

Ductile Fiber Reinforced Panels for Seismic Retrofit

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Summary

An infill system consisting of ductile fiber reinforced composite panels with bolted connections is being developed for seismic retrofits. A combination of laboratory and numerical studies are being used to evaluate and develop components of the infill system. Initial results suggest that the composite infill panels are capable of increasing the lateral load capacity, the stiffness and the energy dissipation capability of a steel frame subjected to cyclic lateral loads.

Introduction

Ductile cement-based composite materials or engineered cementitious composite (ECC) materials, which are comprised of a Portland cement or mortar matrix and low volume fraction of polymeric fibers, represent a new kind of material for use in seismic retrofits. Ductile cement-based composites are unique due to their high tensile strain capacity. The material was originally developed from micromechanical tailoring of fiber and matrix properties and the resulting composites show multiple, fine (steady-state) cracking and significantly higher tensile ductility than that of conventional cementitious materials. The material also exhibits pseudo-strain hardening and therefore energy dissipation (Li 1998).

In the current research, two types of infill wall panel systems are being evaluated for use in steel framed structures, as shown in Figure 1. The different infill systems are a complete bay infill (Figure 1a) and a beam-type infill (Figure 1b). The infill panels are constructed using the ECC material in lieu of a traditional concrete or brick masonry. This research builds upon previous research by Kanda et al., (1998). The panel systems are unique in their use of bolted connections between panels, with either bolted or welded connections to the frame. The system has several advantages in retrofit applications including rapid installation, ability for relocation (if necessary) and ease of replacement after damage during seismic events. In this paper, the combination of ongoing numerical and laboratory studies, which are being used to evaluate and develop the infill panel system, are described.

To develop the ECC infill panel system, there are three focus areas in the ongoing research:

1. Evaluation of the cyclic response of ECC materials.
2. Evaluation of the panel connection capacity.

3. Optimization of panel geometry and layout in retrofit applications.

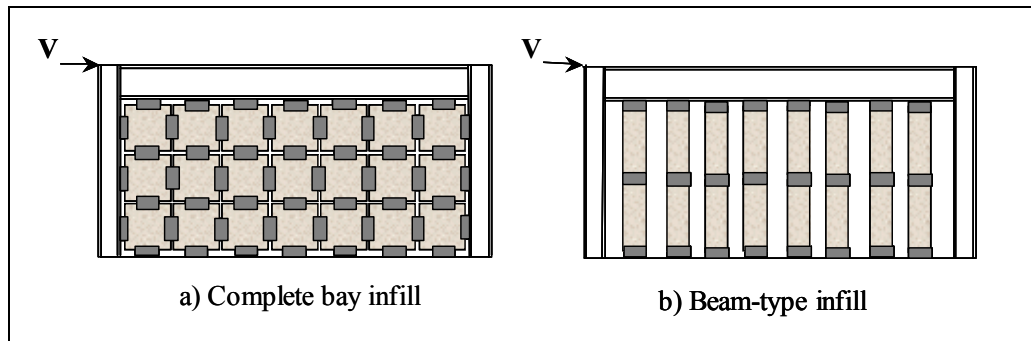


Figure 1. Panel infill systems under development

Results presented in this paper describe ongoing efforts in focus areas 2 and 3.

Panel Connection Tests

The infill panel concept being developed uses pre-tensioned bolted connections both between the panels and at the connection of the panels to the frame. In this application, the behavior of the bolted connections is conceptually similar to slip-critical connections in steel structures. Kanda et al., (1998) were the first to investigate the use of pre-tensioned bolted connections. The geometry of their tested specimens resulted in a compression failure of the specimens outside of the connection region.

In the current research, compression and shear capacities of ECC panels with pre-tensioned bolted connections are being investigated. Figure 2 shows the geometry of some of the specimens tested. This represents the compression capacity in a connection such as that shown in Figure 1b. The bolts used in the connections are 19 mm ASTM A490 high strength bolts with the pre-tensioning load slightly below AISC specifications (AISC 1988) for slip critical connections. The pre-tensioning load is selected to limit the compressive stresses within the connection region. This is necessary to prevent localized crushing during bolt tensioning. The pre-tensioning load in the bolts is monitored using load cell washers, which allow the variation of bolt load to be recorded during testing. In order to provide additional space for alignment of the connections, bolt holes in both the steel angles and the ECC blocks are 22 mm in diameter, which is 2 mm larger than AISC specifications. The testing is performed in a displacement controlled, 2670 kN MTS test frame at an approximate displacement rate of 4 mm per minute. The displacement was stopped during the testing to allow for photographs of the specimens to be taken. The loading is applied perpendicular to the axis of the bolts. Six displacement transducers (three per side) are used during testing to monitor the deformation and the slip of the specimen. The location of the transducers is shown in Figure 2.

Two different interface conditions were studied. During the initial testing, the ECC specimens were tested without any modification to the formed surfaces. Figure 3 shows the load displacement response of a test specimen with a plain-formed surface. The specimen began to slip at a load equal to approximately 338 kN. After the specimen began to slip, the load gradually increased until a

compressive failure occurred in the top section. The compressive failure initiated as the ECC began bearing on the bolts in the connection region.

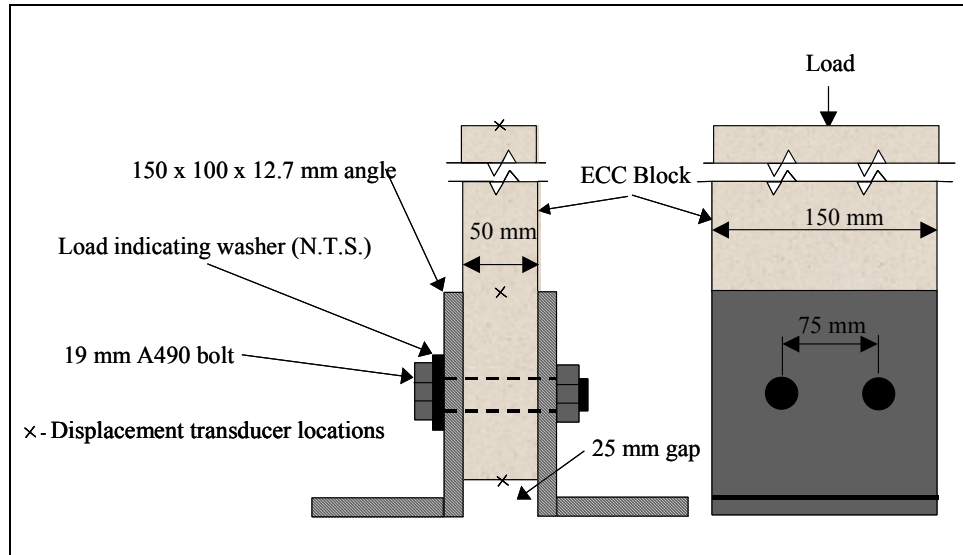


Figure 2. Schematic representation of ECC shear connection test

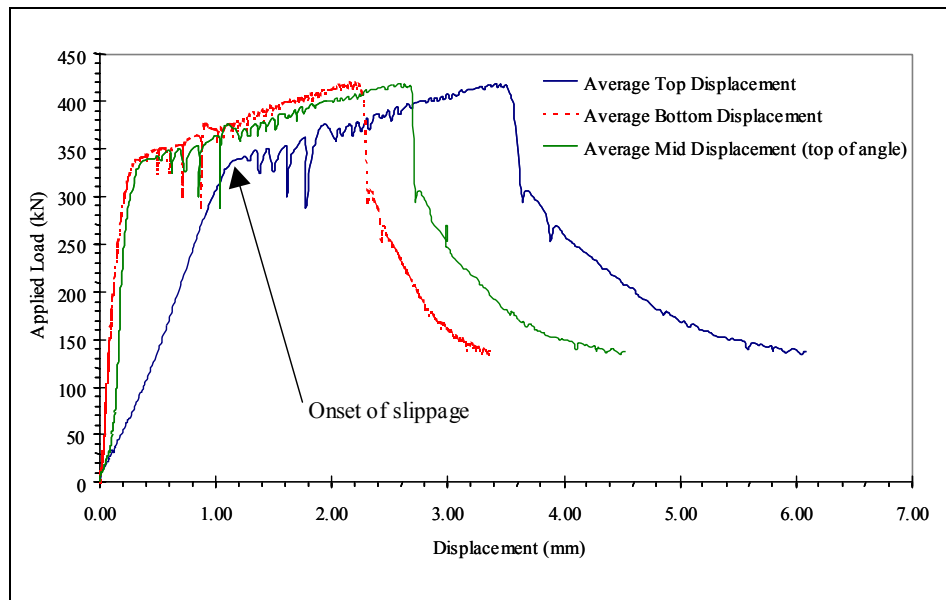


Figure 3. Load displacement results from connection test

In subsequent testing, both the ECC specimens and the steel angles were sandblasted to increase the friction between the ECC block and the steel angle. Test results indicate that sandblasting increases the shear capacity of the connection region. Table 1 shows a summary of the bolted connection test results. In Table 1, the slip coefficient was calculated using Eq. 1, which was adopted from the AISC specifications for the use of high strength bolts:

$$k_s = \frac{s'l}{2cf} \quad (1)$$

where k_s = slip (interface friction) coefficient, cf = total bolt pretensioning force and $s'l$ = load at which the deformation rate increases.

Table 1. Summary of average panel connection tests

| Interface type | Clamping force [kN] | Slip load [kN] | Slip coefficient |
|----------------|---------------------|----------------|------------------|
| Formed | 267 | 338 | 0.63 |
| Sandblasted | 267 | 463 | 0.87 |

Values of the slip coefficient obtained from testing are being used to evaluate the size and number of required bolts between precast panels and at the connections to steel frames. Test results are also being used to model the confined ECC material in the connection regions. Additional tests are underway to evaluate the effect of loading in line with the axis of the bolts (shear strength of the connection shown in Figure 1b), as well as the effect of creep in the connection region.

Preliminary Retrofit Analysis

The infill installation can be used to increase the stiffness and the energy dissipation capacity of a structure, as well as to limit deflections. The primary goals of such installations are to protect the existing structure as well as critical secondary systems such as piping systems and hospital equipment. To contribute to the achievement of these goals, a clear understanding of the ways by which the ECC panel retrofit alters the structural properties (stiffness, strength and energy dissipation) must be developed. At the same time, the panel geometry must be selected so that it minimizes the number of panels per frame while maintaining the portability and flexibility of the system.

To begin the evaluation of the effect of added infill walls, a finite element model of a single bay of a steel frame from MCEER's demonstration hospital was created. Multi-bay frame models are also being investigated. Frame members for the single bay model are 2-noded beam elements. The infill panels and the steel connections are modeled using 4-noded plane stress elements. For the steel frame and panel connection members, an elastoplastic material model with isotropic hardening is used. Panel reinforcement is modeled as embedded grid reinforcement. ECC material is modeled using a simplified material model that includes a multilinear stress-strain curve wherein the transition points on the stress strain diagram are obtained from uniaxial tension tests. The tension model used in the current analysis is based on a total strain fixed-crack model. A parabolic softening model is used for the compression branch. The model has secant unloading and reloading in both tension and compression.

A beam-type infill panel addition (as shown in Figure 1b) is being evaluated. An infilled frame is cyclically displaced to three drift levels: 0.25%, 0.5% and 1%. In the simulation, 0.5% grid reinforcement in each direction is used in the panels. The panel thickness is equal to 100 mm. Figure 4 shows some results from the simulations. In the figure, results for three different panel

aspect (panel height (l)/panel depth (d)) ratios are shown. The number of panels is varied to keep the ratio of infill panel area to total panel area approximately constant. The percentage of infilled frame area is indicated in the figure legend. For comparison, the result from an evaluation of the bare frame is also shown.

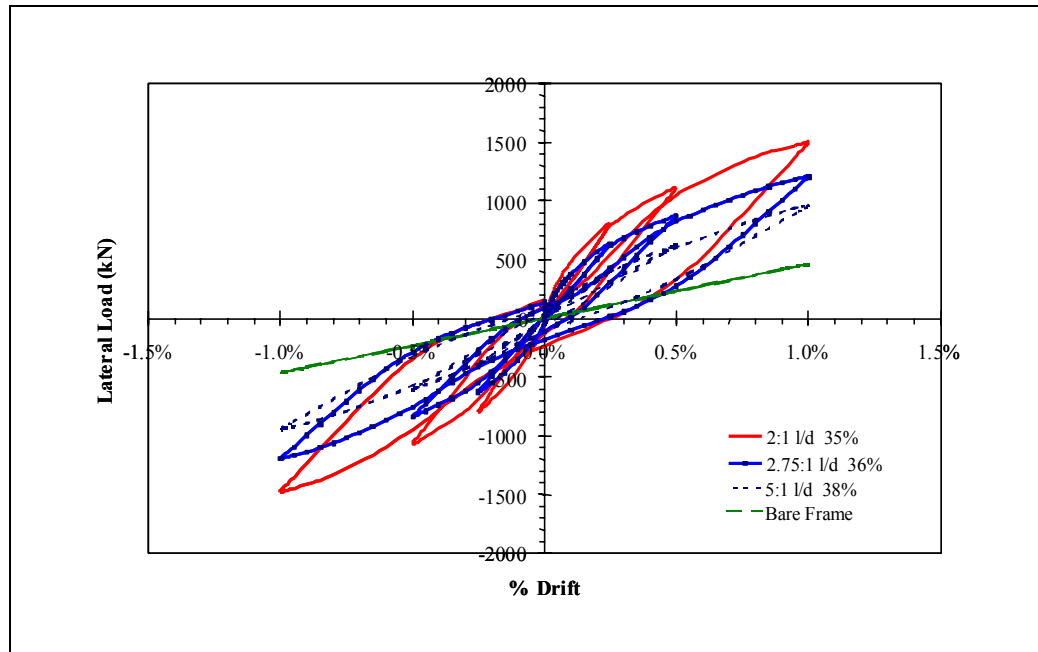


Figure 4. Summary of finite element simulation results from beam-type infill system

Results indicate that beam-type infill panel systems can significantly increase the stiffness of the frame, as well as the energy dissipation during cyclic loadings. In the analysis of the bare frame, yielding is observed to occur at the base of the columns at approximately 1% drift. In the infilled frames, yielding was observed to occur at similar drift levels. This indicates that the infill addition can simultaneously protect the frames and increase the stiffness.

Results from numerical studies are being used to identify promising systems for experimental investigations. Further development of ECC material models will allow for more accurate and efficient evaluation of ECC infill panels for seismic strengthening, stiffening and energy dissipation.

Concluding Remarks

An infill system of ECC panels with bolted connections is being developed for seismic retrofit. A combination of laboratory and numerical studies are being used to evaluate and develop components of the infill system. ECC infill panels are capable of increasing the lateral load capacity, stiffness and energy dissipation capability of a steel frame subjected to cyclic lateral loads.

The feasibility of bolted connections between panels has been demonstrated experimentally. Values of the slip coefficients calculated from test results allow for simple design of ECC panel connections. These test results demonstrate the viability of the infill panel concept.

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