Measured bearing capacity of rooted caisson under vertical compressive loading

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ABSTRACT

Based on the principle of bionics, caisson with roots surrounding shaft is successfully used as bridge foundation in China. To investigate the influence of roots on the vertical compressive bearing capacity of caisson, this work performed the field vertical loading tests of caisson by self-balance approach in Wangdong Yangtze River Highway Bridge. The results show that the attenuation amplitude of axial force of rooted caisson is larger than that of non-rooted caisson. Moreover, compared with non-rooted case, the ultimate bearing capacity of caisson with roots from simplified self-balance method has risen by 126%, which means that roots have a significant role in enhancing bearing capacity of caisson.

Keywords: bridge foundation; rooted caisson; bearing capacity; self-balanced method

1 INTRODUCTION

Large diameter caisson foundations, which can provide higher bearing capacity, are widely used as bridge foundation. However, caisson with oversize diameter could make it difficult to construct. In this case, a new caisson type named rooted caisson (Yin, 2007; Gong et al., 2008) is proposed to reduce caisson dimension and to improve bearing capacity on the basis of bionics, as depicted in Fig.1. Currently, rooted caisson foundations are successfully used in four extra-large bridge projects in China (Mu et al., 2010; Gong et al., 2010; Huang et al., 2011).

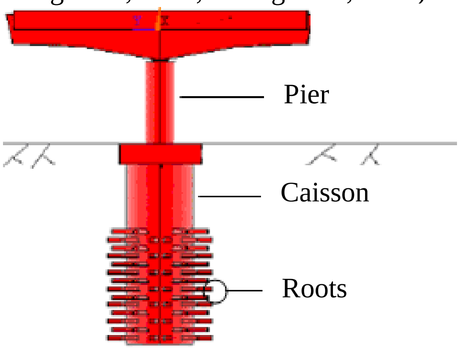


Fig. 1. Schematic diagram of rooted caisson foundation

To compare the vertical compressive bearing behavior between rooted and non-rooted caissons, this work performed two in-situ loading tests by self-balanced method (Gong et al., 2002) (i.e., another terminology of improved O-cell method in China) in Wangdong Yangtze River Highway Bridge in China. Furthermore, this paper investigates the contribution of root system to the bearing capacity of caisson foundation to reveal the mechanism of roots.

2 DESIGN OF ROOTED CAISSON

As shown in Fig.2, the design length of selected caisson foundation is 47 m and corresponding diameter and wall thickness is 5 m and 0.9 m, respectively. The thickness of cap and bottom is 1.5 m and 3.5 m.

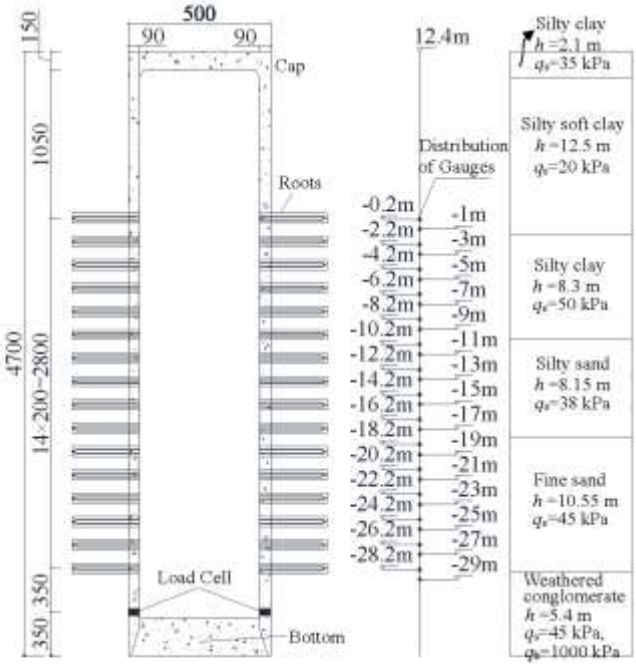
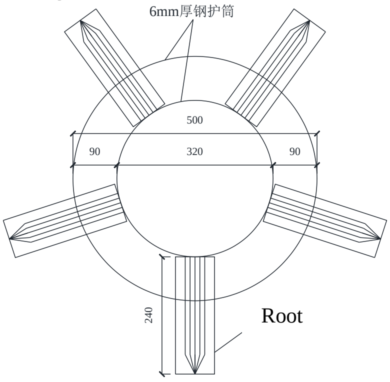


Fig. 2. Schematic diagram of rooted caisson structure

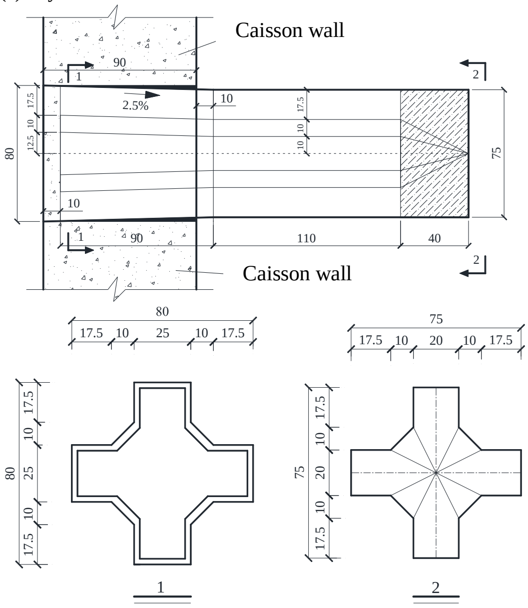
The caisson as discussed above has 15 layers of roots and each layer has 5 roots. The distance between each layer is 2.0 m. The layout and design details of

Caisson wall

roots for each section is shown in Fig.3. Subsequently, the construction procedures for roots caisson is shown in Fig.4.



(a) Layout of roots for each section



(b) Constructional detail for root

Fig. 3. Design of roots

(a) Reserved holes

(b) Root product

(c) Squeezing by jack

(d) Sealing roots' end

Fig. 4. Construction of roots

3 TESTING AND ANALYSIS

3.1 Testing method

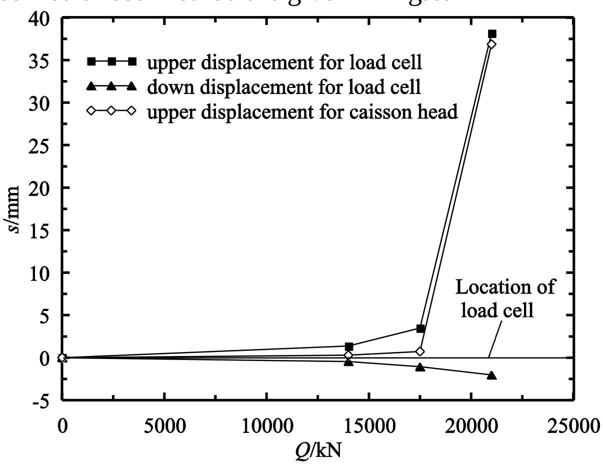
The estimated bearing capacity of rooted caisson is very high and conventional testing technology cannot get ultimate value. Thus, this project adopted self-balanced method to effectively obtain the bearing behavior of rooted caisson. Self-balanced technology is proposed by Southeast University on the basis of O-Cell method and has been typically used for bridge projects in China. The annular load cell is fixed at 3.5 m location above the caisson tip (as shown in Fig.2). The ring load cell with 16 tons weight is composed of 10 hydraulic jacks, as shown in Fig.5.

Fig. 5. Schematic diagram of annular load cell

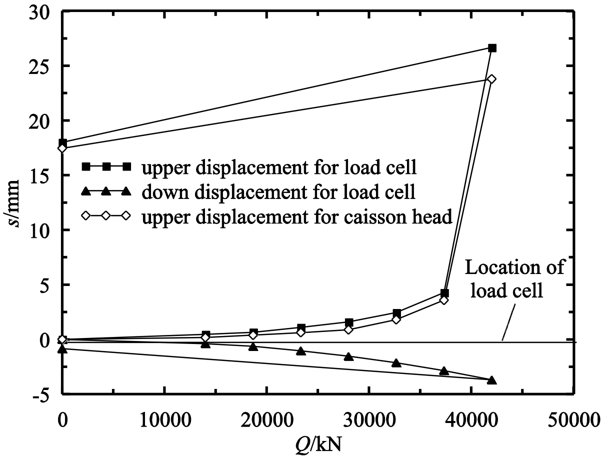
To compare the bearing characteristics between rooted and non-rooted caissons, the testing is divided into two stages. Firstly, 30 days after the completion of caisson construction, loading test is performed to obtain the bearing capacity of non-rooted caisson foundation. Secondly, 75 days later, the roots are embedded into soil mass. And then, 10 days after roots construction, the loading test for rooted caisson foundation is performed. The axial forces and skin resistance of caisson shaft are deduced by the values of strain gauges arranged along caisson (as shown in Fig.2).

3.2 Load-displacement curves

The *Q*-*s* curves (i.e., load-displacement curves) for rooted and non-rooted caissons obtained by self-balanced method are given in Fig.6.



(a) *Q*-*s* curves for non-rooted caisson



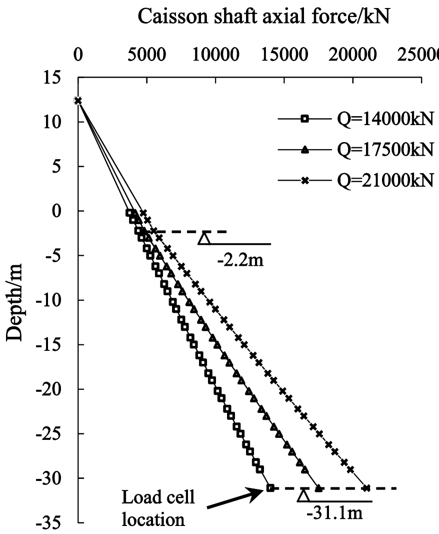
(b) *Q-s* curves for rooted caisson

Fig. 6. *Q-s* curves for caisson by self-balanced method

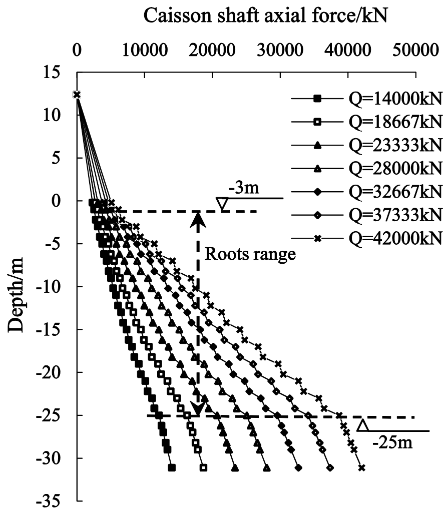
As depicted in Fig.6(a), when load reaches to the third loading level (i.e., 2×21000 kN), the upward displacement of upper part of caisson above load cell has an abrupt change. As a result, the second loading level, 17000 kN, is chosen as the ultimate bearing capacity for upper part of non-rooted caisson. Similarly, the ultimate bearing capacity for upper part of rooted caisson is 37333 kN, as shown in Fig.6(b).

3.3 Axial force distribution of caisson shaft

As shown in Fig.7, the distribution of shaft axial force for non-rooted caisson is similar to that of rooted caisson. The shaft axial force decreases along caisson depth from load cell location to caisson head. The attenuation amplitude of axial force is almost linearly with depth for non-rooted caisson, as shown in Fig.7(a). However, for rooted caisson, the shaft axial force decreases with stepped distribution characteristics due to the existence of roots as shown in Fig.7(b). Moreover, at the same depth, the attenuation amplitude of axial force of rooted caisson is larger than that of non-rooted caisson, which implies that the roots surrounding caisson shaft can bear vertical force effectively.



(a) Non-rooted caisson

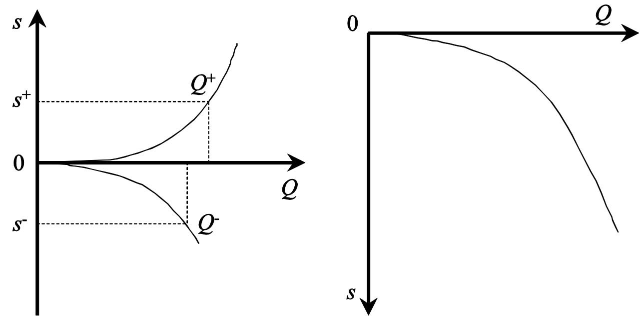


(b) Rooted caisson

Fig. 7. Axial force distribution tested by self-balanced method

3.4 Equivalent conversion of test results

For the design purpose, the test results from self-balanced method should be translated to conventional vertical static load test curves, as shown in the following Fig.8.



(a) Self-balance curves (b) Equivalent conversion curve

Fig. 8. Conversion of *Q-s* curves tested by self-balanced method

According to the equivalent conversion approach (JT/T 738-2009), the conversion of *Q-s* curves for non-rooted and rooted caisson is described in Fig.9. It is clearly that both *Q-s* curves are nonlinear without reaching ultimate values.

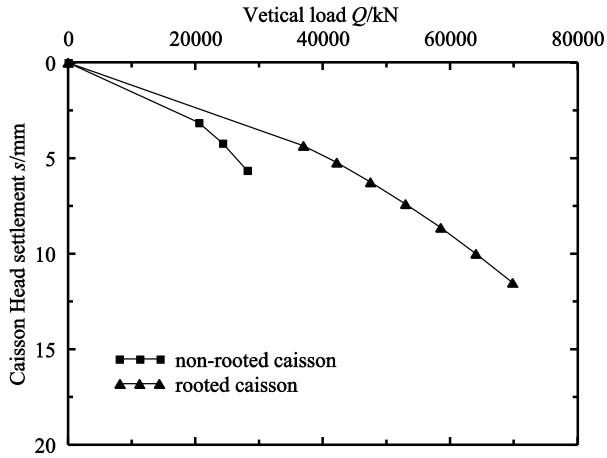


Fig. 9. Transformed *Q-s* curves of non-rooted/rooted caisson

Moreover, the vertical compressive bearing capacity and corresponding stiffness of rooted caisson are larger than that of non-rooted caisson from the *Q-s* curves, which indicates that roots have a significant effect on reducing caisson settlement.

To evaluate the ultimate bearing capacity for caisson, a simplified approach proposed by Gong and Dai (2006) is expressed as

$$Q_u = \frac{Q_{upper} - W}{\gamma_a} + Q_{lower} \quad (1)$$

in which Q_u is the compressive ultimate value. Q_{upper} and Q_{lower} are the failure loads for upper part caisson and lower part caisson (i.e., caisson shaft is divided into two parts due to existence of load cell). W is the foundation weight including caisson weight and roots weight. γ_a is the conversion factor. For this case, the conversion factor γ_a =0.75 according to Chinese code (JT/T 738-2009).

Based on Fig.6, the ultimate value of lower part caisson is larger than that of upper part, which indicates that limit settlement corresponding to ultimate value for upper and lower caisson part is different to each other. As a result, this work adopts an exponential expression to fit the *Q-s* curve of lower caisson part. Then substituting limit settlement of upper caisson part into the proposed exponential expression to obtain the calculated ultimate bearing value for lower part. Taking Fig.6(a) as an example, the relation between downward displacement s_{lower} of load cell and corresponding compressive load Q_{lower} is expressed as

$$s_{lower} = a \times Q_{lower}^{b} \quad (2)$$

where a and b are the fitting parameters.

Translating Eq. (2) to logarithmic form and substituting data from Fig.6(a) into this logarithmic expression, the result can be expressed as

$$\lg s_{lower} = -15.773 + 3.7217 \lg Q_{lower} \quad (3)$$

By setting s_{lower} = s_{upper} (i.e., upward displacement of load cell)=3.47 mm and the compressive load Q_{lower} equals to 24171 kN from Eq. (3). Moreover, the foundation weight W=$W_{caisson}$+W_{roots}=7696 kN. Thus, the ultimate bearing capacity Q_u for non-rooted caisson is 3.78×10^4 kN on the basis of Eq. (1). By the same way, the ultimate bearing capacity Q_u for rooted caisson is 8.51×10^4 kN. Compared with non-rooted case, the bearing capacity of caisson with roots has risen by 126%.

4 CONCLUSION

Based on the bionics, rooted caisson foundation for bridge is proposed and successfully used in China. To evaluate the influence of roots on bearing capacity of caisson, this work performs an in-situ study on the vertical compressive bearing characteristic of rooted caisson by self-balanced method and obtain some useful conclusion:

(1) After roots construction, the shaft axial force of caisson decreases with stepped distribution behavior and the attenuation amplitude of axial force of rooted caisson is larger than that of non-rooted caisson.

(2) The vertical compressive stiffness of rooted caisson is larger than that of non-rooted caisson, meanwhile, the bearing capacity of caisson with roots has risen by 126%, which means that roots have a significant role in enhancing bearing capacity of caisson.

(3) Self-balanced method can obtain bearing capacity of rooted/non-rooted caisson effectively, which is worth using widely in new type foundation like rooted caisson.

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