ULTRA-DUCTILE ENGINEERED CEMENTITIOUS COMPOSITES FOR SEISMIC RESISTANT STRUCTURES

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1 INTRODUCTION

The experimental research study discussed in this paper focuses on the effect of substituting concrete in conventional reinforced concrete members with a ductile engineered cementitious composite (ECC) for the purpose of improving their response to reversed cyclic loading conditions. The performance of conventional reinforced concrete is strongly influenced by the limited ductility of concrete, which causes deterioration of reinforced concrete flexural members by shear crack formation, bond splitting, spalling, and disintegration in the plastic hinge region.

ECC is an ultra-ductile fiber reinforced cementitious composite material with a tensile strain capacity on the order of several percent. Based on this unique material property of ECC, the interaction with structural reinforcement in direct tension is characterized by compatible deformations of the reinforcement and ECC matrix in the elastic and inelastic deformation regime. In this paper, the effect of this unique composite deformation mechanism on the load-deformation response of reinforced ECC column members will be conceptually outlined, experimentally verified, and analyzed. More specifically, the behavior of reinforced concrete and ECC structural members with steel and FRP reinforcement will be contrasted with respect to their deformation capacity, energy dissipation, and damage evolution. An attempt will be made to quantitatively differentiate composite damage into desired energy dissipation by reinforcement yielding and detrimental composite deterioration by crack formation and disintegration.

2 RESULTS AND DISCUSSION

The behavior of reinforced ECC members under reversed cyclic loading conditions was experimentally investigated and contrasted to reinforced concrete using column specimens with 1400mm height and square cross-sectional dimensions of 240mm. The specimens were horizontally loaded in a cantilever mode at 1200mm from the column base, which was embedded in a relatively stiff transverse beam.

The response of the steel reinforced specimens (S-1 reinforced concrete, S-3 reinforced ECC) (Figure 1) beyond formation of a plastic hinge at the column base is effectively determined by the inelastic deformation behavior of the longitudinal reinforcement in tension and the respective cementitious matrix in compression. Beyond yielding, composite damage in specimen S-1 due to bond splitting and

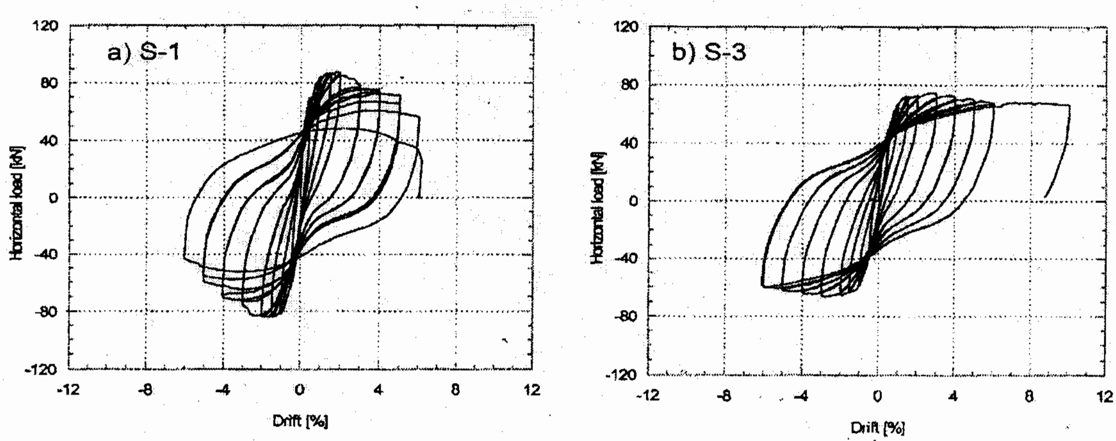

Fig. 1 Load –deformation response of specimens a) reinforced concrete and b) reinforced ECC

subsequent cover spalling (Figure 2a) lead to an abrupt reduction in flexural resistance (Figure 1a) and further composite deterioration in the plastic hinge region by propagating shear cracks and crushing of the concrete core. In contrast, specimen S-3 maintains composite integrity (Figure 2b) especially at the column base and a stable flexural deformation mode.

Compatible inelastic deformations between reinforcement and ECC reduce interfacial bond stress, and bond-splitting and cover spalling are not observed. In addition, ECC provides shear resistance and confinement of the column core and the longitudinal reinforcement, which are maintained at large inelastic deformations particularly in the plastic hinge region. Consequently, composite action between steel reinforcement and ECC is preserved. At this stage, inelastic compressive deformations in ECC occur in a rather ductile mode, resulting in stable inelastic reinforcement deformations in tension and compression at load reversal. Despite crushing of ECC in the column cover and in parts of the column core, its lateral confinement effect is preserved at specimen deflections of 10% drift at essentially constant flexural resistance (Figure 1b). Throughout the entire loading procedure, specimen S-3 maintains a flexural deformation mode without shear failure.

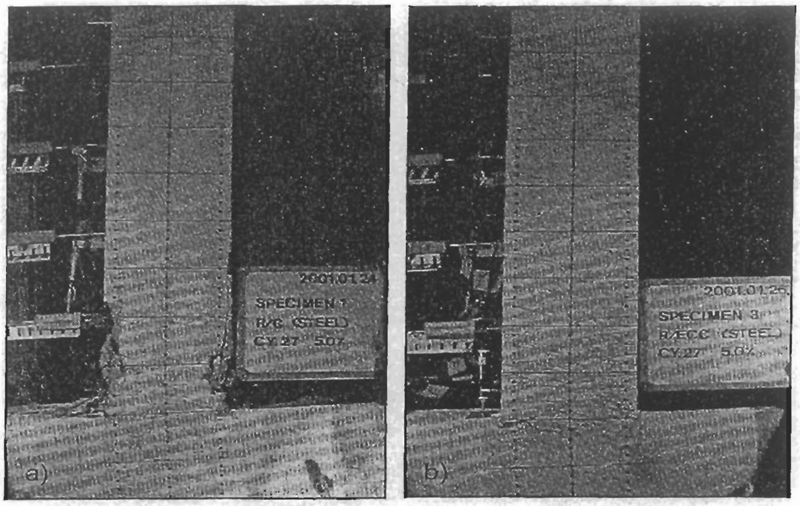

Fig. 2 Deformed shape of a) S-1 and b) S-3, both with steel reinforcement

3 CONCLUSIONS

The structural performance of steel reinforced ECC flexural members is characterized by relatively stable inelastic load-deformation behavior and large deflection capacity. In comparison to reinforced concrete, the ductile deformation behavior of ECC has a significant effect on the composite integrity particularly in the plastic hinge region and therefore the structural composite maintains stable inelastic deformations of the steel reinforcement, i.e. ECC assists stable steel reinforcement yielding in order to utilize its energy dissipation capacity to a maximum extent. However, the direct contribution of ECC to energy dissipation is negligible.

The damage mechanism of reinforced ECC has been quantitatively described and compared to reinforced concrete by means of a matrix damping index, which characterizes the level of matrix damage in a structural composite. This index has been introduced in an attempt to distinguish between advantageous and detrimental damage mechanisms. Specifically, the discrepancy in equivalent damping ratio between a hypothesized ideal damage mechanism and the experimentally obtained response can be attributed to energy dissipation mechanisms in the cementitious matrix such as crack formation, interfacial debonding, friction, spalling, and crushing. Except friction, these energy dissipation mechanisms are not repeatable and tend to diminish stable composite action particularly at large inelastic deflections by spalling, shear cracking, and propagating compressive failure. Furthermore, the resistance to shear in reinforced ECC has been found to be sufficiently provided by the inherent shear capacity of ECC and does not require transverse steel reinforcement.

The response of FRP reinforced ECC members investigated in this study were found highly sensitive to compressive deformations in the cementitious matrix. Prior to failure, FRP reinforced ECC showed elastic load-deformation response and stable flexural crack formation. However, compressive strain demand on the FRP reinforcement lead to failure at relatively small column deflections similar to those observed in FRP reinforced concrete.

The replacement of concrete with ECC in R/C structures should lead to enhanced collapse resistance and reduced repair requirements subsequent to earthquake loading.