Study on physical and mechanical properties of flowing mud in the Shenzhen area

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Abstract. Flowing mud is a kind of special soil with fluidity under gravity. It is found that the flowing mud has ultra-high water content, high limit moisture content, and its strength is very low due to the large amount of free water. Therefore, the shear strength evaluation is not appropriate. With the increase of preloading load, the shear strength increases continuously. However, the coefficient of consolidation is small and the consolidation time is long.

1. Introduction

In water transport engineering, a kind of fluidness silt is often encountered, which has the characteristics of high water content, high void ratio, very fine soil particles and very low strength. This kind of soil is called flowing mud, which can be divided into two types according to its genesis. One is the beach and bottom mud formed naturally by water environment and the other is the dredged soil formed by dredged mud and hydraulic fill. It is very difficult to reinforce the foundation when the construction is carried out on the flowing mud. The cost is high and the effect is poor [1-2].

2. Project Introduction

Qianwan Bay of Shenzhen is adjacent to the Pearl River Estuary and Lingdingyang in the West. In Shenzhen Qianwan reclamation project, nearby dredged soil was used to form the land area, and the vacuum combined preloading method was used to reinforce the foundation. In order to analyze the physical and mechanical properties of flowing mud in construction area, a special experimental study was carried out.

The soil was sealed for storage and transportation, and there was no obvious bleeding phenomenon after it was delivered to the laboratory. Moisture content tests, density, specific gravity tests, limit moisture content tests, grain distribution analysis tests, material composition tests, consolidation shear test tests and vane shear tests were carried out.

3. Physical properties of flowing mud

Soil moisture content ranged from 93.4% to 98.6%, with an average of 95.7%; density ranged from 1.45g/cm³ to 1.50g/cm³, with an average of 1.48g/cm³; specific gravity ranged from 2.739 to 2.774, with an average of 2.759. Thus, the uniformity of soil was good.
104 groups of limit moisture content tests were completed by photoelectric liquid plastic limit combination instrument. The cone depth distribution corresponding to the moisture content was shown in Figure 1.

![Figure 1. Relationship between water content and cone depth](image)

When the depth of 76g cone sinking into the soil sample is 10mm, the moisture content is the liquid limit. The liquid limit moisture content of flowing mud was 48.0% to 56.8%, with an average of 51.2%; the plastic limit was 22.5% to 34.0%, with an average of 27.6%; the plasticity index was 19.0 to 28.9, with an average of 23.6%.

4. Shear test results of micro vane

The flowing mud formed by hydraulic filling has high moisture content and low strength, which can flow under gravity. The strength of the soil cannot be measured by ordinary geotechnical test instruments, such as the direct shear apparatus and the triaxial test apparatus. In order to study the strength characteristics of this kind of fluid soil, the mud micro vane shear apparatus was selected for shear test \[3\]. Its structure is the same as that of the conventional vane shear apparatus. The specification of cross plate head was D20mm × H40mm × 1mm, as shown in figure 2. 1g - 20g weight were used to load step by step until they were damaged. A total of 30 groups of experiments were carried out, with an average value of 1.10kPa, a minimum value of 0.67kPa and a maximum value of 2.27kPa. The results show that the shear strength of the vane is very low, it is easy to be disturbed and its sensitivity is high.

![Figure 2. Cross plate head](image)

Water plays an important role in the strength of fine-grained soil. Water is attached to the surface of soil particles first, and the combined water of two soil particles is affected by the common gravity of two adjacent soil particles at the same time, forming a certain connection strength between the two soil particles. With the increase of soil moisture content and the increase of soil particle spacing, the gravitation between the two soil particles decreases, and the corresponding gravitation of combined water also decreases. Because of the large degree of freedom of water, its dynamic coefficient of viscosity is far less than the friction coefficient between soil particles. Therefore, with the increase of the thickness of the combined water, the friction resistance of the relative movement between the soil
particle decreases, that is, with the increase of the water content, the shear strength of the soil decreases gradually. When the content of combined water exceeds the maximum holding capacity of soil particles, free water will appear in the soil, which will greatly reduce the connection strength between the soil, and the shear strength will rapidly decrease with the increase of water content. With the increase of water content, the friction and attraction between soil particles have become very small, and the shear strength of soil tends to zero. There is a large amount of free water in the mud, which leads to its very low strength. The water content of the test sludge is up to 95.7%, which is twice of the liquid limit. For this kind of flow soil with very low strength, the shear strength should not be used, and the dynamic coefficient of viscosity is recommended as the evaluation index.

5. Shear test results of consolidated quick direct shear test
In order to study the shear strength of the soil strengthened by flowing mud, the direct shear tests were carried out after the soil samples were preloaded and consolidated. The preloading loads were applied in stages, and the last stage loads were 50, 75, 100, 125, 150, 200, 300, 400kPa respectively. After the deformation of samples was stable under the last stage load, the loading was continued for three days to eliminate secondary consolidation. Due to the large consolidation deformation of the flow mud, the height of the samples was obviously reduced, so the shear containers were properly treated to ensure that the shear plane was in the middle of the height of soil samples.

The shear test was carried out by electric four-way direct shear apparatus. The vertical load was equal to the preload load, and the shear rate was 0.8mm/min. The data were collected by computer. The shear displacement of soil samples was generally 5mm-6mm. If the shear deformation had peak strength within 4mm, the peak strength was taken as the shear strength. If there was no obvious peak value, the shear strength corresponding to 4mm deformation was taken as the shear strength. It is found that the peak strength of most samples is not obvious when the deformation is less than 4mm.

158 groups of consolidated fast shear tests are carried out, and the test results are shown in table 1 and figure 3.

| vertical load (kPa) | 50 | 75 | 100 | 125 | 150 | 200 | 300 | 400 |
|---------------------|----|----|-----|-----|-----|-----|-----|-----|
| Avg                 | 19.7 | 27.5 | 33.3 | 39.9 | 44.8 | 58.6 | 83.8 | 110.5 |
| Max                 | 27.3 | 39.4 | 43.8 | 53.8 | 59.0 | 72.9 | 108.5 | 138.4 |
| Min                 | 16.1 | 19.2 | 22.6 | 23.9 | 37.0 | 44.4 | 51.2 | 68.2 |

Figure 3. Relationship between vertical load and shear stress
From the data in table 1, the average shear strength of the tested soil can be calculated:

\[ c_{eq} = 7.4kPa, \phi_{eq} = 14.4^\circ \]
Compared with the results of the vane shear test, the shear strength of the consolidated flowing mud increased significantly, and with the increase of the preloading load, the shear strength continued to increase. However, due to the small coefficient of consolidation, it takes a long time for preloading to reach stability\cite{4}. Therefore, the strength of flowing mud can be improved, and how to improve its strength growth rate will be the direction of future research\cite{5}.

6. Conclusion and suggestion
(1) Flowing mud has the basic characteristics of high moisture content, high limit moisture content, high compressibility, low density, low strength and low coefficient of consolidation, which belongs to the typical soft soil.

(2) It is found that there is a large amount of free water in the mud, which leads to its very low strength. For this kind of flow soil with very low strength, the shear strength should not be used, and the dynamic coefficient of viscosity is recommended as the evaluation index.

(3) Because of the high pressure shrinkage and the low consolidation coefficient, the deformation of the sample is large and the consolidation process is slow. After consolidation, the shear strength of soil sample is obviously improved, which shows that drainage consolidation method is feasible in theory. The future research focus is to improve the strength rate of flowing mud.

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