A Seismic Retrofit for Masonry Infill Walls using Ductile Concrete

Marios A. KYRIAKIDES
PhD Candidate
Stanford University
Stanford, CA, USA
mkyriakides@stanford.edu

Sarah L. BILLINGTON
Associate Professor
Stanford University
Stanford, CA, USA
billington@stanford.edu

Summary

Understanding and assessing the seismic performance of masonry infilled reinforced concrete structures has been a significant area of research over the last several decades. There is both field and laboratory evidence of masonry infilled reinforced concrete structures not adequately designed for earthquake loading that demonstrated the catastrophic contribution of the unreinforced masonry infill to the structure due to its interaction with the bounding frame. There is a lack of reliable and effective retrofit techniques for this group of structures. A new retrofit technique specifically for unreinforced masonry infills in non-ductile reinforced concrete frames is currently under investigation. The technique uses a ductile fiber-reinforced mortar material referred to as Engineered Cementitious Composites, or ECC. A series of experiments have been performed in order to examine the impact of a thin layer of ECC applied on masonry alone as well as when it is applied on a masonry wall bounded by a non- ductile reinforced concrete frame. Results indicate that the ECC can help keep unreinforced masonry walls in tact to large lateral drifts, adding significant ductility to the structural system under cyclic loading.

Keywords: Non-ductile reinforced concrete frames; masonry infills; walls; engineered cementitious composites; sprayable; retrofitting.

1. Introduction

Structures with unreinforced masonry infills can be found in many places such as the western United States and in countries of the Mediterranean region. Masonry infills have been widely used because of their good thermal and acoustic insulation properties, for aesthetic reasons and for fire resistance. However, recent earthquakes (e.g., 1999 Kocaeli, 2003 Boumerdes) have demonstrated the vulnerability of masonry infilled structures. In the case of masonry infilled concrete frames, the interaction between the bounding frame and the infill wall can lead to different failure mechanisms depending on their strength and relative stiffness.

A new retrofit technique specifically for unreinforced masonry infills in non-ductile reinforced concrete frames uses a sprayable, ductile fiber-reinforced mortar material referred to as Engineered Cementitious Composites, or ECC. The aim is to develop a cost-effective retrofit technique for such structures that will improve the seismic performance of the frame-infill system by enhancing its ductility and delaying its strength degradation. Compression and flexural tests of masonry specimens with various retrofits using sprayable ECC have been performed in order to investigate the impact of a thin layer of ECC on plain masonry specimens in terms of changes in stiffness, strength and ductility. Triplet tests using ECC have also been performed to study the bond between the brick surface and the ECC. Three small scale infilled frame tests have been completed to date to validate the proposed retrofit technique. This project is a collaboration of three Universities through the National Science Foundation’s Network for Earthquake Engineering Simulation (NEES) research program.

2. Experimental Investigation of ECC as a retrofit

2.1 Retrofit System

The use of a spray-on ECC layer is proposed to tie the masonry wall together as it is undergoing cyclic lateral loads. Furthermore, by tying the ECC to the reinforced concrete beams above and below the wall an alternate shear path is provided for the lateral load through the wall rather than having the load shed to the columns after the wall is damaged and cause a brittle failure. ECC is a

https://doi.org/10.2749/222137908796291868

good candidate material for achieving improved ductility in that it can achieve uniaxial tensile strains of up to 3% while maintaining its load-carrying capacity (i.e. final crack localization will occur after 3% strain).

2.2 Small scale tests

From the prism tests it was found that the thin layer (13mm) of ECC on a single-wythe brick specimen increases the compressive capacity beyond what would be expected from the layers compressive strength . In addition, through flexural testing it was found that the increase in strength and ductility is very large when 13mm of ECC is troweled onto the brick surface in particular when a small amount of steel reinforcement is added. Unretrofitted beams carried 20-25 times less load than specimens with 13mm of ECC with a high brittle failure. Significant multiple cracking of the ECC was observed at the joints for unreinforced ECC and throughout the constant moment region (area of direct tension on the ECC) when the ECC was reinforced (figure 1). It is noted that debonding between the ECC and the brick is advantageous for multiple cracking in direct tension but less so in compression where delamination buckling can occur.

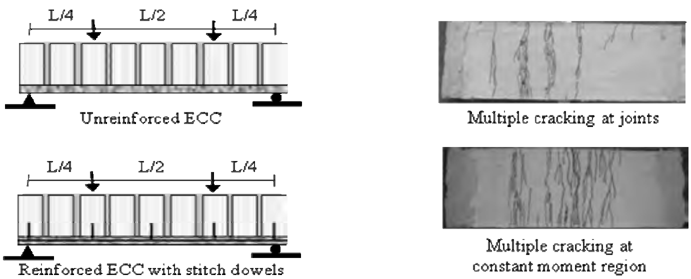
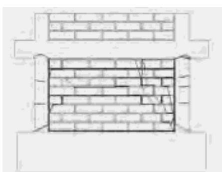
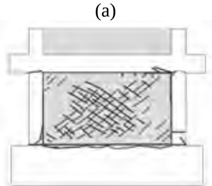


Fig. 1: Cracking response of 4-point bend specimens with unreinforced ECC (top) and with ECC reinforced with 0.1% steel (by area) and attached to screw anchors ("Stitch dowels") grouted into the masonry. View from underneath the specimen at the ECC layer.



(a)



(b)

Fig.2: Damage pattern of (a) unretrofitted specimen and (b) retrofitted specimen

The small-scale infilled frame tests have shown that a thin ECC layer with reinforcement can restrain the diagonal cracking and bed joint sliding in the masonry wall. When shear dowels are used between the ECC layer and the concrete beams, an alternate path of the load is developed and shear failure at the columns is avoided. Figure 2a shows the final damage pattern of the unretrofitted specimen that demonstrated a knee-braced mechanism in both directions with sliding along mortar joints and diagonal cracking. Figure 2b shows the corresponding damage pattern of the ECC retrofitted specimen with shear dowels. No shear failure was observed at the columns until high drift levels were reached.

In a fourth small scale infilled frame test, a similar retrofit approach will be evaluated wherein the shear dowels to the base beam are unbonded, thereby transferring shear but not tension between the wall and base beam. The objective of this dowel design is to lessen the strength increase of the retrofitted wall and increase the deformation capacity with less strength degradation. Based on the results of the Stanford wall tests, the most promising retrofit will be evaluated in a two-thirds scale frame with a double-wythe infill at the University of Colorado at Boulder followed by shake table testing on a 2-bay 3-story structure at UCSD. The research team will use the results of all experimental phases of the project to develop simplified analysis methods to predict the performance of retrofitted and unretrofitted unreinforced masonry infilled reinforced concrete frames.