CEMENT DEEP MIXING APPLIED TO SOFT CLAY IN MEKONG DELTA

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ABSTRACT: The first implementation of a massive cement deep mixing work by "wet method" in Vietnam is reported. The site is located in the center of Mekong Delta, where the ground is extensively covered with soft clay. Two advanced Deep Mixing (DM) method were applied to improve a soft clay deposit in the site efficiently and economically. The work started on 15th of June, 2006, and finished on 27th of January, 2007. It is confirmed that both of the property of improved soil and the performance of DM improvement system are satisfactory.

Keywords: Deep Mixing; Soft Clay; Soil Improvement

1. INTRODUCTION

Deep Mixing (DM) method is an effective technique to improve soft soil ground, in which stability, consolidation and liquefaction are major problems when it is subjected to construction works. This technique has been widely used in Japan for decades to stabilize soft clays and loose sands, and cumulative volume of improvement has exceeded 50 million cubic meters in 2004 [1].

This paper describes DM application for civil works in a thermal power plant project undergoing in the suburb of Can Tho City, Vietnam. The project site is located in the center of Mekong Delta, which is widely covered with soft clay deposit. The volume of soil improvement by DM method for this project is approximately 270,000 m^3 in total. This is the first massive use of DM improvement in Vietnam.

Two advanced DM methods were employed in order to do the soil improvement work efficiently and economically. Both methods classified into "wet method", in which binder in slurry form is used. The one is Contrivance-Innovation Clay Mixing Consolidation (CI-CMC) method. CI-CMC method with two mixing shafts was employed for the project. The number of mixing shaft is the same as conventional method. However, CI-CMC method incorporates some new techniques that make it possible to use mixing blades larger than conventional DM method. The other one is CDM-Land 4 method. This method uses four mixing shafts. The number of shafts enables to make an improved soil column that has a cross section larger than conventional two-shaft method.

This paper presents outline of soil improvement work by DM method in the project. Figure 1 shows the plan of the power plant. The site faces Hau River, in which loading and unloading jetties for the power plant are located. DM method was applied to improve soft soils in five areas in the figure.

2. PURPOSE OF DM WORK FOR THE PROJECT

Cross sections of the soil improvement in five areas are presented in Fig. 2, together with the arrangement of soil columns, design strengths of stabilized soil column and improvement ratios specified in the contract. The volume of improvement and the number of columns are also listed for each cross section in Fig. 2. The purposes of soil improvement for Revetment area are 1) to protect shoreline and 2) to provide a firm support for sheet pile wall. For the other areas, the purposes are 1) to achieve slope stability after cutting and 2) to minimize settlement in foundation soil.

The soils where excavation is planned and no improvement is specified were also improved by a small amount of cement slurry. The purpose of this is to improve trafficability for excavators, and to facilitate the transportation of excavated soils by dump trucks.

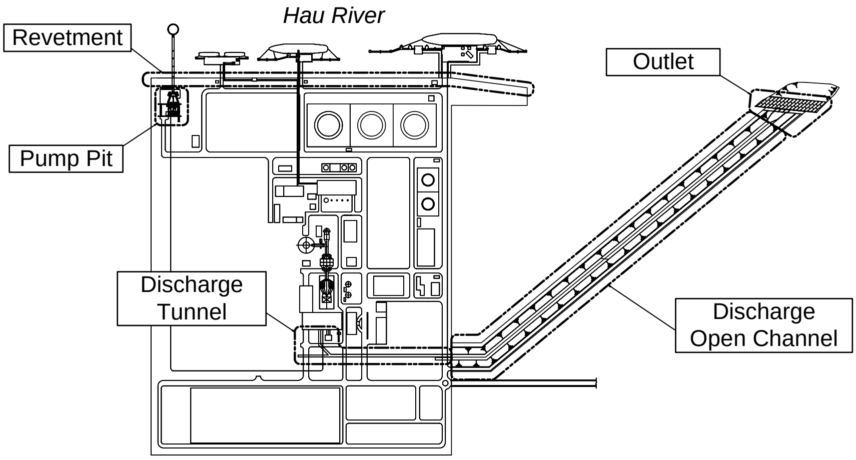

Fig.1 Plan of the power plant and areas where DM method was used

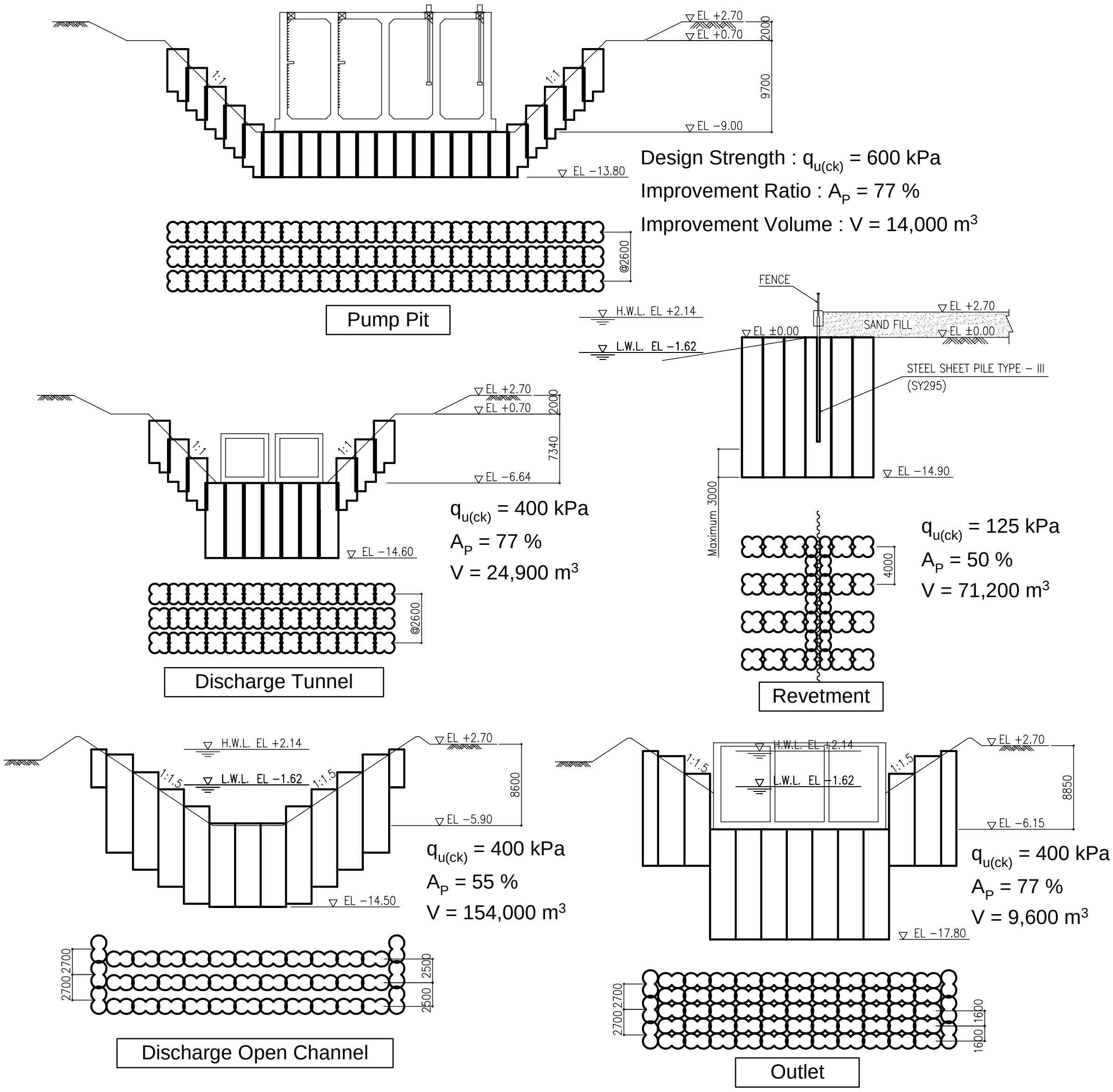

Fig. 2 Cross sections of soil improvement

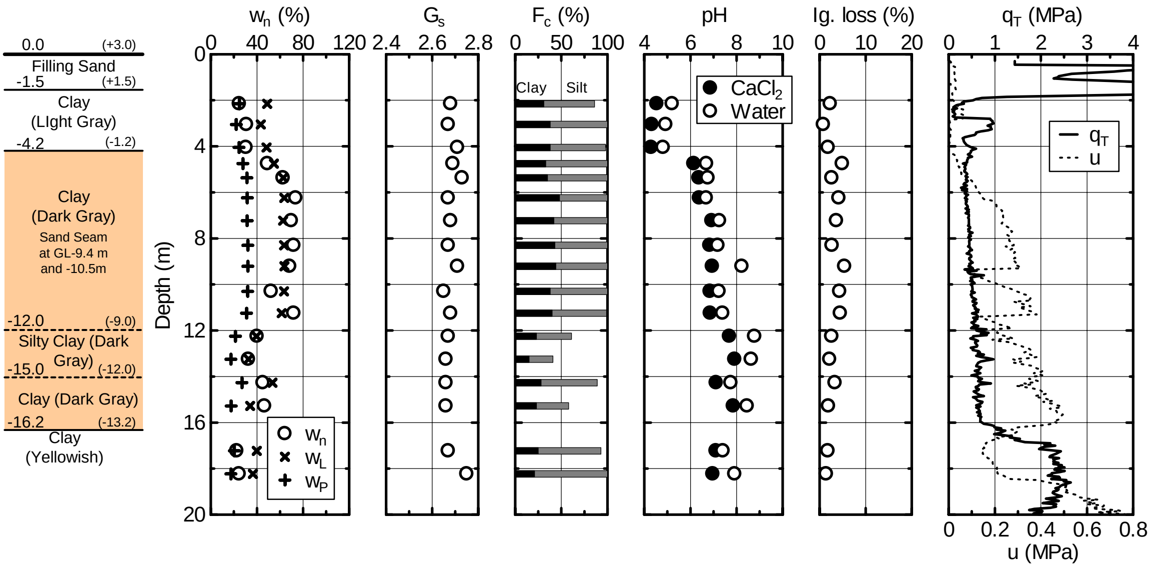

Fig. 3 Typical subsoil profile of the site

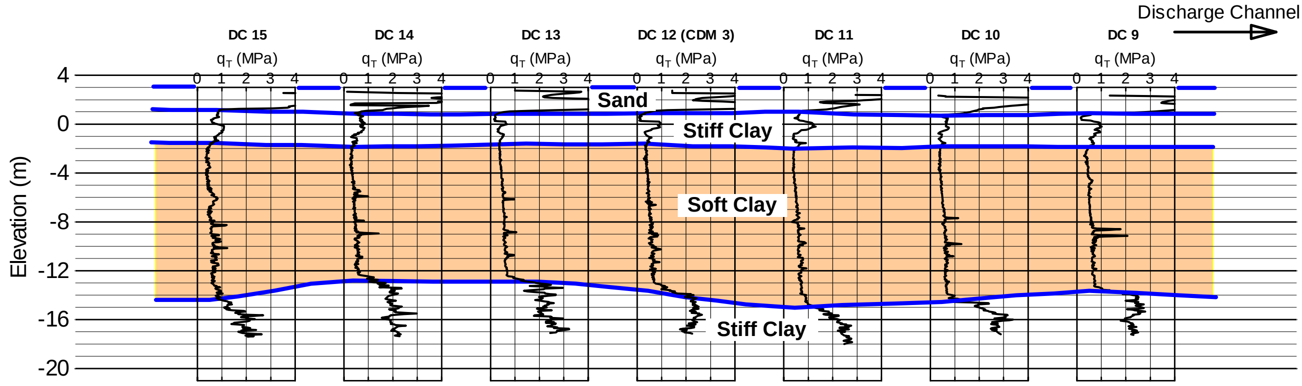

Fig. 4 Subsoil profile of Discharge Tunnel area according to CPTu data

3. SOIL INVESTIGATION

In order to study subsurface soil condition of the site, 35 CPTu and 5 bore holes were made. There is a sand layer on the top all over the site except Discharge Open Channel area. This sand layer was filled about 6 years before, and has an average thickness of 2 m.

Figure 3 indicates typical subsoil condition obtained from a bore hole in Discharge Tunnel area. The surface of the original ground is covered with a stiff clay layer. Below the depth of 4.2 m, a soft clay deposit, which was subjected to DM improvement, is found. Natural water content of the soft clay deposit is from 35 to 75 %. The values of pH measured according to ASTM D 2976 fall slightly acid side at the top of the soft clay, and slightly alkali side at the bottom. The amount of organic matter determined according to ASTM D 2974 (440 degree Celsius was applied) is less than 5 %. Cone resistance q_T, which is corrected by pore pressure generated during penetration, of this deposit is around 0.5 MPa, and is increasing slightly with depth.

An example of subsoil profile determined from CPTu data is presented in Fig. 4 for Discharge Tunnel area. As can be seen in the figure, it is very easy to detect layer boundaries by CPTu data. Considering other areas, the thickness of the soft clay deposit varies from 11 to 20 m.

In-situ undrained shear strength s_{uf} of the soft clay deposit was investigated by field vane test (FVT) and direct shear test (DST). Test apparatus used for DST is Mikasa's type (Takada [2]). In order to take high quality undisturbed samples for DST, stationary piston thin wall sampler was used. The location of the sampling is inside Revetment area. In DST, specimen is first consolidated at an effective overburden stress in the ground until primary consolidation is reached, then, sheared at a

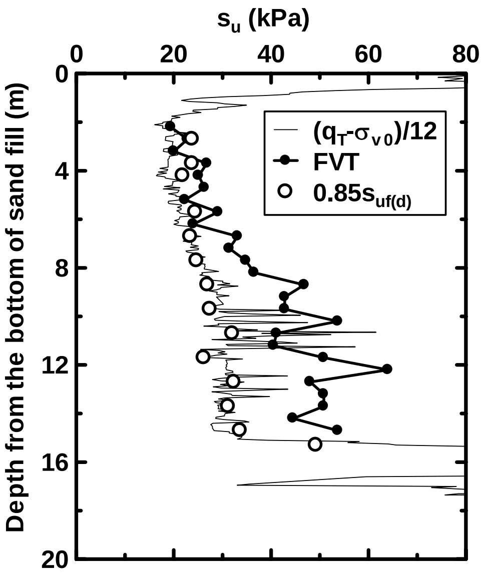

Fig. 5 Undrained shear strength of the soft clay deposit

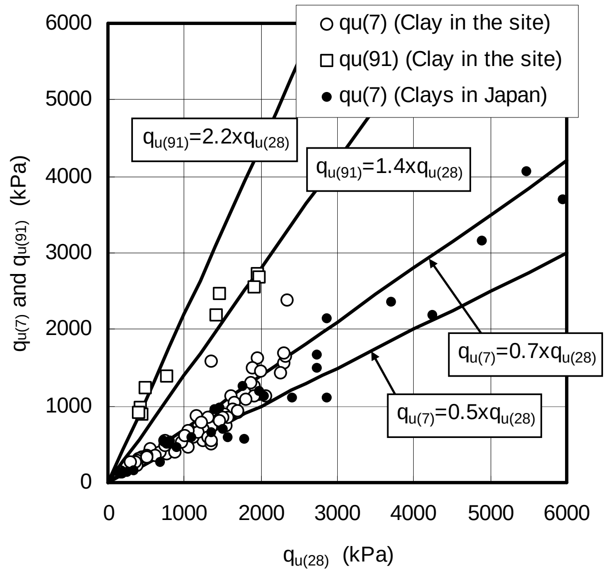

Fig. 6 The ratios of $q_{u(7)}/q_{u(28)}$ and $q_{u(91)}/q_{u(28)}$ for laboratory specimens

deformation rate of 0.25 mm/min with constant volume condition, which is equivalent to undrained shear. This procedure is called recompression method (Jamiolkowski et al. [3]). The size of the specimen for DST is 6 cm in diameter and 2 cm in height. Undrained shear strength for stability analysis can be given by $0.85s_{uf(d)}$ (Hanzawa [4]), where $s_{uf(d)}$ is s_{uf} determined by the above mentioned procedure of DST, and the value of 0.85 is the correction factor for rate effect on shear strength. Figure 5 presents undrained shear strength profile of the soft clay deposit obtained by FVT and DST together with CPTu point resistance q_T-σ_{v0} divided by N_{kT}=12, where σ_{v0} is overburden in total stress. Relatively high values of FVT in the lower depths suggest that the deposit contains a lot sand seems in this portion.

4. LABORATORY TRIAL MIX

The soft clay was sampled to conduct laboratory trial mix, from which relationship between cement content and compression strength can be determined. This relationship gives a basis to decide cement content applied to the field according to strength requirement of stabilized soil. Mixing of clay and cement slurry was carried out according to the standard procedure in Japan [5]. Water-cement ratio of the slurry was 100 %. This ratio was applied for all of the mixing in laboratory and for actual soil improvement in the site.

Ordinary Portland cements manufactured by three local companies were used for the mixing. In laboratory trial mix, a cement from a local company showed better performance than the other two companies. However, in the field trial described later, no substantial difference was found among different cements made by different manufacturers.

Cement mixed soil was filled in plastic molds to make specimens for compression test. The size of the specimen for the test is 5 cm in diameter and 10 cm in height. The specimens were cured in a moist condition for 7 and 28 days. For some mixes, 91-day curing was included. Compression strengths of stabilized soil were measured by unconfined compression test (ASTM D 2166, Standard Test Method for Unconfined Compressive Strength of Cohesive Soil). It was verified through the laboratory trial mix that the difference in clay properties such as water content, plasticity index and clay fraction shown in Fig. 3 did not so much affect compression strength of stabilized soil.

Figure 6 reveals the ratio of 7-day strength $q_{u(7)}$ and 91-day strength $q_{u(91)}$ to 28-day strength $q_{u(28)}$. The figure also shows the data obtained for clays found in various regions in Japan (commentary in Ref. [5]). The ratio of $q_{u(7)}/q_{u(28)}$ ranges from 0.5 to 0.7, and the clay in the site occupies the same range as Japanese clay as presented in the figure, showing that there is no difference in development of compression strength between Vietnamese and Japanese clays. The ratio of $q_{u(91)}/q_{u(28)}$ varies from 1.4 to 2.2.

Fig. 7 Mixing blades of (a) CI-CMC machine and (b) CDM-Land 4 machine

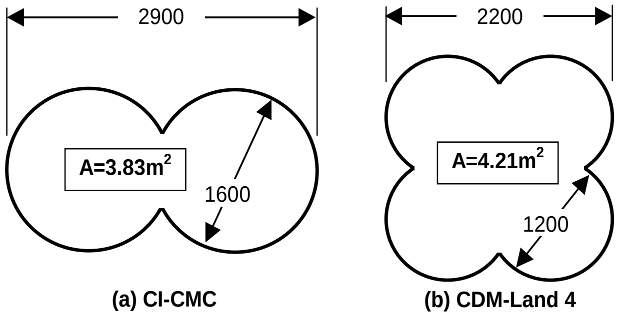

Fig. 8 Cross sections of stabilized soil column used for the project

5. DISTICTIVE CHARACTERISTICS OF DM METHOD USED FOR THE PROJECT

In order to carry out the soil improvement work efficiently and economically, two advanced DM methods, Contrivance-Innovation Clay Mixing Consolidation (CI-CMC) method and CDM-Land 4 method, were employed. Since both methods use slurry form binder, they are categorized into "wet method". CI-CMC method was used for Discharge Open Channel area, and CDM-Land 4 method was used for the other areas. The machines for the methods including slurry plant were shipped to the site from Japan.

The machine for CI-CMC method has two mixing shafts as presented in Fig. 7(a). Each shaft is equipped with mixing blades at three different levels. Slurry injection nozzles are mounted on the lowest blades. The diameter of the blades is 1.6 m. The most important and greatest technical advantage of this machine over conventional ones is in the slurry injection system. Immediately before the cement slurry passes through the injection nozzles, compressed air is mixed with the slurry. The compressed air produces very wide splash of cement slurry as revealed in Fig. 7(a), which greatly improves mixing efficiency. Furthermore, the jet of cement slurry slices surrounding soil, and consequently, reduces resistance of soil against the rotation of mixing blades. Eventually, it becomes possible to use large blades and to make stabilized soil columns that have a cross section larger than conventional method. Since the air comes back to the ground surface during mixing, there is no air remaining in the body of improved soil. A 50 to 60 ton class crawler crane is required as a base machine to mount the CI-CMC system. More detailed description of this method can be found in Harada et al. [6].

The machine for CDM-Land 4 has four mixing shafts as presented in Fig. 7(b). Each shaft has four mixing blades at four different levels. The diameter of the blades is 1.2 m. Although the fundamental technique of improvement such as slurry injection is the same as conventional method, CDM-Land 4 method increases execution speed and reduces construction cost. The improving ability of this method is approximately twice as much as ordinary 2-shaft machine. The same class base machine as for CI-CMC method is needed for CDM-Land 4 method. Yoshida and Kawamura [7] have presented the detail of this method.

Figure 8 shows the dimension of stabilized soil column of each method used for this project. The sectional areas are 3.83 m^2 for CI-CMC method (2-shaft machine) and 4.21 m^2 for CDM-Land 4 method (4-shaft machine). The dimension of the latter is 1.1 times as large as that of the former. Typical cycle time of the improvement in this project is presented in Fig. 9 for both methods. When the depth of improved soil column is around 16 m, CI-CMC method needs 47 min for one operation, while CDM-Land 4 method needs 54 min. The time required for every 1 m improvement is 2.94 min for the former and 3.25 min for the latter. The former is 1.1 times faster than the latter. Therefore, improvement ability of the two methods

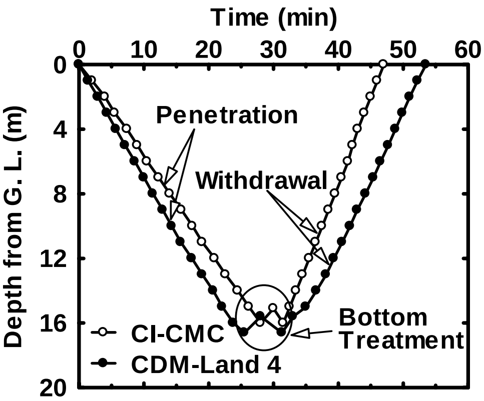

Fig. 9 Cycle time of DM improvement

in terms of square meter for every one minute is the same.

Both methods inject cement slurry during penetration. Rotation of blades continues all the way through the improvement, from the start of penetration to the end of withdrawal, while no injection is made during the process of bottom treatment and withdrawal. Both methods controls and monitors the flow of cement slurry for each mixing shaft.

As can be seen in Fig. 2, stabilized soil column partially overlap with the neighboring columns. When making a column is expected after the hardening of a precedent column has started, retarding agent is sometimes mixed with cement slurry to make the precedent column. Since the improvement work in this project proceeded every day, a special care for overlapping was not needed.

6. TRIAL EXECUTION IN THE FIELD

When there is no enough experience of DM soil improvement in the neighboring area, trial execution is usually carried out in order to confirm performance of DM system and compression strength of stabilized soil column. In some cases, the number of blade rotation and slurry concentration are also subjected to trial in the field. In this project, trial execution for both methods was conducted in Discharge Open channel and Pump Pit areas, and 11 test columns were installed with different amount of cement slurry injection for a unit volume of soil. The number of blade rotation and slurry concentration were fixed. Instead, Ordinary Portland cements from two manufacturers were tested. It was confirmed through the field trial with actual machines that 1) 28-day compression strength $q_{u(28)}$ of all the test columns met the requirement in the contract, 2) there was no difference between cements from two manufacturers, and 3) the machines and slurry plant systems worked as expected.


Fig. 10 Core-pack sampler and undisturbed samples

In order to verify strength characteristics of the test columns, undisturbed sampling was performed continuously from the top to bottom of each test column. This is the most popular procedure in Japan, because uniformity of improved soil can be observed with one's own eyes. The sampler used was “Core-pack Sampler”. It is 1.5 m long and has an outer diameter of 86 mm. The sample length is 1 m and the diameter is 67 mm. The samples are retrieved within a plastic film. Figure 10 shows pictures of the sampler and recovered samples.

The sampling was carried out 7 to 10 days after the test columns were made in order to investigate the values of $q_{u(14)}$ and $q_{u(28)}$. The sampling was also carried out two months later to measure $q_{u(91)}$.

Unconfined compression strength of improved soil at a depth was evaluated by averaging test results for three specimens taken from a 1-meter long sample. Specimens for the test were prepared by cutting the samples by a metal saw. Both ends of the specimen were trimmed by a cutting knife to make flat surface. The specimens were wrapped by plastic film, and cured in a moist condition.

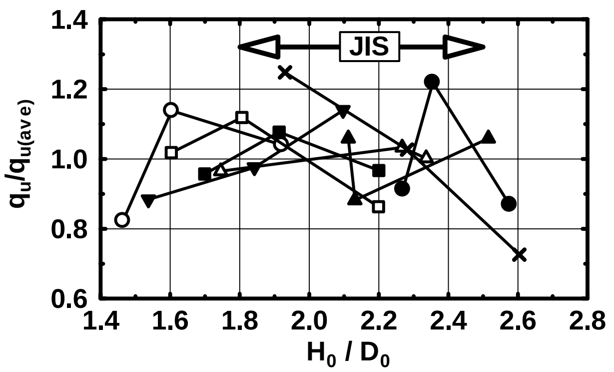

Fig. 11 Effect of specimen height on compression strength

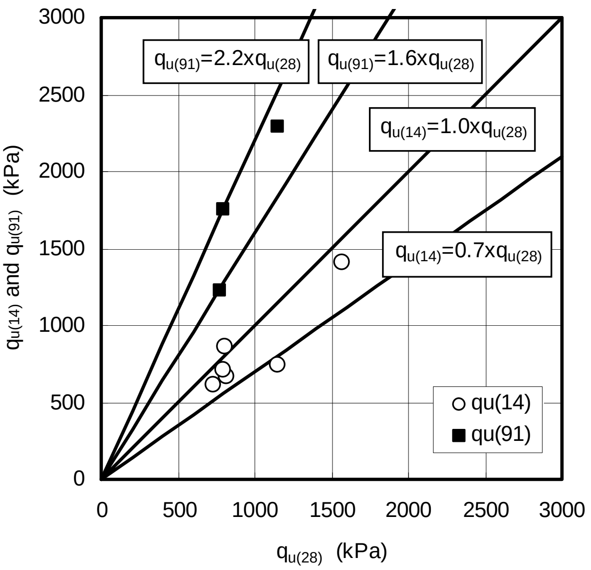

Fig. 12 The ratios of $q_{u(14)}/q_{u(28)}$ and $q_{u(91)}/q_{u(28)}$ for test columns

According to JIS A 1216 (Method for unconfined compression test of soils), the height of specimen should be 1.8 to 2.5 times of the diameter. ASTM D 2166 includes a little stricter requirement: the height should be 2 to 2.5 times of the diameter. Since the diameter of samples was 67 mm, the height of specimens should be around 140 mm. However, because there were some cracks in the samples took place during sampling, specimens were not necessarily met the requirements in the test standards mentioned above. Therefore, some 3-specimen sets include such a specimen that is out of the height requirement in the standards. Figure 11 presents test results for some sets that contain off-JIS specimen. In the figure, H_0/D_0 is the ratio of initial height and diameter, q_u is compression strength of each specimen and $q_{u(ave)}$ is the average of each 3-specimen set. This figure does not show any trend that a smaller height of specimen results in a higher compression strength. It can be said

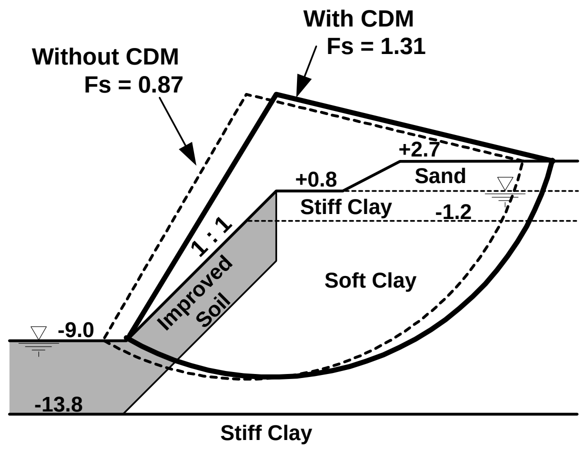

Fig. 13 Slope stability analysis for Pump Pit area

from the figure that the height of specimen never affects compression strength as long as the value of H_0/D_0 exceeds 1.5.

The ratios of $q_{u(14)}/q_{u(28)}$ and $q_{u(91)}/q_{u(28)}$ obtained for the test columns are presented in Fig. 12. The ratio of $q_{u(91)}/q_{u(28)}$ evaluated in the field is from 1.6 to 2.2, which is almost the same as the ratio determined by laboratory-made specimens shown in Fig. 6. The ratio of $q_{u(14)}/q_{u(28)}$ in the filed varies from 0.7 to 1.0, which is between $q_{u(7)}/q_{u(28)}$ and $q_{u(91)}/q_{u(28)}$ determined in laboratory. The compression strength of cement treated soil continues to increase as reported by Ikegami et al. [8], in which very long term strength of cement stabilized soil has been studied.

7. STABILITY ANALYSIS OF THE CUTTING SLOPE

The slope in Pump Pit area is the highest among cutting slopes shown in Fig. 2. How to evaluate the stability of a slope with stabilized soil is very difficult, because it is needed to understand precisely the interaction between very hard improved soil and surrounding soft soil. Although the failure mode of the slope is unknown, conventional approach such as circular slip analysis was employed. The result of the analysis is indicated in Fig. 13 for the cases with and without soil improvement. DM improvement increases safety factor for stability of the slope up to 1.31 from 0.87. Figure 14 reveals the slope in Pump Pit area after excavation. This figure confirms that the slope is stable, and demonstrates that the conventional analysis is acceptable from practical point of view.

Fig. 14 Picture of the slope in Pump Pit area

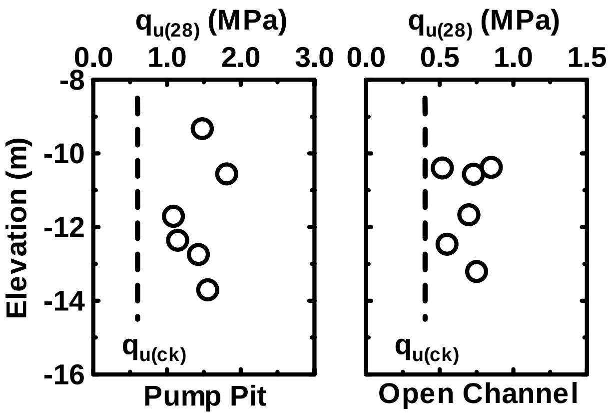

Fig. 15 Compression strength of stabilized soil column.

8. COMPRESSION STRENGTH OF IMPROVED SOIL COLUMN

Bore holes were drilled to take undisturbed samples of stabilized soil with Core-pack sampler as quality assurance activity. Figure 15 presents compression test results (average of 3 specimens) for Pump Pit area and Discharge Open Channel area. This figure clearly shows that The DM improvement was executed successfully and the compression strengths met the requirement specified in the contract.

9. SUMMARY

The DM improvement work for this project started in the middle of June, 2006, at Discharge Open Channel area (CI-CMC method) and Pump Pit area (CDM-Land 4 method). Typical cycle time of DM improvement work is already shown in Fig. 9. The work was carried out on two-shift and the daily progress was about 20 columns for each method. The work finished on 27th of January, 2007. It is confirmed from the DM work in the project that both of the property of improved soil and the performance of DM improvement system are satisfactory. The soil improvement in this project implies that DM method is effective to stabilize soft soils found in the Southeast Asia.

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