Ocean Engineering 117 (2016) 311–320

Contents lists available at ScienceDirect

Ocean Engineering

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

Experimental investigation of current-induced local scour around composite bucket foundation in silty sand

Tongshun Yu [a,b,*], Jijian Lian [b], Zhongqiang Shi [b,c], Hongzhen Wang [b]

[a] College of Engineering, Ocean University of China, Qingdao 266100, China
[b] State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China
[c] China Harbour Engineering Company Ltd., Beijing 100027, China

ARTICLE INFO

Article history:
Received 8 September 2015
Received in revised form
29 December 2015
Accepted 20 March 2016
Available online 4 April 2016

Keywords:
Local scour
Composite bucket foundation
Current
Maximum scour depth

ABSTRACT

In recent years, local scour has received attention because it may have a negative effect on coastal structures. Because of the large-scale arc transition and other special constructs, flow patterns around composite bucket foundation are complicated, and the local scour around composite bucket foundation has rarely been reported in the literature. In the present study, a detailed laboratory testing program on model with diameters of 150 cm and 75 cm embedded in silty sand was conducted in a flume. The scouring process and equilibrium scour hole geometry under steady and bidirectional current were investigated in detail. A procedure was suggested to predict the ultimate scour depth based on the observed variation of the scour depth over a limited time period. The equilibrium scour depth under a bidirectional current was approximately 16% less than that under a steady current, and there were two spoon-shaped scour holes in the steady current scour, whereas four saddle-shaped scour holes were discovered in bidirectional current scour. Based on these results, a functional relationship was suggested between the scour depth and other parameters, such as the diameter of the foundation, Shields parameter and median diameter of the soil bed.

1. Introduction

Mono-pile, gravity-base, tripod, jacket structure and suction caisson foundations are widely applied in the development of offshore wind power (Byrne and Houlsby, 2003). Mono-pile structures are the most widely used in offshore wind structures and gravity foundation is the second most common. However, the strict requirements for construction equipment and technologies restrict the wide application of mono-pile structures in China. Gravity foundation structures require more than 5000 t of concrete for the effective transmission of wind turbine loads, and the construction cost of the jacket foundation structure is high. A new offshore foundation, the wide-shallow composite bucket foundation, is shown in Fig. 1 and was proposed by Lian et al. (2011, 2012) and Ding et al. (2013) due to the advantages of reduced construction cost and shortened construction period compared to conventional foundations. The composite bucket foundation usually has a large diameter (generally larger than 20 m, especially for wind turbines with more than 3 WM power in China) and an aspect ratio (the skirt length to the foundation diameter) of less than 0.5 (Liu et al., 2014). The foundation takes full advantage of the high tensile capacity of steel strands and the high compressive capacity of concrete so that the problem of transferring the large moment and horizontal loads from the tower to the foundation can be solved by designing the pre-stressing arc transition structure. However, because of the large-scale arc transition and other special constructs, as shown in Fig. 1, the flow pattern around the composite bucket foundation under the action of current is complicated, which is illustrated schematically in Fig. 2. It is inaccurate to estimate the scouring depth using empirical formulas based on other types of foundations, such as pile foundations.

Local scour of sediments around ocean structures has been studied extensively because it has been identified as one of the key factors that cause structure failure or undesired deposition in coastal and offshore engineering. To investigate scour when designing waterway, coastal and offshore structures, numerical analysis (Lu et al., 2005; Zhao and Cheng, 2010b) and experimental study (Sumer and Fredsøe, 2000; Pagliara and Kurdistani, 2013) are the two main methods for the determination of the scour depth. Usually, a numerical hydrodynamic model is proposed in numerical analysis, whereas in experimental study, test flumes and measurements are designed. Kim et al. (2014) built a hydrodynamic model with an adaptive multilevel structure Cartesian

* Corresponding author at: College of Engineering, Ocean University of China, Qingdao 266100, China.
E-mail address: tshyu707@ouc.edu.cn (T. Yu).

http://dx.doi.org/10.1016/j.oceaneng.2016.03.045
0029-8018/

Fig. 1. Photograph of a composite bucket foundation.

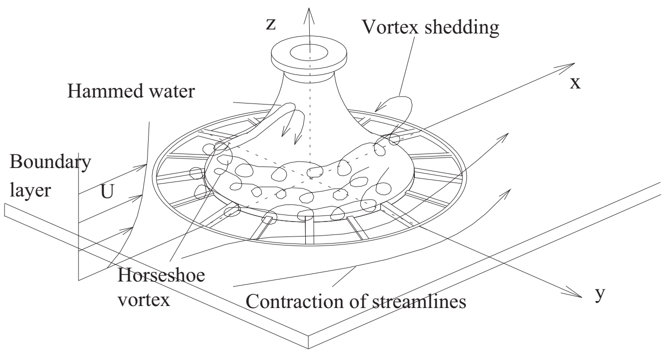

Fig. 2. Sketch of the flow around a composite bucket foundation.

grid to analyze the local scour around cylinders in a side-by-side or tandem arrangement. Dixen et al. (2013) described the results of scour around a half-buried sphere exposed to a steady current by combined numerical and experimental investigation. Because of the scaling effect, laboratory tests tend to overestimate scour depth measurements (Lee and Sturm, 2008b). Despite the effect of scaling, laboratory tests are still widely used as the main method for investigating local scour mechanisms (Lee and Mizutani, 2008a; Zhao et al. 2012). There are also some empirical formulae that are used to predict the maximum scour depth for various coastal structures at the prototype size. Matutano et al. (2013) summarized the most important formulations developed for predicting the maximum scour depth of mono-pile foundations under different flow conditions (steady current only, waves only, or steady current and waves). Amini et al. (2012) provided a reasonable formula to predict the scour depth at pile groups under steady flows.

With these methods, several researchers have assessed the scour depth around traditional coastal structures, including vertical circular cylinders (Zhao et al., 2010a; Roulund et al., 2005), submarine pipelines (Lu et al., 2005), bridge piers with different shapes (Khosronejad et al., 2012), rubble mound breakwaters (Sumer and Fredsøe, 2000), and new types of structures (Pagliara and Palermo, 2008; Pagliara and Kurdistani, 2013; Zhang et al.2009). Most of the studies of the local scour around marine structures have focused on scour due to waves (Sumer and Fredsoe, 2001), currents (Rambabu et al., 2003; Zhao et al., 2010a) or combined waves and currents (Qi and Gao, 2014; Cheng et al., 2014). Myrhaug et al. (2009) derived the scour depth below pipelines and around single vertical piles for combined waves plus currents. Most previous studies placed an emphasis on the scour around various traditional and new types of coastal structures, but few studies have examined the flow and effect of scour around composite bucket foundation due to the lack of laboratory observations. There is no published literature on the local scour around composite bucket foundation.

The present study investigates the flow and scour around composite bucket foundation via laboratory tests. The main objectives of this study were to investigate: (1) the mechanism of scour around a composite bucket foundation subject to a steady and bidirectional current; (2) the difference between the scour characteristics under a steady and bidirectional current; and (3) the relationship between the maximum scour depth and other dimensionless parameters. The arrangement of this paper is as follows. In Section 2, the test setup, the approach used for the tests and the test procedure are presented. The results of the scour test for a composite bucket foundation under steady and bidirectional current are presented in Section 3. A comparison of the results under a steady and bidirectional current and discussions are given in Section 3, and the conclusions of the paper are given in Section 4.

2. Test setup and measurements

2.1. Dimensional analysis

The local scour around a composite bucket foundation under the current involves a complex interaction among current, foundation and its neighboring soil. There are many variables that play relevant role on the scour around a composite bucket foundation, such as the foundation, sand-bed and fluid properties. The foundation properties can be characterized by its diameter (B). The sand-bed properties can be summarized by median diameters of soil (d_{50}), sediment grain density (ρ_s), coefficient of permeability (k_s), shear modulus of soil skeleton (G), and degree of saturation (S_r). The fluid physical properties can be characterized by water density (ρ_w) and kinematic viscosity of water (ν). The current flow can be characterized by water depth (h), velocity of the current (u), and representative near-bed velocity of the current flow (U_c). The gravitational acceleration (g) is included among the variables. Based on the aforementioned analysis, the equilibrium scour depth (h_b) can be described by the following functional relationship:

$$h_b = f\,(B, d_{50}, \rho_s, k_s, G, S_r, \rho_w, \nu, h, u, U_c, g, \cdots) \quad (1)$$

Vortex formation is the most important mechanism of scour in front of the composite bucket foundation, and some parameters can be ignored in Eq. (1). Applying the Buckingham π theorem to these dimensional parameters, the scour for the composite bucket foundation is dependent on the following non-dimensional parameters:

$$f\left(\frac{h_b}{h}, \frac{B}{h}, \frac{d_{50}}{h}, Re, Fr, \theta\right) = 0 \quad (2)$$

where Re is the Reynolds number, F_r is the Froude number and θ is the Shields parameter. In the above equation, the Reynolds number can be ignored because the seabed acts as a rough wall with scour occurring (Lee and Mizutani, 2008a). These parameters are discussed in Section 3.3.4.

2.2. Test setup

The laboratory scour experiments around composite bucket foundation under current were conducted in the water flume at the State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, China. The water flume was 35 m in length, 7 m in width and 1.6 m in height. A movable sand basin of