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Testing and analysis of a laterally loaded bridge caisson foundation in gravel

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Abstract

This paper presents the results of an in situ lateral load test on a caisson-type foundation of the old Niu-Dou Bridge in Ilan County, Taiwan. The caisson was 12 m long and had circular cross-sections whose diameters were 5 m in the upper portion and 4 m in the lower portion. The test site was located on soil with a high gravel content. A site investigation, including laboratory and field tests, was carried out. A six-component Winkler-beam model was applied to simulate the caisson response in the lateral load test. To determine the nonlinear properties of the Winkler springs, a method based on large-scale geotechnical field testing was proposed. With this method, the soil springs could be properly set and the Winkler-beam model could reasonably capture the lateral behavior of the caisson foundation.

Keywords: Caisson foundation; Gravel; In situ test; Lateral loads; Numerical simulation; Winker-beam model (IGC: E4/E12/H1)

1. Introduction

Caissons and piles are commonly used types of deep foundations in bridge engineering. They are deeply embedded in the soil to support the weight of the structure and to resist the lateral loads transmitted from the structure, e.g., lateral soil pressure, wind loads, earthquake loads, etc.

In designing a bridge foundation, the lateral response of the foundation is of considerable importance, because it often governs the final design. For obtaining the lateral response of deep foundations, many analysis methods have been developed, ranging from complex finite element models to simple beam-spring models. In engineering practice, the Winkler-beam model is a popular method for analyzing the behavior of piles under lateral loads (e.g., Hetenyi, 1946; Reese et al., 1974; Kramer and Heavey, 1988; Chiou and Chen, 2007). In this model, the piles are simulated by beam elements and the lateral soil reactions are simulated using independent horizontal spring elements (i.e., Winkler springs). Similar modeling concepts are also applied to caissons (e.g., Japan Road Association, 1990; Railway Technical Research Institute, 1997; Gerolymos and Gazetas, 2006a,b). Compared to piles, caissons generally have relatively large cross-sections, but shallow embedment, such that they behave like a rigid foundation and the soil within the embedded depth of the caissons is influenced by the caisson movement. Therefore, the modeling of a laterally loaded caisson requires more types of soil springs to simulate the different sources of soil resistance, including the normal stress and the shear stress along the perimeter of the caisson

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and the shear force on the base of the caisson, creating further difficulty in determining the soil spring properties. In addition, in situ lateral load tests on the caisson are essential for examining the applicability of the analysis models and the associated spring properties (Macklin and Chou, 1989; Yoshii et al., 1989).

In 2010, the National Center for Research on Earthquake Engineering (NCREE) of Taiwan conducted a series of in situ loading tests on the old Niu-Dou Bridge in Ilan County, Taiwan. The test site was located on soil with a high gravel content. The tests included three cyclic push-over tests on three of its pier columns and a monotonic lateral load test on one of its caisson-type pier foundations. The aim of these tests was to investigate the seismic capacity of actual bridges and to examine the applicability of existing analysis methods.

In this paper, we focus on the results of the aforementioned lateral caisson load test. A six-component Winker-beam model is used to analyze the response of the test caisson; the performance of the model is examined as well. To accurately determine the spring properties, a method based on large-scale geotechnical field tests is proposed.

Fig. 1. Niu-Dou Bridge.

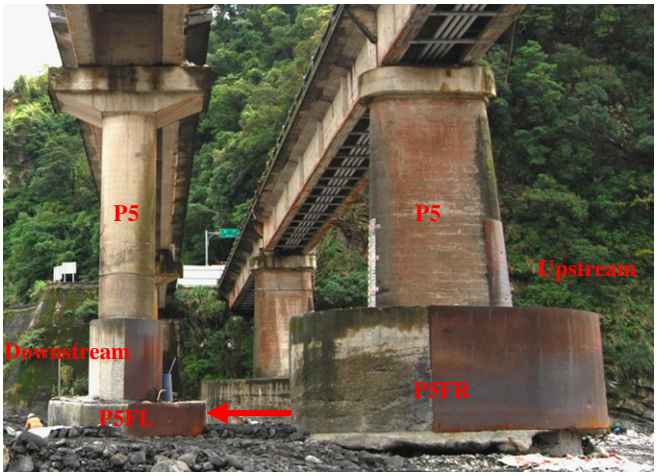

Fig. 2. Lateral load test on caisson foundation P5FL.

2. Lateral caisson load test

The new Niu-Dou Bridge in Ilan County, Taiwan was opened to traffic in October 2010, and the old bridge was demolished 2 months later in December 2010. Before the old Niu-Dou Bridge was removed, NCREE conducted a series of in situ loading tests on it with the approval of the Directorate General of Highways, Ministry of Transportation and Communications of Taiwan. The old Niu-Dou Bridge, crossing the Nan-Yan River, was composed of two independent bridge structures, each supporting opposite directions of vehicular traffic flow, as shown in Fig. 1. Both bridge structures had seven spans with pre-stressed concrete I-girder-type decks. The bridge structure on the upstream side was built in 1961 and its pier columns were elliptically sectioned. The bridge structure on the downstream side was built in 1995 and its pier columns were circularly sectioned.

In the lateral caisson load test, caisson foundation P5FL at Pier #5 of the downstream bridge structure was monotonically pushed, as shown in Fig. 2. This caisson was 12 m long and originally had a 4-m-diameter circular section. After being hit by many typhoons, the diameter of its section was enlarged to 5 m from the caisson top to a depth of 2.8 m to prevent flood scouring.

Fig. 3 shows the test setup. The soil surface around the test caisson was leveled to 1 m below the top of the caisson.

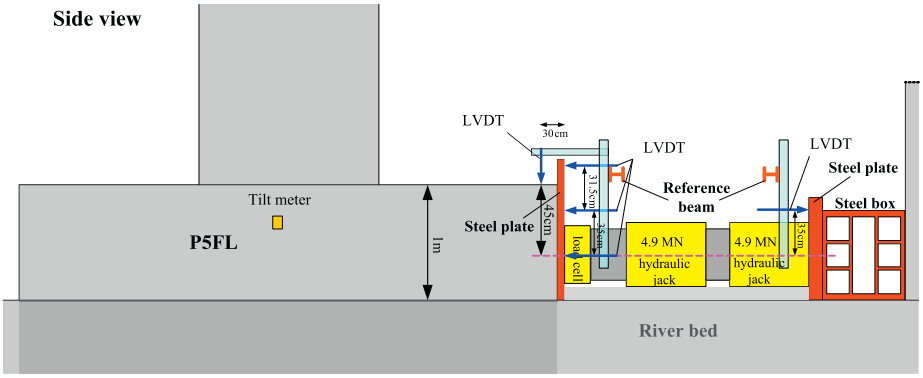

Fig. 3. Test setup.