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Aseismic retrofitting of unreinforced masonry walls using FRP

Mohamed A. ElGawady*, Pierino Lestuzzi, Marc Badoux

Swiss Federal Institute of Technology at Lausanne EPFL, Ecole Polytechnique Fédéral de Lausanne (EPFL-ENAC-IS-IMAC), Lausanne 1015, Switzerland

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Abstract

Many of existing unreinforced masonry (URM) buildings are seismically vulnerable and require retrofitting. This paper investigates in-plane seismic behaviour of URM walls before and after retrofitting using fiber-reinforced polymers (FRP). Dynamic in-plane tests were carried out on five half-scale specimens with two different effective moment/shear ratios namely 0.7 and 1.4. The specimens were retrofitted on a single side using different types and structures of FRPs. The test specimens were subjected to a series of synthetic earthquake motions on a uni-axial earthquake simulator. The retrofitting technique improved the lateral strength and stiffness of the URM walls. Moreover, the fundamental frequency and the initial stiffness of each specimen remained approximately constant before and after retrofitting. During the test, the slender specimens failed in flexural. For specimens failed in flexural, the measured FRP axial strains showed that the strain distributions along the specimens' cross-sections are approximately linear even at failure. Hence, the flexural strengths of the specimens were calculated using linear elastic approach. The measured lateral resistances of slender specimens are approximately 130% of the calculated flexural strength. This difference attributed to the difference in the nominal ultimate strains of FRPs and the real values at failure. The measured axial strains in FRPs during this test were approximately 50% of its nominal values. In addition, the shear strengths of the squat specimens were calculated using two different models. The calculated shear strengths approximately range from 99 to 177% of the measured lateral resistances.

Keywords: Seismic retrofitting

1. Introduction

Existing unreinforced masonry (URM) buildings constitute a significant portion of existing buildings around the world. Recent earthquakes have repeatedly shown the vulnerability of URM buildings. Moreover, based on modern design codes most of the existing URM buildings need to be retrofitted. For example, in Switzerland, a recent research [1] carried out on a target area in Basel shows that from 45 to 80% of the existing URM buildings, based on construction details, will experience heavy damage or destruction during a moderate earthquake event. This brought to light the urgent need to improve and develop better methods of retrofitting for existing seismically inadequate. The main structural elements that resist earthquakes in these buildings are the old URM walls URM buildings. Several conventional techniques are available to improve seismic performance of existing URM walls. Surface treatments (ferrocement, shotcrete, etc.), grout injections, external reinforcement, and center core are examples of such conventional techniques. Several researchers (e.g. [2]) have discussed the disadvantages of these techniques: available space reduction, architecture impact, adding heavy mass, corrosion potential, etc. Modern composite materials offer promising retrofitting possibilities for masonry buildings and present several well-known advantages over existing conventional techniques. A recent literature review for using of composites for retrofitting of URM walls have been presented in [3]. This paper presents a pioneer dynamic in-plane tests carried out on half-scale single leaf unreinforced masonry walls retrofitted with composites (URM-WRC). The objective of this study was to

* Corresponding author. Present address: Civil and Environmental Engineering Department, The University of Auckland, Private Bag 92019, Auckland, New Zealand. Tel.: +64 9 373 7599; fax: +64 9 373 7462.

E-mail address: melg003@ec.auckland.ac.nz (M.A. ElGawady).

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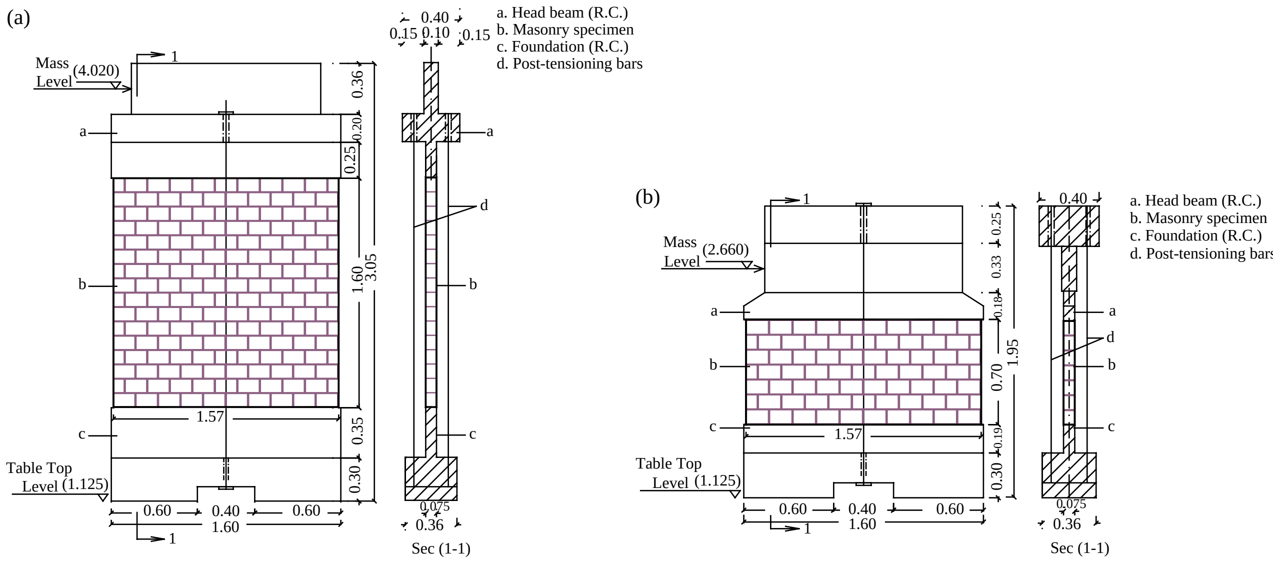

Fig. 1. Specimens dimensions in meter, (a) slender and (b) squat.

compare the seismic behavior of URM walls before and after retrofitting with composites. Another objective was to examine the ability of existing simple analytical models to predict the lateral strength of URM-WRC.

2. Experimental program

2.1. Test specimens

The test specimens had two aspect ratios (Fig. 1): slender walls and squat walls; also, two mortar types were used: weak (M2.5) and strong (M9). In addition, different types of FRP (Table 1) and retrofitting configuration (Figs. 2 and 3) were used to retrofit the specimens. Anchorage failure of the FRP was prevented by clamping the FRP ends to specimen's footing and cap beam using steel plates and screw bolts (since anchorage problem is out of the scope of this research). Both the cap beam and footing pad were pre-cast reinforced concrete.

The test walls were tested twice: first, the URM specimens were tested, as reference specimens, till a pre-defined degree of damage; secondly, these reference specimens were retrofitted using composites and retested. The focus of this paper is on the comparisons between the retrofitted and URM specimens. More details about the behavior of the URM specimens are presented in [4]. The specimens were retrofitted on a single side only. This way of retrofitting was successfully used in different research programs for retrofitting of URM walls using composite material (e.g. [5]).

Each specimen is designated by a name that reflects their characteristics; Tables 2 and 3 explain the specimens' names and give a complete list of the tested specimens. For instance, L1-WRAP-G-X means a slender specimen (L) which was constructed using mortar type (1) and was retrofitted with fabric (WRAP) of glass (G) fiber in a diagonal (X) configuration. Also, Figs. 2 and 3 show summary of the tests that were carried out on the specimens. It should be noted that specimen L1-LAMI-C-I where a virgin URM specimen was upgraded with two vertical plates of CFRP was designed to study the shear resistance of slender URM walls rather to investigate the effect of using vertical plates as retrofitting of existing URM walls. Since, in this specimen and in order to force a shear failure, the flexural strength of the specimen was increased with minimal increment in its shear strength. As such, this specimen herein after is considered as a reference

Table 1
FRP used in the experimental program

Commercial name	FRP (Fiber)	$Warp_W$ (g/m^2)	$Weft_W$ (g/m^2)	f_t (MPa)	E (GPa)	ε (%)
SikaWrap-400A 0/90	Aramid	205	205	2880	100	2.8
SikaWrap-300G 0/90	Glass	145	145	2400	70	3
MeC Grid G4000	Glass	139	119	3450	72	4
Sika CarboDur S512	Carbon	93	–	2800*	165**	1.7
Sika CarboDur T1.214	Carbon	26	–	2400*	135**	1.6

$Warp_w$ and $Weft_w$, Weight of fiber in the warp and weft directions respectively; f_t and E, Fibers nominal tensile strength and E-modulus respectively; ε, Ultimate strain; *, Composite tensile strength; **, Composite E-modulus.