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Analysis of Shear Test on Pile-soil Interface

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Shearing slippage damage is the main failure type at the interface of pile and soil, when the pile-top load increase, the piles displacement gradually increase and the pile and soil will occur shear failure from top to bottom, besides, the lateral friction resistance of pile foundation will reach the maximum value gradually. The friction resistance of pile foundation should largely depend on the pile-soil interaction, in most cases, it will form shear bonds near the interface of the soil, once the shear bonds penetration and sliding, which marks the pile-soil interface damage.

1. Introduction

The mechanical properties of the pile-soil interface directly relate to the calculation of the shaft resistance of pile foundation, which affects the mechanical effects of structure under the influence of dynamic and constant load. Therefore, the research on the mechanical property of the pile-soil interface has important significance for ensuring the bearing capacity of foundation and maintaining the stability of upper structure.

Currently research on mechanical properties of the pile-soil interface show that the mechanical properties of the interface has some similarities with the shear test of soil, and the pile-soil interface shearing test shows that contact shear process will also appear militancy and pressure hydraulic, and in the shear failure stage, it will also produce strain softening phenomenon (Brown. 1994; Deng et al. 2002; Sulem et al. 2006); at the same time, the shear-bond properties of the interface is different from that in soil, and the related properties of the two materials will affect the formation position and thickness of the shear bond etc. Numerous research results show that the shear strength of the interface may exceed the soil shear strength, which result that the shear bond may appear in a certain distance away from the interface, but not necessarily limited to the pile-soil interface (Vesic, 1977; Lee et al. 200; Makris et al. 1997).

Zhao Yuan Songhuajiang Bridge is located on State Road 203 Zhao Yuan to Songyuan highway, is the junction of Jilin Province and Heilongjiang Province. The total length of the bridge is 2678 m, 23.5 m clear width, and it has pivotal position at State Road 203. (Gaaver. 2013; Bhowmik et al. 2013; Jie et al. 2011). in this experiment, in order to research the shear failure properties of the soil and the pile-soil interface, using Zhao Yuan Songhuajiang Bridge soil samples to simulate the shear failure process of different soil (coarse sand, fine sand, clay) and concrete at different normal pressure discusses the shear strength characteristics of pile-soil interface.

2. Basic physical and mechanical tests of soil samples analysis

The basic physical and mechanical tests of soil were done in this project, combined with the pile foundation tests of Zhao Yuan Songhuajiang Bridge, to research the mechanical properties of soil-concrete interface in the shearing process.

2.1 Density determination

Using Ring Sampler measure the density of five groups soil in different sampling depths, and the soil classification mainly includes: fine sand, coarse sand, clay, the test results of the ten soil samples shown in table 1.

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Table 1: Soil bulk density test results

Soil sample number	Sampling depth (m)	lithology	ring-knife number	bulk density (g/cm^3)	Average (g/cm^3)
1-5	4.45~4.60	Fine sand	B87	2.03	2.00
			B90	2.01	
1-10	12.20~12.35		B23	1.98	
			B1	1.97	
1-16	17.15~17.30	clay	A31	1.96	1.90
			B98	1.96	
2-16	16.00~16.20		A53	1.82	
			A23	1.86	
2-24	24.50~24.70	Coarse sand	B53	2.12	2.14
			A76	2.15	

2.2 Determination of cohesive soil liquid and plastic limit

Using cone liquid limit device test the liquid limit of cohesive soil, the device is 76g weight,. When testing, making the cohesive soil with different water content fill the cup and play the conical instrument in clay surface, and then release of conical instrument make it into the soil sample, if the vertebral insertion depth up to 10mm, at this time, the water content of soil sample is liquid limit of cohesive soil. Liquid limit test results are shown in Table 2.

Table 2: The result form of clay liquid limit test

Sample number	Sampling depth (m)	lithology	liquid limit water content (%)	Average (%)
1-16	17.15~17.30	clay	40.88	40.51
			40.13	
2-16	16.0~16.20		35.01	34.95
			34.89	

The test of clay liquid limit use rubbing method, put the clay soil sample on the frosted glass, and rubs it into 3mm in diameter. the plastic limit water content is called when the soil sample appear crack of 1cm. The result of the plastic limit test as follow:

Table 3: The result form of plastic limit test

Sample number	Sampling depth (m)	lithology	Plastic limit water content (%)	Average (%)
1-16	17.15~17.30	clay	21.24	19.45
			17.66	
2-16	16.0~16.20		24.59	25.48
			26.37	

2.3 The test of compression and consolidation

The shear strength of vertical loading is related of the contact surface between soil and construction. in order to know about the relationship of stress and strain. Test the soil sample with compression and consolidation method. The test use Leveraged compression apparatus, get soil sample with cutting ring, the volume of cutting ring is 100 cm^3, 2 cm in height, when set up the instrument, in order to guarantee soil sample is pervious to water fully, put filter paper and porous stone on and under the saturated soil sample. Apply the

load with 0.05, 0.1, 0.2, 0.3, 0.4 MPa individually, the compression deformation within 0.005 mm is which called steady criterion of compression and consolidation, select 3 kind of soil sample to test with compression and consolidation method, the result shown in table 4.

Table 4: The result form of compression and consolidation test

Sample number	lithology	particle density (g/cm^3)	Water content (%)	Dry density (g/cm3)	Initial void ratio	Compressibility (Mpa^{-1})	Compression modulus Es (Mpa)
1-5	clay	2.70	33.81	1.35	1.00	0.57	3.50
1-16	Fine sand	2.69	14.89	1.68	0.60	0.14	11.44
2-24	Coarse sand	2.68	11.33	1.87	0.43	0.14	10.24

3. Soil-concrete medium shear test

3.1 Medium shear experimental equipment

Use medium shear apparatus test different soil sample (coarse sand, fine sand, clay) and the shear mechanical property of concrete contact surface. the soil sample selected is 1-5 clay, 1-16 fine sand, 2-24 coarse sand. Its experimental equipment as follow.

Figure 1: Medium shear test device

During the test, the shear box vertically fixed two diagonal dial indicators to measure the vertical deformation, horizontally arranged diagonally two dial indicator for measuring horizontal deformation gauge is calculated by the vertical and the horizontal size of the pressure. When the vertical load using a loading method, loading after readings thereafter measured once every 5min until the difference between two adjacent vertical dial

indicator readings twice less than 0.005 mm, consider soil and concrete vertical deformation and stability. In the sample vertical deformation stability of the applied strain level of use and other ways to shear loads. Control shear displacement rate in 0.4 mm/min, when the horizontal shear stress constant while increasing horizontal displacement, it can be considered a shear surface damage, end of the trial (Czurda et al. 1997; Iverson et al. 2010; Lia et al., 2013.).

3.2 Preparation of medium shear test specimen

The mix concrete of the samples and the construction site is the same, the mixture ratio; water: cement; sand; gravel = 0.330: 1: 1.346; 2.194, these materials can be obtained directly from the site and not added the super plasticizer in the mixing process. When preparing the soil samples directly put them into the shear groove, the size of shear groove is 155 mm×125 mm×4 mm.

3.3 Determine the normal stress of shear plane

This test results will be applied to the test pile foundation of Zhao Yuan Songhuajiang Bridge Project, so the normal stress should be selected legitimately during the test, and the test should accurately reflect the mechanical properties of pile-soil interface, only in this way can more accurately estimate the value of the friction resistance. In the medium shear test, each sample is applied to a total of five normal stress, according to following method determine the five normal stress: lateral stress under natural stratigraphic pressure is σ 1, lateral stress under the ultimate load of pile foundation is σ 4, then using the interpolation method calculate σ 2, σ 3, σ 5.

Where σ 1 can be determined according to the following formula:

$$\sigma_x = \frac{\mu_1}{1-\mu_1}\sigma_y$$

$$\sigma_y = \gamma h$$

u_1 : Poisson's ratio of each stratigraphic

h: stratigraphic depth around the midpoint

3.4 Interface shear test results analysis

According to the test data analysis, the shear properties of soil -concrete interface meet the mohr-coulomb criterion within the scale of engineering loading. For the cohesive soil, (soil sample 1-5), shear test process has the following characteristics:

1) When improving the soil vertical stress on the condition of loading with equal constant strain rate, Shear stiffness increases gradually. But when shearing surface reaches the yield strength under different vertical load, the horizontal displacement is usually between 0.2 mm to 0.8 mm.

2) The interface between cohesive soil and concrete will generate an obvious strain-hardening phenomenon during the process of shearing. And with the increase of vertical load, the strain-hardening phenomenon will be more obvious.

3) Draw the vertical load and shear stress (crest strength and residual strength) curve, shown as figure 2-15. It shows that shearing surface will present obvious caking when using linear fitting and it has similar characteristics to the cohesion in cohesive soil.

4) According to the Mohr-Coulomb strength criterion, the shear bond strength is 30 Kpa, and the friction angle is 18°.

Table 5: The Test result table

number	Sample number	lithology	σ(t/m^2)	τ_p (t/m^2)	τ_y (t/m^2)	C_P (t/m^2)	φ_p (°)	C_y (t/m^2)	φ_y (°)
1	1-5	clay	10.3	8.5	4	3	18	2	12.5
			100	26	9.5				
			185.6	56	27				
			286.7	100	68.5				
			379.1	137	86				
2	1-16	Fine sand	2.4	4	2	0	25	0	13
			94.8	40	8				
			187.8	100	36				
			297.9	126	70				
			387.1	195	98				
3	2-24	Coarse sand	9.6	3	2.2	0	26.5	0	15.5
			101	50	28				
			194	103	52				
			292	125	80				
			387	226	110				

For the sand (soil sample 1-16 is fine sand, soil sample 2-24 is coarse sand), they have follow shear properties:
When shearing surface appears to yield phenomenon, its horizontal shear displacement is between 0.2 mm to 0.6 mm, changing the vertical load has little effect on it.
1) Sand does not show the strain-hardening phenomenon and after the peak strength its strength is almost unchanged as the shear strength increases.
2) Draw the vertical load and shear stress (crest strength and residual strength) curve, shown as figure 2-16,2-17.It shows that shearing surface does not appear the similar characteristics as cohesiveness of cohesive soil and on the contrary it has the similar characteristics to cohesion less soil.
3) Fine sand and coarse sand show the similar shear properties. Using Mohr-Coulomb strength criterion to describe the mechanical properties, the friction angle of fine sand and concrete is 25 °, coarse sand and concrete friction angle is 26.5 °.

4. Conclusions

1) The peak shear stress of soil-concrete interface has a good linear relationship with the normal stress; the Mohr-Coulomb strength criterion can meet the project requirements.
2) As for clay, the results also show an existence of cohesion, in this test, the bond strength of soil samples is 30kpa, and the stress strength is determined by friction angle (18°).
3) In the Coulomb model, sand showed strong shear strength, which is mainly reflected by friction angle, in this test, the friction angle of medium coarse sand (26.5°) is slightly larger than fine sand (25°).
4) Under different normal loads, the horizontal relative displacement is within 1mm when the soil-concrete interface produces shear failure, in practical engineering, the settlement value of pile foundation is much larger than this range.so it can be seen the lateral friction resistance often takes precedence over the end to take effect, which consistent with practical experience.

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