

OPTIMISATION OF UHPFRC-STRENGTHENED SQUARE BRIDGE PIERS FOR ENHANCED IMPACT RESISTANCE

R. Thulakshan, P.L.N. Fernando *

Department of Civil Engineering, University of Moratuwa, Moratuwa

The increasing vulnerability of waterway bridges to vessel collisions underscores the urgent need for intrinsic structural enhancements to improve impact resistance. Historical bridge failures such as the Sunshine Skyway Bridge (1980), I-40 Bridge (2002), and more recently, Francis Scott Key Bridge (2024) demonstrate the catastrophic consequences of ship–bridge collisions, including structural collapse, economic loss, and casualties. Conventional reinforced concrete (RC) piers, though cost-effective, exhibit brittle failure modes such as crushing, spalling, and shear cracking under high-energy impacts. Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) has emerged as a promising material due to its superior compressive strength, tensile resistance, ductility, and energy absorption capacity compared to conventional concrete. However, casting entire bridge piers with UHPFRC is not economically feasible due to its high material cost. Instead, optimised jacketing techniques that use UHPFRC strategically in critical regions have gained increasing research interest. The objective of this study is to evaluate the structural performance of square-shaped bridge piers strengthened with UHPFRC jackets and to propose strengthening configurations that maximise impact resistance with minimal material usage. In this study, a detailed numerical modelling approach was adopted using the advanced finite element software LS-DYNA. The baseline model consisted of a 3.1 m × 3.1 m square pier, 15 m in height, subjected to collision with a fully loaded Jumbo Hopper barge of mass 1,723 tons travelling at 8 knots (4.11 m/s or 14.8 km/h). The pier was designed as an RC column with typical reinforcement detailing, while nonlinear material models were defined to capture the dynamic behaviour of concrete, steel, and UHPFRC under high strain rates. The model was validated against published studies by replicating a similar barge–pier collision scenario. Next, two jacketing strategies were investigated. Scheme-1, the conventional full-ring jacketing method, involved wrapping the pier surface with continuous UHPFRC layers of varying thicknesses (200 mm, 400 mm, 600 mm) and lengths (2 m, 3.5 m, 5 m, and full height). Scheme-2, the proposed corner-only method, applied triangular UHPFRC jackets at the four corners of the pier, with side lengths of 0.75 m, 1.15 m, and 1.55 m across similar jacketing lengths. A comprehensive parametric study assessed the influence of these variables on pier displacement, stress distribution, strain energy absorption, and damage mitigation. The results showed that in Scheme-1, increasing jacket thickness improved impact resistance more effectively than increasing length, with a thickness of 400 mm yielding optimal performance. Scheme-2 demonstrated superior material efficiency, as uniform corner-only jacketing along the full pier height achieved minimal damage with a 12% usage of UHPFRC by volume. The study concludes that strategic application of UHPFRC, particularly through corner-only jacketing, provides an economical and effective solution to enhance pier resilience against barge impacts. Findings highlight that optimised geometric distribution of UHPFRC is more critical than overall volume, offering practical guidance for both retrofitting and new bridge design.

Keywords: Barge-pier collision, Damage mitigation, Impact loading, Pier displacement, UHPFRC jacketing

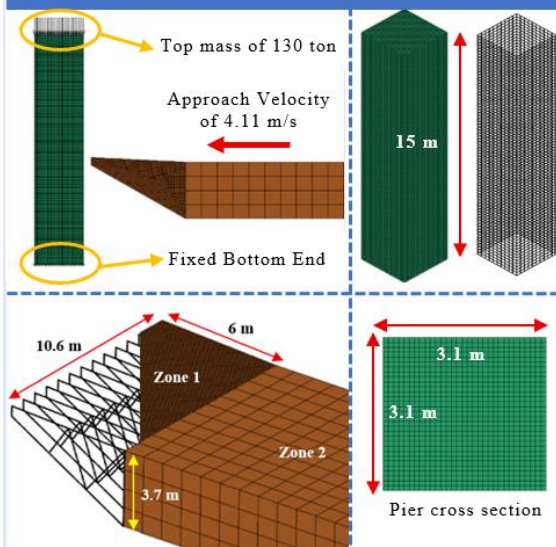
* Correspondence: lakshithaf@uom.lk

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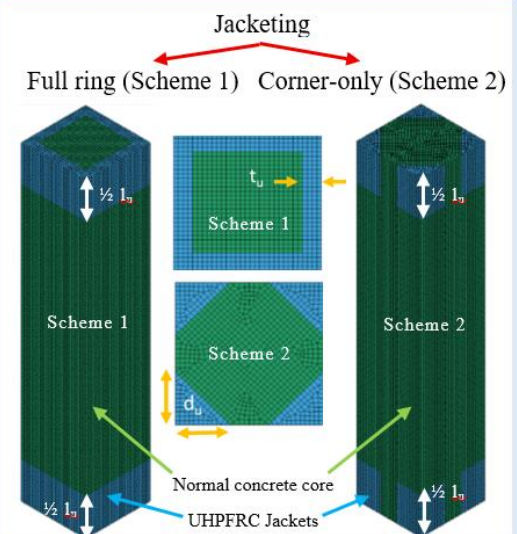
Typical Protective Techniques for Bridge Piers



FEM Study

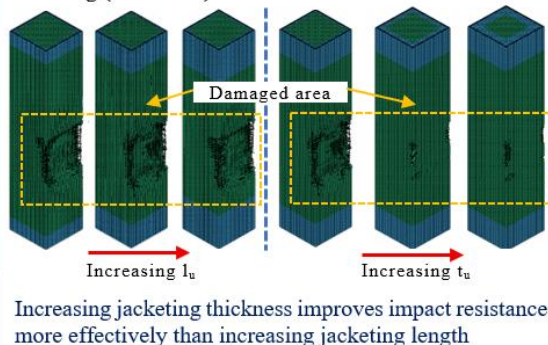


Methodology



Results and Conclusions

Full ring (Scheme 1)



Corner-only (Scheme 2)

Optimal performance is achieved with full-height corner-only jacketing

$$(l_u=15 \text{ m}, d_u=0.75 \text{ m}, V_r=12\%)$$

Right-angled triangular corner jacketing can outperform full-perimeter schemes with similar UHPFRC use, but optimal size depends on pier geometry

Damaged area

