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Design approach to a method for reinforcing existing caisson foundations using steel pipe sheet piles

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Abstract

This paper proposes a steel pipe sheet pile (SPSP) reinforcement method for existing caisson foundations in water. The technique involves driving SPSPs around the caisson foundation and connecting them to it with reinforcing footing. To support the rational design of reinforcements using this method, the following factors influencing the technique's effectiveness and related mechanical behavior should be considered: (1) the conditions of the caisson/SPSP reinforcement footing connection; (2) the caisson/SPSP flexural rigidity ratio; (3) the distance between the caisson and the SPSP wall; and (4) the pile length. However, as the influence of these factors on the reinforcement effect and mechanical behavior has not yet been clarified, the current method has no standardization for the concept of the load transfer mechanism in reinforced foundation systems, and the ultimate lateral bearing capacity of existing caissons has been largely ignored in previous construction. This paper describes centrifuge model tests and three-dimensional elasto-plastic finite element total stress analysis conducted in relation to real cases in order to identify a more effective and rational reinforcement structure. The static lateral bearing capacity and seismic performance of reinforced foundations were investigated, and the following factors were considered: (1) the conditions of the caisson/SPSP reinforcement footing connection; (2) the caisson/SPSP flexural rigidity ratio; and (3) the pile length. Finally, a structural design flow is proposed based on the experimental and numerical simulation results. A chart to facilitate determination of appropriate reinforcement structures is also presented.

Keywords: Caisson; Bearing capacity; Centrifuge model test; Finite element method; Reinforcement; Steel pipe sheet pile foundation; IGC: E04/H01

1. Introduction

After the Southern Hyogo Prefecture Earthquake of 1995, highway/railway bridge design codes were revised to provide much higher levels of structural safety and reliability against tremors. Seismic reinforcement has been promoted for piers of regular and elevated bridges designed according to the pre-quake code, and most elevated bridges on Shinkansen lines and highways have now been reinforced. However, some river bridges on national and prefectural roads have undergone only limited strengthening. To improve the situation and provide higher reliability for such structures, a project to promote the reinforcement of regular and elevated bridges was implemented from 2004 through 2007. However, when seismic waves hit bridges for which only pier reinforcement has been implemented, relatively weak parts such as foundations may

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yield because the dynamic characteristics of the entire bridge structure have changed. In this context, it is important for the whole bridge structure, including its foundations, to have a high level of seismic resistance. However, few foundations in Japan have been reinforced due to factors such as the long construction period and high cost involved because of limitations in terms of space and traffic, and the reinforcing effect and mechanism of such strengthening have not been fully investigated. Reinforcement is also required for bridge foundations with insufficient bearing capacity due to liquefaction, riverbed degradation and localized scouring.

The two reinforcement methods recently developed for foundations involve (a) ground improvement and (b) addition of new structures (Japan Road Association, 2000). Both techniques have several possible approaches depending on the reinforcement material used, and their scope of application is limited (Kishishita et al., 2003; Fukada et al., 2005; Nishioka et al., 2008; Bao, X. et al., 2012, etc.). An appropriate method needs to be selected in line with the reinforcement target and ground/construction conditions. Although most of these approaches have already been applied in the field, their reinforcement effects and mechanisms remain unclear, and no specific construction or design methods have been authorized. Accordingly, it is necessary to develop a rational and simple reinforcement method by which the earthquake-proof performance of entire bridge structures can be guaranteed, and to establish techniques for evaluating reinforcement effects, assessing the bearing capacity and seismic stability of existing foundations, and clarifying the required level of seismic stability.

2. Characteristics of the steel pipe sheet pile reinforcement method

This paper outlines the steel pipe sheet pile (SPSP) reinforcement method (Fig. 1), in which SPSPs are installed around existing caisson foundations and their joints are interlocked, and the piles and caisson are connected with a reinforcing footing. The technique increases the lateral bearing capacity of reinforced foundation systems, and is suitable for structures in water because SPSP walls can stop water from entering the work space based on their welded interlocking joint structure (Fig. 2). However, the following factors still need to be clarified for design and construction using the SPSP reinforcement method: (1) the load distribution between the existing caisson and the added SPSP wall; (2) an appropriate footing connection type; and (3) the point bearing capacity of SPSPs installed with limited overhead clearance. Accordingly, the current method has no standardization for the concept of the load transfer mechanism for reinforced foundation systems, and the ultimate lateral bearing capacity of existing caissons

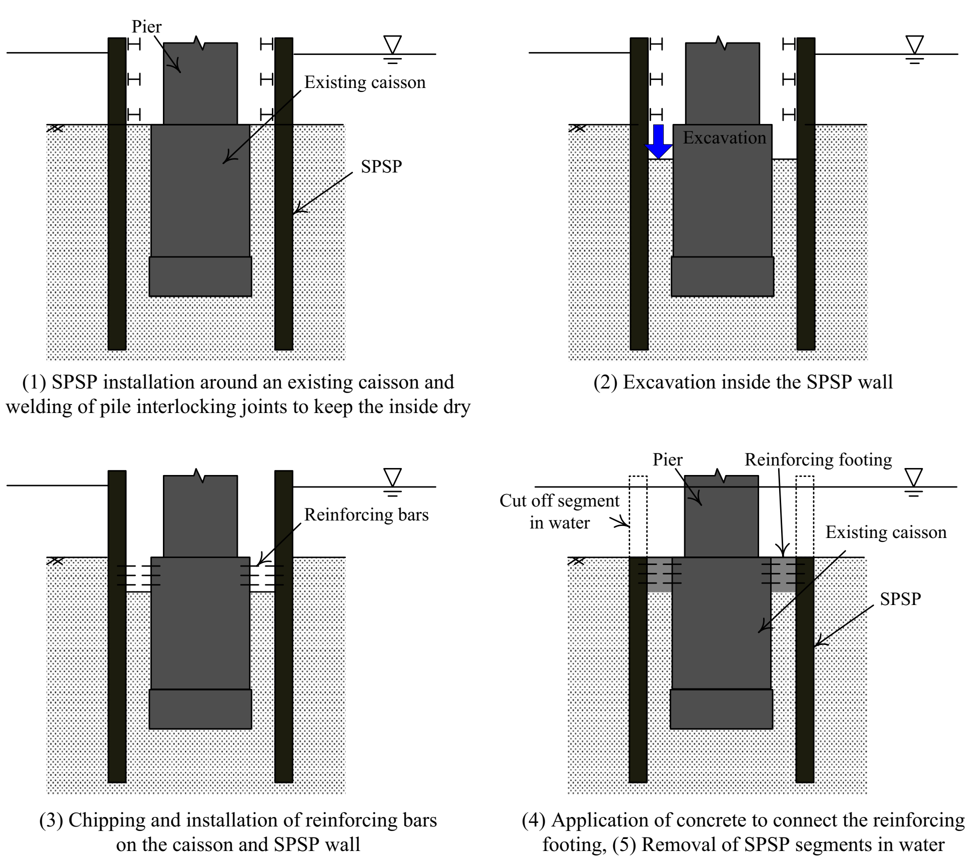

Fig. 1. Construction flow of the SPSP reinforcement method. (1) SPSP installation around an existing caisson and welding of pile interlocking joints to keep the inside dry; (2) excavation inside the SPSP wall; (3) chipping and installation of reinforcing bars on the caisson and SPSP wall; (4) application of concrete to connect the reinforcing footing; and (5) removal of SPSP segments in water.