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# Large-scale pilot test study on bearing capacity of sea-crossing bridge main pier pile foundations

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**Abstract.** Due to the sea-crossing bridge span is generally large and main pier pile foundations are located in deep water and carry large vertical load, sea-crossing bridge main pier pile foundations bearing mechanism and load deformation characteristics are still vague. Authors studied the vertical bearing properties of sea-crossing bridge main pier pile foundations through pilot load tests. Large tonnage load test of Qingdao Bay Bridge main pier pile program is designed by using per-stressed technique to optimize the design of anchor pile reaction beam system. Test results show that the design is feasible and effective. This method can directly test bearing capacity of main pier pile foundations, and analysis bearing behaviors from test results of sensors which embedded in the pile. Through test study the vertical bearing properties of main pier pile foundation and compared with the generally short pile, author summarized the main pier pile foundations vertical bearing capacity and the main problem of design and construction which need to pay attention, and provide a reliable basis and experience for sea-crossing bridge main pier pile foundations design and construction.

**Keywords:** sea-crossing bridge; main pier pile; vertical bearing capacity; large tonnage load test

## 1. Introduction

In recent years, the construction of sea-crossing bridge has entered the golden age of rapid development, the number of sea-crossing bridge is growing faster. Cheng and Liu (2012) results of the study show that soil-pile interaction has significant effects on the reliability of steel cable-stayed bridges. Sea-crossing bridge main pier piles are subjected to lateral loading due to wind, waves and currents, piles installed in marine environments are susceptible to scour depending on wave and current characteristics and soil types (Mostafa 2012). A number of piles experienced significant structural damage due to storm surge and wave action (Robertson *et al*. 2007). Since the bridge span is long, the main pier pile foundations are in the deep water, and carrying large vertical loads, which vertical bearing performance need to be specialized studied.

Wu *et al*. (2013) show that the bearing mechanism of pile during installation and loading process which controls the deformation and distribution of strain and stress in the soil surrounding

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pile tip is complex and full of much uncertainty. The precise prediction of maximum load carrying capacity of bored piles is a complex problem because the load is a function of a large number of factors. These factors include method of boring, method of concreting, quality of concrete, expertise of the construction staff, the ground conditions and the pile geometry (Elsamee 2012). Qian *et al*. (2013) and Ter-Martirosyan Zaven Grigor'evich (2012) study showed that taking account of compressible properties of the pile material leads to qualitatively new distribution of shearing stresses over the surface of a cylindrical pile and pile-soil stress transfer mechanism has not yet been fully understood. The sea-crossing bridge main pier pile foundations are more complex, its bearing mechanism and load deformation characteristics are still vague, therefore, there is no better computational theory and method that can accurately quantify the long pile bearing mechanism. Elsamee (2013), El-Gendy (2013) and Wang and Ye (2005) researches all indicate that in-situ pile load test is the most effective and reliable means. The main pier bridge pile foundations load testing is difficult and need to be designed for its tremendous loads and water environment.

Through the Qingdao Bay Bridge piles test results, authors studied the Bridge pier vertical bearing properties of sea-crossing bridge main pier pile foundations and provided good reference to the sea-crossing bridge main pier pile foundations design and construction.

## 2. Project overview

Qingdao Bay Bridge is the longest cross-sea bridge which has 41,580 meters length. Its main bridges are cable-stayed and the suspension bridges, and their foundations are all bored piles. Qingdao Bay Bridge is more complex geological conditions, including mud, silt loam, sand, coarse sand, gravel sand, strongly weathered mudstone containing brecciated, weakly weathered argillaceous sandstone, breccia weak weathered rock. Quaternary overburden of silt, silt loam, sand, coarse sand, gravel sand, etc., about the thickness of 26 m.

Qingdao Bay Bridge pile foundations engineering has large-scale and complex geological conditions, we need to carry out load tests to measuring soil lateral friction and pile bottom resistance force, and ensure the reliability and economy of the bridge.

Fig. 1 Overall picture of Qingdao Bay Bridge

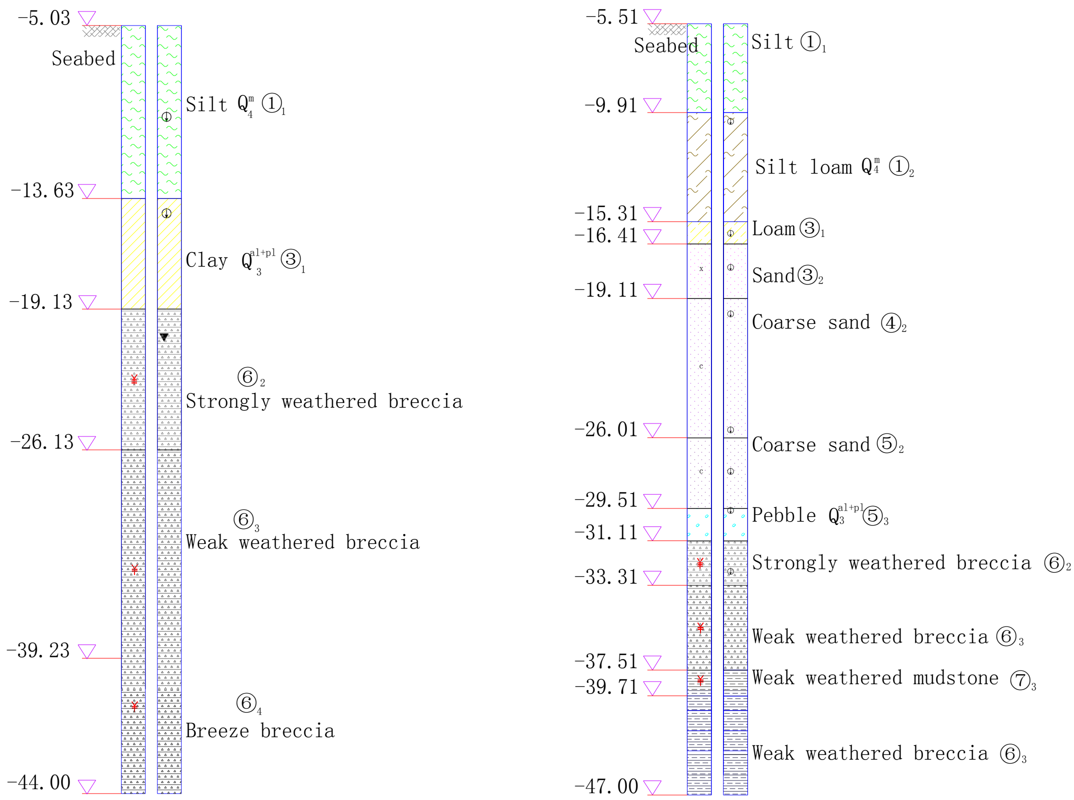
## 3. Test design

### *3.1 Test pile engineering geology*

The bridge site widely distribute mudstone, breccia, sandstone. In order to determine the conditions and the layering of these major geotechnical engineering geological characteristics, we choice test pile bridge site location at a distance of about 30 m. Geological holes were set near each test pile to ascertain the location of the test pile geological conditions. Geological conditions of each test pile test pile geologic column are shown in Fig. 2.

### *3.2 Design of test pile*

Checking compressive strength of test piles to determine the concrete design labeled C35. According anchor pullout ability to determine the depth of buried anchor. Because of larger tonnage loaded, pulling crack resistance of the anchor piles cannot provide sufficient assurance anchor pullout force, if only ordinary steel bar. Therefore also emplaced prestressed steel bar to meet the requirements of anchor piles cracking. Test piles parameters are in Tables 1 and 2.



(a) 1st test pile (b) 2nd test pile

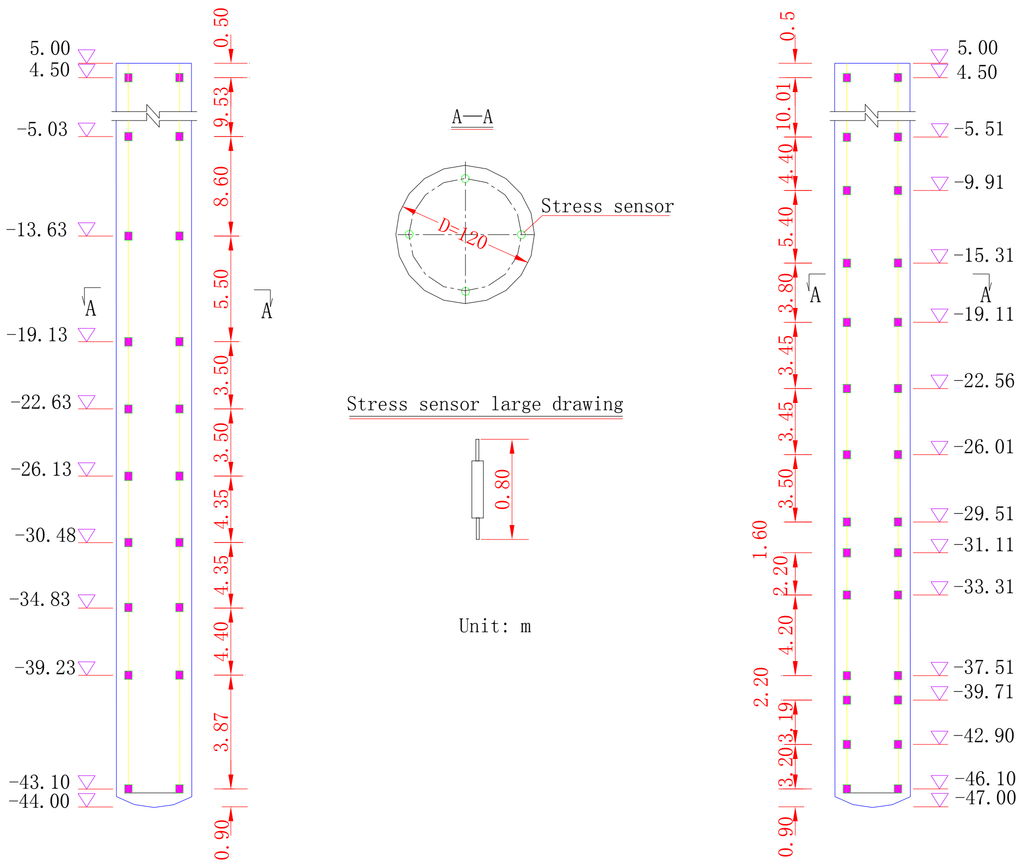
Fig. 2 Geologic columns of test piles

Table 1 The 1st test piles parameters

| Pile type | Quantity | Pile length (m) | Pile diameter (m) | Pile concrete grade | Tonnage of load (kN) |
|---|---|---|---|---|---|
| Test pile | 1 | 49.000 | 1.2 | C 35 | 38000 |
| Anchor pile | 4 | 54.000 | 1.8 | C35 | |

Table 2 The 2nd test piles parameters

| Pile Type | Quantity | Pile length (m) | Pile diameter (m) | Pile concrete grade | Tonnage of load (kN) |
|---|---|---|---|---|---|
| Test pile | 1 | 52.000 | 1.2 | C 35 | 40000 |
| Anchor pile | 4 | 57.000 | 1.8 | C35 | |




(a) 1st test pile (b) 2nd test pile

Fig. 3 Test piles stress sensor layout

Stress sensors are embedded in pile to test stress under pile top load. Each test section of the test pile symmetrically arranged four stress sensors. The stress sensors are directly welded with the reinforcement; Fig. 3 shows the test pile stress sensor layout, Fig. 4 shows the test pile stress sensor installation photo.

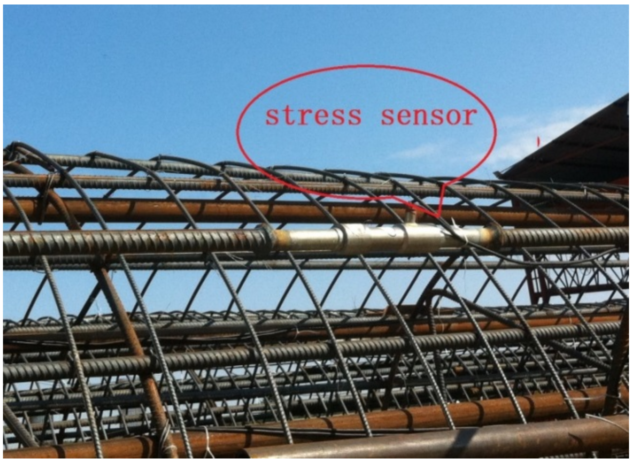



Fig. 4 Test piles stress sensor installation photo

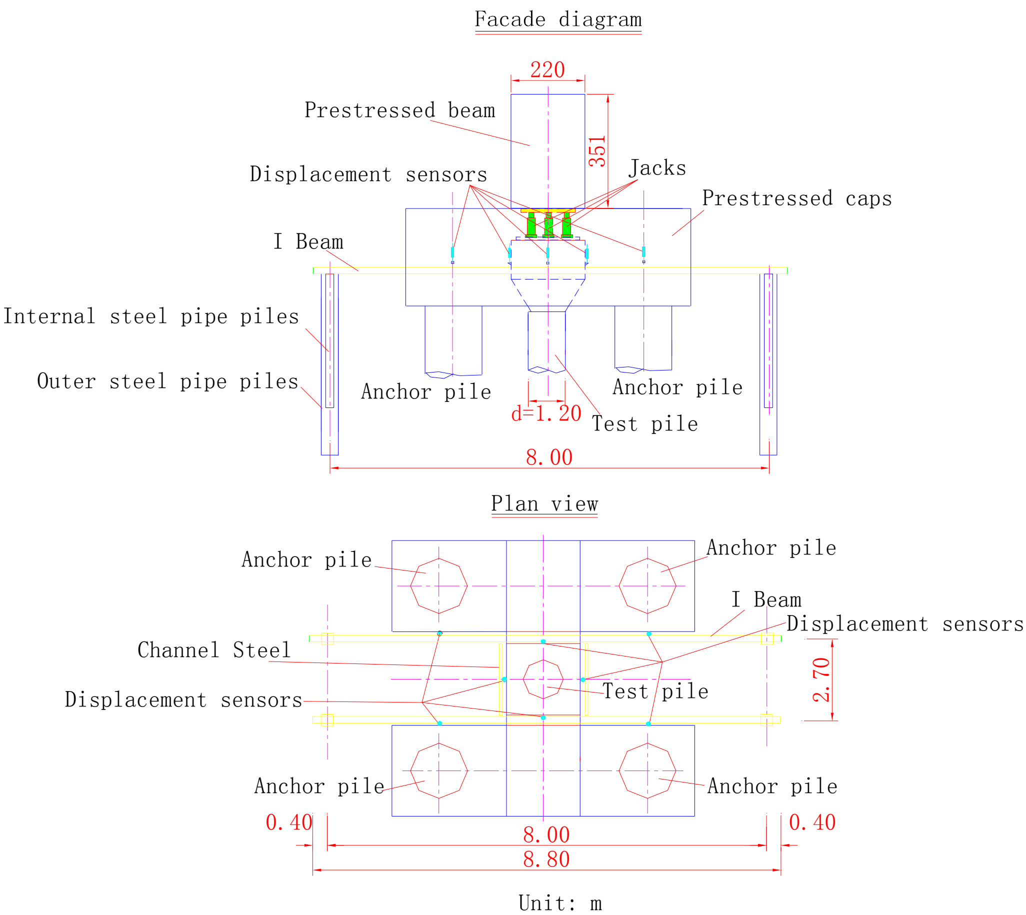



Fig. 5 Load test system layout

### *3.3 Load test system*

Using prestressed anchor piles, prestressed caps and prestressed beam form the load reaction system. Reaction system used five jacks to parallel load. each jack model and maximum rated power is the same, jacks itinerary is 20 cm. Reaction system and loading system designed according to 40000 kN . Fig. 5 shows load test system layout, Fig. 6 shows whole load test system photo.

### *3.4 Test system*

#### *3.4.1 Load measurement and control*

Using static load test system to control jacks loading. This system connects the oil jack plus multi-channel sensor automatically controls each grade load and automatic replenishment. System settings are set up for each grade load limit of 1/25. Fig. 7 shows load jack photo.

Fig. 6 Whole load test system photo

Fig. 7 Load jack photo

Fig. 8 Displacement sensor photo

Table 3 Pull test results of anchor piles on the test pile load maximum tonnage (Unit: mm)

| Test pile No. | Anchor pile No. | | | |
|---|---|---|---|---|
| | W1 | W2 | W3 | W4 |
| 1# | 4.22 | 4.56 | 4.45 | 4.35 |
| 2# | 3.29 | 3.78 | 4.10 | 3.24 |

### *3.4.2 Measuring test piles settlement and monitoring the amount of pull anchor*

In the top of the test piles arranged four intelligent displacement meter to observe vertical displacement. Displacement meter range is 100 mm, with an accuracy of 0.01 mm. Each anchor piles install a displacement meter to monitor pull displacement. Fig. 8 shows displacement sensor photo.

### *3.4.3 Pile stress testing*

Pile stress was measured by using automatic acquisition system to test the embedded stress sensor.

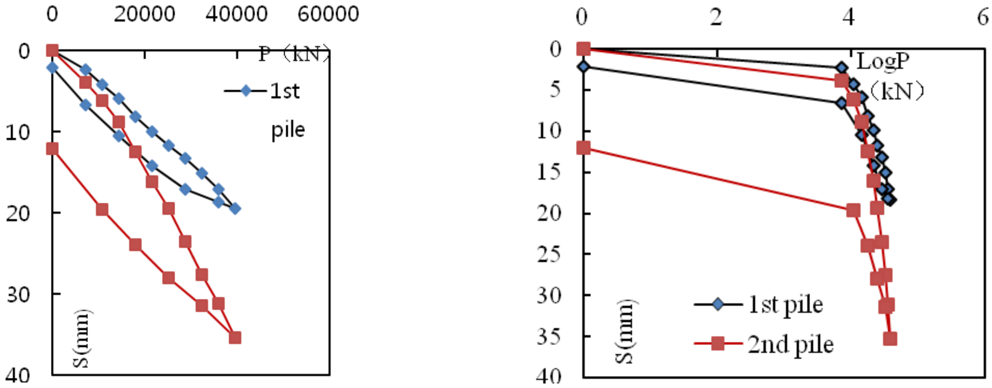
### *3.4.4 Reaction system deformation monitoring*

Reaction beam deformation was monitored by measuring displacement meter which was placed in the bottom and sides of the beam.

## 4. Test results and analysis

### *4.1 Anchor piles uplift test results*

Table 3 shows the displacement of the two anchor piles at maximum load, the test results show that the anchor piles uplift displacement is small, indicating no major anchor pile deformation.




(a) P-S curve (b) LogP-S curve

Fig. 9 Test Piles vertical static load test results

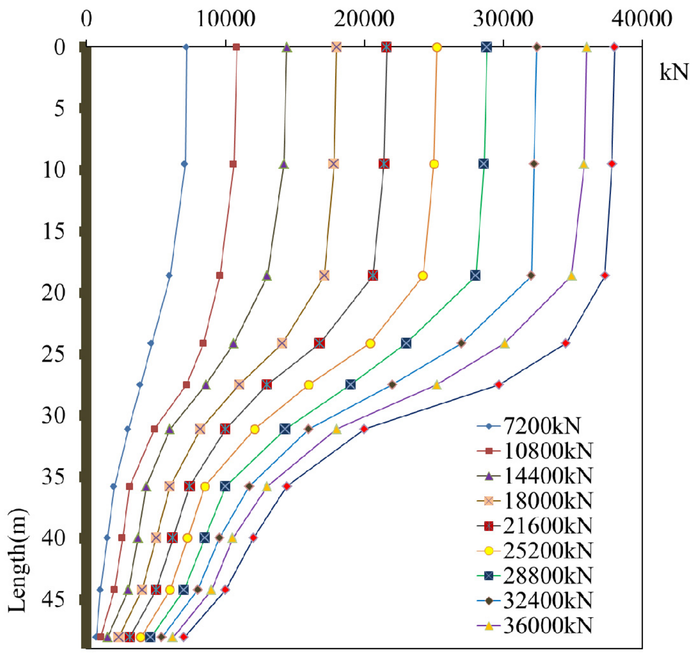



Fig. 10 The 1st test pile test section axial force diagram

### *4.2 Analysis of test piles vertical bearing behavior*

The biggest load of 1st and the 2nd test piles are 38000 kN and 40000 kN. Test piles vertical static load test P-S curve and LogP -S curve are shown in Fig. 9.

Test piles bearing performance results are analyzed as follows:

(1) Two test piles P-S curve are slowly varying type, no obvious steep drop, and still haven’t

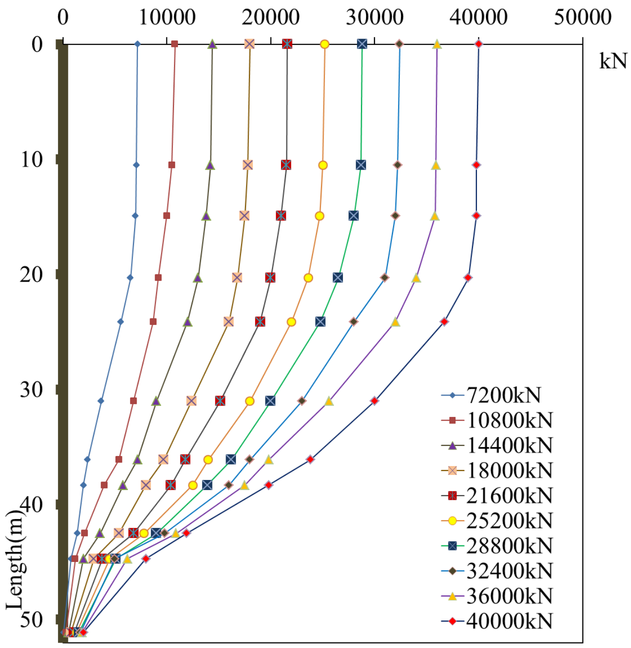



Fig. 11 The 2nd test pile test section axial force diagram

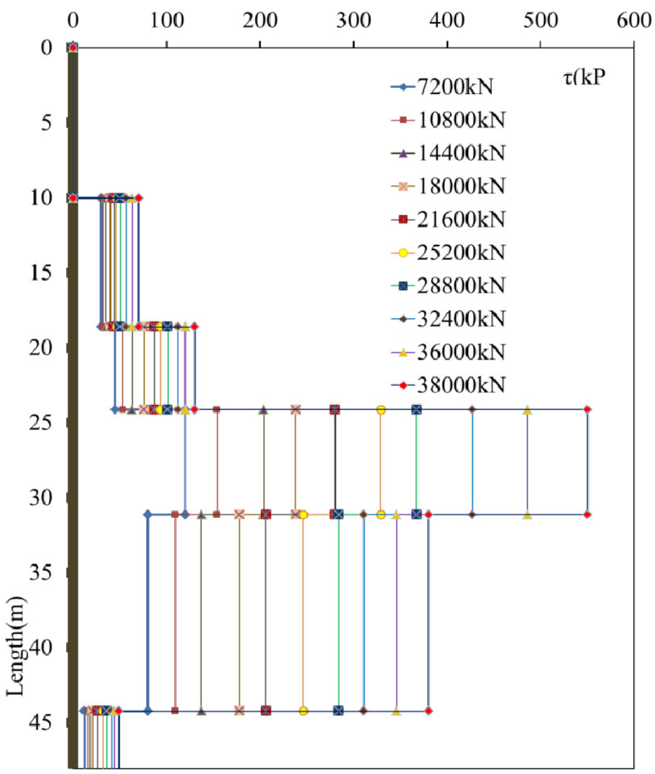



Fig. 12 The 1st test pile soil unit lateral friction

appeared ultimate bearing capacity, and which is consistent with Xu and Liu (2010) test results of model experimental research.

(2) Since the test pile soil characteristics change, the geological conditions are relatively good 1# pile settlement was significantly less than 2# test pile under the same load, Geology have great influence on the settlement of the pile, while the length of the pile has little effect on the pile settlement.

### 4.3 Characteristics of test piles axial force

Axial force distribution of test pile under vertical static load are showed on Figs. 10 and 11. Test results are analyzed as follows:

(1) Figs. 10 and 11 show that test piles axial force gradually decreases under different loads with increasing buried depth of piles, Pile axial force is very small at the bottom of the pile. Although the two test piles are embedded in rock, but by the axial force distribution can be seen in these two test piles performance as friction piles characteristics, which is completely different with short rock-socketed pile.

(2) From test piles section axial force diagram, we can see test piles axial force reduced relatively quickly after 25 m, which corresponds to the test piles geology. The lower part of the geology is better which carry most loads of pile top.

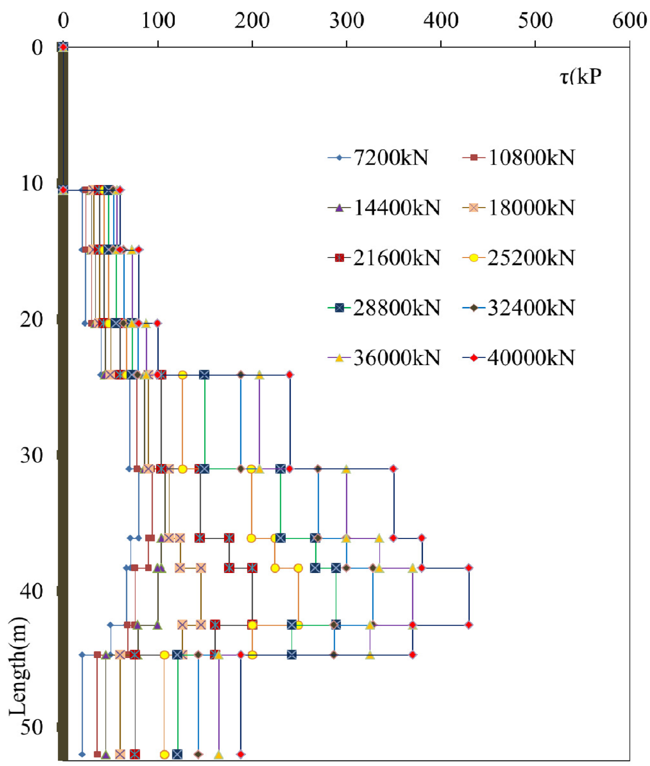



Fig. 13 The 2nd test pile soil unit lateral friction

### *4.4 Test piles lateral friction characteristic analysis*

Test piles unit lateral friction at the vertical load are shown on Figs. 12 and 13. The lateral friction test results of test piles are analyzed as follows:

(1) We can see different geological properties of the pile side, its lateral friction play degree are also different from Figs. 12 and 13.
(2) Generally speaking, with the top of the pile load increases, lateral friction of soil layers also increased. upper side friction of soft soil Increase more slowly, but lateral friction of hard soil increased faster.
(3) Test results show that the measured unit lateral friction value of soil is larger than the norm, especially in the lower part of the soil is much larger than the specification value, which is due to the same soil characteristics as the depth increases its internal stress condition is not the same, showing the lateral friction will increase. This indicates that the long pile geological lateral friction values should consider the depth effect.

## 5. Conclusions

Through large-scale pilot test study on bearing capacity of sea-crossing bridge main pier pile foundations, we draw the following conclusions and implications:

(1) Bearing capacity of sea-crossing bridge main pier pile foundations performance as friction piles, which Q-S curve is slowly varying type even embedded in rock.
(2) The bearing capacity of sea-crossing bridge main pier pile foundations is controlled by the settlement, we cannot rely on the increase of pile length to improve pile bearing capacity, can consider increasing the diameter of pile, pile soil contact area and other measures to improve pile bearing capacity.
(3) The same name soil in different depth of pile lateral friction value are different, which has been verified in the test study, so the sea-crossing bridge main pier pile foundations lateral friction value should consider the depth effect, otherwise there will be a lot of difference with the actual performance.
(4) The sea-crossing bridge main pier pile foundations compression amount is relatively large for huge load, so we cannot assume the pile as a rigid body in the process of calculation.
(5) The sea-crossing bridge main pier pile foundations design urgent need bearing capacity calculation methods and means which included in the to coordinate the deformation of pile-soil.
(6) Because of sea-crossing bridge main pier pile foundations is long and the constructed in the sea, construction quality directly affect the sea-crossing bridge main pier pile foundations bearing properties, such as pore forming verticality, mud weight, drilling and piling time have different degrees of influence on the bearing properties of the pile. Therefore, it is necessary to form a complete, sophisticated construction techniques to ensure sea-crossing bridge main pier pile foundations bearing capacity to meet the design requirements.

## References


Cheng, J. and Liu, X.L. (2012), "Reliability analysis of steel cable-stayed bridges including soil-pile interaction", *Steel Compos. Struct., Int. J.*, **13**(2), 109-122.

El-Gendy, M.M., El Araby, I.A. and Kamal, M.A. (2013), "Comparative examinations of single bored piles using international codes", *Eng.*, **5**(10), 796-806.

Elsamee, W.N.A. (2012), "Evaluation of the ultimate capacity of friction piles", *Eng.*, **4**(11), 778-789.

Elsamee, W.N.A. (2013), "New method for prediction pile capacity executed by Continuous Flight Auger (CFA)", *Eng.*, **5**(4), 344-354.

Mostafa, Y.E. (2012), "Effect of local and global scour on lateral response of single piles in different soil conditions", *Eng.*, **4**(6), 297-306.

Qian, Y.M., Xu, G.H. and Wang, R.Z. (2013), "Experimental research on failure behavior of soil around pile under gompression", *TELKOMNIKA: Indonesian J. Electrical Eng.*, **11**(4), 2013-2017.

Robertson, I., Riggs, H., Yim, S. and Young, Y. (2007), "Lessons from Hurricane Katrina Storm Surge on Bridges and Buildings", *J. Waterway, Port, Coastal, Ocean Eng.*, (Special Issue: Tsunami Engineering), **133**(6), 463-483.

Ter-Martirosyan Zaven Grigor'evich, Trinh Tuan Viet (2012), "Interaction of a long single pile that has a double-layer base with account for compressibility of the pile shaft", *Vestnik MGSU* , Iss 4, 28-34.

Xu, Y. and Liu, Z.R. (2010), "Model experimental research on mechanical characteristics of large diameter overlength pile-group foundation in loess", *J. Experiment. Mech.*, **25**(6), 81-88.

Wang, T. and Ma, Y. (2005), "Study on over-length drilled pile bearing behavior under vertical load", *Rock Soil Mech.*, **26**(7), 1053-1057.

Wu, Y., Yamamoto, H. and Yao, Y. (2013), "Numerical study on bearing behavior of pile considering sand particle crushing", *Geomech. Eng., Int. J.*, **5**(3), 241-261.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