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National Center for Research on Earthquake Engineering

Words from Director General:

Continuing to Promote Services, Striving for Innovative Research and Development

Shyh-Jiann Hwang, Director-General, NCREE

Founded in 1990, the National Center for Research on Earthquake Engineering has established a good reputation, both at home and abroad, through years of hard work and has made outstanding service contributions. I took over the post of Director General of the center in February this year. The first priority is to maintain the reputation of the center while continuing to promote its service capacity. The next priority is to devise new ideas to scale further peaks in research; the first strike will be to promote research and development work near the faults.

The island of Taiwan is full of active faults. There are a total of 33 fault lines associated with the Type-I active fault. A total of 8.6 million people live within the range of 10 kilometers of the faults, accounting for about 1/3 of Taiwan's population. Their lives and properties are both affected by the near-fault effect. The surface vibration near the faults has the characteristics of huge displacement with high velocity. It has a particularly destructive effect on structures. Under the efforts of former director, Professor Kuo-Chun Chang, the Tainan Laboratory of our center has been set up at the Kuei-Jen Campus of National Cheng Kung University and officially opened for operation on August this year. The Tainan laboratory possesses a long-stroke high-speed shaking table and biaxial testing system, which are important equipment for studying near-fault effects. We should make the best use of this sharp tool to solve the serious earthquake threat in Taiwan.



Director-General Shyh-Jiann Hwang

Experiments and parsing have always been the right and left hands of civil engineering research. Some projects require experimental means and some are suitable for analytical solving. However, combining experiments with analytical calculations is an even stronger and more powerful research tool. The center should promote hybrid-type experimental research to discover an entirely new research and development methodology for earthquake engineering. On this important subject matter, I am very pleased to invite Professor Keh-Chyuan Tsai, a former director, to organize an integrated research group and lead the domestic academic community to contribute together with my colleagues.

During the opening ceremony of Tainan Laboratory in August this year, we were fortunate to invite experts and scholars from earthquake engineering both at home and abroad to come together. We all expressed affirmative attitude on the existing achievements of the center and also very much looked forward to the future research of the center. The participating experts and scholars conferred earnestly and made many suggestions. There are many problems to be solved in the future, but it is important to focus on continuous efforts. The center has full-time staff and regular budgets. It is incumbent that we should shoulder these missions.



Tainan Laboratory houses long-stroke high-speed shaking table and biaxial testing system

Simplified Procedure to Simulate the Interaction between Low-rise Building and Liquefiable Soil

Chih-Chieh Lu, Associate Researcher, NCREE

Introduction

On February 6, 2016, a local magnitude (M_L) 6.6 earthquake struck southern Taiwan, contributing to devastation in the Tainan area. Based on the field investigations conducted by a survey team from the National Center for Earthquake Engineering (NCREE), serious soil liquefaction appeared in Huian St and Sanmin St. Figure 1 shows the damage of a three-story building in Huian St. due to the Meinong earthquake. In addition to the recent Meinong earthquake, there have been many catastrophic earthquakes in history that have caused soil liquefaction, resulting in serious loss of life and property, such as the 1964 Niigata earthquake and the 1995 Kobe earthquake in Japan, and the 1999 Chi-Chi earthquake in central Taiwan (Hwang et al., 2003). Because soil liquefaction degrades the strength of the soil, the structure right above the liquefied soil will tilt and settle due to the insufficient bearing capacity of the liquefied foundation soil. Because the demolition and reconstruction of the existing old buildings in the urban area are difficult, reinforcement and assessment of existing buildings in potential areas of soil liquefaction become an important issue in the engineering field. The Ministry of the Interior of Taiwan has also been actively promoting various projects to enhance the safety performance of old buildings located in soil liquefaction potential areas.



Fig. 1. Damages to a three-story building at Lane 161, Huian Street (Annan District)

Concept of the Research

Simulation of the highly nonlinear interaction between the liquefied soil and the surface structure is difficult to achieve since the mechanical behavior of the liquefiable soil would dramatically change when excess pore water pressure is generated during seismic shaking. In practice, the so-called parameter reduction approach is preferred. By reducing the soil parameters to a certain level, the mechanical behavior of the liquefiable soil could be approximately captured. Hence, using this method, the modeling of the interaction between the liquefiable soil and the structure becomes easier and gives rational results. The key issue of the approach is to suggest a suitable parameter reduction of liquefiable soil under different liquefaction conditions to the corresponding modeling tools such as the spring model or the finite element method/finite difference method (FEM/FDM). With regard to the spring model, some Japanese codes have provided their recommendations for designers to follow, whereas the parameter reduction suggestion for FEM/FDM, which is a more powerful soil-structure interaction (SSI) simulation method, is still lacking. Therefore, this two-year project focuses on establishing a parameter reduction factor for FDM; the first year will establish a simplified procedure for FDM to model the interaction between the liquefiable soil and structure. For this purpose, first, liquefaction case history databases will be collected from the 1999 Chi-Chi earthquake and 2016 Meinong earthquake. Using these databases, standardized soil profiles for each studied area would be built. The critical liquefiable layers of the standardized soil profiles would be identified by the evaluation of local Hyperbolic Function (HBF), and the settlement of the structure due to soil liquefaction will then be analyzed by FDM using the parameter reduction approach. The parameters of the critical liquefiable soil will be reduced until the calculation results are comparable to the observed settlement of the structure, as shown in Figure 2.

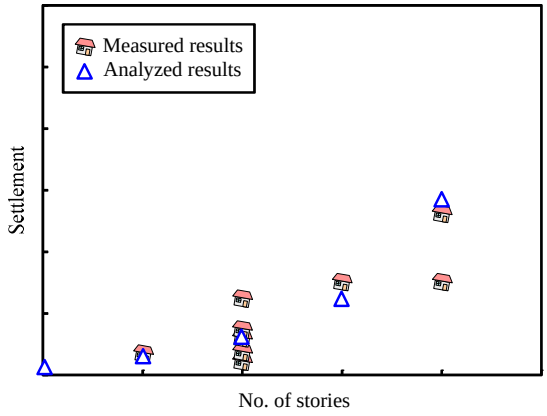


Fig. 2. Comparison of the analyzed and measured settlements

Conclusion

The FEM/FDM is relatively reasonable for simulating the SSI compared with the spring model. With a suitable parameter reduction, the interaction between a low-rise building and the liquefied soil can be simulated with more effectiveness. Therefore, this study aims to establish an assessment procedure using FDM for the seismic performance of a low-rise building located on the surface of liquefiable soil. The results of this project, which is currently in progress, will be integrated and a suggestion for the parameter reduction of the liquefiable soil will be summarized. In addition, the results are expected to be useful to assess the rationality of the proposed soil reduction factor in the soil liquefaction code and serve as a reference for future amendment.

Pore Pressure Buildup Model and Liquefaction Evaluation Method in Marine Sediments

Wen-Chien Tseng, Project Assistant Researcher, NCREE

Introduction

With the rise in the global environmental awareness, the development of renewable energy has become a major trend in energy development today. Therefore, green energy is important and imperative in power supply, such as offshore wind power. However, offshore wind turbines are installed on seabed, their foundation is subjected to lateral force mainly due to wind, waves, and currents.

The geology of the western marine area of Taiwan is found to be loose and composed of weak sediment layers and reclaimed land. When typhoon waves strike, a dynamic wave pressure is transmitted downward to the weak overburden layers from the seabed surface, which can cause liquefaction, leading to disasters in the marine engineering field. In addition to the direct wave loading on the offshore structures, their failure can also be caused by cyclic wave loading at the seabed beneath the base of the structure and by earthquake loading; in both cases, the resulting excess pore pressure induces instability of the seabed and causes liquefaction as shown in Fig. 1.

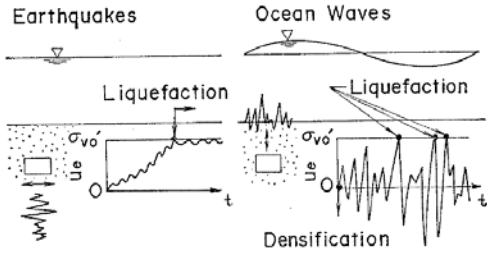


Fig. 1. Characteristics of wave-induced and earthquake-induced excess pore pressures (Zen, 1990)

Pore Pressure Buildup and Liquefaction Assessment Method in Seabed

Wave-induced liquefaction phenomenon in marine sediments is the most unstable failure type, which leads to the vertical displacement of sediments. Some scholars proposed wave-induced liquefaction assessment methods in the 1980s, including Nataraja & Gill (1983), Ishihara & Yamazaki (1984), and Chen & Yang (1996).

Poulos (1988) indicated the main reason for the instability of the seabed is wave-induced excess pore-pressure buildup. Recently, Chang (2004), Jeng (2007), Huang et al. (2012), and Chien et al. (2014) proposed the criteria for pore-pressure buildup in the case of the wave-induced seabed response integrated into an assessment method. The characteristics of all these methods are described as following:

(1) Nataraja and Gill method: Based on the assessment of earthquakes, a simplified analysis is proposed to assess wave-induced liquefaction by using the SPT-N value.

(2) Ishihara and Yamazaki method: Assessment of the soil liquefaction resistance and liquefaction potential at various water depths is performed on the basis of the relative density of sand.

(3) Chen and Yang method: The liquefaction thickness of the seabed is obtained, and the distribution of wave-induced stress and soil strength with respect to the seabed depth are estimated.

(4) Chang method: The relationship between number of cycles and liquefaction resistance strength of sandy seabed is established using a CKC triaxial testing system, considering the time factor integrated into an evaluation procedure.

(5) Jeng method: A new approximation is proposed for the prediction of the maximum liquefaction depth. Numerical results indicate that the residual mechanism is particularly important for large wave loading.

(6) Huang et al. method: Considering the criteria of liquefaction induced by both oscillatory and residual pore pressures, the analytical solution of the maximum depth of porous sandy seabed under wave loading is derived.

(7) Chien et al. method: A pore-pressure buildup model is established by using their test results, and the model is integrated into a simple evaluation methodology to perform liquefaction analysis under wave loading.

Field Investigation in Seabed

At present, the most commonly used field tests for assessing liquefaction potential in engineering are the SPT-N and CPT-qc methods. In the alluvial deposit and reclaimed land of the coastal and harbor areas, liquefaction potential assessment based on the CPT-qc value is more suitable and reliable. The SPT-N method can obtain immense information and access to more accurate soil classification and soil physical properties.

The offshore wind-power industry majorly uses the CPT-qc as a designated parameter estimation method mainly because this method has the advantage of including a continuous record of soil layer variation. In addition, the human factors can be ignored due to test of high repeatability and the method is therefore more accurate and scientific compared with SPT. However, if SPT is conducted with drilling operations in loose sandy seabed, the reliability of soil parameters is lower as the seabed is susceptible to wave loading.

Summary

The different development backgrounds of the various methods proposed for assessing pore-pressure buildup and liquefaction in seabed result in the differences in the parameters used, the analytical procedures, and their limitations. These differences often lead to obtaining varying assessment results. This study will discuss and analyze the advantages of the various methods and field tests as well as their limitations in order to determine a suitable seabed liquefaction assessment method that can be applied to the offshore marine environment.

Validation of the Random Vibration Theory-Based Seismic Ground Response Analysis Using STRATA Program

Shang-Yi Hsu, Yu-Wei Hwang, Chia-Hung Liu, Ya-Han Hsu, NCREE

Introduction

Following the accident at the Fukushima Daiichi nuclear power plant, an updated seismic hazard analysis was required to be conducted for all operating nuclear power plants in the United States (USNPPs). According to the Seismic Hazard and Screening Report of USNPPs, the seismic ground response analysis based on the random vibration theory (RVT) has been proverbially used for site effect assessment in seismic reevaluation of NPPs.

In this study, the STRATA program was used to conduct the seismic ground response analysis of the target site condition. Furthermore, the results from a traditional approach (e.g., SHAKE) using 30 spectrum-compatible input motions and those obtained from the RVT-based method were compared.

Numerical Example

(1) Site profile and target spectrum of bedrock

A 55.6-m-deep soil profile consisting of gravel, weathered rock, and intact rock layers overlaying half-space was analyzed in this study. The bedrock of this site was at a depth of 55.6 m. The site condition and shear wave velocity profile are shown in Fig. 1. Here, the outcrop of the bedrock was the input motion location of the target spectrum, indicated by the red line in Fig. 2.

Depth (m)	Thickness (m)	Soil Type	Vs (m/s)	Unit weight (kN/m^3)
0	2.8	gravel	300	21
2.8	5.5	weathered rock	500	24
8.3	17.4	intact rock 1	700	25
25.7	7.6	intact rock 1	700	25
33.3	22.3	intact rock 2	1000	25
55.6	Half-Space	bedrock	1200	25

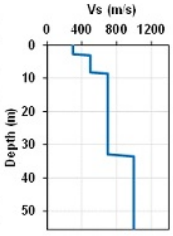


Fig. 1. Soil profile

(2) Artificial earthquakes as input

For the comparison of the traditional and RVT-based methods of seismic ground response analysis, 30 artificial time histories, compatible with the target spectrum, were generated as input motions for the case study. The approaches used for achieving spectrum compatibility in this study are as follows:

a. Ten artificial events using the real earthquake records near the target site as the seed and retaining the phase angles of the records;

b. Ten artificial events using the real earthquake records near the epicenter as the seed and retaining the phase angles of the records;

c. Ten artificial events with random phase angles simulated using the SIMQKE program.

The input spectra of all 30 artificial spectrum-compatible events (ArtiEQ events) and the target spectrum obtained using traditional method and RVT-based method, respectively, are shown in Fig. 2.

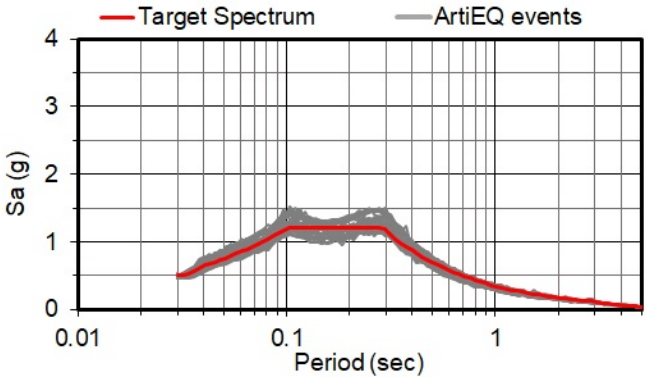


Fig. 2. Input spectra at the outcrop bedrock

Analysis Results and Comparison

Fig. 3 compares the 5% damped acceleration response spectra at the ground surface. As the result shown, the spectral acceleration (Sa) value developed by RVT method are in good agreement with the average result from the tranditional analysis.

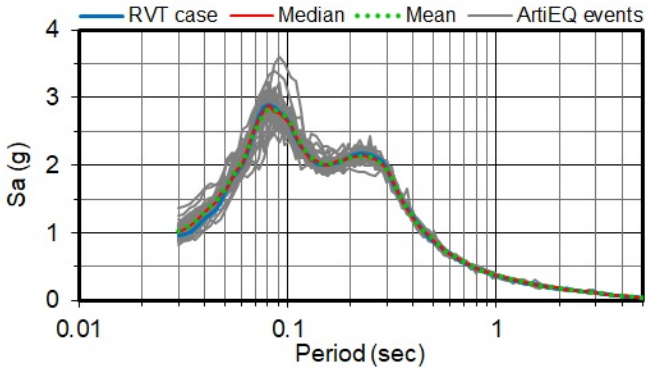


Fig. 3. Comparison of 5% damped acceleration response spectra at the ground surface

Summary

In this study, two approaches for seismic ground response analysis were compared and validated. Using the RVT-based method, the input motion was characterized by the target response spectrum directly, and all responses (e.g., shear strain of layers, acceleration profile, and response spectra) were calculated as statistical averages. Therefore, this approach does not face the difficulties, such as with the simulation methodology and the selection of the representative earthquake seeds, which are associated with generating spectrum-matching time histories and the variability of analysis results caused by the artificial input motions. Hence, the RVT-based seismic ground response analysis is suitable for application in the seismic design and seismic hazard reevaluation for NPPs.

Introduction to the new Laminar Shear Box

Chia-Han Chen, Assistant Researcher, NCREE
Jin-Hung Hwang, Head of Geotechnical Division, NCREE

Introduction

Physical model tests are used for understanding the failure mechanism and verifying the analytical and design methods used in geotechnical earthquake engineering, such as analyses of ground response, soil liquefaction-related problems, and seismic soil–structure interaction. For the physical model test method, a soil container is required for simulating soil in a level ground of an infinite extent. In 1999, Prof. Tzou-Shin Ueng proposed a mechanism for the two-dimensional shear box at the National Center for Research on Earthquake Engineering (NCREE). The final design and manufacturing of the shear box were performed in cooperation with the Mechanical Industry Research Laboratories at the Industrial Technology Research Institute (ITRI), Hsinchu, Taiwan. In 2011, the NCREE constructed the second laminar shear box for the research on a bridge subjected to multiple disasters.

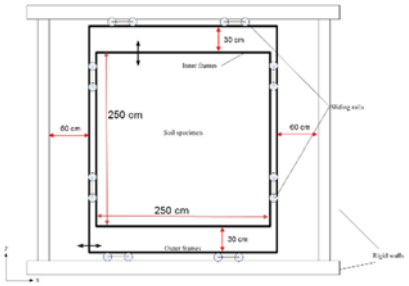
In recent years, the Taiwanese government has been vigorously promoting the development of green energy. Taiwan is located in a subtropical zone with rich wind resources beneficial to develop offshore wind power. However, because Taiwan is frequently affected by multiple natural disasters such as typhoons and earthquakes, the developed guidelines for design and certification of offshore wind turbines for the areas in Europe or the US may not be applicable directly to Taiwan wind farms. Therefore, it is necessary to establish a test platform for the study of multiple disasters on offshore wind turbines, including the site-specific seismic response, soil liquefaction, and seismic soil–foundation interaction problems. In view of this, the NCREE plans to develop a new flexible boundary shear box with functions that facilitate not only research and testing of offshore wind turbines but also multi-purpose applications such as determination of near-fault effects on ground motion, bridges, structures, etc. After the preliminary planning, experts and scholars have been invited to the consultation meetings to build consensus. At present, the new laminar shear box is in the detailed design and production stages. This paper introduces the conception and specifications of this shear box.

Conception of the Shear Box

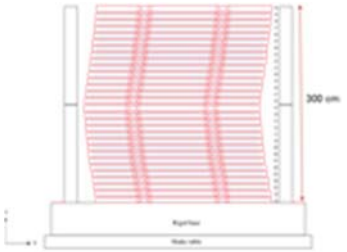
To perfectly satisfy the soil behavior in a level ground of an infinite extent in response to an earthquake, the container must meet the following guidelines: (1) the cross-section of the container must be maintained in a fixed plane and must not be laterally expanded during the test; (2) during the test, the container's shear stress on the vertical plane and the horizontal plane must be equal, so that the stress condition of the soil element is pure shear; (3) the container should be massless; (4) the soil should be able to move freely at different depths; and (5) the water tightness of the container must be maintained. However, the above guidelines cannot be completely achieved in reality, so the actual application still needs to be compromised. Ueng et al. (2000) proposed a unique mechanism for the biaxial laminar shear test box without torsion; for the new shear box, the same mechanism has been adapted, leading to the enlargement of the specimen dimension, especially the height, to meet future research needs.

Configuration

Figure 1 shows a schematic of the new laminar shear box. The size of the specimen is 2500 mm × 2500 mm × 3000 mm. The shear box is composed of 30 layers of frames. Each layer consists of an inner and an outer frame and is made of a special aluminum alloy owing to its sufficient strength, rigidity, and lightweight nature, which allows the inertial effect of the frame on the soil movements to be minimized.



(a) Plan view



(b) Side view

Fig. 1. Schematic drawing of the laminar shear box

As indicated in Figure 1, there are sliding rails at various depths on the two opposite sides of the outer steel walls in order to provide a friction-free movement of the outer frames in the X-direction. Similarly, sliding rails are also provided on every layer of the outer frame such that every layer of the inner frame can move in the Y-direction relative to the outer frame. With these 30 layers of inner and outer frames, the soil at various depths can move freely in the horizontal plane according to the wave actions induced by the shaking of the table. Considering that near-fault earthquakes may cause larger permanent deformation, the maximum displacements in the X- and Y-directions are ±600 mm and ±300 mm, respectively.

Design and Pre-Testing of a Scaled Model of an Embankment Dam on a Shaking Table

Hsuan-Chih Yang, Associate Researcher, NCREE

Introduction

Taiwan is geologically young and it is therefore necessary to build reservoirs as a measure for water storage to maintain the livelihood needs. Various types of reservoirs such as embankment dams, gravity dams, and arch dams have different functions and are made of different materials. Each of them has its advantages and applicability. Embankment dams are built of materials that are found adequately near the dam site, and the requirements for site conditions are relatively less stringent than those of other types of dams. Therefore, the embankment dam is the most popular reservoir design in Taiwan. However, the severe damage of the dam may cause socio-economic loss and reduction in the dam's lifespan. Based on the past earthquake damage records, the embankment dam is found to be susceptible to damage due to earthquakes. The Fujishima dam located in Suagawa, Fukushima, Japan, suffered a dike break during the Great East Japan Earthquake in 2011 (Fig. 1).



Fig. 1 Damage of the main dam of the Fujishima dam (GEER, 2011)

Design and Production of Scale Embankment Dam

In the Liyutan reservoir located in Sanyi, Miaoli, acceleration sensors have been embedded during its construction. Hence, this dam has the most complete records of the dam behavior during earthquakes in Taiwan. The dam has suffered damage during the 921 Chi-Chi earthquake. Therefore, this study chose the Liyutan reservoir as the object of the scaled model test.

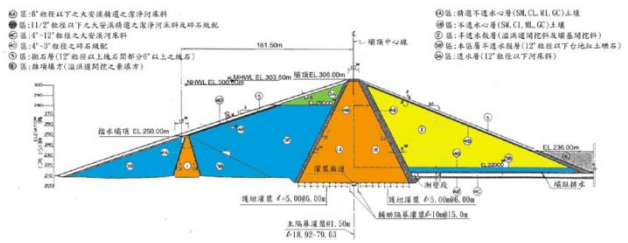


Fig. 2 Section of the Liyutan reservoir (WRA website)

The Liyutan reservoir is a central core roller embankment dam with a height of 96 m and length of 235 m. The upstream and downstream grade ratios are 1:3 and 1:2.5, respectively. The design section of the dam is shown in Fig. 2. The scaled model was cast in a fixed sand box of inner dimensions 4.4 m × 1.3 m × 1.1 m. The dimension of the 1/160-scaled model was 3.36 m × 1.3 m × 0.6 m. In this study, only the core and the shell layers of the dam were cast, which were made of red clay and filled with quartz sand from Vietnam, respectively.

The scaled dam model was constructed based on the stratified rolling method requirements of the dam to achieve a relative density of more than 98%. The general physical and dynamic properties of soil materials were tested for numerical simulation. Fig. 3 shows the scaled dam model on a shaking table.



Fig. 3. The scaled model of the Liyutan reservoir

Test Process Planning

Since the mode and the seismic behavior of the scaled dam model will be different from the original dam, the modal frequency of the scaled dam model will be analyzed before the test. Multiple earthquakes with different distances and depths from the dam will be selected for the input motion. The dynamic response of the scaled model will be observed and compared with the results of the subsequent numerical simulation. Accelerometers, piezometers, and pressure gauges were embedded in the model during its construction. Industrial high-speed cameras, motion capturing system, and consumer video equipment will be used to observe the deformation and failure areas of the overall displacement field on the slope of the scaled dam model.

Summary

This study is expected to establish a method and process of shaking table tests of a scaled dam model. The numerical simulation and digital image analysis technology will facilitate effective analysis of the process and test results.

Review on Standards for Soil Investigations of Offshore Wind Farms and Localized Suggestions

Yung-Yen Ko, Associate Researcher, NCREE

Introduction

Energy is essential for the development of a nation and its economy. In consideration of environment protection and sustainability, renewable energy is currently being exploited worldwide. Taiwan receives southwest airflow in summer and northeast monsoon in winter. In addition, 4C Offshore, an independent marine energy consultancy, has recognized the offshore area in western Taiwan to have excellent wind resources. Thus, offshore wind power has become a major focus area in renewable energy generation in Taiwan. According to the "Thousand Wind Turbines" Project promoted by the Ministry of Economic Affairs, Taiwan, 450 onshore and 600 offshore wind turbines will be installed by 2025 to generate a total of 4.2 GW wind power capacity, of which 3 GW will be generated from offshore wind.

The foundation of the support structure of an offshore wind turbine is to safely transfer the loads induced by the action of wind, waves, currents, and earthquakes to the seabed. Therefore, the foundation must have sufficient bearing capacity and displacement control ability, and its design is critical to an offshore wind turbine. If the design is insufficient, the safety and functionality of the wind turbine cannot be assured, whereas if the design is too conservative, the installation cost will be increased and the profit may be reduced

The performance of an offshore foundation is directly related to the engineering properties of the supporting seabed soil. For the offshore foundation design to be accurate and reasonable, soil investigations of the seabed are essential. Through boring, probing, and sampling, the stratigraphy and the characteristics of soil can be obtained to examine the safety and performance of the support structure of an offshore wind turbine and to assess the feasibility of installation methods. This study reviews the standards for soil investigation of offshore wind farms in several widely used design guidelines for wind turbines; the review includes the objective, methods, extent and range of the investigations, number of borings, methods and amount of sampling, requirements for laboratory tests, and special concerns about foundations subjected to cyclic loads such as earthquakes. In addition, localized suggestions are proposed based on the review.

Review of Standards for Soil Investigation of Offshore Wind Farms

Design Guidelines for Wind Turbines

The following design guidelines for wind turbines are reviewed in this study:

- International Electrotechnical Commission (IEC) (2009), Design Requirements for Offshore Wind Turbines, IEC 61400-3.
- Japan Society of Civil Engineers (JSCE) (2010) Guidelines for Design of Wind Turbine Support Structures.
- Germanischer Lloyd (GL) (2012), Guideline for the Certification of Offshore Wind Turbines.
- American Bureau of Shipping (ABS) (2015), Guide for Building and Classing Bottom-Founded Offshore Wind Turbine Installations.
- DNV GL (2016), Support Structures for Wind Turbines, DNVGL-ST-0126.

Investigation Objective and Timing

The standards regarding the objective and timing of soil investigations of offshore wind farms are as follows:

- Soil investigations shall be performed to provide adequate information to characterize soil properties. (IEC)
- Detailed soil investigations are to quantitatively investigate the soil strata (geology, thickness and depth of each layer), soil properties (bearing capacity, strength, deformability and dynamic characteristics) and ground water level which are necessary for design. (JSCE)
- The subsurface investigation is to obtain reliable geotechnical data concerning the stratigraphy and properties of the soil. These data are to be used to assess whether the desired level of structural safety and performance can be obtained and to assess the feasibility of the proposed installation method. (ABS).
- The soil investigations shall provide all necessary soil data for a detailed geotechnical design and should be carried out before the design. However, in the scenario when no soil investigations are available yet when the foundation is designed, conservative assumptions shall be made for the soil properties. These shall be confirmed by soil investigations before the start of construction. (DNV GL)

Executor of Investigation and Assessment

The standards regarding the executor of soil investigations and assessment are as follows:

- The soil properties at a proposed site shall be assessed by a professionally qualified geotechnical engineer. (IEC)
- An interpretation of soil data is to be submitted by a recognized geotechnical consultant.(ABS)
- An experienced geotechnical engineer who is familiar with the considered foundation concepts and who represents the owner or developer should be present during the soil investigations on the site. Depending on the findings during the soil investigations, actions may then be taken, as relevant, to change the soil investigation program during its execution. (DNV GL)

Investigation Methods and Extent

The standards regarding the methods and extent of soil investigations are as follows:

- Soil investigations should normally comprise site geological survey, topography survey of the sea floor, geophysical investigations, borings and in-situ testing, and soil and rock sampling with subsequent laboratory testing. (IEC, ABS, DNV GL)
- Soil investigations shall include one or more soil borings to provide soil samples for in-situ tests and laboratory tests to determine data suitable for definition of engineering properties. Site-specific soil data shall in principle be established for each foundation within the wind farm. The number and depths of borings required shall depend on the number and location of wind turbine foundations in the offshore wind farm, the soil variability in the vicinity of the site, the type of foundation, and the results of any preliminary geophysical investigations. (IEC)
- To account for possible soil variability, a lower bound and an upper bound soil profile are to be established. (ABS)
- The extent of ground investigations and the choice of soil investigation methods shall take into account the phase of the project; the type, size and importance of the wind turbine structure, the actual type of soil deposits and the complexity of soil and terrain conditions. The soil and rock parameters provided shall cover the scope required for a detailed and complete foundation design, including the lateral extent of significant soil layers, and the lateral variation of soil properties in these layers. (DNV GL)

Investigation Range (Depth and Area)

The standards regarding the general requirements for the range (depth and area) of soil investigations include:

- Soil investigations shall be performed throughout the depth and area that will affect or be affected by the foundation structure. (IEC)
- To establish the soil characteristics at the foundation locations, borings or probings are to be taken at all foundation locations to a suitable depth of at least the anticipated depth of any pile penetrations plus a consideration for the soil variability as described below. (ABS)
- The area to be covered by soil investigations shall account for positioning and installation tolerances. Soil investigations shall provide relevant information about the ground to a depth below which possible existence of weak formations will not influence the safety or performance of the wind turbine support structure. (DNV GL)

The standards regarding the investigation depth for pile foundations are as follows:

- For pile-supported structures, the minimum depth of a bore hole for either individual or clustered piles is to be the design penetration plus a zone of influence. The zone of influence is to be at least 15.2 m (50 ft) or 1.5 times the diameter of the cluster, whichever is greater, unless it can be demonstrated by analytical methods that a lesser depth is justified.
- For design of pile foundations, a combination of in-situ testing and borings with sampling should be carried out to sufficient depth. If potential end bearing layers or other dense layers, which may create driving problems are found, this scope should be increased. If no special reasoning is given by the designer, this should be at least half a pile diameter below the pile tip for pile foundations against lateral loads, and at least 3 pile diameters below pile tip for axial loads. (DNV GL)

The standards regarding the investigation depth for gravity foundations are as follows:

- For a gravity-type foundation, the required depth of at least one boring is to be at least equal to the larger horizontal dimension or three times the smaller dimension of the base, whichever is greater. In-situ tests are to be carried out, where possible, to a depth that will include the anticipated shearing failure zone
- For design of gravity-based foundations, the soil investigations should extend at least to the depth of any critical shear surface. Further, all soil layers influenced by the wind turbine structure from a settlement point of view should be thoroughly investigated.

Number of Borings and In-Situ Tests

The standards regarding the amount of borings and in-situ tests in soil investigations are as follows:

- Site-specific soil data shall in principle be established for each foundation within the wind farm. The cone penetration test (CPT) may be used for this purpose at wind turbine locations where soil boring is not undertaken. For calibration of the CPTs, one CPT shall be performed in the close vicinity of one of the soil borings. (IEC)
- The subsurface investigation program is to consist of an adequate number of in-situ tests, borings, probings and geophysical investigation to examine all important soil and rock strata at each foundation location. If probings are used, they are to be calibrated with the data obtained from conventional boring in the vicinity of the probing. Additional bore holes of lesser depth are required if discontinuities in the soil are likely to exist within the area of the structure. (ABS)
- For multiple foundations such as in a wind farm, the soil stratigraphy and range of soil strength properties shall be assessed per foundation location (or per group of foundations within the entire area when very homogeneous soil conditions prevail). For solitary wind turbine structures, one boring to sufficient depth for recovery of soil or rock samples for laboratory testing is recommended as a minimum. When non-homogeneous soil deposits are encountered or when difficult or weak grounds are identified locally, it may be necessary to carry out more borings and CPTs. In cases where soil

conditions are highly varying within small spatial areas and foundations with a diameter of more than 20 m are used, more than one boring or more than one CPT per wind turbine position may be needed (DNV GL)

- In principle boring and standard penetration test (SPT) shall be conducted at each wind turbine. (JSCE)

Sampling Method and Amount

The standards regarding the method and amount of soil and rock sampling are as follows:

- It is of critical importance that soil and rock samples obtained as part of a soil investigation program are of a sufficiently good quality to allow for accurate interpretation of soil and rock parameters for use in design. For requirements to soil and rock sampling, reference is made to ISO 22475-1. (DNV GL)
- Field samples for laboratory work are to be retained and carefully packaged to minimize changes in moisture content and disturbance. Samples are to be sent to a recognized laboratory for further testing. They are to be accurately labeled and the results of visual inspection recorded. (ABS)
- A reasonably continuous profile is to be obtained during recovery of the boring samples. The recovery of the materials to a depth of 12 m (40 ft) below the mudline is to be as complete as possible. Thereafter, samples at significant changes in strata are to be obtained, at approximately 3 m (10 ft) intervals to 61 m (200 ft) and approximately 8 m (25 ft) intervals below 61 m (200 ft). (ABS)

Requirements for Laboratory Tests

The standards regarding the requirements for laboratory tests are as follows:

- For sand and clay, direct shear and triaxial tests are relevant types of tests for determination of strength properties. Shear strength properties of low-humified peat can be determined by ring shear tests For rocks, unconfined/uniaxial compressive strength tests can be used. (DNV GL)
- At least one undrained strength test (vane, drop cone, unconfined compression, etc.) on selected recovered cohesive samples is to be performed in the field. The testing in the laboratory is to include at least (1) unconfined compression tests on clay strata where needed to supplement field data; (2) water content and Atterberg limits tests on selected cohesive samples; (3) density tests of selected samples; (4) as necessary, to develop appropriate constitutive parameters or stress-strain relationships from either unconfined compression tests, unconsolidated undrained triaxial compression tests, or consolidated undrained triaxial compression tests; (5) grain size sieve analysis, complete with percentage passing 200 sieve, on each significant sand or silt stratum. (ABS)
- For pile-supported structures, consideration is to be given to the need for additional tests to adequately describe the dynamic, creep and set-up characteristics of the soil as well as the static and cyclic lateral properties of soil-pile system. For gravity structures, laboratory tests are also to include, where necessary, shear strength tests with pore pressure measurements, cyclic loading tests with deformation and pore pressure measurements, and permeability and consolidation tests as required. (ABS)

Special Concerns about Cyclic Degradation, Soil Liquefaction and Seismic Site Effect

Regarding cyclic degradation of soil strength and stiffness, as well as soil liquefaction during earthquakes, most guidelines do not propose corresponding standards for soil investigations. However, if the standards for foundation design are included, some concerns can be summarized as follows:

- The effects of cyclic loading on the soil properties, called cyclic degradation, shall be considered. It is important that the p-y curves used for representation of the lateral support account for the cyclic degradation effects in the lateral resistance and stiffness. In seismically active areas, the effects of possible liquefaction of the soil shall be evaluated for the site-specific conditions, including differential settlements or tilt due to soil liquefaction. (DNV GL)
- The effect of cyclic loading which may cause a reduction of shear strength, bearing capacity and stiffness of the soil shall be investigated. The effects of possible liquefaction of the soil in seismically active areas shall be considered with great care and sound engineering judgement, always taking the special site conditions and experience from similar projects into account. (GL)
- The influence of cyclic loading on soil properties is to be considered and possible reduction of soil strength is to be investigated. Other possible cyclic load effects, such as changes in load-deflection characteristics, liquefaction potential, and slope stability are also to be considered. (ABS)
- For weak or liquefied ground, the ground deformation caused by earthquakes may not be neglected. Therefore, the stresses on the pile induced by the ground deformation shall be considered. In evaluating the lateral capacity of the foundation in liquefied ground, the horizontal subgrade reaction coefficient shall be reduced. (JSCE)
- Gravity-type foundations shall be verified against soil liquefaction. (IEC, GL)

Concerning the soil properties for the evaluation of seismic site effect, related standards are as follows:

- In seismically active areas, it may be necessary to obtain information about the shear modulus of the soil to depths which may have influence on the design in view of shear wave propagation due to earthquakes. (DNV GL)
- If the ground has liquefaction potential, the reduction of rigidity of the liquefied ground shall be assessed in the ground response analysis. (JSCE)

Localized Suggestions for Soil Investigations of Offshore Wind Farms

Investigation Objective and Timing

The suggestion regarding the objective and timing of soil investigations of offshore wind farms are as follows:

- Soil investigations of offshore wind farms shall provide all necessary soil data for a detailed geotechnical design, including the stratigraphy and properties of the soil that may influence the design and installation of the wind turbine. These data are to be used to examine the safety and performance of the wind turbine support structure and to assess the feasibility of the proposed installation method. The investigations should be carried out before the design, or conservative assumptions shall be made for the soil properties, which shall be confirmed by soil investigations before the start of construction.

Executor of Investigation and Assessment

The suggestion regarding the executor of soil investigations and assessment are as follows:

- The interpretation of soil data and the assessment of the soil properties at an offshore wind farm shall be submitted by a geotechnical engineer or an engineer in the related field who has the professional qualification. An experienced geotechnical engineer who is familiar with the considered foundation concepts and who represents the owner or developer should be present during the soil investigations on the site. Relevant actions may then be taken to change the soil investigation program during its execution depending on actual findings.

Investigation Methods and Extent

The suggestion regarding the methods and extent of soil investigations are as follows:

- Soil investigations should normally comprise site geological survey, topography survey of the sea floor, geophysical investigations, borings and sampling, and in-situ and laboratory testing. The investigation extent and the choice of investigation methods shall consider the phase of the project; the type, size, and importance of the wind turbine structure; the actual type of soil deposits; and the complexity of soil and terrain conditions. The data provided should be sufficient to define the engineering properties of soil at each foundation and should cover the possible soil variability for the need of detailed foundation design.

Investigation Range (Depth and Area)

The suggestions regarding the range (depth and area) of soil investigations are as follows:

- Soil investigations shall be performed throughout the depth and area that will affect or be affected by the foundation structure and shall account for positioning and installation tolerances so that the stratigraphy and properties of the soil can be comprehensively examined. Furthermore, the investigation shall be performed to a depth below which possible existence of weak formations will not influence the safety or performance of the wind turbine support structure.
- The minimum depth of a borehole for either a monopile or group piles shall be the design penetration plus a zone of influence. The zone of influence is to be at least 3 times the pile diameters for a monopile and at least 15 m or 1.5 times the lateral dimension of the pile cluster for group piles, whichever is greater, unless it can be demonstrated by analytical methods that a lesser depth is justified.
- For a gravity-type foundation, the required depth of boring should include the anticipated shearing failure zone and shall be at least equal to the larger horizontal dimension or three times the smaller dimension of the base, whichever is greater. Furthermore, all soil layers influenced by the wind turbine structure from a settlement point of view should be thoroughly investigated.

Number of Borings and In-Situ Tests

The suggestion regarding the number of borings and in-situ tests in soil investigations are as follows:

- For solitary wind turbine structures, a minimum of one boring to sufficient depth for the recovery of soil or rock samples for laboratory testing is recommended. In cases where soil conditions are highly varying within small spatial areas, when difficult or weak grounds are identified locally, and foundations with a diameter of more than 20 m are used, it may be necessary to carry out more borings. The CPT may be used for this purpose where soil boring is not undertaken, yet it should be calibrated with the data obtained from conventional boring in the close vicinity of the CPT.

Sampling Method and Amount

The suggestions regarding the method and amount of soil and rock sampling are as follows:

- The drilling and sampling methods shall be chosen in such a way that unacceptable disturbance of the soil samples is prevented. Thin-wall samplers (push samplers) are preferred to obtain undisturbed samples. However, where the sample recovery is poor using the thin-wall samplers, split-barrel samplers (hammer samplers) may be used instead. Blow counts measured during hammer sampling shall be recorded and presented on the borehole logs.
- Field samples are to be accurately labeled and the results of visual inspection are to be recorded. Then, samples are to be carefully packaged and sent to a recognized laboratory for further testing.
- The recovery of boring samples to a depth of 20 m below the mudline is to be as complete as possible, at 1.5-m intervals as a minimum requirement. From a depth of 20 m to 60 m, samples are to be obtained at 2-m intervals, and at 3-m intervals below 60 m.

Items of Laboratory Tests

The suggestions regarding the items of laboratory tests

considering cyclic degradation, soil liquefaction, and seismic site effect are as follows:

- At least one undrained strength test, such as the unconfined compression, pocket penetrometer, torvane, or vane shear, on selected recovered cohesive samples is to be performed on the investigation vessel.
- Other laboratory tests include (but not limited to):

1. Tests for the physical properties of soil such as water content and unit weight (these two are suggested to be conducted on the investigation vessel), specific gravity, void ratio, relative density, sieve analysis for granular soil, and Atterberg limits for cohesive soil.
2. Tests for the drained and undrained shear strength of soil, including the unconfined compression test for cohesive soil where needed to supplement field data, direct shear test for granular soil, unconsolidated undrained or consolidated undrained triaxial test for cohesive soil, and consolidated drained triaxial test for granular soil.
3. One-dimensional consolidation test for cohesive soil stratum where the consolidation settlement may lead to stability concerns.
4. Cyclic loading tests such as dynamic triaxial test and cyclic simple shear test on undisturbed samples to examine their cyclic degradation characteristics or liquefaction resistance for weak alluvial deposits where the cyclic degradation or soil liquefaction may be an issue.
5. In seismically active areas, the ground response analysis is needed to evaluate the seismic site effect. To this end, resonant column test, dynamic triaxial test, or cyclic simple shear test shall be conducted to obtain the dynamic property curves of soil that describe the variation in shear modulus and damping ratio with respect to the shear strain, which are necessary for ground response analysis.

Future Works and Vision

This manuscript is part of the MOST Project "Studies on Hazard Risk Evaluation for Support Structures of Offshore Wind Forms and Essential Experimental Technology for Critical Components". The next step is to invite experts in geotechnical engineering, offshore geotechnical investigation, and offshore wind power from academia and industries for consultation meetings in order to collect their opinions. Thus, localized standards for soil investigations can be supplemented and revised accordingly. For the upcoming huge need for soil investigation of offshore wind farms during the promotion of offshore wind power in Taiwan, the achievement of this project can serve as a reference for planning and execution in engineering practice.

The 10th JWWA/WRF/CTWWA Water System Seismic Conference

Gee-Yu Liu, Research Fellow, NCREE

The 10th JWWA/WRF/CTWWA Water System Seismic Conference was held at NCREE Tainan Laboratory on October 18-20, 2017. It was organized by Chinese Taiwan Water Works Association (CTWWA), Taiwan Water Corporation and NCREE. The predecessor of the Conference is the US-Japan Water System Seismic Conference, a bi-lateral activity between Water Research Foundation (WRF, USA) and Japan Water Works Association (JWWA). It was expended into a tri-lateral version in Taipei in 2009. Therefore, this was the second time for CTWWA to host the Conference.

More than 180 participants, including 9 delegates from the US and 31 delegates from Japan, joined the Conference. A total of 37 papers were presented in keynote speeches and various sessions. The Conference began with three keynote speeches: (1) "Damage and restoration of drinking water systems caused by 0206 Tainan earthquake" by President Nan-Tzer Hu, CTWWA, (2) "Lessons learned from damage to drinking water supply system in the 2016 Kumamoto earthquake in Japan" by Prof. M. Miyajima, Kanazawa University, and (3) "Developing a seismic resilient pipe network using performance based seismic design procedures" by Dr. Craig A. Davis, Los Angeles Department of Water and Power. The topic of presentation sessions include: (1) experiences and lessons learnt, (2) seismic preparedness and emergency response, (3) evaluation of water system components, (4) assessment and information system, (5) pipe testing, analysis, and design, and finally (6) pipeline enhancement strategy. Panel discussions were organized on October 19 afternoon. The topics for discussion were assigned to: (1) "How are you going to balance seismic risk with mitigation cost?" and (2) "How are you going to react to an Earthquake Event?" Further exchange and sharing of experiences and comments had been guaranteed. Finally, a technical tour to the construction site of Tseng-Wen Reservoir Sediment-Sluicing Tunnel was arranged for foreign participants. The tour ended with a visit to the Chimei Museum.

The Conference proceedings have been published as an NCREE technical report (No. NCREE-17-013), ready for download and reference.



Fig. 1. Group photo of the foreign delegates

Motion Capture Measurement System

Cho-Yen Yang, Wang-Chuen Lin, Shieh-Kung Huang, Yi-An Lee, Assistant Researcher, NCREE
Shiang-Jung Wang, Research Fellow, Yuan-Sen Yang, Associate Professor, NTUT, NCREE, Jenn-Shin Hwang, Professor, NTUST

Introduction

A reference is required for installing conventional contact measurement instruments. Undoubtedly, the reference rigidity and any vibration induced by the testing system will greatly affect the measurement accuracy. Not to mention the measurement error caused by the interaction between two mutually orthogonal movements. In addition, arranging a large number of data transmission and power supply cables complicates and rendered the test inefficient, especially for a large specimen tested using a large testing system, e.g., the long-stroke and high-speed earthquake simulator with a plane size of 8 m × 8 m and a maximum displacement capacity of ±1 m in the National Center for Research on Earthquake Engineering (NCREE) Tainan laboratory. To provide a better test environment and to meet further test requirements in this laboratory, a new, advanced non-contact measurement system, the motion capture system, was planned and installed.

Evolution of Motion Capture System

The optical measurement system, the third generation of measurement technology in its development history and termed as “motion capture,” has been developing since 1970s. The most significant progress compared with the previous generation is that additional power supply for the markers attached to the target is no more needed. It has been widely applied in film industries to produce a more realistic animation by tracing and recording markers on animals and actors. With increasing the measurement accuracy and distance, this technology has recently been applied in different industries and even used for academic research purposes. An application example in a large structural laboratory is the shaking table “E-Beetle” in the Tokyo laboratory of the Shimizu Corporation. The capture directions of the cameras installed around the shaking table can be adjusted in a remote control manner, which can enhance the test efficiency and provide a better measure result.

Features of Motion Capture System

As mentioned above, the markers of the motion capture system (Fig. 1) do not need data transmission and power supply cables, and they can be attached to the target effortlessly by using twin adhesive. The camera of the motion capture system (Fig. 2) is considerably light, weighing approximately 1.5 kg. Multiple cameras are installed to synchronously capture all the arranged markers. The maximum sampling rate is 180 FPS, and the measurement accuracy is guaranteed to be less than 1 mm with a measurement distance of 25 m, which is able to satisfy the most dynamic test requirements in earthquake engineering research fields.

The operation software provides a graphical user interface, which can easily adjust all parameters except for manual setup, focus adjustment, and calibration of the cameras. During the system calibration and synchronization processes, the space traces of the calibration wand captured by each camera can be checked real-time on the screen. During the measurement, displacement, velocity, acceleration, and other physical quantities that most researchers are often interested in can be displayed on the screen in a real time manner (Fig. 3), which is very helpful for researchers to immediately understand the results and make correct decision during the test. It is anticipated that with the motion capture system, the NCREE Tainan laboratory can provide a more robust testing service for domestic and international academia and industries.



Fig.1. Markers and their installation



Fig.2. Cameras of motion capture system



Fig.3. Software user interface

Workshop on Periodic Foundation for Seismic Protection of Important Facilities

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Shiang-Jung Wang, Chiun-Lin Wu, Research Fellow, NCREE
Shyh-Jiann Hwang, Director, NCREE, Kuo-Chun Chang, Professor, NTU, Yi-Lung Mo, Professor, UH
Witarto Zuo, Doctoral Candidate, UH

The workshop was held in the National Center for Research on Earthquake Engineering (NCREE) on October 26, 2017; it focused on the three-year international cooperative research project of applying periodic materials to the foundation of critical nuclear power plant (NPP) facilities undertaken by the University of Houston (UH), U.S. Department of Energy (U.S. DOE), Argonne National Laboratory, Electric Power Research Institute (EPRI), and NCREE. In addition to domestic participants, Mr. Thomas P. Miller, Director of Accelerated Innovation, DOE; Ms. Alison Krager Hahn, Federal Program Manager; Dr. Richard Sause, Professor of Lehigh University; Dr. Youssef Hashash, Professor of University of Illinois at Urbana-Champaign; and Mr. Lawrence Burkett, Senior Structural Designer of Maffei Structural Engineering, were invited to attend this workshop.

The opening remarks and brief introduction of the NCREE were made by Prof. Shyh-Jiann Hwang, Director of NCREE. Afterward, Mr. Thomas P. Miller introduced the energy conservation policies and research projects that the U.S. DOE has been devoting to. Then, Dr. Yi-Lung Mo, Professor of UH, explained the concept of periodic foundation, which has the property of preventing the propagation of elastic waves within certain frequency bands and seismically protecting the superstructure in horizontal and vertical directions with very limited displacement responses. In the past two years, the effectiveness of the periodic foundation of a steel structure that was intended to simulate a scale-down NPP facility has been experimentally verified in the NCREE. Dr. Shiang-Jung Wang also introduced the construction processes of the test specimens.

A series of demonstration tests were conducted after Dr. Yi-Lung Mo and Dr. Kuo-Chun Chang, Professor of National Taiwan University (NTU), explained about the testing facilities and specimens. The acceleration and displacement responses as well as the reduction level were displayed real-time, which verified the expected performance of periodic foundation.

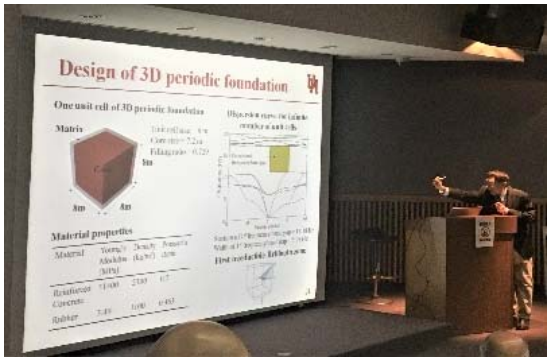


Fig. 1. Speech by Professor Yi-Lung Mo



Fig. 2. Demonstration tests in NCREE

Planning of Soil Mechanics Laboratory in NCREE Tainan Laboratory

Yung-Yen Ko, Associate Researcher, NCREE

Introduction

The Taiwan Strait has been recognized to have excellent wind resources, and thus offshore wind power has become one of the focuses of renewable energy. An offshore wind turbine could be subjected to the actions of wind, waves, currents and earthquakes, and the corresponding loads have to be transferred safely to the seabed through the foundation of its support structure. Therefore, the foundation must have enough bearing capacity and displacement control ability. Marine geotechnical investigations are essential for reasonable offshore foundation design. Through boring, probing and sampling, the strata and the engineering properties of soil can be understood. Furthermore, laboratory tests on soil samples can be conducted for the basic physical properties, strength, deformability and dynamic characteristics of the soil to serve as design parameters. In order to achieve the goal of 3GW offshore wind power by 2025, about 600 wind turbines will be installed in the offshore wind farm in western Taiwan, where the seabed is mostly composed of weak alluvial deposits. In order to comprehensively understand the engineering properties of the ground and to account for the possible variability, at least one borehole at each wind turbine position should be executed. Because the amount of laboratory soil tests of each borehole may be around dozens, the total need can be up to tens of thousands. Hence, the establishment of more professional laboratories are necessary. NCREE has been long devoted to geotechnical engineering researches, and the space for soil mechanics laboratory has been prepared in NCREE Tainan Laboratory just opened in August, 2017. If the related equipment can be set up, testing services with high quality and public recognition will be provided to meet the huge need for soil laboratory tests.

Equipment Configuration

Based on the services of existing academic and industrial soil mechanics laboratories in Taiwan and the laboratory soil test items of foreign offshore wind farms, the equipment is configured, as shown in Fig. 1. The objective is to establish a soil mechanics laboratory to provide full services for the need of offshore geotechnical investigation. Details are as follows:

Equipment for Soil Physical Properties

This equipment is to determine the physical properties of soil and for soil classification, which are basic information for foundation design. Therefore, it is essential for a soil mechanics laboratory. Items include:

- Oven, electronic balance, constant temperature water tank, soil mixer, standard sieves, sieve shaker, liquid limit device, and related containers and tools: these are used to determine soil physical properties such as the particle size distribution, unit weight, specific gravity, water content and plasticity parameters.
- Relative density apparatus (vibrating table, mold sets and pouring funnels): it is used to estimate the denseness of sandy soil for engineering practice.

Equipment for Shear Strength and Compressibility of Soil

This equipment is to determine the shear strength and compressibility of soil, which are necessary for the estimation of the bearing capacity and settlement of the foundation. Hence, it is fundamental mechanical test equipment for a soil mechanics laboratory. Items include:

- Direct shear apparatus: it can be used to perform quick shear test (Q test), consolidated quick shear test (Q_c test) and slow shear test (S test) to determine the shear strength of sandy soil for the estimation of bearing capacity of foundation in sand.
- Triaxial testing system: it can be used to perform consolidated drained (CD), consolidated undrained (CU) and unconsolidated undrained (UU) triaxial tests to determine the drained and undrained shear strength of all kinds of soil for the estimation of foundation bearing capacity under various loading conditions.
- One-dimensional consolidation apparatus: it is used to determine the compressibility of clay for the estimation of the possible consolidation settlement of the ground.

Equipment for Dynamic Properties of Soil

Concerning an offshore wind turbine subjected to the actions of wind, waves, currents and earthquakes, the site effect of earthquakes and the dynamic stiffness of the foundation should be accurately estimated, and the liquefaction potential should also be reasonably assessed. Therefore, this equipment is to provide the soil dynamic properties for the corresponding analyses. Items include:

- Dynamic triaxial testing system: it can be used to determine the liquefaction resistance of soil and its dynamic properties such as shear modulus and damping ratio at a larger strain range for the evaluation of the performance against liquefaction and the dynamic impedance of the foundation.
- Resonant column testing system: it can be used to determine the dynamic properties of soil at a smaller strain range and to conduct cyclic torsional shear test as well for the evaluation of the dynamic impedance of the foundation.
- Cyclic simple shear testing system: it can simulate the stress state of soil under the action of seismic shear waves and thus can be used to determine the

shear strength, liquefaction resistance and the dynamic properties of soil at a larger strain range for the evaluation of the bearing capacity, the performance against liquefaction and the dynamic impedance of the foundation. The specimen is usually a short cylinder with its length smaller than its diameter. Thus, the specimen length is smaller than that of the dynamic triaxial test, of which the length-to-diameter ratio is usually 2. That is, more tests can be conducted at the same amount of soil samples, which is competitive in marine geotechnical investigation because the cost for undisturbed sampling is rather high.

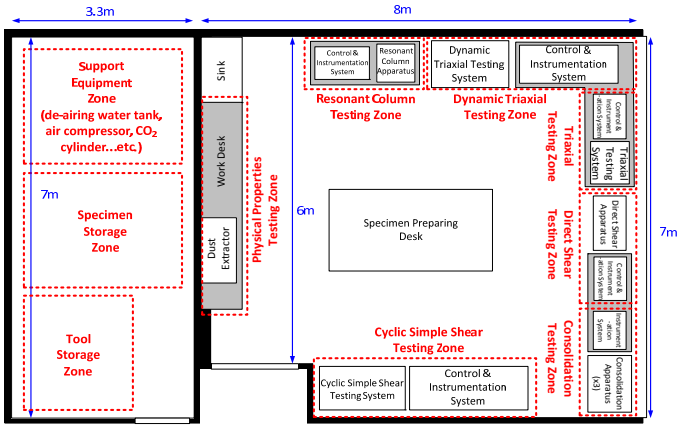


Fig. 1. Layout plan of soil mechanics laboratory in NCREE Tainan Laboratory

Expected Benefits

The proposal of establishing this soil mechanics laboratory has been delivered to the Ministry of Science and Technology for review. If it can be accomplished as planning, the NCREE Tainan Laboratory can be equipped with geotechnical testing capabilities in addition to its original structural testing facilities. Furthermore, high-quality and recognized testing services can be provided to meet the huge need for soil laboratory tests related to the geotechnical investigation of offshore wind farms. Thus, it will be helpful to achieve 3GW offshore wind power by 2025, which is one of the goals of renewable energy development in Taiwan.

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