Influence of silt content on shear strength of sandy soil

Jinbu Li¹, Hao Geng², Guorong Zhang³, Guangri Jin⁴*

¹Department of civil engineering, Yanbian University, Yanji, Jilin, China
²Department of civil engineering, Yanbian University, Yanji, Jilin, China
³Department of civil engineering, Yanbian University, Yanji, Jilin, China
⁴Department of civil engineering, Yanbian University, Yanji, Jilin, China

First author: Jinbu Li (2000 -), male, born in Rizhao, Shandong Province, majoring in geotechnical mechanics. e-mail: 1987793456@qq.com.

Corresponding author: * Guangri Jin (1980 -), male, from Yanbian, Jilin Province, Ph.D., master supervisor, mainly engaged in geotechnical mechanics. e-mail: grjin@ybu.edu.cn.

Received date: January 10, 2021

Abstract: Direct shear tests were carried out on silt standard sand specimens with four silt contents of 0%, 5%, 10%, 20% under three conditions of average maximum dry density, optimal moisture content and saturation, respectively. The effects of different contents and different states on internal friction angle and cohesion of sand specimens were studied. It is found that the internal friction angle and cohesion increase with the increase of silt content under the condition of average maximum dry density and optimal water content, and with the increase of silt content, the internal friction angle decreases and the cohesion increases in saturated state.

1. Introduction

On the one hand, the shear strength is of great significance for the safety of the project [1]. The failure of the soil in the project is usually shear failure, such as the landslide of the slope engineering, the extrusion of part of the soil along a sliding surface when the foundation bears too much load. The generation of the sliding surface in the soil is caused by the shear stress on the sliding surface reaching the shear strength of the soil [2]. So it is very important to study the shear strength of soil.

On the other hand, under the hydraulic action, silt is widely distributed in the river basins in China after long-distance carrying and depositing. Silt and sand are common soil types in engineering construction, which can be seen everywhere along the river [3]. In the natural state, muddy silt and sand are interlaced and fused with each other under the long-term geological structure and external load, and the relative content changes. However, it sometimes goes through the process of humidification and dehumidification, which seriously affects the ability of soil to resist load and makes the shear capacity of soil change significantly. Therefore, it is very important to study the relationship between different contents of muddy silt and different water contents on the shear strength characteristics of sandy soil. In this paper, the relationship between the shear strength index of sandy soil and different contents of muddy silt and water content is studied and analyzed. The purpose is to understand the variation law of shear strength characteristics of sandy soil under the condition of different contents of silt and different
water content, and to provide mechanical parameters for the mixing of silt and sandy soil in foundation construction site in the future.

2. Materials and test methods

2.1. Raw materials
The sand used for the test is ISO standard sand of China, which is produced by Xiamen ASO standard sand Co., Ltd.

The mucky silt used for the test is local soil, which is collected near Yanxi bridge in the middle and lower reaches of Buerhatong River in Yanji city. It passes through a 0.075mm diameter sieve, and then is washed, precipitated and dried.

2.2. Physical property experiment of materials
In order to study the influence of silt content and moisture content on shear strength of sandy soil, a series of basic physical properties experiments were carried out.

2.2.1. Gradation analysis test. The sieve analysis test of grading analysis (SL237-1999) is carried out for sand with 0% silt content and three kinds of silt standard sand combinations with 5%, 10% and 20% silt content respectively. The grading curve obtained from the test is shown in Figure 1.

![Figure 1 grading curve of test soil sample](image)

When the silt content is 0%, only in the case of sand, the mass percentage of the soil with the maximum particle size less than 0.075mm is 0.07%, the mass percentage of the soil with the diameter less than 0.25mm is 22.68%, the mass percentage of the soil with the diameter less than 0.5mm is 35.24%, the mass percentage of the soil with the diameter less than 1.0mm is 70.11%, and the mass percentage of the soil with the diameter less than 2.0mm is 99.93%. Gradation analysis shows that the curvature coefficient is 1.207, the coefficient of non-uniformity is 5.625, and the gradation is good. According to the classification standard of GBJ145 - 90 soil, the code of the soil is SW.
2.2.2. Liquid plastic limit test. The liquid plastic limit joint test (SL237-1999) was carried out on the mucky silt used in the test, and the liquid plastic limit curve image is shown in Figure 2.

The liquid limit and plastic limit of the silt are 38.2 and 28.5, respectively.

2.2.3. Compaction test. The compaction test (SL237-1999) was carried out on the sandy soil and silt used in the test, and the experimental results are shown in Table 1.

| name      | relative density (g/cm³) | Maximum dry density (g/cm³) | Optimum moisture content (%) |
|-----------|--------------------------|----------------------------|-----------------------------|
| Standard sand | 2.71                     | 1.85                       | 1.28                        |
| Silt      | 2.654                    | 1.43                       | 6.20                        |

The specific gravity of sand is 2.71g/cm³, the maximum dry density is 1.85g/cm³, and the optimal water content is 1.28%; the specific gravity of silt is 2.654g/cm³, the maximum dry density is 1.43g/cm³, and the optimal water content is 6.20%.

2.3. Experimental methods
The test method is carried out in accordance with the "geotechnical test regulations" (SL237-1999) [4]. The size of the test piece is Φ 150 mm × H300 mm. The shear speed was 1 mm / min, and the slow shear (s) method was used.

The test specimen is divided into three conditions
The first type is the average maximum dry density group (the maximum dry density of sand is 1.85g/cm³, and the maximum dry density of silty soil is 1.43g/cm³. Combined with the test results, we control the maximum dry density of the sample to be 1.64g/cm³ of the average value of silt and sand.) The second category is the optimal moisture content group, and the third type is the saturated state group (the sample bubble is 24h in pure water, so that it is fully saturated).

There are four kinds of silt standard sand specimens with silt content of 0%, 5%, 10%, 20% in each category. The specimens under different test conditions (3 × 4) are subjected to horizontal shear force along the fixed shear plane under the action of vertical compressive stress of 50kpa, 100kpa and 200kpa respectively.
3. Experimental results and analysis

3.1. Experimental results
In order to understand the variation of shear strength characteristics of sandy soil with different silt content and water content, direct shear test was carried out. The variation results of internal friction angle and cohesion are shown in Fig. 3 and 4 respectively.

![Figure 3](image1.png)  variation curve of internal friction angle
![Figure 4](image2.png)  cohesion curve

3.2. Result analysis
For the internal friction angle obtained in the experiment, the experimental results can clearly find that the internal friction angle obtained in the saturated state is less than that in the maximum dry density and the maximum water content; and with the increase of silt content, the internal friction angle obtained in the maximum dry density and the optimal water content also increases gradually, and decreases gradually in the saturated state small.

From the test results of cohesion, it is obvious that the average maximum dry density of cohesion in any silt content state is greater than the optimal moisture content, and the optimal moisture content state is greater than the saturated state, and the cohesion of specimens shows an upward trend with the increase of silt content in the three test cases.

Under the condition of average maximum dry density, when the silt content is 0%, the internal friction angle is 28.462 ° and the cohesion is 0.951kpa. At this time, the material composition of the specimen is only sand. When the silt content is 5%, the internal friction angle rises to 28.99 ° and the cohesion rises to 1.7536kpa. Compared with the silt content of 0%, the overall density of the specimen increases slightly, and the soil becomes slightly dense. The change of dry density is an important factor affecting its deformation strength characteristics [5]. The cohesive force between soil particles is slightly strengthened, and the cohesive force between soil particles is more compact, so the internal friction angle and cohesive force increase. When the content of silt changes from 5% to 10%, the internal friction angle becomes 34.82 ° and the cohesion becomes 2.668kpa. At this time, the overall density of the soil increases slightly, and the suction between soil particles increases, so the internal friction angle and cohesion increase. When the content of silt becomes 20%, the internal friction angle becomes 37.525 ° and the cohesion becomes 4.126kpa. At this time, the density of soil particles in the specimen increases, the silt is obvious, and the properties of soil tend to silt, so the internal friction angle and cohesion increase.

Therefore, because the dry density of silt is less than that of sand, with the increase of silt content, the density increases correspondingly, and the occlusion between soil particles becomes stronger, which is similar to the research conclusion of Huang Ze et al. [6], the cohesion between soil particles becomes larger, and the resulting strength has a certain trend of increasing.

Under the optimal moisture content, when the silt content is 0%, the internal friction angle is 27.144 ° and the cohesion is 0.27kpa. At this time, the material of the specimen is only sand, and the actual
optimal moisture content of pure sand is less than the optimal moisture content. The difference between the two values is the largest. When the silt content is 5%, the internal friction angle is 30.785° and the cohesion is 1.168kpa. Therefore, the internal friction angle and cohesion increase. When the silt content changes from 5% to 10%, the internal friction angle becomes 34.092° and the cohesion becomes 1.265kpa. The difference between the two kinds of moisture content values is more reduced, and the degradation of water is also relatively reduced. Therefore, the internal friction angle and cohesion show an increase. When the silt content is 20%, the internal friction angle is 39.943° and the cohesion is 2.856kpa. At this time, the real optimal moisture content of the sample material is closer to the optimal moisture content. For the sample soil, the excess water is relatively reduced, and the degradation of water is also relatively reduced, so the internal friction angle and cohesion are increased.

With the increase of silt content, the increase of density and the decrease of void ratio, the water in the soil mainly exists in the form of binding membrane around the soil particles, while the water in the binding membrane cannot move, which is also conducive to the exertion of the surface tension of water in the soil [7]. Therefore, with the increase of density, the strong binding force between the water in the water membrane and the soil particles also makes the strength increase to a certain extent.

In the saturated state, when the silt content is 0%, the internal friction angle is 27.872° and the cohesion is 0.01kpa, the non lubrication effect of water is prominent on the polished surface such as quartz [8], and the pure sand contains a large amount of quartz, which makes the effect obvious, and the particle shape has an impact on the shear strength of sand [9] at this time, the particle diameter of the sample is relative to other silt content When the silt content becomes 5%, the internal friction angle becomes 25.641° and the cohesion becomes 0.704kpa, The diameter of soil particles is relatively smaller, the content of soil particles is relatively increased, and the cement is also relatively increased. Water can degrade the cement [10], so the internal friction angle is reduced, but the change of soil mineral composition has a greater impact on the cohesion [11], so the cohesion is increased. When the silt content is 10%, the internal friction angle is 20.567° and the cohesion is 1.0296kpa, and when the silt content is 20%, the internal friction angle is 20.567° and the cohesion is 1.0296kpa The internal friction angle becomes 17.203° and the cohesion becomes 1.597kpa, because with the increase of cement, the cementation of water becomes obvious, and the cementation between soil molecules decreases, so the internal friction angle becomes smaller, but the cohesion still increases due to the change of composition.

Water has two harmful effects on soil. On the one hand, the existence of water will reduce the suction between soil particles; on the other hand, the existence of pore water will change the effect of applied stress, and then affect the mechanical properties of soil. This is similar to the conclusion of Hu Zhanfei [12]. With the increase of water content, cohesion and internal friction angle decrease to some extent, which is similar to that of Yang Xuehui [13].

4. Conclusion
The results show that the influence of silt content on shear strength of sandy soil is as follows

1. Under the condition of maximum dry density and optimal water content, with the increase of silt content, the internal friction angle and cohesion show an upward trend. Under the condition of saturation, the internal friction angle shows a downward trend and the cohesion shows an upward trend.

2. The internal friction angle and cohesion of the specimen under saturated condition are less than those under maximum dry density and maximum water content.

Acknowledgments
Thank you for your help and support.

Fund Project
first class undergraduate major construction project of Yanbian University (ydjf [2020] No.16)

Reference
[1] Yang, J. (2020) Discussion on foundation and construction safety [J]. Value engineering.
[2] Chen, X., Lin, J. (2013) Soil mechanics Foundation (5th Edition) [M]. Tsinghua University Press, Beijing.

[3] Wang, Q., Zhang, W., Xi, W. (2011) Experimental study on silt foundation loading in Yellow River alluvial plain [J]. Construction Technique.

[4] Ministry of Water Resources of the People's Republic of China. Specification for geotechnical test: SL237-1999[S]. (1999) China water resources and Hydropower Press, Beijing.

[5] Huang, W. (1983) Engineering properties of soil [M]. Water resources and Hydropower Press, Beijing.

[6] Huang, Z., Zhang, P., Xiao, D., Yang, F. (2015) Experimental study on shear strength of remolded loess [J]. Sichuan Architecture Science Research Institute, 41(04): 36-39.

[7] Bai, L., Ma, W. (2018) Study on properties of artificial silt with different sand content [J]. Journal of the Yangtze River academy of Sciences, 35(02).

[8] JAMES K.M. (1988) The principle of soil property analysis in geotechnical engineering [M]. Nanjing Institute of Technology Press, Nanjing.

[9] Liu, Q., Xiang, W., Lehane, B.M. et al. (2011) Experimental study on influence mechanism of particle shape on shear strength and pile tip resistance of sandy soil [J]. Journal of rock mechanics and engineering, 30(2): 400-406.

[10] Li, G. (2004) Advanced soil mechanics [M]. Tsinghua University Press, Beijing.

[11] Lu, Z. (1999) Study on shear strength of unsaturated soil [J]. China Railway Science, 20(5): 10-16.

[12] Hu, Z., Fu, Y. (2001) Experimental study on shear strength of soft clay with different initial moisture content [J]. Shanghai geology, (1): 38-42.

[13] Yang, X., Dang, J., Jiang, C. (2008) Triaxial test of unsaturated remolded loess [J]. Subgrade engineering, (4): 139.