Dewatering Flocculated Dredged Soil Slurry with Application of Overburden Pressure

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Abstract - *Dewatering of dredged soil slurry is the most important part in land reclamation projects. Since over the years, due to urbanization, there is a rapid growth of population and development of the economy. Hence, land scarcity is one of the major problems faced by people in the world. To solve such problems, the inoperable region must be converted to land for a useful purpose. Such regions include water-logged areas that have high water content, which need to be transformed into useful lands for human needs. The soil slurry collected from these lands is characterized to have low permeability and high compressibility and has nearly or no shear strength. These limitations can be overcome by providing proper dewatering methods. One of the methods used in the dewatering or consolidation process is by using vertical drains in that area. Even though dewatering can be achieved by a natural draining process with the help of vertical drains under an application of an overburden pressure but this may take a bit longer duration than expected. In order to make dewatering more efficient and quicker, flocculants can be added to the soil slurry. With the use of these flocculants, that is., ferric chloride ($FeCl_3$) in varying percentages, dewatering can be effectively achieved. A model test is conducted by applying an overburden pressure on the surface to study the effect of flocculant in the dredged soil slurry under a surcharge preloading. An improved settlement rate and water discharge were obtained with the flocculant-aided soil slurry as 14.12 mm and 809 mL respectively under a surcharge loading when it is compared to the sand drain. This shows that the flocculant at its optimum percentage content can be provided for better dewatering results.*

Key Words: Dredged soil slurry, Flocculant, Model test, Settlement rate, Water discharged, Overburden pressure.

1.INTRODUCTION

Due to urbanization, one of the major problems faced by people around the world is land scarcity. Hence, to overcome such a problem, the available unusable lands need to be reclaimed by the dredging process and converted into usable lands. In some localities which are located near the coastal areas, the dredged soil collected from such areas has a large amount of water present in it. And hence they have very low or no strength at all. They are also said to be highly compressible and have low permeability, which later upon surface disturbance, may cause settlement due to high water content and thus lead to damage to the adjacent structures or to the structure constructed above the ground level. Some may also experience differential settlement due to improper dewatering processes. This is mainly observed in soft soils such as clayey soil and silt where they have low permeability due to its finess nature. Since they are fine particles, it takes a large period for the dewatering or consolidation process. And hence the settlement rate will be smaller. So, before using these types of soils for the land reclamation process, the soil slurry needs to be dewatered properly. Hence the main important part of the land reclamation process is to reduce the water content of the collected dredged slurry by the effective process. There are various techniques for dewatering such as sump wells, simple pumping, gravity drainage, etc. One such method is by applying an overburden pressure on the surface of the ground.

In order to improve the dewatering efficiency, some chemicals can be added to the soil slurry. This helps the individual soil particles to aggregate together and form flocs, which makes dewatering more efficient. In wastewater treatment organic and inorganic chemicals are added, this can also be applied to this dredged soil slurry. Some of the applications of using flocculant are that it can be used for tailing in mixing oil sand and for dewatering.

In this study, model tests are conducted for the collected dredged soil in combination with the flocculant under an overburden pressure.

2. LITERATURE REVIEW

Some of the collected literatures are discussed below;

- Varghese. G et. al. (2012) : The study mainly focuses on dewatering lateritic-lithomarge (L-S) soil with vertical sand drains under a pressure of 50 kg to 200 kg load. It explains the consolidation process using vertical drains which can be used in the construction of roads and railways. The coir fibers used as a reinforcement in the vertical drains improved the consolidation process when they are subjected to an overburden pressure. With the use of 50 % L and 50 % S soil, the settlement rate increased up to 24.8% due to the addition of coir fibers randomly in the vertical drain when it was compared to the same soil combination with no coir reinforcement vertical drain. An increment in settlement rate of 16.1 % was obtained with the addition of randomly placed coir fiber reinforcement in the vertical drain with 25 % L and 75 % S soil combination when compared to that soil mix combination when coir reinforcement was not introduced to the vertical under load variation from 50 kg to 200 kg. For 0 % L and 100 % S combination, a settlement of 32.6 % increase was observed under a load ranging from 50 kg to 200 kg when it was compared to the soil mix with vertical drain alone.

- Chen. S et. al. (2016) : This paper concludes that the use of cationic polyacrylamide (CPAM) shows a better result than other flocculants used. The optimum dosage for CPAM was obtained as 2 kg/t. With the use of jute fiber, sludge dewatering improved by introducing several numbers of pores in the sludge cake along with CPAM and thus offering various numbers of channels for draining but the settlement rate was diminished due to increment in sludge content. It was also observed that with use of hydrogen peroxide (H_2O_2), it could improve the dewatering capacity due to the release of water-bound particles. But, using more than 100 kg/t hydrogen peroxide (H_2O_2) led to negative results. It is said that with the help of CPAM, the settling time and dewatering performance of sludge improved due to a decrease in the binding of particles, neutralizing charges, and by increasing the permeability.
- Absari. F et. al. (2018) : This study shows the comparative study of prefabricated vertical drains under vacuum preloading and surcharge loading. The degree of consolidation achieved at 90% consolidation under vacuum preloading was obtained as 74% which is more effective compared to that under surcharge preloading using Asaoka Method. In both preloading methods, the consolidation settlement linearly increases with time. But it was shown that the settlement that occurred from consolidation under surcharge preloading was more compared to vacuum preloading. By using Asaoka Method, the coefficient of consolidation ratio was obtained as 5.90 in the case of vacuum preloading while the coefficient of consolidation ratio obtained under surcharge preloading was in the range of 2.21 to 4.25. By using PLAXIS 2D, the consolidation time that is required by surcharge preloading was found to be more effective when compared to vacuum preloading with the same loading intensity.
- Fu. H et. al. (2018) : This paper includes the consolidation of dredged slurry under a combination of vacuum preloading and electro-osmosis consolidation using different flocculants. Under the settling column test, the inorganic ferric chloride flocculant showed a better result when compared with aluminum sulphate as a flocculant when used with dredged slurry. But, with the addition of flocculant, an increase in the water discharge quantity was obtained and an increase in the size of soil particles when it was compared to conventional electro-osmosis and vacuum preloading techniques. It also gives a higher average shear strength of the soil. This increases the permeability of the soil and increased the shear strength of the soil. Even though the addition of a flocculant can improve the dewatering performance and the consolidation process of soil, the electrodes used in the electro-osmosis get corroded quickly due to the presence of salt content in the flocculant.
- Cai. Y et. al. (2019) : This study includes the application of flocculants in the dredged sludge under vacuum preloading various conclusions. The optimum flocculant percentage was obtained as 0.08 % for anionic polyacrylamide (APAM) which is an organic flocculant and 0.8 % for ferric chloride ($FeCl_3$) which is an inorganic compound under vacuum preloading by using settling column test. Water discharge was found to be increased to 46.5 % and 56.8 % for APAM and $FeCl_3$ respectively. The heavy metals present in the soil flow out along with water drainage under vacuum preloading. But when flocculant is added to the soil slurry, it gets solidifies by about 80 %. Here, one-tenth of APAM is only required for advanced dewatering compared to $FeCl_3$ when considering the drainage effect.
- Chenhui. L et. al. (2019) : This paper explains the effect of the consolidation process which is conducted in both laboratory and field tests under the influence of vacuum pressure. In soils near the ground surface, the PVD having longer lengths showed much higher vacuum pressure when compared to PVD having shorter lengths. In the laboratory model test, the degree of consolidation and vane shear strength was obtained as 51 % and 18.2 kPa whereas, in the practical test, it was obtained as 72.1 % and 26 kPa below a depth of 6 m from the surface.
- Lu. Y et. al. (2020) : This paper describes the dewatering of the stored landfill sludge using $FeCl_3$ and a Fenton reagent with varying additive contents. It showed that both the reagents had an improving effect consolidation process as well as the permeability of the landfill sludge. The 4 % of Fenton reagent with Fe^{2+} showed better performance than with 8 % content. The permeability coefficient drops below a load of 50 kPa. After the addition of Fenton, it was noted that the initial coefficient of consolidation was higher when compared with that of $FeCl_3$.And it was observed that as the pressure increases the coefficient values also increase until it reaches 100 kPa. The greater influence was observed for the Fenton has a coefficient of consolidation until it

reaches 50 kPa. The $FeCl_3$ provides a coagulation effect and oxidation whereas the Fenton reagent provides depolymerization and oxidation.

3. OBJECTIVES

The main objectives of the study conducted are listed as follows;

- To find the effectives of flocculant when it is introduced to the soil slurry under the application of an overburden pressure.
- To know the optimum percentage of the flocculant which can be added in the soil slurry with the help of vertical drains during dewatering process.
- To determine the rate of settlement when the soil is treated with various percentages of flocculant under an overburden pressure.
- To determine the quantity of water which is discharged during the dewatering process of flocculated soil slurry under a uniform surcharge preloading.
- To compare the settlement rate and the amount of water discharged from the dewatering process under same intensity of continuous application of overburden pressure of both normal soil with vertical drain (NVD) and flocculated soil with vertical drains.

4. SCOPE

The scope for the study can be concluded and they are given below as follows;

- The size of the vertical drain used in the dewatering process can be varied according to the site conditions.
- By providing with a greater number of vertical drains may or may not improve the efficiency of the dewatering performance.
- The materials used to make the dewatering process quicker can be varied according to the cheap availability.

5. MATERIALS USED

The materials used in this study are obtained from various regions and are tested according to the Indian Standard specifications.

5.1 Dredged slurry

The dredged slurry was obtained from Thiruvananthapuram, Kerala, and was found to have a high-water content of 87.36 %. It was darkish grey in color and was found 1.5 m depth below the ground level. Table 2 shows the properties obtained for the dredge slurry in accordance with the Indian Standard. The liquid limit was obtained as 29.00 % and the plastic limit was 20.20 %. Fig. 1 shows the gradation curve according to the IS 2720 (Part 4) - 1985, where the percentage of clay was found as 50.05 % and classified as low plasticity clay (CL). The percentage of clay was obtained as 50.05 % according to the IS code.

Table – 1: Soil Properties

Moisture content, w (%)	87.36
Liquid limit, w_L (%)	29.00
Plastic limit, w_P (%)	20.20
Plasticity index, PI (%)	8.80
Specific gravity, G	2.56
% clay	50.05
% silt	49.95
Soil classification	CL

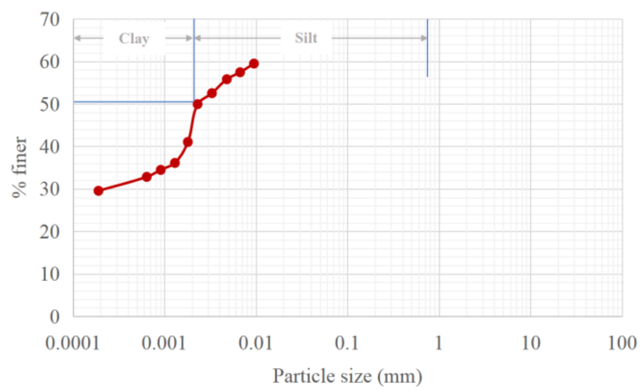

Fig - 1: Particle size distribution of Dredged soil

5.2 Flocculant

Flocculant used in this study is ferric chloride ($FeCl_3$), which is collected from a local market in Thiruvananthapuram, Kerala. These compounds are commonly used in process of waste water treatment during dewatering. It is an inorganic compound used for assisting in dewatering during the consolidation process in the soil slurry. It was obtained in a dry powdered form. Table 2 shows the properties of $FeCl_3$ from the manufacturer.

Table – 2: Properties of Ferric Chloride

Molar mass (g/mol)	162.2
Density (g/cc)	2.9
Melting point (ºC)	307.6
Boiling point (ºC)	316.0

5.3 River sand

River sand was collected from Thiruvananthapuram, Kerala and it was used as a draining material in the vertical drain. It was collected and dried for it to be used as the draining material in the vertical drain. Its properties as shown in table 3. From the soil gradation curve by Indian Standard shown in Fig 2, the uniformity coefficient and the coefficient of curvature were obtained as 6.15 and 1.86 and the soil was classified as well-graded sand (SW).

Table – 3: Sand Properties

Moisture content, w (%)	9.10
Specific gravity, G	2.65
% gravel	1.60
% coarse sand	1.80
% medium sand	28.00
% fine sand	68.60
Uniformity coefficient, C_U	6.15
Coefficient of curvature, C_C	1.86
Soil Classification	SW

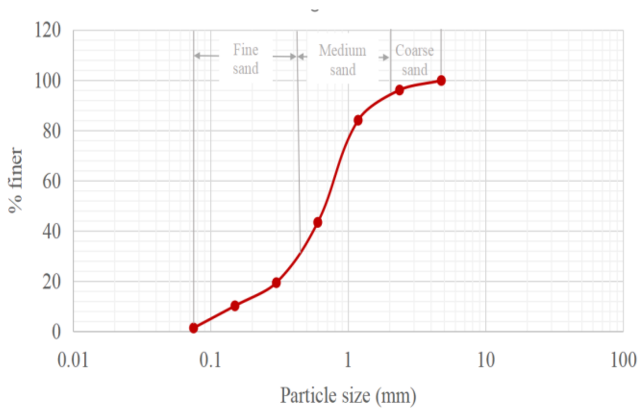

Fig - 2: Particle size distribution of River sand

6. RESULTS AND DISCUSSIONS

The results of the settlement rate and water discharge are obtained under surcharge preloading on the model test and they are as follows;

6.1 Settlement rate

The settlement obtained from the model test under a period of 14-day were obtained for both NVD and flocculant-aided soil slurry.

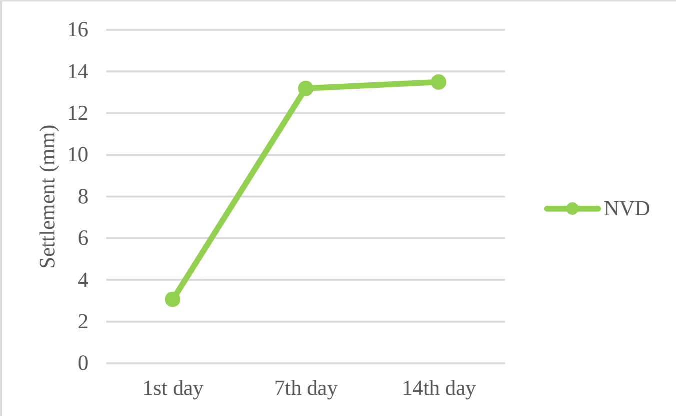

Chart -1: Settlement versus time for NVD

Chart 1 shows a graphical representation of the settlement rate with respect to the duration for normal soil with vertical drain (NVD) where sand is kept as the draining materials. From the graphical representation (chart 1) it is shown that as the duration of surcharge loading increases the settlement rate also get increased. The settlement occurred at the first day was obtained as 3.06 mm for NVD under surcharge preloading and its corresponding settlement occurred at the end of 14-day consolidation process were obtained as 13.49 mm under the same intensity of surcharge loading.

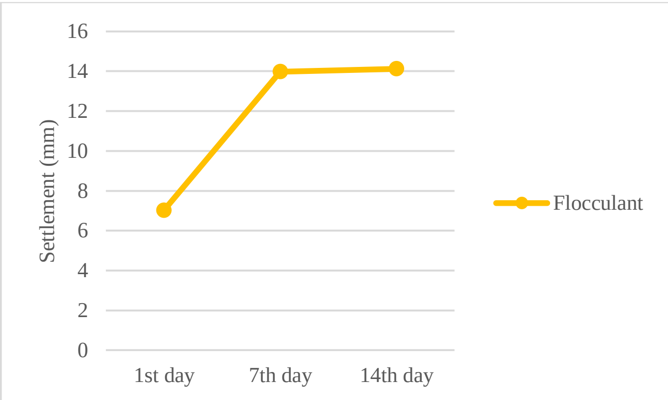

Chart – 2: Settlement versus time for flocculant-aided soil slurry

The same set of the model test was conducted with the soil when flocculant is added to the soil slurry. The settlement rate corresponding to flocculant-aided soil slurry is represented at Chart 2 as shown. The same increment trend in NVD was also observed for flocculated soil slurry, that is., as the duration increases the rate of settlement get also increased. But with the use of flocculant in soil slurry, the settlement rate increased. The rate of settlement occurred from flocculant-aided soil slurry was 7.03 mm at the first day and 14.12 at the end of 14-day consolidation process after the continuous application of surcharge load at its surface.

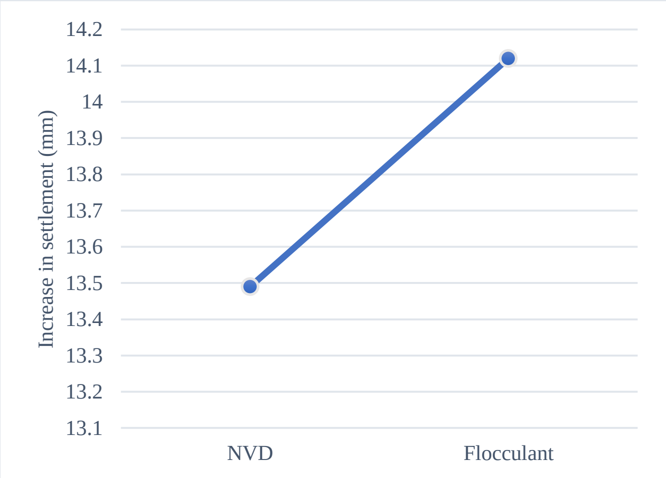

Chart – 3: Variation in Settlement for NVD and Flocculated soil slurry after the 14-day consolidation process

The rate of settlement obtained at 14-day consolidation with the application of surcharge loading of same intensity throughout the period for both NVD and flocculant-aided soil slurry are shown in chart 3. It was observed that, with the use of flocculant in soil slurry, the settlement rate increased from 13.49 mm for NVD to 14.12 mm for flocculated soil slurry.

6.2 Water discharged

The results for water discharge obtained under the application of surcharge loading till 14-day consolidation process were obtained for both NVD and flocculant-aided soil slurry.

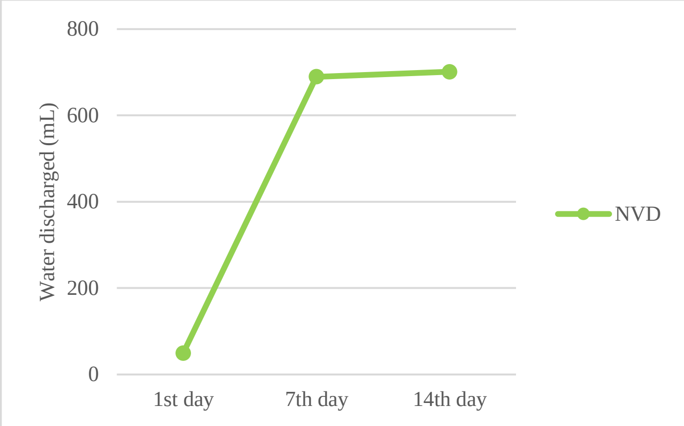

Chart – 4: Water discharge versus time for NVD

Chart 4 shows a graphical representation of water discharged for a duration of 14 days for NVD. It was shown that as time increases the water discharged from the consolidation model will also get increased. The discharge obtained for NVD at the first day were obtained as 49 mL and at the end of 14-day consolidation were obtained as 701 mL under surcharge loading of continuous application of load till the end of 14-day consolidation process.

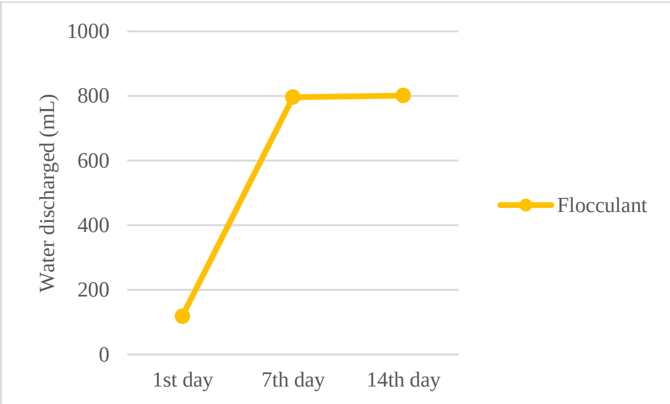

Chart – 5: Water discharge versus time for flocculant-aided soil slurry

The water discharged with respect to duration is represented in Chart 5 as shown for flocculant-aided soil slurry. The water discharge was also increased in case of flocculant-aided soil slurry when the time increases. The water discharge at 1st day were obtained as 119 mL and 801 mL at the end of 14-day when flocculant is added to the soil slurry. With the use of flocculant at its optimum content, the water discharge was found to increase when compared to other percentages of flocculant.

[8] Chenhui. L, Junfeng. N, Jingchun. ,Hongtao. F, Xiuqing. H, Donghai. X, Youchang. L, Zhi. G, Zhengde. X & Qiang. Y, "Consolidation Effect of Prefabricated Vertical Drains with Different Lengths for Soft Subsoil under Vacuum Preloading", Advance in Civil Engineering, Vol. 2019, 12 pages.

[9] Fu. H, Hu. X, Li. X, Wang. J, Yuanqiang. C & Zhao. R, "Vacuum preloading and electro-osmosis consolidation of dredged slurry pre-treated with flocculants", Engineering Geology, Vol. 9, September 2018.

[10] Lu. Y, Tran. C. Q, Vu. V. Q, Wu. Y, Yao. J & Zhang. X, "Insight into conditioning landfill sludge with ferric chloride and a Fenton reagent: Effects on the consolidation properties and advanced dewatering", Chemosphere 252, pg: 126-528, August 2020.

[11] Hu. Z (2021), "Experimental study on flocculation-Vacuum-Electroosmosis method for strengthing soth soil foundation in coastal area", Earth and Environmental Science,Vol. 643, pp: 012167.

[12] Jia. H, Jian. C, Keat. T. S, Pang. L. K & Trang. V. T (2017), "Sedimentaation behaviour of flocculant-treated soil slurry", Marine Geosources & Geotechnology,Vol. 35 (5), pp: 593-602.

[13] John. J & Thomas. U (2016), "Improvement of Coir Reinforced Clay Soil by Natural and Synthetic Prefabricated Vertical Drains", International Journal of Engineering Research & Technology, Vol. 5, Issue 03, ISSN: 2278-0181.

[14] Khoteja. D, Pan. Y, Pu. H & Zhou.Y (2021), "Rapid treatment of high-water-content dredged slurry using composite flocculant and PHD facilitated vacuum", Marine Georesources & Geotechnology.

[15] Kiran. N. M. B, Prasad. V. S. D & Shivanarayana. C (2016), "Stabilization of Marine Clay Using Ferric Chloride and Quarry Dust", International Journal of Engineering Research and Development, Volume 12, Issue 3 (2016), pg: 01-09.

[16] Varghese. G, Ramakrishna. H, Kumar. H. G. N, Prashanth. L. D & Santosh. G, "A Model Study on Accelerated Consolidation of Coir Reinforced Lateritic Lithomarge Soil Blends with Vertical Sand Drains for Pavement Foundations", Open Journal of Soil Science, Vol. 2, Issue 3, September 2012.