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Computational analysis of using strain hardening cementitious composite for seismic retrofit of masonry walls

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ABSTRACT

To overcome low resistance of masonry walls to seismic loads, strengthening with the strain hardening fiber reinforced cementitious composite (SHCC) is being proposed as a new seismic retrofit method. The effectiveness of the SHCC was evaluated through finite element simulations of the masonry wall model with and without SHCC. Pushover and dynamic analyses were conducted to assess seismic capacity and demand of the models. According to results, proposed method is a promising approach to improve the strength and ductility of masonry walls.

1. INTRODUCTION

Unretrofitted masonry structures have low capacity to resist seismic loads, which results in formations of cracks, failures of elements and collapses of structures. Several factors affect the resistance of masonry wall to seismic loads such as low tensile strength and ductility, improper mortar mix design, variation in shapes of units, poor quality of components and irregularities in plane and vertical directions (Dogangun 2008). In order to prevent masonry structures from damages due to earthquakes, several techniques are applied: wrapping with fibers, using energy-dissipation devices, adding reinforcement elements, using innovative ductile materials, etc. (Garofano 2016). The focus of this study is the enhancement of masonry walls by applying strain-hardening material – Strain Hardening Cementitious Composite (SHCC).

The SHCC is a special type of High Performance Fiber Reinforced Concrete, which is made of cement, fine sand, high-modulus short fibers and supplementary cementitious materials (Ali 2017). In contrast with conventional concrete which is brittle under flexural loading, the SHCC performs as a metal after first crack and exhibits 500 times higher strain capacity and can maintain low crack width of less than 60μm which make it

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beneficial for structural use (Sahmaran 2008). However, at the same time, SHCC does not satisfy sustainability requirements, because its production requires two to three times more cement than conventional concrete (Wang 2007). To overcome this factor, geopolymer is used to replace Ordinary Portland Cement binder in SHCC mix. In one of the recent researches, Nematollahi (2018) studied the potential of geopolymer based composites to become 'complete' replacement of OPC, and came to conclusion that the developed geopolymer composites exhibited either comparable or superior performances to typical SHCC in all mechanical aspects. Although material properties of the SHCC with geopolymer has been examined, little research has been undertaken to study performance of the material at structural level. Therefore, the effect of retrofitting with the material on seismic performance of masonry wall is still undetermined. Consequently, the proposed study is focused on the analytical investigation of seismic behavior of the masonry wall strengthened with the geopolymer SHCC.

2. MODEL DEVELOPMENT AND METHOD

Two separate computer models were developed on finite element analysis tool for nonlinear pushover and dynamic analyses using smeared crack concept. For pushover analysis, the model of a masonry wall strengthened with the SHCC layer at both sides is shown in Fig. 1a. The results of the pushover analysis in the form of force-displacement curves were used as input properties for the development of the simplified model for dynamic analysis, which is shown in Fig. 1b. The mechanical properties of the masonry wall and the SHCC were obtained from the experiment conducted by Ganz (1982) and Nematollahi (2015), respectively. Also, the wall and SHCC material models were verified by experimental tests. The wall geometry was taken from a prototype structure, and has dimensions of 6000x3000x230mm. It was subjected to 10kPa dead load and 1.92kPa live load.

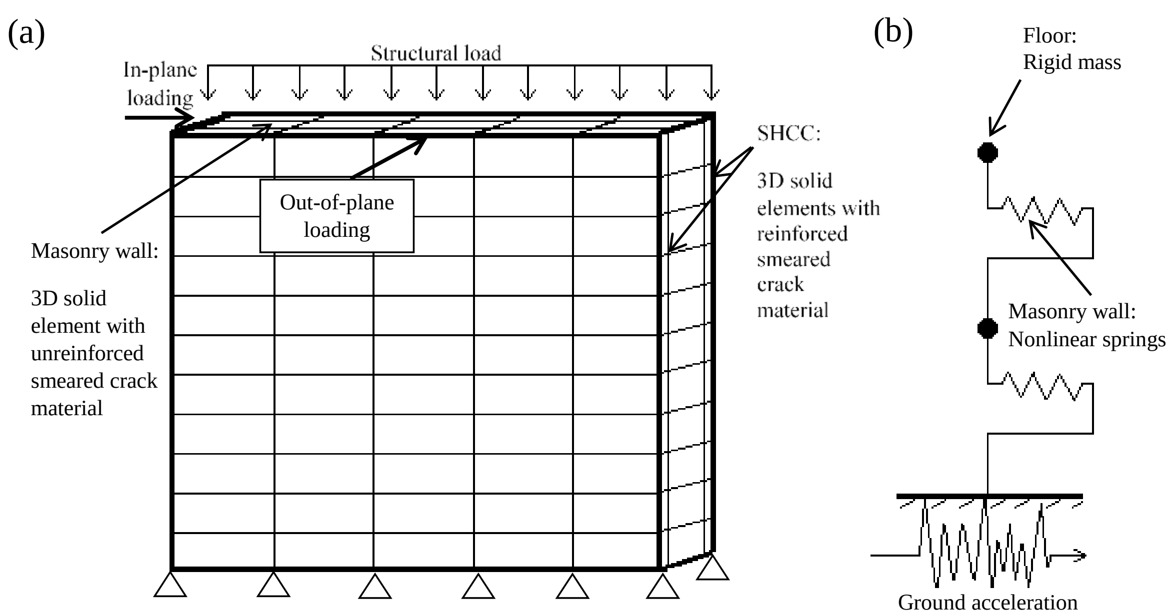

Fig. 1 Analytical models for: (a) Pushover analysis; (b) Dynamic analysis

In order to conduct pushover analysis, the model was subjected to monotonically increasing lateral loads, after which the effects of the SHCC thickness and ductility were investigated. To test the resistance of the model for ground motion records, the dynamic analysis was performed on one- to four-story structure models involving earthquakes with 2% and 10% chances of exceedance in 50-year.

3. RESULTS AND DISCUSSION

The results of the pushover analysis is given in the form of the curve “base shear vs. drift of the top of the wall”, where the drift is the ratio of the horizontal displacement of the wall to its height. Fig. 2a shows the pushover curves for the masonry model only and the models with 10, 15 and 20mm SHCC layer. As seen, the SHCC strengthening significantly enhanced the strength and ductility of the model. It can be noticed that the increase in the SHCC thickness corresponds to increase in the strength. For instance, the model with the 10mm SHCC showed 78% higher strength than the masonry wall only, the 15mm SHCC – 105%, and the 20mm SHCC – 140%. In addition, the strengthening increased the ductility of the wall model: the 10mm SHCC – 66% increase, the 15mm SHCC – 41%, and the 20mm SHCC – 34%. Opposite to the strength, the ductility of the wall reduced by applying the thicker layer of the SHCC, possibly because the thicker layer provided higher confinement of the masonry.

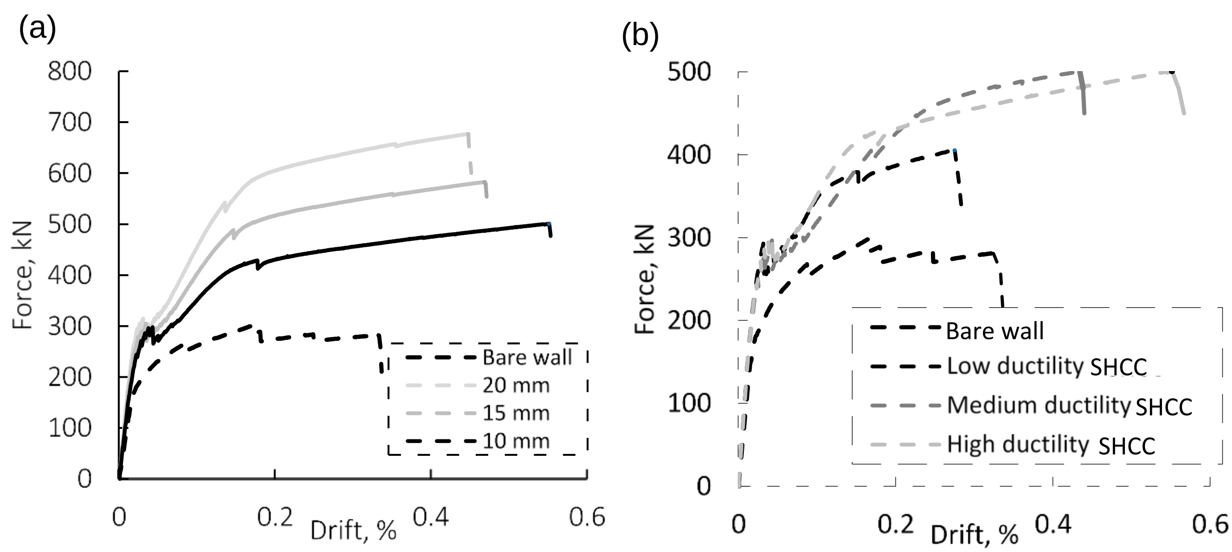

Fig. 2 Pushover curves for different: (a) SHCC thicknesses; (b) SHCC ductility

The second study parameter is mechanical properties of the SHCC. Three different ductility levels of the material were considered: low (0.7% ultimate strain), medium (2.3%) and high (4.75%). Fig. 2b shows pushover curves for the masonry wall model only and the models with low, medium and high ductility 10mm SHCC layers. As observed, the higher ductility of the SHCC, the stronger the masonry wall. Depending on the ductility of the SHCC, the strength of the wall increased from 44% to 78%. However, the strengthening of the wall with the low ductility SHCC decreased the wall's ductility by 12%. The possible reason is that the failure of the model was controlled by the fracture of fibers in the SHCC. The medium and high ductility SHCC increased overall ductility of the model for 34% and 72%, respectively, meaning that the SHCC with only a certain level of ductility can positively affect the seismic performance of the masonry wall.

For the dynamic analysis, one- to four-story masonry wall models with the SHCC layers were subjected to 10 ground motion records with 2 and 10% chances of exceedance in 50-year. After the earthquake simulation, the drifts of each floor were obtained and averaged. Fig. 3 shows the results of the dynamic analysis in the form of "average maximum experienced drift normalized by the drift capacity of the wall vs. number of stories, N". The drift capacity is defined by the model divergence, and shown as a trendline in the figure. As seen, the application of the SHCC improved the seismic performance of the model by reducing the story drift about three times for both earthquake cases. From the analysis under earthquake with 2% of exceedance chance (Fig. 3a), it was found that after strengthening, the ductility of four- and three-story models increased by 78 and 74% respectively in comparison to bare wall model, and one- and two-story strengthened models did not exceed their drift capacities. The results of the dynamic analysis involving the earthquakes with 10% chance of exceedance are shown in Fig. 3b. In this case, all strengthened models could resist the earthquakes, while only one-story bare wall model could do that.

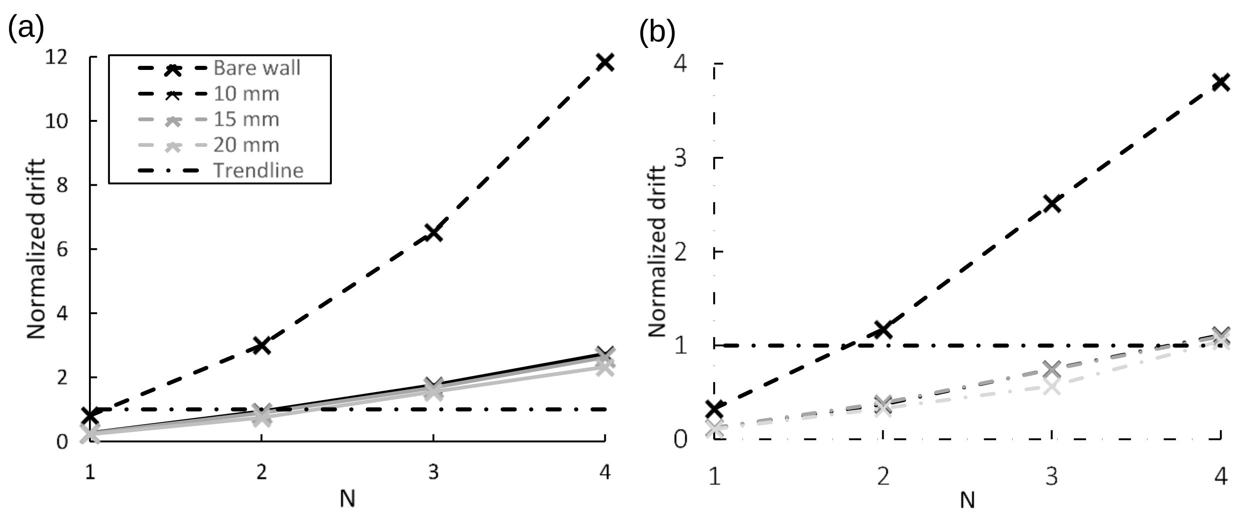

Fig. 3 Dynamic analysis results for exceedance chance of: (a) 2%; (b) 10%

4. CONCLUSION

This study investigated the effect of the strengthening the masonry walls with the geopolymer SHCC. The pushover and dynamic analyses showed that the proposed method is a promising approach to improve seismic performance of masonry walls. Application of the SHCC on the both surfaces of the wall increased its strength and ductility by 78-140% and 34-66% depending on the thickness of the SHCC layer. Also, it was found that the ductility of the SHCC affects its strengthening ability. The higher the ductility of the SHCC, the stronger and more ductile the masonry wall.

To evaluate the effect of the SHCC strengthening on the seismic demand of the model, dynamic analysis was conducted involving earthquakes with 2 and 10% chance of exceedance. According to results of the analysis on the one- to four-story masonry wall models, the SHCC significantly decreases the drift experienced by the structure thereby increasing its resistance to earthquake. For both ground motion cases, the experienced average drift of the models with the SHCC was three times less in comparison to the models without strengthening.

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