LIFE-CYCLE SEISMIC PERFORMANCE ASSESSMENT OF COASTAL PIERS CONSIDERING IN-PLANE NON-UNIFORM CORROSION

Y. Gu[(1)], S.H. Zhou[(2)], J.C. Wang[(3)]*

[(1)] *Professor, College of Civil Engineering, Fuzhou University, Fuzhou 350108, Fujian, China, cinoa@fzu.edu.cn*
[(2)] *Ph.D. Student, College of Civil Engineering, Fuzhou University, Fuzhou 350108, Fujian, China, 2500510037@fzu.edu.cn*
[(3)] *Associate Professor, College of Civil Engineering, Fuzhou University, Fuzhou 350108, Fujian, China, jingchengwang@fzu.edu.cn*

Extended Abstract

Chloride-induced corrosion is a major cause of long-term deterioration in coastal reinforced concrete (RC) bridges. For rectangular bridge piers, corrosion is in-plane non-uniform because corner rebars are exposed to two-sided chloride ingress, whereas mid-face rebars are mainly governed by one-dimensional diffusion. However, life-cycle seismic assessments commonly idealize corrosion as uniformly distributed over the cross-section. This simplification may overestimate seismic capacity and underestimate seismic fragility, particularly for piers with severe corner deterioration. Motivated by the field observations shown in Fig. 1, this study investigates the influence of in-plane non-uniform corrosion on their life-cycle seismic performance.

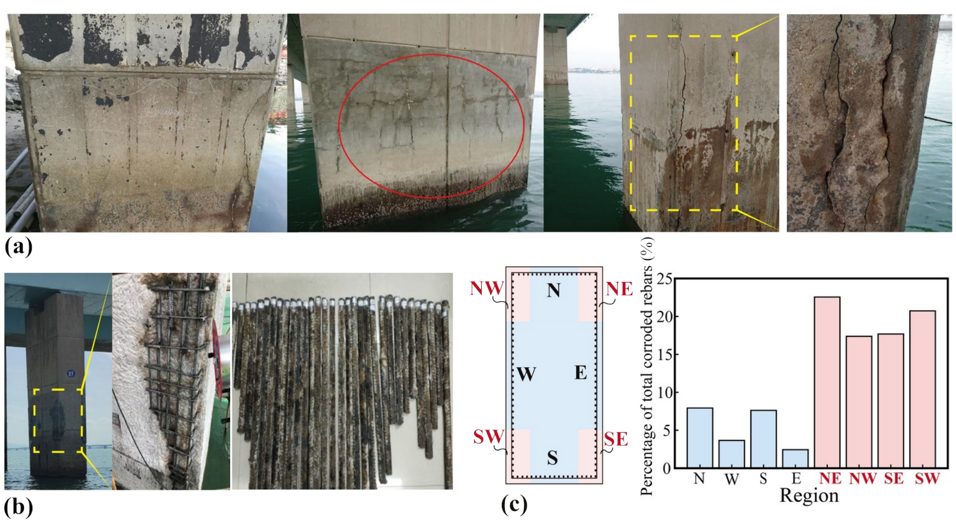

Fig. 1. Investigation results of in-plane non-uniform corrosion of coastal rectangular bridge piers in Xiamen: (a) concrete cracking was observed in the corner region due to rebar corrosion; (b) corroded rebars were extracted from the bridge pier; (c) statistical summary of corroded rebars.

A time-dependent corrosion modeling framework is developed to distinguish the corrosion evolution of corner and mid-face rebars. The in-plane non-uniform corrosion level is defined as the ratio between the corrosion mass loss ratio of corner rebars and that of mid-face rebars. Consistent with previous studies, the corrosion model is established based on three assumptions: (a) the surface chloride concentration assigned to the cross-section is assumed to remain constant; (b) the chloride concentration in the corner zones is taken as 2.01 times that in the mid-face zones; and (c) for simplicity, the corrosion penetration depth of rebars is assumed to be positively correlated with the chloride concentration. Based on these assumptions, the time-dependent corrosion mass loss ratios of corner and mid-face rebars are calculated and introduced into deterioration models for rebar, bond-slip behavior, concrete confinement, and shear resistance.

The proposed framework is implemented in OpenSees for nonlinear seismic analysis, as illustrated in Fig. 2. The pier is modeled using displacement-based beam-column elements with fiber sections. Longitudinal rebars are represented by the Reinforcing Steel material model, while cover and core concrete are modeled using Concrete02. A zero-length bond-slip element is adopted at the pier base to account for anchorage degradation, and a zero-length shear spring is incorporated to capture possible transition from flexural behavior to flexure-shear or shear-dominated failure. The numerical model is validated against experimental RC pier specimens with different failure modes, showing acceptable agreement in lateral force–displacement response and failure mechanism.

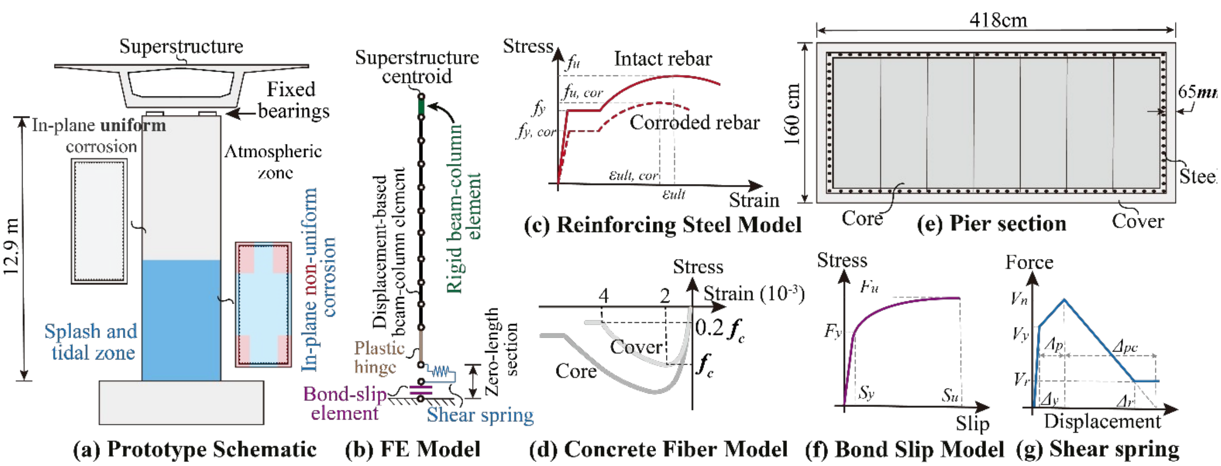

Fig. 2. Schematic illustration of the FE model, constitutive models of RC materials, bond-slip element, and shear springs.

The framework is applied to a representative rectangular pier of Xiamen Bridge, which was constructed in 1992 and inspected in 2022. The pier has a height of 12.9 m, a concrete compressive strength of 37.5 MPa, and 92 longitudinal rebars with a diameter of 28 mm and a yield strength of 335 MPa. The corrosion analysis indicates that corner rebars initiate corrosion earlier and deteriorate faster than mid-face rebars. At a service time of 30 years, the corrosion mass loss ratios of longitudinal and transverse rebar in the corner region reach 22.2% and 34.8%, respectively, compared with 2.8% and 10.7% in the mid-face region.

Multi-level seismic capacity models are established through pushover analysis, while probabilistic seismic demand models are developed using the cloud approach. Fragility curves are generated for slight, moderate, extensive, and complete damage states under both in-plane uniform and in-plane non-uniform corrosion assumptions, as illustrated in Fig. 3. The results show that seismic fragility increases significantly with service time. More importantly, the uniform corrosion assumption underestimates seismic risk because it fails to capture intensified degradation of corner rebars. The discrepancy between the two assumptions becomes more evident at higher damage states and longer service periods, where local rebar deterioration and flexure-shear interaction become more dominant.

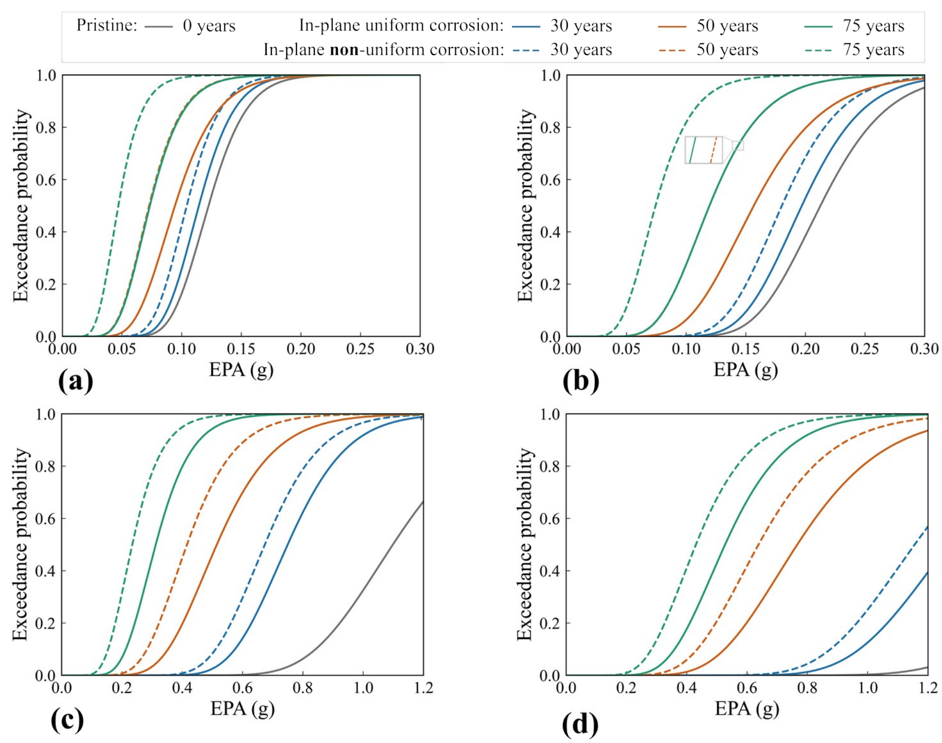

Fig. 3. Lifetime fragility curves for the pier under corrosion: (a) slight damage; (b) moderate damage; (c) extensive damage; and (d) complete damage.

A parametric study further shows that the influence of in-plane non-uniform corrosion increases with the average corrosion mass loss ratio. Piers with lower axial

load ratios and higher shear-span ratios are more sensitive to in-plane non-uniform corrosion, whereas the effect of cross-sectional length-to-width ratio is not monotonic. These findings indicate that in-plane non-uniform corrosion should be explicitly considered in life-cycle seismic assessment and maintenance decision-making for coastal rectangular RC bridge piers.

Keywords: *Coastal bridge; Rectangular pier; In-plane non-uniform corrosion; Seismic fragility.*