SAMPLING DISTURBANCE EFFECT ON STRENGTH OF SOFT CLAY

INFLUENCE DE REMANIEMENT SUR LA RESISTANCE DES ARGILES MOLLES

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SYNOPSIS: The disturbance caused by different sampling method and its influence on the strength of soil were examined first at three sites, the mechanical disurbance induced by sampling operation was simulated in the laboratory so that its effects can be explained and analyzed.

INTRODUCTION

To investigate the influence of sampling disurbance induced by the conventional sampling technique currently used in China, and to study the effectiveness of fixed piston thin-walled sampler in comparison with thick-walled open drive tube sampler, comparative study on sampling of soft clay was accomplished in Harbours of Lianyungang (Wei et al., 1988) and Chiwan (wei et al., 1989), and on Guang-Shen Highway (Wei et al., 1990) during last few years.

DISTURBANCE CAUSED BY DIFFERENT SAMPLING METHOD

To identify the disurbance level of samples reasonably, some quantitative indices have been proposed recently, such as strain at failure, the ratio of undrained deformation modulus to shear strength, additional compression during reconsolidation under the in situ overburden pressure, and ratio or degree of disturbance with various definition (Wei, 1987) etc. Among others, it is most clear and simple to use the strain at failure in the unconfined compression test as a quantitative index of the sample disturbance. It is shown by the experience, for the soft clay with medium sensitivity and medium plasticity, the quality of sample may be considered as fairly good when the strain at failure in the unconfined compression test $\varepsilon_f = 3 \sim 5\%$. If $\varepsilon_f = 5 \sim 10\%$, the sample is probably disturbed to a certain extent, while $\varepsilon_f > 10\%$. the sample is disturbed seriously.

The typical frequency distribution for the strain at failure of samples obtained in Chiwan is shown in Fig. 1, and the average strain at failure of samples obtained in the above mentioned three sites are summarized in Table 1. It is shown by these results that not only the mean value but also the deviation of the strain at failure for the thin-walled samples* is much smaller than those for thick- walled samples, the former is only half of that for the latter. This fact strongly indicate that sampling disturbance of thin-walled samples is much samller than that of thick-walled samples.

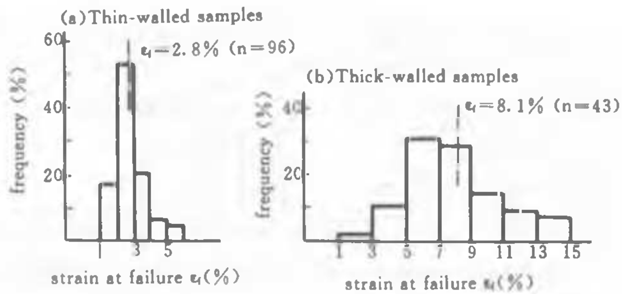


Fig. 1 Frequency distribution of ε_f for samples in Chiwan

Table 1. Strength test results of thin-and thick-walled samples

test \ parameter \ sampler \ site		Lianyungang		Chiwan		Guang-Shen Highway	
		thin	thick	thin	thick	thin	thick
UC	ε_f(%)	3.0	6.3	2.8	8.1	3.2	7.1
	$\frac{q_u}{2}$(kPa)	6.5	4.0	6.5	4.4	18.0	12.0
CU	A_f	1.11	1.05	1.12	1.07	-	-
	$\varnothing_{cu}$(°)	12	13	12	13	-	-
	$\varnothing'$(°)	26	26	26	26	-	-

Note: UC represents unconfined compression test

* For brevity, samples obtained with thin-and thick-walled sampler are called thin-and thick-walled samples respectively.

It is shown by test results that the undrained strength, especially the unconfined compression test result, is most sensitive to the sampling disturbance. Therefore, the comparison of unconfined compression test results of thin-walled and thick-walled samples is used as the primary index to evaluate the effectiveness of the thin-walled sampler. The frequency distribution of unconfined compressive strength of thin-walled soft clay samples on Guang-Shen Highway is shown in Fig. 2, and the strengths of samples obtained from the above-mentioned three sites are summarized in Table 1. It is seen that, the mean value for the undrained strength of the thin-walled samples is greater while its deviation is less than that of thick-walled samples. In comparison with thick-walled samples, the unconfined compressive strength of thin-walled samples increases generally by 50%. On the contrary, it is shown that the consolidated undrained strength of the disturbed sample will be overestimated. Due to the sampling disturbance, there will be remarkable additional compression when the sample is reconsolidated in laboratory. The strength increment thus induced is large enough to compensate or even exceed the structural strength loss of the soft clay with medium sensitivity due to sampling disturbance. Therefore, the hysterisis loop will be formed on the consolidated undrained strength envelope near the in situ overburden pressure σ'_{vo}. upon unloading and reloading until the consolidation pressure is greater than $(3\sim4)\sigma'_{vo}$. That is to say, if the disturbed sample is reconsolidated under the pressure less than or equal to σ'_{vo}, the consolidated undrained strength thus determined may be greater than that of undisturbed sample under the same consolidation pressure, while the consolidated undrained strength of both kinds of samples will be essentially equal under the consolidation pressure greater than $(3\sim4)\sigma'_{vo}$.

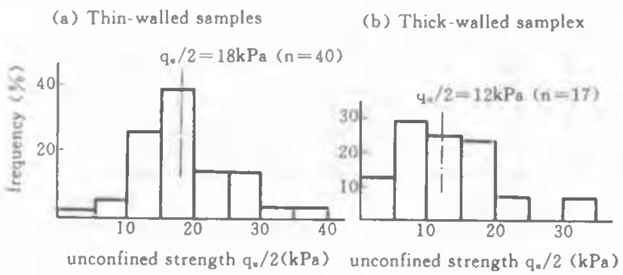


Fig. 2 Frequency distribution of unconfined compressive strength of samples on Guang-Shen Highway

SIMULATION OF SAMPLING DISTURBANCE IN LABORATORY

The sampling disturbance may be simulated in laboratory in two ways. The first one is "perfect" sampling, in which only the stress release and the stress redistribution after extraction of samples from the foundation soil is considered. The oth er is"actual" sampling, in which both the stress release and stress redistribution and mechanical disturbance are involved. Besides, to analyze the sampling disurbance induced by these two different sampling ways, a kind of so called" in situ" sample is also simulated, which represents the properties of the completely undisturbed soil in situ, and is used as the reference in comparison with "perfect"and"actual"samples.

Mechanical Disturbance History

If the total stress acting on the Ko-consolidated sample in laboratory is removed, the sample will undergo the stress release and stress redistribution as well. To simulate the mechanical disturbance effect in laboratory, it is necessary at first to know how the disturbance happens to the sample. Therefore, the formula for calculating sample disturbance obtained by Baligh et al, (1987) with" strain path method"is used here.

$$\varepsilon_{zz} = -ln\{ 1-\frac{2t}{B}\frac{z/B}{[1+4(z/B)^2]^{3/2}}\} \quad (1)$$

where ε_{zz} is the axial strain at the centerline of sampler, B and t is the outer diameter and thickness of sampler respectively, z is the vertical distance from the bottom of sampler. It can be seen from Eq. (1), ε_{zz}(max)and ε_{zz}(min)occur at $z/B=\mp\sqrt{2}/4\approx\mp0.35$ and are equal in their absolute values.

$$\varepsilon_d = |\varepsilon_{zz}(max)| = |\varepsilon_{zz}(min)| = 0.385\frac{t}{B} \quad (2)$$

where ε_d is defined as the disurbance strain which represents the sampling disturbance level. It is indicated in Fig. 3 that the soil has been subjected to three distinct phases of undrained deformation during the insertion of sampler into soil.

An initial compression phase ab ahead of the sampler ($z\leqslant-0.35B$) where ε_{zz} increases from zero to the maximum value ε_{zz}(max).

An extention phase bc in the vicinity of cutting edge ($|z|<0.35B$) where ε_{zz} decreases rapidly from ε_{zz}(max) to the minimum ε_{zz}(min).

A second compression phase cd inside the sampler ($z\geqslant0.35B$) during which ε_{zz} approaches to zero.

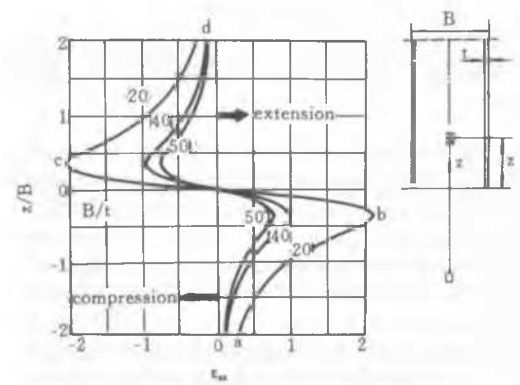


Fig. 3 Strain history at centerline of sampler

Therefore, strain history of sample in the process of sampler insertion involves the above mentioned "compression-extention-compression" deformation phases and the magnitude of "compression-extention-compression" ε_d reflects the mechanical disturbance level.

Laboratory Simulation of Mechanical Disturbance

The thoroughly mixed, soaked, boiled mixture of kaolin (80%)

and silty sand (20%) was one-dimensionally consolidated under vertical consolidation pressure of 50kPa. Then the triaxial specimens, which is 7 cm in height and 3.91 cm in diameter were cut from the consolidated block. After saturation with vaccum and storage in moist container, the specimen were mounted in triaxial apparatus to prepare samples with different strain histories. The coefficient of lateral pressure at rest of the soil tested was measured beforehand to be $K_o = 0.5$, so the triaxial specimens were at first consolidated under the in situ pressure of $\sigma'_{vo} =$ 200kPa and $\sigma'_{ho} = 100$kPa with a back pressure of 100kPa to ensure complete saturation of specimens. Then the" compression-extention-compression" deformation and the stress release were successively exerted on the sample if necessary. The procedure to prepare" in situ", "perfect" and" actual" samples in triaxial apparatus are shown in Table. 2

Table 2. Process for "in situ","perfect",and"actual" samples

process / sample	(1) Ko-consolidation $\sigma'_{vo}=200$kPa $\sigma'_{ho}=100$kPa	(2) additional disturbance ε_d	(3) release of stress σ'_{vo}-$\sigma'_{ho}=100$kPa
"in situ"	yes	no	no
"perfect"	yes	no	yes
"actual"	yes	yes	yes

Effect of Disturbance on Strength of Sample

Undrained test results of three kinds of samples

The mechanial distrubance level varies with the types of sampler and sampling operation. For the above-mentioned thin-walled sampler with outer diameter $B = 80 \pm 0.5$mm and thickness $t = 2.0 \pm 0.1$mm ($B/t = 40$), it is calculated with Eq. 2 that the disturbance strain ε_d is approximately equal to 1%. Hence, the" actual" samples prepared with $\varepsilon_d = 1\%$ just simulate the thin-walled samples. The undrained test results of the" in situ", "perfect" and" actual" (thin-walled) sample prepared according to Table 2 are shown in Fig. 3 in which the solid line represents the test results of above-mentioned three kinds of sample. It is shown that S_{ud}(58kPa)< S_{up}(62kPa)< S_{uo}(67kPa), and ε_{fd} (3.6%) > ε_{fp} (1%) > ε_{fo} (0.35%), where S_u is the undrained strength, ε_f is the strain at failurc, and the subscript o, p and d represents" in situ", "perfect" and" actual" respectively.

It is very interesting that the magnitude of the stain at failure for" actual" (thin-walled) sample in laboratory is just in the range of $\varepsilon_f = 3 \sim 5\%$ which has been widely used as an empirical criterion to identify the high quality sample of clay with medium sensitivity, and very close to the data obtained in the above-mentioned field study. This result not only provides an experimental basis for judging the rationality of the above-mentioned empirical criterion, but also proves that the sampling with thin-walled sampler in our field study was so perfectly accomplished that little additional disturbance was induced due to careless operation.

It should be pointed out that even for laboratory-prepared soil with low sensitivity ($St \leqq 2$)* and the simulated thin-walled sample with high quality, the undrained strength of" actual" sample is about 15% lower than the" in situ" strength where the contributions of stress release and mechanical disturbance take share alike. For the most natural soft clays with medium sensitivity ($s_t = 4 \sim 8$) along the coast of China, the disturbance effect will be certainly more remarkable than that obtained in the simulating test.

Variation of undrained strength with disturbance level ε_d

The samples were firstly consolidated to the in situ pressure $\sigma'_{vo} = 200$kPa and $\sigma'_{ho} = 100$kPa, then $\varepsilon_d = 0$ ("perfect sample"), 0.5 %, 1%, 1.5%, 2%, 3% and ∞ (remoulded sample) were exerted to the samples respectively followed by unloading for one day, and the" actual" samples with different disturbance level were obtained. The undrained test results of these samples are shown in Fig. 4. It is indicated that the undrained strength S_u decreases linearly and the strain at failure increases with the increasing disturbance level ε_d respectively (Fig. 5)

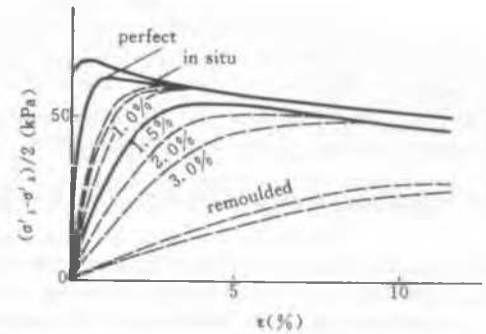
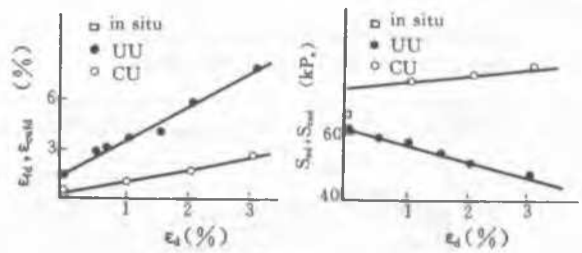


Fig. 4 Undrained stress strain curves



(a) ε_{fd}, $\varepsilon_{cufd} \sim \varepsilon_d$ (b) S_{ud}, $S_{cud} \sim \varepsilon_d$

Fig. 5 Variation of strength and strain at failure with ε_d

Table 3. UU and KoCU test results of samples with ε_d

parameter	sample	in situ	perfect	actual					remoulded
	ε_d	-	0	0.5	1.0	1.5	2.0	3.0	∞
Su (kPa)	UU	67	62	59	58	54	51	48	28
	K_oCU	67				77		79	81
ε_f (%)	UU	0.35	1.3	2.8	3.6	4.0	6.0	8.0	11.5
	K_oCU	0.35			1.0		1.7	2.6	

For conventional thick-walled sampler with B=100 mm and t =5mm, which has been widely used in China, it is calculated with Eq. 2 that the disturbance level ε_d is about 2%. That is to

* The sensitivity is obtained from the ratio of strength for" actual" (thin-walled) sample to that for remoulded sample shown in Table 3, $s_{ud}/s_{ur} = 2$

say, the" actual" sample with $\varepsilon_d = 2\%$ just simulate the thick-walled sample, It is shown in Table 3 that the difference between the undrained strength of thick-and thin-walled" actual" samples is less than 15%, while the difference between the actual thick-and thin-walled samples obtained in the field study mentioned above is about 50%. This indicates that the influence of sampling disturbance on natural soft clay with higher sensitivity is obviously larger than that on the labortory-prepared sample with lower sensitivity. Moreover, the sampling disturbance is induced not only by the use of thick-walled sampler, but also by the irrational operation, for example, boring with washing or churning of bailer, penetrating of sampler by hammering instead of jacking, the waved movement of the drilling barge on the sea, long distance transportation and long time storage of sample and so on. These influences always result in larger strain at failure ε_f, generally in the range between 7% and 8%, or even greater than 10% (Wei et al., 1990) in comparison with $\varepsilon_f = 6\%$ obtained in the laboratory from the "actual" thick-walled ($\varepsilon_d = 2\%$) sample (Table 3). This fact implies that the thick-walled samples may be seriously disturbed due to careless operation.

Variation of consolidated undrained strength with disturbance level ε_d

The"actual" sample with $\varepsilon_d = 1\%, 2\%, 3\%$ and ∞(remoulded) and unloading time T=1day were reconsolidated to the" in situ" pressure $\sigma'_{vo} = 200$kPa and $\sigma'_{ho} = 100$kPa under K_o condition, while the additional volumetric compression induced by reconsolidation was measured. Then the undrained tests were carried out on the reconsolidated samples and the results are shown in Fig. 6 and Table 3.

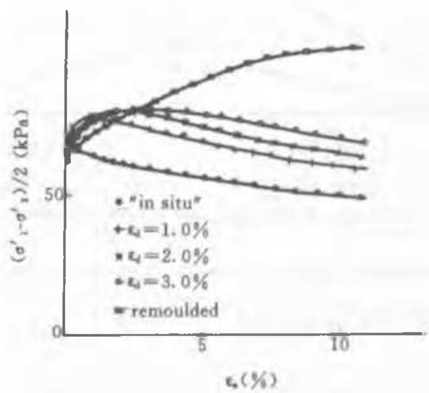


Fig. 6 Consolidated undrained stress

It is indicated that both the K_o-reconsolidated undrained strength S_{cud} and the strain at failure ε_{cufd} of the"actual" samples increase linearly with the increasing disturbance level ε_d. This is coincident with the results in the field study. It is also shown that by reconsolidation to the" in situ" stress, the undrained strength of the" actual" samples with $\varepsilon_d = 2\%$ and 1% (corresponding to the thick-and thin-walled sample respectively) is 18% and 15% higher than that of the "in situ" sample.

CONCLUSIONS

The mechanical properties of soft clay determined in the laboratory and hence the economical propriety of the engineering design of soft clay foundation were influenced remarkably by the disturbance of soil samples. The sampler is the key factor which controls the quality of samples. However, the boring method, sampling operation, transportation and storage of samples, as well as the preparation and testing technique also have direct effect on the laboratory test results.

High quality samples can be obtained with thin-walled samplers provided that the operating instruction has been conscientiously followed, while the samples obtained with conventional thick-walled samplers are often seriously disturbed. For example, in comparison with the thick-walled samples, the strain at failure decreases by more than 50%, the unconfined compressive strength increases by 50~60%, when thin-walled samples are used.

It is shown by the simulation of the sampling disturbance effect that the strain at failure of" actual" thick-and thin-walled sample is about 3.5% and 6.0% respectively, this result is coincident with that in the field study.

It is indicated that the undrained strength of simulated thin-walled"actual" sample with sensitivity St=2 is about 15% lower than that of simulated" in situ" sample, where the contributions of stress release and mechanical disturbance take share alike, while the difference between the undrained strengths of the" actual" thin-walled sample and" actual" thick-walled sample is 15%, which is far less than 50% obtained in the field study. The main reason is that the samples in the latter are obtained from natural soft clay with sensitivity St=4~6. Hence, for the most soft clay along the coast of China, the influence of sampling disturbance is certainly larger than that obtained in the simulating test, and should not be treated incautiously.

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