Seismic Testing of Anchor Failures on Unreinforced Masonry Buildings
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For centuries, historical monuments in Europe have been built using the technique of securing timber diaphragms to the perimeter walls through the implementation of adhesive anchors. This structural component has proven to be beneficial in retrofitting buildings subject to the seismic frequencies of natural disasters by providing additional connections within the frame and therefore reducing the distance of which unsupported walls must span. These anchors are stable in out-of-plane loading and easily applied to the existing joists of the structure. Over a century ago, this application was adopted in New Zealand to help strengthen buildings along the Australian fault line with the use of external anchor plates and the technique has evolved to a wide-spread use throughout the construction industry. After the devastating earthquake in Christchurch in 2011, these anchors came under examination as one of the main failures to the buildings subject to the natural disaster. It was uncovered that prior to their implementation in New Zealand's unreinforced masonry buildings, few tests were conducted on these anchors and little was actually know about the strength of these adhesive techniques.

The last months were spent investigating the failure of these anchors in more detail, specifically in Christchurch and other small towns affected by the recent earthquakes in New Zealand. The severity and timing of these disasters allowed for immediate field testing of the actual existing buildings, many of which were scheduled to be demolished. To test the performance of the anchors first-hand, there was an expedition to Whanganui in which we installed and tested variations of these anchors in an existing building. Later these results were combined with previous data collected from buildings tested in Christchurch as well as results concluded from photographic evidence of the Christchurch site. This project remained the main focus of our work here at the University of Auckland, New Zealand and the following will provide further explanation of the details involved in our research.

The site for our testing was an abandoned Liquor store in Whanganui, New Zealand. The two story masonry warehouse provided the necessary space and materials needed to install 144 anchors over the week spent testing. The anchors installed ranged in rod diameter, embedment depth, angle of entry, and adhesive material used. Both 12mm and 16mm diameter threaded steel rods were drilled either 100mm, 200mm, or 300 mm at a 22.5 degree or 0 degree entry angle in order to test all different types of installation techniques recorded in the damaged buildings. Epoxy or grout was used as the adhesive for the anchors, representing the intended decade at which the buildings were constructed. Once cured, the anchors were loaded with tension using a hydraulic pump and steel test frame (Figure 1). The maximum pull-out force was derived using a calibrated pressure gauge. The frame used was specifically designed to clear the 45 degree zone of influence at the largest depth of 300mm. Two strain gauges were also implemented in testing device to accurately measure the distance the rod was displaced. Figure two illustrates the set-up for the anchor testing.

The observed failure that occurred most often was the localized fracturing of the anchor-embedded brick and “punching” of the surrounding bricks. This fracturing typically did not extend further than the immediate bricks around the anchor. A computer monitor and software was used on site to collect data points of the increasing force in relation to the distance recorded by the strain gauge. These points would later be graphed back at the University, resulting in individual stress vs strain curves for each anchor.

Bed joint shear tests were conducted on site as well, with nine different locations chosen from throughout the building. This test requires the removal of one brick and vertical mortar joint, which will be collected as test samples. A pressure controlled hydraulic pump is then inserted into the gap and loaded in compression until sliding failure of the surrounding masonry is observed. The pressure is then recorded and the shear strength is then capable of being calculated. The cohesion factor of the masonry can also be found from these results (Equation 1).

Back at the laboratory in Auckland, brick and mortar compression tests were conducted to calculate the strength and density of the buildings’ masonry. All brick samples were capped with plaster and cured before being subject to compression test ASTM C 67-03a. The strength of the mortar joints was tested in the mortar samples collected from the building by referencing the height-to-width ratio detailed in Assessment and Improvement of Unreinforced Masonry Buildings for Earthquake Resistance (AIUMBER 2012) to account for the irregular sample geometry. Using the empirical relationship given, the average masonry compressive strength was found as well as the density of the masonry (Equation 3, 4).

This testing procedure was repeated weeks later on a smaller in Auckland at an additional test site, extracting 20 already existing anchors in total.

Towards the end of our stay in Auckland, a second trip to Whanganui was proposed to extract the existing anchors in the same building tested previously. Although this trip will take place days after we depart, preparations have begun to be made, such as the work of designing a second testing rig that would lie horizontally along the joists of the building, able to counteract the moment caused by the hydraulic pump underneath. Many designs were considered, and it was concluded that the combination of hollow steel beams with the shear strength of plywood would be the most stable. Many of the results have yet to be published and will be first reviewed before being used in the final destruction report to the Royal Commission at the end of this year. These tests are just a small addition to a larger database of results that has been referred to as the one of the most extensive post-disaster research report in the world.

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REFERENCES

Faculty of Engineering, The University of Auckland. "Assessment and Improvement of Unreinforced Masonry Buildings for Earthquake Resistance (AIUMBER 2012)." (2011): n. pag. Print.

ASTM Journals. "C1531-09 Standard Test Methods for In Situ Measurement Of Masonry Mortar Joint Shear Strength Index." *American Society for Testing and Materials*04.05 (2011): n. pag. Print.

Institution of Professional Engineers New Zealand. "New Zealand Society for Earthquake Engineering Inc." *Building Safety Evaluation in Emergencies*. N.p., n.d. Web. 21 August 2012. <http://www.nzsee.org.nz/publications/building-safety-evaluation-in-emergencies/>.

Dizhur, D., Ingham, J. M., Moon, L., Griffith, M., Schultz, A., Senaldi, I., Magenes, G., Dickie, J., Lissel, S., Centeno, J., Ventura, C., Leiti, J., and Lourenco, P. (2011). ‘Performance of Masonry Buildings and Churches in the 22 February 2011 Christchurch Earthquake’, Bulletin of the New Zealand Society for
Earthquake Engineering

APPENDIX:

Figures

Figure 1: The steel frame testing set-up including the strain gauges and hydraulic pump.

Figure 2: Overall anchor pull-out testing set up including the on site monitor and computer to record the force and displacement results.

Equations

$$c_i = \beta\left(\frac{V_H}{A_j} - Q_{G+Q}\right)$$

Equation 1: Masonry cohesion, c, is determined from individual shear strength test values (ci) where: VH is the shear force at first movement of a masonry unit; Aj is the net mortared area of the bed joints above and below the test brick; QG+Q is the estimated gravity stress in the brick at the time of testing; and β is collar joints reduction factor for multi-leaf masonry walls.

$$f'_m = 0.7\, f_b'^{\,0.75} \times f_j'^{\,0.3}$$

Equation 2: the average masonry compressive strength, f'm, can be calculated using the average brick compressive strength and average normalised mortar compressive strength

$$\rho_m = 1578 + 5f'_b + 8f'_j$$

Equation 3: the density of masonry, ρm, is estimated using the average brick compressive strength and average mortar compressive strength