Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 1627

NON-DUCTILE REINFORCED CONCRETE FRAME CONSTRUCTION AND ALTERNATIVE BUILDING TECHNOLOGIES FOR REGIONS OF HIGH SEISMIC RISK

Svetlana Brzev[1]

ABSTRACT

This presentation provides an overview of the challenges related to the design and construction of reinforced concrete (RC) frame buildings in areas of high seismic risk, and discusses sustainable alternative construction technologies. RC frame construction is frequently used in regions of high seismic risk across the world. And yet, past earthquakes have revealed major seismic deficiencies in these buildings, some of which led to catastrophic collapses, resulting in thousands of deaths. Causes for the unsatisfactory performance lie in the absence of special seismic detailing of key structural elements, inadequate material quality, absence of construction supervision, and/or inadequate design. The problem is further aggravated by the use of unreinforced masonry infill walls, which are typically not accounted for in the seismic design of these buildings. In fact, these walls significantly affect the way in which the building responds to earthquake ground shaking and often cause inadequate seismic performance.

The author proposes confined masonry as an alternative building technology characterized by a higher level of seismic safety than non-ductile RC frame construction, which can be achieved at a comparable cost and construction complexity. The discussion will address the challenges associated with modifying established construction practices and introducing new building technologies such as confined masonry. One of the challenges is associated with developing and enforcing codes and standards for the design and construction of confined masonry. A global guideline titled Seismic Design Guide for Confined Masonry Buildings (EERI, 2009) was developed to address this challenge. It is expected that the guideline will have a positive impact on reducing seismic risk in the countries where RC frame construction could be substituted by confined masonry.

[1] Department of Civil Engineering, British Columbia Institute of Technology, 3700 Willingdon Avenue, Burnaby, BC, V5G 3H2, Canada
[2] UNAM, Ciudad Universitaria, Mexico, DF 04510, Mexico

Background

The use of reinforced concrete (RC) construction in the modern world stems from the wide availability of its ingredients - reinforcing steel as well as concrete. The most common type of RC construction for housing is in the form of cast in-situ frames with concrete floor and roof systems. These three-dimensional RC frames are made functional for habitation by building walls called infill walls. These walls are built after the concrete frame construction has been completed; reinforcement and anchorage to the adjacent frame elements (beams and columns) is usually not provided. The infills can be constructed by using a variety of masonry units: clay bricks or hollow clay tiles, hollow or solid concrete blocks, etc.

RC frames are frequently used for construction of residential and commercial buildings in regions of high seismic risk, such as Latin America, southern Europe, North Africa, Middle East and Southeast Asia. Detailed reports on RC frame construction practices in these countries are available in the World Housing Encyclopedia (WHE) (EERI/IAEE 2000). Recent earthquakes across the world, including the 1999 Izmit and Ducze earthquakes in Turkey, the 2001 Bhuj earthquake in India, the 2001 Chi Chi earthquake in Taiwan, the 2003 Boumerdes earthquake in Algeria, and the recent 2008 Sichuan, China earthquake revealed major seismic deficiencies in these buildings, some of which led to catastrophic collapses causing death tolls measured in thousands.

Causes for the unsatisfactory performance lie in the absence of special seismic detailing of key structural elements, inadequate material quality, absence of construction supervision, and/or inadequate design by architects and engineers without formal training in seismic design. The problem is aggravated further by the use of unreinforced masonry infill walls. In usual design practice, the effect of infills is not accounted for. But, these walls significantly affect the way in which the building responds to earthquake ground shaking and may cause significant torsional effects. Challenges associated with the construction of RC frames in areas of high seismic risk are discussed by Murty et al. (2006) and Brzev et al. (2008).

There are at least two alternative building technologies which are expected to ensure a higher level of seismic safety than the non-ductile RC frame building system with masonry infills; these are confined masonry and RC frames with shear walls. Confined masonry is intended for low- to medium-rise buildings and it is discussed in detail in this presentation, while the RC shear wall systems are mostly used for high-rise construction.

Confined Masonry Construction

Confined masonry construction consists of masonry walls (made either of clay bricks or concrete block units) and horizontal and vertical RC confining members built on all four sides of a masonry wall panel. Vertical members, called tie-columns, resemble columns in RC frame construction except that they tend to be of far smaller cross-sections. Horizontal elements, called tie-beams, resemble beams in RC frame construction, as shown in Figure 1. In worldwide applications, confined masonry is used for non-engineered low-rise construction (one- to two-storey buildings) and also for engineered construction such as medium-rise apartment buildings (up to six storeys high). For a detailed discussion on the basic concepts and global applications of confined masonry constructions refer to Brzev (2008).

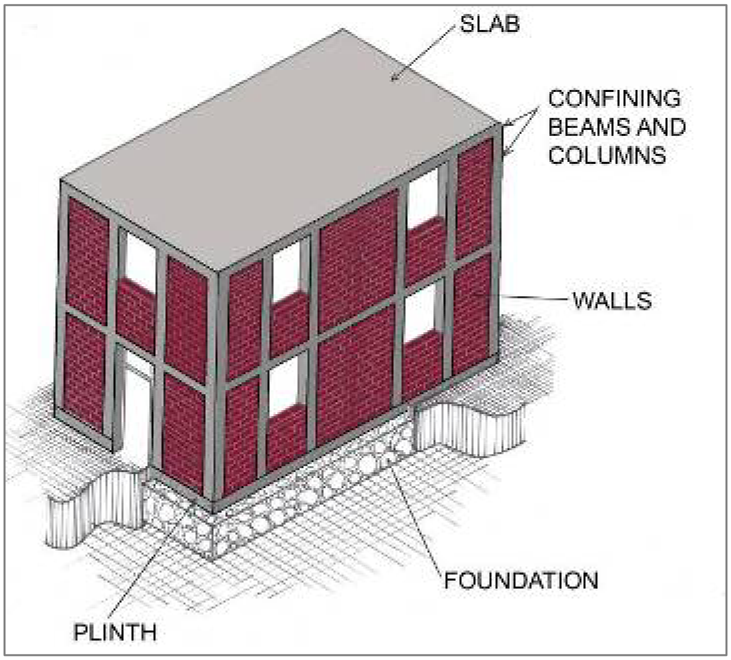

Figure 1. A typical confined masonry building.

The appearance of a finished confined masonry construction and a RC frame construction with masonry infills may look alike to lay people, however these two construction systems are substantially different. The main differences stem from the construction sequence illustrated in Figure 2 and the manner in which these structures resist gravity and lateral loads. In confined masonry construction, confining elements are not designed to act as a moment-resisting frame; as a result, detailing of the reinforcement is less intricate. In general, confining elements have smaller cross-sectional dimensions than the corresponding beams and columns in a RC frame building. It should be noted that the most important differences between confined masonry walls and infill walls is that infill walls are not load-bearing walls, while the walls in a confined masonry building are load-bearing walls. A transition from RC frame to confined masonry construction in most cases leads to savings related to concrete cost, since confining elements are smaller in size than the corresponding RC frame members. Also, less reinforcement and less intricate detailing is required for confined masonry construction than for RC frame construction. Therefore, in this case “less means more”. For practical design guidelines related to confined masonry construction refer to Blondet (2005).

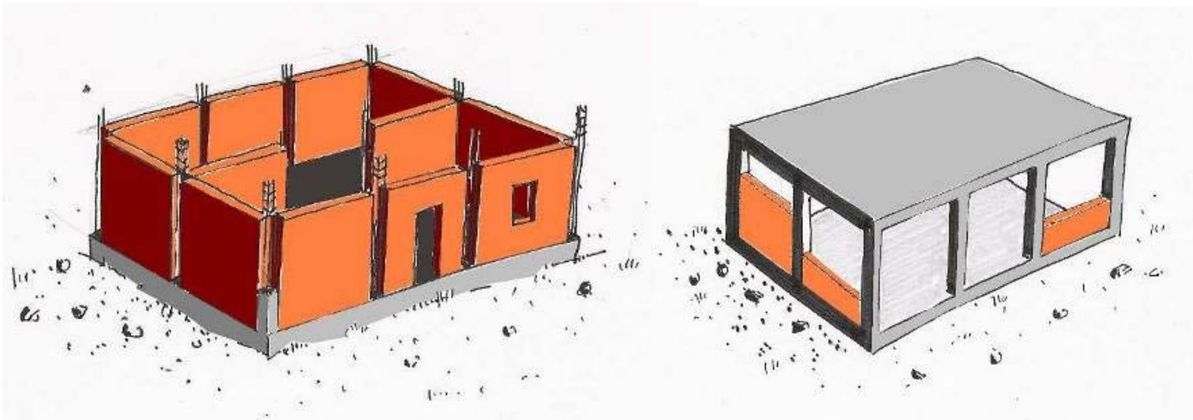

Figure 2. Confined masonry construction (left) and RC frame construction (right) (Credit: Tom Schacher).

Confined masonry buildings have demonstrated satisfactory performance in past earthquakes. In general, buildings of this type do experience some damage in earthquakes, however when properly designed and constructed they are able to sustain earthquake effects without collapse. Confined masonry construction has been exposed to several major earthquakes in Latin America: the 1985 Llolleo earthquake in Chile (magnitude 7.8) (Moroni et al. 2004); the 1985 Guerrero-Michoacan (magnitude 8.0) (Schultz, 1994) and the 2003 Tecoman (magnitude 7.6) earthquakes in Mexico (EERI, 2006); the 2001 El Salvador earthquakes (magnitude 7.6 and 6.6) (Dowling, 2004); the 1970 Chimbote (magnitude 7.0) and the 2007 Pisco (magnitude 8.0) earthquakes in Peru (EERI, 2007). The reconnaissance reports have confirmed that confined masonry buildings had performed very well in these earthquakes. It should be noted that this statement applies to buildings regular in plan and elevation, which are lightly loaded and have rather large wall density. In such cases, confined masonry tends to be quite forgiving of minor design and construction flaws, as well as material deficiencies. Poor seismic performance has been noted only when gross construction errors, design flaws, or material deficiencies have been introduced in the building design and construction process. Poor performance is usually associated with tie-column omissions, discontinuous tie-beams, inadequate diaphragm connections, and inappropriate structural configuration. Confined masonry has demonstrated similar seismic performance in a few other countries, including China, Indonesia, and Iran. For further information on the mechanisms of seismic load resistance and the seismic performance of confined masonry construction refer to Brzev (2008).

To promote the wider use of this technology, the author has participated in developing a global design guideline Seismic Design Guide for Confined Masonry Buildings, which will be referred to as the Guide in this paper (EERI, 2009). The Guide was developed by a group of international earthquake engineering experts with experience and interest in confined masonry construction. The recommendations are based on design and construction experience and research studies from countries and regions where confined masonry construction has been practiced for several decades, including Mexico, Peru, Chile, Argentina, Iran, Indonesia, China, Algeria, and Slovenia. References to relevant provisions of international standards and codes have been made in the Guide.

The purpose of the Guide is to:

- Explain the mechanism of seismic response of confined masonry buildings for in- and out-of-plane seismic effects and other relevant seismic response issues,
- Recommend design provisions related to the layout and wall density, and prescribe minimum size requirements for structural components of confined masonry buildings (tie-columns, tie-beams, walls), reinforcement size and detailing in the form of prescriptive provisions for low-rise buildings (1- to 2- stories high),
- Recommend rational procedures for seismic design of medium-rise buildings up to 4-5 stories high, and
- Provide a summary of the seismic design provisions for confined masonry buildings from relevant international codes.

This Guide is expected to be useful to design engineers, academics, code development organizations and non-governmental organizations in countries that do not have seismic design provisions for confined masonry construction. However, the document may also be a useful reference for design engineers and other professionals in the countries that have codes which address confined masonry construction. Refer to Brzev and Meli (2010) for a detailed overview of the Guide.

References

Blondet, M. (2005). Construction and Maintenance of Masonry Houses – For Masons and Craftsmen, Pontificia Universidad Catolica del Peru, Lima, Peru (free download available at www.world-housing.net).

Brzev, S. and Meli, R. (2010). Development of Global Design Guideline for Confined Masonry Buildings in Regions of High Seismic Risk, Proceedings of the 9th US National and 10th Canadian Conference on Earthquake Engineering, Toronto, Canada (accepted for publication).

Brzev S., Greene, M., and, Murty, C.V.R (2008). Non-Ductile RC Frames and Alternative Improved Construction Technologies, Proceedings of the 14th World Conference on Earthquake Engineering, Beijing, China.

Brzev, S. (2008). Earthquake-Resistant Confined Masonry Construction, National Information Center for Earthquake Engineering, Kanpur, India (www.nicee.org)

Dowling, D.M. (2004). Adobe Housing Reconstruction after the 2001 El Salvador Earthquakes, Lessons Learned Over Time - Learning From Earthquakes Series, Volume 5, Earthquake Engineering Research Institute (EERI), Oakland, California, 69 pp.

EERI (2009). Seismic Design Guide for Confined Masonry Buildings, Earthquake Engineering Research Institute, Oakland, California (draft version).

EERI (2007). The Pisco, Peru Earthquake of August 15, 2007, EERI Special Earthquake Report, Newsletter, Earthquake Engineering Research Institute, Oakland, California, October 2007.

EERI (2006). The Tecomán, México Earthquake January 21, 2003, An EERI and SMIS Learning from Earthquakes Reconnaissance Report, Technical Editors S.M. Alcocer and R.E. Klingner, Earthquake Engineering Research Institute, Oakland, California, March 2006.

EERI/IAEE (2000). World Housing Encyclopedia, Earthquake Engineering Research Institute and the International Association for Earthquake Engineering (www.world-housing.net).

Moroni, M.O., Astroza, M., and Acevedo, C. (2004). Performance and Seismic Vulnerability of Masonry

Housing Types Used in Chile, Journal of Performance of Constructed Facilities, ASCE, Vol.18, No.3, pp.173-179.
Murty, C.V.R, Brzev, S., Faison, H., Comartin, C.D., and Irfanoglu, A. (2006). At Risk: The Seismic Performance of Reinforced Concrete Frame Buildings with Masonry Infill Walls, Earthquake Engineering Research Institute, Publication No. WHE-2006-03, First Edition, 70 pp. (free download available at www.world-housing.net).
Schultz, A. E. (1994). Performance of Masonry Structures During Extreme Lateral Loading Events, Masonry in the Americas, ACI Publication SP-147, American Concrete Institute, Detroit, pp.21-55.