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Temperature effect on compression and collapsibility of residual granitic soil

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Original scientific paper

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Temperature effect on compression and collapsibility of residual granitic soil

This research aims to investigate the effect of temperature changes on the compression index and collapse potential of the residual granitic soil that is widely encountered in Malaysia. An experimental study was conducted on the compacted soil using a modified temperature-controlled oedometer. Temperatures of 27, 40, and 60 °C were applied on two series of soil specimens with different values of dry density. Experimental results showed that the value of compression index is independent of temperature. On the other hand, heating caused a reduction in collapse potential, which was more pronounced at low dry density.

Key words:

Temperature, Compression index, Collapse potential, Residual granitic soils

Izvorni znanstveni rad

M. Kholghifard, K. Ahmad, N. Ali, A. Kassim, R. Kalatehjari, F. Babakanpour

Utjecaj temperature na stišljivost i potencijal kolapsibilnosti rezidualnog granitnog tla

U ovom se radu istražuje utjecaj temperaturnih promjena na indeks stišljivosti i potencijal kolapsibilnosti rezidualnog granitnog tla na koje se često nailazi u Maleziji. Zbijeno tlo analizirano je pomoću modificiranog edometra s kontrolom temperature. Dvije serije uzoraka tla s raznim vrijednostima suhe gustoće ispitane su pri temperaturama od 27, 40 i 60°C. Rezultati ispitivanja pokazuju da vrijednost indeksa stišljivosti ne ovisi o temperaturi. S druge strane, grijanje dovodi do smanjenja potencijala kolapsibilnosti, a ta je pojava izraženija pri niskim vrijednostima suhe gustoće.

Ključne riječi:

temperatura, indeks stišljivosti, potencijal kolapsibilnosti, rezidualna granitna tla

Wissenschaftlicher Originalbeitrag

M. Kholghifard, K. Ahmad, N. Ali, A. Kassim, R. Kalatehjari, F. Babakanpour

Temperatureinflüsse auf die Kompressibilität und Kollapsibilität von residualen Granitböden

In dieser Arbeit wird der Einfluss von Temperaturveränderungen auf den Kompressibilitätsmodul und das Kollapspotenzial in Malaysia häufig vorkommender residualer Granitböden untersucht. Proben verdichteten Bodens sind mittels eines modifizierten Ödometers mit Temperaturkontrolle analysiert worden. Zwei Versuchsserien mit Bodenproben verschiedener Trockendichten sind für Temperaturwerte von 27, 40 und 60°C durchgeführt worden. Die Resultate haben gezeigt, dass der Kompressibilitätsmodul nicht von der Temperatur abhängt. Andererseits führt ein Temperaturanstieg zur Reduktion des Kollapspotenzials, und diese Erscheinung ist ausgeprägter für niedrige Werte der Trockendichte..

Schlüsselwörter:

Temperatur, Kompressibilitätsmodul, Kollapspotenzial, residuale Granitböden

1. Introduction

Over the past two decades, geotechnical engineers have been increasingly examining thermal influences on physical and mechanical properties of soil. Firstly, researchers attempted to explain the influence of temperature changes on the volumetric and strength parameters of soil samples through experimental studies [1, 2]. Therefore, earlier research mostly focused on engineering properties of soil at temperatures of less than 50 °C. Present-day activities relating to geotechnics, such as the storage of nuclear waste, deep offshore well drilling, and foundations subjected to temperature changes, have led researchers to study the thermo-mechanical behavior of soils at temperatures of up to 100 °C and above.

Several researchers [3-6] have explored thermal effects on the physical and mechanical behavior of clayey soils. A general outcome of these studies is that an increase in temperature induces a decrease in the void ratio of normally consolidated soil, whereas warming may cause swelling in overconsolidated soils. These studies also show that the thermal volumetric behavior of unsaturated soils is influenced by the overconsolidation ratio and suction.

On the other hand, the hydro-mechanical behavior of heavily compacted clayey soils surrounding waste disposal zones are considerably influenced by the long term elevation in temperature [7, 8]. Francois & Laloui [8] point to a slight reduction in water retention capacity of soil due to increase in temperature. Cekerevac and Laloui [4] study the thermo-mechanical behavior of some artificial clayey soils to assess their use as a buffer for nuclear waste containers. They claim that an increase in temperature of a saturated soil to less than the boiling point of water (100 °C) impacts the volume change, shear strength, and stiffness of soil.

Over the past fifty years, many studies have been conducted to evaluate parameters affecting the collapse potential of compacted soils [6, 9-11]. However, literature review shows that no data is currently available about the effects of temperature on the collapse potential of the residual granitic soil. Thus, results obtained by experimental study of temperature effects on the compression index and collapse potential of the residual granitic soil are presented in this paper.

2. Materials and methods

2.1. Basic properties of the soil

The reddish brown residual granitic soil samples for this study were collected from the depth of 1.7 m at the Universiti Teknologi Malaysia (UTM) campus. Classification tests employed according to BS1377: Part 2 [12] revealed that the soil is the silt of high plasticity, MH. In addition, X-ray diffraction (XRD) analysis results indicated that the representative soil sample consists of quartz, mica and feldspar as its non-clay minerals, and kaolinite and montmorillonite as its clay minerals. Results of the standard Proctor compaction test applied to achieve maximum dry density of soil are shown in Figure 1. Some basic engineering properties of samples are presented in Table 1.

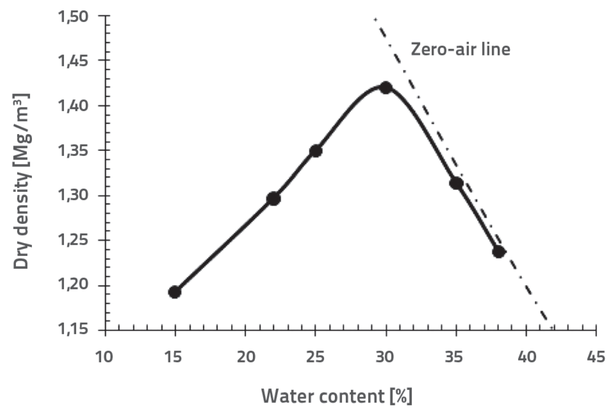

Figure 1. Compaction curve of residual granitic soil

Table 1. Basic properties of residual granitic soil

Property	Value
Liquid Limit [%]	68
Plastic Limit [%]	35
Plasticity Index [%]	33
Specific Gravity	2,67
Sieve Analysis and Hydrometer	
Gravel [%]	3
Sand [%]	36
Silt [%]	40
Clay [%]	21
Optimum Moisture Content [%]	30
Maximum Dry Density [Mg/m³]	1,41
Natural Dry Density [Mg/m³]	1,21
Natural Water Content [%]	26

2.2. Preparation of compacted soil samples

The air dried representative soil sample passing the 2 mm sieve was completely hand-blended at the designed water content of 30 %. The mixture was permitted to achieve equilibrium for 24 hours in a sealed plastic cover. The required mass of prepared wet soil samples was compacted to different dry densities using the hand-operated dynamic compaction process based on BS1377: Part 4 [13]. Characteristics of tested soil samples are summarized in Table 2.

Table 2. Properties of prepared compacted samples

Specimen (Series)	Dry density [Mg/m³]	Compaction [%]	Initial water content [%]	Temperature [°C]	Initial void ratio
A	1,21	85	30	27 / 40 / 60	1,21
B	1,35	95	30	27 / 40 / 60	1,03

2.3. Test performance

This experimental study consisted of a series of double oedometer tests conducted on soil specimens under various values of temperature at different initial dry densities. A modified oedometer shown in Figure 2 was used for the testing.

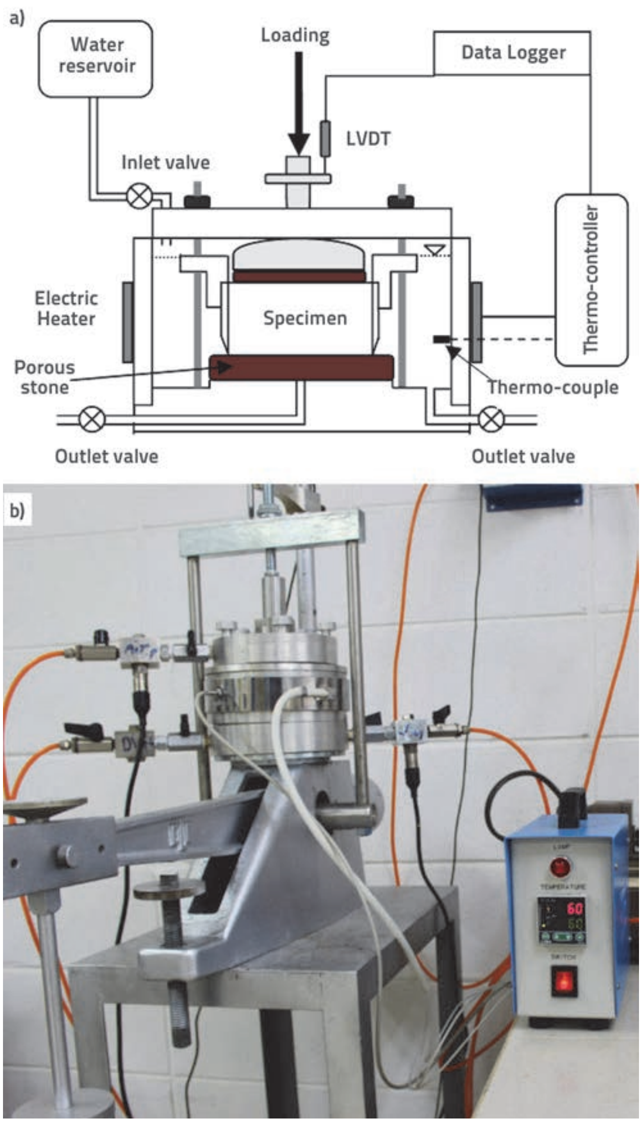

Figure 2. Modified oedometer: a) schematic diagram; b) photograph

The modified oedometer consisted of a conventional oedometer device, a ring-shaped heater with an external oedometer ring, a thermocouple, a water tank, and a thermo-controller unit. In addition, the conventional oedometer device was customized by means of a temperature chamber which was connected to the thermo-controller unit accurate to ±1 °C. The thermo-controller was capable of controlling temperatures of up to 90 °C.

Double-oedometer tests [14] were carried out to determine the collapse potential of two series of the residual granitic soil samples. This method consists of two consolidation tests conducted on two identical specimens in each series. These identical specimens were placed in oedometers and kept at a low pressure (1 kPa). One of the specimens was initially fully saturated and kept at a low pressure (1 kPa) for 24 h, after which the specimen was loaded up to 400 kPa using the standard incremental loading procedure. The other specimen was incrementally loaded up to 400 kPa at its initial water content without soaking. The difference in void ratios of the soaked and unsoaked specimens was considered as the collapse potential. For each series of specimens, the double-oedometer test was conducted at three different temperatures (27, 40, and 60 °C) using a modified oedometer. The soil specimen temperature was indirectly increased by heating the water in the annular space between the external ring of the oedometer and the specimen ring. The calibration test indicated that an average time required for the specific temperature maintained in the circular space to reach the center of the specimen was about 18 min. As a result, the desired temperature must be kept for at least 20 min before beginning any test.

The collapse potential was determined at vertical stress levels of 25, 50, 100, 200, and 400 kPa for all specimens. The collapse potential (C_p %) of the specimens was calculated using the following equation specified in ASTM D 5333 [15]:

$$C_p(\%) = \left[\frac{e_i - e_f}{1 + e_0}\right] \text{ x } 100\% \tag{1}$$

where e_0 is the initial void ratio, e_i and e_f are void ratio values obtained by oedometer tests at initial water content and in saturated condition, respectively, under the same vertical stress.

3. Results and discussion

Figures 3 and 4 show void ratio versus vertical stress graphs based on double-oedometer tests performed on samples of series A and series B, respectively, at different temperatures.

The intersection of the elastic compression slope and the plastic compression slope was defined as the preconsolidation stress as shown in Figure 3 and Figure 4. This method was also employed by Lloret *et al.* [16]. Table 3 presents the preconsolidation stress (at which yield occurs) for both groups in moist conditions.

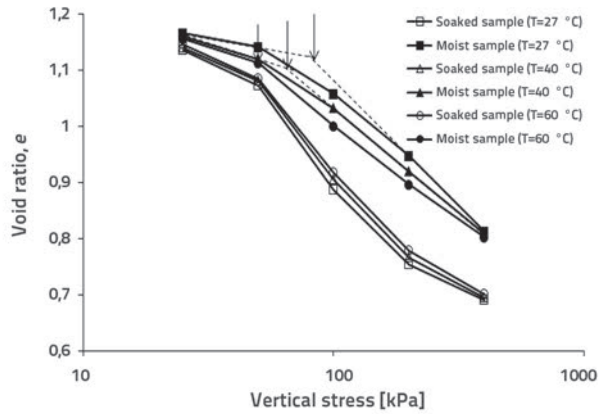

Figure 3. Compression curves for series A specimens

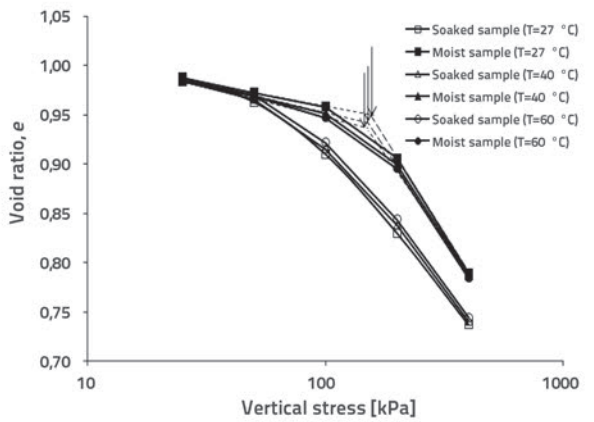

Figure 4. Compression curves for series B specimens

It can be noticed that the preconsolidation stress of soil specimens decreases with temperature. However, this was negligible for the denser specimen. A similar behavior for clay was reported by Cekerevac & Laloui [4]. Approximately similar shapes of compression curves for each series were observed at different temperatures. In addition, the difference among the compression curves at different temperatures for the denser samples (series B) was insignificant because the compression caused by the applied load is controlling the soils response. The lower void ratio values for both series at higher temperatures can be explained by the produced thermal compaction phenomenon [4] or thermal hardening phenomenon [6].

Table 3. Preconsolidation stress in moist condition

Soil specimen (Series)	Preconsolidation stress [kPa]		
	27 [°C]	40 [°C]	60 [°C]
A	81	65	50
B	150	149	148

Figures 5.a and 5.b show normal consolidation lines (NCL) for moist specimens of both series A and B, respectively. NCL properties are given in Table 4. The temperature effect on the compression index of soil was studied by comparing NCL values at different temperatures. The slopes of the NCL obtained from graphs, known as the compression index (C_c), are presented in Table 4. The results show that the compression index slightly decreases with an increase in temperature. In other words, the effect of temperature on the compression index was negligible.

Table 4. Properties of normal consolidation lines (NCLs)

Soil specimen (Series)	Dry density [Mg/m³]	Temperature [°C]	Best fit equation for normal consolidated part of compression curve	Slope of NCL (C_c)
A	1,21	27	y = -0,361 log(x) + 1,7614	0,361
		40	y = -0,350 log(x) + 1,7224	0,350
		60	y = -0,343 log(x) + 1,6907	0,343
B	1,35	27	y = -0,286 log(x) + 1,5634	0,286
		40	y = -0,276 log(x) + 1,5344	0,276
		60	y = -0,270 log(x) + 1,5142	0,270

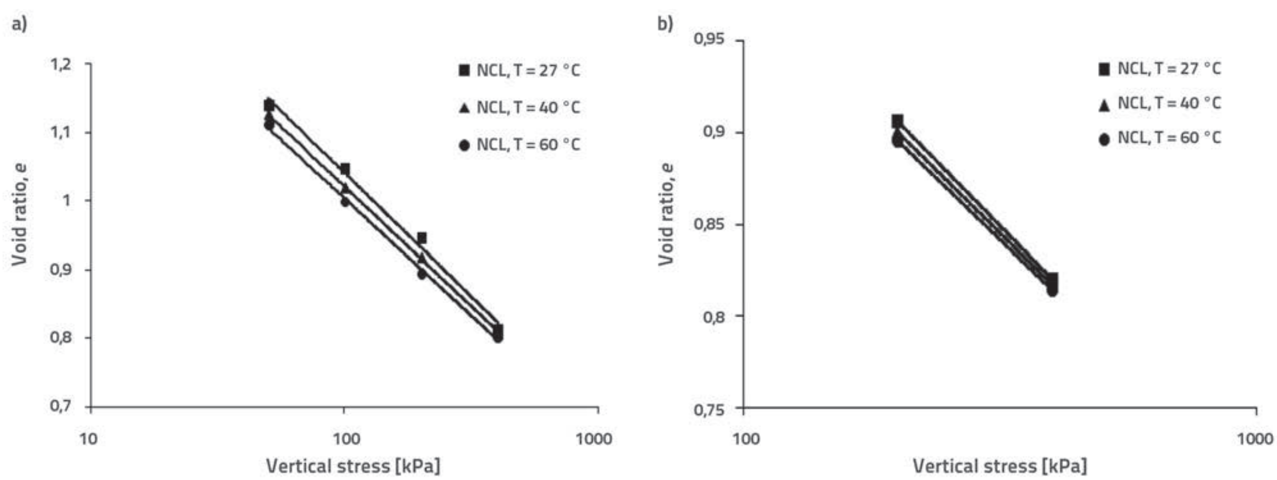

Figure 5. Normal consolidation lines (NCL) at 27, 40, and 60 °C for moist specimens of: a) series A; b) series B

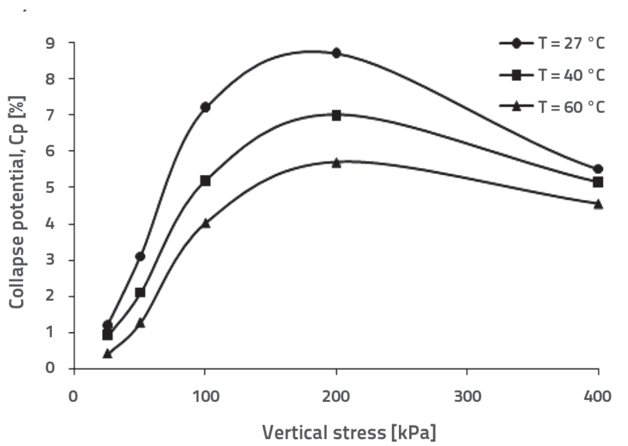

Figure 6. Collapse potential for series A specimens at 27, 40, and 60 °C

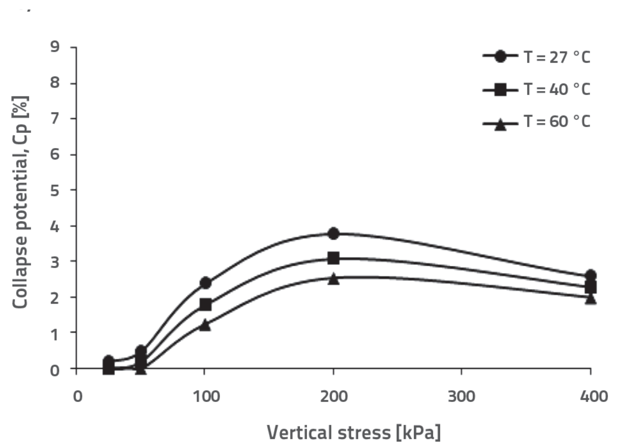

Figure 7. Collapse potential for series B specimens at 27, 40, and 60 °C

The influence of temperature on the collapse potential (*Cp*) of soil samples is presented in Figures 6 and 7. It can be seen that the collapse potential of specimens decreases with an increase in temperature for both series A and B due to thermal compaction or thermal hardening. The reduction for looser specimens was more significant than that of denser specimens. The maximum reduction of *Cp* amounted to 3.01% and 1.25% for series A and B, respectively.

The maximum collapse potential was observed at vertical stress of approximately 200 kPa, for both series A and B at 27 °C. However the influence of heating on *Cp* was less obvious as the applied vertical stress increased. The collapse potential of the soil increased initially to a maximum value with an increase in vertical stress, and then it decreased at higher levels of vertical stress. Medero *et al.* [17] reported similar behavior for an artificial cemented soil.

Conclusion

Based on the experimental results obtained by oedometer testing of a residual granitic soil, the following main conclusions can be made:

- The preconsolidation stress of the residual granitic soil reduced with the rise in temperature. However, this reduction was negligible in case of denser samples.
- Normal consolidation lines (NCLs) at different temperatures were slightly moved in a parallel trend. This means that the compression index (slopes of the NCL) of the soil can be considered independent from temperature.
- The collapse potential of soil decreased with an increase in temperature. The reduction was more pronounced for looser samples than for denser samples. However, the collapse potential of samples increased up to the maximum value with an increase in vertical stress, and then it decreased at higher levels of vertical stress.

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