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Recent Advances in Quantitative Sensitivity Analysis for Dynamic Construction Control of Prefabricated Steel-Concrete Composite Cable-Stayed Bridges

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Abstract

Prefabricated steel–concrete composite cable-stayed bridges are a major form of industrialized bridge construction. Dynamic construction control and parameter sensitivity quantification are critical to ensuring structural safety and final alignment. Ultra-high-performance concrete (UHPC) has become a preferred material for precast segment connections due to its superior bond performance with reinforcing bars. This paper reviews recent advances in quantitative sensitivity analysis for dynamic construction control, focusing on the bond behavior of lap-spliced rebars in UHPC, key influencing parameters, and time-varying sensitivity characteristics. Research shows that steel fiber content, rebar diameter, lap length, cover thickness, and transverse reinforcement dominate bond strength and system sensitivity. The bond stress distribution along lap length varies significantly under different configurations, directly affecting structural stability during construction. Finally, existing challenges and future research needs are briefly discussed.

Keywords

Prefabricated Steel–Concrete Composite Cable-Stayed Bridge; Dynamic Construction Control; Quantitative Sensitivity; UHPC; Lap-Spliced Rebars; Bond Behavior

1. Introduction

Prefabricated concrete structures feature rapid construction, controllable quality and low environmental impact, and have become a primary form of industrialized construction. For long-span cable-stayed bridges, the performance of segment connections directly determines structural behavior and construction efficiency. UHPC exhibits ultra-high strength[1], strain-hardening behavior and excellent durability. Its bond performance with rebars is much better than normal concrete,

and the anchorage length can be shortened by about 70%. Thus, UHPC is increasingly adopted in lap-spliced rebar connections for prefabricated bridges.

Dynamic construction control depends on real-time simulation, monitoring and correction to achieve the target state. Quantitative sensitivity analysis identifies dominant parameters and quantifies their influence on structural responses. This paper reviews the bond behavior of lap-spliced rebars in UHPC and its application in sensitivity quantification for dynamic construction control of prefabricated steel–concrete composite cable-stayed bridges.

2. Bond Behavior of Lap-Spliced Rebars in UHPC

2.1. Test Methods and Failure Modes

Two main test methods are used: beam tests and direct tension tests. Beam tests reflect real structural stress with high fidelity but have complex setups. Direct tension tests are simpler and more suitable for mechanism studies. According to bar arrangement, they are divided into single-row and double-row tests.

Failure modes mainly include rebar pullout, UHPC splitting and rebar fracture. Single-row specimens usually fail by splitting. In double-row tests, UHPC splitting often shows an X-shaped crack pattern[2].

2.2. Key Parameters Influencing Bond Strength

Bond strength is mainly affected by six factors:

(1) Steel fiber volume fraction: Bond strength increases significantly with fiber content within1% – 4%. A volume fraction ⩾2% is recommended for reliable lap splicing.

(2) Rebar diameter: Bond strength generally decreases with increasing diameter due to Poisson's ratio and shear-lag effects.

Lap length: Longer lap length leads to more non-uniform bond stress distribution and lower average bond strength.

(3) Clear spacing: Non-contact lap splices provide better bond performance than contact splices. Most codes require clear spacing to exceed bar diameter and fiber length.

(4) Cover thickness: Bond strength increases with cover thickness within 4d, as thicker cover enhances confinement.

(5) Transverse reinforcement: Stirrups restrain crack propagation and slightly improve bond strength, while stirrup type has little effect.

2.3. Bond Stress Distribution

Bond stress along the lap length is non-uniform and closely related to lap length. It is nearly uniform at 2d, double-peak at 4d, and single-peak at 6d–8d. This distribution feature determines the local bond performance and affects structural sensitivity during construction.

3. Quantitative Sensitivity in Dynamic Construction Control

Dynamic construction control of prefabricated steel–concrete composite cable-stayed bridges is time-varying and strongly dependent on segment connection stiffness. The sensitivity of construction responses is dominated by:

(1) Material parameters: UHPC steel fiber content, elastic modulus, and bond strength of lap-spliced rebars.

(2) Geometric parameters: rebar diameter, lap length, clear spacing, cover thickness, and segment positioning error.

(3) Construction parameters: cable tension error, segment erection sequence, and UHPC curing age.

(4) Environmental parameters: temperature, humidity, and thermal gradient affecting early-age UHPC performance.

Quantitative studies show that steel fiber volume fraction, lap length, and rebar diameter are the most sensitive parameters. Their variations directly change connection stiffness and cause alignment and internal force deviations during construction. Time-varying bond performance of UHPC at early ages also increases parameter sensitivity in the early construction stage[3].

4. Challenges and Future Research

Despite great progress, several challenges remain:

Bond behavior under combined tension, bending, shear and cyclic loads is insufficiently studied.

A unified method for multi-parameter coupled sensitivity analysis is lacking.

Long-term bond degradation and its effect on construction stability are not clear.

Standard specifications for sensitivity-based construction control are incomplete.

Future research should focus on bond mechanisms under complex stress, dynamic sensitivity considering damage evolution, and intelligent construction control combined with digital twin technology[4].

5. Conclusions

(1) UHPC significantly improves the bond performance of lap-spliced rebars and allows shorter lap length in prefabricated bridges.

(2) Bond strength is sensitive to steel fiber content, rebar diameter, lap length, cover thickness and transverse reinforcement.

(3) Bond stress distribution along the lap length is non-uniform and governs the sensitivity characteristics during construction.

(4) Quantitative sensitivity analysis based on UHPC bond behavior supports refined dynamic construction control.

(5) Further studies are required for complex stress states, cyclic loading effects and unified evaluation approaches.

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