# MASONRY INFLUENCE IN SEISMIC PERFORMANCE OF BUILDINGS - CASE STUDY IN PERU

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## SUMMARY

The use of masonry walls, either as structural bearing elements or as non structural elements, has shown an important influence in seismic performance of buildings. In Peru, brick units and confined masonry is the main material used for walls in low rise buildings. This paper covers briefly the seismic performance of Peruvian low rise buildings in several earthquakes, in which masonry walls have had an important influence in the structural behaviour.

## INTRODUCTION

The country of Peru is located facing the Pacific Ocean, and periodically moderate and strong earthquakes hit the country. The main source of these earthquakes is caused by the subduction of the Nazca plate under the South American plate.

On the other hand, masonry is the preferred material for wall construction in low rise buildings in most of the country. Both structural bearing walls and nonstructural walls of brick masonry may be found in housing, office and school buildings.

Structural bearing walls in old buildings (built during the first half of 20$^{th}$ century) are non reinforced and made of clay bricks, typically have 0.25m width, and are 1 to 3-story high. More recent buildings use confined walls made of clay bricks, in which the masonry wall is surrounded by reinforced concrete elements; wall width varies from 0.24 to 0.13m. This system is the most popular for buildings 1 to 5-story high. Reinforced masonry of hollow blocks filled with grout are less popular, but several buildings have been constructed having 4 to 5-story high, specially for medium class housing; wall width varies from 0.20 to 0.14 m, depending on the unit material (concrete or silica lime) and dimensions. Figure 1 shows some masonry buildings in Peru. Non structural walls include interior partitions in reinforced concrete frame buildings, fences, and parapets. In these cases, typically reinforced concrete columns (and beams sometimes) are used to provide resistance to out-of-plane seismic loads (see figure 1, middle left).

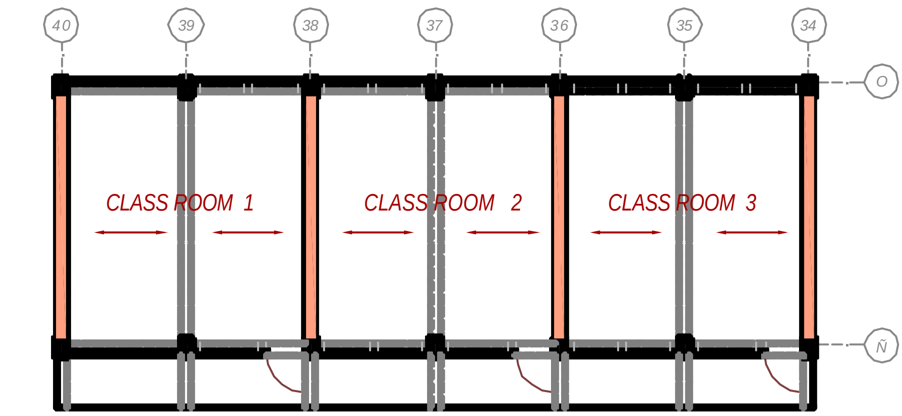
Therefore, masonry has an important influence in the seismic performance of buildings in Peru. This paper describes some cases observed in recent earthquakes in Peru.

Figure 1. Typical masonry buildings (housing, schools) in Peru, using bricks and blocks for structural and nonstructural walls

## MASONRY IN PERUVIAN SCHOOL AND UNIVERSITY BUILDINGS

Peruvian school and university buildings are typically 1 to 4-story high and use masonry as structural bearing walls and nonstructural partition walls. A typical classroom building structure has reinforced concrete elements in the longitudinal direction with masonry nonstructural walls, and a combination of confined masonry walls and reinforced concrete frames in the transverse direction. All masonry walls (structural and nonstructural) are made of clay bricks. The floors typically are one-way joist slabs, parallel to the longitudinal direction, and transfer the vertical loads to the walls and frames in the transverse direction. Stairways are usually an independent structure, leading to a distribution corridor in the upper stories where the classrooms are located. Figure 2 shows a typical Peruvian 2-story school building, older than 1997.



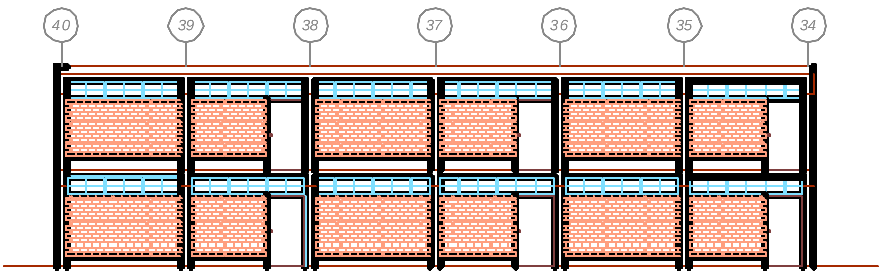




Figure 2. Typical old school building in Peru, has structural masonry walls in the transverse direction and nonstructural walls in longitudinal direction

The seismic resistant structure of typical Peruvian school buildings older than 1997, feature a weak longitudinal direction (flexible concrete frames) and a strong transversal direction (rigid masonry walls). Moreover, nonstructural masonry walls in the longitudinal direction usually are poorly isolated from the concrete frame, and can produce short-column effect even in moderate earthquakes. The 1996 Mw 7.5 Nasca earthquake (Quiun et. al. 1997) in central Peru coast, produced several damages to school buildings, mainly due to excessive lateral displacements in the longitudinal direction, that concluded in shear failure in short columns (figure 3). However, in the transverse direction, confined masonry walls were very effective to control lateral displacements and therefore no damage was observed.

Figure 3. School buildings affected in Nasca earthquake, only in the longitudinal direction

Similar behaviors in other school buildings were observed in the 2001 Mw 8.4 Atico earthquake (Muñoz, et. al. 2004) in south Peru. Figure 4 shows affected buildings in 3 different cities, 1 and 2-story high, in which nonstructural but stiff masonry walls produced short columns, while structural confined walls in the other direction avoided damage.


Figure 4. School buildings affected in Atico earthquake, only in the longitudinal direction

Another type of failure could be observed in a university 3-story building. The nonbearing walls with a lintel concrete beam, had diagonal cracking indicating that those walls worked resisting in-plane seismic forces (figure 5).

This earthquake also hit several new type school buildings designed and constructed following the recommendations of the Peruvian Seismic Code of 1997, (SENCICO 1997,

updated in 2003). The new schools are considered essential buildings and the maximum allowed drift for concrete buildings was lowered to 0.007. They feature strong reinforced concrete columns in the longitudinal direction and maintained the stiff masonry walls in the transverse direction, resulting in no damage. Also, the nonstructural masonry walls in the longitudinal direction were better detailed and properly isolated from the concrete frame; walls need RC columns and beams to withstand out-of-plane seismic loads (figure 6).

Figure 5. Nonbearing walls in university building damaged in Atico earthquake

Figure 6. New school buildings without damage in Atico earthquake

From the lessons learned from the recent earthquakes in Peru, brick masonry walls have demonstrated that they can be very useful in school buildings, both as bearing structural walls resisting in-plane vertical and lateral loads, and as nonstructural partition walls, on which the wall has to be designed for out-of-plane seismic loads.

## MASONRY IN PERUVIAN HOUSING BUILDINGS

Since 1961 to 2005, five national housing census have been performed in Peru, and many other population census. The data recollected is used by planning agencies to study the evolution, distribution and growth of the people and their basic needs (housing, water supply, etc.). A significant question is "What is the predominant material in the walls?" Comparing the last two census, the brick and block walls have replaced adobe as the predominant material (table 1). Therefore, research studies on masonry buildings are extremely important.

Table 1. Predominant material in housing walls as percentage of total (INEI 2005, 1993)

| Wall material | 1993 | 2005 |
|---|---|---|
| Brick and blocks | 35.7 % | 45.9 % |
| Adobe | 43.3 % | 37.0 % |
| Others: wood, straw, stone, etc. | 21.0 % | 17.1 % |

In the first half of the $20^{th}$ century, many single houses (1 to 3 stories) and multistory residential buildings (3 to 5 stories) in Peru have used unreinforced masonry for bearing and non-bearing walls, mostly using clay bricks. In these older buildings, bearing walls usually have 0.25m width independently of the building height. The non-bearing inner walls usually have 0.15m width and were called bracing walls. These buildings (figure 7) have withstood several earthquakes without any damage, perhaps due to good soil conditions and a high wall density in the main structural directions, that maintained the structural walls in the elastic range (San Bartolome 1994). It must be mentioned that at that time, bricks for use in all walls were 100% solid.

Figure 7. Old unreinforced masonry buildings without damage in Lima

Between about 1940 and 1965, the use of concrete columns as confinements and braces in bearing walls was introduced. This way of reinforcing masonry in Peru was still lacking of experimental and engineering studies. Also, the needs of more space in urban constructions lead to thinner walls of 0.15m width, reducing the wall density. Some collapses in unreinforced 2-story buildings occurred in the 1970 earthquake (Mw 7.8) in central Peru in bad soil conditions (figure 8). Failures displayed include: 1) sliding of the roofs; 2) tension failure; 3) overturning due to out-of-plane bending moments; and 4) shear.

Figure 8. Unreinforced masonry buildings damaged in the 1970 earthquake

The need of reinforcement in modern masonry construction becomes clear after 1970. Confined masonry walls (plain masonry surrounded by concrete columns and beams, cast after the wall construction) become the most popular structural system for low-rise buildings, allowed by the Codes to have up to 5-stories.

In more recent years, popular and informal constructions have misunderstood the way confined masonry must work. Concrete columns and beams are wrongly thought to be more important than the masonry itself, and the use of hollow and tubular bricks for bearing walls and seismic resistant walls are quite common. The 2001 Atico earthquake and recent 2007 Pisco earthquake showed the importance of having a minimum wall density (wall area respect to plan area) and the use of solid bricks, to prevent damage. Several houses collapsed or had heavy damage due to insufficient walls in the first floor and poor quality construction in the city of Tacna in southern Peru (figure 9) in 2001; similar failures could be observed in the city of Pisco in central Peru in 2007.

These particular issues, a minimum wall density, the need for solid units in structural walls, as well as quality control of masonry, are assessed in the new Peruvian Masonry Code (SENCICO 2006) as explained below. More features of this code concerning confined masonry are given by San Bartolomé and Quiun (2006).

A building with floors that act as rigid diaphragms must have a minimum wall density as indicated by equation 1. It also establishes that bearing walls must have solid bricks, defined as those in which the bearing surface net area must be 70% or more than the gross area.

$$\frac{\Sigma Lt}{A_p} \geq \frac{ZUSN}{56} \qquad (1)$$

Where $Z$, $U$, and $S$ are defined as seismic zone factor, importance factor and soil factor, respectively, in the Peruvian Seismic Code (SENCICO 2003); $N$ is the number of stories of the building; $L$, is the total confined masonry wall length; $t$, is the wall thickness; and $A_p$, is the typical story area. If Eq.1 is not satisfied, some masonry walls may be replaced by reinforced concrete walls or the wall thickness should be increased. To use Eq.1 in the former case, the RC wall should be transformed to masonry using the transformed section principle.

Figure 9. Collapsed housing buildings in the 2001 earthquake

The poor structural configuration of Tacna buildings has been also combined with the use of artisan-made hollow concrete units in bearing walls (figure 10). Such units dimensions are 400x200x150 mm. They feature 3 circular holes 120 mm diameter each in only one of the bearing surfaces, while the other is completely full; the holes area is around 40% of the gross area, therefore the units classify as hollow and should not be used for structural walls. For placement, the surface with holes is located downwards so that mortar may be placed in the full surface. Laboratory tests on masonry of this hollow units indicate that prisms subjected to axial compression have a compression resistance of $f'_m$=1.7 MPa, and small walls subjected to diagonal compression have a shear resistance of $v'_m$=0.26 MPa (Quiun et. al., 2005). As a reference, the Peruvian Masonry Code states that typical values for solid artisan units, are $f'_m$=3.4 MPa, and $v'_m$=0.5 MPa. Therefore, the Tacna hollow units do not fulfill any of the requirements for use in structural walls. However, despite the poor quality of the material and the recent collapses, these units are still popular.

The recent Pisco earthquake of August 15, 2007 (Mw 7.9), showed a poor performance of several confined masonry buildings that did not comply the 2006 Masonry Code specifications. Some of the main points were: 1) weak artisan clay bricks and hollow concrete blocks in bearing walls (figure 11); 2) poor wall density; and, a wrong construction sequence, in which the columns were constructed before the masonry wall was erected (figure 12). In this last case, the out-of-plane failure was observed in the upper stories where the accelerations are higher and the vertical load is small (figure 12, middle). As in previous earthquakes, old school buildings have heavy damage specially in short columns and collapsed fences (figure 12, right), while those built after 1997 were undamaged.

Figure 10. Artisan concrete hollow blocks used in Tacna, southern Peru, poor quality confirmed by laboratory tests

Figure 11. Crushing of poor quality units in masonry buildings in Pisco after the 2007 earthquake; hotel (left) and hospital (right)

Figure 12. Collapse of masonry buildings in 2007 Pisco earthquake, low wall density (left); wrong sequence in construction (middle); and old school fence (right).

## CONCLUSIONS

The masonry walls used in Peru are mostly unreinforced in older buildings, and confined by concrete elements in modern constructions. Brick and block confined masonry are widely used in Peru, especially in housing, offices and schools.

Seismic behavior of such buildings in recent Peru earthquakes have demonstrated that structural confined masonry walls are efficient in the drift control, resisting perfectly well moderate to strong earthquakes. However, nonstructural masonry walls badly located can provoke unexpected damage such as short columns, and a minimum masonry wall density should be provided to avoid sudden collapses.

Hollow units as well as artisan units of poor quality have to be discarded for bearing walls in multistory buildings in seismic areas,. Unfortunately, there are a lot of popular and informal

constructions that still use them. Retrofitting projects should be developed for those buildings to avoid collapses in future earthquakes.

The 2006 Peruvian Masonry Code incorporates several requirements and recommendations for adequate design and construction of masonry buildings, and dissemination is now an important activity to perform.

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