Engineering Structures 132 (2017) 671–683

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Experiments on prefabricated segmental bridge piers with continuous longitudinal reinforcing bars

Changsu Shim [a,*], Sangyong Lee [b], Seongjun Park [b], Chandara Koem [b]

[a] School of Civil and Environmental Engineering, Urban Design and Studies, Chung-Ang University, Seoul, Republic of Korea
[b] Chung-Ang University, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 4 August 2016
Revised 29 November 2016
Accepted 30 November 2016

Keywords:
Cyclic test
Post-tensioned precast bridge pier
Seismic performance
Ductility
Energy absorption capacity

ABSTRACT

Prestressed precast concrete bridge piers have recently been considered as an excellent design alternatives because of their recentering capability under seismic actions. Axial prestressing is designed to control cracking at precast joints by service loads. In this paper, a combination of continuous mild reinforcing bars and prestressing tendons is suggested for enhancing the seismic performance as well as economy of post-tensioned precast bridge piers. Cyclic tests were conducted to measure and observe the behavior of the proposed bridge pier system. By preventing buckling and fracture of the reinforcing bars in the plastic hinge region, the test specimens showed improved structural behavior up to a drift level of 8% without reduction in their flexural strength. Energy absorption capacity was also investigated. An appropriate magnitude of initial prestressing force was found to be an essential design consideration for preventing fracture of tendons by lateral displacement of columns.

1. Introduction

In seismic regions, a prestressed precast segmental bridge pier has many design challenges in terms of structural performance, durability and cost. For the structural performance of the pier, connections between segments are main concerns to ensure serviceability, safety and seismic performance. Even though quality control of precast segments is better than cast-in-place concrete members, the joints between segments must be properly protected against corrosion. Assembly of the segments requires accurate geometry control, and 3D engineering emerged in precast concrete industry for digital manufacturing and geometry control [1–4].

Axial prestressing is introduced to control joint opening and cracking at service loadings. For short columns, full prestressing can be used for design philosophy while partial prestressing is more appropriate for high-rise bridge piers. Billington and Yoon [5] 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. Ou et al. [6] investigated seismic performance of precast unbonded posttensioned bridge columns with bonded longitudinal mild steel reinforcements continuous across the segment joints. Optimum ratio of energy dissipation bars to enhance hysteretic behavior was proposed as 0.5%. Kwan and Billington [7] proposed a segmental precast bridge pier system using both bonded reinforcement and unbonded post-tensioning. Bonded mild reinforcement crossing the precast joints provides hysteretic energy dissipation as well as controlling crack widths. However, there are issues of durability, serviceability and efficiency of prestressing steels for given design conditions. Sideris et al. [8] performed shake table tests on hybrid sliding-rocking bridge with internal unbonded posttensioning. The tests showed that joint sliding at the columns provided energy dissipation, while joint rocking provided self-centering to the structure.

The axial steel design using prestressing bars and steel tubes can provide enough strength and ductility even though the axial reinforcing bars are not continuous across the joints that was investigated by Shim et al [9]. Experimental study on prefabricated composite columns was also conducted by Shim et al [10]. Precast composite columns with prestressing showed a significant increase in the maximum strength of columns as the applied prestress increased. While the ultimate strength of composite columns with prestressing can be increased by higher prestress, the displacement ductility of the prestressed composite column decreased as the prestress increased. Level of prestressing to enhance seismic performance needs more investigation. Bonded

* Corresponding author.
E-mail addresses: csshim@cau.ac.kr (C. Shim), lsy12344@cau.ac.kr (S. Lee), sakano@nate.com (S. Park), koemchandara@cau.ac.kr (C. Koem).

http://dx.doi.org/10.1016/j.engstruct.2016.11.070
0141-0296/

and unbonded prestressing for precast hollow bridge piers were studied by experimental programs [11,12]. The bridge pier with bonded prestressing strands showed better energy dissipation capacity and higher strength. The partial precast segmental column showed excellent energy dissipation capacity and damping ratio [12]. For accelerated bridge construction, grouted splice sleeve connectors were used, and experimental evaluation showed satisfactory hysteretic performance which exceeds the drift demand in large earthquakes [13].

A self-centering precast concrete pier with external energy dissipators was proposed and a theoretical model for the pier was also validated [14]. Parametric studies using a linear form of constitutive models for precast prestressed concrete segmental columns were suggested to predict the deformation of the columns [15]. In order to provide numerical models of post-tensioned precast concrete columns, a two-plastic-hinge model using the moment curvature analysis was proposed by Chou et al. [16].

The prefabricated bridge pier investigated in this research is a segmentally precast concrete system with bonded post-tensioning. Combination of continuous reinforcing bars and prestressing steels was proposed to enhance current practices in terms of erection efficiency, durability of the segment joints and seismic performance. Design is based on partial prestressing concept by continuous reinforcing bars crossing the joints as shown in Fig. 1. Location of longitudinal bar in a column section is determined to maximize effectiveness of each material strength and ductility of each component. Anchorages of the post-tensioned strands are located at the sides of a foundation to enhance efficiency of site work. Cyclic tests were conducted to investigate seismic performance of the proposed precast segmental columns.

2. Experimental program

2.1. Test specimens

A laboratory testing program was planned to investigate the static and seismic behavior of the proposed bridge pier system under cyclic loading. A total number of five precast pier specimens were fabricated and tested, as shown in Fig. 2. A circular solid section with a diameter of 800 mm was designed. The distance between the point of fixity and the loading point was 2750 mm. The aspect ratio of the pier specimens was 3.44. The pier consists of three segments which are a footing and two column segments.

Table 1 summarizes the characteristics of the test specimens. Main test parameters were axial steel ratio including prestressing steel and continuous longitudinal reinforcement, spacing of transverse reinforcement, and effective prestress. T75 represents that spacing of transverse reinforcement of the column is 75 mm. A-type specimens had continuous mild reinforcing bars which were connected by mechanical splices at the precast segment joints. B-type specimen (T75PT1B) had a prestressing tendon only without continuous longitudinal reinforcement. Three different prestressing forces were applied to the column for axial compression. Axial load in Table 1 represents summation of prestressing

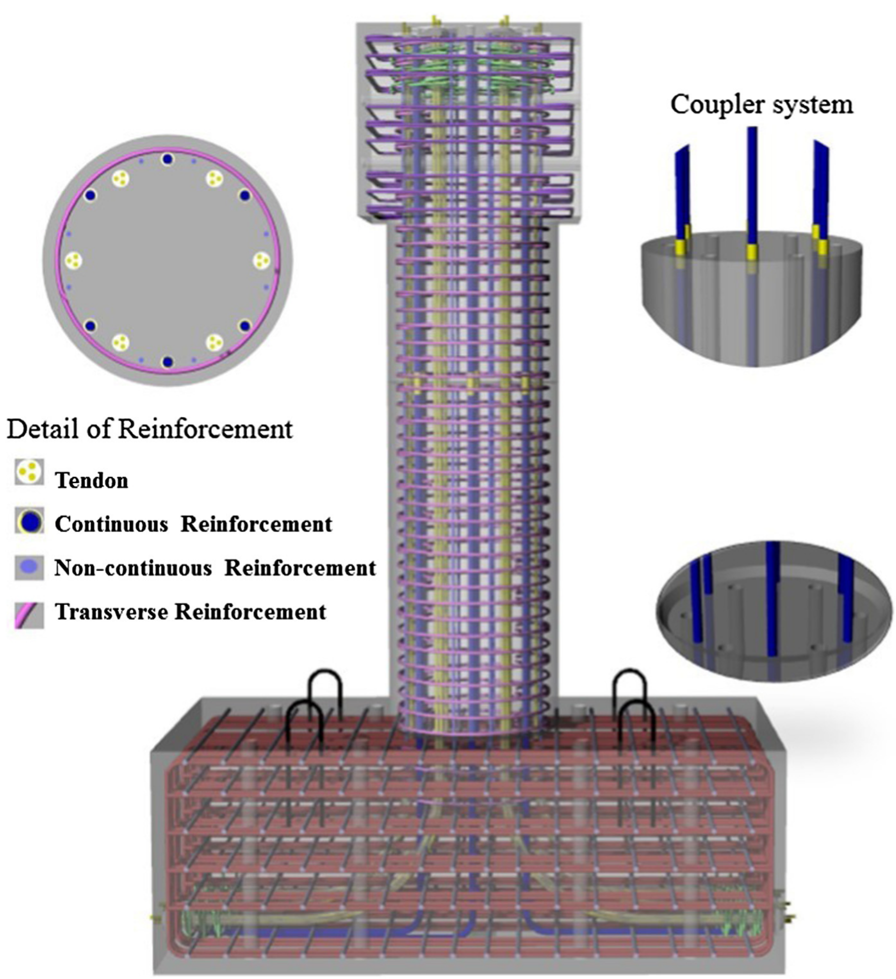

Fig. 1. Precast concrete bridge pier.