Full-Depth Rapid Repair of Airfield Rigid Pavements with Ultra-High-Performance Fiber-Reinforced Concrete Precast Panels (UHP-FRC-PCP) and Life-Cycle Cost Analysis

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Abstract

This paper presents the implementation of precast ultra-high-performance fiber-reinforced concrete (UHP-FRC) panels in a repair project for airfield pavement at Dallas/Fort Worth International Airport. The use of UHP-FRC material results in substantial improvements to the sustainability of concrete structures, attributed to its dense microstructure and damage-resistant characteristics. These characteristics can significantly reduce the amount of repair, rehabilitation, and maintenance work, thereby giving the airfield pavements a longer service life. This implementation project used a novel approach for repairing concrete pavement that involves utilizing precast UHP-FRC panels in conjunction with a minimal amount of cast-in-place UHP-FRC to connect pavement sections without the use of dowel bars. Laboratory experimental results proved the feasibility of using this novel method for rapid pavement repair. Based on preliminary life-cycle cost analysis, repairing a typical airfield pavement using conventional cast-in-place concrete is approximately 45 times more expensive than using UHP-FRC precast panels over a 50-year analysis period. This novel repair method addresses the strong need to develop rapid and sustainable UHP-FRC materials for repairing runway, taxiway, and apron pavements that can be easily cast onsite without special treatments.

Keywords: UHP-FRC, Repair, Airport, Pavement, Runway, Sustainability, Life-Cycle Cost.

1. Airfield Pavement Repair

Infrastructure durability issues can result in significantly higher life-cycle costs when compared to the costs of initial construction and materials. Fast pavement deterioration can be caused by overloaded and increasing traffic (FAA, 2014) and other environmental loads such as summer heatwaves, droughts, freezing temperatures, and flooding. As a result, the cost of pavement maintenance, including replacement and rehabilitation, could increase significantly due to the impacts of climate change and changes in transport demand. Indeed, pavement maintenance is one of the significant expenses associated with airport development (FAA and USDOT, 2022). Additionally, the expenses associated with delayed or canceled flights can be substantial and may be the determining factor in selecting a construction method. This is especially critical for paving projects that involve closing a runway, taxiway, or aircraft parking area. Therefore, it is essential to use fast construction methods at the airfield to reduce the duration of these impacts.

2. A Novel Repair Method Using UHP-FRC Precast Panels

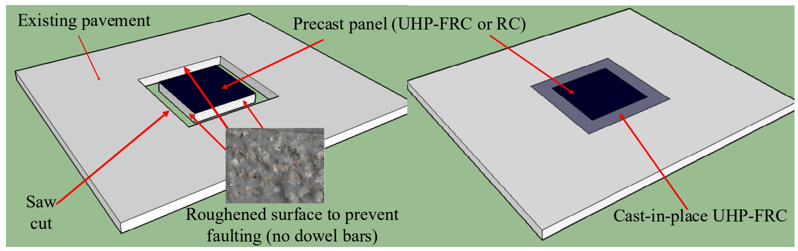

Figure 1: Pavement repair using UHP-FRC precast panels without dowel bars

This project investigated the practicality of using ultra-high-performance fiber-reinforced concrete (UHP-FRC) in rapid pavement repair by leveraging its high early strength, damage-resistant properties, and high durability. In this method (Figure 1), a precast UHP-FRC panel is used along with cast-in-place UHP-FRC. The vertical repair surfaces of the existing concrete pavement are roughened on site. Prior to transportation to the site, the perimeter surfaces of the precast UHP-FRC panel are roughened, eliminating the need for dowel bars. The depth of the precast UHP-FRC is the same as the existing pavement thickness. After placing the roughened precast UHP-FRC panel in the repair area, the joint is filled by UHP-FRC. Only a narrow cast-in-place UHP-FRC joint measuring 4 to 6 inches (100 to 150 mm) in width is poured onsite.

Traditional repair of concrete pavement involves saw cutting to extract the damaged section, resulting in a smooth surface at the cut. Dowel bars are subsequently used to connect the new and existing concrete pavement, transferring the force and preventing faulting between the two surfaces. However, recent experiments conducted by Karmacharya and Chao (2018) suggest that dowel bars, traditionally used to prevent faulting, do not significantly contribute to the load transfer at the interface at the peak load. Instead, some degree of vertical deformation of the pavement, such as faulting, is necessary before dowel bars can effectively carry the load. Based on this finding, it can be inferred that substituting dowel bars with a roughened interface is a viable option. Karmacharya and Chao (2018) demonstrated that a roughened surface (equivalent to a concrete surface profile (CSP) of 5) produces a strong bond resistance, which effectively prevents faulting. The substitution of dowel bars with a roughened surface can eliminate the time required for dowel bar preparation, such as drilling holes and waiting for the epoxy to harden. Although drilling holes may be quicker than roughening the surface, the curing process for the epoxy can take several hours. The new approach presents several benefits, including: (1) elimination of dowel bars, (2) reduction in pavement thickness, (3) early strength gain and material resilience, (4) precast serves as the most effective emergency repair technique, and (5) on-site precasting eliminates transportation costs associated with off-site precasting.

3. Implementation of Rapid Taxiway Repair at Dallas/Fort Worth International Airport

Figure 2 illustrates the implementation of UHP-FRC precast panels, surface roughening, and onsite UHP-FRC joint grouting. The entire installation, including demolition, was completed within 6 hours. Notably, UHP-FRC material reached a compressive strength of 5 ksi (35 MPa) in 16 hours.

Figure 2: Implementing UHP-FRC precast panels, surface roughening, and onsite UHP-FRC joint grouting

4. Comparison of Life-Cycle Costs for Airfield Pavement Repair Methods: Conventional Cast-in-Place Concrete versus Precast UHP-FRC

The life-cycle cost analysis assumes the following: (1) the repair dimensions are 22' × 18' × 17" (6,706 mm × 5,486 mm × 432 mm), (2) the repair section is located in a critical runway at DFW airport, such as runway 18R/36L, (3) the repair time is equivalent to the runway closure time as the safety regulations require the entire runway to be closed during repairs, (4) labor and equipment costs are equal for both repair methods, (5) conventional cast-in-place repair is performed every 5 years, while the UHP-FRC precast panels last 50 years due to its high durability, (6) a discount rate of 1.5% is used for Net Present Value calculation, and salvage value is not considered, (7) conventional concrete material cost is \$125/yd³ and repair time is 7 days, (8) UHP-FRC panel pavement repair material cost is \$1,500/yd³ and repair time is 1 day, (9) the estimated cost of closing the runway at DFW airport is \$315,663 per day.

According to the results, a typical airport runway repair using the conventional approach would cost approximately \$7,950,761 over a 20-year analysis period, while the same repair using the UHP-FRC based method would cost approximately \$346,829 (a life-cycle cost ratio of Conventional/UHP-FRC = 23 times). If the analysis period is extended to 50 years, the cost of the conventional method repair would increase to approximately \$16,208,283, while the UHP-FRC based repair method would still cost \$346,829 (a life-cycle cost ratio of Conventional/UHP-FRC = 47 times).

5. References

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