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Experimental evaluation of seismic performance of precast segmental bridge piers with a circular solid section

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ABSTRACT

Rapid bridge construction is in high demand in the construction industry, due to strict requirements on work-zone safety and traffic control during construction. Prefabricated bridge piers have been proposed for the fast construction of bridge substructures. This study deals with quasi-static tests on precast piers with bonded prestressing bars and steel tubes. One of the most crucial aspects in the design of precast prestressed concrete bridge piers is the seismic performance. Seven precast pier specimens with single-segment and two-segment systems were fabricated. The main test parameters were the number of prestressing bars, the prestressing force, and the location and number of joints between the segments. Test results showed that the introduced axial prestress allowed the restoration of the deformation under small lateral displacements, resulting in minor damage. However, there was no effect of the prestress on the self-centering capability when the plastic hinge region was damaged severely due to a large lateral displacement. Judging from the observed damage, the design of the joints in precast piers should focus on the first joint between the foundation and the pier segment, for crack control. In order to satisfy the current required displacement ductility, it is necessary to have the same amount of transverse reinforcements as in reinforced concrete piers. As the steel ratio increases, the plastic deformation and its energy absorption capacity increase after reaching its maximum strength. The number of joints showed some influence on the energy absorption capacity.

1. Introduction

In the civil engineering community, increasing attention is being paid to prefabricated structures and systems that enhance current bridge construction methods. The adoption of prefabricated structures in urban areas moves work out of the right-of-way to a remote site, minimizing the need for lane closures, detours, and narrowed lanes. This in turn reduces traffic and environmental impacts, increases constructability, and improves safety. The design and construction of prefabricated bridge pier systems can vary depending on the application.

Many researchers have reported on experiments and analyses on precast pier systems. Nasir et al. [1] proposed a bridge pier with precast prestressed concrete panels as formwork and verified the structural performance by cyclic load tests. Hewes [2] performed experiments and analytical studies on precast concrete segmental bridge columns with internal unbonded prestressing tendons. He investigated the seismic behavior of the columns and proposed an analytical model to describe the force-deformation behavior. Billington and Yoon [3] also have done cyclic tests on unbonded post-tensioned precast columns with ductile fiber-reinforced concrete. This combination consisting of post-tensioning with the ductile fiber-reinforced cement-based composite in precast segments at potential hinging regions, resulted in increased energy dissipation and improved integrity under cyclic loadings. The unbonded post-tensioning for precast piers was also investigated by Ou et al. [4,5]. They developed an analytical modeling based on columns both with and without mild steel across the segment joints, and proposed a height of the column with mild steel, and a limit to the steel ratio. Precast concrete systems for rapid construction of bridges were introduced by Hieber et al. [6]. Footing-to-column connections, column-to-column connections, and column to cap-beam connections were described. The seismic performance of precast column–foundation connections that were assembled by post-tensioning was investigated by Nishiyama and Watanabe [7].

There are three categories of design issues with precast columns: (1) static performance under the combined loading conditions of axial compression and bending, (2) serviceability and durability of the joints, and (3) the seismic performance in terms of ductility, energy dissipation, and self-centering

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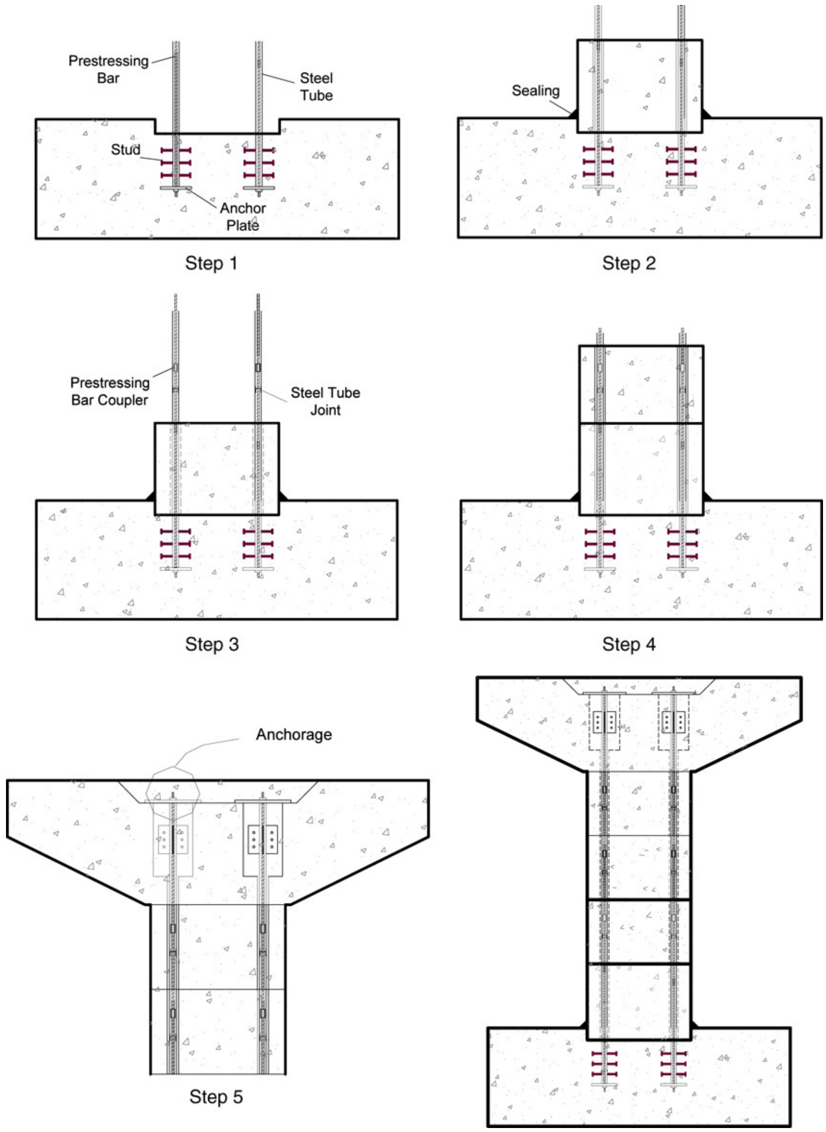

Fig. 1. Construction process of precast bridge pier.

capability. Both single-column piers and multiple-column piers can be constructed with precast concrete depending on the dimensions of the piers. Axial prestressed steel or continuous mild reinforcing bars need to be determined to obtain enough static capacity for an axial-moment interaction diagram that considers ductility requirements. Transverse reinforcements, especially in the plastic hinge region, should be placed to achieve the required seismic performance. Constructability can be considered for the adjustment of leveling and the durability of the joints.

In this paper, a new precast bridge pier system for relatively small bridge piers, using prestressing bars and steel tubes, is proposed. Coupling of the prestressing bars and steel tubes is done in the segment sheath hole, rather than at the joints. Stud connectors are welded on the embedded steel pipes to allow anchoring of the pier segment to the footing. Live anchorages are placed in a pier cap segment, using a bolt–nut type anchor. In the proposed system, there are no reinforcing bars crossing the precast segment joints except prestressing bars. Epoxy is used between the segments to achieve greater bond strength than the tensile strength of the concrete. Fig. 1 shows the proposed precast bridge piers. The system is adequate for the construction of substructures in urban areas for light-railway lines. If large lifting equipment is available, single-column piers can be used to speed up construction. The test parameters investigated were the number of segments, the axial steel ratio, the prestressing force, and the transverse reinforcement details. Quasi-static tests on precast piers were conducted to verify the static and seismic performance.

2. Experimental program

2.1. Test specimens

A laboratory testing program was performed to evaluate the static and seismic performance of the proposed bridge pier system under cyclic loading. Commonly, the diameter of bridge piers used for light-railway lines in urban areas is around 1–2 m. Seven precast pier specimens with a circular solid section of 600 mm diameter were fabricated and tested, as shown in Fig. 2. Two single column piers and five multiple column piers were designed with no mild reinforcing bars across the joints. The aspect ratio of the pier specimens was 3.5, which leads to flexural failure.

Table 1 summarizes the characteristics of the test specimens. A threaded prestressing bar of 32 mm diameter was used to enhance the bond between the bar and the surrounding concrete. The steel