



# EARTHQUAKE HAZARD CENTRE NEWSLETTER

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## Editorial

Three months ago Nepal experienced a damaging earthquake. Occurring on 25th April, and with a magnitude of 7.8 Mw, the quake caused a high loss of life and many injuries, as well as tremendous physical damage. Approximately 9000 people were killed, over twice that many injured, 600,000 houses collapsed and half of that number were partially damaged. Thousands of school classrooms collapsed, with many others assessed as unsafe. Over 7000 school blocks require demolition and rebuilding. Of course, the quake caused a lot more damage as well, such as to infrastructure, particularly by landslides down the steep alpine valleys. All this loss is a terrible tragedy and our hearts go out to all those who have been, and still are suffering.

As I write this editorial, thanks to the computer 'split screen' function, I Google "Nepal earthquake building collapse" and see hundreds and hundreds of images of

collapsed and heavily-damaged buildings. The scale of damage is horrific. Most of the affected buildings are unreinforced masonry of fired clay bricks, stone masonry and adobe. But many RC buildings also collapsed, and strewn amongst the debris are large volumes of timber. The earthquake has shown no respect to any one material, and neither has it respected age. Many valued historic buildings, as well as newer buildings have been torn apart. And what is particularly sobering is that seismic experts are saying that this earthquake was not even the "big one". Even higher magnitude earthquakes are expected to strike the Kathmandu Valley in the future.

So what does all of this damage tell us? It reminds us that most construction in a seismic region is unsafe unless specifically designed and built to resist earthquakes. Conventional approaches without special attention to earthquake effects can't be expected to survive moderate to severe ground shaking. The only way for buildings to emerge relatively unscathed after such an earthquake is for them to be carefully designed using internationally-proven and accepted techniques, and then constructed under a strict quality assurance regime. Safe construction starts with education. The public needs to know the dangers of buildings not being specifically designed to resist earthquakes. Then strenuous efforts are required to train structural engineers, architects, contractors and others in the building industry how to design and build safely.

Broken Nepal is yet another reminder of the vulnerability of other countries. Hundreds of cities and towns are equally as vulnerable as those in Nepal and unfortunately, one day they too will experience similar levels of damage – unless we act now. Now is the time for the public, politicians and members of the building industry - all of us in fact, to take steps to reduce future preventable losses. Application of the resources described on the following pages of this newsletter would be an excellent start.

# Earthquake-resistant design and construction resources

The following resources that are summarized in this article are freely available from the World Housing Encyclopedia website <http://www.world-housing.net/tutorials>. The contents of each tutorial is listed together with several images and selected text so that readers can appreciate what the tutorial offers.

## EARTHQUAKE-RESISTANT CONSTRUCTION OF ADOBE BUILDINGS: A TUTORIAL

Authors: Marcial Blondet, Gladys Villa Garcia M., Svetlana Brzev and Álvaro Rubiños. 2011

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- Introduction
- Earthquake performance
- Improved earthquake performance of new adobe
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  - Adequate Soil Properties and Construction Quality
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  - Robust Layout
- Seismic reinforcing systems for new and existing adobe
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- Seismic protection of historic adobe buildings
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*Selected figures and text from the Tutorial:*

### Improved Earthquake Performance of New Adobe Construction

Due to its low cost, adobe construction will continue to be used by impoverished people in many regions of the world, including those regions with high seismic risk. The implementation of cost-effective building technologies to improve the seismic performance of adobe buildings is critical to achieving seismic safety for a substantial portion of the global population. Based on state-of-the-art research and observations from past earthquakes, the key factors for improving the seismic performance of adobe construction are:

Adequate soil properties and construction quality

- Wall construction
- Robust layout
- Use of improved building technologies with seismic reinforcement

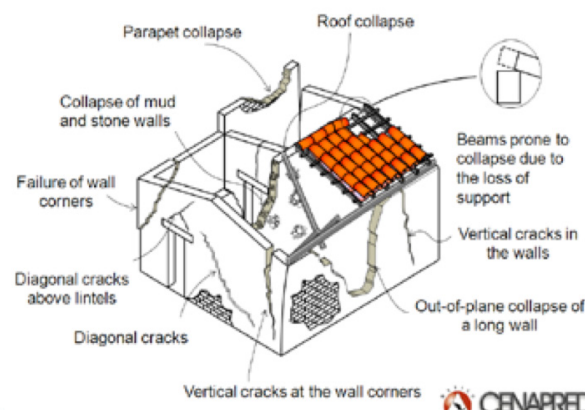


Figure 1. Seismic deficiencies of adobe masonry



Figure 2. Out-of-plane wall collapse



Figure 3. Total collapse of adobe walls

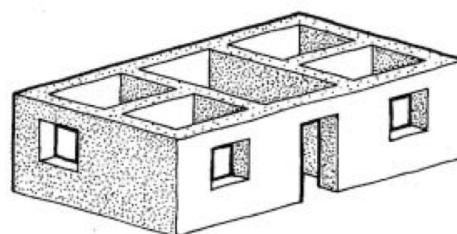


Figure 4. The Safest Building Form is a Squat, Single Story House, with Small Windows and a Regular, Compact Plan with Frequent Cross-Walls

### Adequate Soil Properties and Construction Quality

The soil properties that have the greatest influence on the strength of adobe masonry are those related to the dry strength of the material and the drying shrinkage process, as discussed below.

- Clay is the most important component of the soil used for adobe construction. It provides dry strength, however it also causes drying shrinkage of the soil.
- Controlled microcracking of the soil mortar due to drying shrinkage is needed for strong adobe masonry construction. Straw and, to a lesser extent, coarse sand are additives that control the microcracking of the mortar due to drying shrinkage, and therefore improve the strength of adobe masonry.
- The quality of construction plays an important role in creating strong adobe masonry.

### Robust Layout

One of the essential principles of earthquake-resistant adobe construction is to use a compact, box-type layout. Key recommendations are summarized below:

- Build only one-story houses
- Use an insulated lightweight roof instead of a heavy compacted earth roof
- Arrange the wall layout to provide mutual support by means of cross walls and intersecting walls at regular intervals in both directions, or use buttresses
- Keep the openings in the walls small and well-spaced
- Build on a firm foundation.
- Walls are the main load-bearing elements in an adobe building. A number of empirical recommendations regarding earthquake-resistant wall construction are as follows:
- The wall height should not exceed eight times the wall thickness at its base, and
- in any case should not be greater than 3.5 m.
- The unsupported length of a wall between cross walls should not exceed 10
- times the wall thickness, with a maximum of 7 m.
- Wall openings should not exceed one-third of the total wall length.
- No opening should be wider than 1.2 m.
- Provide piers of at least 1.2 m width between openings.

### Seismic Reinforcing Systems for New and Existing Adobe Construction

Ring beams (also known as a crown beams, collar beams, bond beams, tie-beams, or seismic bands) are one of the most essential earthquake-resistant provisions for load-bearing masonry construction. A ring beam ties the walls together and ensures that the building behaves like a box when subjected to earthquake ground shaking (a box

effect is critical for satisfactory earthquake performance). The ring beam must act like a belt and must be strong, continuous, and securely tied to the walls. It must be placed atop all walls, its width should match the wall width, and it must provide support for the roof. The ring beam can be made of wood, eucalyptus logs, or bamboo. A wooden ring beam is built using long timber members and transverse pieces nailed at 400 mm spacing. The wooden beam is made of 75 mm by 75 mm members.

During an earthquake, adobe walls are subjected to tensile stresses that they are unable to resist, thus cracks appear and the walls break into large pieces. This damage can lead to either the partial or total collapse of the structure. To prevent this, vertical and horizontal seismic reinforcement must be placed at critical locations. The reinforcement must be continuous and can be either inside the wall or attached to the wall surface.



*Figure 5. A wooden ring beam*



*Figure 6. Vertical and horizontal reinforcement*



## **CONSTRUCTION AND MAINTENANCE OF MASONRY HOUSES: For masons and craftsmen**

Editor: Marcial Blondet. 2005

### **Contents:**

- Natural Hazards
  - Natural hazards in Peru
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- Plans for your house
- Why are drawings useful?
- The design of your house
- Sample house plans
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## **SEISMIC DESIGN GUIDE FOR LOW-RISE CONFINED MASONRY BUILDINGS**

Prepared by: Roberto Meli, Mexico; Svetlana Brzev, and other participants. 2011.

### **Contents:**

- Introduction
- Scope and Objectives
- 1.2 What is Confined Masonry Construction?
- Key Components of a Confined Masonry Building
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### **What is Confined Masonry Construction?**

Confined masonry construction consists of masonry walls and horizontal and vertical reinforced concrete (RC) confining elements built on all four sides of a masonry wall panel. Vertical elements, called tie-columns, resemble columns in RC frame construction except that they tend to be of far smaller cross-sectional dimensions. Most importantly, these RC members are built after the masonry wall has been completed. Horizontal elements, called tie-beams, resemble beams in RC frame construction but they are not intended to function as conventional beams since confined masonry walls are load-bearing. Alternative terms, horizontal ties and vertical ties, are sometimes used instead of tie-beams and tie-columns.

The key features of structural components of a confined masonry building are discussed below:

- Masonry walls transmit the gravity load from the slab(s) above down to the foundation (along with the RC tie-columns). This document addresses confined masonry construction consisting of masonry walls made of solid clay bricks, hollow clay tiles, or concrete blocks. The walls act as bracing panels, which resist horizontal earthquake forces acting in-plane. The walls must be confined by RC tie-beams and tie-columns and should not be penetrated by significant openings to ensure satisfactory earthquake performance.
- Confining elements (RC tie-columns and RC tie-beams) are effective in improving stability and

integrity of masonry walls for in-plane and out-of-plane earthquake effects. These elements prevent brittle seismic response of masonry walls and protect them from complete disintegration even in major earthquakes. Confining elements, particularly tie-columns, contribute to the overall building stability for gravity loads.

- Floor and roof slabs transmit both gravity and lateral loads to the walls. In an earthquake, floor and roof slabs behave like horizontal beams and are called diaphragms. The roof slabs are typically made of reinforced concrete, but light-weight roofs made of timber or light gauge steel are also used.
- Plinth band transmits the load from the walls down to the foundation. It also protects the ground floor walls from excessive settlement in soft soil conditions and the moisture penetration into the building.
- Foundation transmits the loads from the structure to the ground. It should be noted that the term “confined masonry” is also used in a general sense for different forms of masonry construction reinforced with additional steel, timber, or concrete elements, however those construction practices are outside the scope of this document.

## Wall layout

Since the earthquake performance of confined masonry buildings largely depends on the shear resistance of masonry walls, it is essential that a sufficient number and total length of walls be provided in each direction. To avoid twisting (torsion) of the building in an earthquake, the walls should be placed as far apart as possible, preferably at the exterior of the building.

## AT RISK: THE SEISMIC PERFORMANCE OF REINFORCED CONCRETE FRAME BUILDINGS WITH MASONRY INFILL WALLS

Authors: C. V. R. Murty, Svetlana Brzev, Heidi Faison, Craig D. Comartin and Ayhan Irfanoglu. 2006

## About the Tutorial

This document is written for building professionals with two key objectives: 1) to improve the understanding of the poor seismic performance of reinforced concrete frame buildings with masonry infill walls, and 2) to offer viable alternative construction technologies that can provide a higher level of seismic safety. Causes for the unsatisfactory seismic performance of these RC frame

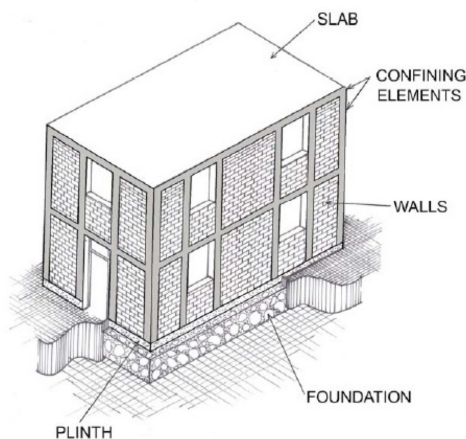


Figure 7. A typical confined masonry building



Figure 8. Performance of a confined masonry building in the 2007 Pisco, Peru earthquake



Figure 9. In-plane shear failure of poorly confined masonry walls in the 2010 Maule, Chile Earthquake

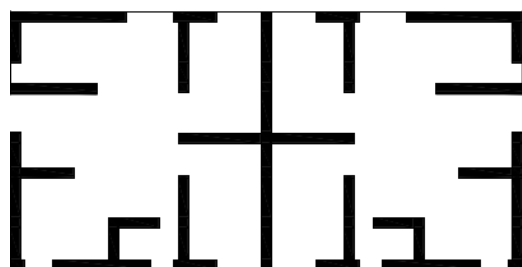


Figure 10. Wall distribution in plan with possibly adequate wall lengths in both N-S and E-W directions

buildings lie in (a) the poor choice of a building site, (b) the inappropriate choice of building architectural forms that offer poor seismic performance, (c) the absence of structural design for expected earthquake behavior, (d) the lack of special seismic detailing of key structural elements, (e) inadequately skilled construction labor, (f) poor quality building materials, and (g) the absence of construction supervision. The problem is aggravated further by the use of unreinforced masonry infill walls, usually made of clay bricks or hollow clay tiles. The effect of infills is usually not accounted for in the design, however these walls may significantly affect the way in which the building responds to earthquake ground shaking and may even cause the building to collapse (as reported often after several major earthquakes worldwide). In general, achieving satisfactory seismic performance of RC frame buildings subjected to several cycles of earthquake ground shaking is considered to be a challenge even in highly industrialized countries with advanced construction technology.

Keeping these challenges in mind, this document proposes two alternative building technologies characterized by a higher level of seismic safety at a comparable cost and construction complexity to RC frame construction; these technologies are confined masonry construction and RC frame construction with RC shear walls. Considering the enormous number of existing RC frame buildings with infills in regions of moderate to high seismic risk across the world, this document also discusses some generic seismic retrofit strategies for these structures that may reduce associated risks. It is important that all those involved in the construction process understand how these buildings perform during earthquakes, what the key challenges are related to their earthquake safety, and what construction technology alternatives might be more appropriate. Authors of this document believe that better understanding of these critical issues will result in improved construction and retrofit practices for buildings of this type, reducing life and property losses in future earthquakes.

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## Masonry Infill Walls

There are two distinct approaches related to masonry infill walls in RC frame buildings. These are:

- To isolate the infills from the frame (must be designed as ductile frames), and



- To integrate the infills into the frame (must be designed as infilled ductile frames).

Each of these approaches requires different detailing and design practices for masonry infill walls. When masonry infill walls are to be isolated from the adjoining frame, two simple ways of ensuring the out-of-plane stability of masonry infill walls that are separated from the RC frame are:

- (a) To break the large masonry infill wall panels into smaller ones; this can be accomplished by providing stiff members made of wood or lightly reinforced concrete in vertical, diagonal and/or horizontal directions, and
- (b) To provide reinforcement in the infill walls; the reinforcement should be provided at regular spacing in the vertical and horizontal direction. Design codes in some countries (e.g., Indonesia) contain provisions on how to improve the out-of-plane performance of masonry infills without interfering with the frame members.

It is suggested to provide practical columns, that is, lightly reinforced RC columns of small cross-section with vertical steel bars loosely inserted into the beam at the top end, at regular intervals along the wall length and at the wall ends. This provision is illustrated in Figure 15. Isolating infills is not an easy task. It is difficult to maintain the gap between practical columns and the frame columns, and ensure that outside weather conditions do not affect the building interior. When masonry infill walls are to be integrated with the adjoining frame, horizontal steel anchors (dowels) need to be provided to tie the wall to the framing columns; these anchors need to be provided at regular spacing in order to ensure force transfer between the wall and the frame. When the wall panel length is large, a practical column should be provided to improve the out-of-plane resistance of the masonry infill wall. Again, it is not easy to reinforce the masonry walls made of solid clay bricks. It has been observed that reinforcing bars tend to corrode, dilate in size and crack the masonry walls. In some projects, stainless steel bars are used to avoid this problem. But, in general, no positive connection is provided between infills and the frame; they are simply built flush to the frame surface. [This is an unsafe practice.]

## IMPROVING THE SEISMIC PERFORMANCE OF STONE MASONRY BUILDINGS

Authors: Jitendra Bothara, Svetlana Brzev. 2011

### About the Tutorial

Durable and locally available, stone has been used as a construction material since ancient times. 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 housing construction in parts of the world where stone is locally available and affordable material.

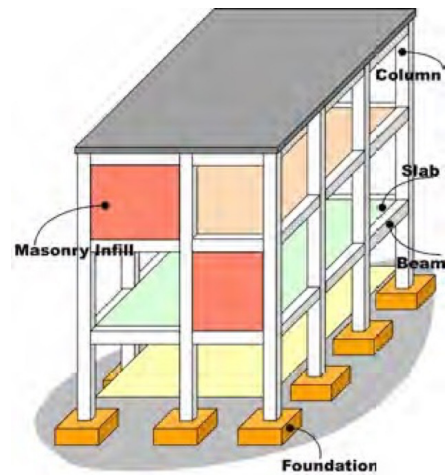


Figure 11. A typical RC frame building with masonry infills and its components

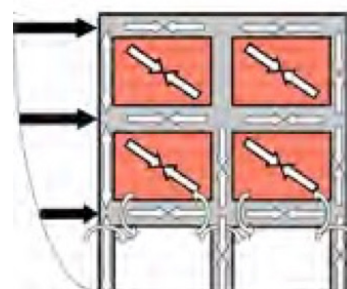


Figure 12. Typical brick infill wall construction in Turkey: masonry infill walls are added after the frame construction is complete



Figure 13. Infill walls influence the behaviour of a RC frame: if the infills are absent at the ground floor level this modifies the load path, which is detrimental to earthquake performance causing a soft storey

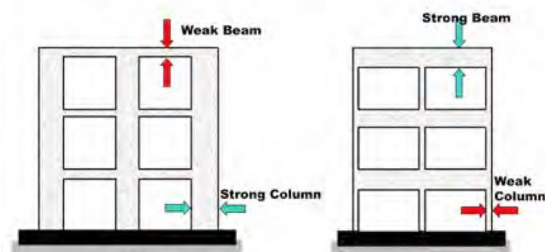


Figure 14. The beams must be designed to act as the weak links in a RC frame building; this can be achieved by designing columns to be stronger than beams

Traditional stone masonry dwellings have proven to be extremely vulnerable to earthquake shaking, thus leading to unacceptably high human and economic losses, even in moderate earthquakes. The seismic vulnerability of these buildings is due to their heavy weight and, in most cases, the manner in which the walls have been built. Human and economic losses due to earthquakes are unacceptably high in areas where stone masonry has been used for house construction. Both old and new buildings of this construction type are at risk in earthquake-prone areas of the world.

This document explains the underlying causes for the poor seismic performance of stone masonry buildings and offers techniques for improving it for both new and existing buildings. The proposed techniques have been proven in field applications, are relatively simple, and can be applied in areas with limited artisan skills and tools. The scope of this tutorial has been limited to discussing stone masonry techniques used primarily in the earthquake-prone 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, such as Europe. For more details on global stone masonry housing practices, readers are referred to reports published in the World Housing Encyclopedia ([www.world-housing.net](http://www.world-housing.net)).

The authors of this document believe that by implementing the recommendations suggested here, the risk to the occupants of non-engineered stone masonry buildings and their property can be significantly reduced in future earthquakes. This document will be useful to building professionals who want to learn more about this construction practice, either for the purpose of seismic mitigation or for post-earthquake reconstruction.

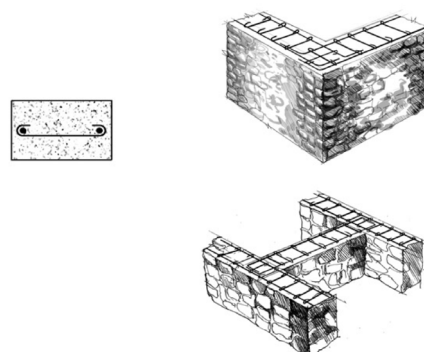
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*Figure 15. Construction of an uncoursed random rubble stone wall in Maharashtra, India*



*Figure 16. Reinforcement layout in RC bands*

## 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.

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