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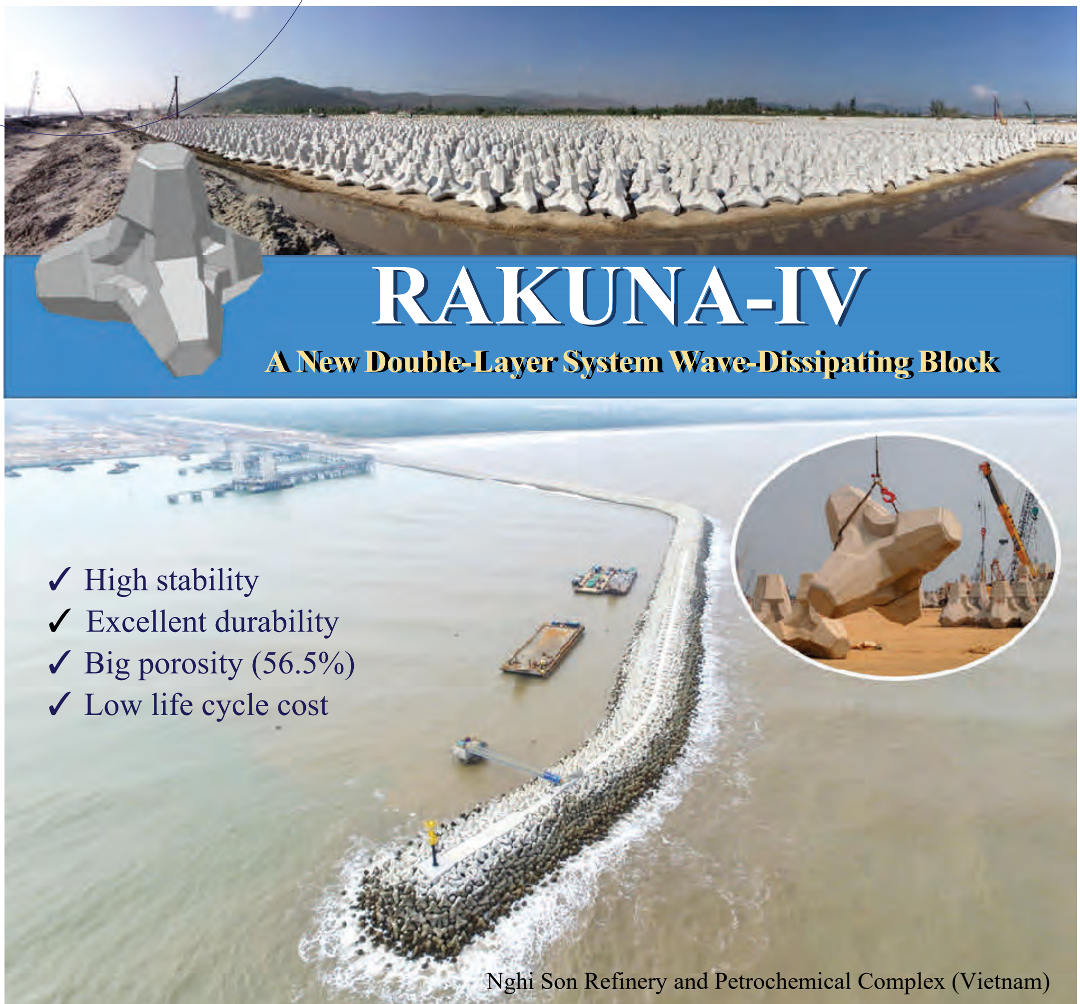

Nghi Son Refinery and Petrochemical Complex (Vietnam)

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Evaluation of Soil Liquefaction Potential by Screw Driving Sounding Test in Residential Areas

1. Background of Technology Development

Earthquakes are frequent in Japan. In many cases large earthquakes have occurred, we have suffered liquefaction damage particularly in soft sandy grounds or reclaimed lands to a greater or lesser extent. Especially after the 2011 Great East Japan Earthquake caused extremely severe liquefaction damage to houses in reclaimed land, the demand for predicting a liquefaction risk in residential areas has been increasing.

In Japan, a liquefaction risk of ground for large buildings is evaluated by estimating factor of liquefaction (F_L) using the N value[1] of the SPT[2] and the fine content of the soil (Fc) taken with the SPT sampler. In case of more important structures, it may be directly evaluated from the resistance of liquefaction (R_L) of a soil obtained by the results of cyclic undrained triaxial test performed with the soil. These methods, however, require too much time and too high cost to investigate residential areas. At present, the following process is taken to identify the ground strength for the construction of small-sized buildings. First, a soil layer is investigated on the strength with the Swedish Weight Sounding test (SWS), and classified on soil type and fine content with a sample taken from the borehole drilled through the SWS test. Then, when the layer of the soil is determined to be a soft sand layer and also deeper than underground water level, it is regarded as a liquefaction prone layer. When the soil layer is determined to be clayey or shallower than underground water level, it is regarded as a non-liquefaction layer. In some cases, a liquefaction risk of ground is estimated through the thickness ratio of each layer. As the damage caused to houses by the 2011 earthquake was conspicuously large although these investigations have been done, much more accurate evaluation methods of ground are essential not only for important structures but also for residential districts. The SDS has the potential to predict a liquefaction risk by estimating the N value and the Fc in a simple way at a low cost. In the study we carried out, it was verified that the N value and the Fc obtained by the SPT could be done by the SDS as well. Moreover, R_L assessed by the SDS results was compared with the values from the cyclic undrained triaxial tests and the SPT.

2. Estimation of Liquefaction Resistance

As an index for the assessment of a liquefaction risk, the liquefaction resistance factor (F_L) is adopted in this report. Based on "Specifications for Highway Bridge" published by Japan Road Association in March 2012, F_L is defined by R_L which can be calculated from the N value and the Fc. It means a risk of liquefaction can be verified without a series of high-cost cyclic undrained triaxial loading tests. When F_L is under 1.0, the soil is regarded to be vulnerable to

[1] The N-value provides an indication of the relative density of the subsurface soil, and used in empirical geotechnical correlation to estimate the approximate shear strength properties of the soils.

[2] Standard Penetration test (SPT) is a common in situ testing method used to determine the geotechnical engineering properties of subsurface soils.

liquefaction. The procedure of calculation is as follows:

where F_L is a liquefaction resistance factor, R is a dynamic shear stress ratio and L is a seismic shear stress ratio.

$$R = C_W R_L \quad (2)$$

where Cw is a correction coefficient of a seismic ground motion characteristic and R_L is a cyclic triaxial strength ratio.

$$L = \gamma_d \times k_{hgL} \times \frac{\sigma_v}{\sigma'_v} \qquad \gamma_d = 1.0 - 0.015x \quad (3)$$

$$F_L = \frac{R}{L} \quad (1)$$

γ_d : an attenuation coefficient of a seismic shear stress ratio in depth direction

k_{hgL} : a design horizontal seismic scale on the surface of ground

σ_v : total overburden pressure (kN/m^2)

σ'_v : effective overburden pressure (kN/m^2)

x : depth from the ground surface (m)

3. The SDS Test

i) Test machine and test method

Photo 1 shows an automatic SDS test machine. It is so small and simple that even one person can control it. A rod equipped with a screw point is the same as that of the SWS. The SDS adopts a monotonic loading system where a rod rotates and penetrates constantly while a load is stepwisely increased at each rotation. The loading started from 0.25kN of load and then kept on increasing by 0.125kN up to 1kN. Measured items were torque (T), total penetration length (L) and settlement velocity (V). These were measured at every rotation of rod. The loading was set back to the initial condition at every 25cm of settlement and this process was made repeatedly. In order to measure rd friction, torque was measured immediately after the rod was lifted up by a few cm and rotated.

Photo1.SDS machine

ii) Estimation of rod friction

In order to estimate torque and a load applied to the tip of rod accurately, rod friction was corrected in the following procedure during the SDS. Fig. 1 shows the concept of estimating rod friction. W_a, T_a, W_f and T_f are defined as applied load, applied torque, vertical rod friction force and horizontal rod friction torque, respectively. Moreover, when a load (W) and torque (T) are defined as values directly applied to a screw point, the relationships between these loads and torques are defined with the following formulas.

$$T_a = T_f + T \quad (4)$$

$$W_a = W_f + W \quad (5)$$

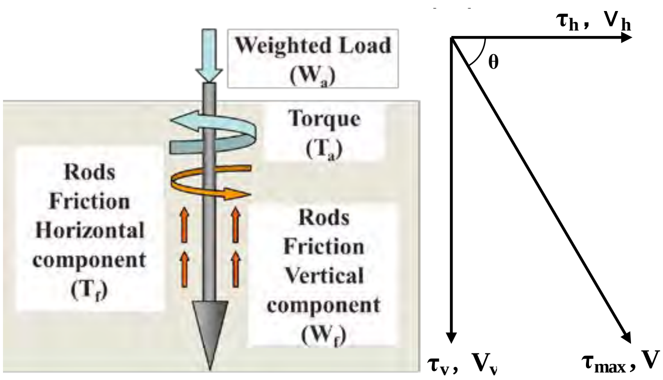

Figure 1. Concept of a rods friction

4. Classification of soil using the SDS test

It was attempted to determine some soil properties using the result of the SDS. Fig. 2 shows the depth distribution of torque obtained at the sites. In addition, the relationship between loads and torque obtained at 25cm penetration is shown in Fig. 3, where data was plotted at two sections of 25cm penetration. According to Fig. 2 and Fig. 3, the relationships were obviously different depending on the types of soil where T increased according as W increased in the sandy soil with a high frictional angle. On the other hand, it was seen that T didn't increase when W increased in the clayey soil without a frictional angle under the undrained condition of loading. Thus, it was concluded that the SDS was capable of categorizing soils by using these responses.

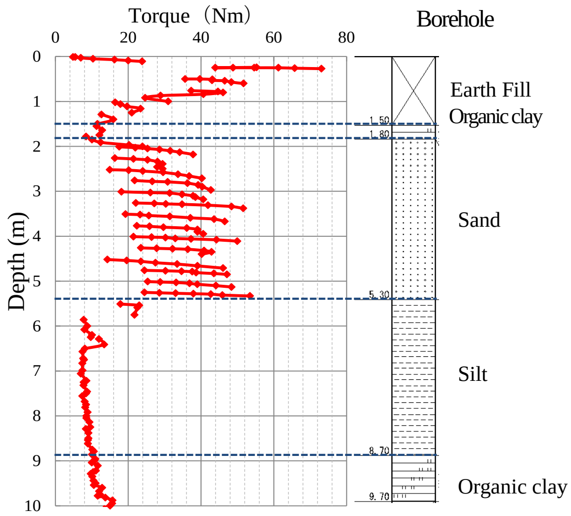

Figure 2. Torque and Types of soil

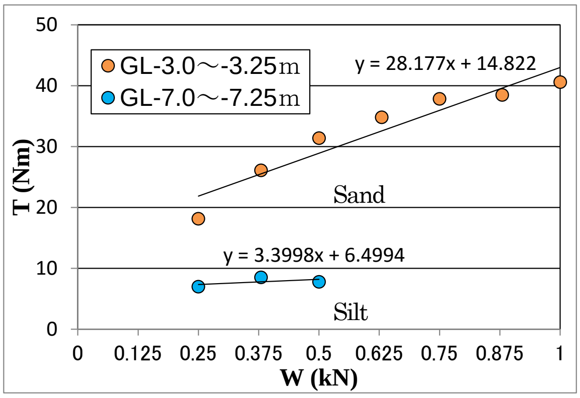

Figure 3. Relationships between T and W compared with Types of soil

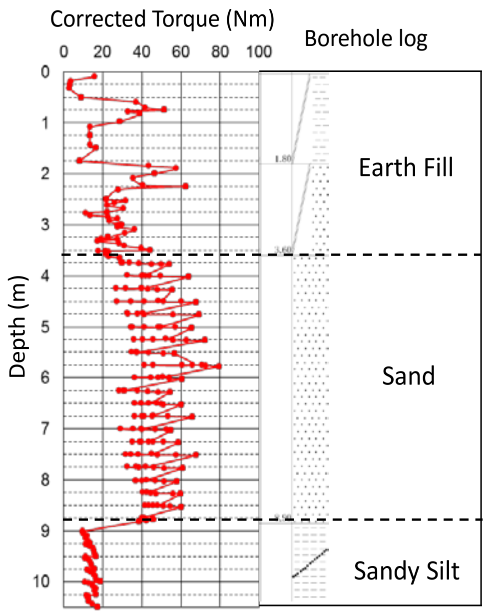

Figure 4. The results in Katsushika Ward, Tokyo

5. Test site

Fig. 4 shows the result of SDS tests conducted at some sites in Katsushika Ward, Tokyo. It shows the depth distribution of torque obtained at the sites. Test sites are more than 360km far away from the epicenter of The 2011 off the Pacific coast of Tohoku Earthquake. The soil profile is composed of earth fill from surface to 1.8m depth and sandy fill layer from 1.8m to 3.6m depth. The layer deeper than that is natural deposited sand from 3.6m to 8.9m overlying a thick natural clay layer.

6. Estimation of F_L using the SDS test

F_L was estimated from the proposed equations by assuming a medium-scale earthquake, called level 1 earthquake. The example of the SDS result in Katsushika in Fig. 5. The results of the N value in the layer from surface to 3.6m depth were omitted from the graphs, as it contained impurities such as broken pieces of concrete or cobble stones. In Katsushika, the values of F_{LSDS} were almost the same as those obtained from the laboratory test, while these were relatively different from the values calculated from the N value.

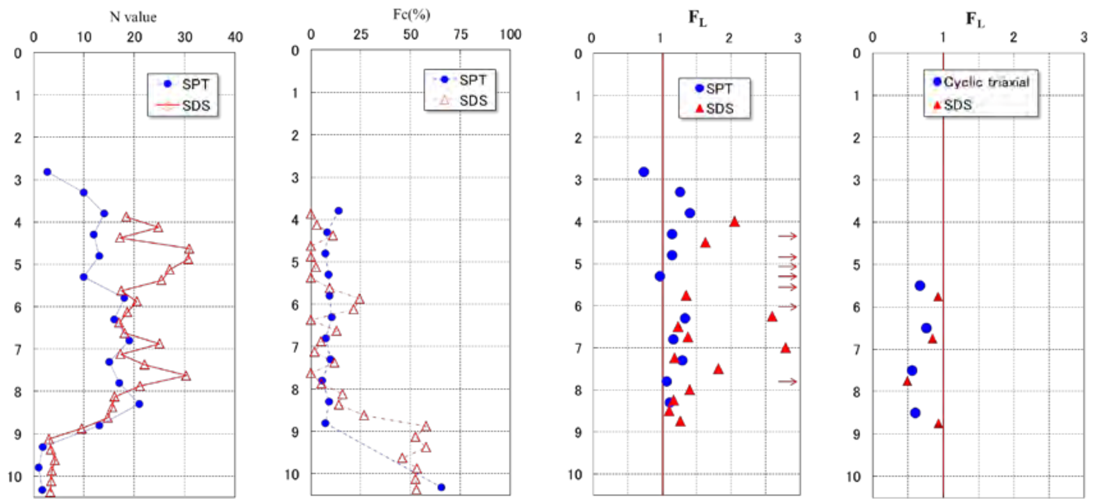

Figure 5. Estimated N, Fc and F_L values from the SDS test in Katsushika compared with SPT tests and laboratory test results

From the results, it was cleared that improvement of the estimation accuracy was necessary in the harder ground where the N value was more than 10. On the other hand, for the results of the F_L around 1, the F_{LSDS} values were the same as both those calculated from the N value and those obtained from the laboratory tests. As a result, it indicated that the SDS could estimate a risk of liquefaction as accurately as the SPT could.

7. Conclusions

1) The estimation of R_L obtained by the regression analysis using the laboratory test data was more accurate than the one calculated from the N value and the Fc, even though there was not many enough number of data for the estimation.

2) There is a possibility that F_L is able to be estimated by the SDS as accurately as the SPT, by estimating R_L in two ways calculating from the N value and the Fc and using the laboratory test results.

3) It was shown that the SDS is one of the simplest methods to investigate a risk of liquefaction efficiently.

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RAKUNA-Ⅳ : A new double-layer system wave-dissipating block

1. INTRODUCTION

A succession of natural disasters such as large typhoons, huge earthquakes, massive tsunami, etc. causes enormous damage for a great number of people. In order to protect national land as well as human life from damage caused by a tsunami or high wave, wave-dissipating blocks is one of the essential prevention measures. Ports and harbors are required to be completely safe to perform their intended functions Nikken Kogaku Co., Ltd. has developed the ideal product with technologies to ensure that safety.

2. Characteristics of RAKUNA-Ⅳ

RAKUNA-IV is a new double-layer system of concrete armor unit which has been researched and developed in 2007 by Nikken Kogaku. Four hollows that RAKUNA-IV has on its surface as unique characteristics increase roughness degree and improve wave dissipating effect. Legs of RAKUNA-IV interlock with hollows of adjacent blocks, which prevents expanding of damage, and improves stability against waves. When porosity is bigger, a number of required blocks decreases, this means the big porosity of RAKUNA-IV such as 56.5% can reduce the total cost. Spaces with various shapes created by the hollows provide a habitat for marine organisms.

Fig.1. RAKUNA-IV block

Steel molds mainly comprising three side plates and one bottom plate were used to manufacture the RAKUNA-IV concrete units. The central hollow parts are fabricated into each plate, thus additional special methods for assembly/dis-assembly of the steel molds are not necessary. Therefore, workability of block manufacturing is same as a conventional TETRAPOD.

Photo1. Mold Fabrication

3. Advantage of double-layer system

Initial stability of RAKUNA-IV is about 1.6 times higher than conventional TETRAPOD with the aid of four hollows in mid-section on block surface and hexagonal shape of legs to interlock. Though initial stability is somewhat lower than that of the typical single-layer system, the spread of damage from external forces on RAKUNA-IV is smaller. For this reason, double-layer system with RAKUNA-IV has a low risk of collapsing for structure in a long term. Double-layer RAKUNA-IV also has a well adaptability with settlement of the soft foundation. Interlocking of armor units become loose when subjected to settlement. When a wave acts on the loose section, there is a possibility that original stability performance of armor units is lowered. However, when the settlement occurs, the first layer in double-layer system follows flexibly to the ground. It is considered that the interlocking would be maintained because when the interlocking of blocks in 1st-layer becomes loose, blocks in 2nd-layer system enter into the loose section. Even if the shape of breakwater is changed by settlement, it is clear to maintain the original stability. Therefore, the double-layer system RAKUNA-IV is considered to fulfill the requirement by the self-healing capacity.

Consequently, the life cycle cost which is the most important in infrastructure projects can be reduced by using RAKUNA-IV with high stability and durability.

Photo2. Double-layer system

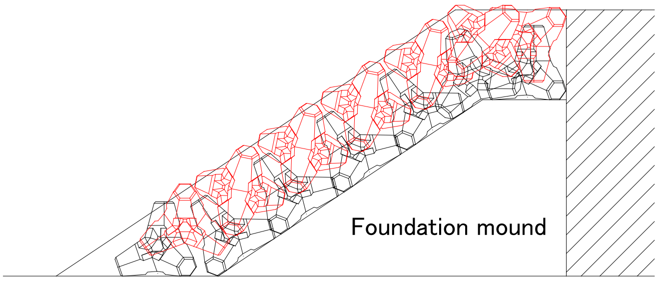

Fig.2. Cross section of double-layer system

4. Major installation record

Nghi Son Refinery and Petrochemical (NSRP) Complex is the second oil refinery to be constructed in Vietnam. RAKUNA-IV is being used for the rubble-mound breakwater protection in the NSRP Project. The breakwater with the total length of 1.55km is completed in Dec.2015. Approximately 700 pcs of 12t block for roundhead and 23,000 pcs 8t block for the trunk section and the revetment were installed in the whole breakwater. In the comparison between the use of RAKUNA-IV and of conventional TETRAPOD, it is expected that the RAKUNA-IV will yield a reduction of 12,000 m^3 concrete volume, and save up to 200 days of the installation periods. These reductions will also lead to a lower construction cost and eventually contribute towards conservation and lowering of CO_2 emission. The mold for producing the RAKUNA-IV blocks for the NSRP project were locally made in Vietnam. The mold were manufactured under the supervision of Nikken Kogaku and ensured same high quality as Japan.

Photo3. Breakwater at NSRP Complex

Fig.3. Location of Nghi Son

Photo4. Installation of RAKUNA-IV

Photo5. Site observation

5. Hydraulic experiments in Vietnam

The stability of the RAKUNA-IV for the NSRP Project was verified in 2D and 3D hydraulic experiments conducted by Vietnam's Thuy Loi University (formerly Water Resource University). Seaward and rear stability, wave overtopping and wave concentration were verified, high stability of RAKUNA-IV along with low overtopping in the design crown elevation were proved, and the acceptability of the overall breakwater design was confirmed by conducting these experiment.

Photo6. 7. 8. Hydraulic experiments in Thuy Loi University

6. Conclusion

By working cooperatively with local institutes such as university through experiments, the design which is adapted to local conditions is achieved. In addition, Japanese high quality and technology are kept because Nikken Kogaku send engineers who supervise the manufacturing through installation to local countries. With its excellent and unique characteristics and an advantage of double-layer system, RAKUNA-IV will protect the safety of ports, breakwaters, revetment and coast from the damage caused by high waves, typhoon, tsunami, coastal erosion, etc. around the world.

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