Engineering Structures 106 (2016) 53–67

Contents lists available at ScienceDirect

Engineering Structures

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

Failure of masonry structures in earthquake: A few simple cost effective techniques as possible solutions

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ARTICLE INFO

Article history:
Received 13 August 2014
Revised 30 September 2015
Accepted 9 October 2015
Available online 11 November 2015

Keywords:
Masonry structures
Earthquake hazard mitigation
Shaking table tests
Low cost
Strengthening

ABSTRACT

Masonry structures have exhibited their extreme vulnerability even in the event of past minor to moderate earthquakes. Junction failure followed by out-of-plane collapse of the wall orthogonal to the direction of strong shaking is the reason of failure of small masonry building structures as shown in a recent literature. In this context, present study makes an attempt to examine the efficacy of a few strengthening techniques of such structures verified through testing a large number of small scale models on shake table. Techniques being cost effective and easy to implement may prove useful in improving seismic performance. Large number of experimental results presented in this study may help in choosing one of the suitable techniques depending on specialties of a particular local condition.

1. Introduction

Unreinforced masonry (URM) is the oldest and most widely used construction material in the world due to esthetics, economy, ease in construction, architectural appearance, fire resistance and effective heat and sound insulation. Unreinforced low-rise masonry building is the popular form of habitat in most of the developing countries. URM walls are the prime load carrying components of masonry buildings. Corner/junction failure and out-of-plane wall failure are the most common type of failure observed in these structures during earthquakes. Fig. 1 presents a few such exemplary cases in India and other countries. The reason may be due to poor interlocking between orthogonal walls. Reasons of severe seismic damage of such structures were examined through post earthquake based damage surveys and were reported in a recent paper [3]. This study clearly indicates that out-of-plane collapse proceeded by separation of the wall resulting from failure of its junction with in-plane walls is the reason of failure of such structures. Such failure mechanism is needed to be arrested by some strengthening mechanism. This study reported a very limited number of experimental results indicating the possibility of a fruitful use of L-shaped horizontal dowel bars and poly propylene (PP) bands. These possibilities are needed to be established in terms of at least broad quantified benefit. Present study not only aims to achieve the same but also explore the possibility of steel wire mesh for similar improvement in behavior. Further, using more than such feasible technique may lead to larger benefit. Keeping these views in the mind such possibilities are also studied. All these studies require less cost as well as normal artisanal skills.

Strengthening of URM structures is a challenge for engineers to minimize the human loss, economic loss and loss of history due to the failure of such structures. The use of different strengthening mechanism to strengthen URM walls is primarily for avoiding brittle failure and increasing the strength, stiffness and ductility and also maintaining integrity of the walls. Generally most of the strengthening techniques used for URM walls are visually intrusive and too costly for application. Retrofitting method proposed in most of the developing countries for strengthening of unreinforced masonry (URM) should be able to take care of the structural demand in terms of strength and deformability. The material chosen should be available easily and should also be low cost from view point of manufacturing and delivery, too.

Quite a good number of researches [4–19] were carried on the issue of strengthening of masonry walls using carbon or glass fiber reinforced polymers (CFRP or GFRP). The study revealed that application of FRP to URM walls resulted with significant increase in ultimate capacity, energy absorption and deformability but the considerable increase in cost and expertise required for application make it difficult for many developing countries like India.

Besides composite materials, few other materials were also used in strengthening URM walls. Taghdi et al. [20] reported that

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http://dx.doi.org/10.1016/j.engstruct.2015.10.014
0141-0296/

Fig. 1. Collapse/damage of unreinforced masonry buildings: (a) corner/junction failure in Uttarkashi earthquake, 1991 (NICEE, [1]) and (b) out-of-plane wall failure in Pakistan earthquake, 2005 (EERI, [2]).

steel strip system was effective in increasing the in-plane strength, ductility and energy dissipation capacity of low-rise masonry and concrete walls being subjected to lateral loading. In a study carried out by Murty et al. [21] revealed that use of twin lintel belt in steel along with vertical corner reinforcement is effective in enhancing the seismic performance of single-storey masonry building.

Another study [22] by using scrap tyre for strengthening masonry houses, showed that strength of the retrofitted model was improved up to 2 times compared to the non-retrofitted one, leading to the increase in damping ratio, energy consumption characteristics of the masonry. Maalej et al. [23] used Engineered Cementitious Composite (ECC) to enhance the out-of-plane resistance of URM walls subjected to quasi-static and dynamic loading. Ma et al. [24] reported that introduction of external pre-stressing was effective in improving flexural resistance, torsional resistance, energy dissipation capacity and overall stiffness of masonry structures. Strengthening of URM walls by using poly propylene (PP) band was experimentally investigated by Mayorca and Meguro [25], Macabuag et al. [26], and Sathiparan and Meguro [27]. The study revealed that, though the peak strength of the structure was not increased by the application of PP band but performance of the wall after crack propagation was significantly increased. It was also reported that use of PP band in retrofitting prevents loss of materials and maintains wall integrity for large deformations leading to enhancement of the safety even against worst-case earthquake scenario. The effectiveness of PP band in significant increase in seismic performance of masonry structure was satisfactory. It was also reported [28] that, use of rubber granulate soft layers may enhance the seismic performance of URM walls.

Indian codes [29–31] and international standards [32,33] also recommend some guidelines regarding design, construction, repair and strengthening of URM buildings. BIS [29,30] specifies the guidelines for openings and provision of longitudinal and vertical reinforcement in masonry walls for better seismic performance. Interestingly there is hardly any study on the quantitative aspect of improvement in strength and other aspects. It is clearly understood that use of steel lintel belt, scrap tyre, cementitious composites, or external pre-stressing are costly techniques. So, these are difficult for implementation in mass scale at least in developing countries as all these require sophisticated equipment and skilled manpower. On the other hand, use of PP band may have a beneficial effect despite being cheap and easy to implement. At this backdrop, the present paper is an effort to judge the efficacy of a few low cost retrofitting techniques including the use of PP band. The present study can be regarded as a follow up exploring the possibilities observed in a previous study [3] along with a few more new techniques for seismic strengthening of masonry building. The retrofitted materials (PP band, steel wire mesh and reinforcing bars) used in here are low cost as well as easily applicable without requiring sophisticated equipment and technical manpower for implementation. Scaled models are constructed using half size bricks having dimensions (120 mm × 57 mm × 35 mm) which are half of the dimensions of traditional size. The details of the property of the materials (brick, mortar, PP band, steel wire mesh and reinforcing bars) used are discussed below in subsequent sections. Testing of both URM and retrofitted walls of three different types, namely, free standing, L-shaped and assembly of four walls were carried out using shake table. Effectiveness of strengthening techniques (applied individually and simultaneously) and nature of failure were studied in details for different cases. This study may be of help for framing guidelines for seismic safety of masonry structures.

2. Experimental program

2.1. Seismic behavior of masonry structures

Horizontal shear failure, corner/junction failure and failure of out-of-plane walls initiated by junction failure are the most common type of failure in unreinforced masonry structures when subjected to seismic excitation. Corner/junction is identified as the weakest portion of such structures. It is needed to improve the integrity of the structures to behave as a single unit and to ensure proper interlocking between orthogonal walls to reduce the causalities during earthquake. Such issue is discussed in details by D'Ayala [34], Murty [35,36], etc. Keeping in view of the above mentioned facts, the present study tried to use PP band, steel wire mesh and reinforcing bars to strengthen URM walls for achieving better seismic performance. Use of PP band and wire mesh help to improve the integrity of the structures. Horizontal reinforcing bars ensure proper interlocking between orthogonal walls.

2.2. Materials used

Half size (120 mm × 57 mm × 35 mm) bricks were used instead of using traditional brick (245 mm × 114 mm × 70 mm) for the construction of the models to simulate a realistic ratio between the dimensions of structural elements and the dimensions of brick. The half brick used for construction of the models was of class 10