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THE NEW PERUVIAN MASONRY SEISMIC DESIGN CODE

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Abstract

Masonry walls are widely used for housing, schools and other buildings up to five stories high all over Peru and other Latin American countries, located in the seismic regions subjected to earthquakes in the subduction zone of the Nasca and South American plates. The Peruvian Masonry Code of 2006, after more than 12 years has been updated by the Peruvian National Committee in which the authors are members. The purpose of the 2020 update is: adapt the Masonry Code to the new Peruvian Seismic Code (2018), divide the specifications regarding confined masonry and reinforced masonry, and also include new items and findings.

The masonry constructions in Peru must be able to resist gravity and earthquake loads. The recent 2018 Peruvian Seismic Code has defined a new Seismic Map and Zone Factors, as well as soil factors. Also, the building irregularities in plan and elevation have different factors to be considered in the value of the shear seismic force. Main updates and new items included in the 2020 Masonry Code are: 1) properties for new materials for bricks and blocks, 2) the use of prefabricated bar arrangements in columns for confined masonry, 3) simplified analysis and design procedure for small confined masonry houses of up to three stories high, 4) guidelines for reinforcing, repairing and retrofitting of masonry walls, and 5) updated specifications for out-of-plane seismic forces on masonry walls used as non-structural elements. The new masonry code makes a separation between confined masonry and reinforced masonry specifications, keeps and makes more emphasis in the performance based criteria for design in confined masonry, and leaves the seismic resistance design for reinforced masonry walls. These modifications take into account that most of the masonry constructions on Peru are of confined masonry; while reinforced masonry is mostly used for partition walls.

It is expected that the new masonry code will be easier to read and follow for engineers, constructors, teachers and officials. Also, current population should be able to understand that seismic resistant buildings with correctly built masonry walls, can withstand earthquakes, as masonry is the main material for popular constructions.

Keywords: Masonry; code; walls; seismic design; reinforcement

1. Introduction

This paper presents the update of the Peruvian Masonry Code for 2020 [1]. Recent experiences of destructive earthquakes that hit Peru in 2007 near Pisco (Mw=7.9) and 2019 in Loreto (Mw=8.0), have shown severe damage to masonry constructions. The use of inadequate materials, low quality of construction by masons without enough knowledge, poor structural configurations, are among the main reasons for the poor performance of damaged masonry buildings, although these issues are covered by the code.

The 2020 Peruvian Masonry Code is an update of the 2006 Code [2], mainly motivated by: 1) the new conditions of the recent 2018 Peruvian seismic Code [3], 2) the need to separate the materials, the construction specifications and seismic design procedure for confined masonry buildings and reinforced masonry buildings, 3) new materials for brick and blocks have been included, 4) a new chapter on simplified design of small masonry buildings is included, 4) a new chapter on repair and retrofit of masonry walls is included, and 5) the chapter on masonry walls subjected to out-of-plane seismic loads has been updated.

The evolution of the Peruvian Masonry Code was discussed in 2017 [4], showing the research done with local materials for several years. The 1977 Peruvian Seismic Code contained a chapter on masonry using elastic design with formulas for stress evaluation and masonry strength. The first Peruvian Masonry Code (Norma E-070 Albañilería in Spanish) published in 1982, established an allowable stress design for gravity and seismic loads in the elastic range. Afterwards, many experimental and analytical researches were done in Peruvian universities (mainly in Pontificia Universidad Catolica del Peru PUCP and Universidad Nacional de Ingeniería UNI), using local materials and masons [5], [6]. As a consequence of those researches, the Masonry Code was updated in 2006 (using the 2003 Seismic code conditions), featuring a performance based seismic design of confined masonry and reinforced masonry buildings [7], [8].

2. Peruvian Seismic Code and its implication in Masonry Buildings

2.1 Seismic map, Seismic zones and Soil conditions

The more important earthquakes that affect the territory of Peru are subduction earthquakes originated by the Nasca Plate going under the South American Plate. The 1977 first Peruvian Seismic Code was updated in 1997, 2003, 2016 and 2018. All these versions contemplate masonry buildings as structures with rigid diaphragms. In the 1977 and 1997 versions, seismic forces were considered to be in service; then for reinforced concrete design, those forces had to be amplified by a 1.25 factor. Following international standards, since the 2003 version, earthquake forces are considered as ultimate forces, therefore a unity factor is used for reinforced concrete design and a 0.8 factor is required for analyzing foundations and masonry in the elastic range. The 2016 Peruvian seismic code changed the seismic map and the corresponding zone factor Z, the base seismic acceleration for 500 years. Earlier versions of the map featured 3 zones, and nowadays the seismic map presents 4 zones in the 2016 and 2018 Codes (Fig.1)

Fig. 1 – Peruvian Seismic Map and zones (1997-2003 left, 2016-2018 right) [3].

The seismic maps indicate that the coast facing the Pacific Ocean has the highest hazard (zone 4). Seismic zones 3 and 2 represent medium seismicity, covering most of the Andean mountains. The Amazon jungle covers most of zone 1, with low seismicity. The Zone factor Z and the soil factor S are used in the next parts of the paper when the seismic analysis of masonry buildings is discussed.

The soil conditions in the earlier codes were constant along the territory. The types of soils affect the seismic forces by the S soil factor; also, soil types have different period values (Tp) in the response spectra. The response amplification factor C was merely defined as C=2.5 (Tp/T), with a limit of C≤2.5. In the 2016 and 2018 Seismic Code [3], the soil factor S depends on the seismic zone. Also new period values (T_p and T_L) are given for the different soil types, affecting the response amplification factor C.

For periods $T<T_p$, C=2.5; for $T_p < T < T_L$, C=2.5 (Tp/T), and for $T>T_L$, $C=2.5 (T_p \cdot T_L / T^2)$. For typical masonry buildings, the number of stories goes from one to five; their mass and rigidity usually gives that the fundamental structural period T is less than Tp, which leads to a C value of 2.5.

2.2 Structural building regularity and seismic reduction coefficient R

The elastic seismic shear force V is reduced by the reduction coefficient R in regular analysis. Masonry buildings (either confined or reinforced) have a basic seismic reduction coefficient R_0 of 3 [3]. This basic coefficient must be reduced, if the building has not structural regularity. The structural irregularities are of two types: in elevation and in plan; also some irregularities are considered as common and extreme. In the earlier Codes up to 2003, any irregularity (in elevation or in plan) required the use of a single reduction factor of 0.75 either the building had one or more structural irregularities. This issue changed in the next Code editions.

Since the 2016 Seismic Code, the evaluation of irregularities and extreme irregularities must consider the seismic zone. All common buildings (regardless of the material), that are used for housing, hotels, offices, and alike, in seismic zones 4 and 3, should not have extreme irregularities. These extreme irregularities are in stiffness, in strength, and torsion. In seismic zone 2 the same common buildings should not have extreme irregularities with exceptions for 2 stories buildings. Seismic zone 1 has no restrictions.

The 2018 Seismic Code [3] defines irregularity factors *Ia* (in elevation, “altura” in Spanish) and *Ip* (in plan). The seismic reduction coefficient *R* is found as: $R = R_0 \cdot Ip \cdot Ia$. Structural irregularities in elevation are: stiffness (or soft story), strength (or weak story), mass irregularity, geometric vertical and discontinuity. Structural irregularities in plan are: torsion, entrant corners, discontinuity of the diaphragm, and non-parallel resistant systems. In both cases of irregularities, if the building has more than one type, the values to use for *Ip* or *Ia* is the lesser one, considering two directions of analysis for the seismic forces. Informal non-engineered masonry buildings may have several of the abovementioned irregularities. Common masonry buildings may present either torsional (Ip=0.75) and entrant corner irregularities (Ip=0.90), or both.

2.3 Allowable drifts

Masonry building structures have a limit of story drift (relative story lateral displacement divided into the story height) of 0.005, since the 1997 Seismic Code. For regular buildings, the lateral inelastic displacements have to be calculated multiplying by 0.75 R the linear elastic analysis results. One of the modifications between the two most recent seismic codes was that for irregular buildings, the factor to amplify the elastic displacements was R in the 2016 code; it changed to 0.85 R in the 2018 code.

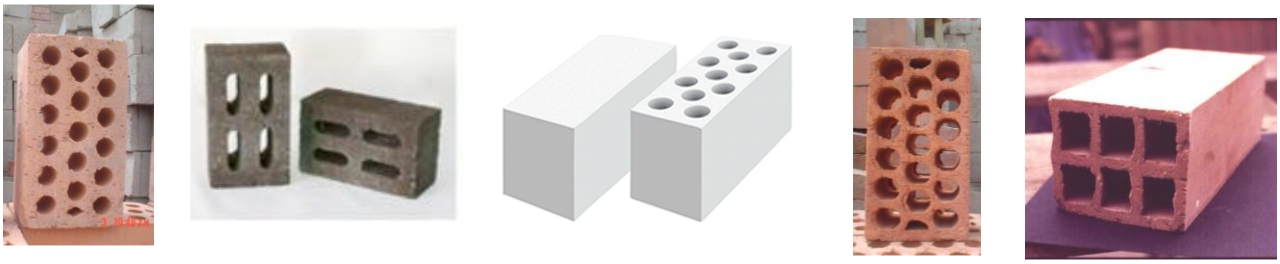
Earlier seismic codes allowed a story drift of 0.01. Peruvian earthquakes from 1996 and 2001 proved that this drift was too high, as damages in several buildings occurred, particularly schools and hospitals [9].

3. The 2020 Masonry code updates in materials

The main structural system used for housing in Peru is confined masonry walls in single houses or multistory apartment buildings, from one to five stories high (Fig. 2).

Fig. 2 – Popular multistory housing buildings with confined masonry walls.

The masonry units used are mostly made of clay, also concrete and silica lime units are available. The clay bricks are hand-made and industrial; the 2006 and 2020 Masonry Codes establish that a solid unit may have up to 30% of holes in the bed area. On the other hand, the concrete and silica lime masonry units, both industrial, meet the Code requirements of solid units. All these units and their properties have been included in the 2020 Masonry Code; Fig. 3 (a) shows the variety of bricks used in Peru for confined masonry walls. However, many users build bearing walls with perforated bricks that have 45-50% of holes, or horizontally-hollow bricks, Fig. 3 (b), contrary to the Code specifications. This improper use happens due to economic reasons and lack of control by the authorities. Such misuse have produced that most informal masonry constructions built with these inadequate units are seismically vulnerable, because they crush in a brittle way.



(a) (b)

Fig. 3 – (a) clay, concrete and silica lime solid units; (b) clay perforated and horizontally hollow bricks.

Table 1 from the 2020 Masonry Code [1] display the typical strength properties for compression of industrial bricks of three different materials, as well as the masonry strength of prisms under axial compression f'_m, and small walls under diagonal compression (shear) v'_m.

Table 1 – Strength properties in 2020 Masonry Code (in MPa)

Material	**Compression strength f'_b**	**Masonry compression strength f'_m**	**Masonry Shear strength v'_m**
Clay	17.6	8.3	0.90
Concrete	17.5	7.0	0.44
Silica lime	12.6	10.1	0.93

Another new issue deals with prefabricated columns for confined masonry. Cyclic lateral load tests made on confined masonry walls, compared columns with conventional ductile steel bars (9% deformation) and welded steel bars arrangements, (6% deformation) [10]. Tests results showed similar behavior up to the Code limit drift of 0.005. Therefore, the 2020 Masonry Code [1] allows the possibility to use such welded steel bars arrangements, limited for two story buildings or the last two stories of a multistory building.

4. Different approaches for Confined masonry and Reinforced Masonry Buildings

4.1 The performance based seismic design for confined masonry buildings.

The 2020 Masonry Code [1] emphasizes the performance-based design for confined masonry buildings, giving more explanation to this approach, introduced in the 2006 Code [2]. Confined masonry design is still the only structural system in Peru featuring such seismic design. The design of confined masonry buildings requires the verification of the structural behavior conditions for moderate earthquakes and severe ones.

For pre-dimensioning purposes, a minimum wall density is presented in terms of resistant shear and the seismic shear force, see Eq. (1). Previous code had a constant k value of 56; it has been updated in the 2020 Code, considering hand-made bricks and industrial bricks. The wall length *L* (includes the columns) and wall thickness *t* are multiplied to provide the shear wall resistant area, *Ap* represents the building plan area, *Z*, *U* and *S*, are the parameters of the seismic code (zone factor, use factor, soil factor), N is the number of stories; k=40 for hand-made bricks and k=60 for industrial bricks. The intention is that buildings with walls of hand-made bricks need a more amount of walls than before.

$$\frac{\Sigma L.t}{Ap} \geq \frac{Z.U.S.N}{k} \qquad (1)$$

The final failure for confined masonry is accepted to be a shear failure, in which the masonry wall resists a shear force *Vm*, and the confinement RC elements are able to keep the wall shear capacity up to the limiting drift of 1/200 = 0.005 for severe earthquakes. Fig. 4 illustrates the concepts of performance-based design for confined walls. The structure of confined masonry walls should be undamaged for a moderate earthquake (approximately drift of 1/800), and be able for an economical repair after a severe earthquake.

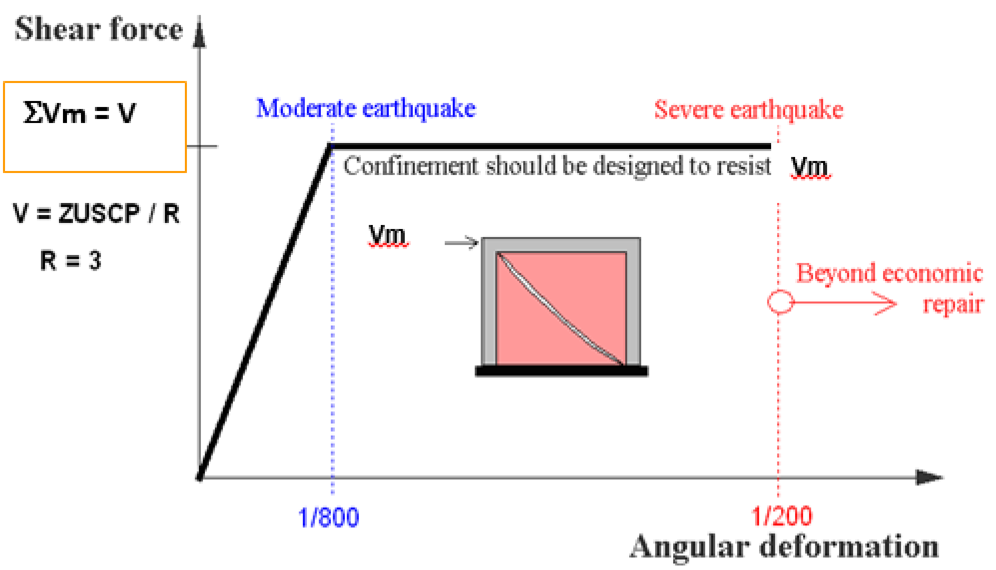


Fig. 4 – Fundamental scheme of the performance-based design for confined masonry walls [4]

Moderate earthquake analysis has to be performed using forces defined as half of the severe earthquake forces given in the seismic Code. This analysis provides elastic shear forces *Ve* in the confined walls, which must remain below from diagonal shear cracking force *Vm*. The calculation of *Vm* must be done for every wall in every story. It must be verified that $Ve < 0.55\ Vm$. With the results of this elastic analysis, lateral drifts of the building are obtained (see item 2.3) and verified to comply the 0.005 limit.

The expressions for *Vm* are as follows, Eq. (2) holds for clay and concrete units, and Eq. (3) holds for silica lime units. For both cases, the aspect wall ratio α was modified in the 2020 Masonry Code as in Eq. (4); this calculation for α is easier than the previous expression (Ve L / Me). The variables in Eq. (2), (3) and (4) are as follows: v'_m is the diagonal shear strength of small square walls; P_g is the wall axial load; *t*, *L* are the wall thickness and length including columns, *H* is the story height of the wall.

Clay and concrete units: $$Vm = 0.5\, v'_m\, \alpha\, t\, L + 0.23 P_g \quad (2)$$

Silica Lime units: $$Vm = 0.35\, v'_m\, \alpha\, t\, L + 0.23 P_g \quad (3)$$

$$1/3 \le \alpha = L/(0.8H) \le 1 \quad (4)$$

The severe earthquake analysis requires firstly the verification of shear resistance capacity. The total seismic force V_E in each direction has to be less than the sum of all shear wall´s capacity Σ *Vm*. If this condition is not fulfilled some walls can be transformed to reinforced concrete.

Secondly, the results of each wall internal forces (shear force *Ve*, bending moment *Me*) from the elastic analysis are amplified by a factor *fu* to obtain the design forces (Vu, Mu) for severe earthquake. The factor *fu* amplifies *Ve* to *Vm1*, the shear capacity of each wall in the first floor. This factor has a minimum value of 2 (ratio of forces between severe and moderate earthquakes) and a maximum value of 3 (the reduction R factor). All the shear forces and bending moments of the same wall have the same factor *fu*.

In the next step, the internal forces (shear *Vc*, tension *T*, and compression *C*) in the confining columns of the first floor (with the shear crack) have to be calculated, using the masonry Code expressions, which depend on the shear force and bending moment of the first floor. For the upper stories, the wall must be checked if it has a shear failure ($Vui>Vmi$) or not. If the upper story reaches its shear failure, its design is similar to the first floor. On the case that the upper story wall does not fail in shear, minimum reinforcement is required for the inner columns if any, while the outer columns only need design under tension and compression due to the bending moment.

4.2 The simplified analysis and design for small regular confined masonry buildings

A significant percentage of Peruvian buildings using confined masonry walls are of medium size high. The objective of this new chapter is to provide a simplified procedure for analysis and design. The following conditions must apply: a) the building height is less than 7.5 m or three stories; b) the building length to width ratio in plan should be less than or equal to 2; c) the ratio between the building height to the minimum plan dimension should be less than or equal to 1.5; d) at least 75% of the vertical loads should be supported by confined masonry walls, aligned vertically; e) the floor slabs should behave as rigid diaphragms; f) the wall distribution in plan should be almost symmetric, with an allowable eccentricity (distance between the mass center and stiffness center) less than 10% of the corresponding dimension in plan.

Also, perimeter walls must be provided to guarantee a minimum plan torsional rigidity, all walls have to be connected to the roof diaphragm. The amount of confined walls in each direction must satisfy Eq. (5), a variation of Eq. (1). The objective is to have elastic behavior of the building even in severe earthquakes.

$$\frac{\sum L\,t}{Ap} \ge \frac{Z.U.S.N}{18} \quad (5)$$

The effective wall area *Ae* given in Eq. (6) is found multiplying the gross wall area *Ag* times an aspect ratio *Fe* given in Eq. (7); then the seismic shear resistance force *Vm* is given in Eq. (8).

$$A_e = A_g \times F_e \tag{6}$$

$$F_e = 1.0 \quad \text{si } h/L \leq 1.33$$
$$F_e = (1.33\ L/h)^2 \text{ si } h/L > 1.33 \tag{7}$$

$$V_m = A_e \times v'_m \tag{8}$$

The shear resistance is then verified, using Eq. (9) in every story "*i*", *Vmi* is the shear resistance force of the wall and V_{Ei} is the seismic shear force at story "*i*".

$$\Sigma\ Vm_i > V_{Ei} \tag{9}$$

After this condition is satisfied, the minimum size of the confining columns is found by multiplying thickness *t* times 300 (if t ≤ 150 mm) or times 250 (if t ≥ 220 mm). The minimum size of the tie beam is the slab thickness times 250 mm. With the gross dimensions set, the longitudinal reinforcement for the confining columns (exterior and interior if any) and tie beam is given in this chapter as a set of 4 bars, varying for stories 1, 2 and 3. The transverse reinforcement is also given, with the same distribution for all the elements. By this way, the simplified analysis leads to a quite easy complete design of buildings with confined masonry walls.

4.3 Reinforced masonry buildings

The 2020 masonry code has divided all the items concerning reinforced masonry walls apart from confined masonry. The buildings of reinforced masonry are seldom used in Peru, mostly reinforced masonry is used for non-structural partition walls, or parapets, or fences. The items include: materials, construction procedure, tests for axial and shear strength, structural configuration, minimum requirements, analysis and design for in-plane forces.

The design of reinforced walls only considers the severe earthquake, with a reduction factor *R*=3 of the seismic forces. Usual design procedures for strength design are used for axial compression, axial plus in-plane bending moment, and shear force.

5. Repair and retrofit of masonry walls

A completely new chapter in repair and retrofit of existing masonry walls is included in the 2020 Masonry Code. It covers unreinforced masonry and both confined and reinforced walls.

5.1 Bearing masonry walls

The criteria for repair or retrofit masonry walls consider the following aspects: wall consolidation, application of external or internal reinforcements, better connections between walls and between walls and roofs, and partial or total substitution of the wall.

Wall consolidation implies substitution of damaged units for new ones, repair cracks in the wall, replacement of the mortar in the joints, and the repair of confining elements in confined masonry walls.

External surface reinforcements can be attached to the wall surface. Meshes of materials that resist tension such as welded wire, polypropylene, of fiber are suitable for this purpose. The attachment to the wall can be a polymer or cementitious material. For example, a confined masonry wall of perforated bricks (45% of holes in the bed area) and a reinforced masonry wall with hollow blocks were independently subjected to cyclic lateral loads and showed important shear cracks. For the repair and retrofit process, steel welded wire meshes covered with mortar were attached to the repaired walls (Fig. 5) and they were tested again [11]. The repaired walls recovered and increased their lateral load capacity, with slight less initial lateral stiffness, because small cracks cannot be repaired.

Another problem regarding structural masonry walls that need retrofit are those built with horizontally-hollow bricks, which should only be used for partition non-structural walls. However, popular informal constructions use such bricks for any wall, because they are cheaper and the authorities are unable to guide and control these constructions. In the structures laboratory of the Pontificia Universidad Catolica del Peru, an experimental research was done to address this problem. The cyclic load test of two walls with horizontally-hollow bricks was done, both W1 and W2 were built using traditional construction and afterwards, wall W2 was retrofitted with wire meshes, covered with cement mortar [12]. Later, two more walls made of similar horizontally-hollow bricks, were tested with the inclusion of vertical load prior to the cyclic load test [13]. These retrofitted walls WV-1 and WV-2, had vertical loads simulating 2-stories and 3-stories, respectively (Fig. 6). An important increase in load capacity and better structural behavior for the reinforced walls was obtained compared to conventional wall W1, due to the mesh reinforcement and the vertical load action that increases the shear capacity. Therefore, using this technique, masonry bearing walls made of inadequate hollow bricks may be retrofitted effectively.

Also according to this new chapter, external reinforcements not attached to the walls, like anchored or posttensioned steel cables, can be used to provide confinement and keep building integrity. Internal reinforcements consist of confining RC columns and beams, inserted into unreinforced masonry walls.

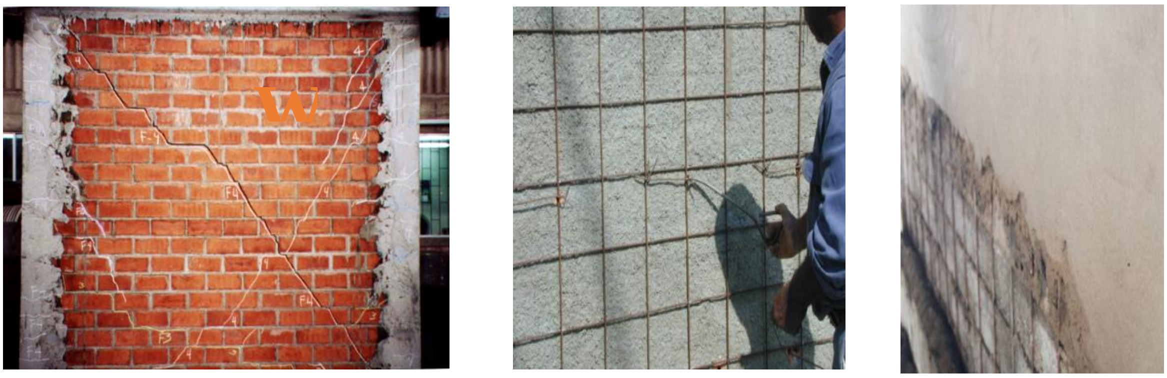


Fig. 5 – Confined masonry wall tested and repaired with wire meshes [11].

Fig. 6 – Confined masonry walls retrofitted with wire meshes, subjected to vertical load and cyclic lateral load [13].

In case of important structural damage, the wall may need partial or total replacement. Special care must be taken to assure a good bond between existing and new materials. Shrinkage due to new concrete poured may produce volumetric changes that have to be considered.

Bearing walls of reinforced masonry that have thin cracks can be repaired by epoxy injections. However the lateral stiffness cannot reach the original wall stiffness, because very small cracks cannot be filled up with the epoxy mix. If the cracks are wider, or the reinforcement bars have buckled, they have to be removed and replaced. After removing the affected zone, the surface must be cleaned, additional reinforcement or welded mesh of equivalent capacity has to be incorporated. Also, to increase the wall resistance, a reinforced concrete layer of minimum 50 mm thickness has to be attached, with a steel ratio of 0.0025 minimum. The additional concrete must be attached to the existing wall with dowels and epoxy. To increase the flexural capacity of the wall, confining elements at both wall ends can be included, properly connected to the wall by dowels. The concrete strength $f'c$ must be 17.15 MPa at least.

5.2 Lateral stabilization of partition walls, fences and parapets

The overturning of walls that provoke danger to people must be prevented, by reinforcement to resist out-of-plane seismic forces. The reinforcements can be external or internal, distributed in vertical, horizontal or transverse directions. Also, the connections between walls and between walls and roofs can be improved.

Typically, reinforced concrete tie columns and beams can be inserted into the existing plain masonry wall. Experimental tests have proven effectiveness (Fig. 7), such as a 1 m tall wall reinforced with RC columns 120x120 mm cross section with a single 8 mm bar [14]. Also, wire meshes properly attached to the slabs or roofs can be used.

Fig. 7 – Experimental tests for out-of-plane reinforcement columns in parapet wall [14].

5.3 Considerations for structural intervention to heritage constructions of masonry

The architecture structural heritage buildings, due to their nature and history (material and assemblage) have a series of difficulties to diagnose and structural intervention. This is because the construction codes must be applied together with international recommendations for heritage constructions.

In the case that the architectural heritage construction is inhabited, the purpose of the structural intervention must guarantee the people's life and the cultural contents in order to prevent any collapse, partial or total.

6. Non-structural masonry walls subjected to out-of-plane seismic forces

6.1 Changes due to the seismic code

In reinforced concrete and masonry buildings, the non-structural masonry walls have to be prepared to resist out-of-plane seismic forces. The 2018 seismic code establishes new specifications for the design of non-structural elements, including masonry walls used as partitions or similar in multistory RC buildings (or similar). Among the specifications, the walls need to be designed to resist the inertia forces of the story floor where they are located. Previous versions of the seismic code considered that the design seismic loads were constant regardless the location of the wall.

6.2 Masonry wall fences

In the new 2020 masonry code, the chapter dealing with design of masonry walls for out-of-plane forces has been updated, considering the changes mentioned in item 6.1. This covers masonry walls used as fences, partitions, parapets, or similar walls inside buildings, with low or null vertical loads. Recent earthquakes in Peru (Atico 2001 M8.4, Pisco 2007 M7.9, Lagunas 2019 M8.0) have shown many collapses due to poor construction or deficiencies in their detailing and design [15] (Fig. 8).

Fig. 8 – Collapse of masonry walls due to poor construction and deficient design.

The main updates are regarding masonry parapets (Fig. 9, left), in which their collapse from upper stories toward the floor is extremely dangerous. Such walls must be reinforced to prevent their failure by overturning. For internally reinforced walls, horizontal and vertical steel reinforcing bars must be properly designed. For plain masonry, either RC tie columns and tie beams, or structural meshes over the whole wall surface can be properly designed and provided (welded wire, polypropylene, fiber meshes are suggested). The reinforcing elements must be properly anchored to the floor slab or to other structural elements, and the reinforcement must be able to take 100% of the tension forces in the parapet wall.

For masonry walls used as fences, the emphasis is given in the stability, because the wall acts as cantilever under out-of-plane seismic loads (Fig. 9, right). Therefore, the foundation must act as a fix support, in order to resist the overturning moments by having a deep foundation using the lateral earth pressure, or a superficial foundation with adequate dimensions and weight.

Fig. 9 – Non-structural masonry walls: parapets and fences.

7. Conclusions

The 2020 Peruvian Masonry Code replaces the previous 2006 code. The main features and updates were discussed in this paper: the recent changes in the seismic code (seismic Zone, soil factor, building irregularities), the new materials and their properties, the separation between the specifications for confined masonry and reinforced masonry, two new chapters on simplified analysis and design for small confined masonry buildings, and the repair and retrofit of masonry walls. Also, updates were done in non-structural wall analysis under out-of-plane seismic forces. It is expected that this new masonry code can be better understood by the people, and that the authorities can be better prepared to guide and to control informal masonry constructions, in order to reduce the seismic vulnerability.

Also, the chapter guidelines in repair and retrofit of walls are expected to help engineers in the process of evaluation and construction of reinforcement elements in vulnerable existing masonry walls, and therefore be able to prevent building damages in future earthquakes.

8. Acknowledgements

The authors acknowledge the work of late prof. Angel San Bartolomé (+) and his contribution to the Peruvian Masonry codes of 1982 and 2006. Also some of his last works is included in the 2020 Masonry Code. The staff of the Structures Laboratory and many students of the Pontificia Universidad Católica del Perú were very helpful in performing the experimental tests to study masonry walls, whose results were used and included in the Code.

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