International Journal of Disaster Risk Reduction 7 (2014) 51–67

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Review Article

A critical review of retrofitting methods for unreinforced masonry structures

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ARTICLE INFO

Article history:
Received 26 March 2013
Received in revised form
6 December 2013
Accepted 9 December 2013
Available online 19 December 2013

Keywords:
Unreinforced masonry
Earthquake
Lateral loads
Brittle
Retrofit

ABSTRACT

Unreinforced masonry (URM) buildings are common throughout Latin America, the Himalayan region, Eastern Europe, Indian subcontinent and other parts of Asia. It has been observed that these buildings cannot withstand the lateral loads imposed by an earthquake and often fails, in a brittle manner. Methods for retrofitting URM buildings to increase the time required for collapse and also to improve the overall strength widely vary. This review has collated information on various types of retrofitting methods either under research or early implementation. Furthermore, these methods are categorized and critically analyzed to help further understand which methods are most suitable for future research or application in developing countries. The comparison of the different methods is based on economy, sustainability and buildability and provides a useful insight. The study may provide useful guidance to policy makers, planners, designers, architects and engineers in choosing a suitable retrofitting methodology.

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2212-4209/$ - see front matter
http://dx.doi.org/10.1016/j.ijdrr.2013.12.004

1. Background to the problem

Earthquakes are results of the deformations of tectonic plates on two sides of a fault resulting from the tendency of relative displacement between the two tectonic plates. These deformations take place over the years, strain energy keeps on accumulating in the tectonic plates. Finally, a slip occurs at the fault when the plates slips back to their original undeformed shape suddenly releasing a tremendous amount of energy. The above process generates earthquakes as per the classical elastic rebound theory. Such earthquakes are called inter-plate earthquakes. However, if there is a weak zone in the plate itself then during the process of accumulation of deformation, a crack may suddenly occur resulting in instantaneous energy release. This also causes earthquake known as intra-plate earthquake. Further, volcanic eruption and removal of mineral ores without adequate protective measures may also be the reasons for generation of earthquake. However, irrespective of the cause of the earthquake, the consequences can be devastating to human lives, see for example Table 1, which lists the casualties from a few past major earthquakes. For some developing countries, there exists a vicious cycle whereby they do not possess the wealth to develop their infrastructure sufficiently to withstand the damages caused by earthquakes and conversely, earthquake damage affects them from developing their economy.

Table 1
Earthquakes causing the greatest number of casualties in the last 100 years.

Year	Location	Casualties
1908	Messina (Italy)	70,000 to 100,000
1920	Gansu (China)	200,000
1923	Kanto (Japan)	143,000
1927	Qinghai (China)	200,000
1932	Gansu (China)	70,000
1948	Ashgabat (Turkmenistan)	110,000
1970	Peru	66,000
1976	Tangshan (China)	255,000
2001	Gujarat (India)	20,000
2003	Bam (Iran)	30,000
2004	Sumatra (Indonesia)	220,000
2005	Kashmir (Pakistan)	73,000
2008	Sichuan (China)	69,197
2010	Haiti	230,000
2011	Sikkim (India–Nepal border)	150

1.1. *Importance of studying unreinforced masonry (URM)*

Earthquakes are one of the most deadly forms of natural disaster, yet human fatality does not occur directly because of ground motions; people die as a result of falling structure. A vast amount of research has been carried out over the last few decades to prevent the collapse of tall buildings, resulting in new building codes and guidelines being written. Such structures are found in wealthy countries and are now reasonably designed for seismic loading that they do not cause many casualties. However, in rural areas of developing countries where people are generally poor and equipped with little knowledge of engineering or construction, very little work has been done to help protect housing against the dangers of earthquakes. In these areas masonry becomes the major form of habitat. These remote areas are difficult to reach for the emergency services meaning that most of the fatalities will occur at the time of the earthquake as rescue is very unlikely. However, the sustainability of masonry structures has been questioned during past earthquakes. These structures perform well under gravity loading due to satisfactory compression carrying capacity of masonry. However, it is a challenging task for the engineering community to improve the shear and tension carrying capacity of masonry structures for achieving better sustainability of such structures during earthquakes. It is therefore vitally important that the engineering community is made aware of this problem, because solving it will save hundreds of thousands of lives.

A history of exposure to the effects of serious earthquakes has allowed the engineering community to progressively increase its knowledge of how buildings respond to seismic activity. Fig. 1 shows how the world has been subjected to large number of earthquakes whose epicenters are distributed all over the world. Table 2 shows