Undrained shear strength and anisotropic yield surface of diatomaceous mudstone

Tokai University Student member ○Najibullah Arsaran
PEC Co.,Ltd Member Masaru AKAISHI
Tokai University Member Motohiro SUGIYAMA

1. Introduction

When constructing a structure on soft rock, adequate research and study are required concerning the shear behavior in the over-consolidation region because soft rock is considered to be in a heavily over-consolidated state. In many of the existing studies concerning the strength of soft rock, triaxial compression tests were conducted using isotropically consolidated samples[1),2)]. In this study, the strength of diatomaceous soft rock anisotropically consolidated under a designated consolidation pressure is examined in undrained triaxial compression tests, and studies are made of the peak and residual strengths of the sample in the over-consolidated state in the initial yield surface and the anisotropic yield surface.

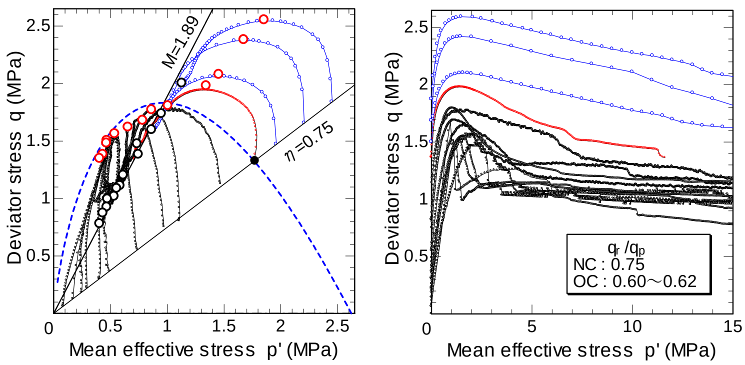
2. Samples and test method

Diatomaceous soft rock sampled in *Suzu* City, *Ishikawa* Prefecture[1), 2)] was used in the test. A specimen 5 cm in diameter and 10 cm in height was made from a rock mass, a cube approximately 40 cm on a side that was free from cracks or discontinuities. Table 1 shows the results of physical tests using crushed fine particles not exceeding 420 μm. The sample has a low gravity and a low natural water content. Samples with an initial natural water content of 120% ± 5% were used in consolidated-undrained triaxial compression tests.

The sample was subjected to anisotropic consolidation under a consolidation pressure p' and then to shear at a strain rate of 0.1 %/min. Consolidation pressure varied at 14 levels from 0.08 to 2.5 MPa. For anisotropic consolidation, the sample was subjected to isotropic consolidation and then only axial pressure was applied so as to achieve an effective stress ratio η (= q/p') of 0.75 while confirming in stages the dissipation of water pressure. Water pressure was dissipated in 24 hours or less in anisotropic consolidation under a consolidation pressure p' of 1.5 MPa or lower. Water pressure dissipation, however, took 4 days in anisotropic consolidation under p' of 2.0 MPa or higher. A back pressure of 0.5 MPa was applied.

Table 1 Physical properties of diatomaceous

ρ_s (g/cm^3)	w_n (%)	w_L (%)	w_p (%)
2.183	108～128	172.7	94.7



(a) Effective stress pass (b) Stress-strain relationship

Fig.1 Results of anisotropic consolidated-undrained test

3. Test results and discussions

The consolidation yield stress of the sample p_c in isotropic consolidation condition is 2.6 MPa and that if K_0 is assumed to be 0.5, yield stress based on the mean effective stress is approximately 1.7 MPa. Effective stress paths and stress-strain relationships for all the samples that were anisotropically consolidated at an effective stress ratio η of 0.75 are shown in Fig. 1 (a) and (b). The results in the normal and over-consolidation regions are indicated in blue and black, respectively. The results of shearing from the black circle at (p', q) = (1.75, 1.31) on the initial yield surface drawn by the original cam clay model represented by a dashed blue curve are shown red in Fig. 1 (a). Effective stress paths shows that in the sample in the normal consolidation region, positive pore water pressure occurred in the initial stages of shear and softening occurred after the maximum deviator stress q_p was reached (red circles in the figure) with the pore water pressure increasing. The maximum effective stress ratio η_{max} is therefore different from η when the maximum deviator stress q_p was reached. The path varies in the ten specimens in the over-consolidation region according to the consolidation pressure or over-consolidation ratio. The path to the maximum deviator stress q_p varies with the decrease of consolidation pressure, or increase of over-consolidation ratio, from leftward to upward and rightward with the changes in dilatancy. Subsequently, drastic strain softening occurred in all the specimens (Fig. 1 (b)). The stress paths under a consolidation pressure of 0.5 MPa or lower show that stress continuously increased along the $q = 3p'$ line until q_p, and softening occurred subsequently while p' was nearly constant. It is worth noting that the points of residual stress q_r at a post-softening axial strain of 15% in all the tests (represented by black circles) are located on a straight line that passes the point of origin. The inclination of the line obtained by the least

Keywords : diatomaceous soft rocks, shear strength, yield surface
Contact details: 4-1-1 Kitakaname, Hiratsuka-shi, Kanagawa 259-1292, Japan Tel.: 0463-58-1211,e-mail : sugi@keyaki.cc.u-tokai.ac.jp

square method is 1.89. In this study, the line is referred to as the critical state line (CSL). The points of maximum deviator stress indicated by red circles may be represented by lines separately in the normal and over-consolidation regions. Discussions will be made concerning the matter in the following chapter.

Table 2 Soil parameters used for the calculation

λ	κ	e_0	ν	M	N
0.642	0.071	2.40	0.3	1.89	1.45

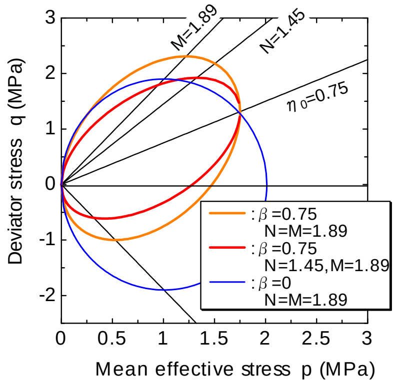


Fig.2 Shape of anisotropic yield function

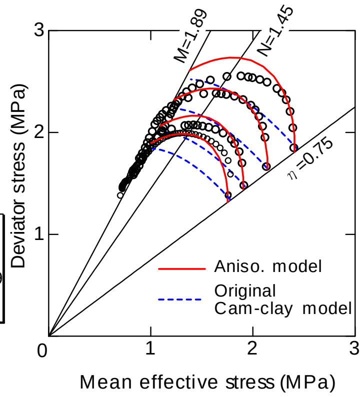


Fig.3 Results of calculation of effective stress path of normally consolidated sample

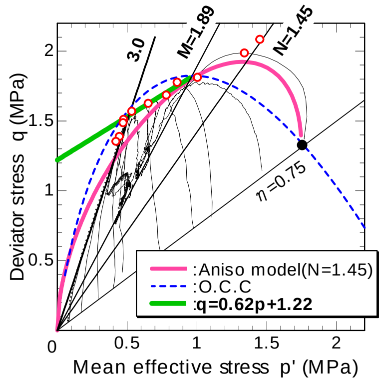


Fig.4 Yield surface in the over-consolidation

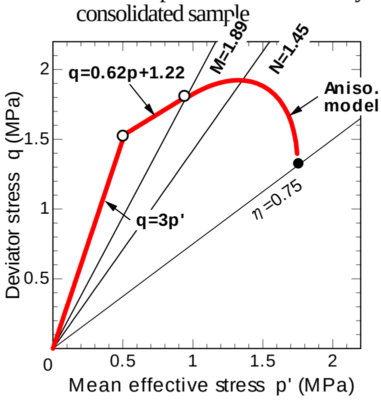


Fig.5 Anisotropic yield surface of diatomaceous mudstone

4. Maximum deviator stress and anisotropic yield surface

4.1 Anisotropic yield function [3), 4)]

Akaishi and others proposed equation (1) as an anisotropic yield function, and examined its applicability to clay or soft rock in a normally consolidated state[3), 4)].

$$F = q^2 - 2\beta pq + \beta^2 pp_0 + N^2(p^2 - pp_0) = 0 \quad (1)$$

where, N and β are empirical constants. It was assumed that N was equal to the effective stress ratio at the maximum deviator stress and that β was equal to the initial stress ratio η_0 at the time of anisotropic normal consolidation. If it is assumed that N is equal to M and β is zero, equation (1) is identical to the yield function of a modified cam-clay model. Fig. 2 shows an example of an anisotropic yield function calculated by combining N and β. The behavior of normally consolidated soil represented by a modified cam-clay model is of strain-hardening type. No strain-softening behavior can be calculated. The anisotropic yield function expressed by equation (1) can reproduce strain-softening behavior if N is assumed to be lower than M[4)]. Fig. 3 shows the results of effective stress path of normally consolidated soil using the material parameters listed in Table 2. It is evident that the results of calculation using the anisotropic yield function is much more in agreement with test results than the results using a modified cam-clay model (represented by dotted lines) based on the assumption that N was equal to M.

4.2 Yield surface in dry side

In order to examine the applicability of anisotropic yield function (N = 1.45, M = 1.89) to over-consolidation region, the yield function was plotted on Fig. 1 (a) and was represent as Fig. 4. The anisotropic yield function that well captured the normal consolidation region and is shown in pink is slightly smaller than the test result on the left (dry side) of the intersection with the critical state line (CSL). The yield surface of the original cam-clay model on the dry side is generally larger than the test result. Then, a green solid line with a series of q_p that crosses CSL was proposed as the yield surface on the dry side. In triaxial compression tests in which axial loading is applied, it is impossible to reach a space upper left of $q = 3p'$[5)]. The red solid line in Fig. 5 was then proposed as the state boundary surface (yield surface) of anisotropically consolidated diatomaceous soft rock.

5. Closing remarks

Triaxial compression tests were conducted on diatomaceous soft rock subjected to anisotropic normal consolidation and over-consolidation, and the maximum deviator stress q_p and residual stress q_r were examined. An anisotropic yield surface is proposed based on the test results. In the future, plasticity potential should be studied while considering the softening behavior in the over-consolidation region.

Refferences

1) Maekawa, H., Miyakita, K.: Mechanical characteristics of diatomaceous soft rock, Proceedings of the Japan Society of Civil Engineers, No. 334, pp.135-143, 1983.

2) Liao, H.,Akaishi, M. Hayashi, M. : Residual strength characteristics of soft rocks with a discontinuous plane, Journal of Geotechnical Engineering, JSCE, No. 529, pp.103-111, 1995.

3) Akaishi, M. et al. : A simple anisotropic clay plasticity model, Mechanics Research Communications, Vol.29, pp.241-245, 2002.

4) Imai, Y., Sugiyama, M. Tonosaki, A. and Akaishi, M.: Yield function for anisotropically consolidated clays, Proceedings of the 41th Japan National Conference on Geotechnical Engineering, pp.287-291, 1991.

5) Atkinson, J. H. and Bransby : The Mechanics of Soils, McGraw-Hill, London, 1978.