

Determination of True Residual Stress within In-situ Sampled Clay

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Abstract— The objective of this study is to establish a reliable way to determine the residual stress in clay. During saturation in triaxial test, using residual stress as back pressure as opposed to the traditional saturation methods leads to better sample quality. In this research the residual stress within the sample is measured and compared against the one that can be predicted with the help of the equation proposed by Skempton in 1954 based on the account of change in total stress during sampling. The results do not exhibit any recognizable trend, in fact sometimes the prediction is quite good while the rest of the time not good. Thus in the absence of a perfect sample, the use of Skempton's equation is more reliable.

Index Terms—clay, perfect sample, residual stress, sampling, saturation, triaxial test, true residual stress

1 INTRODUCTION

During triaxial testing we require a sample with as minimal disturbance as possible. The in-situ conditions needs to be preserved as best as possible. Practically speaking is almost impossible to have a perfect sample (without disturbance). Inevitable disturbance may be encountered during sample extrusion, trimming etc. Presence of foreign material like silt or sand may also lead to pore water pressure dissipation thus the measured residual stress may not necessarily the true value. Tube samples of Taipei silty clay sampled from within the environs of Taipei 101 were used. Taipei Silty clay normally has hydrostatic water levels to be 2 metres below the surface. Skempton (1954) proposed an equation that may be used to estimate residual effective stress within a sample based on the account of total stress changes.

Residual effective stress also called the initial mean effective stress, stored effective stress or effective stress after sampling is the effective stress remaining in the soil sample after sampling, handling and storage (Skempton & Sowa 1963, Ladd and Lambe 1964, Hight 2003). This is a concept rooted in perfect sampling concept (Lambe and Ladd 1964) where there would be no disturbance except that from stress relief. The difference between sampling effective stress and the residual

effective stress is caused by disturbance rather than stress relief. This implies that the residual stress can be a qualitative measure of sample disturbance (Finno et al, 2006). The sample swelling thus disturbance during saturation, can be minimized by applying an effective stress equal to the measured residual stress before adding water to the specimen, Finno et al., 2006. This implies that the sample quality may be improved further if the correct or 'true' residual stress is used. This is informed by the fact that due to storage and sample handling the sample may undergo inevitable pore pressure dissipation and hence the measured residual stress may not necessarily be the 'true' value. The measured residual stress is applied as back pressure during saturation. In the conventional saturation process a very small back pressure (0~10kPa) is normally used. The basic soil properties are summarized below in **table 1**.

TABLE 1
Summary of the basic soil properties

USCS	Properties
w _n (%)	33.0~40.0
LL(%)	38.0 ~38.5
PL(%)	26.0~26.3
PI(%)	12.0~12.2
SL(%)	7.5
γ _t (kN/m ³)	18.0~20.0
G _s	2.7
e ₀	0.98

2 Idealized concept of stress relief during sampling and the consequent pore water pressure changes.

During sampling the soil undergoes unloading thus stress release. This means that after sampling the underlying layers now carry less load than before this situation is similar to axial extension in the triaxial test.

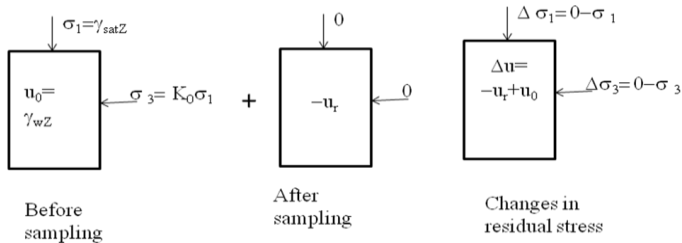


Fig. 1: Illustration of the stress release concept.

$$\Delta u = B\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3) \tag{1}$$

$$u_0 + \Delta u = p'_r \tag{2}$$

The **equation (1)** as proposed by Skempton in 1954 can be used to estimate the changes due to stress relief. *k₀* for saturated soil is taken as 0.5, B=1 and A=2/3 for axial extension synonymous to unloading

during sampling (Holtz & Kovacs 1999).

3 Effective stress measurement

The effective stress, *p'_r*, was evaluated prior to saturation through the response of excess pore-water pressure as isotropic stress increments applied with drainage lines closed (Lambe and ladd 1963). The total confining stress, *σ_c*, was increased in 50kPa from 100kPa to 300kPa and reduced in 100kPa from 300kPa to 100kPa. In each load increment step the pore water, *u*, was allowed to equilibrate within 30-60 min. The same procedure was followed in reducing *σ_c*. Expected response of *u* to *σ_c* is as shown in **Fig. 2**. Linear regression applied to this data, the matric suction within the sample can be taken as the value of *u* at *σ_c*=0. Following the general concept of effective stress, the residual effective stress, *p'_r* may be defined:

$$p'_r = -u_r \tag{3}$$

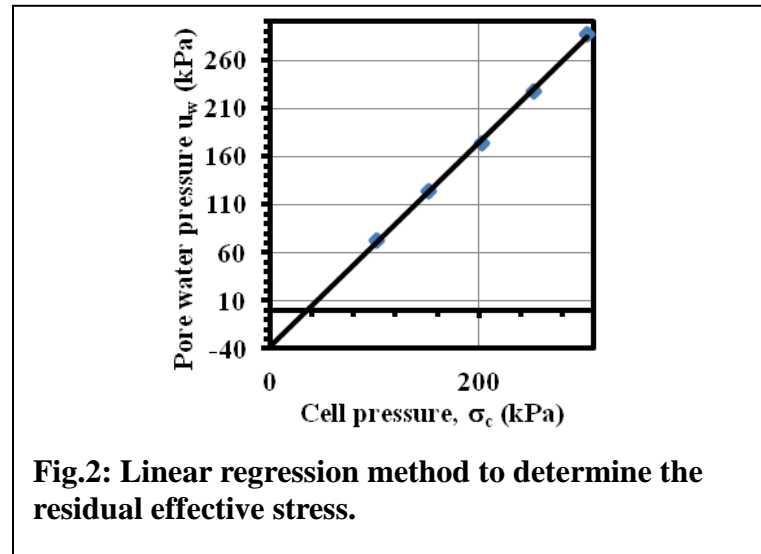


Fig.2: Linear regression method to determine the residual effective stress.

4 Results of Experiments

i. Measured residual effective stress against the estimation from equation.

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TABLE 2

Summary of measured residual stress against the estimation from Skempton’s formula.

Test	Sample depth,m	Water content, w (%)	Measured residual stress (kPa)	Calculated residual stress (kPa) eqn 2	Effective vertical stress (kPa)
Sample 1	3.23	36.3	37.05	36.40	46.26
Sample 2	3.43	35.74	15.00	37.61	47.92
Sample 3	9.23	33.07	5.00	68.60	96.55
Sample 4	3.12	40.01	35.00	35.94	45.34

When the consolidation stress is higher than the in-situ pre-consolidation stress the soil sample is at the virgin consolidation line (VCL), where it is normally consolidated. Presence of foreign materials e.g silt, organic matter may lead to residual stress dissipation. Some minimal disturbance may also be caused to the sample during trimming. Thus the measured residual stress may not be the actual, correct or the ‘true’ residual stress immediately after sampling. Due to this, the results from **equation 2** are considered more reliable.

Table 3:

Comparing the void ratio changes when traditional saturation is used and when residual stress is used as back pressure

Test	e_0	Δe	$\Delta e/e$	Δe_1	$\Delta e_1/e_0$
Sample1	0.98	0.03	0.03	0.24	0.24
Sample 2	0.96	0.05	0.05	0.11	0.11
Sample 3	0.89	0.08	0.09	0.12	0.13
Sample 4	1.11	0.04	0.04	0.16	0.14

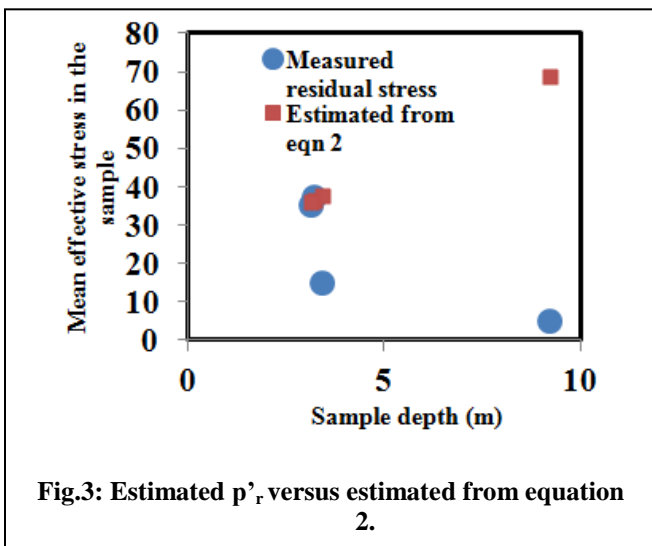


Fig.3: Estimated p'_r versus estimated from equation 2.

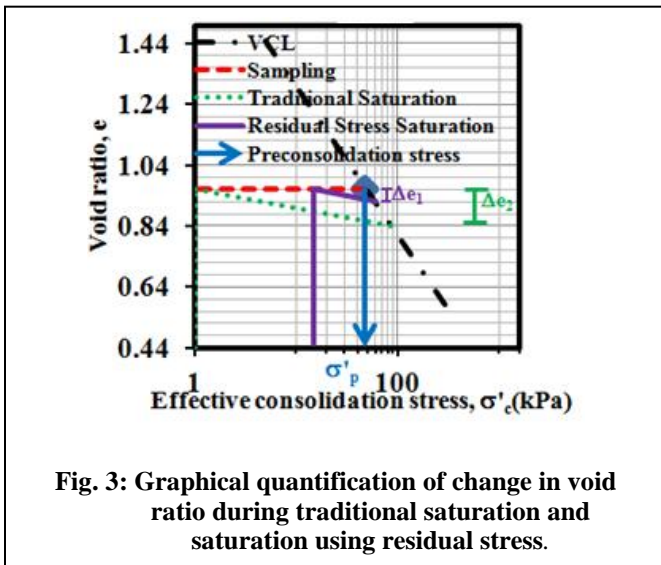


Fig. 3: Graphical quantification of change in void ratio during traditional saturation and saturation using residual stress.

Table 4:

Classification of sample quality based on the void ratio change during recompression

Sample quality	Volume change $\Delta e/e_0$
Very Good	<0.04
Good to Fair	0.04~0.07
Fair to Poor	0.07~0.14
Very Poor	>0.14

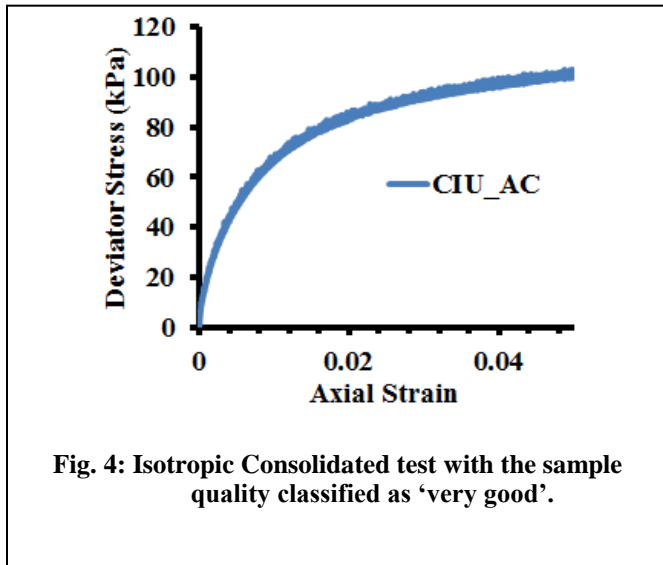


Fig. 4: Isotropic Consolidated test with the sample quality classified as 'very good'.

6 DISCUSSION

Comparison between the measured residual stress and the estimation from **equation 2** do not exhibit any recognizable trend, in fact sometimes the prediction is quite good while at other times it is not good. This may be explained in the light of inevitable disturbance of the sample probably due to presence of foreign material slight disturbance during trimming etc. Thus in the absence of a perfect sample, the use of Skempton's equation to predict the residual stress is more reliable.

When the measured residual stress is used the volumetric changes are far much less as compared to when traditional saturation process is employed. The classification of sample quality ranges from 'Fair to Poor' to Very good when residual stress is used as back pressure. When conventional saturation i.e when 1kPa is used as back pressure during saturation the classification is from 'Very Poor' to 'Fair to Poor'. It is expected thus, that if the 'true' residual stress estimated from **equation 2** is used all the samples would fall within the 'Very Good' quality classification.

7 CONCLUSION

When measured residual stress is used as back pressure

during saturation in the triaxial test the sample quality is quite improved. Since the sample may often than not be disturbed even if slightly so that the measured residual stress is not the expected true residual stress, hence in the absence of a perfect sample the prediction from **equation 2** would be more reliable.

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