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UPGRADING THE PERFORMANCE OF STEEL BEAMS USING FASTENED ADVANCED COMPOSITE MATERIALS

By

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Abstract

Bonding Fiber-Reinforced Polymers (FRP) is commonly used to enhance the structural performance of existing steel beams; however, the brittle failure at the adhesive risks the effectiveness of the bonded system. Fastening FRP is recently proposed to avoid the brittle failure of the adhesive. Promising outcomes of few studies on fastened FRP-steel system provoked the interest to investigate the effects of various fastening parameters on the performance of fastened FRP-steel beams.

This study investigates, experimentally and numerically, the impact of various fastening parameters on the performance of fastened FRP-steel beams. The proposed method involves fastening carbon-glass hybrid FRP (HFRP) strips to the tension flange of steel beams using FRP anchors or steel bolts. The experimental program tests forty-seven full-scale steel beams in two phases depending on the fastener material. The first phase utilized steel bolts to assess the effects of HFRP length, HFRP thickness, spacing between steel bolts and bolt layout on the behavior of the fastened HFRP-steel beams. Moreover, fiberglass FRP anchors were used in the second experimental phase to investigate the efficiency of the proposed technique while using different spacing between the FRP anchors and HFRP thicknesses. The observed failure modes along with the measured loads, deflections and strains were reported. A detailed analysis of the composite action at the HFRP-steel interface was also conducted.

The experimental results revealed a ductile failure of the strengthened beams, controlled by steel yielding, lateral torsional buckling, local buckling of the compression flange and bearing between the steel bolts and the HFRP strips. The strengthened beams exhibited yield load enhancement ranging between 4.9% and 15.1%, and improvement in the ultimate load from 8.5% to 22.2%. The results highlighted the significant influence of the bearing between steel bolts and HFRP, as well as the elastic modulus of the steel beams relative to that of the HFRP strips, on the composite action of the strengthened beams. Increasing the HFRP length enhanced the utilization of HFRP and reduced the mid-span deflection by up to 51.2%. Reducing the spacing between the bolts improved the yield and ultimate loads and enabled a better contribution of the HFRP strips to the overall stiffness of the system. Moreover, empirical equations were developed to enable predicting the ultimate load of fastened HFRP-steel beams and to anticipate the load-deflection behavior of similar strengthened beams with maximum deviation of 5.7% in the ultimate load.

Utilizing FRP anchors to fasten the HFRP strips improved the ultimate load in the range of 0.3% to 11.2%. Meanwhile, reducing the spacing between the FRP anchors enhanced the ultimate load and the composite action, and reduced the mid-span deflection by up to 39.5%. Doubling the HFRP thickness reduced the ductility of the beams due to the shear fracture of the anchors. The experimental findings emphasized the importance of using sufficient number of fasteners to avoid the system failure by anchor fracture.

ANSYS software was used to model the behavior of the strengthened beams. The developed model was validated against the experimental measurements with maximum deviation in yield and ultimate load predictions of 3% and 10.2%, respectively. The verified model was used to conduct an extensive parametric study to assess the effects of a wide spectrum of variables including; HFRP thickness, bolt spacing, steel grade, loading scheme and beam length. The numerical results verified the effectiveness of the proposed technique in enhancing the performance of the strengthened beams with up to 16.7% and 34.5% gain in the yield and ultimate loads, respectively.