Test Specimens for the Retrofit of Non-ductile RC Frames with Masonry Infill: A Summer of Fabrication

By
Nancy Lee
San Francisco State University
Stanford University
Sarah Billington, PhD
Marios Kyriakides, PhD Candidate
Abstract

Masonry-filled walls are a common structural element in numerous buildings both old and new. Many of these buildings and structures are located in seismic regions, and must withstand cyclic loads. Some of these structures will fail after repeated loading, causing massive damage and injury. Unfortunately, since masonry infill walls are not considered structural components, very few methods exist to determine the seismic fitness of these walls. It will be very beneficial if assessment tools were developed to evaluate brick buildings and structures. Novel retrofit techniques should also be explored in order to lessen the damage burden in these buildings caused by earthquake devastation.

Current research conducted at Stanford University hope to accomplish these goals. One-fifth scale, masonry infill reinforced concrete walls were constructed, and will be placed under cyclic load. In terms of retrofitting older buildings with brick-filled walls, engineered cement composite (ECC) was thought of as a possible candidate. Various brick specimens with an ECC appliqué were prepared and will be tested. The ultimate goals of this project are twofold: to test the feasibility of ECC for retrofitting masonry infill walls, and to contribute to standardized methodologies for assessing masonry infill buildings and structures.
Problem studied

Brick has been used for constructing structures and dwellings for hundreds of years. Although it is used as a major building component throughout the world, brick is not considered a structural element. Therefore, bricks are not included in the analysis of a structure’s response to different loading conditions. Unfortunately, brick is readily available, and most people are familiar with its workability. Because masonry is so prevalent in many regions of the world, it should be considered as a structural element and analyzed accordingly.

At mild loading conditions, wall systems with brick inlay act as one unit. At higher loads, masonry starts to behave independent of its frame. And, if the infill is too strong, the reinforced concrete columns can exhibit brittle failure. In buildings with multiple floors, the brick inlay can induce a soft-story mechanism and contribute to building failure. Therefore, developing retrofitting techniques for brick inlays will prove beneficial in terms of preventing major damage and injury during large seismic loads.

Since masonry infill have been recognized as a structural element recently, consistent methodologies for its analysis have not been created. Researchers and practicing engineers alike must first collect much needed data to categorize brick and mortar properties. Second, the interaction between brick, mortar and their associated frames must be studied. The data collected then must be compiled into a standardized and usable analytical tool to reasonably predict the behavior of a particular masonry infill wall system under different loading conditions.

As many of the world’s buildings and structures contain brick components, retrofit methods must be formulated to decrease human and monetary costs during earthquakes and other deleterious loading conditions. Since it is nearly impossible, not to mention extremely expensive, to rebuild all masonry buildings, a mortar-based approach, namely engineered cementitious composite (ECC), was thought of as being a likely candidate for a retrofitting material. In general terms, ECC is any composite that contains cement and fibers. ECC used as large structural elements tend to contain metallic fibers, whereas for smaller components the fibers are plastic. Addition of the fibers increases the ductility of the cementitious elements, increasing their ability to withstand seismic forces.

Objective

The project currently conducted by Marios Kyriakides at Stanford University has two objectives. The first objective is to study the behavior of brick inlay walls under seismic loading conditions. The data collected will hopefully contribute to a standardized analytical tool for measuring the seismic fitness of brick buildings and structures. The second objective is to study the usefulness of applying ECC as a retrofit technique.
Research approach

In order to achieve the first objective, 1/5 scale, masonry-infill reinforced concrete walls must be fabricated. The second objective is achieved by mixing batches of ECC, and analyzing its affect on smaller brick samples. ECC will also be applied to the scaled brick and concrete walls to test its overall effectiveness as a retrofit material. I participated in the fabrication of test specimens for both sections of the project this summer.

Outcomes

Fabrication of Wall Specimens

The initial step in the fabrication of the wall specimens is formwork. The formwork for the first two walls were already finished when my internship started, so I did not get to participate in that step. Second, the steel reinforcement in the beam and columns of the walls had to be prepared. The beams contained #3 rebar reinforcements, the columns contained steel rods (average diameter 0.186 inch), and the base contained a rebar cage composed of #3 and #5 rebars. The base rebar cages for the first two forms were already fabricated before the start of my internship as well.

Much of the time in the first few weeks of my internship was used for preparing the reinforcements because of strain gage attachment. In order to see how the rebar or steel rod was responding to seismic loading, strain gages must be attached at specific locations (Figure 1). The gages are attached with glue to smooth surfaces, so the ridges on the rebars must be filed down (Figures 2 and 3). This was done manually because research parameters dictated the filed surface area could not fall below a certain percentage. Although the steel rods appeared smooth, upon close inspection bumps and dips were visible. So, the rods had to be sanded as well. As can be imagined, this was not a quick and easy process, especially for one who is inexperienced with metalwork.

Figure 1. Strain gage placement within wall specimen.
Strain gage attachment was a time-consuming process even after the steel surfaces were smoothed. There was a multi-step washing and etching procedure for the steel surface (Figure 4). After preparing the steel surface, there was a multi-step process for picking up the strain gages. Then glue is applied to the steel surface, and a strain gage was pressed onto the steel until the glue dried (Figure 5). The main reason for these procedures was to ensure that both the steel and strain gage surface was free of dust and debris. It takes about 30 minutes to attach a single strain gage from surface washing to glue drying.

The strain gages had to be protected from moisture because they will be contained within concrete. So, four layers of water-resistant coating were applied. The first two coats were of one latex compound, applied two hours apart. The third coat was of a different compound, and it was applied two hours after the second coat. Twenty-four hours later, the final coat of a third compound was applied. This last coat takes 24 hours to cure as well.

Next, the reinforcements were placed into the formwork. This is actually easier said than done because of the limited space in certain areas of the formwork (Figures 6 and 7). The fact that all parts were formed manually means there will
be irregularity, which in turn means that not all parts will fit as planned. Some time was spent in putting all the steel parts together while working within project specifications (i.e. spacing of reinforcements).

Then comes casting, where concrete is poured into the completed formwork with reinforcements. Gaps within the formwork were sealed to prevent concrete leakage, and oil was applied onto the wood to prevent concrete adhesion. The concrete used was a commercially available mix, purchased from a local home improvement retailer. Although pouring concrete seemed an easy task, it proved to be an exhausting, physical experience (Figure 8). Nonetheless, I was very satisfied with the results of my labor when I saw the finished walls (Figure 9).
After the concrete is poured and cured for two weeks, the forms were removed. Removing the form proved to be time-consuming as well as frustrating. The forms are made of wood; the pieces of which are nailed or screwed into place. The original thought was that the forms can be removed easily, in their original configuration, and be reused for the last two walls. During the de-forming process, many of these wood pieces were recalcitrant and refused budge. So, these pieces were destroyed to prevent harm to the frame. The concrete frames were then lifted and placed upright, ready for the brick inlay. Finally, two professional masons were invited to lay the bricks inside the concrete frames, and the first two wall specimens were completed (Figure 10).

The final step for setting up the brick and concrete wall for testing is placing it onto the testing platform. The base of the wall had to fit on top of a steel beam and between two steel bumpers (Figure 11). Then, the base had to be bolted down onto the beam. This is to ensure that the wall does not slide off the beam during testing. Once again, this procedure was easier said than done. The concern here was that if the base were forced onto the beam, microfractures can form, and thus biasing the results. So, some time was spent on reducing the surface area of the portion of the base closest to the bumpers. After a few trial and error attempts, the base finally settled onto the beam (Figure 12).
To prepare for the next two forms, rebars had to be cut and bent to make stirrups for the base cages, and reinforcement for the beams in the frames (Figures 13 and 14). Strain gages must be attached, as well. So, the entire process of filing, sanding, and cleaning the surfaces, then gluing the gages begin anew.

**Figure 13. Cutting rebars.**

**Figure 14. Rebars bent into stirrups and beam reinforcements.**

**ECC**

To study the feasibility of ECC for retrofitting masonry walls, smaller specimens had to be fabricated. The specimens I made were 9-brick tall beams. The bricks and mortar mixture used were the same as those for the concrete frames. After a 2-week curing period, a wire mesh grid was glued onto one surface of the brick beam for reinforcement (Figure 15). Project parameters dictated the attachment of the wire mesh.

**Figure 15. Brick beam specimen with wire mesh and bonding agent awaiting ECC application.**
The mix ratios of ECC ingredients are non-proprietary and readily available (Li and Lepech, 2005). The fiber chosen was polyvinyl alcohol, 5mm long, and so fine that it can become airborne (Figure 16). The mixture was prepared in a mixer in the same manner as a cake batter (Figure 17). The workability of the mixed ECC was only 15 minutes, so one must act quickly during its application. Curing time is 14 days. Tests are also being done to see if using a bonding agent will enhance ECC adherence to the brick, thereby relinquishing the need for wire reinforcement.

Unfortunately, my internship ended before any of the mason-infill walls were tested. Although I was able to mix a few batches of ECC and apply it onto a few brick beams, I did not participate in any of the flexural tests. However, I did witness a number of 3-brick, ECC-bonding agent test results. The preliminary findings are encouraging. Of all the specimens tested, fracture occurred along the brick and not along the mortar joint. This is most significant because brick walls tend to fail at mortar joints. Since the data is currently being analyzed, I am not at liberty to reveal any of the results. However, common sense alone says that the research is heading in the right direction.

**Possible future work**

Since the research at Stanford University is the first of three, there definitely will be future work that will expand upon the results. The University of Colorado at Boulder will perform medium-sized tests, and use the data from the Stanford study to initiate a mathematical model. Then, the University of California at San Diego will test a ¾ scale two-bay, three-story reinforced concrete frame on an outdoor shake table. Perhaps the outcome of the combined studies will generate more research on mathematical modeling, standardized methodologies, and retrofit techniques for buildings and structures with masonry infill.

On a personal level, I wonder if the plastic fibers used in ECC is harmful to humans or the environment. In a world of green technology, we would not want to go one step forward (retrofitting buildings with ECC to save human lives) to
take two steps back (for example, if it was found that the fibers caused respiratory problems). Therefore, I would like to see more research done on the sustainability of ECC, and if the fibers used would have harmful effects.

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References


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