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Study on Cone Penetration Test of Sand Layer along Southwest Coast of Hainan Island

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Abstract. Coastal dunes are widely distributed along the southwestern coast of Hainan Island paralleling to the coastline. Cone penetration test is a commonly used in-situ testing method in geotechnical engineering, it has strong advantage in sand layer which is difficult to obtain undisturbed sample. Through the cone penetration tests and the laboratory test on sand with different densities and grain size distributions, the correlation between in-situ test index and laboratory test index was analyzed. It is found that the hit number of standard penetration test is linearly correlated with the tip resistance of cone penetration test, so the density of sand can be judged by the value of tip resistance. The content of silt and clay in sand has a great influence on side friction and friction ratio of cone penetration test, and the friction ratio is linearly related to the content of silt and clay. For different sand with same geological origin, the particle-size distribution has great impact on the friction ratio, the larger the main particle size is, and the smaller the friction ratio is. For same sand with different geological origin, the content of silt and clay of sand is different, and the cone penetration test curve and the particle-size distribution curve are also different.

1. Introduction

The coastal dunes are widely distributed along the southwestern coast of Hainan Island in parallel with the coastline, and the thickness of the sand layer on the dunes is relatively large. As the Hainan International Tourism Island, the "21st Century Maritime Silk Road" and other national strategies advance, the infrastructure construction in Hainan Island has taken on booming situation, all kinds of infrastructure is relatively concentrated on the coastal areas, whose foundation soil all encounter this layer of sand. In order to meet the needs of infrastructure development and construction in the southwestern coastal area of Hainan Island, it is of great engineering significance to understand the engineering properties of the sand layer in this area [1].

Cone penetration test is a commonly used in-situ test method in geotechnical prospecting work, which has the rapid and continuous, easy operation and wide application range characteristics [2, 3], it has strong superiority, especially the sand layer which is not easy to obtain the undisturbed sample.

This paper conducted a series of contrast studies of in-situ tests and indoor geotechnical tests for sands on the coastal dunes in the southwestern coastal area of Hainan Island based on a coastal avenue project in Hainan Province, which obtained the empirical relationship between in-situ test indicators and soil mechanics indicators and provided new ideas for the result application of cone penetration test in geotechnical engineering in the southwestern coastal area of Hainan Island.

2. Test Plan

The test site is located on the coastal dunes on the southwestern coast of Ledong Li Autonomous County, Hainan Province, a series of cone penetration tests were conducted on the sand layer with the TLSY-L_2-25 cone penetration vehicle, meanwhile, the standard penetration test (heavy type) and drilling sampling were carried out in the vicinity of the test point, the cone penetration test point is represented by a solid circle, the point of drilling sampling and the standard penetration test are represented by hollow circles, and the linear arrangement of the coastal test site is shown in Figure 1, the correlation among the cone penetration test, the standard penetration test results and the indoor geotechnical test indicators were obtained through the statistics of in-situ test results data.

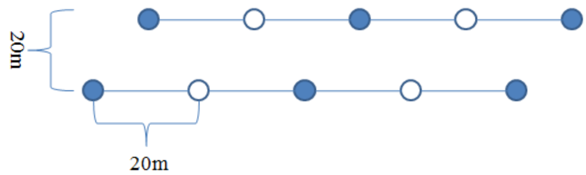

Figure 1. Sketch of experimental site.

3. Test Results and Analysis

The soil classification of cone penetration test and indoor particle analysis test can usually obtain consistent results, while cone penetration cannot distinguish fine sand and silt, therefore, all can be divided into fine silt sand, according to the results of cone penetration test, the soil layers in this test site can be divided into gravel, coarse sand, medium sand, fine silt sand clay, etc.

3.1. The correlation between sand density and standard penetration hit number

Statistical analysis is carried out for standard penetration hit number (N) and cone tip resistance (q_c) of cone penetration results, side friction (fs) and friction-resistance ratio (F), it can be seen from Figure 2 and Figure 3 that the standard penetration hit number N is linearly correlated with the cone tip resistance (q_c), correlation is shown in formula (1), its correlation coefficient R^2=0.913, while standard penetration hit number has little relationship with side friction and friction-resistance ratio.

$$N=1.689q_c+1.397 \quad (1)$$

The density of sand can be divided into density, medium density, slightdensity and looseness in caaordance with the standard penetration hit number N, therefore, the corresponding relationship between the cone tip resistance and the density of sand can be obtained, as shown in Table 1 below, then the density of sand can be judged directly according to the cone tip resistance value of cone penetration. Combining the previous research results [5, 6], it is feasible to evaluate the density of sandy soil in the southwestern coastal area of Hainan Island by cone tip resistance of cone penetration test.

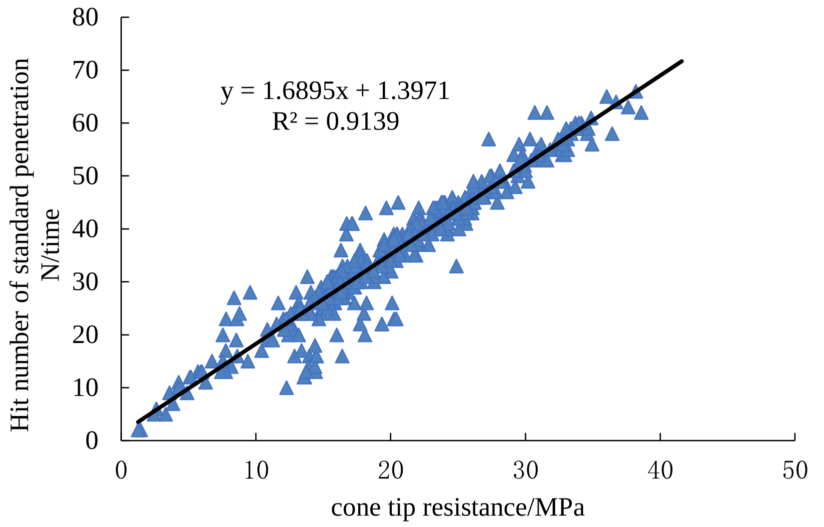

Figure 2. Relationship between the hit number of standard penetration and cone tip resistance.

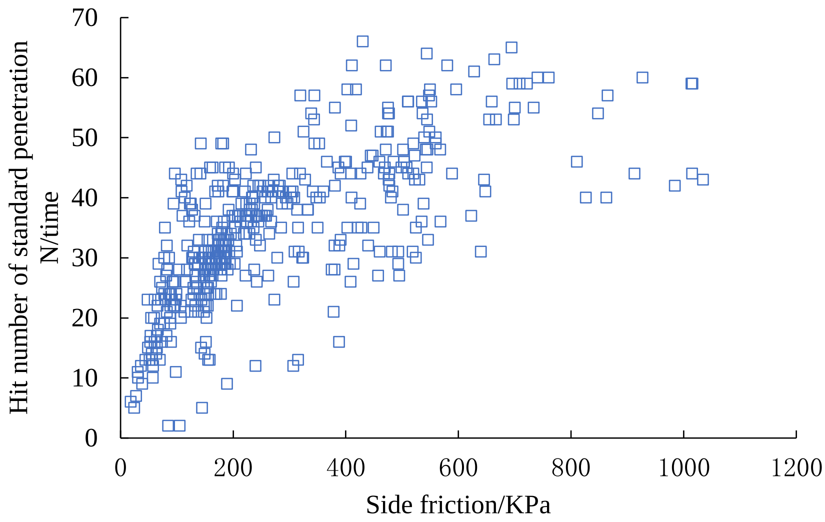

Figure 3. Relationship between the hit number of standard penetration and side friction in sand.

Table 1. Relationship between the density and cone tip resistance of sand

cone tip resistance /MPa	sand density
$q_c \leq 5$	loose
$5 < q_c \leq 8$	slightly dense
$8 < q_c \leq 17$	mediumdense
$q_c > 17$	dense

3.2. The relationship between particle-size distribution of sandy and friction ratio

The development of coastal dunes is the latest event in the Holocene, which has generally formed since 3000 years. The shallow sand layers are mainly marine sediments, the upper part of the sediments is mainly coarse sand, while the lower part is mainly fine silt, which is brown-red and brown-yellow, as

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shown in Figure 4, the sand layers on the dunes are thicker, the maximum thickness is more than ten meters, the sand layers of shallow marine sediment are generally homogeneous and non-stratified.

Below the marine sedimentary sand layer is the littoral sedimentary sand layer, which is grey-white and brown-yellow, the sedimentary unit is characterized by the mixing of clay blocks in the sand layer, the latter comes from the erosion of waves on the underlying strata, it is presumed to be the sediments in the early stage of transgression, on the one hand, waves carry sand particles from the open sea, on the other hand, waves transform the underlying strata and makes sand and clay mix together [8].

(a)marine facies (b)littoral facies

Figure 4. Photograph of the core

The friction ratio result of adjacent cone penetration test points JK06+56, JK06+57, JK06+58 are listed in Table 2 for analysis, the same sand layer takes the average value of the friction ratio on the cone penetration curve. It can be seen from Table 2 that the particle-size distribution has a great influence on friction ratio for the sand with the same geological origin, the larger the particle size of the main particle group, the smaller the friction ratio, the friction ratio of the gravel is about 0.5, and friction ratio of fine silt sand is greater than 2. The order of friction from small to large is: gravel < coarse sand < medium sand < fine silt sand.

Table 2. Friction ratio of different sand layers(same geological origin)

JK06+56		JK06+57		JK06+58	
soil layer	*F*/%	soil layer	*F*/%	soil layer	*F*/%
coarse sand (1.5-6.3m)	0.91	coarse sand (1.6-6.5m)	0.96	coarse sand (0.7-6.1m)	0.94
silt fine sand (6.4-9.9m)	2.02	silt fine sand (6.6-10.5m)	2.18	silt fine sand (6.2-11.5m)	2.17
coarse sand (10-13m)	0.63	coarse sand (10.6-14.5m)	0.93	coarse sand (11.6-15.3m)	0.92
medium sand (13.1-16.2m)	1.43	gravel (14.6-16.0m)	0.52		

Table 3. Friction ratio of different sand layers(different geological origin)

JK07+41		JK07+42		JK07+53		JK07+54	
soil layer	*F*/%	soil layer	*F*/%	soil layer	*F*/%	soil layer	*F*/%
medium sand (0.7-2.5m)	1.35	medium sand (0.9-2.0m)	1.07	silt fine sand (0.4-2.5m)	1.48	coarse sand (0.6-1.8m)	0.81
silt fine sand (2.6-6.9m)	1.82	silt fine sand (2.1-6.4m)	1.47	silty clay (2.6-6.7m)	3.59	silty clay (1.9-4.6m)	2.48
coarse sand (7.0-10.7m)	0.51	coarse sand (6.5-11.1m)	0.52	**silt fine sand (6.8-12.1m)**	**3.09**	**silt fine sand (4.7-9.2m)**	**3.41**
silty clay (10.8-12.3m)	2.86	silty clay (11.2-12.4m)	3.29	**coarse sand (12.2-13.6m)**	**1.83**	**coarse sand (9.3-11.0m)**	**1.43**
coarse sand (12.4-14.6m)	**1.84**	**coarse sand (12.5-15.0m)**	**1.94**				

The friction ratio result of cone penetrations of different sandy soils under different geological origins is also shown in Table 3, the upper sandy soils are marine facies and the lower sandy soils are littoral facies (**the bold part in Table 3**), it can be seen from Table 3 that the friction ratio of the lower coarse sand is much higher than that of the upper coarse sand, similarly, the friction ratio of the lower silt fine

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sand is also higher than that of the upper silt fine sand, it can be seen that the friction ratio of sandy soil is not only affected by particle-size distribution, but also related to geological origin.

3.3. The relationship between content of silt and clay of sand and friction ratio

The studies of Suzuki [9] and Cai [10] have shown that the friction ratio has a certain correlation with clay content, friction ratio of smooth part of sand layer in cone penetration curve of test site in this paper and content of silt and clay (ρ) obtained from particle-size distribution test of sand with corresponding depth in adjacent drilling sampling point are selected for analysis, it was found that the content of silt and clay has a great influence on friction and friction ratio on the side wall, the higher the content of silt and clay is, the greater the side friction is, the greater the friction ratio is, the relationship between the sand friction ratio F (%) and the content of silt and clay ρ (%) are obtained, as shown in Figure 5, there is a good linear correlation between the content of silt and clay and the friction ratio, R^2=0.982, the correlation is shown in the following formula (2):

$$\rho=10.734F-0.746 \tag{2}$$

The particle-size distribution curves of representative silt-fine sand, medium sand, coarse sand and gravel are shown in Figure 6, in particular, although it is named as silt-fine sand, the content of silt and clay in soil samples varies greatly from more than 10% to more than 30%, and their particle distribution curves show completely different shapes, similarly, the content of silt and clay in the upper layer of coarse sand in some drilling sampling point is 8%, the content of silt and clay in the lower coarse sand is 15.9%. The different content of silt and clay is due to different geological origins, the upper sandy soil is marine sand, therefore, the silt-clay particle has low clay content and low friction ratio, the lower sandy soil is littoral sands, sandy soil and clay blocks are mixed, which results in a high content of silt and clay in the lower sandy soil and a high friction ratio, it corresponds to the results of friction ratio of different sandy soil layers under different geological origins in Table 3. Therefore, the cone penetration curves and particle-size distribution curves of sands with different geological origins are different.

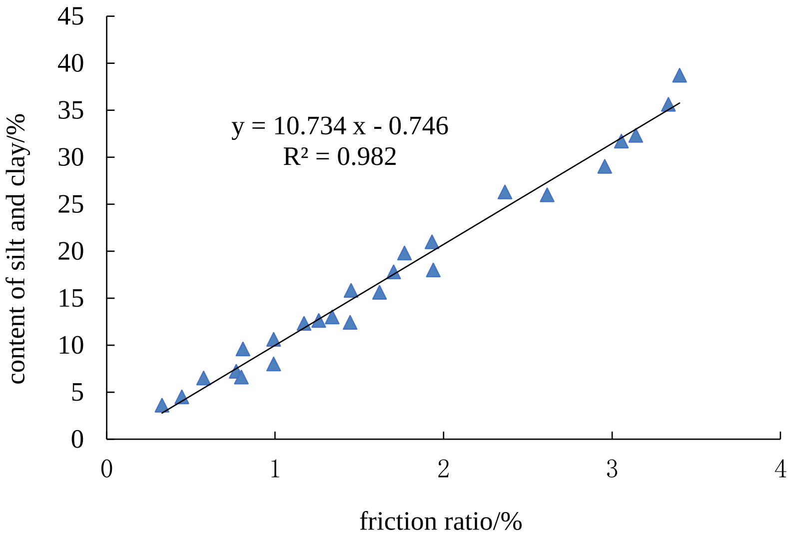

Figure 5. Relationship between friction ratio and content of silt and clay in sand.

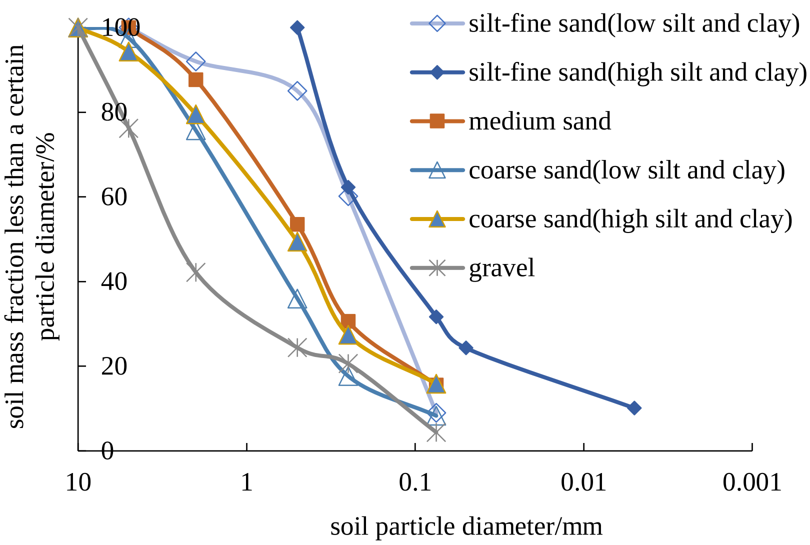

Figure 6. The grain-size distribution curve of sand.

4. Conclusion

(1) The hit number of standard penetration test is linearly correlated with the cone tip resistance of cone penetration test, and the sand density can be judged by the value of cone tip resistance.

(2) The grain-size distribution has a great influence on the friction ratio for different sandy soils with the same geological origin, the larger the particle size of the main grain group of the grain-size distribution, the smaller the friction ratio.

(3) The content of silt and clay of sand has a great influence on side friction and friction ratio of cone penetration test, the friction ratio is linearly related to the content of silt and clay.

(4) The content of silt and clay in the same kind of sand is different due to different geological origins. The content of silt and clay in upper sand is low, then the friction ratio is low, and content of silt and clay in the lower sand is high, and then the friction ratio is high, there are differences in cone penetration curves and particle-size distribution curves, resulting in different engineering properties.

Acknowledgments

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