Seismic Performance of FRP–Prefabricated UHPC Panel Rectangular Composite Bridge Piers

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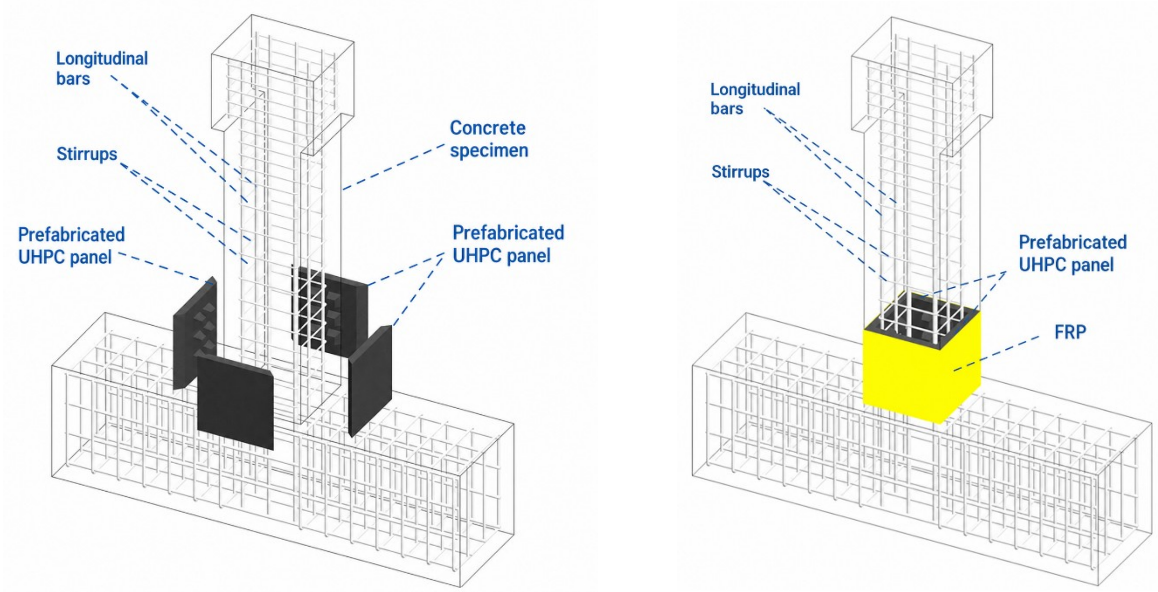
Extended Abstract

Bridge piers are critical load-carrying and lateral-resisting components in bridge systems. Severe pier damage during earthquakes may interrupt transportation networks and delay post-earthquake emergency response. Therefore, developing rapid, reliable, and durable strengthening techniques for reinforced concrete bridge piers is important for improving seismic resilience. Conventional strengthening methods, such as section enlargement, steel jacketing, and external prestressing, can improve structural capacity, but they often involve long construction periods, increased self-weight, corrosion-related maintenance, or complex anchorage details. Although cast-in-place UHPC and FRP strengthening methods have shown promising performance, each has inherent limitations when used alone. Cast-in-place UHPC requires strict on-site casting and curing conditions, while FRP mainly provides passive confinement and contributes little to local compressive resistance, particularly for rectangular bridge piers.

To address these limitations, this study proposes an FRP-confined prefabricated UHPC panel composite strengthening system for rectangular bridge piers. The system consists of a normal concrete core, longitudinal reinforcement, segmented prefabricated UHPC panels, multi-keyed interfaces, and an external FRP confinement layer. The prefabricated UHPC panels serve as stay-in-place formwork during construction and participate in load resistance during service. The UHPC panels provide a high-strength external shell, local compressive resistance, crack control, and durability protection. The external FRP layer supplies continuous transverse confinement, restrains panel outward deformation, limits joint opening, and improves the integrity of the composite system. The multi-keyed interface enhances mechanical interlock between the UHPC panels and the core

concrete. Therefore, the proposed system is not a simple combination of two high-performance materials; rather, it is based on functional complementarity among UHPC, FRP, and the keyed interface.



(a) Installation of prefabricated UHPC panels

(b) Formation of FRP external confinement

Fig. 1 Schematic of the fabrication process of the FRP–prefabricated UHPC panel strengthened specimen

The structural performance of the proposed system was investigated through axial compression tests, quasi-static cyclic tests, finite element analysis, and design-oriented theoretical modeling. The axial compression tests verified the composite action among the UHPC panels, FRP confinement, and core concrete. The cyclic tests further demonstrated that the composite piers exhibited fuller hysteretic loops, improved lateral load-carrying capacity, favorable ductility, and enhanced energy dissipation compared with conventional RC piers. The ductility factors of the composite specimens were greater than 5, indicating satisfactory deformation capacity. The observed damage patterns confirmed that the UHPC panels suppressed cover concrete spalling, the keyed interface improved shear transfer, and the FRP layer restrained transverse expansion and panel outward deformation.

A fiber-section finite element model was established in OpenSees and used to identify key design variables, including axial compression ratio, reinforcement parameters, concrete strength, and UHPC panel height. In addition, design-oriented axial and flexural capacity models were developed.

The results indicate that the proposed FRP–prefabricated UHPC panel system can effectively improve the seismic performance and damage resistance of

rectangular bridge piers. The study provides a new strategy for rapid post-earthquake strengthening and offers a preliminary theoretical basis for the design of this type of composite bridge pier system.

***Keywords**: Machine Learning； Ultra-High-Performance Concrete (UHPC)； Fiber-Reinforced Polymer (FRP)； Design Methodology； Fragility Analysis*