Construction and Building Materials 178 (2018) 195–203

Contents lists available at ScienceDirect

Construction and Building Materials

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

In-plane behaviour of unreinforced masonry panel strengthened with welded wire mesh and mortar

C. Shermi [a,b,*], R.N. Dubey [a]

[a] Earthquake Engineering Department, Indian Institute of Technology Roorkee, Roorkee, India
[b] Central Building Research Institute, Roorkee, India

HIGHLIGHTS

- Effectiveness of a commonly used strengthening technique for unreinforced masonry is examined for its in-plane behaviour.
- The presented technique is economical and easy to use.
- Increase in strength, and ductility was observed in strengthened URM specimen.

ARTICLE INFO

Article history:
Received 12 July 2017
Received in revised form 24 March 2018
Accepted 10 April 2018

Keywords:
Unreinforced masonry
In-plane behaviour
Welded wire mesh
Strengthening
Ductility
Stiffness

ABSTRACT

About one third of the world population lives in unreinforced masonry (URM) structures, URM is certified as the most vulnerable building during earthquake. Hence there is a necessity to find a suitable economic solution to strengthen the URM structures so that they can resist earthquake load. The present experimental study aims at investigating the behaviour of URM and URM strengthened with welded wire mesh (WWM) as reinforcing material and 1:3 cement : coarse sand mortar. A series of 6 unreinforced masonry (URM) panels and 18 reinforced panels were constructed using two different types of mortar and were subjected to diagonal axial compression tests. Three types of WWM which are locally available in market have been used in this study. Test results show significant increase in strength, ductility, with useful suggestions for practical utilization of this technique.

1. Introduction

Unreinforced masonry (URM) structures are the most common and oldest form of building construction technique existing in the world. In most of the developed and developing countries masonry is still being widely used in practice due to its low cost and easy construction technique. URM is unquestionably recognized as the type of construction most vulnerable to earthquakes. Most of the existing URM buildings seem to be the oldest buildings which tend to be at great risk during earthquake. In most cases masonry structures are constructed without any consideration for seismic loading resulting in huge loss of life as experienced in the past earthquakes (Bhuj 2001, Kashmir 2005, Uttarkashi 1991, Killari 1993). During earthquake, URM buildings experience seismic loading both in-plane and out-of-plane. However, their relative magnitude depends on the type of diaphragm i.e., how the wall is connected with the roof.

The recent earthquakes have created a necessity to review the capability of existing structures during earthquake, and to find a suitable strengthening technique to strengthen a newly constructed masonry structure or to retrofit an existing old structure. Various rehabilitation and retrofitting techniques are available to enhance the seismic performance of URM buildings. These techniques include application of fiber reinforced polymers (FRP), ferrocement overlay (surface coating), shotcrete overlay, center core technique, grout injection, application of steel elements, bed joint reinforcement, post tensioning, etc. A review of various rehabilitation and retrofitting methods and their advantages and disadvantages may be found elsewhere [15,2,32,22,25,27,20,11,13,19,20,25,27,29,35]. These well-established techniques need to be verified for local materials and building system commonly used in practice. Among all available options, ferrocement overlay is a technique which is easy in application, rapid in construction and very low in cost, especially in developing countries with no heavy machinery and high-level

* Corresponding author at: Central Building Research Institute, Roorkee, India.
E-mail addresses: shermi@cbri.res.in (C. Shermi), dubeyfeq@iitr.ac.in (R.N. Dubey).

https://doi.org/10.1016/j.conbuildmat.2018.04.081
0950-0618/

Nomenclature

Symbol	Explanation
f_b	compressive strength of brick
f_c	compressive strength of mortar
f_m	compressive strength of masonry
t	thickness of the panel
L	length of the panel
H	height of the panel
P	diagonal force measured experimentally
τ	shear stress
ΔV	diagonal shortening along the axis of applied force
ΔH	diagonal elongation measured perpendicular to the axis of applied force
g	gauge length
γ	shear Strain
ρ_H	horizontal reinforcement ratio
ρ_V	vertical reinforcement ratio
p_{max}	maximum applied load
τ_{max}	maximum shear stress
d_y	yield drift
d_u	ultimate drift corresponding to 0.8τ
μ	ductility specimen damaged before testing

skilled workers. In this technique, steel welded wire mesh (WWM) is connected or anchored to the surface of masonry through bolts/ screws/ steel rods subsequently covered with plaster coating.

Strengthening of masonry using FRP, steel cord, steel grid, polymer grid etc. has been widely used in practice. In this study an attempt has been made to strengthen the URM using WWM and 1:3 mortar. Ferrocement is a commonly used strengthening system. This is a cementitious composite layer laminated with metallic mesh and has advantages such as a high tensile strength-to-weight ratio and superior cracking behaviour [35,30,25,8], [10], [21,31]. An extensive study has been carried out on usage of fibre reinforced cementitious material (FRCM) and textile reinforcement for strengthening/ retrofitting of masonry. Various researchers have studied the in-plane and out-of-plane behaviour masonry strengthened with FRCM and textile reinforcement [31,32,16,14,13,17,1,36]. The bond behaviour of fibre when bonded to masonry has also been studied by D'Ambrisi et al. [15].

Kadam [25] has previously used ferrocement as a strengthening material in URM using different reinforcement percentage and various anchoring technique and found that WWM along with micro concrete increases the in-plane shear capacity of masonry effectively. Prawel [33] showed that ferrocement overlays increased the efficiency of diagonal tensile strength, stiffness and deformation capacity of masonry panels. The strength enhancement in brick masonry columns by encasing with precast ferrocement revealed that the cracking and failure stresses of column with precast ferrocement jackets have substantially been increased compared to control specimens while exhibiting much ductile response. Ferrocement is found to be an effective system in out-of-plane strengthening of unreinforced two-way masonry walls.

Very few studies are available in strengthening of masonry with ferrocement, but a considerable number of researches have been carried out in reinforced concrete structures with ferrocement. It is evident from literature that ferrocement is an effective material for strengthening of both masonry and concrete [33]. It is found to be most effective and economical, easy to use and like FRP reinforcement it does not require application of epoxy.

Textile reinforced mortar is another promising technique for masonry retrofit which combines the advantages of both conventional and modern techniques [32]. In this technique textile grid of fibres is bonded to the surface of masonry using specially developed mortars. The grid form of the fibres has similarity with WWM and results in good bond with the masonry.

2. Experimental program

2.1. Material properties

Tests were performed to characterize the mechanical properties of the material used in this investigation. Two types of cement sand mortar ratio (1:4 and 1:6) which are widely used in practice in India have been chosen for this study. The test samples were constructed using brick of size 230 mm × 110 mm × 70 mm. The masonry test samples of set 1,3,4 and 5 were constructed using 10 mm thick 1:4 cement sand mortar and sample set 2,6,7 and 8 were constructed using 1:6 cement sand mortar as per conventional construction practice with the help of a local mason. English bond with alternate header and stretcher was used to construct the masonry samples. Mechanical properties of the materials were studied as per ASTM standards. Compressive strength test of mortar cube was carried out as per ASTM C109-11 [3]. The compressive strength of brick was obtained in accordance with ASTM C67-11 [6] and compressive strength of masonry was estimated in accordance with ASTM C1314-11 [4]. The tensile strength of WWM was obtained as per ASTM A370-11 [7]. The test results are represented in Tables 1 and 2.

2.1.1. Mixing, casting and curing of masonry specimens

The in-plane shear behaviour of URM panels of two types of mortar ratio (1:4 and 1:6) and masonry panels strengthened with welded wire mesh (25 mm, 38 mm, 50 mm spacing) and cement mortar. The descriptions of test samples are given in Table 3. Eight unreinforced specimen and twenty four reinforced specimens were tested under in-plane shear. Different cement sand mortar ratio (1:4 and 1:6) which are commonly used in India have been chosen for this study. WWM of various spacing 25 mm; 38 mm; 50 mm which are commonly available in local market were chosen as reinforcement to strengthen URM. The WWM was reinforced

Table 1
Mechanical properties of masonry.

Property	Standard Test Reference	Average Value	COV
Compressive strength of brick (f_b)	ASTM C67-11	10 N/mm^2	15.23%
Cube compressive strength of 1:4 cement-sand mortar (f_c)	ASTM C109/C109M-11	2.5 N/mm^2	13.25%
Cube compressive strength of 1:6 cement-sand mortar (f_c)	ASTM C109/C109M-11	1.45 N/mm^2	15.5%
Compressive strength of 1:4 brick masonry (f_m)	ASTM C1314-11	3.95 N/mm^2	14.2%
Compressive strength of 1:6 brick masonry (f_m)	ASTM C1314-11	2.17 N/mm^2	12.24%
Elastic modulus of 1:4 brick masonry (E_m)	ASTM C1314-11	2540 N/mm^2	14.2%
Elastic modulus of 1:6 brick masonry (E_m)	ASTM C1314-11	2280 N/mm^2	12.24%