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Experimental investigation on cyclic behavior of coastal bridge piers with non-uniform corrosion under biaxial quasi-static loads

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HIGHLIGHTS

- Biaxial quasi-static tests for non-uniform corroded coastal bridge piers are conducted.
- The strength, deformation and energy dissipation capacity of different levels of corroded piers are analyzed.
- Coupling effect of biaxial load action is investigated.

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ABSTRACT

Corrosion-induced damage on coastal bridge piers reduces the seismic performance of structures. Biaxial earthquake excitation makes the degradation even worse. In this study, cyclic tests of four corroded bridge piers with different levels of non-uniform corrosion damage along the elevation were conducted under biaxial pseudo-static cyclic loads, while another corroded bridge pier was applied with only a uniaxial load for comparison. First, the experimental program, including the specimen design, accelerated corrosion in laboratory, test facility, measurement instrument, and loading protocol, is introduced. Then, based on the test results, the experimental observations, hysteretic characteristics, strength, ductility, curvature distribution, and energy dissipation of the specimens are analyzed to investigate the effects of the corrosion degree and biaxial horizontal loading condition. The test results indicate that the seismic performance of bridge piers is strongly affected by biaxial horizontal loads, and the increase in local damage due to non-uniform corrosion makes the performance deterioration more severe.

1. Introduction

Earthquakes are a common natural hazard with strong randomness and unpredictability. The randomness of the earthquake event exhibits not only in the occurrence time, location, and magnitude, but also in the propagation direction. However, due to the complexity of structures owing to the strong nonlinearity of materials, most of previous studies on seismic performance of structures are mainly focused on unidirectional earthquake excitation, which does not always match with the real earthquake scenario [1–4]. Actually, an earthquake incident with multi-component is a more common occurrence in civil infrastructures [5]. Understanding the bidirectional seismic performance of the structures is a major challenge for the researchers and engineers [6,7].

The quasi-static test is a conventional method for investigating the seismic performance of building columns and bridge piers. Up to the present, many quasi-static tests have been conducted to investigate the cyclic behavior of structures under unidirectional earthquake excitation [8–10]. However, few tests were carried out for structures under bidirectional earthquake excitations. To reveal the load-path effect of the biaxial seismic action, Bousias et al. [11] performed a series of cyclic tests using 12 reinforced concrete (RC) columns. It was found that compared to an identical column under unidirectional earthquake action, the coupling effect of bidirectional earthquake attack reduced the strength and stiffness of the structures in both directions while increasing the hysteretic energy dissipation. Using unidirectional and bidirectional quasi-static tests, Tsuno and Park [12] also investigated the damage characteristics of bridge piers considering different loading patterns. The test results showed that the ultimate displacement of the unidirectional action is significantly larger than that of the biaxial loads. From the test results of Qiu et al. [13], the same conclusion was also made. Focused on this issue, some other experiments were also conducted by researchers [14,15] to investigate the seismic performance of RC columns, including strength, stiffness,

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energy dissipation, and damage index, with different structural configuration, reinforcement and load paths. The test results also demonstrated that the stiffness and strength degradations were more serious under biaxial cyclic loads. Recently, Rodrigues et al. [16,17] also experimentally investigated the cyclic behavior of columns strengthened by CFRP or steel plates jacketing under biaxial cyclic loads.

In earthquake-prone regions, existing structures with corrosion-induced damage face a more severe challenge due to the multiple hazard actions of earthquake and corrosion. To understand the seismic performance and failure mechanism of such types of civil infrastructure, Yang et al [18] conducted cyclic tests on five corroded columns with different degrees of corrosion. The experimental results indicated that the flexural strength, stiffness, ductility, and energy dissipation capacity were all continuously degraded with increasing degree of corrosion of the reinforcement. Cyclic test results of four coastal bridge piers with different corrosion degree also showed this phenomenon [19]. In the experimental investigation by Ma et al [20], the influence of axial compression ratio on the seismic behavior of 13 corroded circular columns was investigated. Experimental results showed that there was more severe degradation on specimens with higher corrosion degrees and axial compression ratios. Meda et al. [21] conducted two full-scale cyclic tests of column specimens. The test results showed that the global behavior of columns under cyclic loads was strongly affected by corrosion damage. In addition to such experiments, some other researchers also investigated methods for establishing numerical models of corroded structures and conducted simulations on the seismic performance of structures with corrosion-induced deterioration [22–24].

The published literature showed that previous experimental and numerical studies on corroded columns were mainly focused on the seismic behavior of structures under unidirectional seismic loads. Relative research works on biaxial seismic actions were very limited and seldom addressed. From engineering practice, it is recognized that biaxial seismic actions would lead damage that is more serious. Furthermore, the combination of corrosion and biaxial seismic actions would make the situation even worse. Thus, there is an urgent need to understand the damage mechanism and the mechanical behavior of corroded coastal bridge columns under such type of complex seismic loads.

Aiming at this problem, this study presents a pseudo-static experiment on the cyclic behavior of corroded bridge piers with non-uniform damage under biaxial seismic loads. The main contribution of this study includes: (1) non-uniform corrosion along the elevation of bridge piers was considered in this experiment to match the specific corrosion damage characteristics of coastal bridges; (2) the seismic actions were applied with a pattern of biaxial cyclic loads, which is much close to the realities of seismic actions on bridge piers, but seldom addressed by the researchers. To achieve this purpose, four identical specimens of RC bridge piers with different corrosion levels considering non-uniform corrosion damage along the elevation were used for the biaxial pseudo-static cyclic tests, and one corroded specimen was adopted for uniaxial cyclic loading for comparison. The main content of this study is organized in two parts. In Section 2, the experimental setup and procedure are introduced. From the test results, the experimental observations, hysteretic characteristics, strength, ductility, curvature, and energy dissipation capacity, are analyzed in Section 3. Finally, the main findings of this experimental study are summarized.

2. Experimental program

2.1. Specimen

Five identical specimens of a coastal bridge pier were designed and constructed to investigate the seismic performance of the structural components with different corrosion damage and load patterns. As shown in Fig. 1, each specimen consists of a rigid

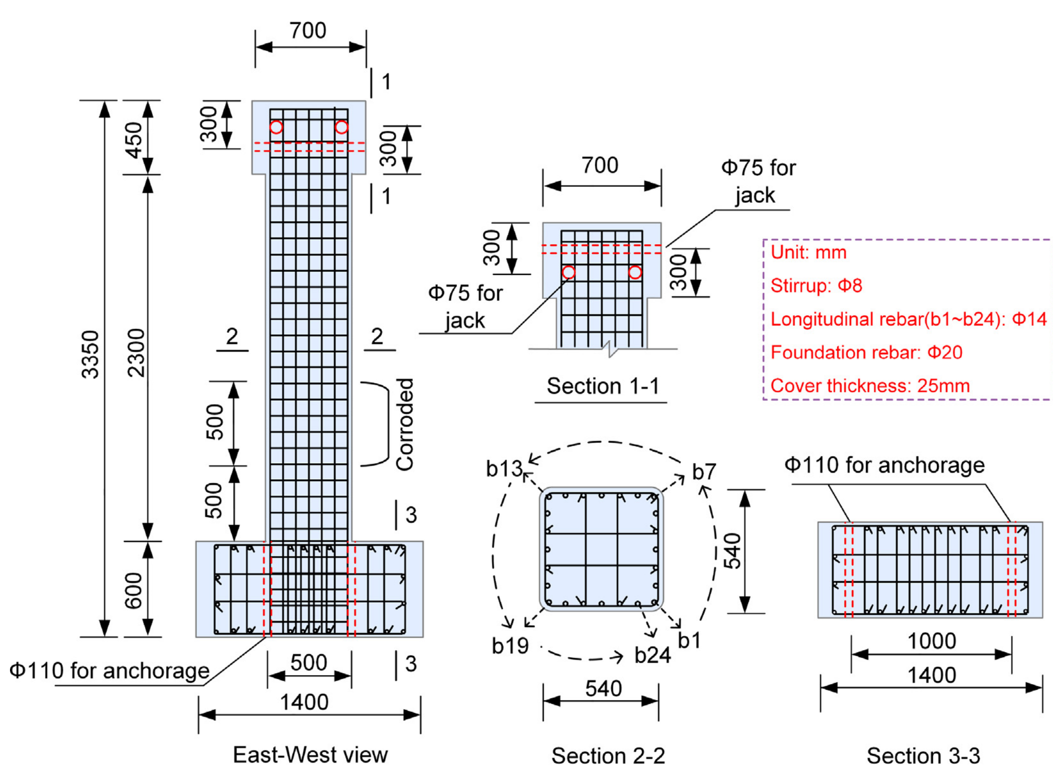

Fig. 1. Specimen geometry and reinforcement details.