



EARTHQUAKE HAZARD CENTRE

NEWSLETTER

Supported by Robinson Seismic Ltd
www.robinsonseismic.com



Vol.14 No.4

APRIL 2011

ISSN:1174-3646

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twice as intense as what new buildings are designed for. The impact on unreinforced masonry buildings was devastating. Most collapsed or were badly damaged, and unfortunately include many if not most heritage buildings.

Given the earthquake intensity, it is not surprising that so much building damage has been observed. Of buildings inspected to date, 20% of all reinforced concrete buildings have been red tagged (too dangerous to enter and possibly due for demolition), 7% of steel and 62% of unreinforced masonry. Ductile detailing of post mid-1970s building has been tested and there will be much interest in research findings yet to be published. However, while the intensity was so high, the duration of shaking was very short – less than ten seconds! It is therefore possible that the plastic deformation observed in laboratory experiments will not be replicated by this earthquake where there may have been only several excursions into the inelastic range.

There will be so much for engineers and architects to learn from this earthquake. Already some surprising and upsetting damage has surfaced, such as flights of stairs collapsing down the stair well of a modern building. Fortunately, such problems do not appear to be widespread, and are a reminder that all building elements must be carefully designed for both the inertia forces and interstorey movements that occur during an earthquake.

Every damaging earthquake is a reminder of the need to take earthquake design very seriously. Let's hope that in the rebuilding of Christchurch, as well as in the many Japanese communities, the new buildings will be less prone to damage in future earthquakes. Here are opportunities for engineers and architects to introduce relatively new damage-avoidance technologies.

MORE LESSONS FROM CHRISTCHURCH

At the beginning of this Editorial I express condolences to the people of Japan and Christchurch who have lost family members, homes and businesses in the two large recent earthquakes. While the February 22nd quake, only 10 km from Christchurch's CBD and at a shallow depth of 5 km, caused serious building damage and loss of life, the scale of that event has been far surpassed by the devastating March 11th earthquake and tsunami striking the north-eastern coast of Japan.

In the October 2010 newsletter I discussed the damage to Christchurch after the 4th September Magnitude 7.1 Darfield earthquake. That event caused shaking that matched approximately 70% of current design standards. Many unreinforced masonry buildings were damaged and thousands of light timber framed houses suffered from ground deformation caused by liquefaction.

However the shaking caused by the lesser magnitude aftershock on February 22nd was far more intense in the CBD of Christchurch. Buildings less than approximately six storeys high were subject to shaking approximately

Virtual site visit No. 24: A multi-storey RC wall and steel frame building

The building visited is a 10-storey commercial building on the outskirts of Wellington's CBD. The structural systems comprise two different systems and materials. For seismic loads acting in the longitudinal direction along the length of the building, inertia forces are resisted by the two unpenetrated walls that enclose two sides of the central shear core. Figure 1 shows one of these walls which is essentially C-shaped, since the two end return walls function as flanges to the longer "web" walls when they resist bending and shear. The shear core is connected to four large piles which are cast more than 10 m deep and provide moment fixity to base of the core.

In the transverse direction two systems resist seismic load. First there are the two coupled-walls in the core. Because of door height penetrations at each floor level these walls are coupled together by strong coupling beams at each storey. In this building they are solid steel beams, designed to flex and yield in a ductile manner. If RC coupling beams were to have been specified they would have required special diagonal reinforcing steel to prevent brittle diagonal shear cracks forming under lateral loads. Because of the relative weakness of the two coupled walls as compared to the longer longitudinal walls, additional strength in the transverse direction is provided by two moment frames, one at each end of the building (Figures 2 and 3). Not only do they resist a sizeable proportion of the transverse forces acting on the building, their other structural role is to withstand building torsion. The small dimensions of the core make it unable to resist torsion all by itself, so with two moment frames separated by the whole length of the building, that long lever-arm together with the strength of the frames ensures very stable resistance against torsion.

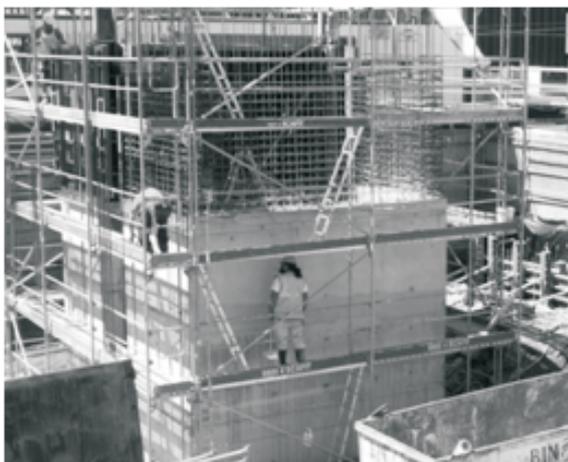


Fig.1 Central shear core two storeys high.



Fig. 2 Shear core to the right, a perimeter moment frame to the left and gravity-resistant structure between.



Fig. 3 Two of the three bays of an end steel moment frame.

SEISMIC RISK ASSESSMENT OF MASONRY BUILDINGS IN ISTANBUL FOR EFFECTIVE RISK MITIGATION

by M. Altug Erberika. From *Earthquake Spectra* Vol. 26, No. 4, November 2010.

ABSTRACT

Unreinforced and non-engineered masonry buildings are highly vulnerable to seismic hazard and constitute a significant percentage of earthquake losses, including both casualties and economic losses. This study presents an engineering application on seismic safety assessment of unreinforced masonry (URM) buildings in Istanbul, Turkey, a metropolitan city under very high seismic risk. Nearly 20,000 masonry buildings were examined through a two-stage assessment procedure in order to identify the addresses of those buildings which are under high seismic risk. Furthermore, the obtained database can be employed in the preparation of an earthquake mitigation strategy for the expected major earthquake in Istanbul. In the first-stage evaluation, buildings are examined visually from the street by considering their basic structural parameters and they are ranked within a priority list in terms of the calculated seismic risk. Next, the buildings identified with higher risk are evaluated in the second stage by using a more detailed procedure. The developed procedure is both an optimal and a practical tool in the seismic risk assessment of large masonry building stocks in a short period of time with limited resources.

INTRODUCTION

Turkey is one of the few countries in the world that experience a major earthquake nearly twice a decade, given the events that have occurred in the last 30–40 years. Most earthquakes that validated this statistical outcome occurred in areas of urban settlement, causing significant casualties and economic losses. Among these events, the 1999 Kocaeli earthquake $M_w=7.4$ has been recorded as one of the largest natural disasters of the twentieth century in Turkey. According to official records, more than 17,000 people died in this earthquake. The number of heavily damaged or collapsed buildings was more than 60,000. The total economic loss was estimated to be \$15–17 billion.

Such a destructive earthquake eventually caused damage or collapse in several different types of structures. In fact, field observations after the earthquake indicated that plenty of frame-type reinforced concrete, masonry, precast, wood-framed, and hybrid buildings were damaged beyond repair or had collapsed. However, among these different types of structures, special attention needs to be paid to masonry buildings, which constitute a significant portion of the building stock in Turkey. It is known that the seismic hazard level is high in most of the settlement areas of Turkey, which are

threatened by several active fault systems. Also, the vulnerability of masonry structures to seismic action is high, leading to the obvious result that people living in masonry buildings are under high seismic risk. This is especially valid for masonry buildings that were not designed for earthquake resistance, including ones that were built without any engineering design at all.

LEARNING FROM THE PAST: SEISMIC PERFORMANCE OF MASONRY BUILDINGS IN TURKEY

It is appropriate to classify masonry buildings in Turkey as rural-type and urban-type buildings. Rural-type masonry buildings, which are very common in small residential areas, towns, and villages, are low-rise dwellings built by using adobe or stone units.

They may be called “non-engineered buildings” since they were constructed in a traditional manner without the intervention of an engineer or an architect. On the other hand, urban-type masonry buildings are low-rise or mid-rise dwellings with a larger floor area when compared to rural-types. However they are generally irregular in plan with many projections. They were constructed by using brick units and concrete blocks and they have an “engineering touch” as opposed to rural-types. The destructive earthquakes that were experienced in Turkey in the last three or four decades revealed the fact that both rural- and urban-type masonry dwellings suffered severe damage or collapse. The situation is not very different in other parts of the world. For instance, considering the most affected areas after the 2007 Peru earthquake $M_w=7.9$, approximately 80% of the nonengineered adobe houses collapsed, and many masonry buildings suffered moderate damage. Figure 4 presents the photos of two collapsed buildings after the 2007 Peru and 1995 Dinar, Turkey $M_w=6.4$, earthquakes. Although these buildings were subjected to earthquakes with quite different characteristics, one could easily claim that these failures took place during the same disaster. Hundreds of thousands of houses collapsed after the Sichuan, China, earthquake $M_w=7.9$, where a significant percent of the collapses occurred in existing unreinforced masonry construction. The masonry walls of the collapsed buildings were generally composed of mud brick or clay brick. Similar types of damage were observed after the Abruzzio (L'Aquila), Italy, earthquake $M_w=6.3$, which caused significant damage to more than 10,000 buildings in the L'Aquila area. In this earthquake, damage to unreinforced masonry structures was again unsurprisingly widespread. Many masonry buildings in the area had been constructed by using stone or clay brick. Most of the deaths in the L'Aquila earthquake were due to the collapse of these seismically vulnerable buildings. Similar scenes had taken place before in Turkey, in which rubble stone masonry buildings with mud mortar and heavy roofs collapsed and killed many people in Bingöl (1971, $M_w=6.7$), Caldiran (1976, $M_w=7.2$), and Kars (1983, $M_w=6.6$) earthquakes.



Fig. 4 Collapsed masonry buildings after TOP: the Peru earthquake (Taucer et al. 2008) and BOTTOM: the 1995 Dinar, Turkey, earthquake (courtesy of METU - EERC).

It can be stated that if a masonry building does not conform to basic engineering principles, it is doomed to suffer from earthquakes of even moderate intensity. Based on field observations after major earthquakes in Turkey, one of the most important findings was that increasing the number of stories in a masonry building generally means increasing the probability of its suffering damage in an earthquake. Each added story is an extra overburden for a building not designed according to seismic provisions. The situation becomes worse if the added story is constructed with a masonry material different from the material of the existing building. Considering all these facts, the maximum number of stories for masonry buildings has been limited depending on the seismic zone in the last three versions of the Turkish Earthquake Code (1975, 1998, 2007). It should also be noted that reinforced or confined masonry construction is not common in Turkey, and it is not covered by the seismic code regulations.

Another important structural parameter that affects the seismic performance of masonry buildings is plan geometry. In an irregular building, the center of mass and the center of rigidity depart from each other, leading to additional shear stresses due to torsional effects. In previous earthquakes, especially after the

1995 Dinar earthquake, it was observed that irregular buildings suffered localized damage and collapses due to torsional effects.

It is also an important fact that total length of the masonry walls in both major orthogonal directions should be sufficient to resist the shear forces that occur during earthquakes with safety. For this reason, there exists a clause in the recent versions of Turkish Earthquake Code (1998, 2007) which enforces the L_d/A ratio (ratio of the total length of walls in one direction to the plan area for a typical story) to exceed a certain limiting value. For residential buildings, this limiting value was given as 0.25 in the 1998 version whereas it was slightly relaxed and reduced to 0.20 in the 2007 edition of the code. Although the L_d/A ratio seems to be a very simple parameter, it has been observed in previous earthquakes that there is significant correlation between structural damage and this parameter. Generally the collapsed or heavily damaged masonry buildings have low L_d/A ratios whereas undamaged or slightly damaged buildings have sufficient wall length that is characterized by higher L_d/A ratios.

Openings in walls are another important parameter somewhat linked to the L_d/A ratio discussed above. Large and numerous openings in a masonry building surely mean that the L_d/A ratio is low, which in turn indicates the potential vulnerability of that building. However, looking at the problem from another perspective, the arrangement of the openings in plan is also very important. In past earthquakes, local failures were observed in masonry buildings where the length of a wall between a corner and an opening, or between any two openings, was small or where the openings were distributed unevenly within the plan of the building. Therefore some limitations about the arrangement of openings in masonry buildings were added to the last three versions of the Turkish Earthquake Code.

The quality and characteristics of masonry wall materials cannot be disregarded in terms of seismic behavior. Adobe units which have been commonly used for the construction of rural-type masonry buildings have poor seismic behavior since the unit strength of adobe is generally low when compared to other material types. It has been observed that especially adobe buildings with more than one story have suffered either extensive damage or collapsed during the past earthquakes. Furthermore the situation becomes even worse if the adobe buildings have heavy earthen roofs. Adobe buildings with heavy earthen roofs usually become death traps during an earthquake and nobody inside can escape. This increases the final death toll significantly. The deficiency of urban-type masonry buildings is that they have generally been constructed by using nonload bearing materials like cellular concrete blocks, perforated clay brick units with high void ratios or clay brick units with horizontal holes although the use of such materials with insufficient strength has been prohibited by the

Turkish Earthquake Code (1998) after the experience of the 1992 Erzincan $M_w=6.6$ earthquake.

Other factors that are closely related with the seismic performance of Turkish masonry buildings on the basis of past experience are the absence/presence of horizontal lintels, connection details for intersecting walls, absence/presence of a rigid floor system, the slenderness ratio of masonry walls, and so on.

PREPARING FOR THE FUTURE: SEISMIC RISK MITIGATION STUDIES FOR MASONRY BUILDINGS IN ISTANBUL

Istanbul is the economic and cultural center of Turkey, although it is not the capital. It is also one of the most densely populated cities in the world, where currently more than 12 million people live in about 1 million buildings. In this huge stock, there exist all types of buildings including masonry. Istanbul has been hit by major earthquakes in the past, and it is highly probable that the city will experience another devastating earthquake in the next few decades.

Shortly after the devastating Kocaeli and Düzce earthquakes in 1999, the Japan International Cooperation Agency (JICA) conducted a detailed earthquake loss estimation study together with the Istanbul Metropolitan Municipality (IMM) and released a report in 2002. This study was based on a scenario earthquake on the western section of the North Anatolian Fault with a magnitude $M=7.5$. They attempted to simulate the historical earthquake that occurred in 1766 in Istanbul. The results of the loss estimation study indicated that Istanbul would be seriously affected from an earthquake of this scale, with more than 60,000 buildings suffering heavy damage or collapse, 63,000 casualties and 120,000 injuries.

The most striking outcome of the JICA study was the fact that the estimated earthquake losses in Istanbul after a devastating scenario earthquake are unacceptably high. This serious issue motivated the IMM to kick off an "Earthquake Master Plan for Istanbul (EMPI)" in 2003 in order to find sustainable solutions for the complex problem of risk mitigation and planning. In EMPI, multi-level strategies have been developed in order to prevent or mitigate seismic risk, prepare emergency rescue and restoration plans for the earthquake prone areas identified in accordance with the risk priorities determined by the JICA study.

One of the most important risk mitigation activities in EMPI is the evaluation of the seismic safety of existing buildings. It also covers the development of strengthening strategies for those buildings which have been considered as comparatively unsafe. In the EMPI project, reinforced concrete, masonry and wood frame buildings were examined separately. For masonry buildings, a two-stage evaluation procedure was developed.

FIRST-STAGE EVALUATION: SIDEWALK SURVEY

In the first-stage evaluation procedure, also referred as the "sidewalk survey," the buildings under inspection are examined from the street by considering their basic structural parameters that can be determined without entering the building. This method is very effective if a considerable number of buildings have to be examined in a short period of time, and the aim is to make a preliminary priority list of buildings in terms of potential seismic risk. Then the results of the first-stage evaluation are used to distinguish the buildings with high damage risk, and they are examined in detail in the second stage.

The second part of the first-stage evaluation is devoted to the assessment of building vulnerability. This part of the study is based on the generation of fragility functions for specific classes of masonry buildings. Using these fragility functions, a performance score (PS) is assigned to each building based on the seismic demand on site which is expressed in terms of PGA. In the final step, the buildings are ranked according to PS and the ones below a threshold limit are identified as "buildings with potential risk." The identified buildings are transferred to the second stage for detailed inspection.

CONCLUSIONS

Non-engineered masonry buildings in Turkey are under high seismic risk. This statement has been confirmed in all medium-to-large magnitude earthquakes for the last 30 to 40 years. Also, considering the fact that existing masonry buildings constitute a significant percentage of the building stock in Turkey, there have been some efforts to assess the seismic safety of existing structures for the purpose of mitigating earthquake risk and losses. The multistage seismic safety evaluation methodology presented in this paper is among these, which can be considered as a part of the Istanbul Earthquake Master Plan. Using this methodology, it has been possible to investigate a large masonry building stock located in regions of high seismic risk in Istanbul in a limited period of time in two stages. The purpose in the first-stage evaluation is to determine a priority list of buildings in terms of potential seismic risk. The obtained data is then used in order to distinguish the buildings with potential risk and examine them in detail in the second stage. A more refined procedure is employed in the second stage evaluation, and the risk levels of the investigated masonry buildings are tagged as low, medium, or high. Hence, by using this methodology, it becomes possible to identify the masonry buildings under high seismic risk among a large population of buildings. The obtained results are valuable in the sense that they can be used as a database during the development of strategies for pre-earthquake planning and risk mitigation for Istanbul.

SUMMARY OF: A TUTORIAL - IMPROVING THE SEISMIC PERFORMANCE OF STONE MASONRY BUILDINGS

This section of the newsletter introduces a brand new publication by the World Housing Encyclopedia. It is downloadable from its website www.world-housing.net

ABOUT THE TUTORIAL

Durable and locally available, stone has been used as a construction material since ancient times. Stone houses, palaces, temples, and important community and cultural buildings can be found all over the world. With the advent of new construction materials and techniques the use of stone has substantially decreased in the last few decades, however it is still used for residential buildings in parts of the world where stone is abundantly available and alternative materials are unaffordable.

Historically, most types of traditional stone masonry have proven to be extremely vulnerable to earthquake shaking. The main reason for poor performance is not the strength of the material but the lack of proper connections both between the stones as well as between various parts of the building. This tutorial on stone masonry therefore focuses primarily on ways to improve the overall integrity of stone masonry buildings in order to improve their seismic capacity. With the help of a

number of pictures and sketches, we present several relatively affordable stone masonry construction techniques that have been proven to be earthquake-resistant by traditional experience as well as scientific research results.

As stone masonry has been used for centuries in many countries around the world, there are numerous distinctly different construction techniques. These are strongly influenced by the construction materials and skills available in the area and the financial situation of the building owner. Even in small geographic areas, very different construction techniques for walls, floors, and roofs can be observed. Therefore, developing a tutorial that elaborates on all possible techniques used worldwide would be extremely difficult, if not impossible. Moreover, the resulting tutorial would be too cumbersome to be used effectively, particularly in the field. Consequently, the scope of this tutorial has been limited to discussing stone masonry techniques used primarily in the earthquake-vulnerable countries of Asia, mostly South Asia. Nevertheless, an effort has also been made to include some stone masonry construction techniques used in other parts of the world, including Europe and Latin America. For more details on these readers are referred to reports published in the World Housing Encyclopedia (www.world-housing.net).

SCOPE OF THE TUTORIAL

It is expected that this tutorial will fill a gap in the perceived lack of information about the earthquake-resistant construction of stone masonry buildings in developing countries, particularly in South Asia. The focus is on random rubble stone construction. The tutorial covers the behavior of stone masonry buildings in earthquakes, the reasons behind their poor performance, and how they can be improved. It provides techniques to improve the seismic performance of stone masonry houses. While aimed at South Asia, the tutorial nevertheless also covers topics which could be helpful to professionals involved in stone masonry construction elsewhere.

The target groups for this tutorial are:

Field level engineers/ technicians
Engineering/ polytechnic students

It is also expected that this tutorial will provide useful reference material for engineering and polytechnic institutes. An extensive bibliography provides a wealth of knowledge sources on stone masonry.

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Stone Masonry Construction Around the World
Key Building Components
Stone Masonry Wall Construction Practices
2. Seismic Deficiencies And Damage Patterns:
Lack of Structural Integrity

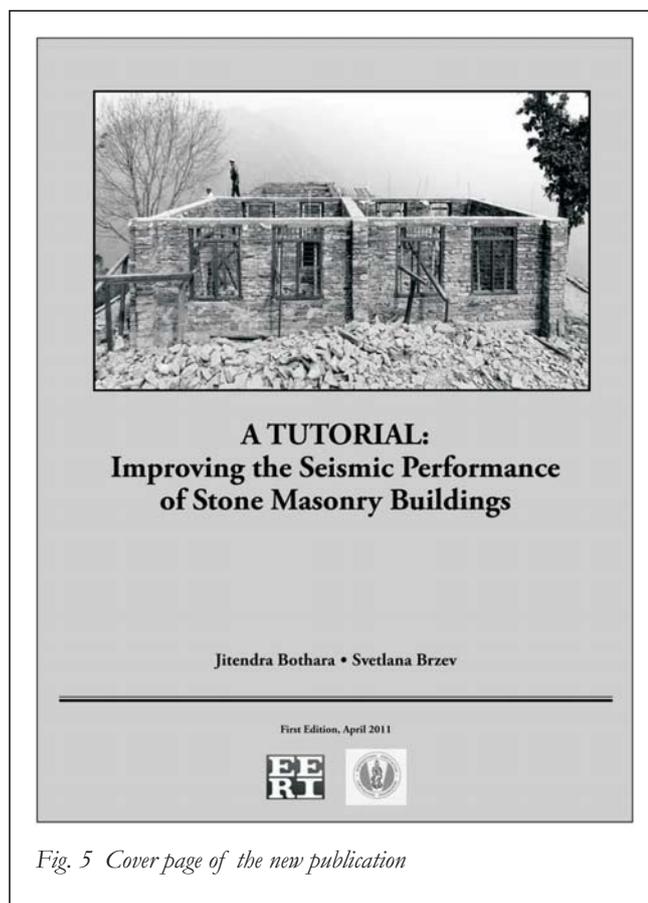


Fig. 5 Cover page of the new publication

- Delamination of Wall Wythes
- Out-of-Plane Wall Collapse
- In-Plane Shear Cracking
- Poor Quality of Construction
- Foundation Problems
- 3. Stone Masonry Construction With Improved Earthquake Performance:
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- Seismic Bands (Ring Beams)
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EXCERPT FROM: SEISMIC DEFICIENCIES AND DAMAGE PATTERNS

Stone masonry buildings are considered vulnerable to the effects of even moderate earthquakes. The excessive thickness of stone walls, often compounded by heavy floors or roof, account for the heavy weight of these buildings, thus resulting in significant inertia forces developed during an earthquake. Stone as a building material usually has a significant strength when subjected to compression, and it is stronger than most other conventional masonry units (bricks and concrete blocks). However, the construction practice where round, unshaped stones and low-strength mortar are used and artisan skills are at a low level results in extremely vulnerable structures. These unsafe practices have been followed due to economic constraints and lack of proper training for local artisans in countries and regions that use stone masonry.

Stone masonry buildings have shown poor performance in past earthquakes, leading to significant human and economic losses. This includes performance in earthquakes in Italy, Greece, Turkey, Montenegro, Slovenia, Algeria, Iran, Pakistan, India, Nepal, and many other countries. In the 2005 Kashmir earthquake (M 7.6), over 74,000 people died in Pakistan, most of them buried under the rubble of traditional stone masonry dwellings. In India, most of the 13,800 deaths during the 2001 Bhuj earthquake (M 7.7) and more than 8,000 deaths in the 1993 Maharashtra earthquake (M6.4) were attributed to the collapse of this type of construction. Examples of devastation caused by heavy damage or the collapse of stone masonry buildings in past earthquakes are shown in Figures 6 and 7.



Fig. 6. Extensive damage to stone masonry buildings in the 2009 L'Aquila, Italy earthquake (photo: T. Schacher)

Figure 7: Extensive damage to stone masonry buildings in the 1993 Maharashtra earthquake (photo: S. Brzev).

The key deficiencies of stone masonry buildings discussed in the following sections are:
 Lack of structural integrity, delamination of wall wythes, out-of-plane wall collapse, in-plane shear cracking, poor quality of construction, foundation problems.

EXCERPT FROM: STONE MASONRY CONSTRUCTION WITH IMPROVED EARTHQUAKE PERFORMANCE

STRUCTURAL INTEGRITY (BOX ACTION)
 Past earthquakes have shown that the damage of unreinforced masonry buildings is significantly reduced when building components are well connected and a building vibrates like a monolithic box, as discussed in

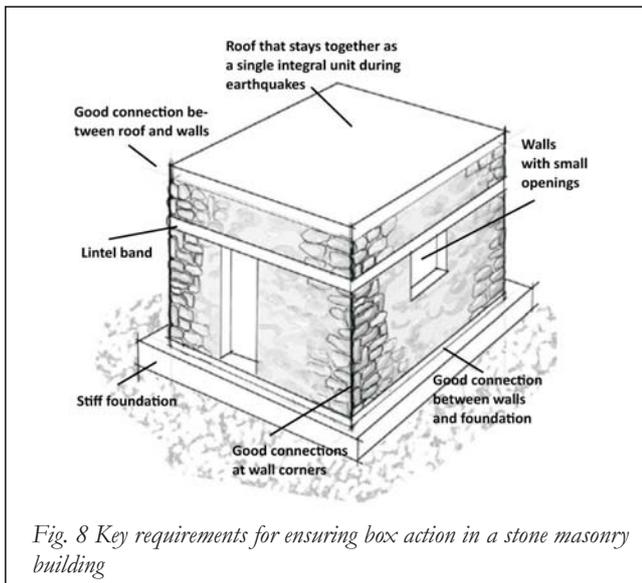


Fig. 8 Key requirements for ensuring box action in a stone masonry building

Chapter 2. In many cases, unreinforced masonry buildings have flexible floors, so there is a need to provide additional elements to tie the walls together and ensure acceptable seismic performance. Structural integrity of a building can be achieved by developing a box action, that is, by ensuring good connections between all building components—foundations, walls, floors, and roof. Key requirements for the structural integrity in a masonry building are illustrated in Figure 8. A ring beam (band) at lintel level is one of the critical provisions for ensuring structural integrity.

SEISMIC BANDS (RING BEAMS) BACKGROUND

A seismic band is the most critical earthquake resistant provision in a stone masonry building. A band, usually provided at lintel, floor and/or roof level in a building, acts like a ring beam or a belt, as shown in Figure 8. Seismic bands are constructed using either reinforced concrete (RC) or timber. Proper placement and continuity of bands and proper use of materials and workmanship are essential for their effectiveness.

Seismic bands hold the walls together and ensure integral box action of an entire building. Also, a lintel band reduces the effective wall height. As a result, bending stresses in the walls due to out-of-plane earthquake effects are reduced and the chances of wall delamination are diminished.

During earthquake shaking, a band undergoes bending and pulling actions. A portion of the band perpendicular to the direction of earthquake shaking is subjected to bending, while the remaining portion is in tension.

Seismic bands can be provided at plinth, lintel, floor, and roof level. In some cases, a lintel band is combined with a floor or roof band. An RC plinth band should be provided atop the foundation when strip footings are made of unreinforced masonry and the soil is either soft or uneven in its properties.

CALL FOR PAPERS

The Centre Disaster Resilience, School of the Built Environment, University of Salford, UK and RMIT University, Australia are organising the next event in the series of “Building Resilience” International Conferences. The event is entitled. “International Conference on Building Resilience: Interdisciplinary approaches to disaster risk reduction and the development of sustainable communities”, and will be held at Kandalama, Sri Lanka from 20th-22nd July 2011.

The Conference will be held in association with the UNISDR's 2010-2011 World Disaster Reduction Campaign 'Making Cities Resilient'. This is also the annual International Conference of the International Institute for Infrastructure, Renewal and Reconstruction (IIIRR), which is a multi-university international consortium which provides overall leadership in research, education, planning, design and implementation for mitigation of the impact of natural disasters and infrastructure renewal and reconstruction projects in tsunami affected underdeveloped regions. The International Journal of Disaster Resilience in the Built Environment will also be supporting this event.

Earthquake Hazard Centre Promoting Earthquake-Resistant Construction in Developing Countries

The Centre is a non-profit organisation based at the School of Architecture, Victoria University of Wellington, New Zealand. It is supported financially by Robinson Seismic Ltd.

Director (honorary) and Editor: Andrew Charleson, ME.(Civil)(Dist), MIPENZ
Research Assistant: Samantha McGavock BAS

Mail: Earthquake Hazard Centre, School of Architecture, PO Box 600, Wellington, New Zealand.
Location: 139 Vivian Street, Wellington.
Phone +64-4-463 6200 Fax +64-4-463 6204
E-mail: andrew.charleson@vuw.ac.nz

The Earthquake Hazard Centre Webpage is at :
<http://www.vuw.ac.nz/architecture/research/ehc/>