V－318

Structural Performance of ECC Anti-Seismic Retrofit Panels

○The University of Tokyo, Student, Shinya TAKEUCHI
The University of Tokyo, Member, Petr KABELE
The University of Tokyo, Member, Hideyuki HORII

1. Introduction

Extensive damage to older reinforced concrete (RC) buildings during recent strong earthquakes highlighted the need not only for increasing the strength of such structures, but also for improvement of their ductility.

Recently developed Engineered Cementitious Composites (ECCs) consist of cementitious matrix and short random fibers. Remarkably, the micromechanical structure (e.g., fiber volume fraction, fiber aspect ratio, etc.) of these materials can be tailored so as to achieve a specified macromechanical performance (e.g., high tensile or shear ductility) [1]. With the introduction of materials, such as ECCs, new anti-seismic retrofit methods become possible. One can consider a retrofit method, in which a structural shear wall is constructed using prefabricated panels made of a highly ductile ECC. It is expected that such a wall, even without conventional steel reinforcement, could exhibit ductility and strength comparable to a monolithic RC shear wall. In the present paper, structural performance of such ECC shear wall panels is studied by means of FEM analysis.

2. Problem setting

We consider that a retrofit shear wall, consisting of several ECC panels, has been constructed between columns and beams of an existing RC frame structure (Fig. 1). We assume that due to horizontal earthquake load, the RC frame undergoes a shear deformation as indicated by the dashed lines in Fig. 1. Such a simplifying assumption allows us to analyze only one of the panels, while the effect of the surrounding RC structure and other panels is represented by a 'frame' of very stiff elements, as shown in Fig. 2. We are interested in estimation of the panel shear strength τ_{av}^{max} (maximum average shear stress τ_{av}) and ductility γ_{av}^{max} (average shear strain γ_{av} when τ_{av}^{max} is reached). Consequently, we consider only monotonic loading. No conventional steel reinforcement of the panels is assumed. The ECC used for the panels consists of cement based matrix and 2% by volume of PVA fibers. This ECC has been tailored so that, under tensile stress it undergoes distributed multiple cracking before a large crack occurs. As a result, the material exhibits overall pseudo strain-hardening after the tensile stress reaches level the of 2.6 MPa, with cracking strain at the peak load ε_{mb}^{c} equal to 5% and tensile strength σ_{mb} equal to 3.5 MPa. In compression, this ECC exhibits a moderate hardening with peak compressive strain ε_0 of 0.46% and compressive strength σ_0 of 28.7 MPa. The analyses of the panels are carried out using a finite element program with a material model earlier developed specially for this type of ECC [2].

3. Results of analyses

For the initial analysis, we used the assumption that the panels were perfectly bonded to each other and to the surrounding RC structure along the whole panel boundary – Fig. 2a. Under such conditions, the panel was undergoing almost uniform straining. The analysis revealed that tensile diagonal cracking started at τ_{av} equal to about 2.6 MPa. However, due to the tensile hardening ability of ECC, the cracking was distributed in the whole panel and the panel was still able to carry increasing load. With increasing load, local failure due the compressive strain capacity ε_0 being reached in portions of the panel, occurred at τ_{av} of about 14 MPa and average shear strain γ_{av} of 0.83%. Even after this point, the panel could carry further increase of load up to τ_{av}^{max} = 15.3 MPa and γ_{av}^{max} = 0.96%, as can be seen from Fig. 3 (case BC1) .The maximum tensile cracking strain at the moment when load reached τ_{av}^{max} was still about 0.4%, which is well below the tensile cracking strain capacity of the material (5%). Thus we conclude that the panel overall shear strength and ductility are controlled by compression.

The target of the panel performance is to match the shear strength and ductility of a monolithic RC shear wall, estimated to be τ_{av}^{max} = 3 MPa and γ_{av}^{max} = 1%, respectively. It is seen that the strength of the analyzed panel exceeds the target value, while the ductility is slightly insufficient. It is expected that the compressive properties of ECC can be further modified by means of material tailoring. For this purpose, the required properties would have to be specified in terms of the uniaxial compressive parameters ε_0 and σ_0. Thus a study has been performed to show, how these two parameters affect the strength and ductility of the panel. The results are summarized in Fig. 4. and show, that the panel ductility γ_{av}^{max} is proportional to ε_0 and almost independent of σ_0, and vice versa, the panel strength τ_{av}^{max} is almost solely affected by the parameter σ_0 and not ε_0.

Assuming a perfect bond along the whole edge of the panel may lead to too optimistic result. The panel-panel or panel-existing structure connection would be probably realized by means of steel joint plates, which would allow

Keywords: structural performance, strain-hardening cementitious composite, anti-seismic retrofit
Contact address: Hongo 7-3-1, Bunkyo-ku, Tokyo 113, tel: 03-3812-2111 (ext.6092), fax: 03-3812-4977

stress transfer only along portions of the panel edges. To investigate the effect of panel jointing, we examined a more realistic case, denoted as BC2 (Fig. 2b), in which only portions of each side of the panel were bonded to the surrounding frame. The result in terms of τ_{av} vs. γ_{av} curve is shown in Fig. 3, with '+' and 'x' markers indicating initiation of tensile multiple cracking and local compressive failure, respectively. One can observe that the curve indicates a softer overall behavior, and both load and deformation at local compressive failure about 50% lower than in case BC1. On the other hand, the increase in load after the local compressive failure until the curve plateaus up is larger in case BC2 compared to BC1 (~3.8 MPa vs. ~1.3 MPa). Upon examining the distribution of tensile cracking strain and compressive plastic strain when the local compressive failure occurs in case BC2, we could see that the above behavior can be attributed to much less uniform strain distribution, with tensile cracking being confined into three diagonal bands and with high concentration of compressive plastic strain near the ends of the joint plates.

4. Concluding remarks

The present analyses indicate that by using ECC material tailored for a pseudo-strain hardening behavior under tension, it is possible to design an anti-earthquake retrofit shear wall panels without any conventional steel reinforcement. Under shear load, these panels fail in compression. Compared to the target values, the ECC panels exhibit sufficient strength but slightly insufficient ductility. Further improvement of the performance can be achieved by tailoring the ECC for higher compressive ductility. It is shown, that strain concentration due to panel joints can considerably reduce both the overall ductility and strength of the panels, meaning that that attention should be paid to the joints detailing.

Acknowledgment

The authors gratefully acknowledge the contribution of Prof. V.C. Li (ACE-MRL, University of Michigan) and Mr. T. Kanda (Kajima Technical Research Institute) to the research presented above.

References

1) Li, V.C.: From Micromechanics to Structural Engineering – the Design of Cementitious Composites for Civil Engineering Applications. ***Proc. of Japan Soc. of Civ. Eng.***, No. 471/1-24, 1993, pp. 37-48.
2) Kabele, P. and Horii, H.: Analytical Model for Fracture Behaviors of Pseudo Strain-Hardening Cementitious Composites, ***J. Materials, Conc. Struct., Pavements***, No. 532/V-30, 1996, pp. 209-219.

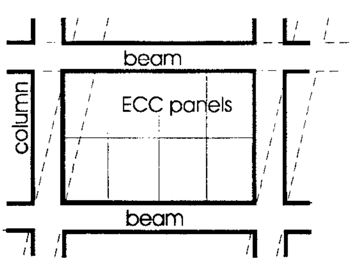

Fig. 1 Original RC frame structure and retrofit shear wall

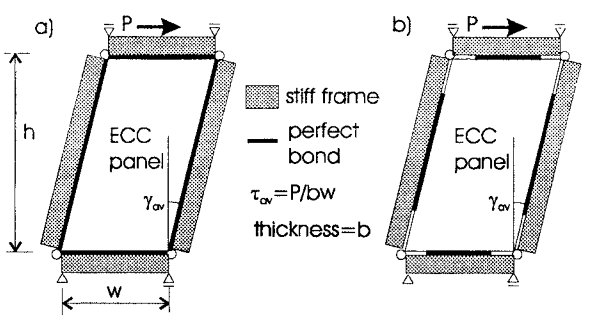

Fig. 2 Simplified model of a single ECC panel (deformed configuration); a) case BC1; b) case BC2

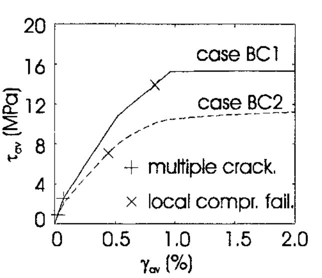

Fig. 3 Structural performance of ECC panels - average shear stress vs. average shear strain

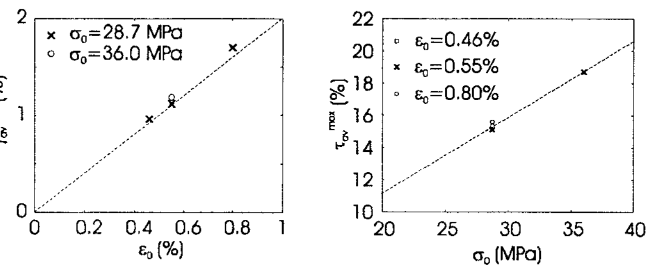

Fig. 4 The relationship between uniaxial compression characteristics and shear ductility and strength of ECC panel