and for such purposes, it was necessary to know its friction coefficient (μ). This table will be complemented with fig 4 (a).

Table 2: Description of the conventional and post-tensioned parapets

| Unit	Clay				Concrete			
Construction	Conventional		Post-tensioned		Conventional		Post-tensioned	
Code	MCA12	MCA24	MCA12	MPA24	MCC12	MCC24	MPC12	MPC24
l (m)	1,20	2,40	1,20	2.40	1.20	2.40	1.20	2.40
h (m)	1,20	1,20	1,20	1.20	1.20	1.20	1.20	1.20
e (m)	0,12	0,12	0,12	0.12	0.12	0.12	0.12	0.12
T_{py} (kN)	0	0	15.423	3097.1	0	0	24.069	48.276
T_{pr} (kN)	0	0	7.832	32.348	0	0	11.732	44.420
T_{yr} (%)	0	0	50.78	104.43	0	0	48.7	100.1
μ	1,03	1,03	1.03	1.03	1.03	1.03	1.03	1.03
N° of turns	0	0	1 1/2	1 3/8	0	0	2 3/8	2 1/8
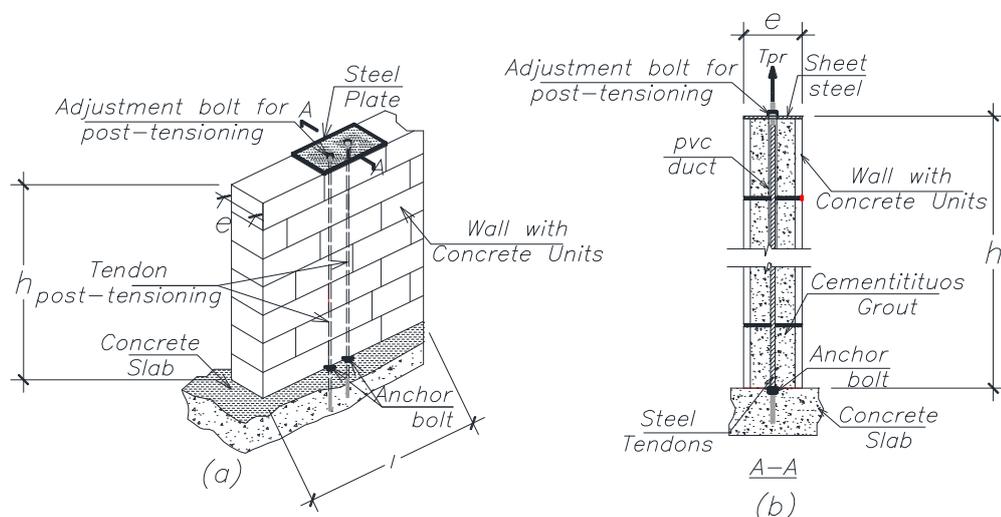
Fig. 4 – Configuration of the post-tensioned wall with concrete units

2.4. Seismic force in parapets

The seismic force (W) applied in the parapets in static conditions, monotonic, increasing, and perpendicular to its plane was determined according to E.070 masonry code from the year 2000 and updated to the 2006 version and following the seismic E-030 from the year 2018. In Eq. (2) the E-070 masonry code indicates that the seismic force (W) is calculated because of the following factors: seismic zone factor (Z), considered as the maximum horizontal acceleration factor on a rigid soil presented as a percentage of the gravity acceleration. The Use factor (U) will depend on the specific use or importance of the building, the coefficient of seismic amplification (C1) interpreted as the factor of amplification of the structural acceleration compared to the ground acceleration of and the wall's self-weight (Pp).

Both codes indicate that the seismic force (W) should be considered perpendicular over the entire surface of the wall as shown in Fig. 4 (a), which will cause a base moment (M_b) because of the load moving over its full height, see Eq. (2). The Eq. (3) shows the effect of the rotation produced by the moment on the base (M_b) that will produce compressive stress (σcs) and tension stress (σts) as seen in Fig. 5 (b) and (c), which is distributed along its entire length (L).

$$W = Z \cdot U \cdot C_1 \cdot P_p \tag{1}$$

$$M_b = \frac{W \cdot h^2}{2} \tag{2}$$

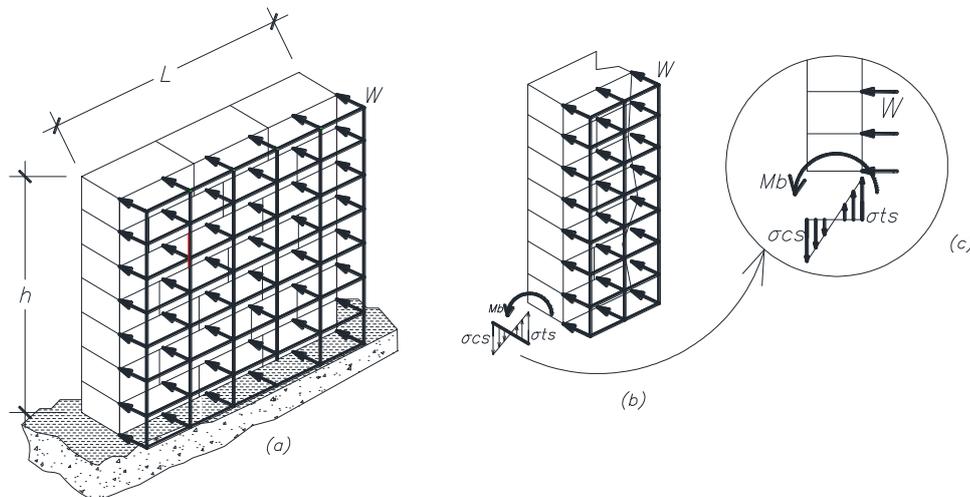$$\sigma_{ts} = \frac{6 \cdot M_b}{L \cdot h^2} \tag{3}$$

Fig. 5 – Distribution of seismic load and stress at the base of the wall

2.5. Post-tensioning force

To search for continuous maintenance of the post-tensioning force (T_{pe}), the equilibrium at its base was analyzed according to the diagram shown in Fig. 5 (b) between the post-tensioning force and the blocking force at the base of the wall (A_{nb}), which under the principle of pressure was raised in Eq. 4. It was necessary to consider the requirements of the ACI Masonry Postensing standard, which states that "The force must not exceed the resistance values of the units that make up the wall, to avoid its breakages".

$$T_{pe} = (\sigma_f - \sigma_c) * A_{nb} \tag{4}$$

It was necessary to assume on this calculated post-tensioned force (T_{pe}) a total loss of 25 % of that force initially required [13], see Eq. (5), It should be noted that this loss would increase the initial post-tensioning force (T_{pe}) by 33.33%. This calculated force (Tpi), required by the Masonry Standards Joint Committee (MSJC) was used concerning the pre-stress force allowed or required in post-tensioned masonry (T_{py}) so that the tendon or rod has an elastic behavior and not yield, see Eq. (6).

$$T_{pi} = \frac{T_{pe}}{0.75} \tag{5}$$

$$T_{py} = \frac{T_{pi}}{0.78} \tag{6}$$

2.6. Compressive forces in post-tensioned parapets

From Fig. 6 (a) it can be deduced that the self-weight of the parapet produces compressive forces (σpp) described in Eq. (7) and distributed throughout the net area of the wall base; the post-tensioning technique is achieved by applying the torque (Tp) that stretch the wires producing the post-tensioned force (T_{pr}). This post-tensioned force also produces compressive forces (σpt) that are transmitted over the entire wall in a trapezoidal form as seen in Fig. 6 (b) and reach the base of the wall, see Eq. (8), by superimposing the two effects we find the total compressive force that occurs at the base of the parapet described in Eq. 9, and illustrated in Fig. 6 (c)
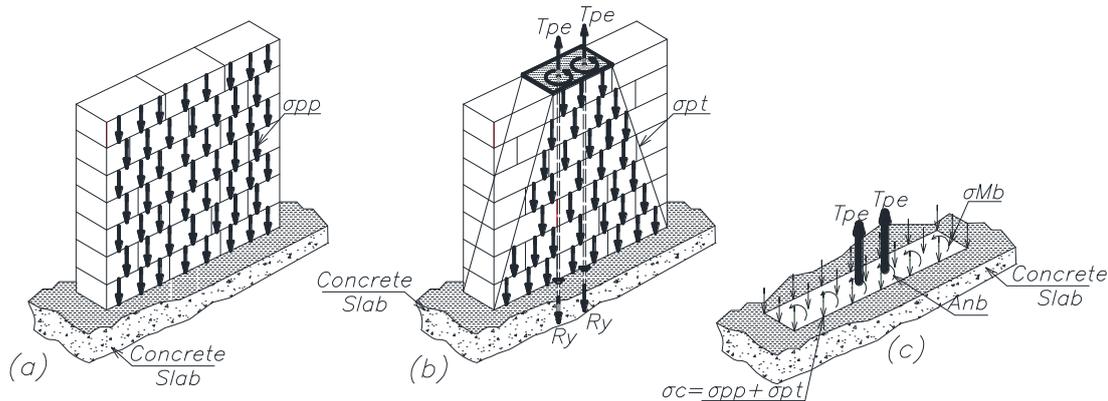

Fig.6 – Distribution of post-tensioned stress on the wall and base

$$\sigma_{pp} = \frac{P_p}{A_{nb}} \tag{7}$$

$$\sigma_{pt} = \frac{Tpr}{A_{nb}} \tag{8}$$

$$\sigma_c = \left(\sigma_{pp} + \sigma_{pt}\right) \tag{9}$$

2.7. Shear stress on post-tensioned parapets

The stress T_{pe} confines the unit by changing the behavior of the shear forces between parapet masonry units and seismic force (W) the shear forces τr in the upper area of the unit were analyzed, see Fig. 7 (a), (b), and (c). This evaluation was carried out under the principle of the basic equation of friction force, the same which is a function of a normal force which, in this case, for the post-tensioning force (T_{pe}) its coefficient of friction

6

of materials in contact μ, and to convert it into stress we will divide them between their corresponding area of the block, see Eq. (10).
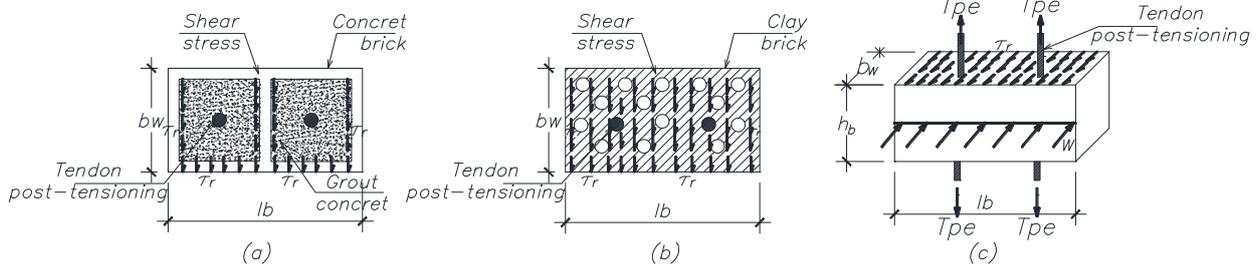

Fig.7 – Shear force on the surface faces of parapet units

$$\tau r = \frac{\text{Tpe}}{4 \cdot l_b \cdot h_b} \cdot \mu \qquad (10)$$

2.8. Parapet wall tests

There were 8 parapets tested inside the facilities of the laboratory of testing materials of the University of Piura (UDEP), the process started with the installation of the metal scaffolding 1. Subsequently, another metal scaffolding was fixed 2. which would hold the displacement measurement devices (deformimeter) and the load distribution device (metal tube) in the parapet as shown in Fig. 8. Once all equipment was installed, we proceed to apply the increasing monotonic load with a hydraulic jack, and the load and deformation were registered until the failure or total collapsed of the wall.
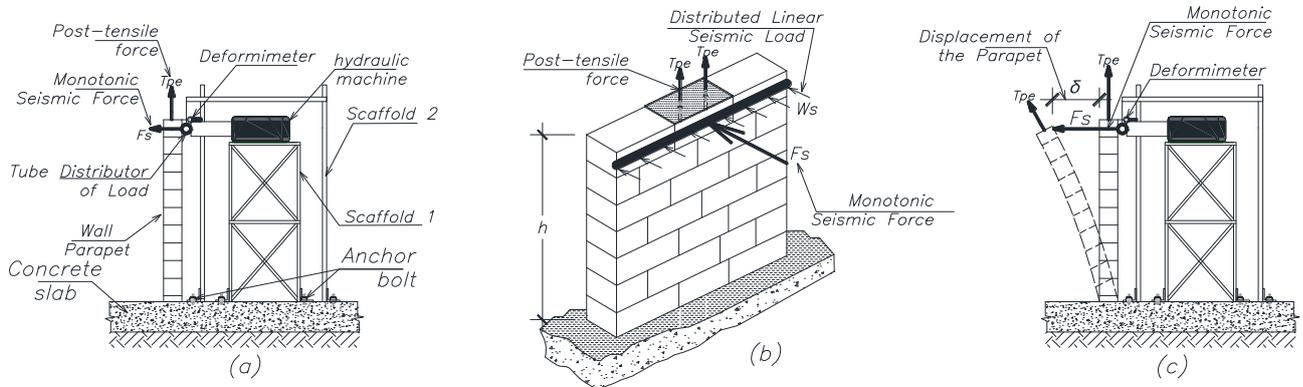

Fig. 8 – Seismic monotonic load test process

3. Experimental results

Fig. 9 shows the force and displacement increments that belong to the carried out tests, by the application of the load case of the force ΔFr1y ΔFr2 obtained an increase of 2.16 times correspond to the walls MAP12 and MAP24. For the case of ΔFr3 and ΔFr4 they obtained a force increase of 1.19 times for MCP12 and 5 times for MCP24. Fig. 10 shows an increase in lateral displacement after the reinforcement yielding, which leads to Δδr1 of 3.75 times for MAP12 and Δδr2 of 8.42 times for the MAP24 parapet, for tests with concrete units the obtained results were, Δδr3 5.37 times for MCP12 and MCP24 sample one Δδr4 53.33 times.
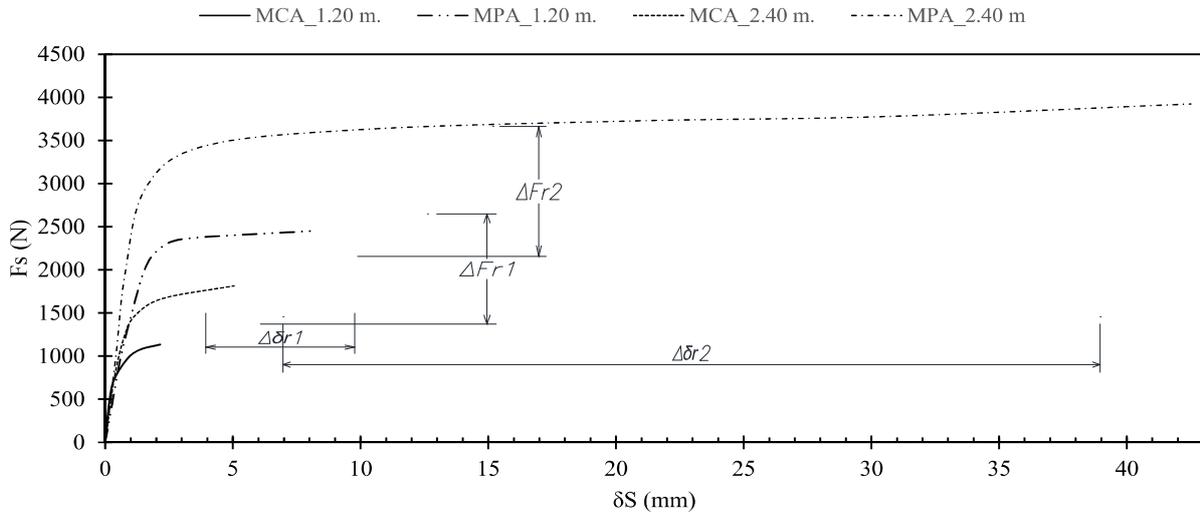
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Fig.9 - Resistance curve and displacement of conventional and post-tensioned clay parapet
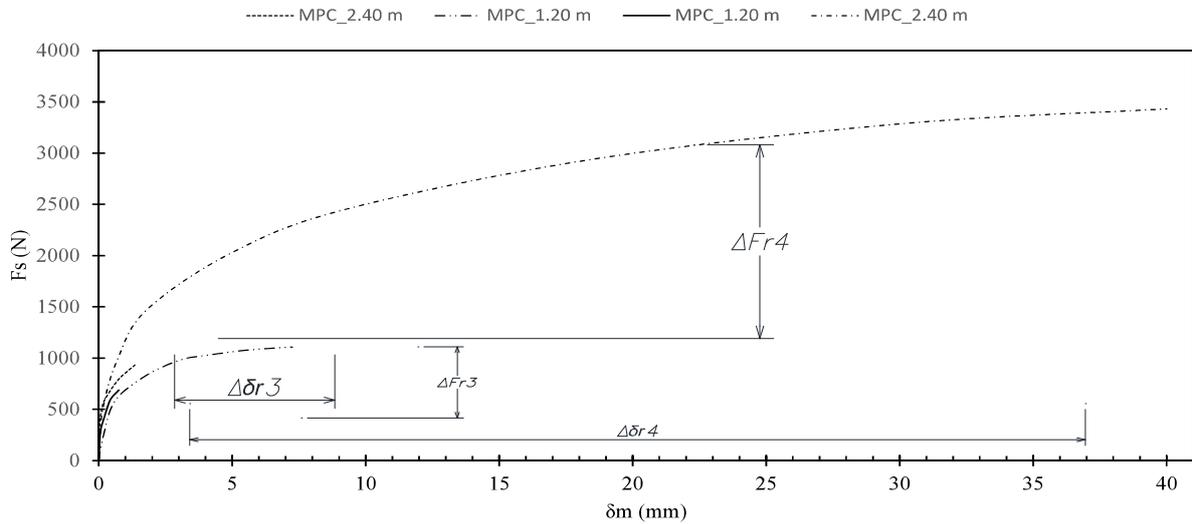

Fig. 10 - Resistance curve parapet displacement with concrete bricks

Fig.11 shows the total percentage earned by the post-tensioned walls, for which it is observed that the force and moment obtained increases a total of 116% for parapets MPA12 and MP24, and 18% for parapets MPC12 and 400% for MPC24. It should be noted that they are the same percentage increase values in force and moment because they are related.
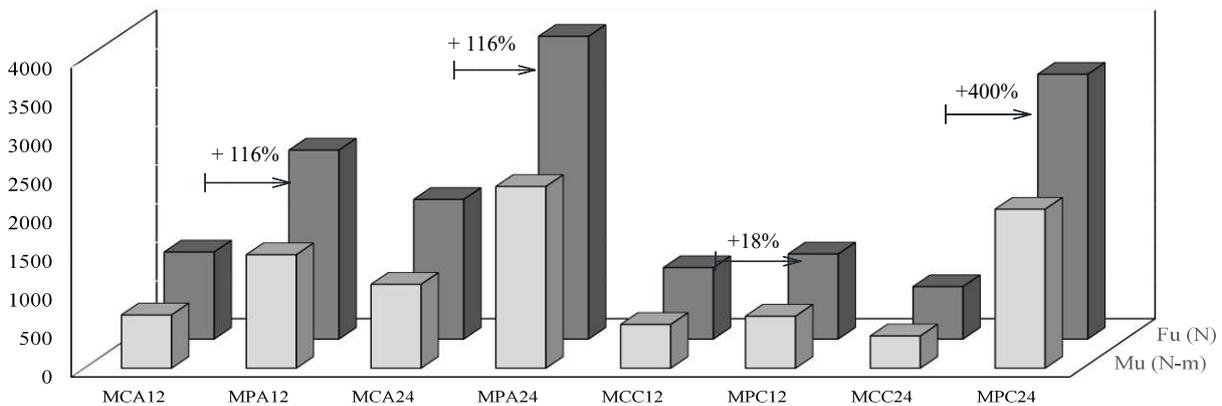

Fig.11- Increased moments and resilience

8

Fig. 12 shows the maximum force values at ultimate tensile strength (σmf) for which indicates the following increments: 116% for the MPA12 and MPA24 parapets, 18% for the MPC12, and 830% for the MPC24. In this same figure, we can also observe an increase in the shear force (τr) on the lower and upper faces of the unit which is determined to be 1000% for the parapets MPA12 and MPA24, 830% for the MPC12 and MPC24.
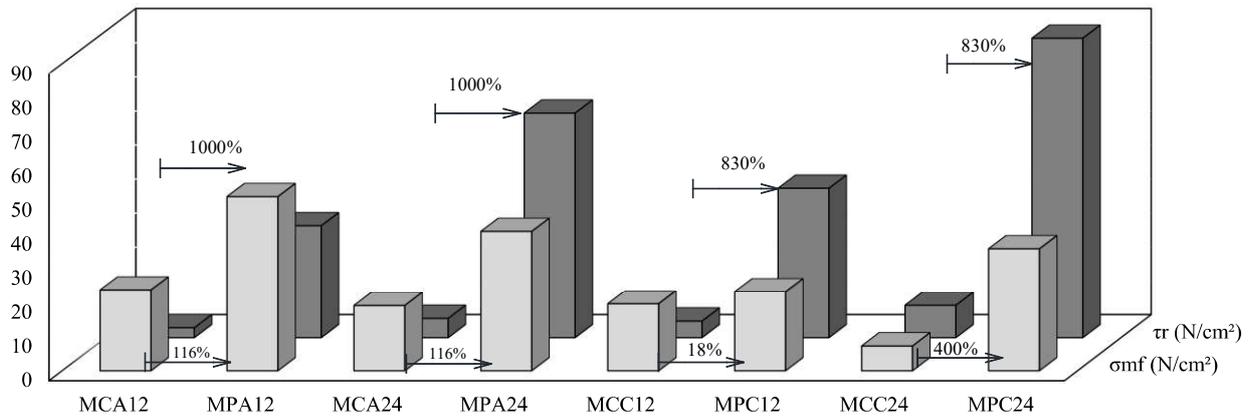

Fig.12 - Increased tensile forces and parapet displacement

4. Discussion of the results

Considering the results obtained in the tests and other calculations of the post-tensioned parapets, it was demonstrated that they increase their strength which will allow them to acquire stability during seismic events [14]. The increase in resistance gained is on average 2 times, values consistent with the tests described in the article "Bracing of existing parapets made of simple masonry" [9]. It has also been shown that its collapse is not immediate by the large increases gained in its displacement that the case of parapets with concrete units has reached 83.3 times. The post-tensioning through its reinforcements incorporates confinement in the parapets due to the compression that is transmitted in almost the entire wall which occurs between the units and the mortar that make up resistance up to 830% in their shear stress. Also, it is a very economical technique and does not require skilled labor [8] as it is applied with torque with a bolt wrench. The mechanical strength of the post-tensioning reinforcement is the same therefore the choice of the diameter will depend on the characteristics of the parapet to obtain the desired capacity increase in its resistance parameters [12].

Within the limitations of this study, it is indicated that the tests were performed for parapets built with clay and concrete units of the height of 1.20 m. and lengths of 1.20 m. and 2.40 m. respectively. However, being an initial and original work within the revised bibliography of our country, it is expected to be considered within the Peruvian technical standard that governs this type of walls as a contribution to state of the art of science [1].

5. Conclusions

The main conclusions derived from the research were the following:

1. This research presents a study of structural reinforcement on masonry walls known as parapets, built with clay and concrete units that during earthquakes suffer severe damage for not having enough rigidity in their plane. The faults that present are located at the base of the parapet, so their detachment of great heights causes damage. A systematic procedure was proposed with a post-tensioning technique used in concrete to perform a quantitative structural performance evaluation in masonry.

2. The confinement acquired by the parapet with the post-tensioning technique increased its resistance in the plane of conventional parapets against seismic loads, increasing its capacity by 2 times for parapets with clay units and 1.20 times for concrete units. This advantage would be favored by the support of the reinforcement or tendon in the parapet by having restrictions on the bottom (anchorage) and top (plate and bolts).

3. The position of post-tensioned reinforcements in the parapets exhibited vital importance in the structural stability due to the support of the force in the direction of the earthquake during the application of the load, something that the conventional walls did not possess. Thus, also its structurally favorable position and location allowed it to significantly increase the cutting efforts between parapet units up to 830% and maintain the wall stable even though the steel had fluid as its lateral displacements increased up to 53 times for walls with concrete units.

4. The mode and fault location of the parapets are controlled by the post-tensioning technique as its technique is a proposed procedure in this easy-to-apply study that achieves great advantages in protecting human lives during seismic events.

5. The collapse of these masonry walls was associated with possible design defects in the thickness or use of the unit, lack of reinforcement in the parapet which dramatically decreased its strength and produced its failure. With this technique, the load capacity is increased, and its collapse is less before loads in its plane.

6. The number of improvements in its cutting forces, traction at its base, resistance capacity, displacements, make it an ideal wall to withstand structural failures under seismic loads because it has proven to be an economical and easy to apply the technique with which increases in its structural characteristics are obtained in the face of a collapse in the buildings.

6. Acknowledgments

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