PERFORMANCE OF CONSOLIDATION TECHNIQUES FOR IMPROVEMENT OF NEWLY DEPOSITED DREDGED MUD BY SCALE MODEL TEST

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ABSTRACT: As an attempt to promote utilization of newly deposited dredged mud as fill material for reclamation sites, this study observes performance consolidation methods for dewatering of liquid mud which is taken from a lake in Hanoi city. Various tests were conducted to observe basic engineering properties of the mud. Subsequently, sets of scale model tests have been established to simulate both self-weight consolidation and prescribed vacuum consolidation. In the first test, the liquid mud is placed into a steel box and deposited by self-weight of fine particles. In the later test, the liquid mud is preloaded using the vacuum pressure. Test results reveal that the self-weight consolidation method shows very low performance, whereas the vacuum consolidation method give much higher performance. In addition, to address the clogging phenomena, vertical drains among Prefabricated Vertical Drain (PVD), Sand Drain (SD) and Filter Pipe (FP) during vacuum consolidation are investigated based on the monitoring data of settlement, water content, undrained shear strength and influencing zone surrounding the vertical drains. As the goal, the SD is suggested for vertical drain during vacuum consolidation when volumetric strain in case of SD, FP and PVD are 12%, 9.1% and 6.2%, respectively.

Keywords: Dredged slurry, Vacuum consolidation, Self-weight consolidation, Clogging effect, Vertical drains.

1. INTRODUCTION

Along with infrastructure development in Vietnam, large amount of liquid muds has been generating from underground construction, dredging work of ponds and/or lakes in city, streams maintenance for water ways or mining exploring. This quantity of mud has been mainly dumped at the disposal sites by hydraulic pumping method, only small amount has been utilized for reclamation. The dredged mud is normally in fluid state with very low engineering properties and almost no bearing capacity. The disposal sites therefore cause serious environmental and ecological issues at its surrounding area, such as: to destroy the geomorphology and landscape; to occupy the agriculture land; to pollute ground water and change flow direction of rivers or streams; to cause the environmental disasters such as mud floods, landslides, etc. Besides having proper strategy on planning of land fund for disposal sites, utilization of dredged mud as landfill reclamation has been therefore strongly demanded for sustainable development.

Literature and engineering projects both indicate that, there are two solutions have been mainly developed for utilization of dredged mud have been applied around the world as following:

(1) Premixing method: The liquid mud is stabilized by using additives. The methodology is that the dredging muds in liquid states is premixed with one or combined additives such as cement, lime, fly ash, etc by using either technique: pneumatic premixing method [1], lightweight material premixing [2], granular technique [3], etc. The engineering properties of treated soil is then developed with time to become stiffer material for filling.

2). Dewatering method: The liquid mud is placing into the reclamation land by hydraulic pumping. The mud slurry in reclamation is then preloaded to become harder condition. The site is subsequently backfilled to create land fund for infrastructure development. Since the dredging slurry has very low permeability and the storage yard is usually thick, a long period is usually needed to achieve the desired primary degree of consolidation. In recent years, vacuum preloading method [4] has been successfully applied to treat the newly reclaimed mud [5, 6, 7]. However, several difficulties that mainly involve the clogging phenomena and platform construction have been also reported [8, 9].

To propose a proper method for treatment of huge mud quantity dredged from a lake in Hanoi city [10], this study presents the experimental study on the performance of the dewatering by self-weight consolidation and vacuum consolidation preloading methods. The results indicate the performance of vacuum consolidation method on improving the newly hydraulic reclamation mud. In addition, the clogging phenomenal and

performance of vertical drains among PVD, SD and FP during vacuum consolidation will be discussed.

2. SAMPLING

2.1 Project Introduction

To validate performance of the dewatering methods, the liquid mud dredged from a Lake in city is applied in this study. Accordingly, Hanoi City plans to launch a dredging work for "Westlake" to deal with environmental pollution and to promote it to become a future tourist area [10]. The project will generate approximate 1.3 million cubic meters of dredged mud. An area of about 30 hectares would be required for dumping such huge amount of dredging mud, while the land fund of Hanoi city for disposal site has been very limited. In addition, disposal of that huge dredged mud has many consequences impacts for the ecological environment.

Since Westlake covers on wide area (total area of the lake is about 500 hectares), the hydraulic suction technique has been recommended in order to ensure the dredging efficiency and to minimize disturbance on aquatic system, ecosystem and sanitary condition in the Lake. The mud is then temporarily gathered at a designate area within the lake, and it subsequently is transported outside the lake by trucks. Accordingly, the mud shall be dewatered to reduce the free water for ease of transportation. Also, a quantity of clean water can be regained to the lake.

2.2 Engineering Properties of the Dredged Mud

The mud samples have been collected at various locations on overall of the lake for checking basic engineering properties. It is seen from Fig.1 that the mud sample behaves as soup with almost no bearing capacity. Fig.2 shows the grained size distribution curves of several dredged samples. It is seen that the muds have very fine particles in comparison with sands according to the Vietnamese standards.

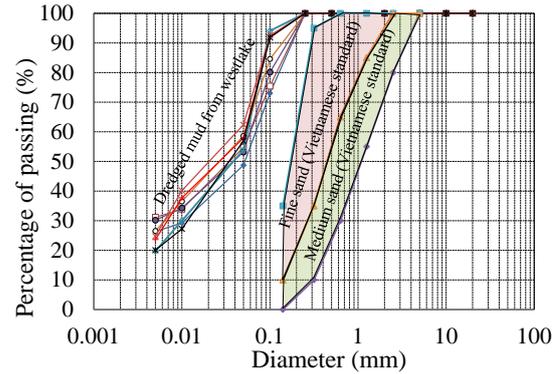Fig.1 Dredged mud sample from Westlake.

Fig.2 Grain size distribution curves of samples

Table 1 shows basic properties of 03 mud samples, where M01 is collected at near the border of the lake, M02 is near the center of the lake M03 locates at between M01 and M02 positions. Notably, the mud has been generated from decay of aquatic plants and animals for many years, so it is very soft with high water content, high void ratio and high organic content. The neutral *pH* values at about 7 also indicate that the mud would be friendly with environment.

Table 1 Physical properties of the mud samples.

No.	γ (kN/m³)	Water content (%)	Δ	Organic content (%)	Clay content, %	pH
M01	13.1	216.3	2.53	11.4	17.7	6.96
M02	12.7	202.5	2.50	22.1	18.6	7.18
M03	12.4	210.9	2.52	18.6	19.4	7.19

X ray-diffraction tests have been conducted according to the ASTM C114 to evaluate the basic chemical components of the mud. The test results derived from Fig. 3 are shown in Fig.4. It is seen that the SiO_2 seems be dominant with about 65% in dry soil mass, and that of Al_2O_3 ranges from 15% to 20% and F_2O_3 varies between 7% and 8%.
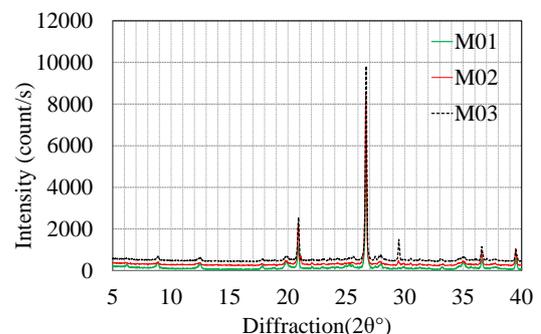

Fig.3   X-ray diffraction results (ASTM C114)

The heavy metal contents in the dredged mud has also analyzed using PV7300 Plasma emission spectroscopy according to TCNB-ICP 01/04 (Vietnamese Standard). Fig.5 shows the typical

heavy metal contents in correlating to the Vietnam National Technical Regulation on Hazardous Waste Thresholds (QCVN 07: 2009/BTNMT). Although the content of several heavy metals (*Ba*, *Zn*) is relatively higher than the threshold values, it is practically validated to be normal fill material.
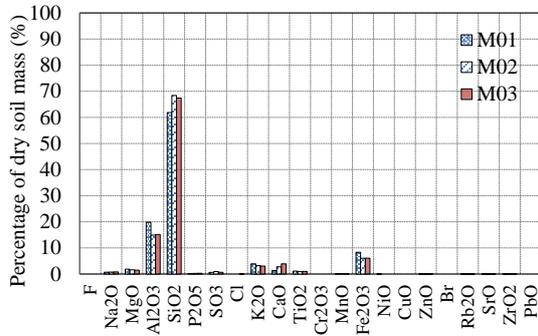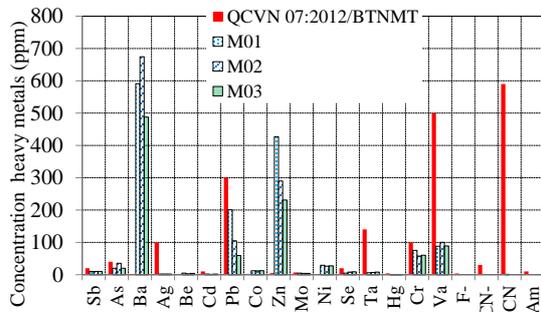

Fig.4 Oxides from X-ray diffraction tests

Fig.5 Concentration of heavy metal in the dredged mud.

3. PERFORMANCE OF CONSOLIDATION TESTS

3.1 Self-Weight Consolidation

3.1.1 Test preparation.
As an attempt to evaluate performance of consolidation of newly deposited dredged mud under self-weight, a consolidation test was conducted on a scale model using a steel box with inner dimensions of 200 cm in length, 150 cm in width and 150 cm in height. According to current technology of dredging sludge by hydraulic suction dredgers, dredged slurry includes 1 part of mud and 3 parts of free water. Therefore, a mixture of 1 m³ of the dredged mud was mixed with 3m³ water in the box to simulate a similar condition of the mixture. The mixture was then stirred to create a homogeneous slurry. The particles settle down with time due to their self-weight. During the process, thickness of mud and free water on the top surface was observed. Equiment and sequence of the test are described in Fig.6.

Fig.6 Sequence of the self-weight consolidation test: a. Preparation of original mud and water mixture; b. Mixture right after stirring; c. Deposition process; d. After deposition and removal of free water on the top surface.

3.1.2 Test results and discussion
The mud layer deposited in the tank is measured at 04 positions (D1, D2, D3 and D4) around the tank during the deposition as shown in Fig.7. It is noted that the mud layer can only be clearly detected after about 1 day from starting time of the test. Under sefl-weight of the mud, a mud layer quickly forms and its volume reduces with time. After about 7 days, volume of the mud layer seems not be reduced. At end of the test, volume of the mud is detected at about 0.98m³.
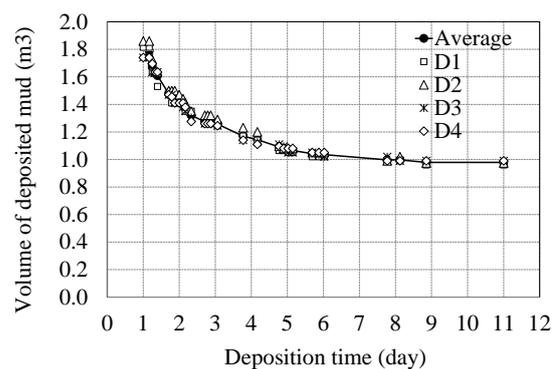

Fig.7 Volume of the mud layer sedimentary from the mixture of mud and water.

Consequently, if the mud slurry after dredging by hydraulic suction is only stored into the closed boundary and mud slurry is therefore only compressed by self-weight, rate of volume reduction will be very less as it is only about 2% for the current project. However, the sedimentary

process could also be governed by scale of the test (thickness of filling layer), particle distribution, type of muds, etc.

3.2 Vacuum Consolidation

3.1.1 Test preparation.

Fig.8 shows schematic of the test. The test equipment mainly consists of several components which are numbered in Fig. 9 as following:

(1): The vacuum system includes a vacuum pump with a power output of 7.5 kW which can generate a maximum vacuum pressure of 95 kPa;

(2): The steel box with dimension of 200 cm in length, 50 cm in width and 150 cm in height (the same box using for self-weight consolidation). The dredged mud was freely poured in the box with thickness of 1 m.

(3): One layer of geomembrane was covered on the top and sealing in the mud to keep airtight condition;

(4): A vacuum gauge is set up right under the geomembrane to monitor the vacuum pressure during loading.

(5): A set of 02 vacuum gauges was also set up at different depths of 0.2m and 0.8 m from the surface in order to observe the transmission of vacuum pressure along the depth.
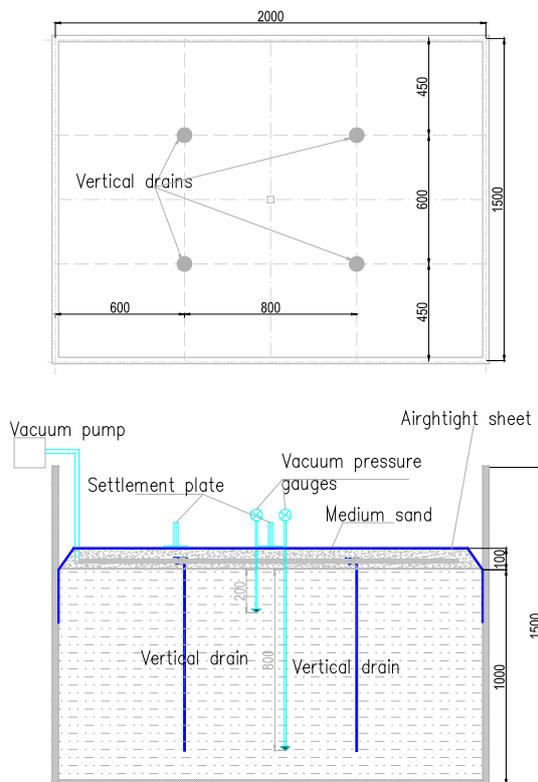

Fig.9   Setting up of the test.

(6): The horizontal perforated pipes wrapped by filter geotextile to connect all the vertical drains.

(7) and (8): To evaluate the effectiveness of different types of vertical drains, this study performed three sets of model tests using either Prefabricated Vertical Drain (PVD), Sand Drain (SD) or Filter Pipes (FP). Detail arrangements of the vertical drains are shown in Fig.8, where the PVD is conventionally comprised a plastic core wrapped by geotextile filter. Permeability coefficient of the filter is 0.014 cm/s. The cross-section of PVD is 100 mm x 3 mm. The SDs with diameter of 5 cm using medium sand were placed in the mud by using a PVC pipe casing, the casing was then carefully removed from the soil. The FP is comprised by a slotted PVC pipe with diameter of 5 cm and wrapped by a geotextile layer for filter. The FPs were also inserted at the same positions with those of PVD and SD. In addition, network of the vertical drains and horizontal pipes was placed into a 0.10 m medium sand layer as using in conventional VCM.

3.1.2 Test results and discussion

1). Distribution of vacuum pressure with depth: Vacuum pressure was monitored during vacuum loading. Fig. 10 presents the vacuum pressure at depth of 0.2 m and 0.8 m from top surface for 03 cases among the vertical drains. The vacuum pressure at shallow depth was quickly reached stable value right after operation of vacuum system. It however needs a specific time to be transmitted at depth of 0.8 m. The delayed time and rising rate increase by sequence of SD, FP and PVD. It can be explained that during a short period of vacuum loading, the whole vacuum loading is focused on

Fig.8 Schematic of the vacuum consolidation test.

the formation of tiny ripples and building of some larger channels. After formation of tiny ripples and building of larger channels inside the soil, the vacuum pressure reaches to stable value because of the silt clogging around the vertical drains, thus no longer development of vacuum pressure can be observed.
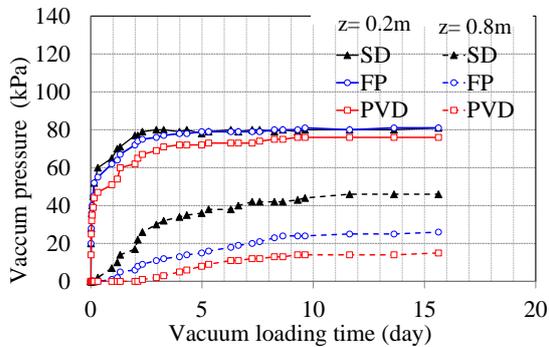

Fig.10 Vacuum pressure during vacuum loading.

2). Settlement and rate of volume reduction: The vacuum loading in case of PVD was removal after about 16 days, until the settlement rate has reached a stable value under 2 mm/day in 5 consecutive days. For a comparison purpose, duration of vacuum loading in other cases of the vertical drains was also be the same.
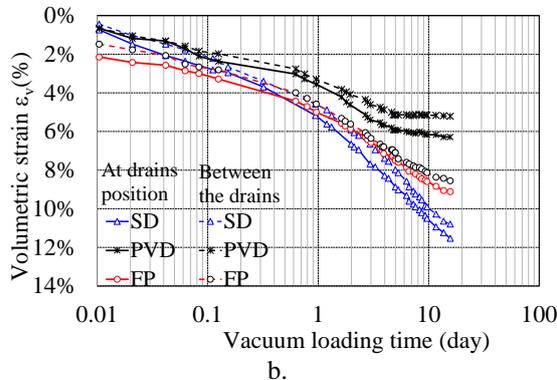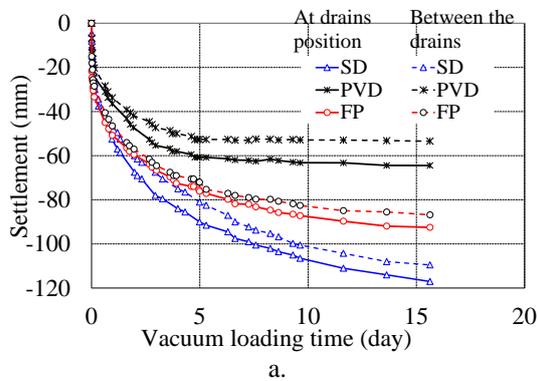

a.

b.

Fig.11 Settlement and volumetric strain during vacuum preloading.

The surface settlement observed at drains location and those between the Vertical Drains location was plotted in Fig. 11.a. Since the test box has very high stiffness, the horizontal deformation could be ignored. Therefore, vertical strain is equivalent to volumetric strain or rate of volume reduction (Fig.11.b). At the end of vacuum loading time, the maximum settlement in case of PVD is only 62 mm with equivalent volumetric strain is 6%. This amount seems be lower than the value reported by Liu [9] as it was 9.3%. However, advantages of SD and FP are revealed with corresponding maximum settlement of 119 mm and 92.5 mm. The equivalent volumetric strain in case of SD and FP is 11.5% and 9.1%, respectively. It is here noted that the volumetric strain or volume reduction rate is a significant parameter for the mentioned project because the transportation cost can be reduced. In addition, the average settlement rate at last 05 days in case of PVD, FP and SD is 1.17, 2.23 and 3.75 mm/day, alternatively. This means that consolidation process as well as workability of FP and SD has still significantly undergone until end of the vacuum loading.

3). Change of engineering properties: After the vacuum loading, variation of water content with distance from the vertical drains and depth was observed. The mud samples were collected at different depths and distances. The variation of water content along the depth at different distances from the vertical drains ($r = 15$ cm, $r = 30$ cm and $r = 45$ cm) and depths from the surface (z=0.2m and z=0.8m) is presented in Fig.12.a. It is seen that the water content increases with the increasing depth and radius distance from the vertical drain in all three cases. This tendency seems be correlated to the transmission of vacuum pressure as mentioned in Fig. 10. However, in case of PVD, water content reduces only about 20% at depth of z = 0.2m and even about 10 % at the depth of z = 0.8 m. Consequently, it can be stipulated that SD case gives the better transmission effect of vacuum pressure, which results in a better preloading effect.

In addition, undrained shear strength, S_u, of the slurry mud before and after vacuum preloading was examined by vane shear test using cutting blade with diameter of 12.7mm and height of 19mm. The test results are shown in Fig.13.b. A significant improvement can be observed after only 15 days of vacuum loading since undrained shear strength of original mud from 1 *kPa* to 2 *kPa* turns to almost over 10 kPa, which is equivalent to that of long-term deposited soft clay. The gained undrained shear strength of clay is relatively lower than the values reported by Wang [6] as it reaches over 20 kPa, it is however noted that the vacuum loading time in the current study is only about 15 days. Moreover, the performance of vertical drains among PVD, FP and SD can somehow reveal since the S_u value increases
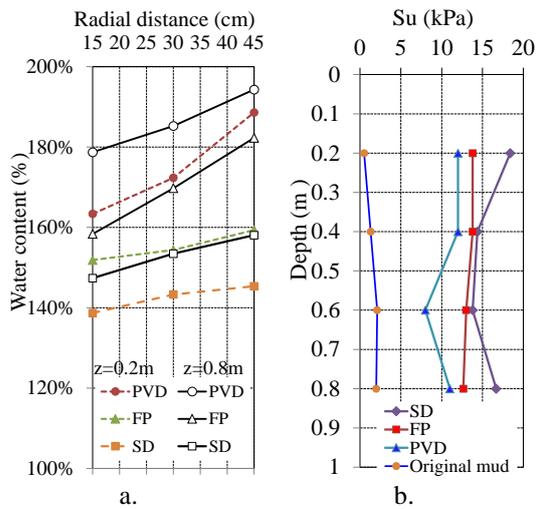
in a sequence.

Fig.12 Variation of water content and undrained shear strength before and after loading.

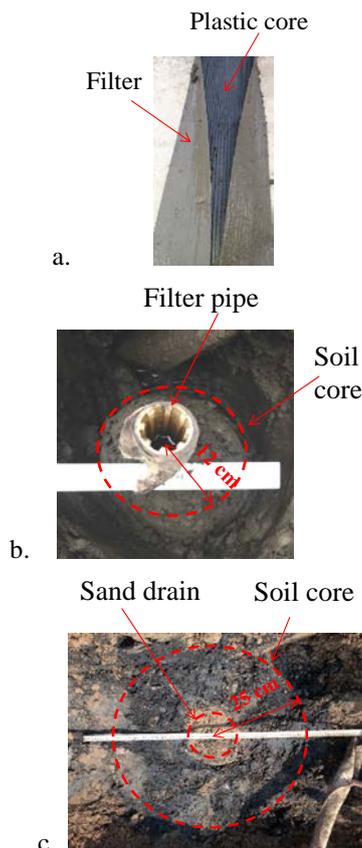*4). Apparent clogging phenomena:*

Fig.13 The vertical drains after removal of vacuum pressure.

Fig.13 shows the vertical drains after removal of the vacuum loading. In case of the PVD, clogging phenomenon was visually observed by necked eye.

A tiny layer of fine particles appeared on surface of filter layer, whereas no soil particle is seen in plastic core (Fig.13.a). In both cases of the FP (Fig.13.b) and SD (13.c) vertical drains, a soil core is clearly created surrounding the vertical drains. In this core area, dredged slurry from liquid state turned into firm state. Radius of soil core in case of FP is about 12 cm, and that in case of SD is approximately 25 cm. Consequently, it is suggested that the SD drain case has a better treatment effect both in decreasing the moisture content and in increasing the process uniformity at different depths.

4. CONCLUSIONS

The dredged mud has been believed to be unsuitable material for reclamation in most case. However, the advanced of VCM creates more possibility to utilize dredging slurry for reclamation, which shall bring benefit in overall cost and environmental protection. Although more detail studies on both technical and economic aspects shall be conducted, following conclusions can be withdrawn from this study:

- The initial dredged mud from the lake which is proposed to be dredged by hydraulic pumping generally has very high-water content and extremely low bearing capacity. These characteristics are challenge if it is utilized for reclamation.
- The dewatering by the self-weight consolidation method proves its low efficiency. Therefore, the dumping sites which are in closed boundary should provide proper drainages in both horizontal and vertical direction to provide more enhancement.
- The performance of VCM for treatment of dredged mud is strongly governed by workability of vertical drains. The conventional VCM combined with PVD may encounter serious clogging problem in vertical drains of high content fine-grained soils. It commonly reduces the drainage efficiency of drainage system, weaken vacuum pressure in soils, and then weaken the soil improvement effect.
- This study recommends SD as a proper countermeasure for vertical drains, since SD shows suitable stiffness, good drainage, and anti-clogging phenomenon. In addition, the sand volume inserted in the mud also increase overall stiffness and bearing capacity of the reclamation area. For practical use, a consideration on both cost and construction feasibility should be detail investigated.

5. ACKNOWLEDGMENTS

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