2019
INTERNATIONAL
SYMPOSIUM

TESTING AND TECHNOLOGY FOR LOAD CARRYING CAPACITY OF DEEP FOUNDATIONS

EDITORS

Ashutosh Trivedi
Delhi Technological University
Delhi, India

Sanjay Kumar Shukla
Edith Cowan University
Perth, Australia

DELHI TECHNOLOGICAL UNIVERSITY
Delhi, India

TESTING AND TECHNOLOGY FOR LOAD CARRYING CAPACITY OF DEEP FOUNDATIONS

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From the Editors

India is poised for great economic growth and engineering development supported by the technological innovations and capacity building in civil engineering structures. The past few decades have witnessed significant scientific and technological developments in small-scale testing. As per the current requirements of technology and repeated demand of engineering community, the selected papers presented at the international symposium on "Testing and Technology for Load-Carrying Capacity of Deep Foundations" have been compiled with graphic and numerical descriptors for the benefit of researchers, engineers and practitioners. The piles and pile groups have been traditionally considered as a function of vertical compression, lateral, pullout and eccentric movements characterized by Q-z, p-y-x, Q-z-t, p-e-y, and Q-e-z effects. The realization of this effect is mostly based upon the model tests. The application of testing and technology for the load-carrying capacity of large diameter deep foundations and retaining structures have been largely self-limiting, worldwide; throughout the millennium due to absence of scientific techniques, prohibitive scale, and proliferating costs.

The use of load cells has been the key part of equipment for the load testing of pile foundation and retaining structures, which are widely used for buildings, bridges and retaining structures. There have been a variety of load-cell instrumentations, digging technology for cast-in-place pile walls, steel pile walls to interface PZT for energy harvesting, PHC piles, diaphragm walls and caisson foundations used as load-bearing and energy geo-structures.

This book considered the eight best submissions selected out of the accepted papers for presentation during the proceeding of International Symposium on Testing and Technology for Load-Carrying Capacity of Deep Foundation at Delhi Technological University, Delhi, India, February 26-28, 2019.

The book offers new studies by experienced researchers on the topics namely historical developments of deep foundations in India, automatic control system for post-grouting construction, self-balanced loading test, offshore wind turbine foundation, bi-directional load testing of deep foundations, deep foundations subjected to combined axial and torsional loads, and energy harvesting from dynamically loaded retaining structures. It gives new insights on patterns and mechanisms that surely shall have an impact on current engineering practices. In particular, the papers have been included to explain how to use some state-of-the-art tools and algorithms to analyze energy and emerging engineering evolutions.

The editors of the book acknowledge the support received from the organizers, reviewers, and sponsors of this symposium, and greatly appreciate Prof. Wei Ming Gong, Professor of Civil Engineering, Southeast University, Nanjing, China, and Prof. Yogesh Singh, Vice-Chancellor, Delhi Technological University, Delhi, India, for their kind support and encouragement.

Ashutosh Trivedi
Sanjay Kumar Shukla

Delhi, India/ Perth, Australia
Vijay Dashami, 2019

About the Editors

Prof. Ashutosh Trivedi is a proclaimed academician. He currently serves as a Professor of Civil Engineering and Dean of Industrial Research and Development at Delhi Technological University. Previously he was a Professor of Civil Engineering and Dean, Faculty of Technology at the University of Delhi, Head of the Department of Civil Engineering at Delhi Technological University, Delhi, India. He obtained his bachelor degree in civil engineering and master degree in soil mechanics and foundation engineering from NIT (Formerly REC), Kurukshetra and PhD from Thapar Institute of Engineering and Technology (TIET), Patiala, India. He has more than sixty research papers, as lead author in the refereed international journals, conferences and symposia. He is a fellow of Indian Association of Structural Engineers and an active member of several professional societies. He has supervised a number of prestigious consultancy and research projects. He has guided more than fifty Masters and PhD candidates for the award of degrees at Thapar Institute of Engineering and Technology, Patiala, India, University of Delhi and Delhi Technological University, Delhi, India. Prof. Trivedi has a couple of patents and PCTs to his credit. He is the recipient of the prestigious Devang Mehta Education Leadership Award for the year 2017. He is a proponent of the role of research thinking in innovation, incubation, research and development. His engineering interests include mechanics of fractured masses, hydraulic flow amid cemented and un-cemented fills, deep foundations and bio-cemented soils and rock masses. He currently serves on the editorial boards of prestigious journals namely Acta Geotechnica and International Journal of Geosynthetics and Ground Engineering.

Dr Sanjay Kumar Shukla is an internationally recognized expert in the field of Civil (Geotechnical) Engineering, He is the Founding Editor-in-Chief of International Journal of Geosynthetics and Ground Engineering. He is also the Founding Research Group Leader (Geotechnical and Geoenvironmental Engineering) at Edith Cowan University, Perth, Australia. He holds the distinguished professorship in Civil Engineering at four international universities in India and Fiji. He graduated in Civil Engineering from BIT Sindri, India, and earned his MTech in Civil Engineering (Engineering Geology) and PhD in Civil (Geotechnical) Engineering from Indian Institute of Technology Kanpur, India. His primary areas of research interest include geosynthetics and fibres for sustainable developments, ground improvement techniques, utilization of wastes in construction, earth pressure and slope stability, environmental, mining and pavement geotechnics, and soil-structure interaction. He is the recipient of the prestigious International Geosynthetic Society Award of the year 2018 for making outstanding contribution to the development and use of geosynthetics, related products and associated technologies through his scientific and technological work by the International Geosynthetic Society. He is an author/editor of 12 books, and more than 230 research papers, including over 140 refereed journal papers. He is a fellow of Engineers Australia, Institution of Engineers (India) and Indian Geotechnical Society, and a member of American Society of Civil Engineers, International Geosynthetics Society and several other professional bodies. He serves on the editorial boards of more than ten international journals. He is an avid researcher and outstanding academician of international repute.

Contents

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Historical Developments and Application of Deep Foundations in India

Ashutosh Trivedi[1], Sadanand Ojha[2], Rajiv Goel[3], Naresh Kumar[1], and Sagar Mehra[4]

Abstract

In the post independent era, India created marvels in civil engineering structures however at a slower pace and scale compared to the south east Asia and China [1]. Other than several examples of utilitarian structures supported by the mammoth deep foundations, one of tallest statues in the world is currently held in India. This paper describes the developments of deep foundation in India with the combination of Indian Standard Codes of Practices and current practices [2].

Keywords: Utilitarian structures, deep foundations, pile groups, current practices.

Contextual Descriptors

The historical developments of engineering in any region, nation, continent or civilisations are essentially associated with the existence of peace and economic prosperity resulting into the grandeur of structural designs standing on the deep foundations. So was the case of ancient civilisations in Egypt, China and India where deep foundation were provided extensively to support castles, forts, temples and other monuments of historical importance. There is no explicit availability of records of their design and analysis which present a complex problem to engineering community to investigate about their acumen in making such foundations. But their stability of standing on the sands of time confirms their wisdom in absence of sophisticated mathematical formalism, coded software and digital replications.

The width of imagination conceals several factors that affect the foundation behaviours. Such factors include mode of loading, soil properties, structural geometry, placement and method of construction. The mode and magnitude of loads transferred from the superstructure influences the selection of well foundation to resist the imposed loads.The origin of well foundations in India credits back to historic Indian engineering activities past two millennianamely in well foundation in South Indian temples and North India monuments.The use of well foundations in India has been for providing deep foundation beneath the water level for monuments, bridges and aqueducts [1, 3, 4, 5].

The current construction practices in India are largely conservative andslow due to labour intensive techniques adopted by small construction companies, clients, and consultants not educated on foundation technologies. Therefore, the cost of foundations is 1 to 10% of the entire civil construction cost of a project. However, in special cases of marine structures and deep bridges the estimated cost had been up to 50 to 60 % of the cost of the constructed facility. Currently deep foundation designed methods are well established [IS : 2911 (Part I/ Sec I) – 1979, IS : 2911 (Part I/ Sec II) – 1979, IS : 2911 (Part I/ Sec III) – 1979, IS : 2911 (Part I/ Sec IV) – 1979] while selection of key parameters namely earth pressure coefficients, which are conservative without consideration of dilation in friction angle andadhesion factor, secondly the cost of project considered prohibitive for detailed investigation. Theuse of p-y, q-z, t-z, p(e) θ, q-p(e) θ plots is not frequent in the practice and there is a need to promote this practice by scientific education [6, 7]. The current practices of pile groups are based upon single pile capacity using 2D (if on rocks)or 3D (soils) spacing.

The engineering industry in India is poised for a major contribution to the rapid development of various sectors of India's economy. There is an urgent need for the deep foundation technologies and practices to ensure that they supplement the overall growth process using current advancement of IPR and research practices [8, 9, 10].

[1] Professor, Department of Civil Engineering, Delhi Technological University, Delhi, India
[2] MD , Swati Structural Solutions Pvt. Ltd., Delhi, India
[3] Director, Arocon Pvt. Ltd., Delhi, India
[4] Research Scholar, Department of Civil Engineering, Delhi Technological University, Delhi, India

Graphic Descriptors

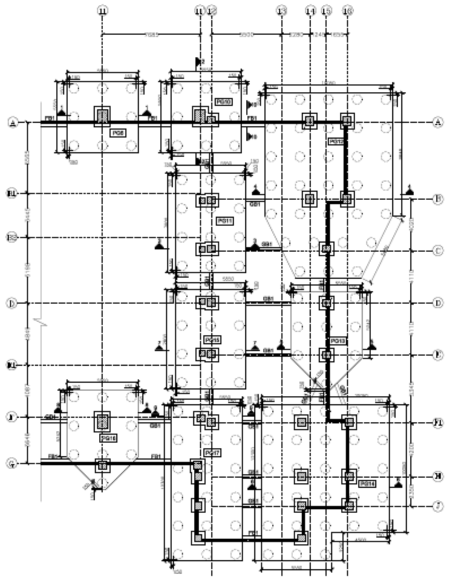

Fig.1 General arrangement of pile cap [4]

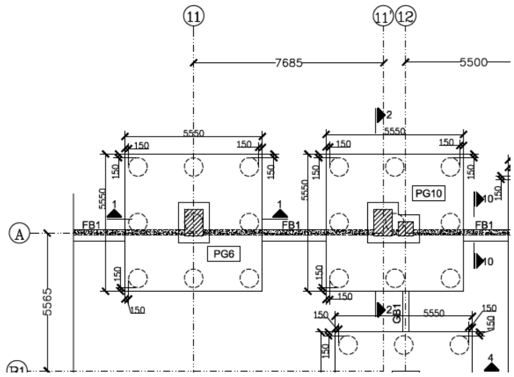

Fig. 2 Enlarged view-plan arrangement [4]

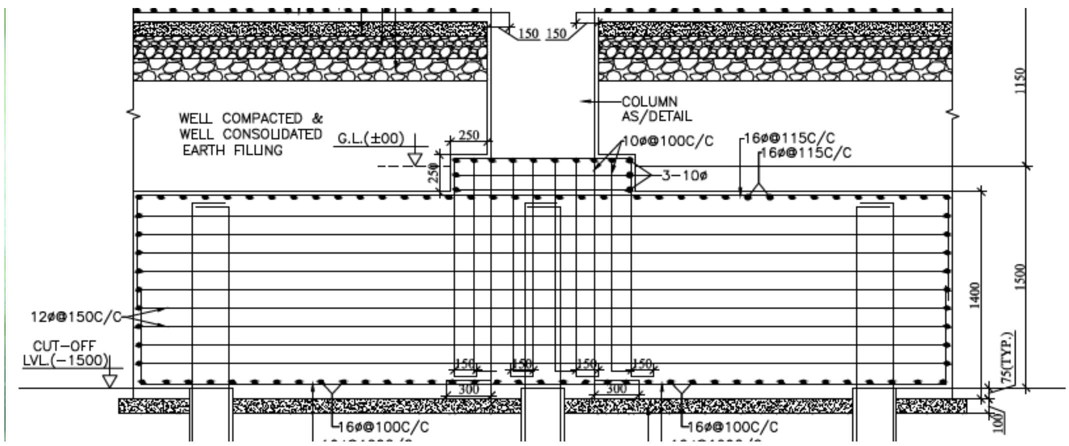

Fig. 3 Sectional elevation of pile cap [4]

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Development of Automatic Control System for Post-grouting Construction and Its Application

Dai Guoliang[1], Gong Weiming[2], and Zhu Jianmin[3]

Abstract

The design of the automatic control system in the process of grouting is introduced. The overall scheme of the system is constructed and a set of automatic controller and data acquisition system are developed.The grouting parameters of pressure, flow and amount is dynamically measured by this instrument using sensor, electron and PC technologies, and applied to engineering practice. The results indicate that the system has the characteristics of fast response, high sensitivity and precision, good stability and so on. The measured data can be uploaded in real time and can realize remote monitoring,yielding reducing the construction management personnel of the grouting site and improving the working efficiency.During the grouting process, the grouting pressure, the flow and other parameters can be reflected to meet the design requirements using the automatic control system. It provides a complete detection method for grouting engineering.

Keywords: post-grouting technique, automatic control system, real-time monitoring, grouting pressure, grouting amount.

Introduction

The post-grouting technique is a kind of engineering technology with strong practicability and wide application range. It has been widely used in the foundation of various fields, such as underground building, bridge, subway, tunnel, and transmission tower. It is mainly used to enhance the strength and stiffness of rock and soil mass and improve its stability and bearing capacity[1-3].At present, the post-grouting technique is mainly used to improve the defects of the construction process of drilled shafts in China, improving the bearing capacity of the pile foundation, reducing the settlement amount, and then optimizing pile length and saving cost.Post-grouting technique of grouting piles is generally divided into three broad categories: tip post-grouting, side post-grouting and combined post-grouting. Among them, the bearing capacity and stability performance of combined ismuch larger than that oftip or side post-grouting. Therefore, combined post-grouting pile has been widely applied in China[4-5].Post-grouting craftwork is an underground concealed engineering, its construction quality and grouting effect are often difficult to carry out intuitive inspection, which needs to be analyzed and evaluated by means of the changes of grouting parameters in the construction process. Therefore, the control of grouting parameters in the construction process is particularly important in the post-grouting project.In this paper, a set of automatic controller and data acquisition system are developed to dynamically measure the grouting pressure, grouting flow and other parameters in the process of grouting construction, and it is applied to practical engineering.

Post-grouting automatic control system

Since the post-grouting project is a concealed project, the infiltration, filling and compaction of the injected grout in the stratum cannot be assessed visually, and the construction quality is difficult to judge intuitively, which limits the popularization of the post-grouting technique.With the continuous advancement of science and technology, electronic equipment and corresponding technologies have been adopted by the grouting technology, and the United States, Japan, Britain, France and other countries have developed semi-automatic or fully automatic equipment for grouting construction monitoring.The development of grouting pressure,

[1] Professor, School of Civil Engineering, Southeast University, Nanjing211189, China
[2] Professor, School of Civil Engineering, Southeast University, Nanjing211189, China
[3]PH.D,NanjingDongdaBi-directionalPileTestCo.,Ltd.,Nanjing210018,China

flow rate and water-cement ratio at any stage can be obtained in time to guide the entire process of grouting.Therefore, in order to make post-grouting technique widely used in bridge pile foundation engineering, automatic control equipment is required to online and dynamically monitor the grouting parameters of the construction process, and the automatically recorded original grouting data can truly reflect the actual grouting. The grouting situation reduces the interference of subjective factors, ensures the reliability of grouting, and improves the efficiency of grouting. Although a monitoring system for some construction process parameters has appeared in the post-grouting engineering, it is quite difficult for the construction personnel and on-site grouting recorder because a large number oficons need to be drawn for monitoring data and the data sorting work is also very tedious.In the overall scheme design of the system, according to the actual conditions of the bridge pile foundation, the specific requirements put forward by the construction and the design unit, the following principles are formulated for the design: 1) the control system should adopt advanced computer technology, and can dynamically monitor the entire grouting process; 2) the control system should have high stability and reliability, and the automatically recorded grouting data is accurate and true; 3) the control system can monitor in real time, the data can be uploaded in real time, and remote monitoring can be realized.

In this paper, the overall system design, according to the actual situation of the bridge pile foundation, the construction unit and the specific requirements of the design unit, the design of the following principles: the control system should use advanced computer technology, online, dynamic monitoring of the entire grouting process; The control system shall be highly stable and reliable, and the grouting data automatically recorded shall be accurate and authentic. The control system can monitor in real time, the data can be uploaded in real time, and can realize remote monitoring.The system is composed of grouting equipment, automatic controller and data acquisition system. The on-site grouting pipeline and equipment layout are shown in Figure 1.

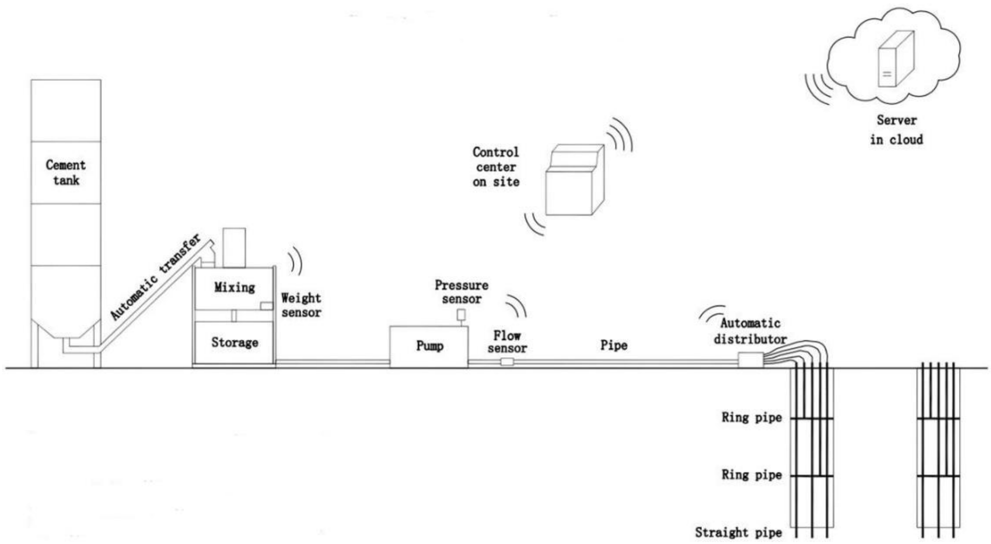

Fig. 1. On-site grouting pipeline and equipment layout

The system consists of grouting equipment, host, sensor and data storage. The equipment includes grouting pump, slurry mixer, slurry tank, pipeline, pressure gauge, and distributor.The host mainly includes the single chip system, the input part (keyboard and keyboard input interface circuit, sensor and single chip input interface circuit), and the output part (display and display interface circuit). The sensor has a weighing flowmeter, pressure sensor and target flow meter.The automatic control system uses the weighing flowmeter, the pressure sensor, and the target flowmeter to detect the cement dosage, the pressure, and the flow parameters in the grouting process, and the grouting parameters in the grouting process are dynamically monitored by the system, and the computer will be collected sensor to analog signal analysis and processing, and displays the detected data in real time.

Compared with the manual recording of the grouting parameters, the automatic control system developed in this paper has many advantages in the grouting construction process:1) the use of automatic control system can play a monitoring role, so that the grouting construction process in the pressure, grouting amount and grouting time and other parameters are guaranteed, which can greatly improve the quality of grouting; 2) the grouting data is true and accurate, and can provide a reliable basis for reasonably control the construction process and correctly analyze the grouting effect;3)the system can greatly reduce the work of internal data sorting, reduce the construction management personnel at the grouting site, and improve work efficiency;4)according to the grouting construction data provided by the automatic control system, the underlying condition can be analyzed correctly and timely, which is beneficial to optimize the design and achieve the safety effect required by the design with minimum engineering quantity;5)through the automatic control system, the construction technical parameters can be optimized, the construction period can be shortened, and the project cost can be saved.

Full-Scale Field Study

Project description

Shishou Yangtze River Highway Bridge is located in Shishou, Hubei Province, Central China. The total length of the proposed bridge is approximately 39.7 km, of which the length of the main bridge and approach bridges is 1.45 km and 8.08 km, respectively. The proposed bridge, which is large-scale project and high technical content, is a world-class bridge project. The large diameter cast-in-place bored pile foundations were employed in the main and approach bridges, with a total of two hundred and ninety-nine piers installed along the main and approach bridges. The results of geological drilling in the proposed bridge site shows that there is no bedrock in the exploration of 180 m, and the regional geological conditions are relatively simple, which is mainly composed of fine sand layer. In order to improve the bearing capacity of the pile foundation, reduce the settlement amount, optimize the design of the pile length, and save the engineering cost, combined tip-and-side post-grouting technique is adopted.

Through the automatic control system of grouting developed in this paper, the test pile TP4 for approach bridge in this project was studied. The test pile TP4 had diameterof 2.0m andwas 52m in length.The TS1 was tipped in the fine sand layer. Three straight grouting pipes are arranged at the pile end, and two cross-section grouting ring pipes are arranged on the pile side. The grouting ring pipe of the first section is 15m away from the pile end, and the spacing between the grouting ring pipes is 15m.

Analysis of test results

The sequence of combined side-and-tip grouting should first perform grouting at the pile side, and then grouting at the pile tip. Additionally, when pile side grouting pipes were attached to the reinforcement cage of the test piles at different levels, the sequence of side grouting should be performed from pile head to pile bottom.There are a total of five grouting pipes at the pile end and side. The grouting takes about 150 minutes, and the amount of cement used is 7.0t. In the process of grouting construction, the automatic controller and data acquisition system are used for the process detection of dynamic grouting parameters.The curve diagram of the detection results is shown in Figure 2.

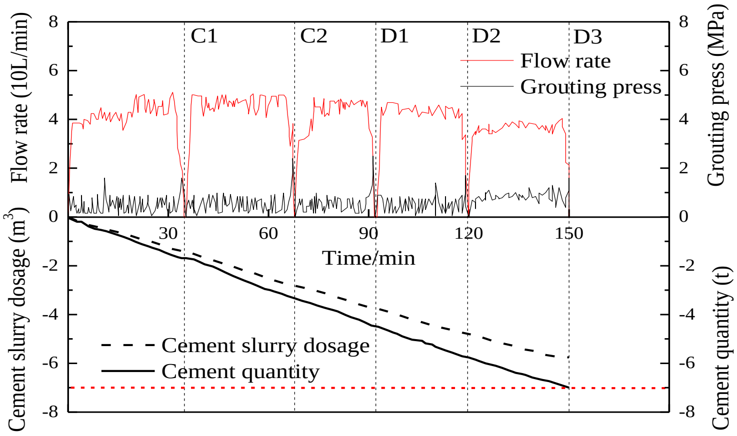

Fig. 2. On-site grouting pipeline and equipment layout

It can be seen from Figure 2 that the dynamic change of the grouting flow rate and the grouting pressure with time can understand the variation of the grouting pressure and the grouting amount with time in the grouting process. The final grouting cement dosage is 7.0t, which is the same as the cement used in the construction.The pressure change is 0.44~4.2MPa, and the average pressure of the final pressure holding for 5min is about 2.0MPa.The flow rate varies from 35~50L/min, and the grouting parameters meet the actual requirements.Therefore, the automatic control system is used to dynamically test the grouting parameters during the grouting process, which can accurately grasp the conditions of the pressed stratum, and can quickly evaluate the grouting effect, thereby reasonably changing grouting pressure, grouting flow and water-cement ratio, yielding the grouting construction more reasonable and effective.

Conclusions

In this paper, by developing a set of automatic controller and data acquisition system, the parameters such as grouting pressure and grouting flow during grouting construction are dynamically detected. The grouting engineer can analyze the pressure, flow, water-cement ratio and other grouting parameters in real time. Accurately grasp the conditions of the stressed stratum, can quickly evaluate the grouting effect, and further rationally change the parameters such as grouting pressure, flow rate and water-cement ratio, so that the grouting construction can be rationally and effectively performed.The detection data of the system can be uploaded in real time and can be monitored remotely, thereby reducing the construction management personnel at the grouting site and improving work efficiency.The results of the case show that the automatic control system in the grouting process can reflect the parameters such as grouting pressure and grouting flow to meet the design requirements. It provides a more complete testing method for grouting engineering.

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The Statistical Study on Bearing Capacity of the Self-Balanced Loading Test

Guoliang Dai[1] and Xiaojuan Li[2]

Abstract

In this paper, 35 projects were collected in this paper, each of them did self-balanced load test (OLT)and traditional top-down load test(COLT) in the same subsoil conditions, then the test pile at OLT and one at COLT in a same project were picked as a comparison group, 132 groups were found. In these groups, the diameter, length, geological condition and construction method of two piles in every groups were same or similar. Data from COLT were taken as references. In addition, some cases were introduced to present the usage of self-balanced loading test in deep foundation,theseinclude root caisson foundation in a bridge and to large diameter pipe piles in a sea wind power plant. Some new load cells, test procedure, and construction technology were also adopted based on the applications to different deep foundations, which could enlarge the application scopes of self-balanced loading test.

Keywords: self-balanced loading test; top-down loading test; bearing capacity; conversion factor; load cell

Introduction

In China, a number of major construction projects, such as high-rise buildings, river- or sea-crossing expressway bridges and offshore wind farms are under construction or to be built in urban and coastal regions. Deep foundations are frequently observed in heavy-load and large-span construction projects. For the large applied loads, the self-balanced static loading test can be adopted [1,2], and it is also called self-balanced test (or Osterberg's cell load test)[3,4]. This method is a prefect alternative to the conventional static top-down load test (COLT). While there exist few researches on the accuracy of bearing capacity and conversion factor γ (the ratio of downward shaft resistance to the upward shaft resistance), not to mention the systematic statistical analysis about them. To solve these problem,132 groups were found. In these groups, the diameter, length, geological condition and construction method of two piles in every groups were same or similar. Data from COLT were taken as references.And some cases were introduced to present the usage of self-balanced loading test in deep foundation.

Graphic Description

Firstly, the bearing capacity of piles and the error between OLT and COLT were statistically calculated, which are shown in Fig.1; bearing capacity from OLT is x-coordinate, from COLT is y-coordinate, the more near to the diagonal x=y is, the less error of bearing capacity between OLTs and COLTs. Then 132 points were given.

[1]Professor, Department of Civil Engineering, Southeast university, Nanjing 201196, Jiangsu, China
[2]Ph.D. student, Department of Civil Engineering, Southeast university, Nanjing 201196, Jiangsu, China

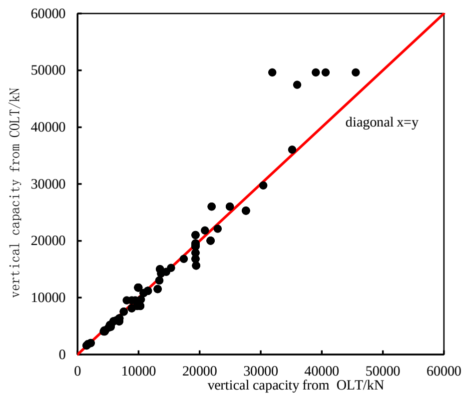
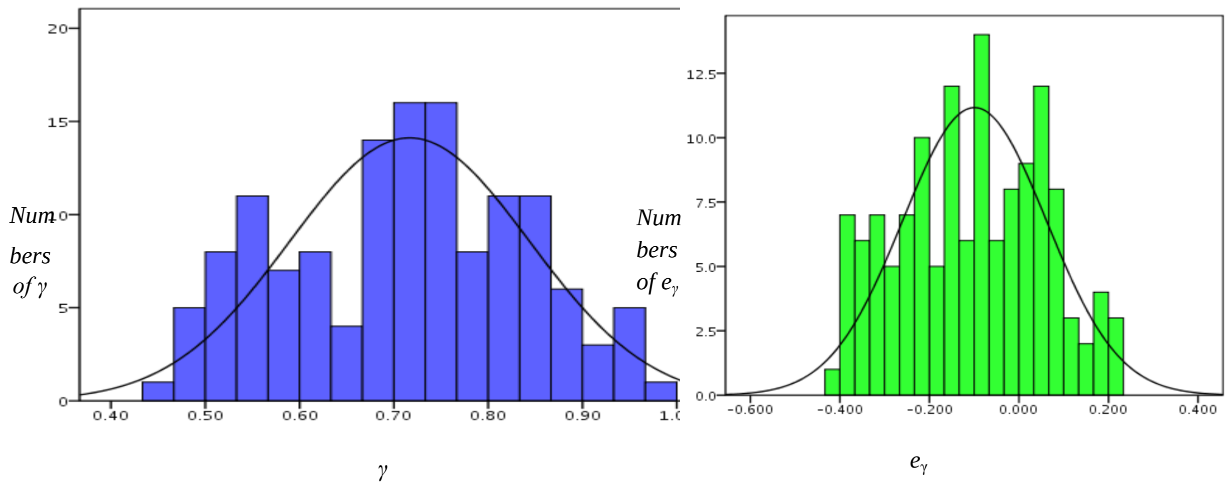


Fig. 1 comparative data of COLTs (y-axis) and OLTs (x-axis)

Fig.1 shows that bearing capacity of piles from two test methods of each comparison group were similar, in other words, data from OLTs is similar or even more conventional than that from COLTs.

From the exist γ criterion in China, the value of γ is 0.8 in clay and silt, and 0.7 in sand, if there are the mixed layers of above soil, the value of γ is the weighted mean depending on the thickness of clay, silt or sand. In order to check the applicability of above criterion, *Q-s* curves from COLT were taken as standards of comparison. The optimal fitting solution of γ were obtained by MATLAB, a typical case of fitting results is shown in table 1 and Fig.2.



(a) (b)

Fig.2the normal distribution of (a) $\gamma$and(b) e_γ from SPSS

Results and Discussion

132 values of γ by curve fitting are obtained, and their statistical analysis results from SPSS are shown in Fig.2and table 1.

From Fig.2 (a) and table 1,the proportion of γ_m smaller than 0.8 is 72.6%, smaller than 0.85 is 84.4%, and the percentage of γ_m between 0.65 and 0.85 is 53.3%.The 95% confidence interval value of γ_m is as following：

$$\gamma_{min} = \gamma_\mu - 1.645\sigma = 0.502$$
$$\gamma_{max} = \gamma_\mu + 1.645\sigma = 0.923 \quad (1)$$

Thus the 95% confidence interval value of γ_m is (0.5, 0.92), and the median is 0.72.

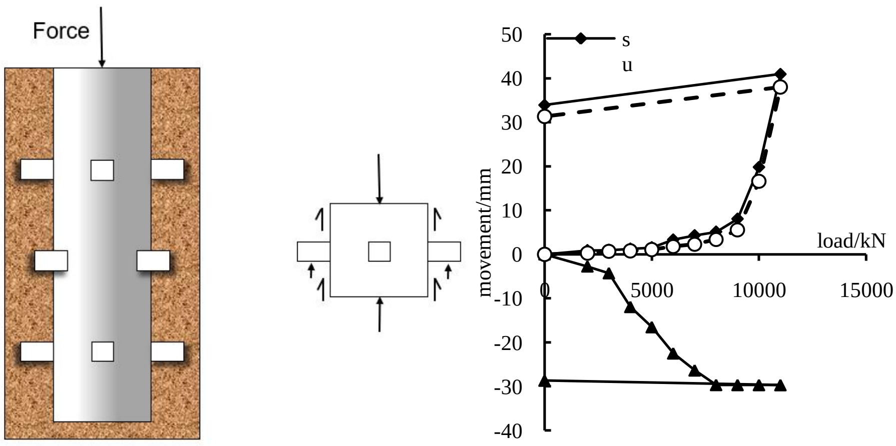
Table1 the normal distribution parameters of γ and e_γ from SPSS

factors	mean value	median	Mode	standard deviation	variance	skewness	Skewness error	Accept normal distribution or not	frequency function
γ	0.713	0.722	0.7	0.128	0.016	0.015	0.209	accept	$fy=\frac{1}{0.128\sqrt{2\pi}}e^{-\frac{(\gamma-0.713)^2}{2*0.128^2}}$
e_γ	-0.108	-0.099	0	0. 160	0.026	-0.007	0.209	accept	$fy=\frac{1}{0.16\sqrt{2\pi}}e^{-\frac{(\gamma+0.108)^2}{2*0.16^2}}$

The value of e_γ reflects the accuracy of γ from exist criterion, when $e_\gamma \le 0$, it means that the γ from exist criterion is larger than real value, which presents that the capacity is more conventional than its real value, when $e_\gamma \ge 0$, the conclusion is opposite. From Fig.2 (b), the proportion of $e_\gamma \le 0$ is 70.4%, the percentage of $e_\gamma \le 11\%$ is 92%, and the 95% confidence interval value of e_γ is (-37%,16%). The results show that the conversion factor γ from exist criterion can successfully satisfy the practical requirements, while the safer range of γ is 0.50 to 0.92.

Case 1 root pile

A cast-in-situ root piles with diameter of 1.6m was tested under self-balanced load test in Chizhou Yangtse River Bridge, China.The pile was belonging to a bridge foundation. The length of pile is 49m.



(a) (b)

Fig.3(a) root pile; (b)load-displacement curves

Case 2:pipe pile in an offshore wind farm

The sea wind power plant near the East Sea Bridge is the first sea wind power plant in China,the self-balanced static loading test is used in preholed foundation. However, in the driven or jacked pipe piles, the load cell cannot be welded on pipe pile at the designed location, especially in open-ended pipe pile. Therefore, a new self-balanced static loading test device is developed for large diameter pipe piles, as shown in Fig. 4. The testing procedure is the same as that of the conventional self-balanced loading test.

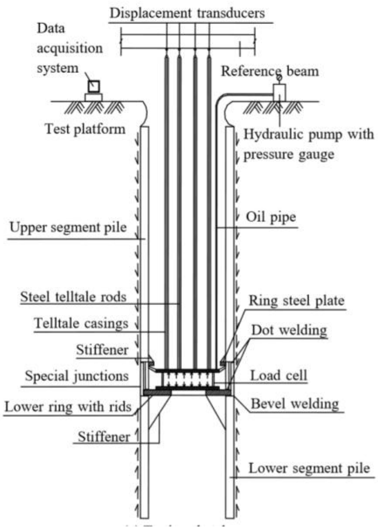


Fig.4 self-balanced static loading test device

Conclusions

the existed code for equivalent load-displacement of pile top can successfully evaluate the vertical load capacity of piles comparing to the results of COLTs and OLTs; The safer range of γ is 0.50 to 0.92.Some cases were introduced to present the usage of self-balanced loading test in deep foundation.

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Development of Offshore Wind Turbine Foundation

Xueliang ZHAO, Weiming GONG, Guoliang DAI

[1]School of Civil Engineering, Southeast University, Nanjing, China 210096

Abstract

The offshore wind turbine, especially the floating offshore wind turbine in the deep sea is a perspective technology in the context of increasing energy demands. Mooring system, as an important unit of the floating offshore wind turbine is emphasized. The methods of in-situ test and the laboratory experimental tests to determine the characteristics and parameters of the sea sediment are reviewed. Some new testing methods such as the full-flow penetrometers are discussed. The most commonly used anchor systems including the suction anchor, the plate anchor, and the dynamically penetrating anchor are discussed. The paper aims to present some future research work that is important for the development of the floating offshore wind turbine technology.

Keywords: offshore wind turbine foundation,sediment characteristics, floating system

Introduction

With the development of the economy, the demand for energy keeps rising. The traditional energy source, thermal power, has severe problems such as the resource exhaust and environmental pollution. The development of clear and renewable energy resource is getting more and more attention from the governments all around the world. In the Global Climate Change Conference in Copenhagen, the Chinese government makes two statements for the contribution to the global climate: the consumption proportion of the non-fossil energy will increase to 15% in year of 2020, and the emission of CO_2 per unit GDP will decrease by 40%-50% comparing with that of 2005. With this background, the wind energy, as a clean and renewable energy, is becoming a focus of the energy development in China as well as in other countries. It is estimated that the emission of the CO_2 for 1 MW/hour could decrease 0.8-0.9 ton from wind power comparing with coal-fired power. Comparing with land wind energy, the offshore energy has more advantages such as high wind speed, stable wind, week wind shear, and little visual and noise pollution. It gets more and more emphasis.

Characteristics of sea sediment

Different sea regions have different soil types. For example, it is usually muddy and soft seabed in the Eastern Sea in China. But it is muddy and silty clay and silty sand of terrigenous clastic deposits in the Southern Sea and Qiongzhou Strait. These different types of soil have different mechanical properties. In geotechnical engineering, the mechanical characteristics as well as the design parameters are usually obtained from laboratory experimental tests. But for the marine soil, since it is usually soft and saturated, it is very difficult, if not impossible, to get undisturbed soil. Because the remoulded soil has significantly different properties with the undisturbed soil, in-situ tests are necessary to get the characteristics and properties of the marine soil. Considering the marine and deep underwater environment, in-situ tests are much more difficult than that on the land. A vessel is usually needed to perform the site investigation and in-situ test. Two approaches, the downhole mode and seabed mode are usually used. The downhole system could be used to perform the in-situ tests. The samples could also be obtained using this system. For the seabed system, the data of the in-situ test are more stable with higher quality since the seabed sediment is less disturbed comparing with the downhole system. The new portable remote operated drill (PROD) system combines the abilities to perform the penetration test and to take samples [3]. The cone penetration test (CPT) and the vane shear test are the two most commonly in-situ tests used.

Although the traditional tests are used widely in the underwater condition, there are some severe problems. For example, the accuracy of the CPT under deep water is a big problem due to the high pore water pressure and the overburden stress. And the strain rate in the vane shear test has significant effect on the test results. Considering the special condition and environment under deep water, a new test method called full-flow penetrometers (T-bar and ball) was proposed and got increasingly applications these years [4] (as illustrated in Fig. 1). It is considered that the shear strength of the soil could be estimated absolutely and directly from the penetrometer test based on the plasticity solutions. The T-bar and ball penetrometers are used to simulate the situations of plane strain and axisymmetric condition respectively. The projected area is about 10 times the coress-sectional area of the shaft, which is thought to be able to minimize the correction due to the overburden stress. In the full-flow penetrometer test, the pull-out resistance is usually measure which is seldom done in the traditional CPT. In addition, cyclic strength of the soil could be measured by cyclic penetration in the full-flow penetrometer tests. Although the full-flow penetrometer tests overcome some shortcoming of the traditional test, there are some problems or uncertainties that need further investigations. For example, the difference between the T-bar and ball penetrometers from the experimental and numerical method has big discrepancy. And the effect of strain rate needs further investigation.

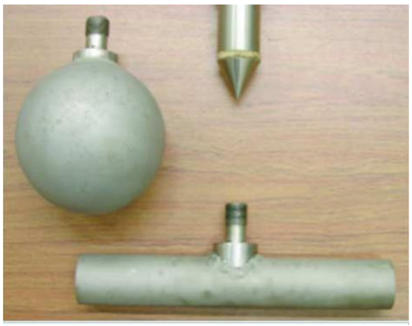

Fig. 1 Photo of T-bar and ball full-flow penetrometers (after DeJong et al. 2013)

In addition to the in-situ tests, laboratory experimental tests are usually performed on the soil sample taking from the site. The classification tests including the density, specific gravity, particle sizedistribution, Atterberg limits, carbonate content, and so on are important to get the soil characteristics. Tests such as mini-vane test and pocket penetrometer are often carried out right after the samples are obtained to get the rudimentary strength of soil in order to minimize the disturbance. Traditional laboratory tests such as unconsolidated undrained compression test (UU) and unconfined compression test (UC) are also usually performed. Cyclic testing on triaxial tests and simple shear tests is important for foundations like suction caisson, and is often carried out consequently [5].

As mentioned, the soil characteristics and mechanical parameters obtained from the in-situ and laboratory tests are the basis for the design of the mooring system. The investigation of the test equipment and method is of importance for the development of offshore wind turbine.

Foundation of the offshore wind turbine

For the offshore wind turbine technology in the deep sea, the foundation is one of the key technologies in view of the economy and safety. On the one hand, cost is one of the biggest bottlenecks that restricted the development of the offshore wind turbine. It is estimated that the cost of foundation is about 20% of the total investment of the wind farm. Investigation of new foundation technology is an important way to cut the cost of the wind farm. On the other hand, as the supporting part of the wind turbine structure, the foundation has direct and significant effect on the safety, reliability, and stability of the wind turbine. Many accidents of the offshore platform, e.g., the platform failure of the Shengli oil platform in 2010, are related to the foundation failure. So it is of significance to investigate the foundation technology of the wind turbine in deep sea.

The foundation types of the offshore wind turbine usually include gravity-based foundation, mono-pile foundation, tripod and jacket foundation, suction caisson foundation, and floating foundation [1]. Most of these types are from concept of the offshore oil and gas platforms. But actually, the foundations for the wind turbine and oil platform have significant difference. From the viewpoint of safety and economy, because it is unmanned operation for wind turbine, the lost and damage is much less than of the oil platform in case of failure. So the economy is one of the most important control indexes. From the viewpoint of load, the load in the horizontal direction is bigger but smaller in the vertical direction for the offshore wind turbine structure, which is quite different from that of the oil platform. So the design of the foundation of the offshore wind turbine is supposed to have big difference with that of the oil platform.

For the wind turbine in shallow sea, the mono-pile and the gravity-based foundations are the two foundation types that used most commonly in the practical project with the technical and economical consideration. These foundation types are good for the region with water depth less than 40 meters. But with the increase of water depth, the costs of these types will increase dramatically. Alternatively, floating foundation becomes a suitable foundation type for the platform in water deeper than 40 m. In the floating foundation, a floating structure is used as the platform for the wind turbine installation, and the platform is anchored in the seabed through a mooring system. The units of the floating structure could be prefabricated onshore. The cost is relatively lower and it is easier for transportation and installation comparing with the traditional fixed foundations. So the floating foundation is more suitable in the deep water from the viewpoint of economy and safety.

Right now, the main types of the floating foundation include the tension leg platform (TLP), Spar foundation, and semi-submersible platform [2]. The main differences of these floating foundations are the floating platform to install the wind turbine. But for any of these foundations, the mooring system is the important part which significantly influences the safety and reliability of the floating platform and consequently affects the safety, reliability and stability of the wind turbine. In China, the study of mooring technology is just in a primary stage. The study of mooring system of floating foundation is of significance for the development of offshore wind turbine from the point of the prospective view.

For the mooring system of floating foundation, the main objects are the sea sediment, the anchor, and their interaction. So the mechanical characteristics and parameters of the marine soil, the design and installation of the anchor, and the bearing capacity and failure mechanics of the mooring system controlled by the interaction between the soil and the anchor, are of interest to many researchers.

Floating offshore wind turbine

After the first offshore wind farm was constructed in Sweden in 1990, the technology of offshore wind power gets rapid development. Till now, more than 20 offshore wind farms have been constructed in China and 9 European countries. Up to the end of 2012, the installed capacity of offshore wind power has reached 5 million kilowatts in Europe and it is planned to reach 40 million kilowatts in 2020 and 150 million kilowatts in 2030.

The offshore wind power resource is abundant in China. The wind resource in the coastal water area only is 3 times that of the onshore. Another significant advantage of the offshore wind power is that the electricity could be transmitted with shorter route to the big cities in the eastern China, which is the relatively developed area and where more energy is demanded. The first experimental wind turbine was installed and run in Liaoning Bay in 2007 in China. And the first commercial offshore wind farm was constructed in 2008 and commenced the service during the Expo 2010 Shanghai. Although the offshore wind started relatively late in China, it develops fast and has gained a lot of experience. According to the "Renewable energy development 12th 5-year plan", the offshore wind turbine capacity is planned to reach 5 million kilowatts in 2015 and 30 million kilowatts in 2020.

Most of the offshore wind turbines running or under construction are in the shallow water less than 40m depth. This is in consideration of the economy and technology. But actually, the deep sea has more potential and advantages than the shallow sea. Firstly, there is more wind energy in the deep sea than in the shallow sea. It is estimated that the wind energies with the depth of 10 m, 30 m, and 60-90 m are 100 million kilowatt, 490 million kilowatt, and 1740 million kilowatt, respectively. That means the wind energy with the depth of 60-90 m is 17.4 and 3.6 times of that of 10 m and 30 m. Secondly, sea function is another limitation of the development of the wind turbine in the shallow sea. For example, the region of the sea area may be limited to the function of military or fishery. This will affect the planning of the offshore wind farm. It is reported that there are four national specially permitted offshore wind turbine projects in Jiangsu province. But none of them is started as planned till now. The main reason is that there are some conflicts for the site selection, cable layout, and the military function, marine transportation, fishery, and so on. But there is no such problem in deep sea. With the consideration of the energy resource and sea function, the deep sea has more potential and is considered to be the future trend for the development of offshore wind turbine.

Anchorage system

Another important unit of the mooring system of floating offshore wind turbine is the anchorage system. Mooring line and anchor are the two components of the anchorage system. For the mooring line, the new materials such as synthetic fiber and polyester line, combined with traditional steel cable and steel chain, are replacing the traditional catenary mooring system [6]. In the traditional catenary mooring system, the loading angle is usually 0° (horizontally). But the loading angle of the new combined mooring system is usually around 30° from the horizon. It changes to taut system or semi-taut system. Since the loading angle has significant effect on the bearing capacity of the anchor system. It is very important to explore the mechanical behaviors of the mooring line and consequently the load transmitted to the anchor.

For the anchorage system, the methods applied widely currently include the suction anchor, the plate anchor, and the dynamically penetrating anchor. Suction caisson is the most commonly used anchorage method in the floating platform. It is considered to be a quite developed and mature product. But there are still some important research works going on. For the installation process, it is known that there are two stages, the self-weight sinking stage and the suction sinking stage. But some problems such as the seepage around the caisson, the effect of the side friction, and the effect of the soil flow during the sinking are still kept unclear. Another hot research topic of the suction caisson is the phenomenon of soil plug. Although a lot of works have been done, the mechanisms of the initiation, development, and formation of the soil plug are still uncertain. Bearing capacity is the second aspect of the suction caisson. Determination of the optimum loading point and loading angle are one of the research topics considering that the uplift bearing capacity is critical for the suction caisson. The bearing mechanics and the bearing capacity of the suction caisson are extensively investigated. But the bearing capacity under cyclic stress is still of interest to many researchers [7].

For the plate anchor, it includes the traditional vertically loaded anchor (VLA) and the suction embedded plate anchor. The principle of the traditional vertically loaded anchor is simple. A problem of this anchor during the installation is the determination of the dragging track and the installation positioning [8]. For the bearing capacity of the vertically loaded anchor, a hot research topic is the stress and bearing characteristics of the anchor plate under the state of six degree of freedom and 3 dimensions. The suction embedded is a new method that combines the advantages of the suction caisson and the traditional loaded anchor. The plate anchor is installed using the suction method by which the position and the penetration depth are certain. And the high vertical bearing capacity of the vertically loaded anchor is utilized. This method is much cheaper than the suction caisson. One problem of the suction embedded plate anchor is the loss of embedment during keying, which has a significant effect on the bearing capacity. This issue has been studied by many researchers [9].

Dynamically penetrating anchor is a new method that developed these years. In this method, the anchor in the torpedo shape is released from a height of 50-100 m from the seabed. The anchor is then embedded in the seabed with the help of the high falling speed. This method is thought to be a much cheaper anchor but with satisfactory capacity comparing with other anchor method. But the embedment of the anchor is a complicated process relating with the fluid dynamics, soil dynamics, collision mechanics, and so on. The issues such as embedment depth and bearing capacity need further investigation [10]. A new dynamically penetrating anchor known as OMNI-Max anchor was development these years [11]. The embedment of this anchor will increase when it is pulled upward. The application of this anchor needs further verification.

Summary and Conclusion

Offshore wind turbine, especially that in the deep sea, is an important direction in the strategy of the energy development in China. Floating foundation is the foundation type that is suitable for the offshore wind turbine in deep sea. As an important unit of the floating foundation, mooring and anchor system have significant effect on the economy, stability, and safety of the offshore wind turbine. For the mooring system, the characteristics and properties of the sea sediment and the anchor, as well as their interaction is the base for the design, installation, and the bearing capacity of the anchor system. The technologies of the site investigation and the laboratory test of the marine soil are reviewed. The popular anchor methods are discussed. The technologies of the deep sea offshore wind turbine, the floating foundation, and the mooring system are all in the primary stage in China. Deep study about these issues will be very meaningful for the energy exploration.

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Bi-directional Load Testing of Deep Foundation in China

Jianmin Zhu[1], Weiming Gong[2] and KaichengYin[3]

Abstract

Bi-directional load testing is widely used in determining the bearing capacity of deep foundations. The principle of bi-directional load testing was reviewed. Different types of loadcells for bored piles, steel pipe piles, PHC pipe piles, diaphragm walls and open caissons were shown. The installation position of the loadcell were concluded. Chinese testing standards issued by the government and some the featured projects were briefly introduced.

Keywords:bi-directional load testing, loadcell, bearing capacity, bored pile, steel pipe pile, PHC pipe pile, diaphragm wall, open caisson

Introduction

In recent years, hundreds of sea-cross bridges, large span bridges over rivers and valleys, high-rise buildings, and offshore wind farms have been built in China. Typical deep foundations, for instance, bored piles, steel pipe piles, PHC pipe piles, diaphragm walls and open caissons, have been widely used in these major projects [1].

The axial bearing capacity of deep foundation is generally very high. Traditional load testing, such as kentledge or anchor pile method, are difficult to carry out. Thus, the bi-directional load testing was developed.

The bi-directional load testing method was first proposed in 1980s by J. Osterberg,it is also called O-cell load testing. In China, the bi-directional load testing was used in practice since 1996, and it was named as self-balanced method. Up to now, the bi-directional load testing has been performed in thousands of projects in China. For the deep foundation tested, the largest bearing capacity is 314 MN, and the largest diameteris 8.0 m [1].

Principle of theBi-directional Load Testing

The principle of the test method is shown in Fig. 1.The loadcell (specially designed jacks) is installed in the pile at a chosen location, which is typically near the bottom of the pile.Then the pile is separated into two parts by the loadcell. Oil pipe and steel telltale rods, which were used to apply load and to measure the displacement, respectively, were led out to the ground surface[1].

The upper and lower portions of the pile are tested against each other. The loadcell works in two directions, upward mainly against shaft friction and self-weight, downward mainly against shaft friction and end resistance. The displacement of the upper and lower portions of the pile are recorded by the computer, and the load applied is controlled by the hydraulic pump. Thus, the two portion pile's *Q-s* curves are obtained.The two *Q-s* curves could be converted to the traditional top-down curve of the whole pile. Then the compressive bearing capacity and the settlement of the whole pile could be determined as traditional top-down testing [1].

Type of Loadcell

The loadcell is the key loading equipment of the bi-directional load testing. Various types of loadcells have been developed for deep foundations. Fig. 2 shows some of the loadcells for bored piles, steel pipe piles, PHC pipe piles, diaphragm walls and open caissons.

[1] PH.D, Nanjing Dongda Bi-directional Pile Test Co., Ltd., Nanjing 210018, China
[2]Professor, School of Civil Engineering, Southeast University, Nanjing211189, China
[3]Chief Engineering, Nanjing Saibao Hydraulic Equipment Co., Ltd.,Nanjing211164, China

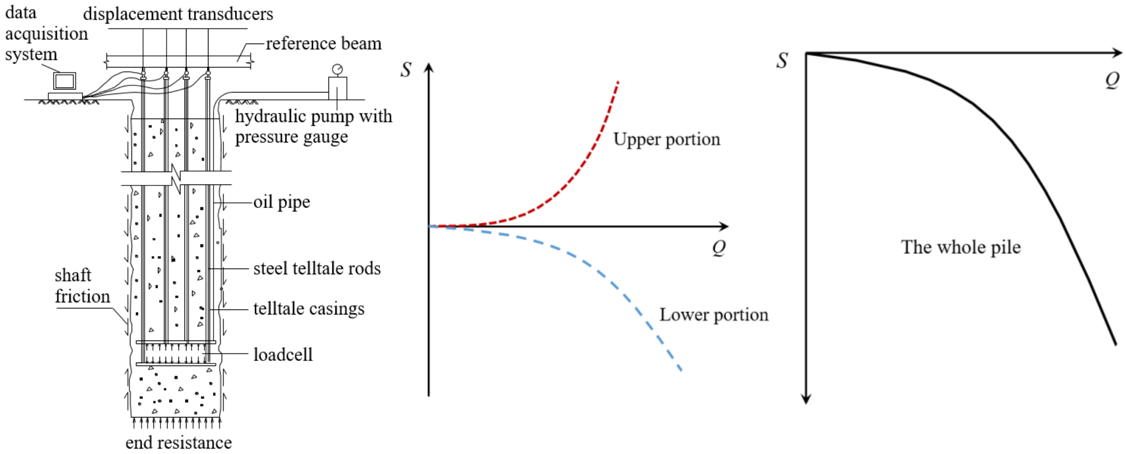


Fig. 1. Principle of bi-directional load testing

a) bored pile-1 b) bored pile-2 c) bored pile-3 d) bored pile-4

e) steel pipe pile b) PHC pipe pile c) diaphragm wall d) open caisson

Fig. 2. Loadcells for different deep foundations

Position Determination of Loadcell

Forsingleloadcell testing, the loadcell could be placed at the position which the bearing capacity of the upper and lower portion pile are approximately the same.

Sometimes, the dual-loadcell testing could be used to precisely determine the ultimate bearing capacity.The pile is divided into the upper, the middle and the lower portions by the loadcells, see Fig.3.

The upper portion pile's bearing capacity Q_u is equal to the shaft friction and the weight of the upper portion, the middle portion pile's bearing capacity Q_m is equal to the shaft friction of the middle portion, and the lower portion pile's bearing capacity Q_l is equal to the shaft friction and the end resistance of the lower portion.The bearing capacity of the three portions shall satisfy:

$Q_u+Q_m>Q_l$ (1)

$Q_u>Q_m$ (2)

$Q_u<Q_m+Q_l$ (3)

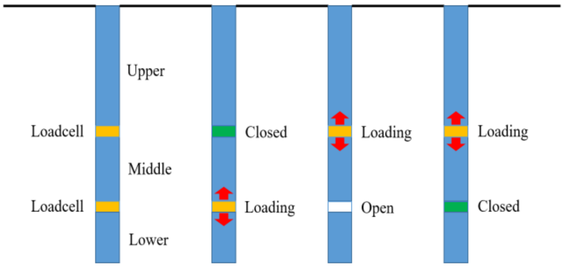


Fig. 3. Dual-loadcell testing

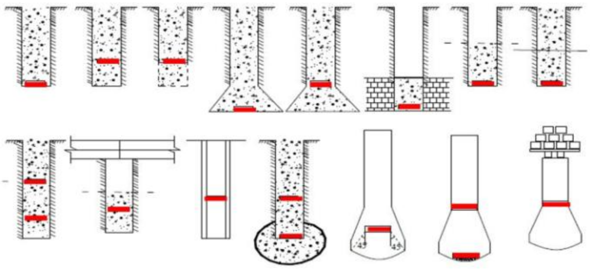


Fig. 4. Position of loadcell

Firstly, loading the lower loadcell, the lower portion's bearing capacity$Q_l$could be tested. Secondly, keeping the lower loadcell open and loading the upper loadcell, the middle portion's bearing capacity$Q_m$could be tested. Finally, keeping the lower loadcell closed and loading the upper loadcell, the upper portion's bearing capacity$Q_u$could be tested.Experienceswere accumulated during the past 20 years. For different testing objectives and different soil/rock layers, the positions of the loadcell were concluded. Fig. 4 shows some of the results [1]

Bi-directional Load TestingStandards

In 1999, the first bi-directional load testing standard was issued in Jangsu, China [2]. In 2009, the second edition was issued [3]. Nowadays, the testing standards for bridge foundations and building foundations have been issuedin 2009 and 2017, respectively [4-5]. The standard for the loadcellwas issued in 2013[6]. Fig. 5 shows some of the standards issued by Ministry of Transport, and Ministry of Housing and Urban-Rural Development, China.

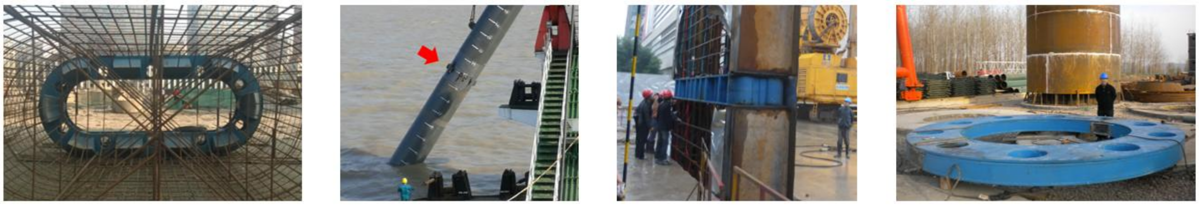
Featured Projects

Thousands of projects had been tested by using the bi-directional load testing method. Deep foundations of many major projects, for instance, over 20 sea-cross bridges (including Hong Kong-Zhuhai-Macao Bridge), over 20 Yangtze River (longest river in China) bridges, tens of high-rise buildings (over 100 m) have been tested. The quantity of projects with bearing capacity over 100 MN has exceeded 30.

Some of the featured projects were shown in Fig. 6.

a) testing standard for bridges b) testing standard for buildings c) standard of loadcell product

Fig. 5.Standards issued by government



a) bored pile b) steel pipe pile c) diaphragm wall d) open caisson

Fig. 6.Featured projects

Fig. 6 a) shows the loadcell for a rounded rectangular bored pile. The tested bearing capacity is 93 MN.

Fig 6 b) shows the loadcell of a steel pipe pile in a sea-cross bridge. The outer diameter is 2.0 m.

Fig. 6 c) shows the steel cage lowering of a diaphragm wall. It is 6.0×1.2 min plane, with the maximum loading capacity of approximately 400 MN. The tested bearing capacity of the diaphragm wall is 314 MN, and it's one of the largest in worldwide.

Fig. 6 d) shows the loadcell of an open caisson. The diameter is 5.0 m.

Conclusions

Bi-directional load testing could be used in various types of foundations. The loadcells for bored piles, steel pipe piles, PHC pipe piles, diaphragm walls and open caissons have been developed successfully. The governmental standards for the testing and the loadcell product have been issued in China. Thousands of projects have been tested by using bi-directional load testingmethod.

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Deep Foundations Subjected to Combined Axial and Torsional Loads

Sagar Mehra[1] and Ashutosh Trivedi[2]

Abstract

Pile foundations are structurally designed to support the weights from the superstructure, wind, sea waves and seismic forces. These loads may intern characterise axial and lateral loads acting on pile foundations. Due to eccentricity of lateral loads, torsional moments are produced. The designers need to check the structures for these increased loads against bearing capacity failures. Three-dimensional numerical model is presented to investigate the response of torque application on axial pile response with soil non-linearity. The interaction between the axial and torsional forces acting on steel pile is investigated. The torque applied at the pile headreduces the ultimate axial pile bearing capacity and increases axial displacement in addition to pile rotation.

Keywords: piles,load deformation response, torque, nonlinear response, numerical studies

Introduction

The design of offshore structures involves consideration of large ratios of lateral to vertical loads, in areas subjected to severe storms. Most pile foundations loaded laterally are likely to undergo torsion due to eccentricity of applied loads. The series of experimentsreported on a single pile and pile groups [1]. The foundation model used for the study of axial and torsional pile response [3]. Current design practice on deep foundations [2] involves separate analysis of the axial and torsional pile responses and does not consider the effect of interaction between the different load directions. The paper investigates the interaction between axial and torsional forces acting on steel pile embedded in soil.

Graphic Descriptor

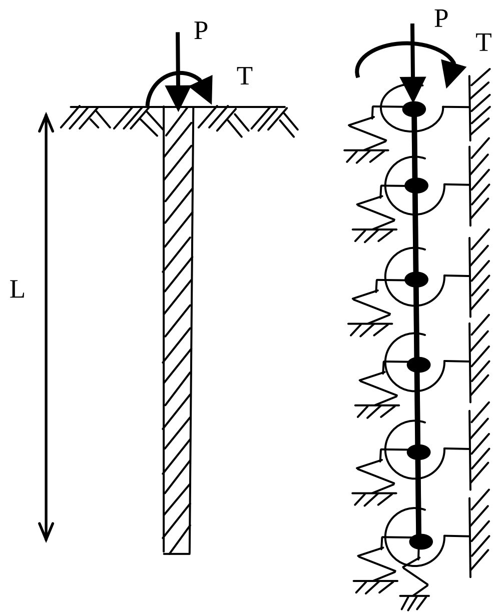

Fig.1. Numerical Pile Model [3]

[1]Research Scholar, Department of Civil Engineering, Delhi Technological University, Delhi 110042, India

[2]Professor, Department of Civil Engineering, Delhi Technological University, Delhi 110042, India

Assuming pile works as a simple beam, the governing fourth and second order differential equations for lateral deflection y and twist angle ϕ of the pile is expressed as

$$E_P I_P \frac{\partial^4 y}{\partial z^4} + k_h \, y = 0 \qquad \text{.... (1)}$$

$$-G_P J\left(\frac{\partial^2 \phi}{\partial z^2}\right) + k_\emptyset \phi = 0 \qquad \text{.... (2)}$$

Analysis and Numerical Descriptor

Three-dimensional plain-strain numerical analysis was carried out to investigatenonlinear behaviour of pile subjected to combined axial and torsional loads. In this the soil continuum Fig.2(b) divided into number of volume elements (C3D10). The boundary conditions Fig.2(a) applied to solve the problem. An elasto-plastic material law with Mohr-Coulomb failure criterionused to describe the behaviour of medium dense sand whereas elastic perfectly plastic model assigned for pile. The model used to compute the response of a typical offshore steel pile. The pile diameter used forinvestigation is 1.6 m and a length of 49 m.

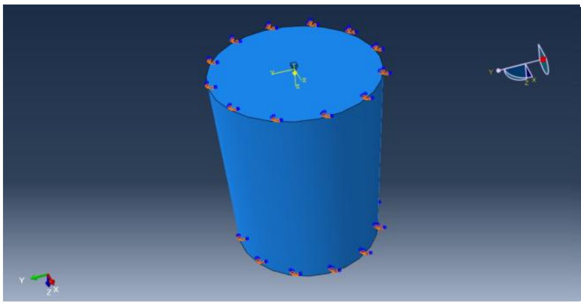

Fig.2. (a) Numerical model with boundary conditions

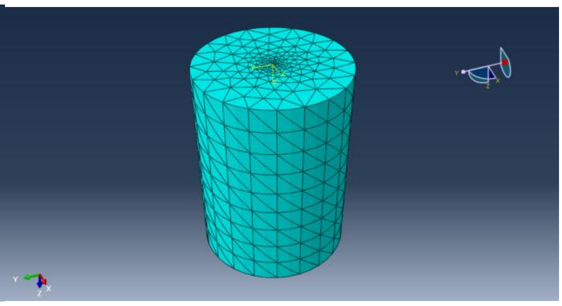

Fig.2. (b) Tet shape (C3D10) mesh

Results and Discussion

The spacial displacement of nodes during combined axial and torsional loads has been shown in Fig.3(a, b).

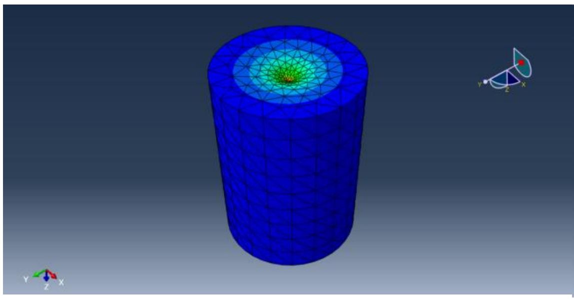

Fig. 3 . (a) Spacial displacement of nodes

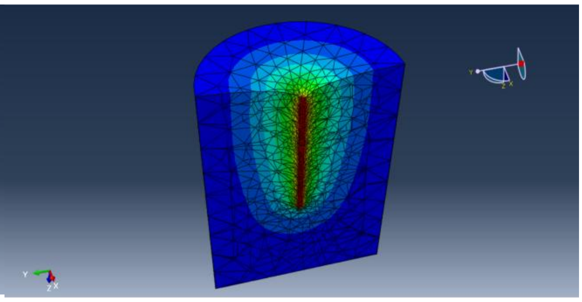

Fig. 3(b) Cut view

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The Application of PZT Patch as Energy Harvester in Dynamically Loaded Retaining Structures

Kumari Nisha[1] and Ashutosh Trivedi[2]

Abstract

The form of energy such as heat, light, wind and vibration can be harvested as electrical energy. This energy is stored and transmitted easily. The smart material namely Lead Zirconate Titanate also known as piezoelectric ceramic (PZT) material has the potential for electromechanical conversion of energy. This paper provides a study of energy harvesting based on mechanical energy due to bounded and embedded vibrations of piezoelectric material. This paper investigate the effect of bounded and embedded PZT patch on energy harvesting due to dynamic loads. Various key aspects that contribute the overall performance of piezoelectric energy harvesting have been analysed with reference to the property of piezoelectric material, stiffness of retaining structure, acceleration and frequency of vibrating structure.

This numerical analysis has been found useful to obtain the efficiency and power density of piezoelectric ceramic (PZT) material in terms of modulus ratio and thickness ratio.

Key words: PZT materials, energy harvesting, retaining structure, modulus ratio, thickness ratio

Graphic Descriptors

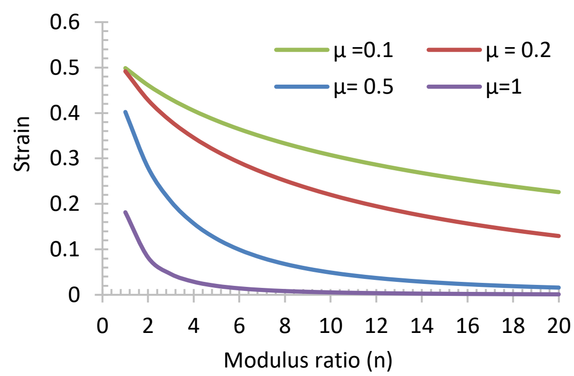

Fig. 1 Variation of average strain in bounded PZT [2]

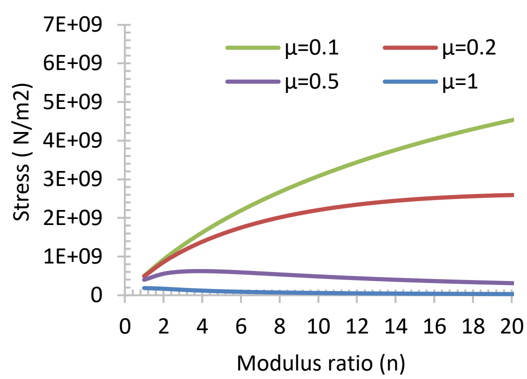

Fig. 2 Variation of average stress in bounded PZT [2]

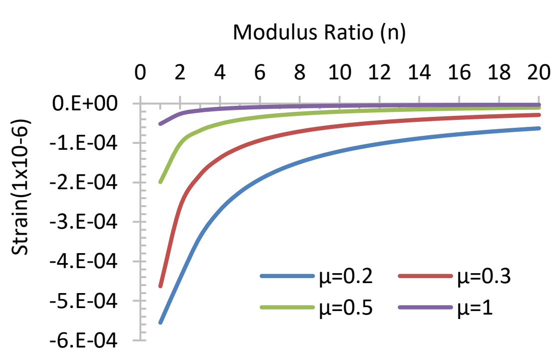

Fig. 3 Variation of average strain in embedded PZT [3]

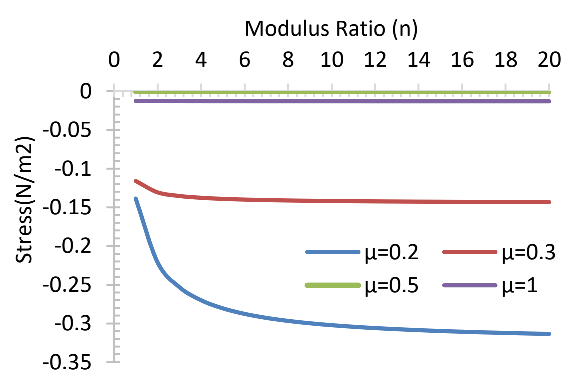

Fig.4 Variation of average stress in embedded PZT [3]

[1] Research Scholar, Department of Civil Engineering, Delhi Technological University, Delhi 110042, India
[2] Professor, Department of Civil Engineering, Delhi Technological University, Delhi 110042, India

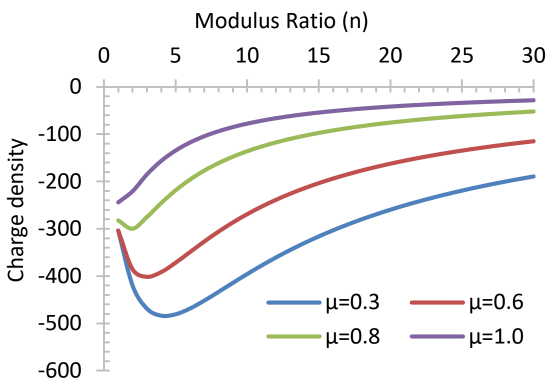

Fig. 5 Charge density for bounded hard PZT

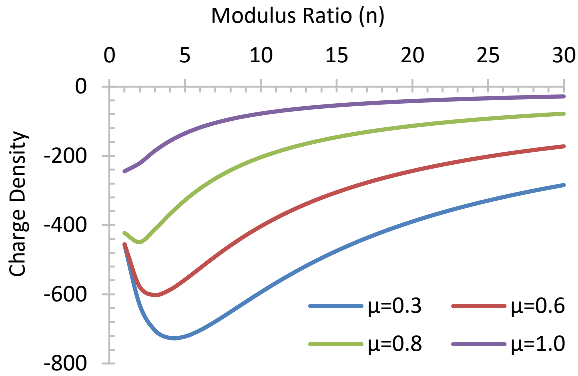

Fig.6 Charge density for bounded soft PZT

Theoretical and Analytical Descriptors

$$\sigma_{PB} = \frac{36nM}{hb_s^2}\left[\frac{(3\mu+2-12a^2b\mu^2n)[24\mu n(a+b)+1]}{[3n\mu^3(1+ba^3)+1][24\mu n(a+b)+1]^2+18(3\mu+2-12a^2b\mu^2n)[2\mu n(1+ab)+1]}\right] \quad \text{-(1)}$$

$$Q_{Top} = \frac{12d_{31}M}{bh_R}\left[\frac{n(1+\mu)(1+\mu n)(3\mu+1)}{3\mu^5n^3+6\mu^4n^2+5\mu^3n+\mu^2n^2+\mu^2+4\mu n+2}\right] \quad \text{-(2)}$$

$$\sigma_{PE} = -\frac{M}{12bh_R^2}\left[\frac{n^2(6\mu^3+4\mu^2)+3\mu^2n+2}{12\mu^5n^4+4n^2(3\mu^4+6\mu^3+14\mu^2)+4n(5\mu^3+9\mu^5+6\mu^4+\mu)-n\mu^3+1}\right] \quad \text{-(3)}$$

Broad Notations

Symbol	Description
M	Bending moment
h_R	Height of retaining wall
b	Width of retaining wall
b_s	Width of backfill
σ_{PE}	Average stress in PZT layer for horizontal dynamic loading
Q_{TOP}	Charge density at top surface of PZT
σ_{PB}	Average stress in PZT layer for vertical dynamic loading
n	Ratio of deformation modulus of PZT patch and retaining material (modulus ratio)
μ	Thickness ratio of PZT patch and retaining material

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Application of Testing and Technology for the Capacity Building of Deep Foundation and Retaining Structures

Ashutosh Trivedi[1] and Sanjay Kumar Shukla[2]

Abstract

The testing and technologies for the deep foundations and retaining structures present a complex problem to the engineers because of associated applications that need the knowledge of engineering behaviour ofthe foundations, the retaining structures and the geomaterials. Such applications are governed by several factors, including the nature of loading, properties of geomaterial, structural geometry of interfaces, and placement and nature of components involved in the system. The nature and magnitude of loads transferred from the superstructure influence the selection of foundation and retaining structures to resist the imposed loads. Although the deep foundation found popular application among the castles and temples of ancient India and China [1], the load application imposes serious problems during the testing procedures which are often simplified as used by development of automatic control systemfor post-grouting construction and their application [2], in evaluation of bearing capacity using the self-balanced loading test [3], development of offshore wind turbine foundation [4] and in bi-directional load testing of deep foundation [5]. The new application of testing and technologies for the deep foundations and retaining structuresfor power generation is associated with the development of offshore wind turbine foundation [4] which are often popular in the coastal areas/countries.The nature and magnitude of loads transferred from the superstructure to the deep foundations as in the case of offshore wind turbine foundation [4] induce combined axial and torsional loads [6] necessitating analysis and design of deep foundations and retaining structures subjected to combined axial and torsional loads [6]. Further new application of testing and technologies for the deep foundations and retaining structuresfor power generation is associated with the development of the application of PZT patch as energy harvester in dynamically loaded retaining structures [7].The numerical studies entail a mechanism of application of Q-z, p-y, Q-t, p-e-y, and Q-e-z to the deep foundations and the retaining structures; secondly, to find out the spring constants, damping ratios, and mass ratio of the system for dynamic design. The mass ratio andfrequency ratioprovide the basis of interactions for analysing the energy generations [6, 7] in the structures subjected to Q-z, p-y, Q-t, p-e-y, and Q-e-z effects.

Keywords: Testing, technology, automatic control system, self-balanced test, bi-directional testing, offshore wind turbine foundation,combined axial and torsional loads, energy harvesting, retaining structures,numerical studies.

Contextual Descriptors

Tall structures, namelytall buildings, offshore platforms, bridge bents and electric transmission towers, and energy harvesters are subjected to significant vertical, lateral, torsional, and dynamic loads of considerable magnitude due to wind and wave actions, ship impacts, or high-speed vehicles [4]. Significant dynamic forces have been transferred to the foundation of towers due to the vertically and laterally loaded high tension wires [4]. The testing procedures are simplified as used by development of Gong Cell control system [2]. The evaluation of bearing capacity using the self-balanced loading test [3], bi-directional load testing of deep foundation [4], and development of offshore wind turbine foundation [5] are the examples of large-scale experimental control exercised by strict implementation. The new application for the deep foundations and retaining structuresfor power generation, associated with the development of offshore wind turbine foundation [5], are often popular in the coastal countries.The nature and magnitude of dynamic loads transferred from the superstructure to the deep foundations as in the case of offshore wind turbine foundation [5] induce combined axial and torsional loads [6] necessitating analysis and design of deep foundations and retaining structures subjected to combined axial and torsional loads [6]. A new application for power generation is associated with the development of the application of PZT patch as energy harvester in dynamically loaded retaining structures [7]. It entails a mechanism of application of Q-z, p-y, Q-t, p-e-y, and Q-e-z to the foundations and structures; secondly, to find out the modulus ratio, damping ratio, and mass ratio of the system for dynamic design. The mass ratio andfrequency ratioprovide the basis of interactions to evaluate energy generations using electronic

[1]Department of Civil Engineering, Delhi Technological University, Delhi, India
[2] School of Engineering, Edith CowanUniversity, Perth, Australia

patches [7] in the structures subjected to Q-z, p-y, Q-t, p-e-y, and Q-e-z effects.The early developments indicate that the block foundations show greater resistance to applied torque than the single pile. The resistance of a single pile and pile groups to the application of p-e-y, and Q-e-z is significant compared to their application in dense sand than in the loose sand. The experimental tests also reveal that the single pile and the centre pile in pile group show similar type of rotational behaviour [8].

Graphic Descriptors

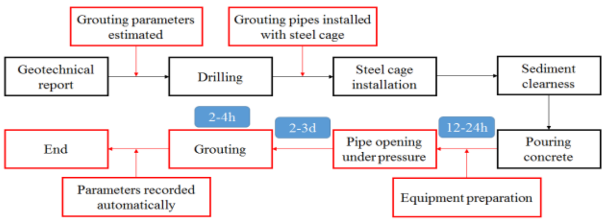

Fig. 3. Control system for grouting line and layout [2]

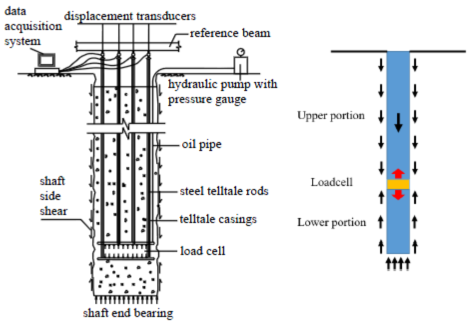

Fig.2 Self-balanced loading device [3]

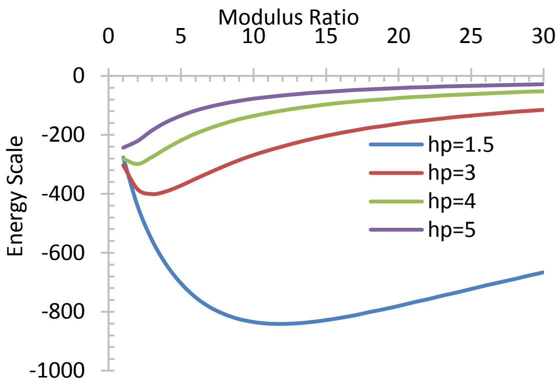

Fig. 3 Mod ratio vs energy output in hard PZT [7]

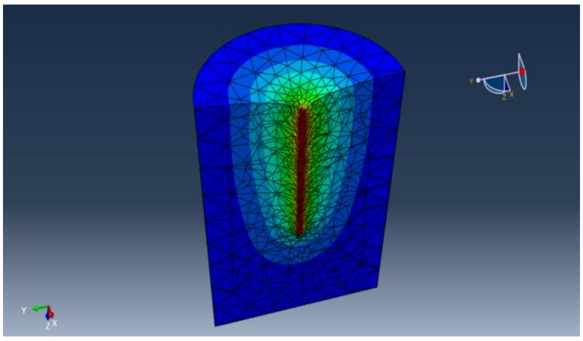

Fig.4 Displacement due to axial and torsional loads[6]

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Author Index

The papers presented in this e-book may be cited as,

Ashutosh Trivedi, Sadanand Ojha, Rajiv Goel, Naresh Kumar, Sagar Mehra (2019) Historical Developments and Application of Deep Foundations in India in Testing and Technology for Load Carrying Capacity of Deep Foundations (Ed. A. Trivedi and S.K. Shukla) ISBN 978-93-5391-519-3, 1-2.

Weiming Gong, Guoliang Dai, Jianmin Zhu (2019) Development of Automatic Control System for Post-grouting Construction and Its Application in Testing and Technology for Load Carrying Capacity of Deep Foundations (Ed. A. Trivedi and S.K. Shukla) ISBN 978-93-5391-519-3, 3-6.

Guoliang Dai, Li Xiaojuan (2019) The Statistical Study on Bearing Capacity of the Self-Balanced Loading Test in Testing and Technology for Load Carrying Capacity of Deep Foundations (Ed. A. Trivedi and S.K. Shukla), ISBN 978-93-5391-519-3. 7-10.

Xueliang Zhao, Weiming Gong, Guoliang Dai (2019) Development of Offshore Wind Turbine Foundation in Testing and Technology for Load Carrying Capacity of Deep Foundations (Ed. A. Trivedi and S.K. Shukla) ISBN 978-93-5391-519-3, 11-14.

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Sagar Mehra, Ashutosh Trivedi (2019) Deep Foundations Subjected to Combined Axial and Torsional Loads in Testing and Technology for Load Carrying Capacity of Deep Foundations (Ed. A. Trivedi and S.K. Shukla) ISBN 978-93-5391-519-3, 19-20.

Kumari Nisha, Ashutosh Trivedi (2019) The Application of PZT Patch as Energy Harvester in Dynamically Loaded Retaining Structures in Testing and Technology for Load Carrying Capacity of Deep Foundations (Ed. A. Trivedi and S.K. Shukla) ISBN 978-93-5391-519-3, 21-22.

Ashutosh Trivedi, Sanjay Kumar Shukla (2019) Application of Testing and Technology for the Capacity Building of Deep Foundation and Retaining Structures in Testing and Technology for Load Carrying Capacity of Deep Foundations (Ed. A. Trivedi and S.K. Shukla) ISBN 978-93-5391-519-3, 23-24.

Delhi Technological University, Delhi 110042

ISBN 978-93-5391-519-3

Cover : Ms. Nisha