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THE EFFECT OF TEMPERATURE ON SOME ENGINEERING AND CONSOLIDATION PROPERTIES OF SOFT SOIL

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This article defines the effect of temperature on some engineering and consolidation properties of soft soil. The purpose of this research, therefore, was to determine the technical characteristics of soft clay consolidation behavior, specifically in terms of temperature influence on varying values of soil established mechanical parameters, including soft soil compression index (C_c), swelling index (C_s), volume change coefficient (m_v), consolidation coefficient (C_v), and the permeability coefficient (k). In this analysis, the use of soft clay in an undisturbed condition was sourced from a swampy location in South Kalimantan Province, Indonesia. Also, the temperatures applied to the specimens were 22°C, 40°C, 60°C, and 70°C. The results showed the influence of temperature modifications on soil compressibility, where extensive heat was responsible for abundant soil compressibility. In addition, the associated parameters, termed soil compression index value (C_c), consolidation coefficient (C_v), and the swelling index (C_s), observed an increase by 3%, 33%, and 22%, respectively. Furthermore, existence of high temperatures limited the unstable soil volume, where the volume change coefficient (m_v) tends to decrease by 3%. Also, varying temperatures essentially altered soil permeability, where the seepage properties of soft clay showed the tendency to increase by 32%, with rising soil temperature.

Key words: temperature, characteristics of consolidation testing techniques, soil compressive behavior, soft clay

INTRODUCTION

The abundance of land mass in Kalimantan, Indonesia are predominantly swamps, with soil types ranging from soft clay to peat. Based on a geotechnical perspective, soft soil characteristics are primarily not suitable for construction. For instance, roads built under this condition showed a tendency for bearing capacity failure, large subsidence, and a relatively long settlement period, as well as low slope stability (easily landslides), without any soil improvement.

Soil consolidation simply refers to water discharge through the pores, due to applied force (load), subsequently leading to land subsidence. Based on existing classical consolidation theory, size and duration of land subsidence are strongly modified by the soil's physical and mechanical properties, as well as the amount of effective load. For example, Holtz [1] generally stated the softer soil conditions are proven to instigate an increase in size and duration. However, till date, the classical consolidation theory in clay has not considered the effects of temperature changes. Similarly, very few current researchers have not developed a comprehensive analysis of these effects on soil consolidation behavior, particularly for soft clay.

Furthermore, soft soils, including fibrous peat, occur abundantly in Kalimantan.

Apart from initiating problems of carrying capacity and land subsidence, these soils also appear very prone to violent land fire events, specifically during dry seasons. Moreover, the existence of peatland fires significantly in-

creases soil temperature of road body heap and the clay mass (base soil), provided the peatlands are positioned at both sides of the road construction.

The increase in subgrade temperature due to heat propagation from land fires is believed to influence the physical and mechanical properties of soft clay. Based on the consolidation theory, the soil demonstrated properties detrimental to the proposed construction, in the form of relatively large subsidence and the duration, under load condition. However, by increasing temperature, the soil consolidation behavior becomes affected, and in turn, possibly influences the magnitude and subsidence duration.

The temperature increase in soil mass of road body areas, commonly occurs, due to heat transfer from surrounding peatland fires in South Kalimantan, Indonesia. In certain road segments, bumpy roads (subsidence non-uniform) are prevalent. A significant effect of high temperature on soil consolidation behavior is assumed to exist, including non-uniform subsidence.

The research on soil characteristics, due to temperature changes is relatively minimal, despite being a phenomenon circumstance. For instance, a temperature rise was observed below the surface. Apart from the problem of heat propagation under the road caused by land fires, the presence of nuclear waste heat facilities in the soil medium was also an influence [2]. The hotness beneath the surface, as a result of embedded gas and oil pipeline activities, produces surrounding heat [4], as well as the heat storage energy reservoirs resident in the soil [5].

This research was conducted to provide solutions to the behavior of soft clay consolidation curve, due to tem-

perature changes, particularly to determine the effect of these heat variations on the value of soil consolidation mechanical parameters, including compaction index (Cc), development index (Cs), volume change coefficient (mv), consolidation coefficient (Cv), and the permeability coefficient (k).

Also, the paper is aimed at developing the results from selected previous investigations encumbered with certain limitations.

A study on the effects of temperature on Kaolinite clay characteristics at 5°C, 15°C, and 40°C., have been reported by Mon's et al [6], prominent researchers from Japan and Denmark. The results showed an increase in temperature also triggered higher compression index (Cc) and consolidation coefficient (Cv). However, the scope obtained by Mon's et al [6] varied from previous researches, with certain limitations in terms of selected clay type in the form of pure kaolinite, and is not classified as soft clay from natural processes, in addition to dominant environmental influence. Moreover, Mon's et al. [6] did not comprehensively discuss the heat effects on the soil consolidation behavior.

Several studies have been conducted related to temperature effects on clay properties, but also experienced certain challenges on the parameters and soil types. These attempts involved Burghignoli et al. [7], Baldi et al. [8], Romero et al. [9], Sridharan et al. [10], Gadzama et al. [11], Laloui [12], Tsutsumi et al. [13], and Towhata et al [14].

Research by Burghignoli's et al. [7] applied clay with excess silt content, and minor sand proportion. The results observed a change in pore quantity during the composting process of soil particles, where temperature change was instigated by the stress and heat histories, and the time interval between the end of the primary consolidation phase and commencement of the heating process.

Baldi's et al. [8] showed intense temperature causes the water volume in soil pores to vary, after examining changes in water volume and mineral systems in clay with low porosity. In addition, temperature is also known to affect the strain of soil volume, and the distance from the surface of soil minerals. Furthermore, the effects of heat on over consolidated Bangkok clay was investigated by Naga's et al [15], where the results revealed higher temperatures probably decline pre-consolidation stress.

Romero's et al [9] have also experimented on the effects of temperature on hydraulic behavior of unsaturated clay. The results showed a temperature surge possess the capability to reduce water content and total suction, as well as alter the clay structure and pore water flow.

The mechanism of changes in saturated soil volume and the concept of effective stress due to temperature influence have been investigated by Sridharan's et al [10]. The results showed extreme temperatures significantly modified the physical forces between soil particles, resulting in changes to pore water flow capacity, water escapes, and water concentration in soil pores.

Several studies have been generated by Gadzama's et al [11], including changes in the Atterberg limit values, due to temperature influence. The results indicated the LL liquid limit value decreased with an expansion in soil temperatures. This condition was caused by the physical and chemical reactions as the heat is added, and subsequently led to the disintegration of bonds in soil particles.

Laloui [12] has studied the thermally induced effects on soil, using a suitable constitutive model for numerical simulations. The results revealed the existence of stress contraction phase at rising temperatures.

The effects of combined strain velocity and temperature on the consolidation behavior of clay soils has been investigated by Tsutsumi et al. [13]. Specifically, the relationship between stress and strain of clay soils during temperature changes was comprehensively analyzed. The results indicated the effective stress of collapse decreased with increasing temperature to form a new soil structure.

Towhata's et al [14] research was based on the volume change behavior of common and excessive consolidated clay kaolinite and bentonite, due to temperature alterations. The results showed a lesser shrinkage volume change, compared to ordinary consolidated clay at applied heat. Furthermore, an increase in soil permeability due to high temperature, causes the viscosity of soil fluids to decline.

MATERIALS AND METHODS

Material

Lom with high stability in undisturbed conditions sourced from swamps in South Kalimantan province, Indonesia, was employed in the consolidation test in determining soil congestion behavior. Table 1 represents the physical and mechanical characteristics of soft clay applied as the test object.

Table 1 also shows the selected clay types were classified as soft clay comprising minimal organic matter with

Table 1: Characteristics of clay used

Properties	Characteristic Value
• Volumetric Weight, γ (kN/m ³)	15.22
• Water Content, Wn (%)	56 – 70
• Organic content, Oc (%)	5 - 8
• Spesific Gravity, Gs	2.63
• Cohesi, C (kN/m ²)	10 -15
• qc CPT, (kN/m ²)	7.5 - 12
• Initial void ratio, eo	1.25
• Liquid limit, LL (%)	60
• Plastic Index, PI (%)	22
• Liquidity Index, LI	0.85
• Activity, A	0.46
• Sensitivity, St	1.56
• USCS Classification	OH - MH

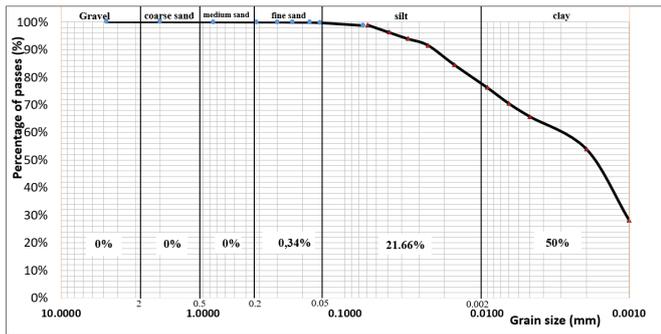


Figure 1: Grain size distribution chart

the OH-MH classification (USCS method). Based on shear strength (cohesion), the soil sample was classified as clay, with very tender properties. This statement was supported by the results of grain size distribution test in Figure 1, where the percentage of silt and clay soils was above 50% and were also classified as fine-grained soil (USC method).

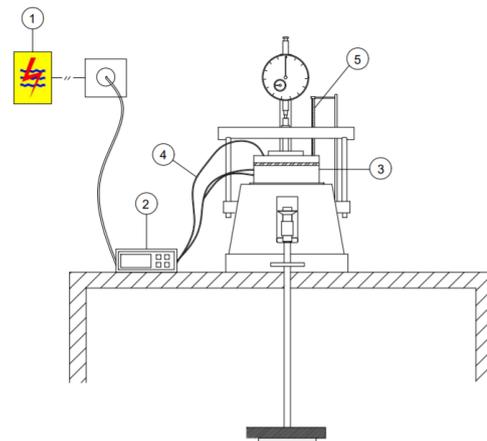
Testing procedure

Figure 2 shows a modified consolidation test instrument (Oedometer). These alterations refer to the research results by Naga's et al [15]. The process was performed within the consolidation cell (outer ring oedometer) by installing an electric heater, pre-connected to the temperature controller with an accuracy of $\pm 0.1^\circ\text{C}$. Furthermore, the controller was also attached to a thermo sensor device to read the amount of water temperature in the consolidation cell needed to match the desired thermometer value.

Subsequently, the temperature control was set in the range of $20\text{--}100^\circ\text{C}$, while the individual temperature was varied at 40°C , 60°C , 75°C , and 85°C . The temperature was assumed to reduce, due to the heat propagation process causing increased temperature of soft clay above normal condition. Based on research implementation, the temperature range values referred to the results of Donna's research regarding the amount of temperature occurring above 39°C , attributed to the burning of plants/plant fibers.

The consolidation test stage involved a higher temperature, prior to load application and reading of the decreasing values from the dial gauge. However, a time lag of approximately 7 minutes was provided, as the heat increased in the consolidation cell. This interval tends to generate temperature homogeneity in soil specimens in the consolidation ring with the water temperature at the outer cell.

Furthermore, the test results with the desired hotness at the final stage were parameters, termed compression index (C_c), consolidation coefficient (C_v), swelling index (C_s), volume change coefficient (mv), and permeability coefficient (k).



Information

1. Power source
2. Temperature controller
3. Consolidation cell which has been coated with an additional layer of heat element around it
4. Thermocouple (temperature sensor)
5. Thermometer

(a)



(b)

Figure 2: Modified consolidation test equipment

(a) Tool scheme

(b) Visual consolidation modification tool

RESULTS AND DISCUSSION

Relation of compression index (C_c) and temperature ($T^\circ\text{C}$)

Figure 3 highlights the temperature (T) influence on compression index (C_c) of the soft clay. The results showed the temperature affects the soil compressibility behavior through changes in the value of the soil compressive index (C_c). Based on Figure 3, intense temperature (T) tends to improve the soil compression index (C_c) by an average of 3%. This condition occurred as a result of changes in the amount of soil void ratio (e) after applying heat.

Figure 4 shows the change in pore quantity (e/e_0) due to extreme heat and also displays the comparison at normal and maximum temperature conditions. Also, an

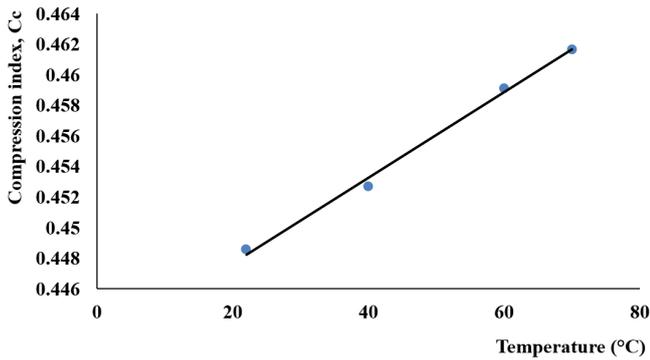


Figure 3: Relationship of compression index (Cc) and temperature variation

increase in applied heat on soft clay tend to enhance this amount, particularly above a stress of 0.5 kg/cm². Meanwhile, hot conditions generated 10% pore improvement, compared to normal state.

Furthermore, the variation in void ratio (e) causes alterations in pore water behavior. Burghignoli's et al [7] stated the deformation process occurred as a result of the dissipation of excess pore water pressure from temperature changes. Baldi's et al [8] have also reported the increase in applied heat instigated varying water volume in the soil pore. The results of Goodman et al research's [17] show minimal changes in soil fabric with increased temperature.

Therefore, extreme temperatures are known to trigger change in the volume of the clay to expand on receiving heat. Furthermore Ng, C.W.W et al [18] degradation of soil structure contributes to plastic thermal strain.

Relationship of consolidation coefficient (Cv) and temperature (T°C)

The consolidation coefficient (Cv) of soft clay was also influenced by temperature variations. This condition aligned with results of the relationship of consolidation coefficient (Cv) and temperature variations (T), as shown in Figure 5. Under these circumstance, higher soil temperatures (33%) obtained substantial coefficient value,

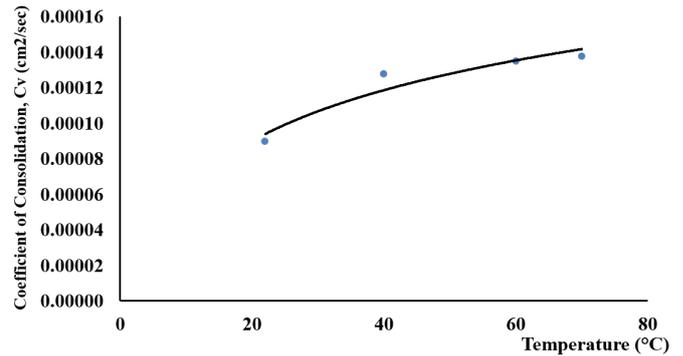


Figure 5: The relationship between the consolidation coefficient (Cv) and temperature variations

and the subsequent modifications significantly influenced clay compressibility behavior.

The increase in consolidation coefficient of soft clay due to temperature was caused by changes in soil pores. Naga et al. [15] reported increasing consolidation coefficient (Cv) alongside heat was due to thermo-mechanical behavior in the soil in form of pore fluid bubbles, resulting to pore cavity expansion and water discharge. Consequently, Romero's et al [9] concluded the rising soil temperature potentially altered the clay fabric and pore water flow. Furthermore, Sridharan et al, [10] revealed the presence of heat in the soil demonstrated a significant effect on the physical forces between soil particles. Therefore, a possible change occurred in the pore water flow capacity, outflow water, and water concentration. Ng, C.W.W et al [19] found that yield stress decreases with decreasing suction (wetting-induced softening). The observed thermal effects on wetting-induced softening are likely because with decreasing suction, the stabilizing interparticle normal force decreases more at a higher temperature.

Relationship between swelling index (Cs) and temperature (T°C)

Figure 5 shows the relationship between the swelling index (Cs) and temperature. However, Figure 6 revealed the extreme soil temperatures influence the soil compressibility through changes in the soil swelling index (Cs). This value also tends to increase by an average of 22%, as temperature intensifies.

Burghignoli's et al [7] stated the creep behavior of soil bonds are affected by changes in soil temperature. Also, Gadzama's et al [11] reported the heat increase tends to trigger particle damage. Shahriar et al [20] show that an increase in the displacement rate leads to reduction in the equivalent plastic strain while an increase in the temperature leads to an increase in the equivalent plastic strain.

Relationship between volume change coefficient (mv) and temperature (T°C)

The results confirmed the volume change coefficient (mv) of soft clay was altered by soil temperature increase. Figure 7 shows enhanced heat effect tends to decrease the volume change coefficient (mv) by 3%. A more sig-

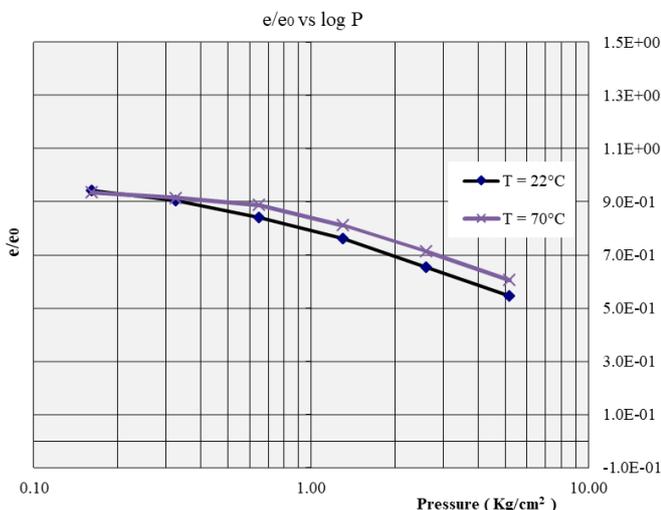


Figure 4: Relationship between e/e0 and pressure at temperature variations

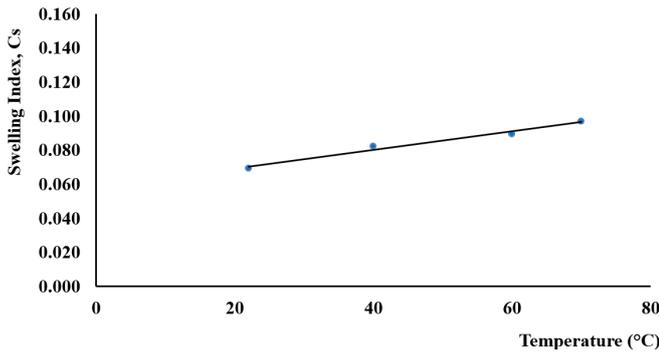


Figure 6: The relationship between swelling index (Cs) and temperature variations

nificant reduction occurred at temperature above 60°C. This condition matched with the results on Kaolin clay by Mon's et al. [6], where the decline was probably due to a relationship with changes in soil stress.

Furthermore, Laloui [12] also stated the tendency of stress contraction phase to occur in the event of temperature surge, while Tsutsumi et al. [13] reported the formation of a new soil structure, under similar conditions. Zhu et al. [21] show that the extended model can reasonably describe the effect of bonding degradation on the stain-rate and temperature dependent behavior of soft structural clay under 1D condition. Ng, C.W.W., et al. [22] also stated the continuous contraction as the number of thermal cycles increased, these observed differences can likely be attributed to different distributions of clay particles in the soil specimens. Ng, C.W.W., et al. [23] found that a semi-empirical equation over-estimated the thermal expansion coefficient of normally consolidated (NC) lateritic clay by about 3 times. Vahedifard, et al. [24] has shown demonstrate the importance of considering temperature effects on the shear modulus of soils.

Relationship between permeability coefficient (k) and temperature (T°C)

Figure 8 shows the relationship between soil permeability coefficient (k) and temperature variations. Based on this figure, heat was believed to influence the permeability behavior of soft clay. Also, increasing temperature (up

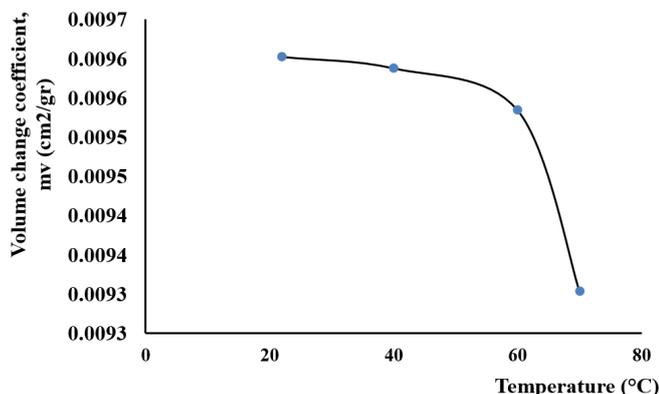


Figure 7: The Relationship between volume change coefficient (mv) and temperature variation

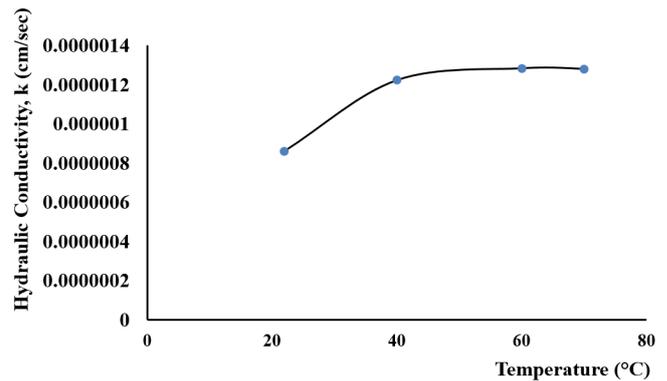


Figure 8: Relationship between soil permeability coefficient (k) and temperature variations

to 40°C) enhanced the soil permeability coefficient (k), by an average of 32%. Subsequently, at values above 40°C, the increment in coefficient (k) becomes more gentle, compared to previous lesser estimates.

Towhata's et al [14] observed an increase in soil permeability due to temperature increase and viscosity decline. Furthermore, Romero's et al [9] in line with Gadzama's et al [11], observed soil heat have a potential to alter the clay soil structure (clay fabric) and pore water flow, due to the behavior of porosity redistribution, heat, and chemical interactions. Vahedifard, et al. [25] also stated nonisothermal applications involving geo-energy systems and soil-atmospheric interaction problems for soil water retention curve.

CONCLUSION

Based on the results and discussion, several conclusions were generated, as follows:

- Temperature variations significantly influenced soil compressibility, as both variables were known to increase proportionately.
- The increment in soil temperature enhanced soil compressibility parameters, termed soil compression index (Cc), consolidation coefficient (Cv), and the swelling index (Cs), by 3%, 33%, and 22%, respectively.
- Consolidation coefficient (Cv) of soft clay showed a greater improvement alongside increasing soil temperature, compared to other technical characteristics.
- High soil temperature possessed the ability to reduce fluctuations in soil volume, where the volume change coefficient (mV) of soft clay tends to decline by 3%, with rising temperature.
- The seepage properties of soft clay were boosted by 32%, also with increasing temperature.

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