NEW PERUVIAN MASONRY DESIGN CODE

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SUMMARY

A new masonry design code has become official in Peru in 2006. The new code features design procedures for both confined masonry and reinforced masonry, with emphasis on adequate seismic behaviour. Confined masonry walls are designed to fail in shear, without losing their lateral load capacity. The procedure is based on strength and seismic performance for two levels of earthquakes: moderate and severe. Reinforced masonry walls are designed for flexural failure with reinforcement to avoid shear failure.

Other feature of the new code is a chapter on the interaction between RC frames and masonry infill walls.

INTRODUCTION

The new Peruvian Masonry Code (SENCICO 2006) has new provisions for the structural design of masonry buildings, covering confined and reinforced masonry. It replaces a allowable stress based Code (ININVI 1982). The changes involve materials, construction procedures, structural analysis and design, and a new chapter deals with infill walls. The authors are members of the technical Committee formed by SENCICO, a institution of the Ministry of Housing and Construction responsible for the Code changes.

The Code introduces for the first time, a seismic performance design of walls for in-plane gravity and seismic forces. Masonry should behave elastically under moderate earthquakes, and reach their ultimate strength for severe earthquakes. Confined masonry is designed to fail in shear, without losing its lateral load capacity. Reinforced masonry is designed for flexural failure with reinforcement to avoid shear failure.

The Code confined masonry design has been presented by San Bartolome and Quiun (2006). This paper presents some other changes dealing with reinforced masonry and infill walls.

MATERIALS

Masonry Units

Basic materials in Peru (figure 1) are clay and silica lime for bricks, and concrete, silica lime for blocks (figure 2). Some industries are trying to introduce concrete bricks and clay blocks. Fabrication of masonry units can be artisan (figure 3) or industrial. Table 1 from the new Code, establishes a classification of units for structural purposes, based on the maximum dimensional variation, the concavity or convexity, and the unit compressive strength. For bearing walls, solid units are required. Solid units are defined as those with a net cross-sectional area in every plane parallel to the bearing surface, equal to 70% or more of its gross cross-sectional area measured in the same plane. Other masonry units are hollow and tubular, to be used for nonstructural walls.

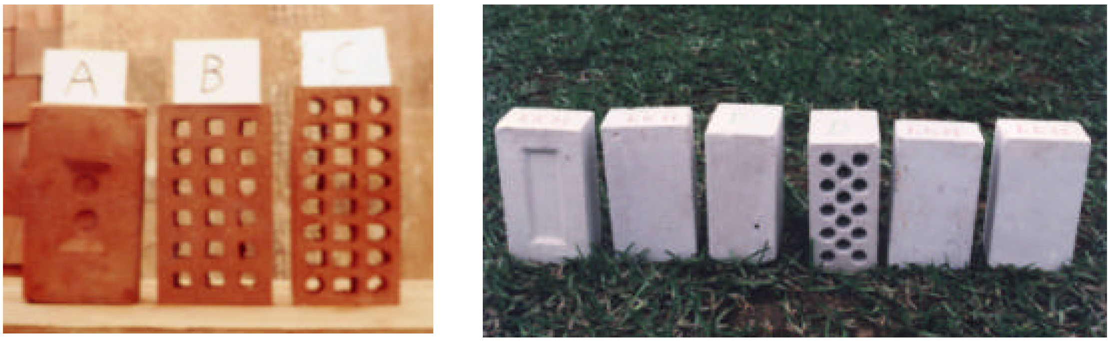


Figure 1. Typical Clay (left) and Silica Lime (right) Bricks in Peru

Figure 2. Typical Concrete (left) and Silica Lime (right) Blocks in Peru

Figure 3. Typical Artisan Fabrication of Clay Bricks in Peru

Table 1. Masonry Units Classification

Class	DIMENSIONAL VARIATION (maximum in percentage)			CONCAVITY or CONVEXITY (maximum in mm)	UNIT COMPRESSIVE STRENGTH f_b' minimum in MPa over gross area
	Less than 100 mm	Less than 150 mm	More than 150 mm		
Brick I	± 8	± 6	± 4	10	4,9
Brick II	± 7	± 6	± 4	8	6,9
Brick III	± 5	± 4	± 3	6	9,3
Brick IV	± 4	± 3	± 2	4	12,7
Brick V	± 3	± 2	± 1	2	17,6
Block (Bearing)	± 4	± 3	± 2	4	4,9
Block (Not bearing)	± 7	± 6	± 4	8	2,0

Mortar and Grout

Two types of mortars are defined in the Code: for bearing and for nonbearing walls. Table 2 indicates the component proportions in volume.

Table 2. Mortar Types

Mortar types	Cement	Lime	Sand
P1 (bearing)	1	0 to ¼	3 to 3 ½
P2 (bearing)	1	0 to 1/2	4 to 5
NP (non bearing)	1	0	Up to 6

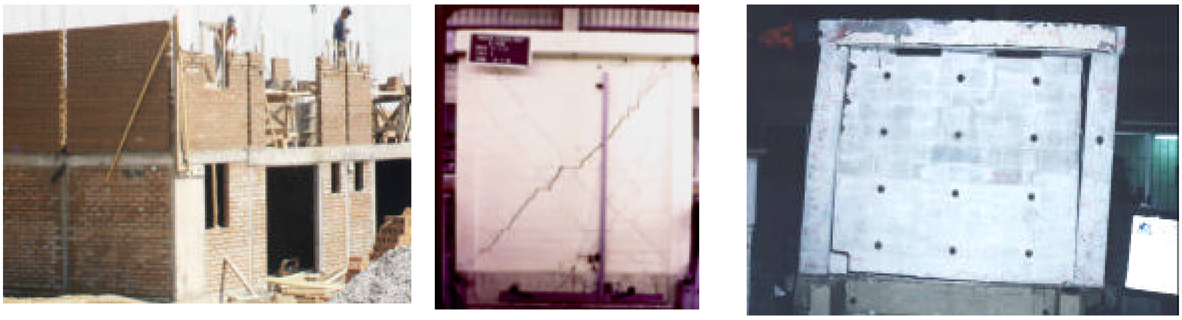
Two types of grout, called fine and coarse, are used in Peru, according to the block cell dimensions. Table 3 indicates the component proportions in volume.

Table 3. Grout Types

Grout types	Cement	Lime	Sand	Small stones
Fine	1	0 to 1/10	2 ¼ to 3	None
Coarse	1	0 to 1/10	2 ¼ to 3	1 to 2

CONSTRUCTION PROCEDURES

Mid rise buildings in urban areas of Peru are mostly constructed using confined masonry. In these buildings, masonry walls are erected first and reinforced concrete confinements are cast afterwards (Figure 4). Vertical confinements (columns) are cast directly against the masonry walls and later, horizontal confinements (collar beams), anchored on the previous ones, are cast monolithically with the slab. This construction sequence produces an integral system of all the involved elements, which behaves differently to infill walls.



Confined Masonry Infill Frame

Figure 4. Confined Masonry Construction Exhibits Different Behaviour than Infill Frames.

Only details of confined masonry are explained here, in relation to the joint between the concrete columns and masonry wall. Toothed and vertical connections (figure 5) are allowed, the former being the traditional construction. However, mortar that may fall during placement has to be cleaned prior to concrete casting, and the concrete vibration has to be done carefully. If the vertical connection is preferred, small wires have to be placed 400 mm in the mortar horizontal layer, and with a hook 125 mm horizontal and 100 mm vertical inside the column.

Figure 5. Confined masonry: connection between masonry and confinement column.

BUILDING STRUCTURAL ANALYSIS AND DESIGN

Methodology

The design procedure is based on numerous static and dynamic tests carried out at the Structures Laboratory of the Catholic University of Peru, theoretical analyses, and actual

behavior of buildings during past earthquakes in Peru and other countries (San Bartolome, 1994). The procedure considers that: 1) the structure will behave elastically during moderate and frequent earthquakes; and, 2) a repairable ductile shear failure will occur in case of severe earthquakes (without loss of lateral load capacity).

Figure 6 illustrates the design considerations. The structure is expected to behave elastically for angular distortions smaller than 1/800. Diagonal cracking in a masonry wall occurs at this point and the corresponding shear force is taken by the confinement elements, which should be designed for this purpose.

Laboratory tests have demonstrated that: 1) damage is economically repairable for inelastic angular distortions smaller than 1/200 (San Bartolomé, 1994); and, 2) there is no lateral strength reduction when the confinement elements are designed to sustain the load that causes the wall diagonal cracking (Vm). Also, the summation of the confined masonry wall strengths in each direction (ΣVm) should be at least equal to the base shear load (V).

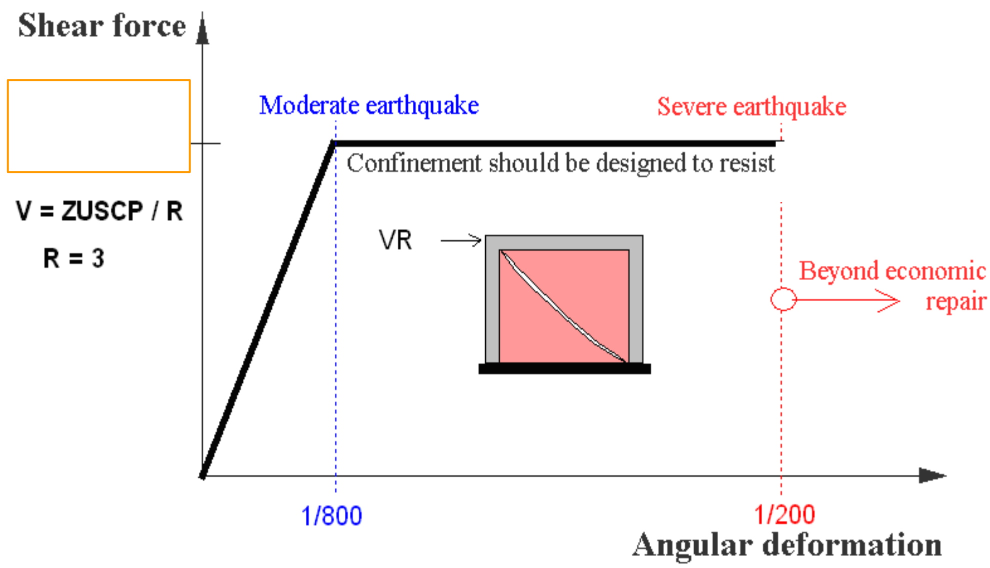


Figure 6. Objectives of the design procedure; V: Seismic design base shear; Z: Ground acceleration according to the zone; U: Importance factor; S: Soil factor; C: Building response coefficient; P: Building weight; R: Reduction factor = 3 for masonry (SENCICO 2003).

It is widely accepted that buildings made of confined masonry walls exhibit shear failure particularly in its lower stories, when subjected to severe earthquakes due to the predominance of the shear deformations over the flexural deformations. This behavior has been observed in real earthquakes as well as experimental tests, either in single walls subjected to cyclic lateral loads and a 3-story half scale building in shaking table test, as shown in figure 7 (San Bartolomé, Quiun and Torrealva, 1992). Although shear failure is considered brittle, confined masonry may exhibit ductile behavior provided that the confinement elements are properly designed, i.e. able to resist Vm.

Design Procedure

The masonry buildings design procedure consists of five steps: 1) verification of the minimum wall density along the building main directions; 2) vertical load design; 3) elastic

analysis for moderate earthquake loads; 4) verification of the elastic shear force against the shear strength Vm; and, 5) design for severe earthquake loads. Steps 1 through 4 are similar for confined walls and reinforced walls.

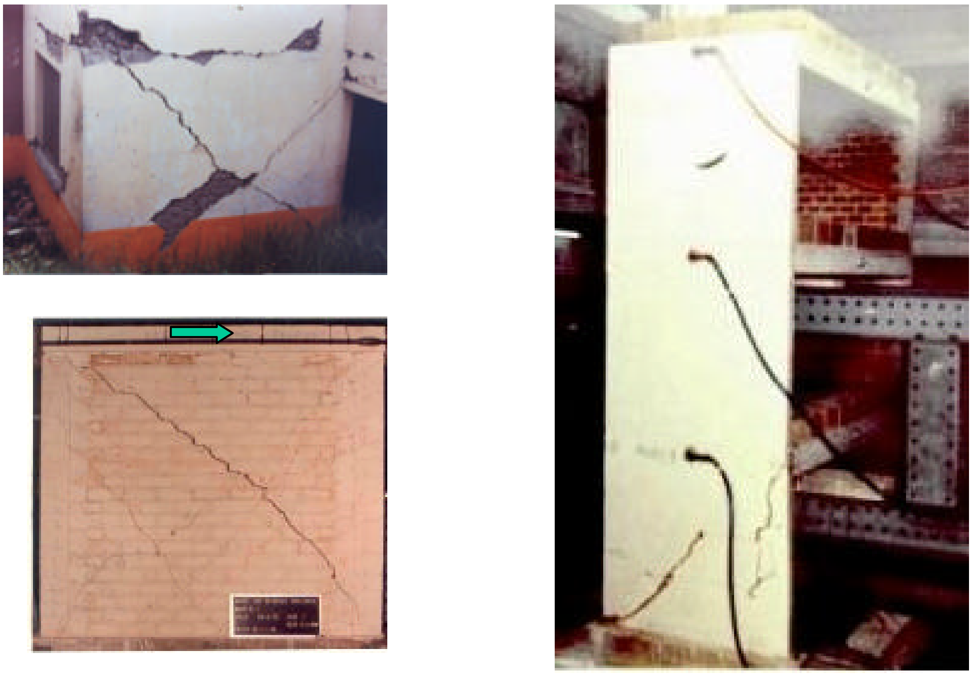


Figure 7. Shear failure in low rise masonry walls

In order to avoid a brittle failure due to insufficient lateral strength or excessive ductility demand, a minimum wall density (step 1) should be provided in each of the building main directions as specified in equation (1).

$$\frac{\Sigma\, L t}{A_p} \geq \frac{Z U S N}{56} \qquad (1)$$

Where Z, U, and S are defined in the Peruvian Seismic Code (SENCICO 2003), N is the number of stories, L, the total confined masonry wall length, t, wall thickness, and A_p, the typical story area.

Step 2 has the purpose of assuring adequate masonry ductility under axial stresses. Experiments have shown that large axial stresses significantly decrease the wall ductility. Therefore, it is specified that the axial stresses do not exceed $0.15f'_m$, where f'_m is the masonry compression strength (ASTM 2003). If the axial stress exceeds $0.05f'_m$, a minimum horizontal steel ratio equal to 0.001 is required.

The seismic analysis comprises step 3. The moderate earthquake is defined in the Peruvian Masonry Code as the one that produces half of the seismic forces of the severe earthquake. In each wall and every story, the shear forces obtained from the elastic analysis (V_e) should not exceed 0.55Vm, to assure the wall elastic behavior in moderate earthquakes.

The code equations to evaluate the shear strength (Vm) for masonry walls were established based on the results of many experiments on full size and small walls. Equation (2) holds for clay and concrete units, and equation (3) holds for silica lime units. For both cases, the aspect ratio α is defined in equation (4).

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

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

$$1/3 \leq a = \frac{Ve\,L}{Me} \leq 1 \quad (4)$$

The variables in equations 2, 3 and 4 are as follows: $v'm$ is the diagonal shear strength of small square walls (ASTM 2002); P_g is the wall axial load; Ve and Me are the shear force and bending moment obtained from the elastic analysis, respectively.

The in-plane aspect ratio height-to-length ($h/L=1/\alpha$) of the wall has shown its influence in the shear strength Vm, in several tests performed on walls under cyclic loading and on the shaking table test shown in figure 7.

The fifth and last step on the building analysis and design procedure is the design for severe earthquake. Firstly, a verification of the building global strength has to be done. Considering the Vm values already calculated, the summation of the shear strength of the first story (ΣVm_1) is determined. This should be larger than the seismic design shear load V. If the strength is insufficient, some masonry walls may be replaced by reinforced concrete walls or the wall thickness may be increased. If ΣVm_1 is larger than R times the base shear V, then the structure will behave elastically and there is no need for further verification, only minimum reinforcement is required for out-of-plane loading.

From hereafter the design for confined and reinforced walls differ. For confined walls, an evaluation of the amplification factors and verification of the diagonal cracking of the walls in the stories above the first floor has to be performed. It is assumed that during a severe earthquake, each wall of the first floor cracks when the shear force reaches its strength Vm_1. In order to obtain the ultimate bending moment and shear forces in the upper floors (M_u V_u), the calculated elastic internal forces (M_e, V_e) should be amplified by Vm_1/V_{e1}, where V_{e1} is the elastic shear force at the first story. The amplification factor should be calculated for each wall and does not need to be higher than R. If the ultimate shear force at i-th story wall, V_{ui} ($i>1$), is larger than Vm_i, the wall at this level will also crack and its confinements should be designed accordingly.

Next, the evaluation of the internal forces of the first floor vertical confinements has to be done. The vertical confinement (column) internal forces may be calculated for simple cases, such as one bay cantilever walls, using equilibrium equations as shown in figure 8. There are no bending moments, because the column has not flexural deformation. For more complex cases, such as several span walls connected through reinforced concrete beams or with transverse walls, the Code includes formulas for ultimate internal shear force (V), tension (T) and compression (C), for interior and exterior columns. Those formulas were obtained from the analysis of models as shown in figure 9. They pay special consideration to the columns on the wall sides to prevent the sliding of the cracked masonry wall. The vertical confinements are designed with the ultimate internal forces V, T, and C, according to concrete design standards, that is, subjected to a combined shear-friction and tension mechanisms. The

concrete core section (inside the stirrups) and the shear reinforcement are dimensioned to prevent concrete crushing (figure 10).

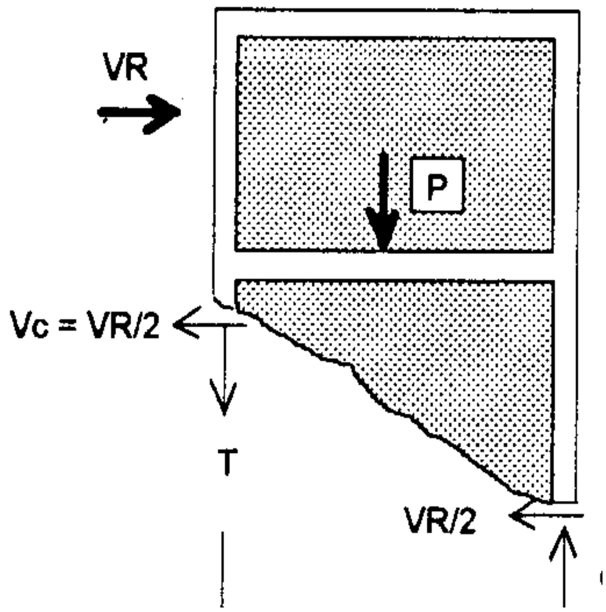


Figure 8. Vertical confinement internal forces of a one-bay wall

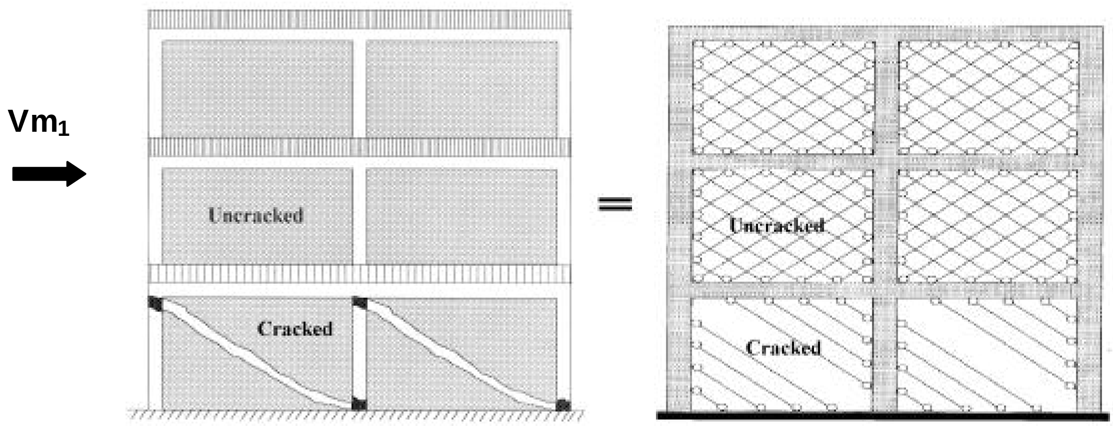


Figure 9. Model used to calculate the forces at the wall confinements in complex cases

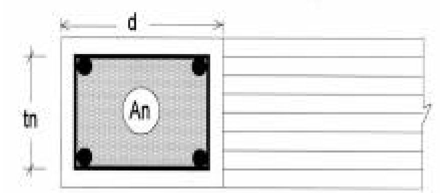


Figure 10. Vertical confinement (column) design forces and section

The horizontal confinements should be able to transfer the seismic loads from the slab to the masonry wall. Only minimum stirrups have to be provided, as the horizontal confinements do not have significant shear loads, because the shear area above the cracked first floor is large.

Finally, the design of the confinements of the stories above the first floor, in case V_{ui} is smaller than Vm_i, the masonry wall resists the seismic forces without cracking. In such case, the vertical confinements should not be designed considering the shear-friction effect. Instead, only the external confinements are designed for the tension, T, and compression, C, produced by the flexural moment $M_{ui}= M_{ei}\times Vm_1/ V_{e1}$. The internal columns do not need to be designed for in-plane actions, because they are integrated to the uncracked masonry wall. However, they should be able to support the wall under out-of-plane seismic actions. The maximum spacing between columns should not be larger than twice the distance between horizontal confinements. The horizontal confinement should be designed by tension, produced by the transmission of seismic forces to the walls.

Regarding the design of reinforced masonry walls, the Code philosophy is that for severe earthquakes, they can develop a flexural tension failure, avoiding fragile failures due to shear or compression. Therefore, the shear reinforcement distributed vertically and horizontally, should provide a shear capacity greater than the nominal shear force, amplified by 1.25 to account for the steel strain hardening. Also, if the compression ends combined stress (axial and bending) exceed 0.3 f'_m, confinement must be provided over the entire length with such high stresses.

INFILL WALLS

The last chapter of the Code is devoted to masonry infill walls in RC or steel frames. This topic is included for the first time ever. It intends to call attention on the masonry influence in the structural frame stiffness, which can produce undesirable effects, such as torsion or short columns. Infill walls are modeled as a diagonal compression strut, (Paulay and Priestley, 1992), using an effective width of 0.25 times the length of the diagonal (fig 11).

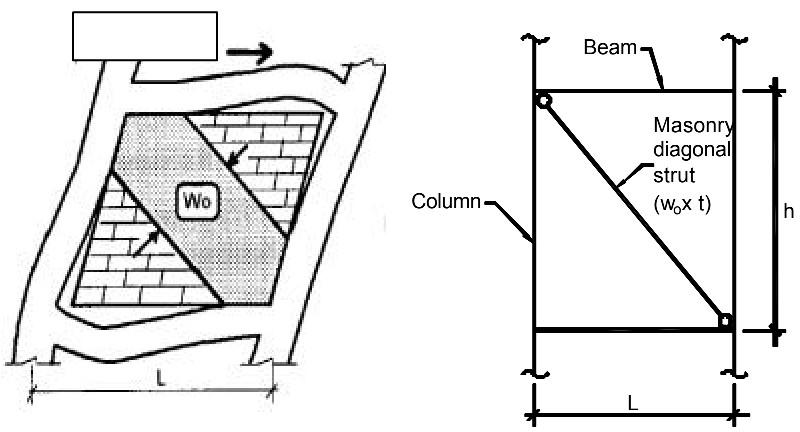


Figure 11. Infill walls modelling

CONCLUSIONS

The 2006 Peruvian Masonry Code has introduced a series of improvements after many years of local research and understanding of Peru construction practice, in which most of the low rise buildings are made of confined masonry. Firstly, brick and block masonry materials requirements were updated. Special attention was focused on seismic design, which includes two stages of verification for walls subjected to in-plane forces. Walls should remain elastic under moderate earthquakes and maintain their lateral load capacity under severe earthquakes.

The Code finally incorporates several modern requirements and recommendations for adequate design and construction of masonry buildings (confined and reinforced), as well as infill walls have been considered for the first time. The task of diffusion and teaching is now an important activity to perform.

REFERENCES

ASTM E519-02, Standard Test Method for Diagonal Tension (Shear) in Masonry Assemblages, 2002.

ASTM C 1314, Standard Test Method for Compressive Strength of Masonry Prisms, 2003.

Paulay T., Priestley M.J.N., "Seismic Design of Reinforced Concrete and Masonry Buildings", John Wiley and Sons, 1992.

San Bartolomé A. "Construcciones de Albañilería" Fondo Editorial, Pontificia Universidad Católica del Perú, Lima, Perú, 1994. (in Spanish)

San Bartolomé A., Website http://blog.pucp.edu.pe/albanileria, Lima, Perú, 2007 (in Spanish).

San Bartolomé A., Quiun D. "Design Proposal of Confined Masonry Buildings", *Proceedings 10th North American Masonry Conference,* St. Louis, 2006, pp. 366-377.

San Bartolomé A., Quiun D., Torrealva D., "Seismic Behavior of a Three Story scale Confined Masonry Structure", *Proceedings, Tenth World Conference on Earthquake Engineering,* Vol. 6, , Madrid, Spain, pp. 3527-3531.

SENCICO, "Norma Técnica de Edificación E.030 Diseño Sismorresistente", Lima, Perú, 2003 (in Spanish).

SENCICO, "Norma Técnica de Edificación E.070 Albañilería", Lima, Perú, 2006 (in Spanish).