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STRAIN RATE AND THERMAL EFFECT ON STRESS-STRAIN BEHAVIOR OF ORGANIC CLAY

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ABSTRACT: Organic deposits are commonly encountered in estuaries regions. Organic matter directly affects the engineering properties of soil. However, all most economic cities in the world are located in this areas consisting of organic soil. Therefore, a technique to improve the properties of organic soil is important. This work is focused on improving engineering properties of organic soil by heating. In order to investigate the behavior, Pakpanang marine deposit clay is selected for this work. The scope of this research is to study the behavior of soil by using temperature control consolidated undrained triaxial compression test. The strain-rate dependency of undrained shear strength, pore water pressure, and stress path are investigated. The influence of normally consolidated (NC) on stress-strain behaviors of soil is examined. The results of tests indicated that the temperature relatively inverse to organic matter of soil and weaken the strength of soil.

Keywords: Compression triaxial test, Temperature, Organic clay, Strain rate, Undrained shear strength.

1. INTRODUCTION

Organic clays are defined as clay with sufficient organic content to affect the soil properties [1]. Organic clays exhibit mechanical properties somewhat different than the customary behavior of inorganic clays. Organic structure is contained within the porous cellular structure of the fibers, a sponge-like structure. The structure can absorb huge amounts of water but it is uncemented water and soil mineral [2]-[6]. Common characteristics of organic clays are high water content, high plasticity, high compressibility, low permeability and low shear strength [7]. The characteristic of soil directly affects the geotechnical engineering work. However, because of rapid economic growth, numerous constructions in present are usually found in estuaries regions, which are lowlands, where sedimentation of organic clay can be found.

In order to solve the critical problem due to engineering properties of organic soil, ground improvement techniques are applied. Because organic matter generally decays when the temperature is increased, the heating process is one of the ground improvement techniques that can be applied during construction.

Behaviors of fine grain soil are very interesting because viscosity behavior directly relates to plasticity and grain size of soil, resulting in time, strain rate and temperature effects. The effects of strain rate and Thermal are very significant to the stress-strain behavior of clay. Several researchers [8]-[15] have investigated the result of the strain rate effect on stress and pore pressure behavior of clay. They found that a higher strain rate results in a higher undrained shear strength: the undrained strength increased by 5-10% per log cycle of strain rate of testing for Saint-Jean-Vianney clay [11], " [12] demonstrated that the undrained shear strength increases by 9-20% for a 10-fold change in strain rate for high plastic natural clays." The studies of the strain-rate effect on pore-water pressure indicate that the strain rate effects to the strength that related to change of excess pore water pressure. Pore-water pressure rises up during shearing at a lower strain rate than a higher strain rate [16]-[18]. Moreover, the higher strain rate affects a higher normalize stiffness, E/σ_c' [10], [11], [18].

There has been a lot of research on the temperature effects on strength and stress-strain behavior of clay. We have found that the results are conflicting. Several investigators have found that increase in temperature decreases shear strength [19]-[23].On the other hand, increasing temperature increases in shear strength [24]-[27]. Investigation of Bangkok clay in drained heating conditions found that increased temperature also increases shear strength and stiffness of the clay. Temperature has no effect on the slope of the critical state and the stress paths tend to move to the right indicating that temperature caused strengthened clay [28]. Temperature affects to stress in clay that related to volume change and pore pressure such as " Campanella and Mitchell [29] shows that higher temperature affects volume change and pore pressure of clay depending on the drainage conditions of the clay's mass. Drained heating, is when the expansion of water leaves the clay mass, increasing the volume thus rearranging the soil's particles. On the other hand, undrained heating causes expansion of water in clay mass inducing development of pore pressure effects on volume expansion." However, there are no clear studies of the strain rate and thermal effect on the stress-strain behavior of organic clay.

By improving engineered properties of organic soil by heating affects relates to viscous behavior of clayey soil in order to predict the soil strength and ground settlement during and after dissipation of the excess pore water pressure, may also change temperature with more accuracy. The thermal conductivity of clay is faster than drainage causes to study in undrained heated conditions. The aim of this work is to understand the mechanical response of organic clay in relation to temperature and strain rate. It should be possible to use these relationships when making rudimentary interpretations of the natural process.

2. MATERIALS AND TEST PROGRAM

In this study, the original clay was recovered from a depth of 4.50 meters to 12.00 meters. The site was within Ban Pakkhaug, Pakpanang, NakhonSiThamarat province, which is on the southern coastline of Thailand. The measured physical properties of the clay samples are summarized in Table1. According to the Unified Soil Classification System (USCS), the clay is classified as organic clay (OH).

Tests were carried out using a temperature controlled triaxial apparatus as shown in Fig. 1. To apply a thermal load to the specimen, heaters were applied in chambers of triaxial cells that filled with water surrounding the sample. During a test, a thermostat was used to control temperature, automatically adjusting the amount of power supplied to the heater based on the feedback from the thermocouple. The soil and water temperature of the triaxial cells were set to equal, at least 1hours was required to achieve thermal equilibrium.

The undisturbed samples were trimmed into a triaxial specimen 50 mm in diameter and 100 mm in height. The specimens were wrapped with filter-paper, side-drains were to implement to accelerate drainage during consolidation and disperse excess pore pressure during shearing. All tests in this study were isotropically consolidated undrained triaxial compression tests in which the cell pressure and shearing rate were kept constant. To investigate the strain rate and thermal effect, the axial strain rates used were 0.02, 0.075, 1, and 6%/min and thermal load were 30 degree Celsius, 45 ˚C, and 60 ˚C. Therefore, the number of testing in this study is 12 as tabulated in Table 2.

In a routine testing procedure, a back pressure of 200 kPa. was applied to the specimen, until B values were found greater than 0.95. Then, the specimens were subjected to isotopically consolidation pressure of 450 kPa. The deviator stress and mean stress in this condition are zero and 250 kPa respectively. After the consolidation process, the thermal load was applied to the specimen under undrained conditions. Excess pore pressure in heat process was generated based on the expansion of water. Finally, the shearing was done in a strain controlled apparatus with strain rate as shown in Table 2

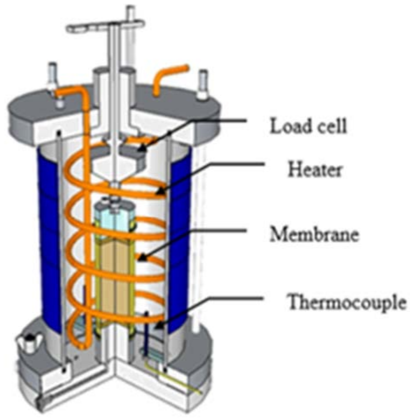

Fig.1 Schematic diagram of temperature controlled triaxial apparatus

Table 1 Physical and basic properties of the organic Pakpanang clay.

Properties		Value	Unit
Natural water content (W_n)		86.81	%
Liquid limit, LL	air dried soil	94.08	%
	oven dried at 110 °C	68.97	%
Plastic limit, PL		32.45	%
Plasticity index, PI		61.62	%
Total unit weight		1.5	t/m^3
Specific gravity, Gs [1]		2.67	-
Sand (0.06-2 mm.) [1]		0.75	%
Silt (0.002-0.06 mm.) [1]		52.67	%
Clay (<0.002 mm.) [1]		43.69	%
Compression Index, C_c [1]		0.668	-
Recompression Index, C_r [1]		0.14	-
Coefficient of Consolidation, C_V [1]		1.034	m^2/year
Void ratio [1]		2.253	-

[1](S. Chewakul, T. Chub-uppakarn and T. Chomphurat, 2013)

Table 2 Details of test condition of consolidated undrained triaxial compression test at elevated temperature units

Drainage Condition on heat process	Strain rate (%/min)	OCR = 1 Temperature (°C)		
Undrained	0.02	30	45	60
	0.075	30	45	60
	1.00	30	45	60
	6.00	30	45	60

3. DISCUSSIONS OF TEST RESULTS

3.1 Thermal Effect on Plasticity Properties of Organic Clays

The liquid limit (LL) is the point at which the consistency is transformed from a plastic state to a liquid state. From experiments, the liquid limit value is decreased when the temperature of the oven is increased as shown in Figure 2. The ratio of the liquid limit of air-dried soil (30 °C) to oven dried soil (110 °C) was found to be 0.73, indicating that the reduction in the liquid limit of oven dried soil was higher than 25%. Hence, Pakpanang clay is classified an organic clay following ASTM D 2487 – 06.

The plastic limit (PL) is the point in which the consistency is transformed from a semi-solid state to a plastic state. From this study, the plastic limit is a constant value along with the temperature of oven drying. As a result, the liquid limit and plastic limit is mostly dependent on soil texture, organic matter, clay mineralogy, and clay content. When the heating process decomposes organic matter, a spongy structure is destroyed, decreases the water layer surrounding soil. Therefore the liquid limit at high temperatures of oven dry is lower than the liquid limit at a low temperature of oven dry.

3.2 Thermal Effect on Undrained Shear Strength of Organic Clays

The undrained shear strength behavior of organic Pakpanang clay subjected to Isotropically Consolidated Undrained (ICU) compression triaxial test in undrained heating conditions, in various temperatures of 30°C, 45°C, 60°C and strain rates of 0.02, 0.075, 1.0 and 6.0 %/min. Fig. 3 shows pore pressure in the specimen is induced by the undrained heating process. The excess pore pressure was generated due to the increased volume of water. The shearing process began after the pore pressure was fully developed. The total elapsed time for undrained heating was about 24 hours. The heating time was the same as the period of the oven dried sample as determined in accordance with the procedures in Test Method of Classification of Soils for Engineering Purposes (Unified Soil Classification System) in ASTM D 2487-06. Heat transfers around all sample and eliminates some organic matter. The test results of normally consolidated (NC) organic clay will be illustrated using three figures as shown in Fig 4 to 6. Fig.(a) shows the relationship between normalized deviator stress and axial stress. Fig.(b) indicates the changes in normalized excess pore pressure with axial strain. In this diagram, the excess pore does not start from point (0.0, 0.0) because of excess pore pressure induced during undrained heating. Fig.(c) displays normalized stress path deviator stress and mean effective stress and the critical state line. Fig (c) shows that the pre-shear effective stress (p'_0) did not keep as a constant because of the uncertainty of the structure making it difficult to control its initial condition.

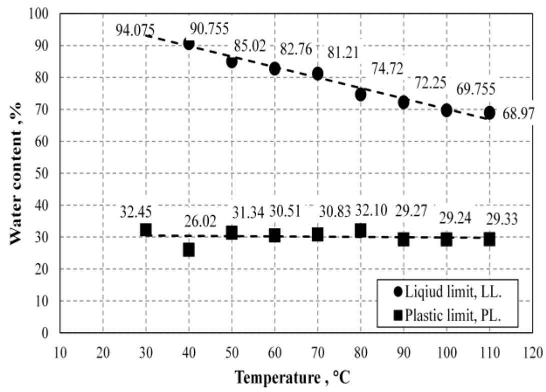

Fig. 2 Liquid limit and Plastic limit values of organic Pakpanang clay air dried and after oven dried.

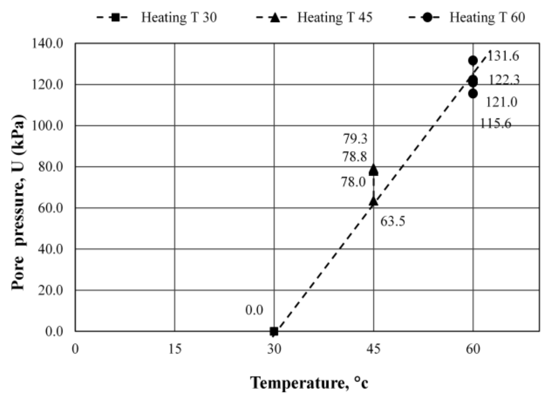

Fig. 3 Changing of excess pore pressure due to undrained heat as a function of temperature.

The exclusive results of this work show that undrained shear strength of organic clay is increased as strain rate increases. In Fig. 4(a), 5(a), and 6(a), the diagrams show the changing of normalized deviator stress, q_u/σ'_c is a direct variable to the change of temperature while the generating of excess pore pressure decreased as the temperature increased. The effect of strain rate and the temperature is shown in softening behavior of fine grain soil and directly related to strain softening. The strain softening behavior of fine grain soil is a result of decreasing of the viscosity and doubling the layer, water in soil structure easily moves out and the pore pressure can be distributed all around soil sample. As the high temperature is implemented, high strain softening as illustrated in Fig 5(a) and 6(a). In Fig. 4(b), 5(b), and 6(b), the undrained shear strength behavior was related to the excess pore water pressure, indicating that there is a tendency that there is higher excess pore pressure generated during low strain-rate because the effect of excess pore pressure that could fully generate and distribute in whole of soil mass. However, with the high strain-rate the excess pore pressure could not fully generate but only on the top and the bottom of soil mass caused low excess pore pressure affecting high shear strength. Pore pressure in the specimen based on shearing state is continuously increased, despite specimens beyond the failure state. The trend of pore pressure at room temperature is affected by organic matter in specimens its cellular structure. When temperature is high (45 ˚C and 60 ˚C), the excess pore pressure will be constant at large strains as shown in Fig. 4(b), 5(b),and 6(b).This is one reason that shear strength of organic clay is lower than inorganic clay.

Fig.7 shows that strains at the failure of normalized deviator stress in high temperatures are lower than low temperature. This result affects the decomposition of organic matter. Specimen structure is formed as a rigid material when the temperature is increased. The effect of the organic matter has on undrained shear strength behavior can be emphasized by pore pressure as shown in Fig.8. Excess pore pressure generated on the shearing process is decreased as the temperature is increased. Undrained shear strength is significantly decreased as the temperature is increased displayed in Fig 9.

Due to the fact that pore water pressure is generated by an undrained heating process and volume of specimens was not changed, (for the study of shear strength behavior), undrained shear strength should be normalized by normalization deviator stress. The relation between normalized deviator stress by effective stress before shearing state and strain rate is illustrated in Fig. 9, where effective stress before shearing state is σ'_c. From Fig. 9, the normalized deviator stress increased as-

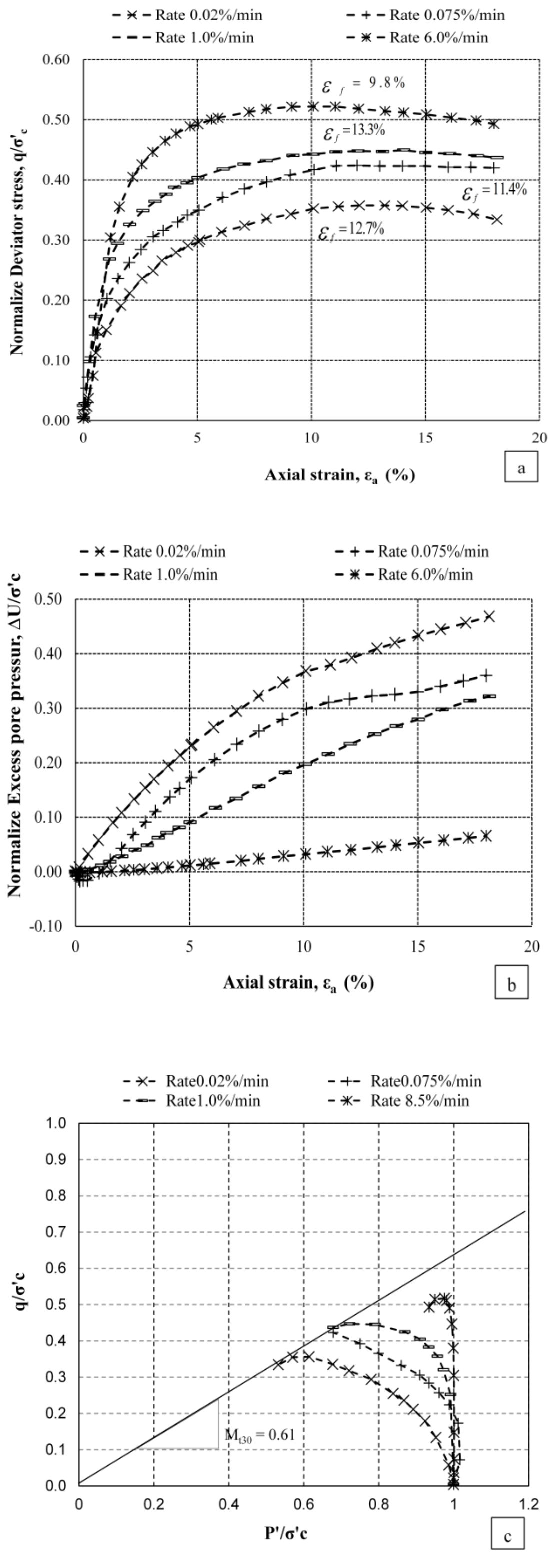

Fig. 4 Result of ICU triaxial compression test in NC organic Pakpanang clay subjected to undrained heating at 30 degree Celsius. (a) Relationship between normalized deviator stress and axial strain. (b) Relationship between normalized pore-water

pressure and axial strain (c) Normalized stress paths for the NC organic clay.

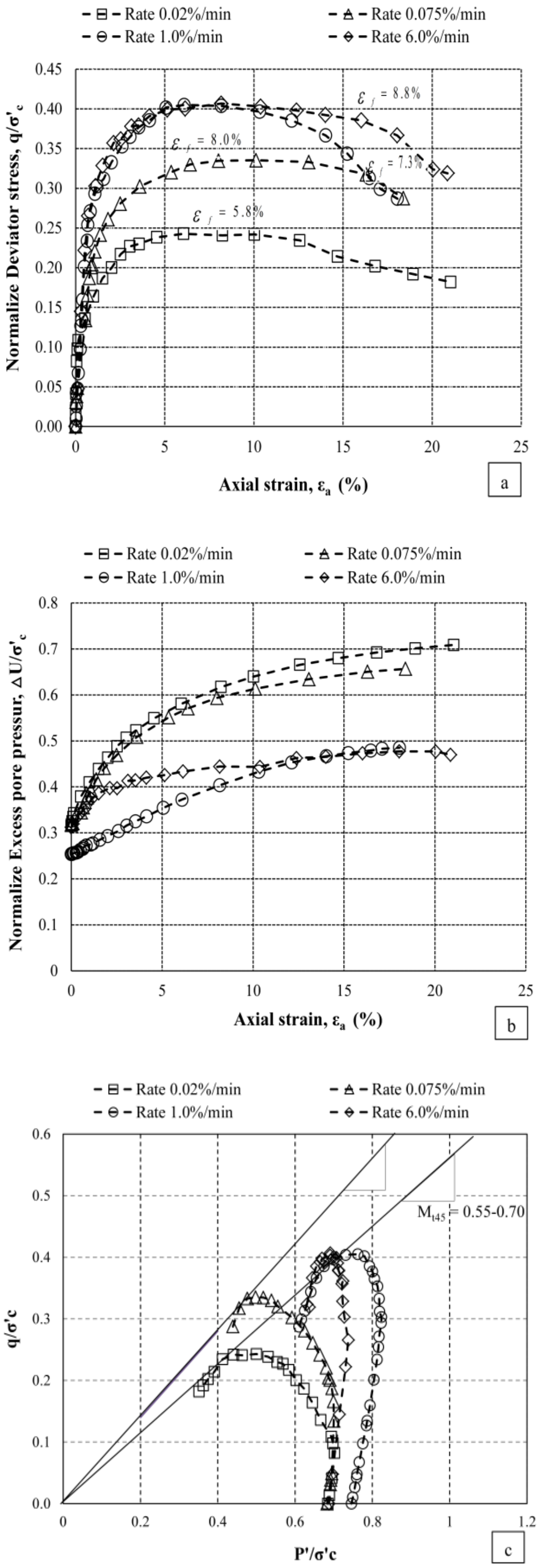

Fig. 5 Result of ICU triaxial compression test in NC organic Pakpanang clay subjected to undrained heating at 45 degree Celsius (a) Relationship between normalized deviator stress and axial strain. (b) The relationship between normalized pore-water pressure and axial strain (c) Normalized stress paths for the NC organic clay.

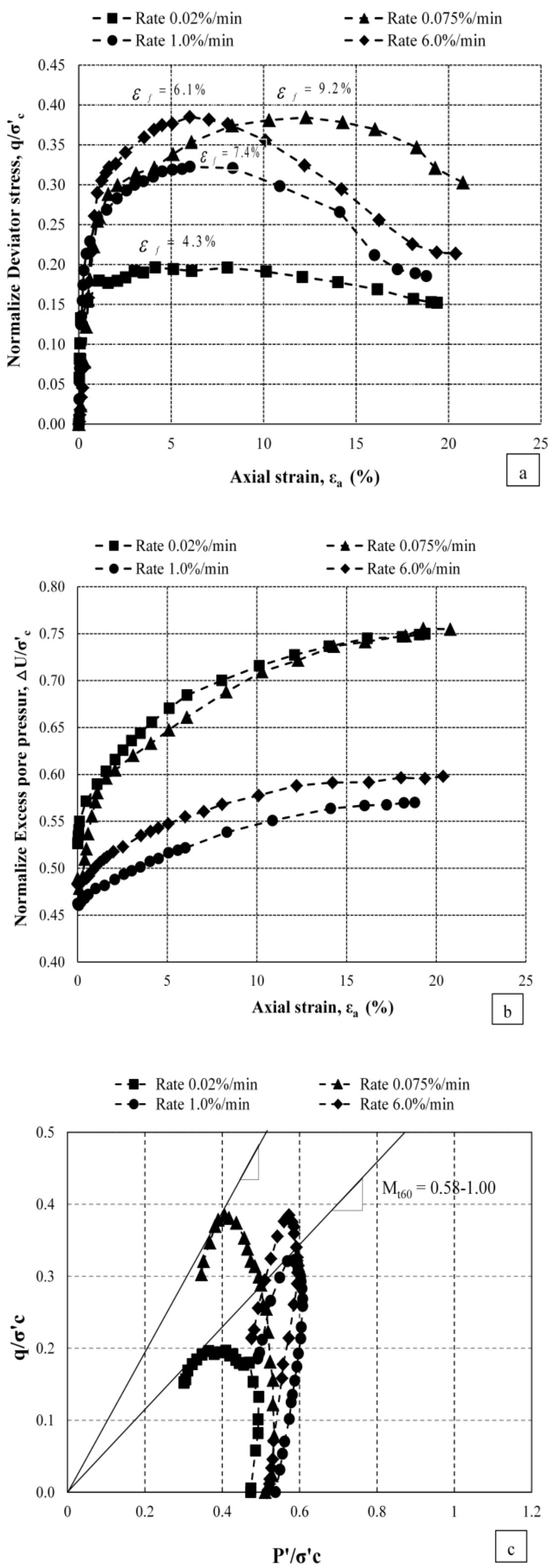

Fig. 6 Result of ICU triaxial compression test in NC organic Pakpanang clay subjected to undrained heating at 60 degree Celsius (a) Relationship between normalized deviator stress and axial strain. (b) The relationship between normalized pore-

water pressure and axial strain (c) Normalized stress paths for the NC organic clay.

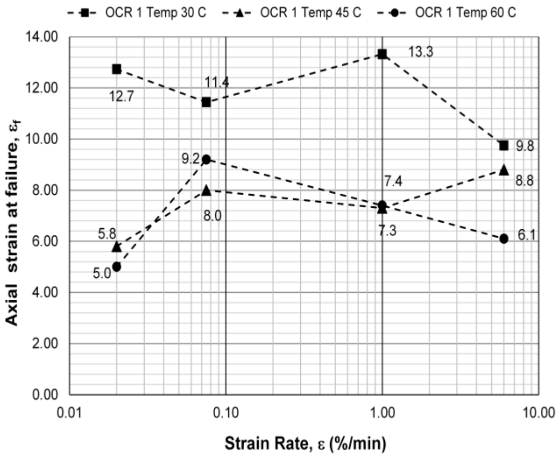

Fig. 7 Relationship between strain at failure and axial strain rate

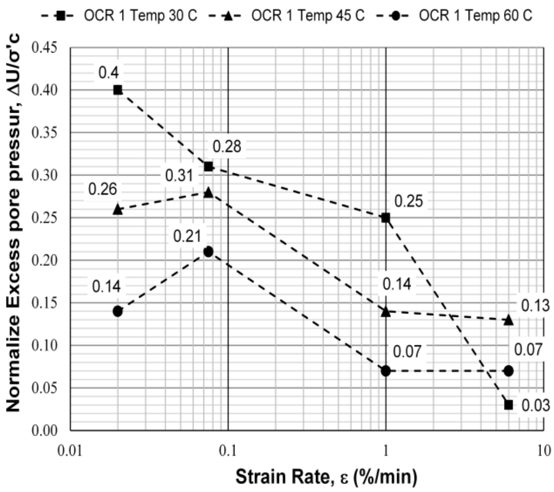

Fig. 8 Relationship between normalized pore water pressure at failure and axial strain rate.

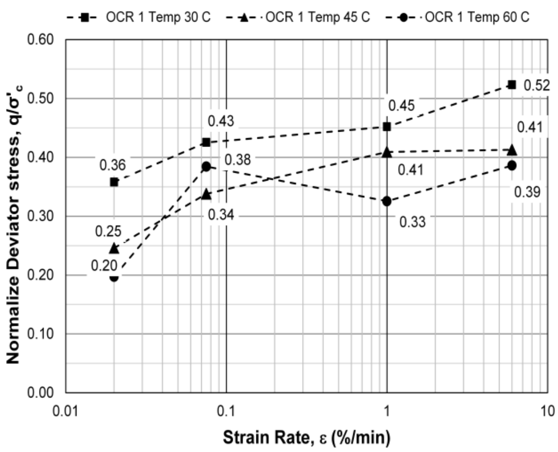

Fig. 9 Relationship between normalized deviator stress at failure and strain rate for NC organic Pakpanang clay.

the strain rate increased, contrary to the increase in temperature, as the lowest strain rate (0.02 %/min) and highest temperature (60 ˚C) given the lowest normalize deviator stress, as the highest strain rate (6.0 %/min) and the room temperature given the highest normalize deviator stress.

3.3 Thermal Effect on Critical State Line

The effect of temperature on the critical state behavior of organic Pakpanang clay was demonstrated at different temperature levels. Fig.

4(c), 5(c), and 6(c), Normalized stress paths for the NC organic clay shows that the heat stress paths tend to move to the left of the specimen tested at room temperature (30˚C). The shifting of the stress path to the left indicates that heat strengthened specimens due to the failure of the specimen at higher normalize deviator stress result from occurring lower excess pore water pressure in the soil mass during shearing. The slope M of critical state lines indicates that NC organic Pakpanang clay, at 30, 45 and 60˚C are in the range of 0.61, 0.55 to 0.69 and 0.58 to 1.00 respectively.

4. CONCLUSION

The object of this research studied the mechanical response of organic clay as a function of temperature and strain rate. As heat destroyed a spongy structure of organic matter that absorbed a water layer around fine soil is decreased. This effect directly relates to Atterberg's limit. Moreover, the decay of organic matter is effect by decreasing of excess pore pressure generated due to expanding of the shearing process. In strain rate effect, the tendency of undrained shear strength is a direct variation to strain rate. The behavior effects pore pressure generating in the shearing process. The slope M of the critical state lines indicates that the trend of slope M does not clearly change. Effect of temperature and strain rate is directly related to the path change of the stress path to shift to the left of the original critical state theory.

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