HYBRID SYSTEMS WITH ENGINEERED CEMENTITIOUS COMPOSITES AND FIBER REINFORCED POLYMERS

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Introduction

Engineered cementitious composite (ECC) is known as a subcategory of high performance fiber reinforced cementitious composites (HPFRCCs). The unique mechanical properties of ECC such as ultra high ductility, tensile strain hardening, and distributed cracking pattern lead to several advantages including damage reduction and tolerance, energy absorption, crack distribution, deformation compatibility, and delamination resistance [1].

Concrete-filled fiber reinforced polymer (FRP) tube (CFFT) is another innovative achievement in structural systems, which not only eliminates the need for transverse steel reinforcement, but also provides improved flexural strength, ductility and energy dissipation [2]. Longitudinal steel was shown necessary for CFFTs to develop adequate hysteretic capacity in seismic regions [3]. It has also been shown that glass FRP (GFRP) tubes with off-axis fibers result in ductile behavior [2].

Given the exclusive properties of the ECC materials, replacing conventional concrete with ECC inside the FRP tube within a CFFT system may allow eliminating or reducing the longitudinal reinforcement. Accordingly, this paper proposes a hybrid system of FRP tube and ECC for bridge columns. The performance of the hybrid system with different lengths of ECC inside the column was investigated by an analytical study. The results were also used to plan an experimental study on ECC-filled FRP tube (ECCFFT) system, currently under way.

Analytical Study

Nine 1/6-scale bridge column models with circular section and with the length and the core diameter of 1,524 mm and 312 mm, respectively, were simulated in this study. The first model – RC, which served as a reference, incorporated conventional concrete and steel reinforcement. The second model – RECC, consisted of only ECC and steel reinforcement. The RC and RECC models included a 4.9 mm diameter steel wire spiral reinforcement of Grade 414 MPa with 279 mm outside diameter placed at a pitch of 31.7 mm. The third model – RCFFT, consisted of conventional reinforced concrete encased by an FRP tube with a thickness of 11 mm made of 17 layers of $\pm 55^{o}$ E-glass fibers and epoxy resin. The mechanical properties of the FRP laminate are presented in Table 1 under the name of GFRP1.

Table 1 Mechanical properties of FRP laminates

Type of FRP	Tensile Strength MPa	Tensile Modulus GPa	Hoop Strength MPa	Hoop Modulus GPa
GFRP1	161	12.6	234	N/A
GFRP2	194	15.9	208	15.9

The fourth model - RECCFFT, was steel-reinforced ECC encased by the same FRP tube without any lateral steel. Longitudinal steel reinforcement of sixteen No. 3 steel bars of Grade 414 MPa was used in the first four columns. The fifth model – ECCFFT, was made of ECC encased by the same FRP tube, however, without any internal steel reinforcement. The next three models – (ECCFFT1, ECCFFT1.5, and ECCFFT2), all had the same FRP tube with no internal steel reinforcement, partially filled with ECC for a height equal to 1, 1.5 and 2 times the plastic hinge length from the base of the column, respectively, and with conventional concrete for the remainder of the column length. The plastic hinge length was taken equal to the column diameter, as established by an earlier study [4]. The last model – ECCFFTG, consisted of another type of glass FRP (GFRP) tube made with three layers of bi-directional ($0^{o}/90^{o}$) E-Glass sheets and epoxy, filled with ECC within the plastic hinge length and conventional concrete for the remainder of the column length, and without any internal steel reinforcement. The mechanical properties of the FRP laminate are presented in Table 1 under the name of GFRP2. The conventional concrete was modeled with a 28-day compressive strength of 45 MPa, whereas the ECC had a compressive strength of 159 MPa. The Open System for Earthquake Engineering Simulation (OpenSees) was used to simulate a pushover analysis of the column models. Each column was subjected to 89 kN constant axial load to simulate dead loads.

Results and Discussion

Figure 1 shows the load-displacement responses from the pushover analysis for the first four columns. Column RC failed at a load of 71 kN, whereas by replacing concrete with ECC, the failure load was increased by 38% to 98 kN. The failure loads for RCFFT and RECCFFT were 142 and 249 kN, respectively. Therefore, ECC increased the capacity by 75% over conventional concrete in presence of FRP tube. Clearly, both the FRP tube and the ECC significantly improve both the ultimate load and ductility of the column.

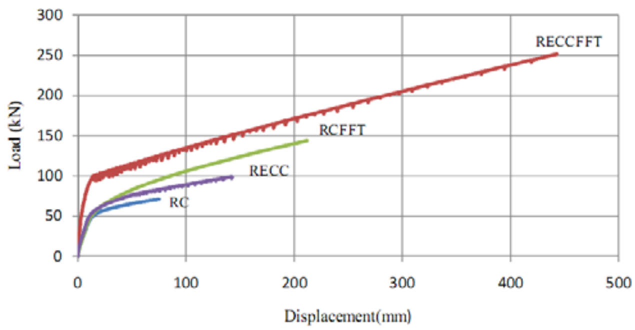

Figure 1 Effects of ECC and FRP tube

Figure 2 shows the plastic hinge lengths for the first four columns, indicating that the FRP tube is much more effective in extending the plastic hinge length of the column than the ECC.

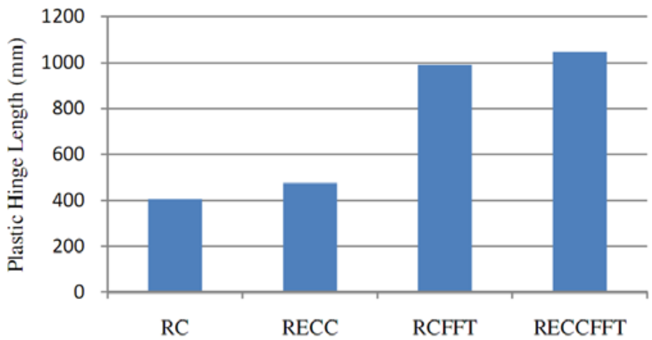

Figure 2 Plastic hinge lengths for Columns RC, RECC, RCFFT and RECCFFT

Figure 3 shows the load-displacement responses for Columns RC, ECCFFT, ECCFFT1, ECCFFT1.5, ECCFFT2, and ECCFFTG1. The figure effectively compares the performances of columns with different lengths of ECC in contrast with the control RC column. Among the three partially ECC-filled columns, ECCFFT1.5 has the most comparable performance to that of the conventional RC column. On the other hand, column ECCFFTG1 failed at significantly higher load capacity, with much less ductility. This behavior may be attributed to the linear elastic stress-strain behavior and the relatively higher modulus of elasticity of the GFRP tube used in this column. This highlights the reason for ductile response of the first type of tube in its off-axis fiber architecture.

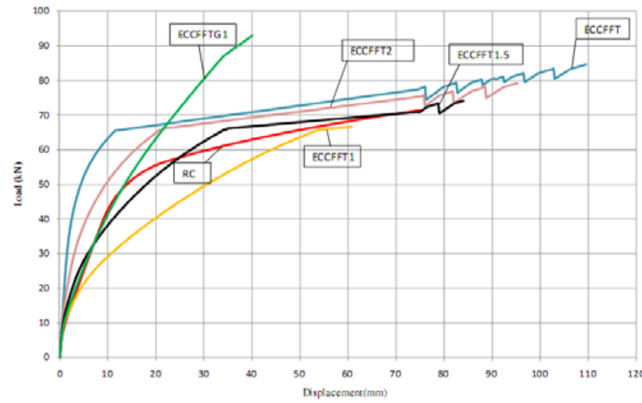

Figure 3 Effects of ECC length and FRP Tube

Conclusion

The results show the feasibility of ECCFFT system without any internal steel reinforcement as an alternative to conventional RC columns. The optimum hybrid system consists of FRP tube with off-axis fiber architecture filled with ECC within a length of 1.5 times tube diameter from the base.

References

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