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Shaking table testing of as-built and retrofitted clay brick URM cavity-walls

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ABSTRACT

Masonry cavity-wall construction incorporates a continuous air gap that separates the inner and outer brick leaves of the wall cross-section. This wall configuration was originally developed because of improved thermal performance and in particular reduced moisture transmission across the wall, as the presence of the air-cavity serves to capture and drain moisture back to the building exterior. However, it was subsequently established that clay-brick unreinforced masonry (URM) cavity-wall buildings typically exhibit poor seismic performance due to inadequate connections between the separate masonry leaves in the wall cross-section. Experimental shaking table testing of five cavity-walls was undertaken with an emphasis on developing and experimentally validating simple and efficient retrofit solutions to improve cavity-wall seismic capacity. Wall specimens closely simulated in-situ conditions for the URM cavity-wall arrangements that are most commonly encountered in New Zealand. Two different retrofit solutions were tested, namely, the addition of mechanical screw-ties with different spacings or a combination of mechanical screw-ties and timber strong-backs. Specimen construction details, retrofit procedures, test set-up and results are presented herein. Reported results include observed crack-patterns, peak ground acceleration (PGA) corresponding to both induced initial cracking and failure, acceleration and displacement profiles at failure, and quantification of the improvement in seismic capacity from using the proposed retrofit techniques.

1. Introduction

Load-bearing clay brick cavity-wall construction has been used in European countries, North America, Australia, and New Zealand since the second half of the 19th century. This type of construction decreases construction materials required, reduces the thermal transmittance of masonry perimeter walls, and restricts the formation of moisture to within the wall air-cavity instead of permitting its entrance to the building interior. Studies on the thermal performance of cavity-walls are available in [1,2]. A cavity-wall combines three lines of rain tightness: (i) run-off down the exterior surface; (ii) absorption by the outer leaf and run-off down the air-cavity face of the outer leaf; and (iii) the air-cavity acting as a capillary break. Nevertheless, condensation in the air-cavity and leaking due to careless bricklaying often cause corrosion of metal cavity-ties [3] (see Fig. 1a and b), which, in conjunction with poor boundary restraints, results in insufficient connections between the exterior and interior leaves of a cavity-wall, leading to increased seismic vulnerability of this type of construction. In areas where past earthquakes have occurred, such as the 1931 Hawke's Bay earthquake (New Zealand, [4]), the 1989 Newcastle earthquake (Australia, [5,6]), the 1994 Northridge earthquake (USA, [7]), and the 2010/2011 Canterbury earthquakes (New Zealand, [8]), severe damage to unreinforced masonry (URM) cavity-wall buildings has been documented. Numerous out-of-plane collapses also occurred during the 2009 L'Aquila earthquake (Italy, [9]) where similar types of cavity-wall constructions were used both as load-bearing and in-fill URM buildings. Along with non-structural URM elements such as chimneys and parapets [10,11], URM cavity-walls pose considerable risk to pedestrians during and after earthquakes, thus the validation and installation of effective seismic mitigation measures is required. Nevertheless, seismic improvement of cavity-wall URM buildings is rarely performed, and it was observed that there is a lack of reported experimental validation to support suitable seismic retrofit techniques was observed in the technical literature. The study reported herein attempts to fill this knowledge gap by presenting the results of six shaking table testing performed on five cavity-walls, with an

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(a) Corroded cavity-ties (b) Corroded cavity-tie (c) Mortar degradation

Fig. 1. Examples of commonly encountered deterioration of cavity-walls.

emphasis on investigating the viability of using screw-ties and timber strong-backs as cost-effective and functional seismic retrofit solutions. These six tests allowed a general overview of the dynamic performance in both the as-built and retrofitted conditions to be gained, while recognising that the comparison and delineation of the influence of each variable considered would have benefited from a large number of tests having been undertaken. The adopted cavity screw-ties were selected based on the outcome of previous research reported by Walsh et al. [12]. Using airbags and a variety of cavity-ties installed at different spacings, Walsh et al. [12] investigated the out-of-plane behaviour of cavity-walls in one-way vertical flexure when both bordered and not bordered by a semi-rigid moment-resisting frame.

A preliminary study [13] was undertaken to identify the most commonly encountered characteristics and deficiencies of cavity-wall buildings to facilitate design of a suitable experimental programme. From a review of 126 documented URM clay brick cavity-wall buildings that were damaged during the 2010/2011 Canterbury earthquakes, the most common cavity-ties identified were horse-toe wire ties and fishtailed metal ties with cross-sectional areas that were often found to be significantly diminished due to corrosion at the mortar bed joints of the outer leaf (see Fig. 1a and b). Un-corroded tie sections sustained approximately 6.0–6.5 kN at tension failure while a sample with a significant amount of corrosion and material loss failed at approximately 2 kN [14]. Typical tie spacings were approximately 600–690 mm horizontally and 450–600 mm vertically. Based on investigation of materials, it was observed that mortar from building debris was typically lime based and composed of clean sand and possessed low average compressive strength ranging from 0.5 to 3.0 MPa [15,16], and accordingly low bond strength. Mortar degradation and the absence of a bond between mortar and bricks were often encountered in damaged buildings as a result of poor workmanship that resulted in water penetration, wash-out of the mortar, and a reduction of mortar strength [17] (see Fig. 1c).

2. Experimental programme

From the preliminary study [13], the most commonly encountered boundary condition, geometric characteristics, and material properties for URM cavity-wall arrangements were selected, and five walls that closely mimicked in-situ conditions were constructed. The parameters of mortar mixes, retrofit screw-tie types, and screw-tie spacings were investigated and shaking table experimental testing was performed. Wall W1 was constructed in the as-built condition while walls W2 and W3 replicated retrofitted walls with 12 mm screws. Wall W4 was first tested in the as-built condition and then retrofitted using with 8 mm screws and re-tested. Wall W5 replicated a retrofitted wall with 12 mm screws and the addition of two timber strong-backs. Table 1 summarises the characteristics of the tested cavity-walls.

3. Specimen construction

Test walls were constructed using a configuration with two single masonry leaves in a running bond pattern with mortar joint thickness of approximately 10–15 mm. Recycled clay bricks obtained from a demolished vintage URM building constructed in the 1930s were used. Recognising that there is significant variability in brick properties within a building, the reuse of vintage bricks introduced realistic material variability into the tests. Brick dimensions were of size (230L × 110W × 75H mm) and two different

Table 1
Cavity-wall test matrix.

Wall ID	Height (mm)	Total wall thickness (mm)	Mortar mix [a]	Retrofit type [b]	Retrofit tie spacing, V & H (mm) [c]	
W1	3000	270	0:1:3	Original wire ties	V - 450	H - 600
W2	3000	270	0:1:3	Φ12 mm screws (type 1)	V - 400	H - 600
W3	3000	270	0:1:3	Φ12 mm screws (type 1)	V - 300	H - 600
W4.1	3000	270	1:2:9	Original wire ties	V - 450	H - 600
W4.2				Φ 8 mm screws (type 2)	V - 300	H - 600
W5	3000	270	0:1:3	Φ12 mm screws (type 1) and timber strong-backs	V - 400	H - 600

Note: All test walls were 1190 mm long.
[a] Cement:lime:sand.
[b] Φ – screw diameter in mm.
[c] V – vertical spacing; H – horizontal spacing.