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Axial resistance of long rock-socketed bored piles in stratified soils

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ABSTRACT

This paper presents the results of static compression load tests performed on long rock-socked bored piles installed in stratified soils. Three bored piles with 34 m in embedded length were instrumented in order to separate the shaft and base resistance, and to allow the determination of the distribution of shaft resistance along the pile shaft. Conventional methods of estimating shaft resistance were assessed. It was found that more than 78% of the shaft resistance was provided by shaft friction at the end of tests. The base resistance has not been fully mobilized in the test. The recommendations of Chinese technical code (JG94-2008) to estimate the shaft resistance were more conservative for long rock-socketed bored piles. Empirical correlations to estimate the shaft resistance are limited due to different geological conditions. The methods which incorporated parameters directly interpreted from standard penetration test (SPT) results provided the most consistent estimates.

1. Introduction

Bored and cast-insitu piles, generally varying between 0.6 and 1.5 m in diameter, are extensively used as the foundation of heavy structures in China. This is due to their high bearing capacity, relatively low cost, easy length adjustments, low vibration and noise levels during installation (Balakrishnan et al., 1999; Chang and Zhu, 2004; Zhang et al., 2013). The increased exploitation of offshore energy resources in recent years makes this kind of pile is preferred in coastal region. These bring new challenges for pile designers as higher capacities and deeper pile penetration are required in a range of soil types (Gavin et al., 2010; Doherty and Gavin, 2011). Many of the current state of the art design approaches are based on the American Petroleum Institute's recommendations (American Petroleum Institute RP2A, 1993) which have been developed from simple empirical methods, based on the results of onshore piles with relatively small diameters. Therefore, application of these methods to vastly different soil conditions and pile geometries is questionable. Reliability studies such as those by Briaud and Tucker (1988), Tang et al. (1990) and Gavin and Lehane (1996) have highlighted the large potential errors associated with these approaches, with coefficients of variation in predicted to measured pile capacities ranging between 30 and 60%, raising doubts over the applicability of factors of safety of 1.5 typically used in offshore pile design (Chow, 1997).

Some researches have been carried out on long bored piles as onshore foundation (Chen and Hiew, 2006; Williamson and Bolton, 2012). Results from those researches show three key characteristics of long, large-diameter piles that differ from conventional piles (Dai et al., 2012): (i) pile weight is a larger percentage of pile bearing capacity; (ii) accounting for pile compression becomes more important in settlement estimation; (iii) mobilization of base resistance requires excessive pile head settlements due to greater axial compressibility of the pile; (iv) soils beneath pile base play an important factor in interpreting the behavior of long axially loaded piles. In the coastal region, from soft normally-consolidated clay (Katzenbach et al., 2000) to very stiff over-consolidated glacial till in the North sea, where undrained shear strength (s_u) values in excess of 600 kPa are encountered (Overy, 2007). The absence of rigorous methods of analysis and the scarcity of full-scale high-quality data from instrumented load tests on single piles means that the use of conventional methods to design large-scale, heavily loaded pile foundations for offshore structure requires extra caution. The field investigation and analysis presented here is intended to provide important information to geotechnical design and research

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engineers regarding the behavior of long rock-socked piles as offshore foundation under static compression load tests. As a result, significant saving in foundation cost, resulting from an economical design, may be achieved. The aim of the tests and analysis is to investigate the following crucial issues in particular: (1) the load-displacement response of test piles; (2) the distribution of shaft and base resistance; (3) the assessment of conventional methods to estimate shaft resistance.

2. Pile test program

2.1. Ground conditions

The field tests were carried out at a construction site in Qingdao, China. A series of laboratory and in situ tests including standard penetration test (SPT) were performed at the site. The locations of the in situ tests are shown in Fig. 1. The site is underlain consecutively with a fill layer, marine deposits, an alluvium layer, and with completely decomposed mudstone (CD mudstone). The fill layer is mainly composed of silty clay with shell fragments. The marine deposits consist of silty and cohesive soil with some shell fragments. The alluvium layer consists of medium dense to dense, fine to coarse sand with some quartz fragments. The CD mudstone is below the alluvium layer. The base of the test piles were founded on the CD mudstone layer and the length in CD mudstone is about 10 m. Soil samples were obtained from drilled holes by using split-spoon samplers to perform laboratory tests. The properties of the soils in different layers were summarized in Table 1. The cohesion c and friction angle φ were determined using consolidated-undrained tests. The water level was found at a depth of 1.90 m below the ground surface.

The SPT (N) data for all boreholes are shown in Fig. 2. The large variation of SPT N values across the test site reflects the range in the depths of the various subunits. The average value of SPT N for the area in which the test piles were installed is shown in Fig. 2.

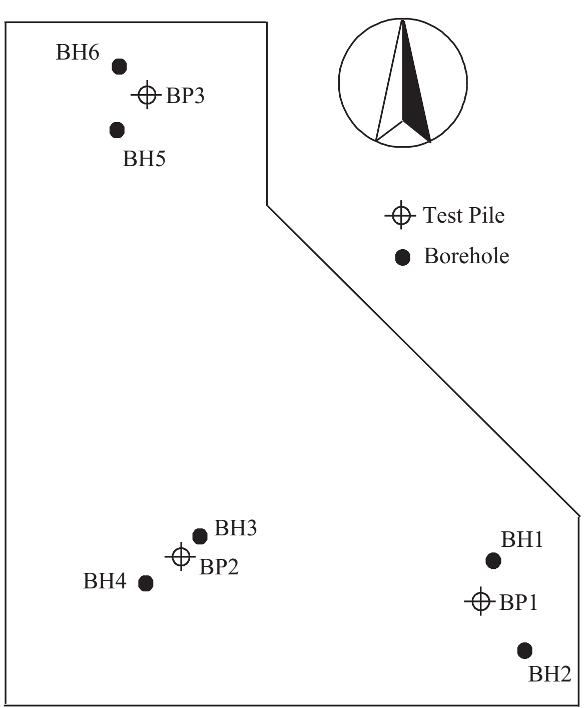

Fig. 1. Location of in situ tests.

Table 1
Subsoil properties.

Soils type	w (%)	γ (kN/m^3)	G_s	LL (%)	PL (%)	c (kPa)	φ (deg)
Fill	23.5	18.8	2.71	28.6	17.5	17.4	6.6
Muddy silt	35.9	17.7	2.70	25.7	16.6	8.7	7.8
Mucky silty clay	37.6	18.0	2.72	31.9	18.8	13.0	6.8
Silty clay	24.1	19.3	2.73	34.0	19.7	35.2	13.7
Medium-fine sand	/	/	/	/	/	0	33
Silty clay	24.4	19.5	2.73	34.8	20.4	33.7	12.3
Medium-coarse sand	/	/	/	/	/	0	36
CD mudstone	18.2	20.0	2.74	41.4	23.6	59.0	18.2

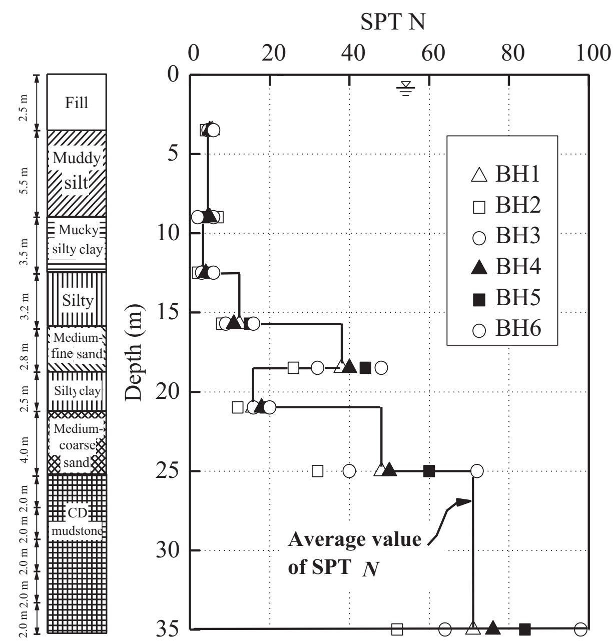

Fig. 2. SPT N_{60} values with depth.

Table 2
Summary of information of test piles.

No.	Diameter (mm)	Depth into CD mudstone (m)	Pile-forming date	Test date	Time (day)	Filling coefficient
BP1	800	10.0	02/01/2013	03/26/2013	53	1.08
BP2	800	10.0	02/06/2013	03/30/2013	52	1.13
BP3	800	10.0	02/25/2013	04/05/2013	40	1.09

2.2. Pile installation and instrumentation

Three bored cast-insitu piles were instrumented, installed, and monitored in the research program. The length and diameter of test piles were 34 and 0.8 m, respectively. The test piles were drilled into CD mudstone layer about 10.0 m during installation. The ultimate bearing capacity of a single pile was estimated as 8160 kN. The test piles were installed using slurry coat method and detailed information is summarized in Table 2. The filling coefficient in the table is the ratio of actual to theoretical concrete volume.