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THE EFFECT OF TEMPERATURE ON THE ENGINEERING PROPERTIES CONSOLIDATION BEHAVIORS OF SOFT SOIL

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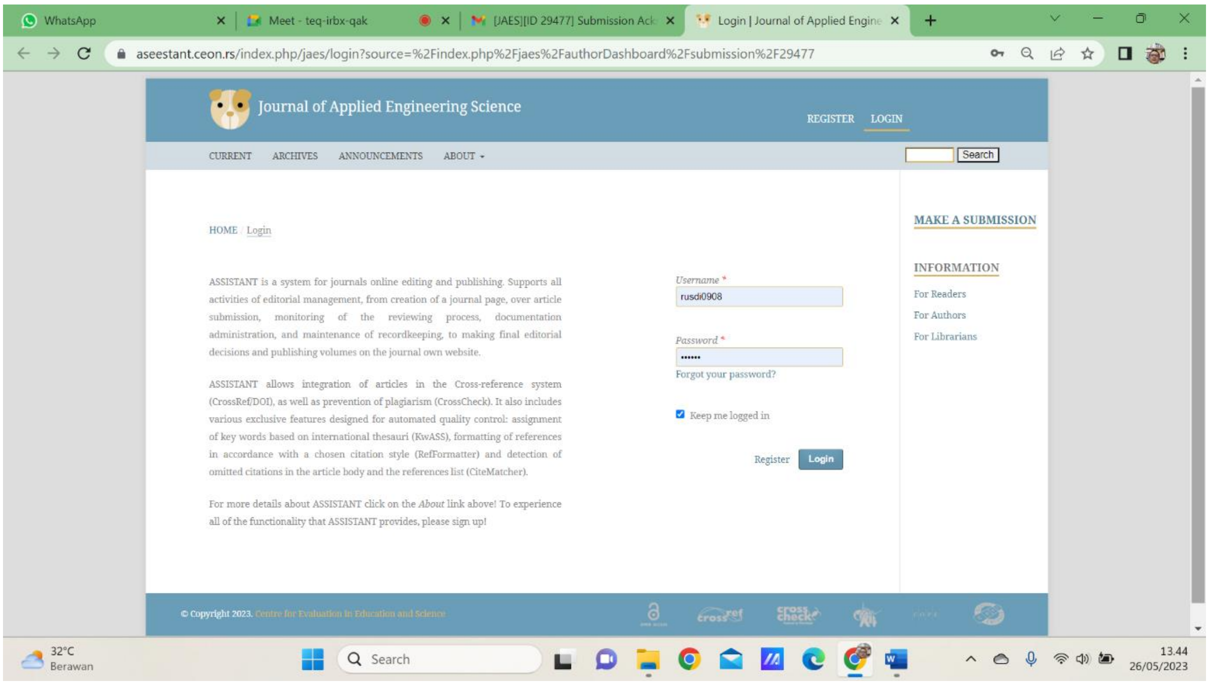
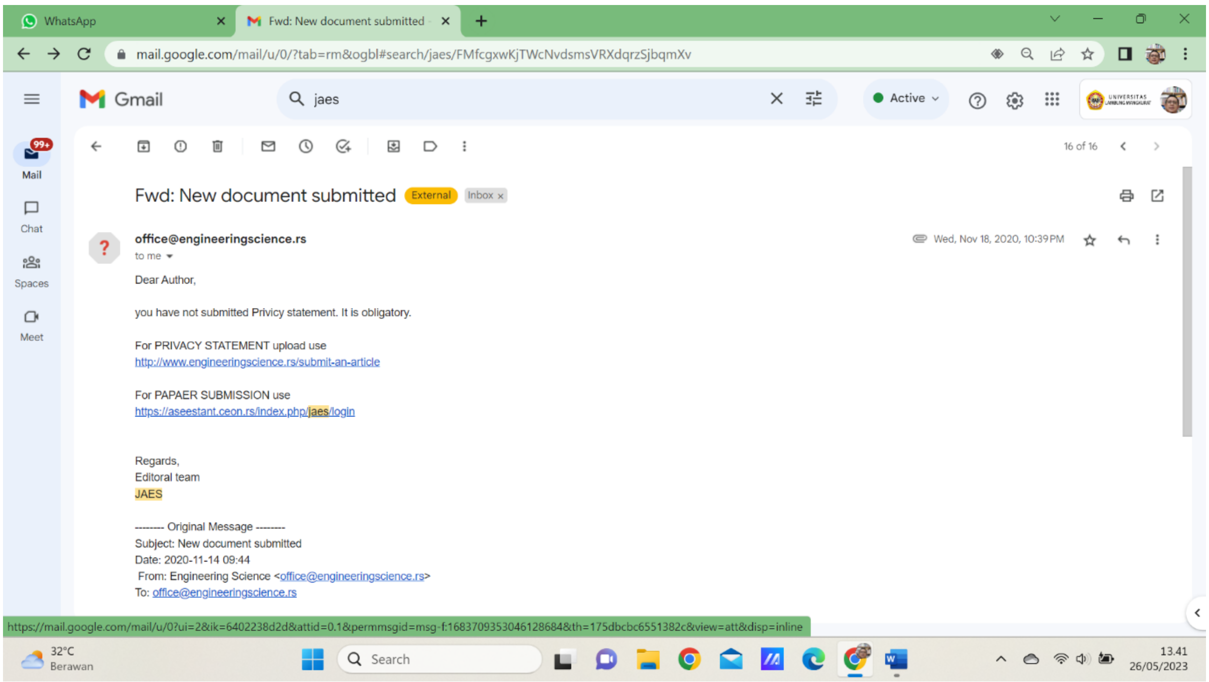
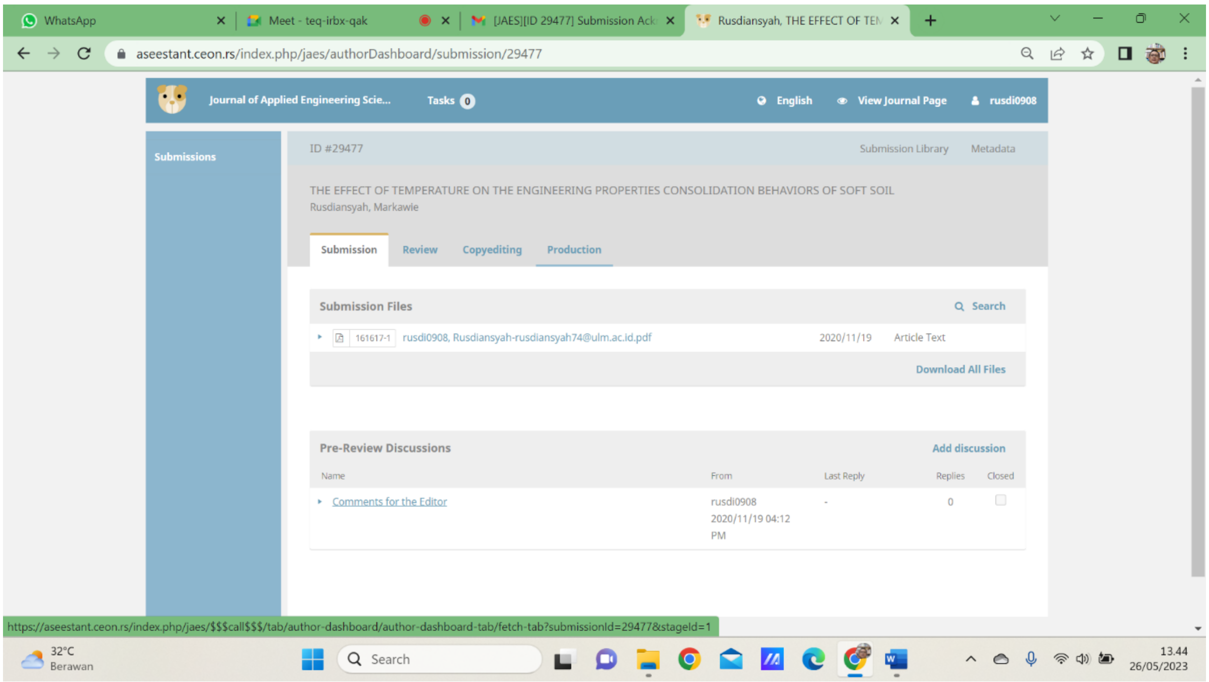
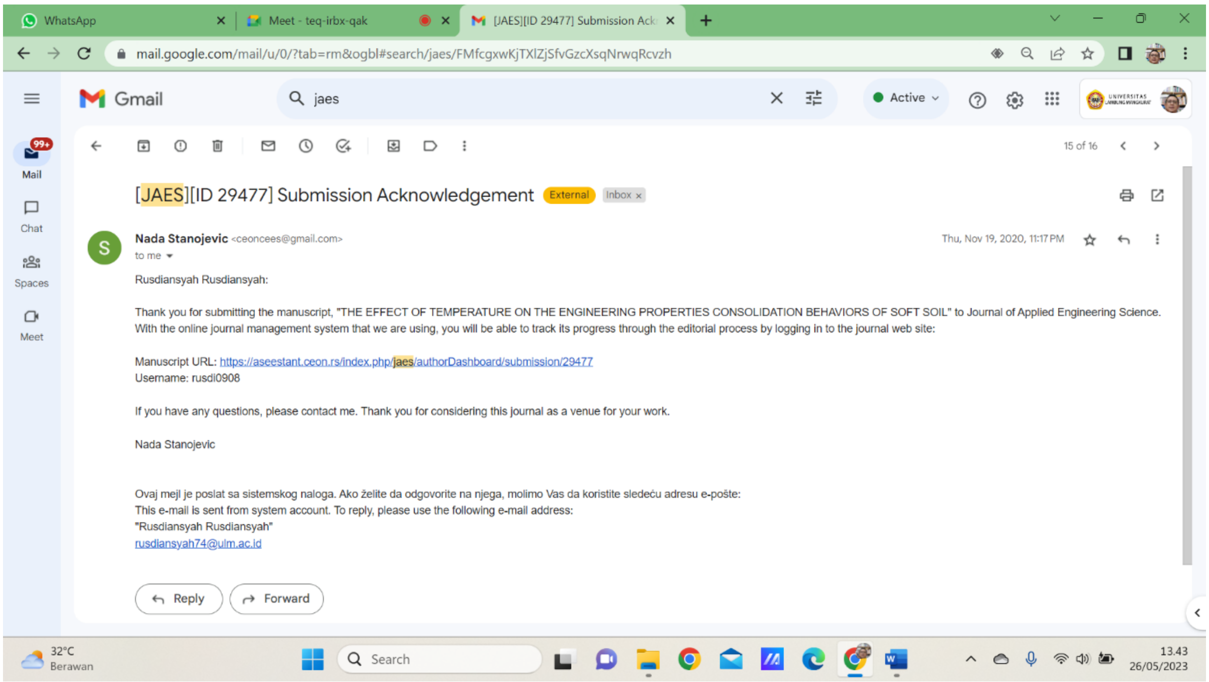
TAHAP 1 SUBMIT ARTIKEL









NASKAH ARTIKEL SUBMIT :

THE EFFECT OF TEMPERATURE ON THE ENGINEERING PROPERTIES CONSOLIDATION BEHAVIORS OF SOFT SOIL

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ABSTRACT

Research on soil behavior due to changes in heat temperature in the soil mass is still relatively small. Even though, the phenomenon of increasing temperature in the soil mass is frequently occured. For example, there is an increase in temperature in the ground besides the problem of heat propagation under the road due to land fires, as well as the presence of waste heat from nuclear power plant in the soil medium, the operation of electric cables in the ground which causes heat, and the gas pipelines and oil pipes embedded in the ground, which generates heat around it, as well as thermal energy storage that are embedded in the soil.

This research was conducted to get answers to how the behavior of the curve of the clay soft soil consolidation is due to changes in temperature. Mainly to get knowledge about the effect of temperature on changes in the value of mechanical parameters of soil consolidation, such as clay soft soil compression index (Cc), swelling index (Cs), volume change coefficient (mv), coefficient of consolidation (Cv), and hydraulic conductivity (k) of clay soft soil. In conducting the research, the material used was clay soft soil in undisturbed condition originating from a swampland locating in South Kalimantan, Indonesia, while the main tool used was a modified consolidation test device by adding an artificial heating device whose temperature could be adjusted with a temperature control device and temperature sensor. The temperatures applied to the test specimens were 40ºC, 60ºC 75ºC, and 85ºC.

The results showed that changes in temperature in the soil could affect the compressibility of the soil, where the higher the temperature (heat) of the soil, the greater the soil compressibility. The increase in temperature in the soil causes an increase in the value of soil compressibility parameters such as the soil compression index (Cc), the coefficient of consolidation (Cv), and the swelling index (Cs). The value of compression index (Cc) of clay soft soils has a greater increase than the increase in other compressibility parameters when the temperature of clay soft soil increases (hot). In addition, the presence of high soil temperatures (hot conditions) in the soil can reduce changes in soil volume, where the volume change coefficient (mv) of clay soft soil tends to decrease if the soil temperature increases. Changes in soil temperature also affect soil permeability, where the seepage properties of clay soft soil tend to increase along with an increase in temperature in the soil.

Key words: Temperature, consolidation test, soil compression behavior, clay soft soil.

1. INTRODUCTION

Most of the lands in Kalimantan, Indonesia are dominated by wetlands, with soil types ranging from clay soft soil to peat soils with soft soil fibers. When viewed from the geotechnical aspect, the properties of soft soil are always unfavorable for the construction. Construction such as roads that are on soft soil has the potential to experience bearing capacity failure, large subsidence and a relatively long duration of settlement, as well as low slope stability (landslides easily) if the soft soil has not been given soil improvement.

Soil consolidation is the occurrence of water discharge through soil pores due to the force (load). As a result of this consolidation, it can result in land subsidence. According to the classic consolidation theory, it shows that the magnitude and duration of land subsidence is strongly influenced by the physical and mechanical characteristics of the soil and the amount of load. Generally, the softer the soil, the greater and the longer the settlement will take (Holtz and Kovacs, 1981). The classical consolidation theory for clay soils so far has not considered the effect of temperature changes that will occur. Similarly, there are relatively few researchers at this time who have not established broad and detailed information on the effect of temperature on the behavior of soil consolidation, particularly for clay soft soil types.

Soft soils such as fibrous peat soils that are abundant in Kalimantan, apart from causing problems of carrying capacity and land subsidence, are also very prone to experiencing land fires during the dry season every year. This is what happened so far in the fibrous peatlands area of South Kalimantan, Indonesia, which routinely occurs during the dry season. The existence of fire on peatlands area certainly has the potential to increase the temperature of the soil mass of the road embankment soil and the clay soft soil which functions as the subgrade, considering the position of the peatlands on the left and right sides of the road construction.

An increase in temperature in the subgrade mass due to propagation of heat from land fires is presumed to affect the physical and mechanical characteristics (consolidation) of clay soft soil in wetlands. Based on the theory of consolidation so far, it shows that clay soft soil has properties that are detrimental to the construction, namely in the form of relatively large land subsidence and relatively long period (duration) of land subsidence when loaded. With an increase in temperature in the clay soft soil mass of wetlands due to peatlands fires, it is predicted that it can affect the behavior of soil consolidation which then affect the size and duration of subsidence of the clay soft soil.

The increase in temperature in the soil mass in the road area always occurs due to the spread of heat from the surrounding peatlands fires in South Kalimantan, Indonesia which always occurs during the dry season every year. In some parts of the road segment there are some bumpy roads (diverse subsidence). It is suspected that there is an effect of hot temperature on the behavior of soil consolidation, one of which is the diverse subsidence.

Research on soil behavior due to changes in temperature in the soil mass is still relatively small. Even though, the phenomenon of increasing temperature in the soil mass is frequently occured. For example, an increase in temperature in the soil is caused not only by the problem of propagation of heat under the road due to land fires, but also due to the presence of waste heat from nuclear power plant in the medium of soil (Davies and Banerjee, 1980), the heat that occurs in the ground which generated by the operation of the electric cable (Abdel Hadi and Mitcell, 1981), gas pipelines and oil pipes are embedded in the ground which generate heat around them (Slegel and Davis, 1977), as well as thermal energy storage that are embedded in the ground (Moritz, 1995).

This research was conducted to get answers to how the behavior of the curve of clay soft soil consolidation is due to changes in temperature. Mainly to get knowledge about the effect of temperature on changes in the value of mechanical parameters of soil consolidation, such as the wetland clay soft soil compression index (Cc), swelling index (Cs), volume change coefficient (mv), coefficient of consolidation (Cv), and coefficient of permeability (k) of clay soft soil.

This research was also conducted in order to develop some of the results from previous research by researchers, where some of the results still have limitations.

For example Mon Ei Ei et al. (2013) are researchers from Japan and Denmark who have conducted research on the effect of temperature on the properties of Kaolinite clay. In their research uses temperatures of 5^{o}C, 15^{o}C, and 40^{o}C. The results of the research show that when the temperature increases, the compression index (Cc) and coefficient of consolidation (Cv) also increase. The research's scope of Mon Ei Ei et al. (2013) is different from the research that has been done. The results of research by Mon Ei Ei et al. (2013) has limitations in terms of the type of clay that is selected in the form of pure Kaolinite which is used and is not classified as clay soft soil that is resulted from natural processes with the dominant environmental influence. In addition, Mon Ei Ei et al. (2013) have not discussed the effect of temperature on the consolidation behavior of clay soft soil in detail.

Several previous researchers have also conducted research related to the effect of temperature on the properties of clay soils, but also have some limitations on the parameters and types of soil studied. Some of the previous researchers referred to are Burghignoli et al. (2000), Hueckel, T (2011), Baldi et al (1988); Naga et al. (2005); Romero et al. (2001); Sridharan and Venkatappa (1973); Gadzama et al. (2016); Laloui (2001); Tsutsumi and Tanaka (2011); Towhata et al. (1993).

Burghignoli et al. (2000). In his research using clay soil which still contains a greater percentage of silt than clay, and contains a fraction of sand. The results of his research indicated that there was a change in the number of pores during the process of composing soil particles when there was a change in temperature which was also influenced by the stress history, thermal history, and the time duration between the end of the primary consolidation phase and the initiation of thermal application.

Research related to the effect of temperature on the behavior of clay soil has also been studied by Hueckel, T (2011) who has stated that an increase in temperature results in changes in the volume of water in the soil pores. In addition, Baldi et al. (2011) have studied volume changes of water and mineral systems in low porosity of clay soils. In his study, it was shown that temperature affects the strain of soil volume, the distance from the surface of soil minerals, and changes in water volume. The effect of temperature on Bangkok clay soil under over-consolidated conditions was investigated by Naga et al. (2005). Among his research results showed that the higher the temperature, the pre-consolidation stress tends to decrease.

Romero et al. (2001) have also conducted research on the effect of temperature on the hydraulic behavior of unsaturated clay soils. The results of his research showed that an increase in temperature in the soil resulted in decreased water content and decreased total suction. In addition, it is also stated that a change in temperature in the soil can result in changes in clay structure and flow of pore water in soil.

The mechanism of controlling volume change of saturated soil and the concept of effective stress level due to the influence of temperature has been investigated by Sridharan and Venkatappa (1973). According to Sridharan and Venkatappa (1973), the presence of thermal temperatures in the soil has a significant effect on the physical forces between soil particles, resulting in changes to the flow of pore water capacity in the pores, water infiltration, and water concentrates in the soil pores.

Gadzama et al. (2016) have produced research including changes in the value of Atterbeg limit due to the effect of temperature. Wherein the value of liquid limit (LL) decreases when the temperature increases in the soil. This is due to physical reactions and chemical reactions in the soil when the temperature increases. As a result, the bonds of soil particles are broken.

Laloui (2001) has studied the thermally induced effects on soil and then used a suitable constitutive model for numerical simulations of the phenomenon. In the results of his research stated that when the temperature increases in the soil, there will be a stress contraction phase in the soil.

The effect of the combined strain velocity and temperature on the consolidation behavior of clay soil has been investigated by Tsutsumi et al. (2011). In his research, he specifically discusses the relationship between stress and strain of clay soil when experiencing temperature changes. Among his research results showed that the effective stress of collapse decreased with increasing temperature. In addition, it is also stated that with an increase in thermal temperature in the soil, a new soil structure will be formed.

Towhata et al. (1993) have conducted research on the behavior of volume changes from normally consolidated and excessively consolidated kaolinite and bentonite clay due to temperature changes. Among the results of his research showed that when the excess consolidated clay soil is heated, it will result in a smaller change in shrinkage volumecompared to normally consolidated clay. Besides that, according to Towhata et al. (1993) stated that there was an increase in soil permeability as a result of an increase in temperature due to a decrease in the viscosity ofthe soil fluid in the soil pore.

2. RESEARCH METHOD

Material

Clay soils with soft consistency in undisturbed conditions originating from the swamps area of South Kalimantan, Indonesia were used in the consolidation test to obtain the behavior of soil compression due to the influence of thermal temperatures. The physical and mechanical characteristics of clay soft soil which are used as test objects in this study are shown in Table 1.

Table 1 shows that the type of clay selected is classified as clay soft soil containing a little amount of organic. In terms of its shear strength (cohesion and sondir results), it shows that the type of clay soil selected as the test object in this study is classified as clay which is close to very soft properties.

Testing Procedure

Figure 1 shows a modified consolidation test instrument (Odoemeter). The modification refers to the results of research conducted by Naga et al. (2005). The modification of the consolidation test equipment is carried out on the perimeter of the consolidation cell (outer ring odoemeter) by attaching an electric heater. The heating element (electric heater) has previously been connected to a temperature controller which has an accuracy of +/- 0.1^{o}C. The temperature controller is also connected to a thermo sensor device that is attached to the water in the consolidation cell to read the amount of water temperature in the consolidation cell which must match the desired thermometer on the temperature controller.

Table 1 Characteristics of research’s clay soil

Properties	Characteristics 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

The temperature controller is set in the range of 20^{o}C to 100^{o}C. In this study, the temperature varied by 40^{o}C, 60^{o}C 75^{o}C, and 85^{o}C with the assumption that the temperature magnitude is the reduced condition temperature resulting from the heat propagation process which raises the temperature of clay soft soil (which is not burned) above normal temperature. In the implementation of this study, the temperature range of these temperature values refers to the results of Donna's (2006) study regarding the temperature magnitude that must be more than 39^{o}C due to burning vegetation/ plant fibers in the field.

In the consolidation test stage by giving a hot temperature, before giving the consolidation load and reading the decrease on the dial gauge, when the temperature has been increased (heat) in the consolidation cell, then a time pause of approximately 7 minutes is given. This time pause will produce temperature homogeneity in the soil specimen in the consolidation ring with the water temperature inside the consolidation outer ring (consolidation cell).

The results of the consolidation test with the desired temperature variation at the final stage are the parameters of the compression index (Cc), the consolidation coefficient (Cv), the swelling coefficient (Cs), the volume change coefficient (mv), and the coefficient of permeability (k).

3. RESULTS AND DISCUSSION

Relation of Compression Index (Cc) and Temperature (T oC)

The effect of temperature (T) on the compression index (Cc) of very clay soft soil is shown in Figure 2. Based on the study’s results show that temperature affects the behavior of soil compressibility through changes in the value of the soil compression index (Cc). In Figure 2, it can be stated that with increasing temperature (T), the soil compression index (Cc) tends to increase as well. It can also show that with increasing temperature in the soil, the soil compression will become even greater. This condition occurs related to changes in the void ratio (e) in the soil after experiencing heat.

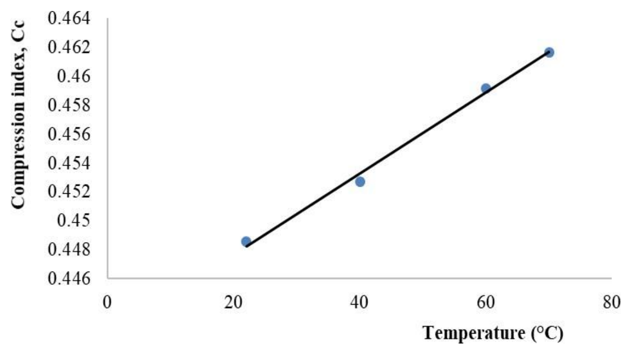
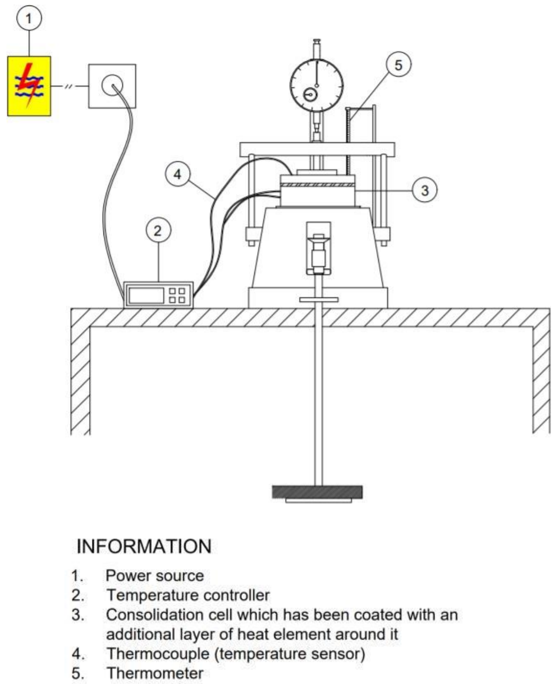


Figure 2 The Relationship of Compression Index (Cc) and Temperature Variations



(a)

(b)

Figure 1 Modified Consolidation Test Tool
(a) Scheme of tools
(b) Visual consolidation tool modification

The change in void ratio (e) due to thermal temperature is shown in Figure 3. Based on this figure, it can be stated that the temperature in a very clay soft soil will increase the void ratio (e) of the soil, especially in conditions after receiving a stress of more than 0, 4kg/ cm^2

The change in void ratio (e) due to thermal temperatures can cause changes in the behavior of pore water in the soil. According to Burghignoli et al. (2000) stated in the results of their research that the deformation process occurs from the phenomenon of dissipation of excess pore water pressure due to changes in temperature. Hueckel, T (2011) also stated that an increase in temperature resulted in a change in the volume of water in the soil pore.

In addition, the presence of hot temperatures results in changes in the volume of clay soils to expand when receiving heat (Baldi et al. 1988)

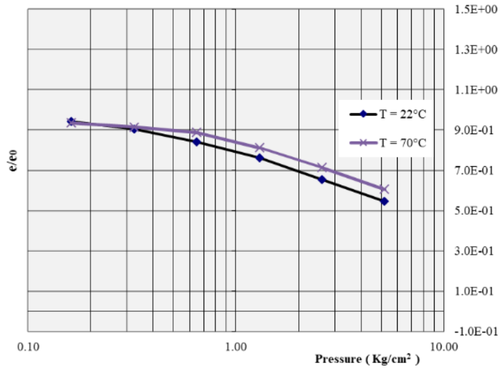


Figure 3 Relationship Between e/eo and Pressure at Temperature Variations

Correlation of Coefficient of Consolidation (Cv) and Temperature (T °C)

The coefficient of consolidation (Cv) of very clay soft soil can also be affected by changes in thermal temperature. This is in accordance with the research results shown in Figure 4 regarding the relationship of the coefficient of consolidation (Cv) and temperature variations (T). Based on thisfigure, it can be stated that the higher the thermal temperature experienced by the soil, the higher the coefficient of consolidation. Changes in the velocity of coefficient of consolidation (Cv) due to temperature have influenced the compressibility behavior of veryclay soft soils**.**

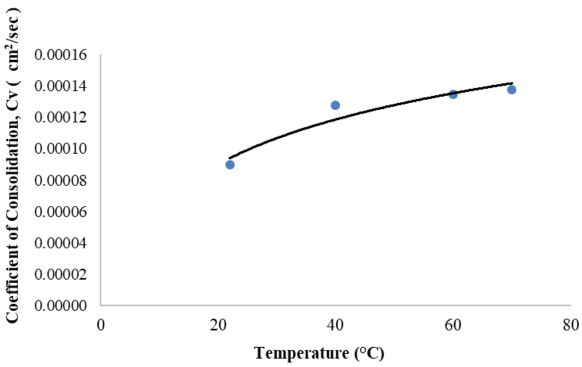


Figure 4 The Relationship Between the Coefficient of Consolidation (Cv) and Temperature Variations

The increase in the velocity coefficient of consolidation of very clay soft soil affected by temperature is due to changes in soil pores. According to Naga et al. (2005) stated that the tendency of increasing velocity of coefficient of consolidation (Cv) along with increasing thermal temperature is caused by thermo-mechanical behavior in the soil in the form of the creation of pore fluid bubbles then the pore cavities expand and then the pore water pushes out. In line with this, Romero et al. (2001) have concluded that an increase in temperature in the soil can change the clay fabric and the flow of pore water. According to Sridharan and Venkatappa (1973), the presence of thermal temperatures in the soil has a significant effect on the physical forces between soil particles, resulting in changes to the pore water flow capacity in the pores, water escapes, and water concentrates in the soil pores.

Relationship Swelling Index (Cs) and Temperature (T ^{o}C)

The relationship between swelling index (Cs) and temperature is shown in Figure 5. Based on the research results shown in Figure 5, it can be stated that the presence of thermal temperatures in the soil affects the behavior of soil compressibility through changes in the value of soil swelling index (Cs). Where the temperature increases, the soil swelling index (Cs) also tends to increase.

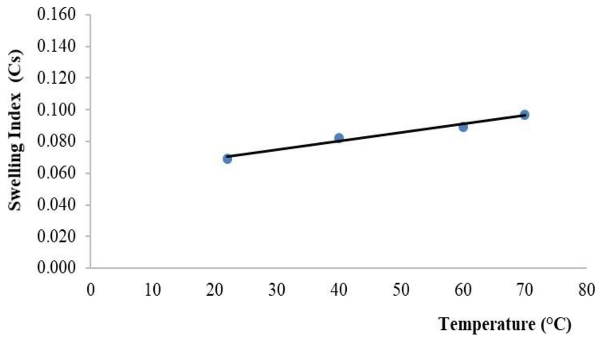


Figure 5 The Relationship Between Swelling Index (Cs) and Temperature Variations

Based on the previous description, this occurs due to changes in soil volume and the influence of soil creep. Burghignoli et al. (2000) stated that the creep behavior of soil bonds can be influenced by changes in thermal temperature in the soil. According to Gadzama et al. (2016), that an increase in soil temperature will result in damage to soil particles.

Relationship between Volume Change Coefficient (mv) and Temperature (T ^{o}C)

Based on the research results, it shows that the volume change coefficient (mv) value of clay soft soil can be influenced by the increase in temperature in the soil. This is as shown in Figure 6 below. In this figure it can be stated that the higher the temperature, the volume change coefficient (mv) of clay soft soil tends to decrease. A more significant decrease in the volume change coefficient resulted when the temperature was more than 60^{o}C. This is in line with the research results of Mon Ei Ei et al. (2013) on Kaolin Clay that a decrease in the volume change coefficient may occur due to a relationship with changes in soil stress during temperature increases.

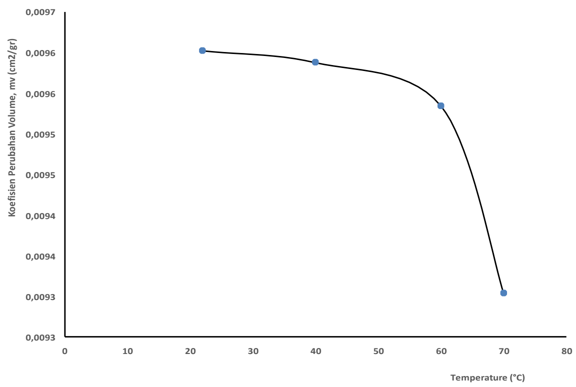


Figure 6 The Relationship Between Volume Change Coefficient (mv) and Temperature Variations

In addition, Laloui (2001) also states that when the temperature increases in the soil, there will be a stress contraction phase in the soil. Meanwhile, according to Tsutsumi and Tanaka (2011) it has been stated that an increase in thermal temperature in the soil will form a new soil structure.

Hydraulic conductivity (k) and Temperature (T ^{o}C) Relationship

Figure 7 shows the relationship betweensoil hydraulic conductivity (k) and temperature variations. Based on this figure, it can be stated that temperature affects the permeability behavior of very clay soft soils. Where the increasing temperature in the soil (in the range of temperatures up to 40°C), the soil hydraulic conductivity (k) also tends to increase. Then at the temperature values above 40°C, the soil hydraulic conductivity (k) also increases but is slower than the previous temperature values.

According to Towhata et al. (1993) and Delage et al. (2000) stated that there was an increase in soil permeability affected by an increase in temperature due to a decrease in the viscosity of the soil fluid in the soil pore. In addition, according to Romero et al. (2001) in Gadzama et al. (2016) that the presence of hot temperatures in the soil can change the structure of the clay soil (clay fabric) and the flow of pore water due to the behavior of redistribution of porosity and heat and chemical interactions.

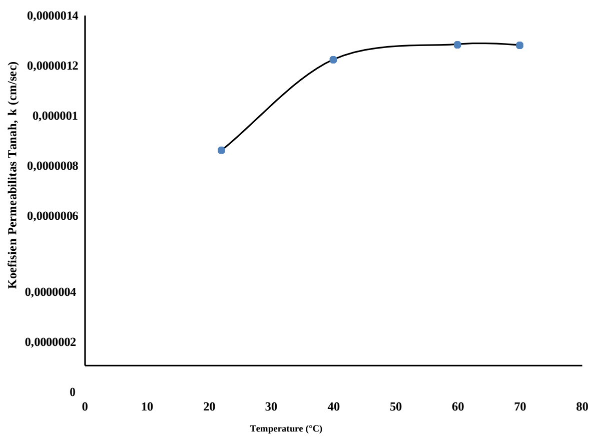


Figure 7 Relationship between Soil Hydraulic conductivity (k) and Temperature Variations

4. CONCLUSION

Based on the results of the analysis that has been described, several things can be concluded as follows:

- Changes in temperature in the soil can affect the nature of the compressibility of the soil, where the higher the temperature of the soil, the greater the soil compressibility.
- The increase in temperature in the soil results in an increase in the value of soil compressibility parameters such as thevalue of compression index (Cc), coefficient consolidation (Cv), and swellingindex (Cs).
- The compression index value (Cc) of clay soft soil has a greater increase than the increase in other compressibility parameters when the temperature of clay soft soil increases.
- The speed of the consolidation process of clay soft soils tends to increase with the increase in temperature in the soil.
- High soil temperature (heat) can reduce changes in soil volume, where the volume change coefficient (mv) of clay soft soil tends to decrease when the soil temperature increases.
- The permeability of clay soft soil tends to increase with increasing temperature in the soil.

5. ACKNOWLEDGMENTS

- Gratitude is presented to the Research and Community Service Instituttion of Lambung Mangkurat University which has supported and helped in financial for the implementation of this research for the fiscal year of 2020.

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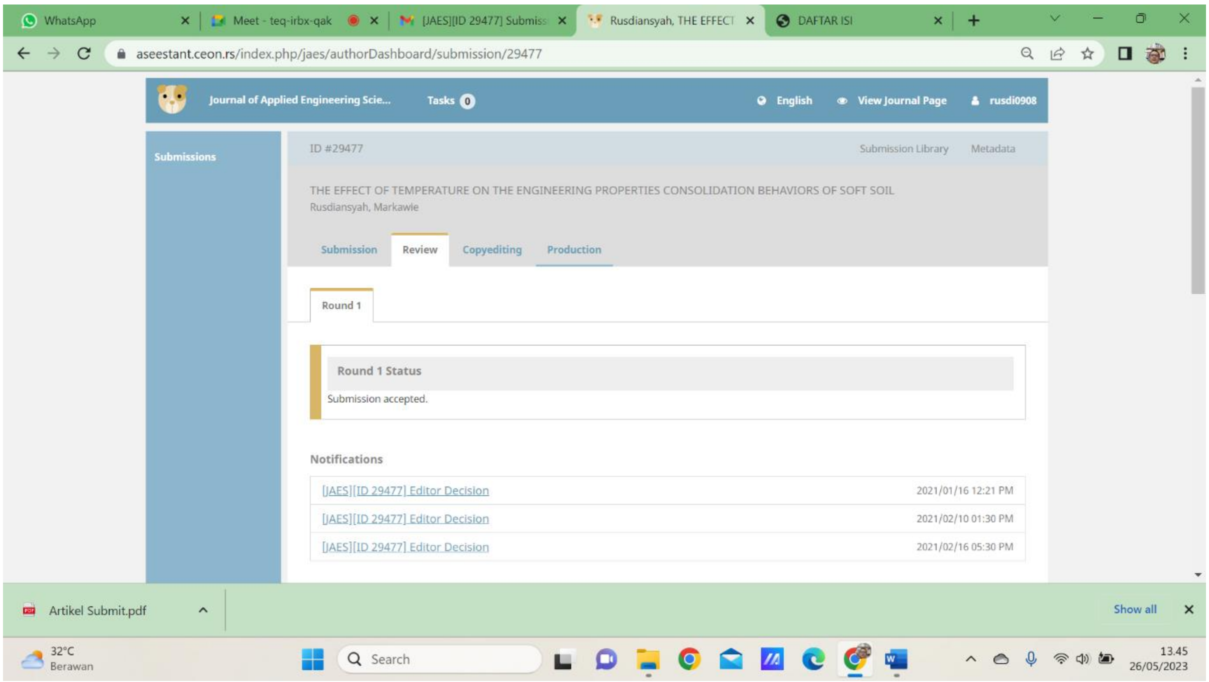
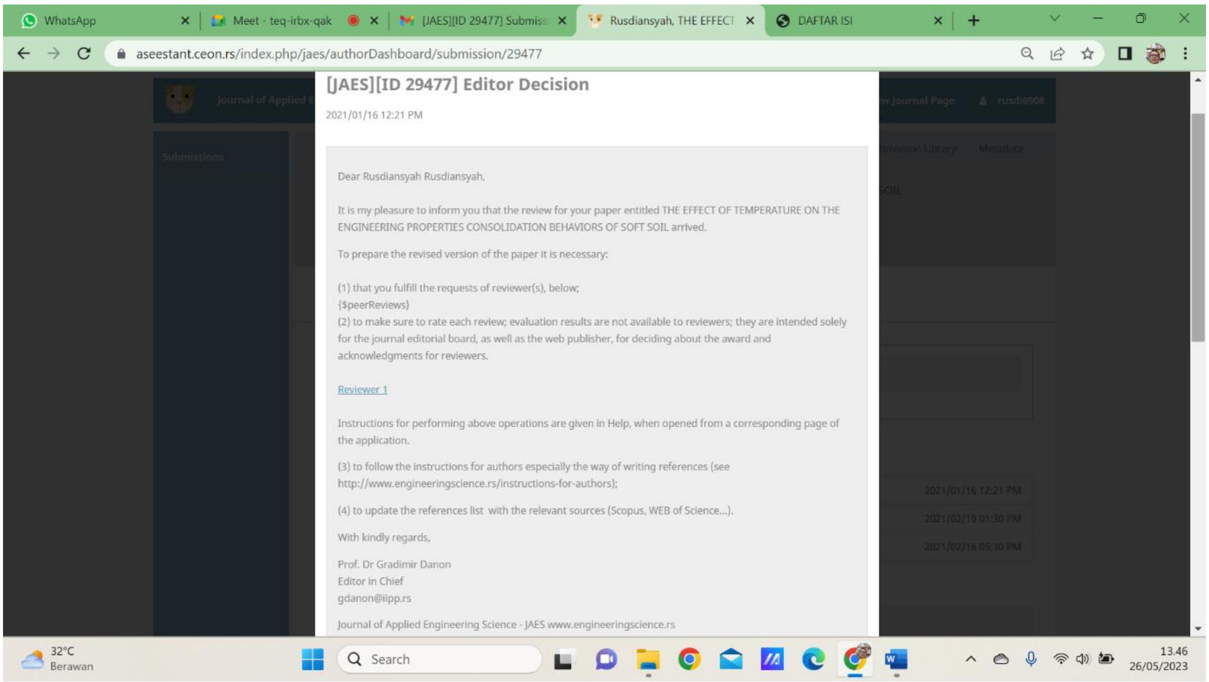
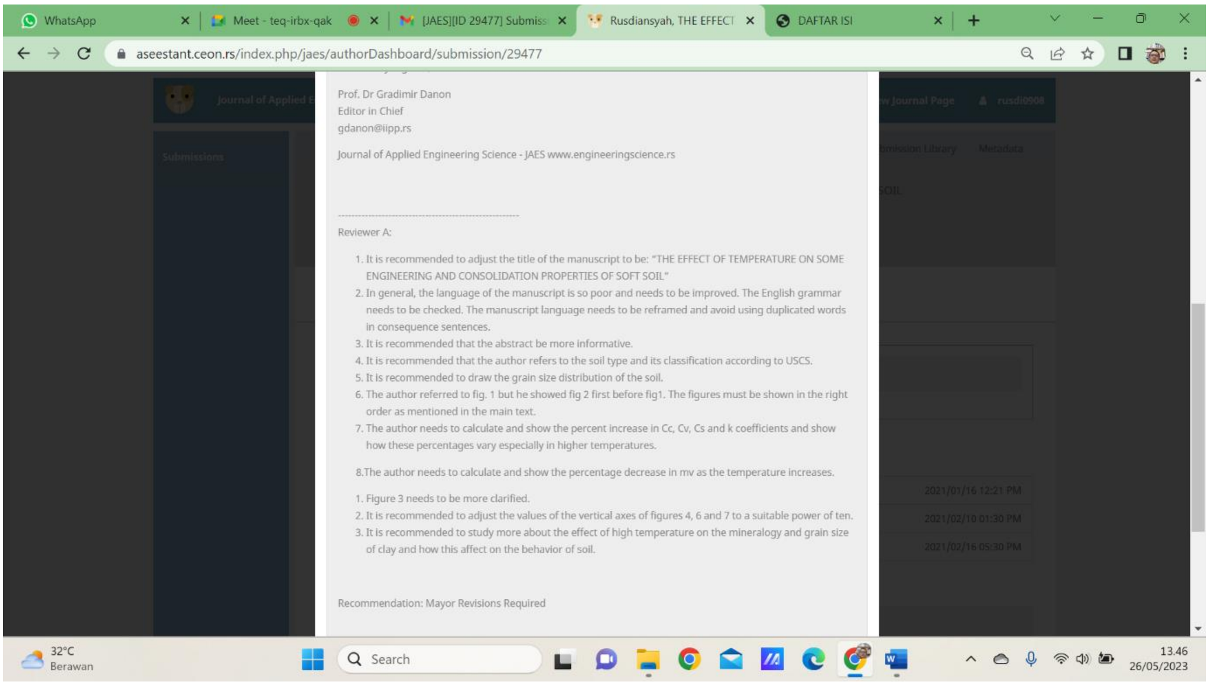
TAHAP 2 HASIL REVIEW 1 (PERMINTAAN REVISI 1)







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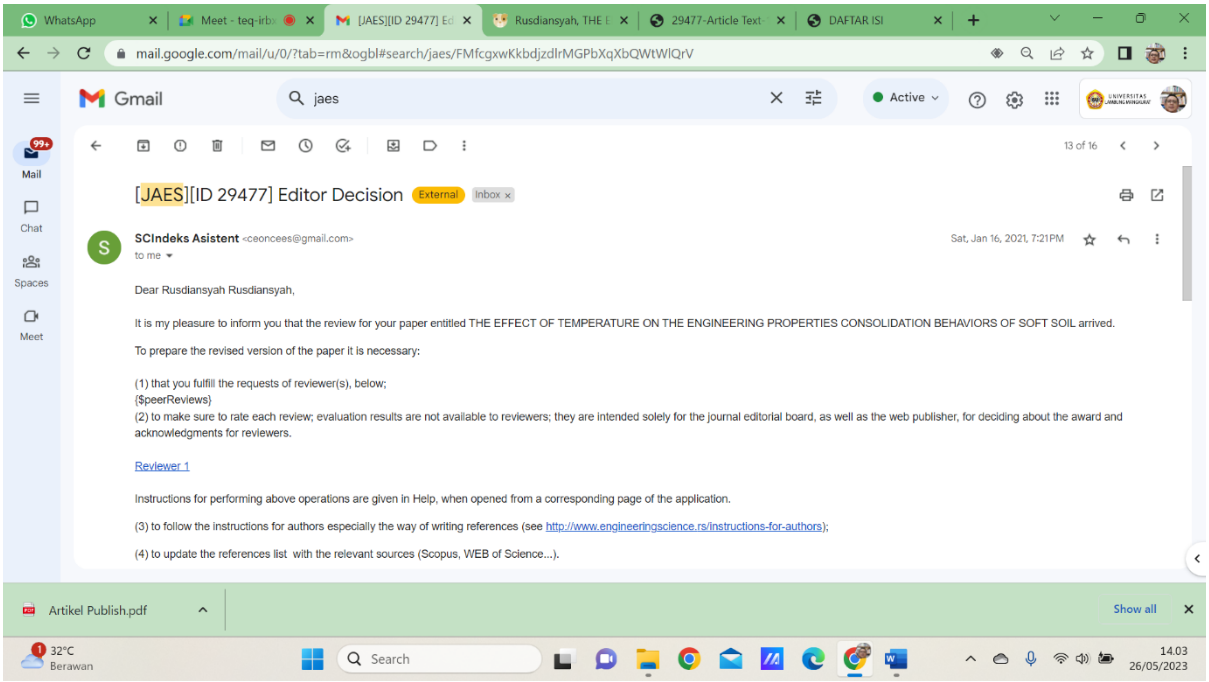
Reviewer A:

1. It is recommended to adjust the title of the manuscript to be: "THE EFFECT OF TEMPERATURE ON SOME ENGINEERING AND CONSOLIDATION PROPERTIES OF SOFT SOIL"
2. In general, the language of the manuscript is so poor and needs to be improved. The English grammar needs to be checked. The manuscript language needs to be reframed and avoid using duplicated words in consequence sentences.
3. It is recommended that the abstract be more informative.
4. It is recommended that the author refers to the soil type and its classification according to USCS.
5. It is recommended to draw the grain size distribution of the soil.
6. The author referred to fig. 1 but he showed fig 2 first before fig1. The figures must be shown in the right order as mentioned in the main text.
7. The author needs to calculate and show the percent increase in Cc, Cv, Cs and k coefficients and show how these percentages vary especially in higher temperatures.

8.The author needs to calculate and show the percentage decrease in mv as the temperature increases.

1. Figure 3 needs to be more clarified.
2. It is recommended to adjust the values of the vertical axes of figures 4, 6 and 7 to a suitable power of ten.
3. It is recommended to study more about the effect of high temperature on the mineralogy and grain size of clay and how this affect on the behavior of soil.

Recommendation: Mayor Revisions Required



[JAES][ID 29477] Editor Decision

SCIndeks Asistent <ceoncees@gmail.com>
to me
Sat, Jan 16, 2021, 7:21PM

Dear Rusdiansyah Rusdiansyah,

It is my pleasure to inform you that the review for your paper entitled THE EFFECT OF TEMPERATURE ON THE ENGINEERING PROPERTIES CONSOLIDATION BEHAVIORS OF SOFT SOIL arrived.

To prepare the revised version of the paper it is necessary:

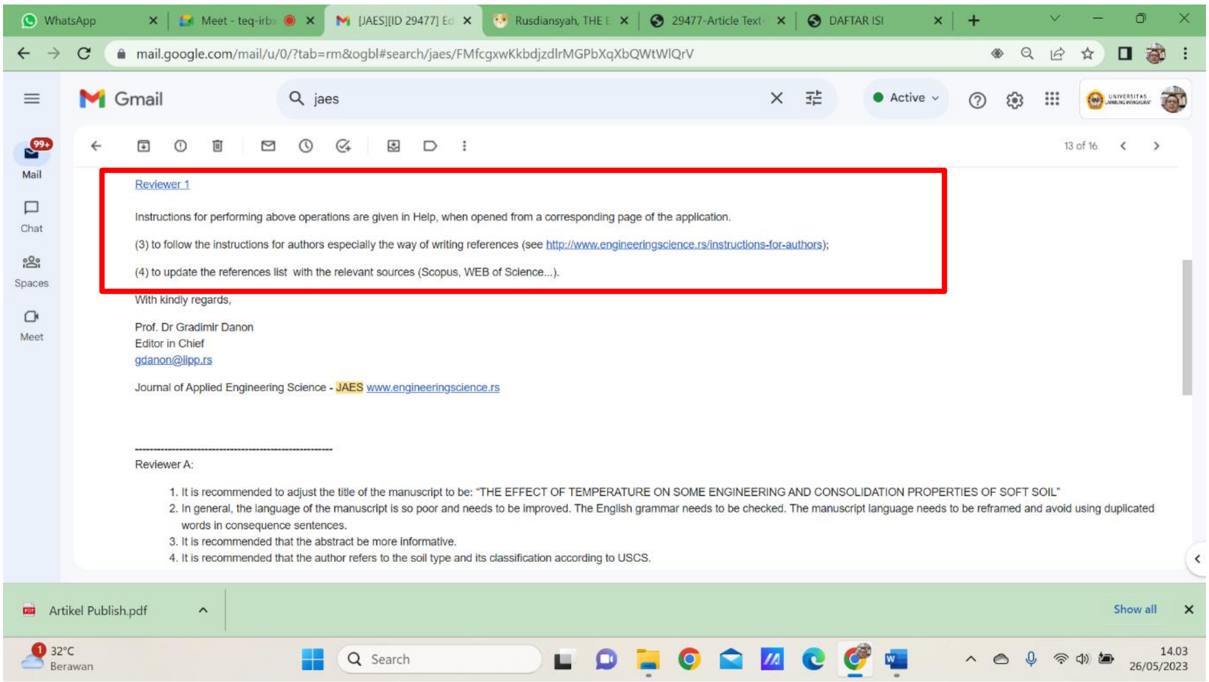
(1) that you fulfill the requests of reviewer(s), below;
{$peerReviews}
(2) to make sure to rate each review; evaluation results are not available to reviewers; they are intended solely for the journal editorial board, as well as the web publisher, for deciding about the award and acknowledgments for reviewers.

Reviewer 1

Instructions for performing above operations are given in Help, when opened from a corresponding page of the application.

(3) to follow the instructions for authors especially the way of writing references (see http://www.engineeringscience.rs/instructions-for-authors);

(4) to update the references list with the relevant sources (Scopus, WEB of Science...).



Reviewer 1

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(4) to update the references list with the relevant sources (Scopus, WEB of Science...).

With kindly regards,

Prof. Dr Gradimir Danon
Editor in Chief
gdanon@ipp.rs

Journal of Applied Engineering Science - JAES www.engineeringscience.rs

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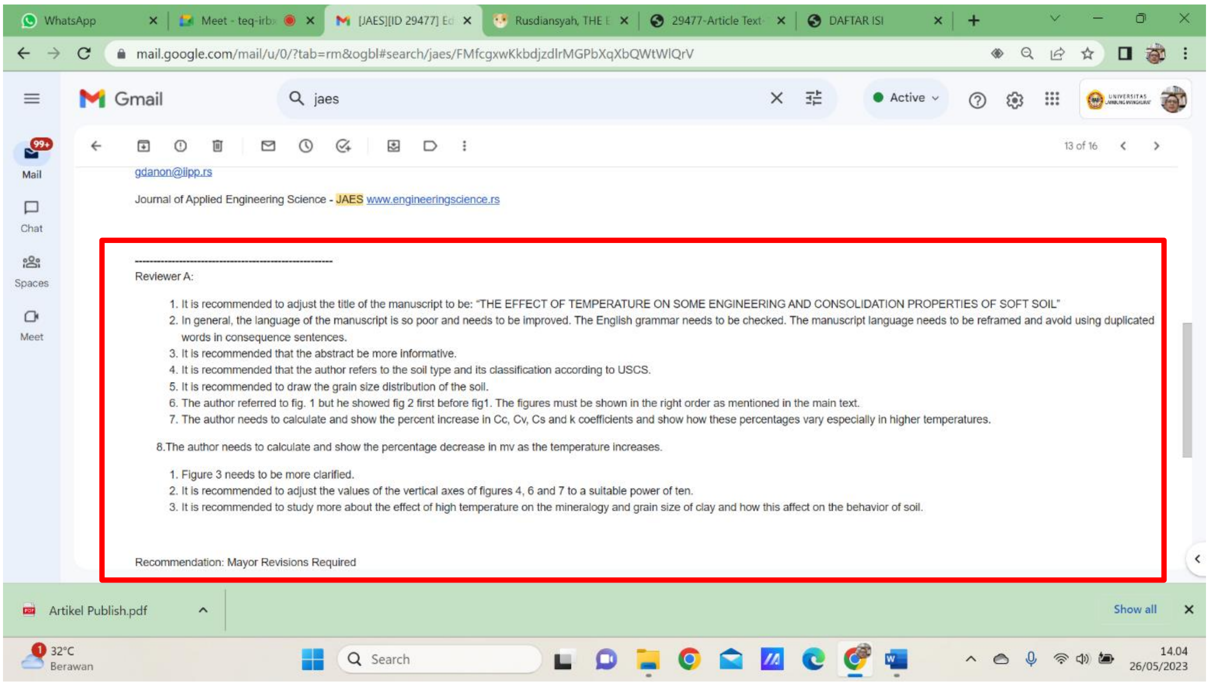
Reviewer A:

1. It is recommended to adjust the title of the manuscript to be: "THE EFFECT OF TEMPERATURE ON SOME ENGINEERING AND CONSOLIDATION PROPERTIES OF SOFT SOIL"
2. In general, the language of the manuscript is so poor and needs to be improved. The English grammar needs to be checked. The manuscript language needs to be reframed and avoid using duplicated words in consequence sentences.
3. It is recommended that the abstract be more informative.
4. It is recommended that the author refers to the soil type and its classification according to USCS.



gdanon@ipp.rs

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4. It is recommended that the author refers to the soil type and its classification according to USCS.
5. It is recommended to draw the grain size distribution of the soil.
6. The author referred to fig. 1 but he showed fig 2 first before fig1. The figures must be shown in the right order as mentioned in the main text.
7. The author needs to calculate and show the percent increase in Cc, Cv, Cs and k coefficients and show how these percentages vary especially in higher temperatures.

8.The author needs to calculate and show the percentage decrease in mv as the temperature increases.

1. Figure 3 needs to be more clarified.
2. It is recommended to adjust the values of the vertical axes of figures 4, 6 and 7 to a suitable power of ten.
3. It is recommended to study more about the effect of high temperature on the mineralogy and grain size of clay and how this affect on the behavior of soil.

Recommendation: Mayor Revisions Required

TAHAP 3 HASIL REVISI 1 oleh AUTHOR

NASKAH ARTIKEL REVISI 1 :

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

Rusdiansyah[1], Markawie[1]

[1]*Lecturer in Civil Engineering Study Program-Faculty of Engineering, Lambung Mangkurat University, Banjarbaru, Indonesia*
Email : rusdiansyah74@ulm.ac.id

ABSTRACT

Soil behavior is significantly influenced by various physical, chemical, biological, or environmental conditions. There has not been adequate research on the these factors, particularly on heat effects. 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 wet soil compaction index (Cc), development index (Cs), volume change coefficient (mv), consolidation coefficient (Cv), 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 (Cc), consolidation velocity coefficient (Cv), and the swelling index (Cs), observed an increase by 3%, 33%, and 22%, respectively. Furthermore, existence of high temperatures limited the unstable soil volume, where the volume change coefficient (mV) 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.

Keywords: 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 increases 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 temperature 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 5ºC, 15ºC, and 40ºC., 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 velocity (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.

METHODOLOGY

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 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 (Odoemeter). These alterations refer to the research results by Naga's et al [15]. The process was performed within the consolidation cell (outer ring odoemeter) by installing an electric heater, pre-connected to the temperature controller with an accuracy of +/- 0.1°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.

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

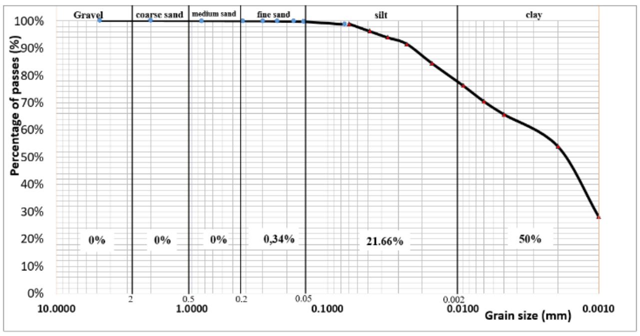


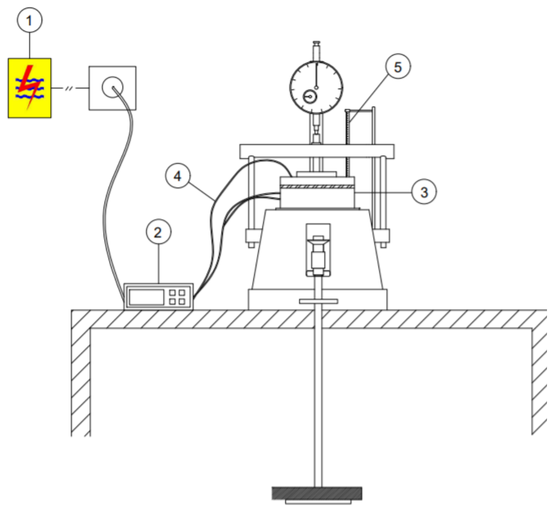
Figure 1 Grain Size Distribution Chart

Subsequently, the temperature control was set in the range of 20 - 100 °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 39ºC, 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 (Cc), consolidation coefficient (Cv), swell coefficient (Cs), 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 (Cc) and Temperature (T ºC)

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

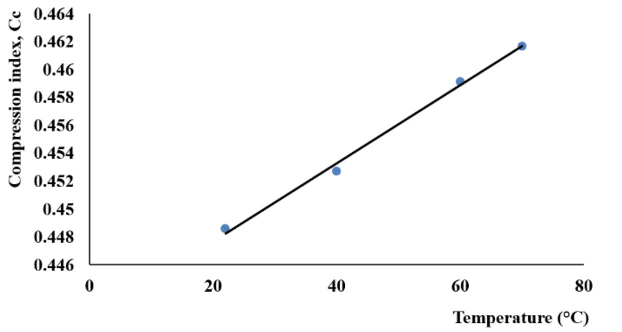


Figure 3 Relationship of compression index (Cc) and temperature variation

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

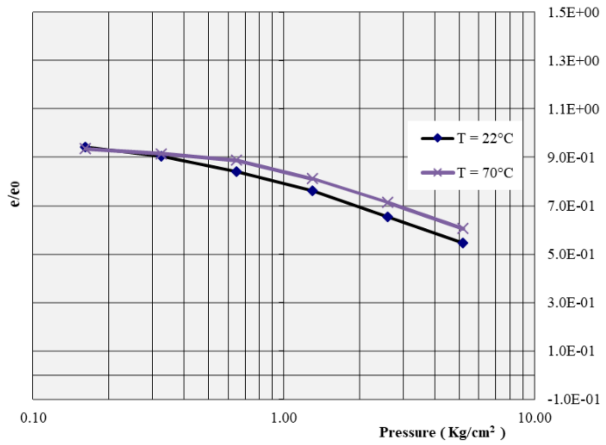


Figure 4 Relationship between e / eo and pressure at temperature variations

Therefore, extreme temperatures are known to trigger change in the volume of the clay to expand on receiving heat.

Relationship of Consolidation Velocity Coefficient (Cv) and Temperature (T °C)

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

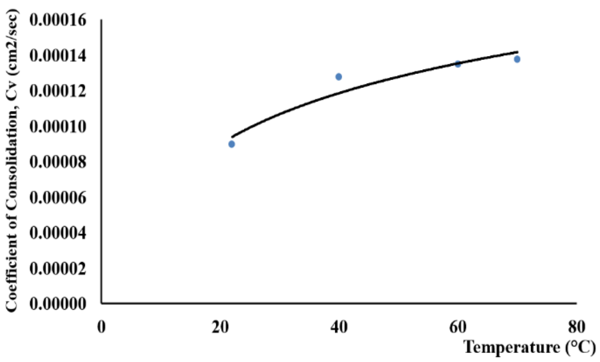


Figure 5 The relationship between the consolidation coefficient (Cv) and temperature variations

The increase in velocity coefficient of soft clay due to temperature was caused by changes in soil pores. Naga et al. [15] reported increasing consolidation velocity 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.

Relationship between Development Index (Cs) and Temperature (T °C)

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

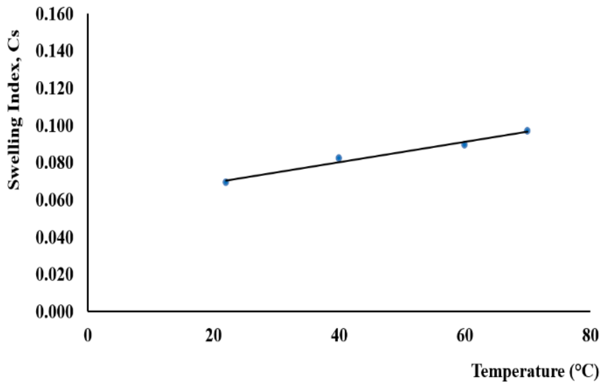


Figure 6 The relationship between Swelling Index (Cs) and temperature variations

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.

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 significant 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.

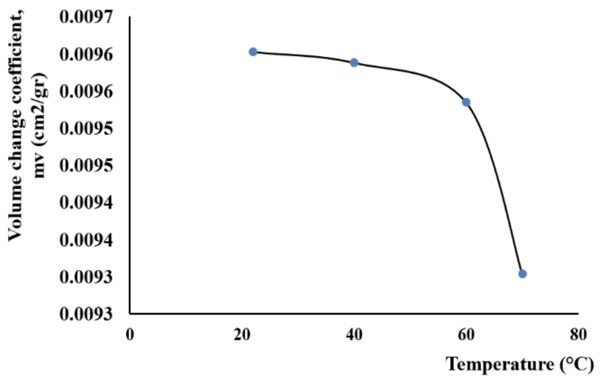


Figure 7 The Relationship between Volume Change Coefficient (mv) and temperature variation

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.

Relationship between Permeability Coefficient (k) and Temperature (T ºC)

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

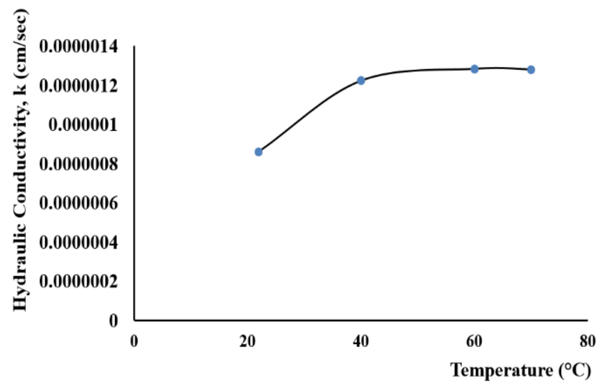


Figure 8 Relationship between Soil Permeability Coefficient (k) and temperature variations

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.

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 velocity coefficient (Cv), and the swell index (Cs), by 3%, 33%, and 22%, respectively.
- Consolidation velocity (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.

ACKNOWLEDGEMENT

The author is grateful to Lambung Mangkurat University through the Institute for Research and Community Service for the support and funding towards implementing this research for the 2020 Fiscal Year.

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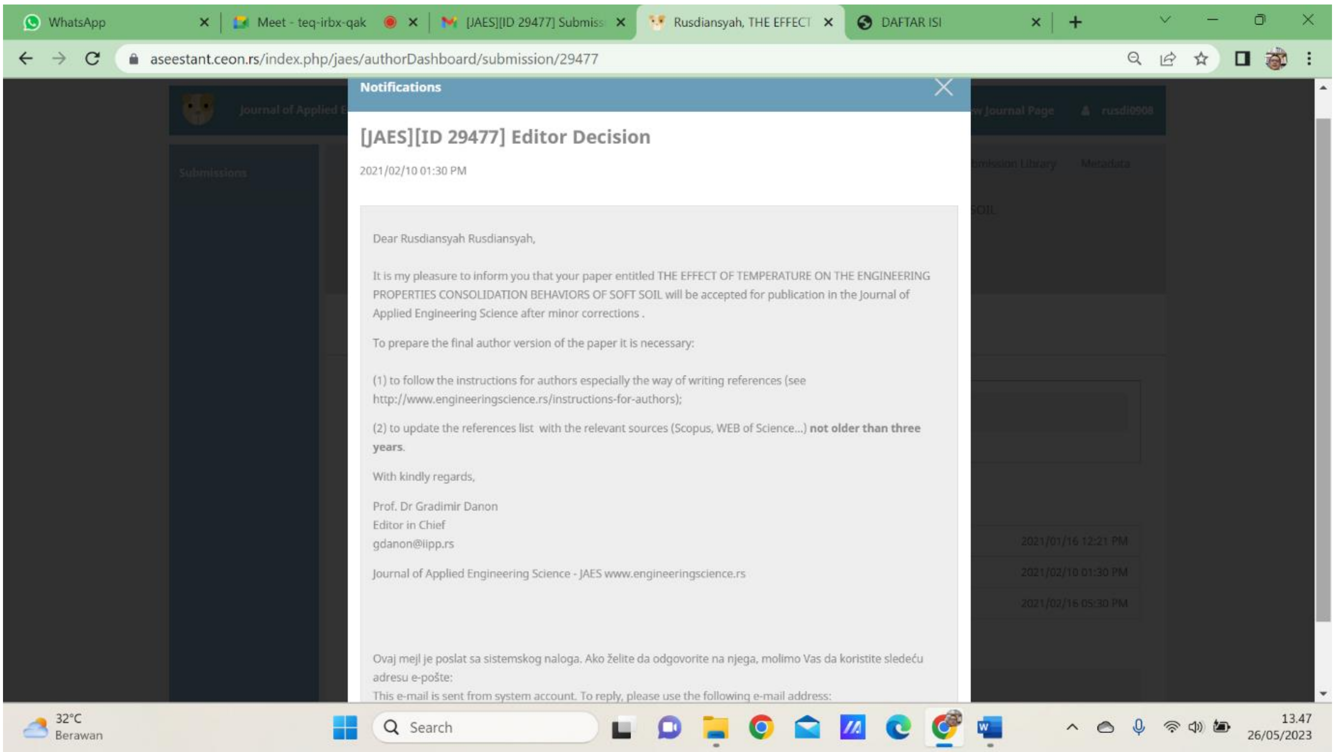
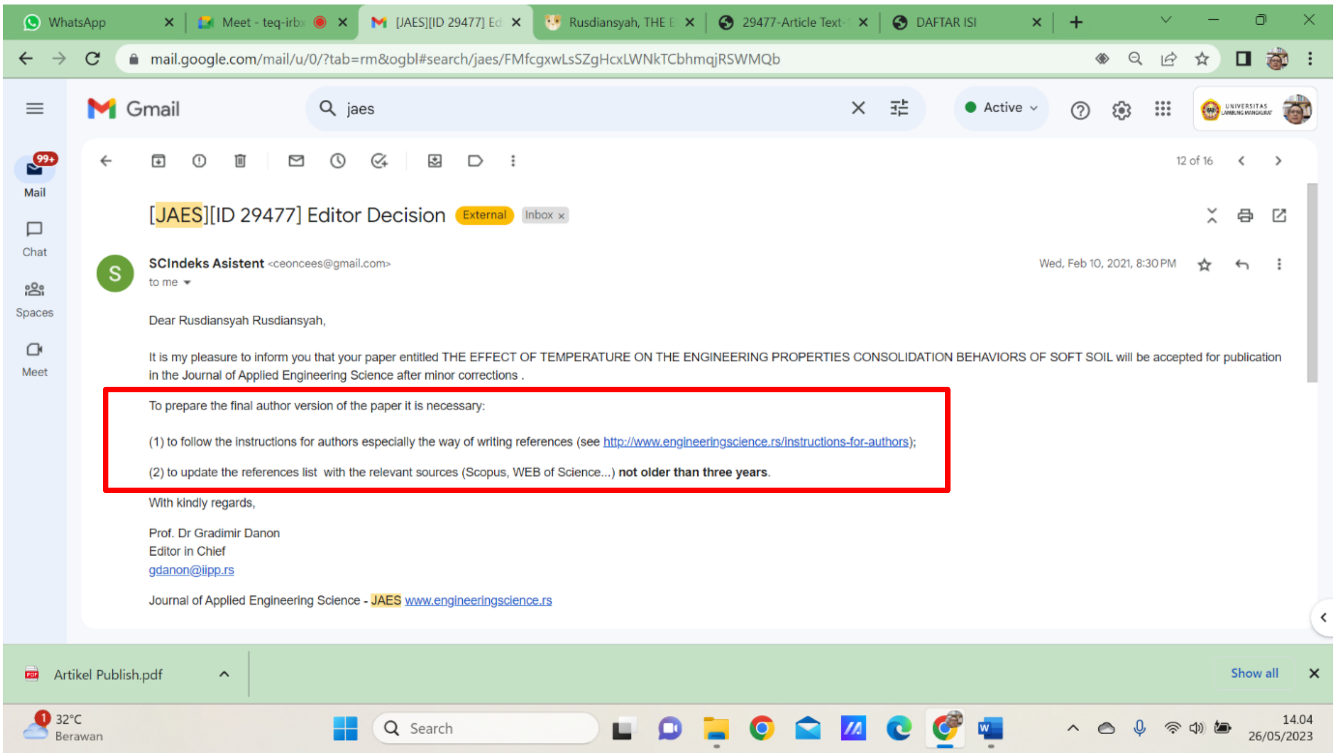
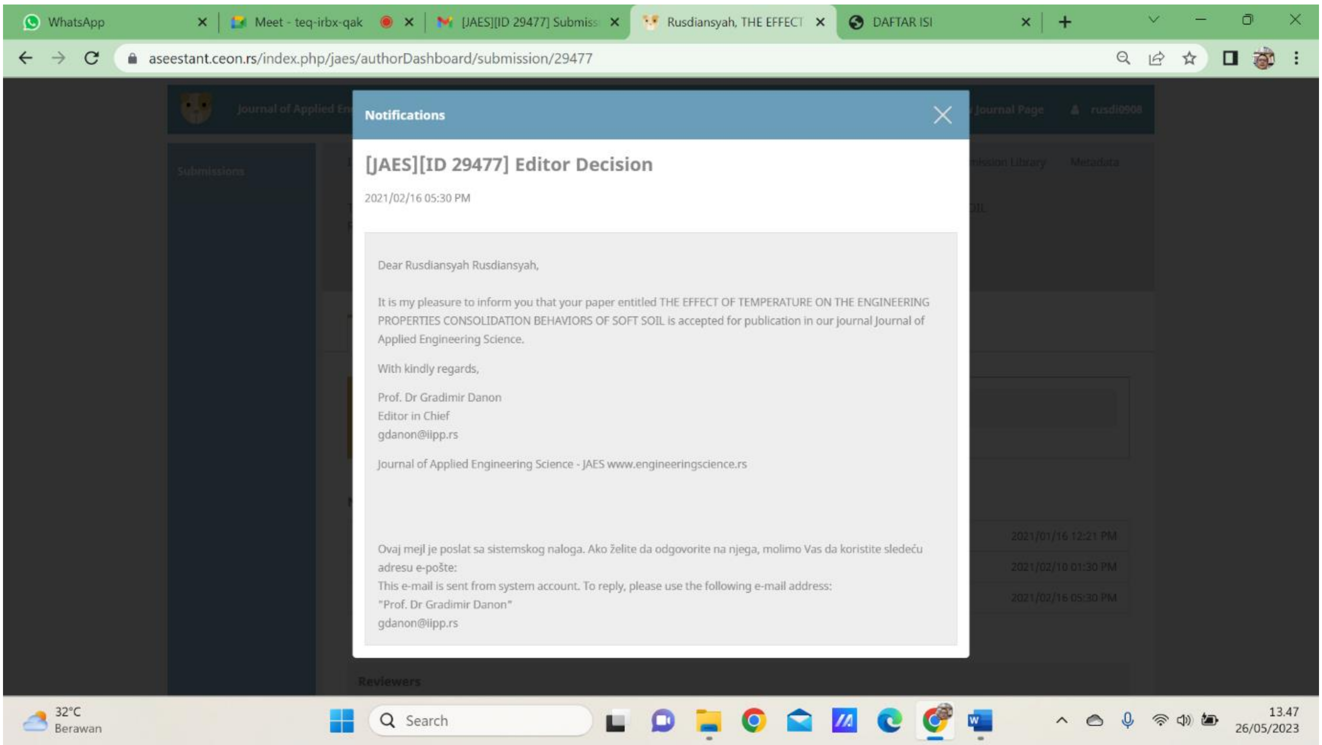
TAHAP 4 HASIL REVIEW 2 (PERMINTAAN REVISI 2)







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Notifications

[JAES][ID 29477] Editor Decision

2021/02/16 05:30 PM

Dear Rusdiansyah Rusdiansyah,

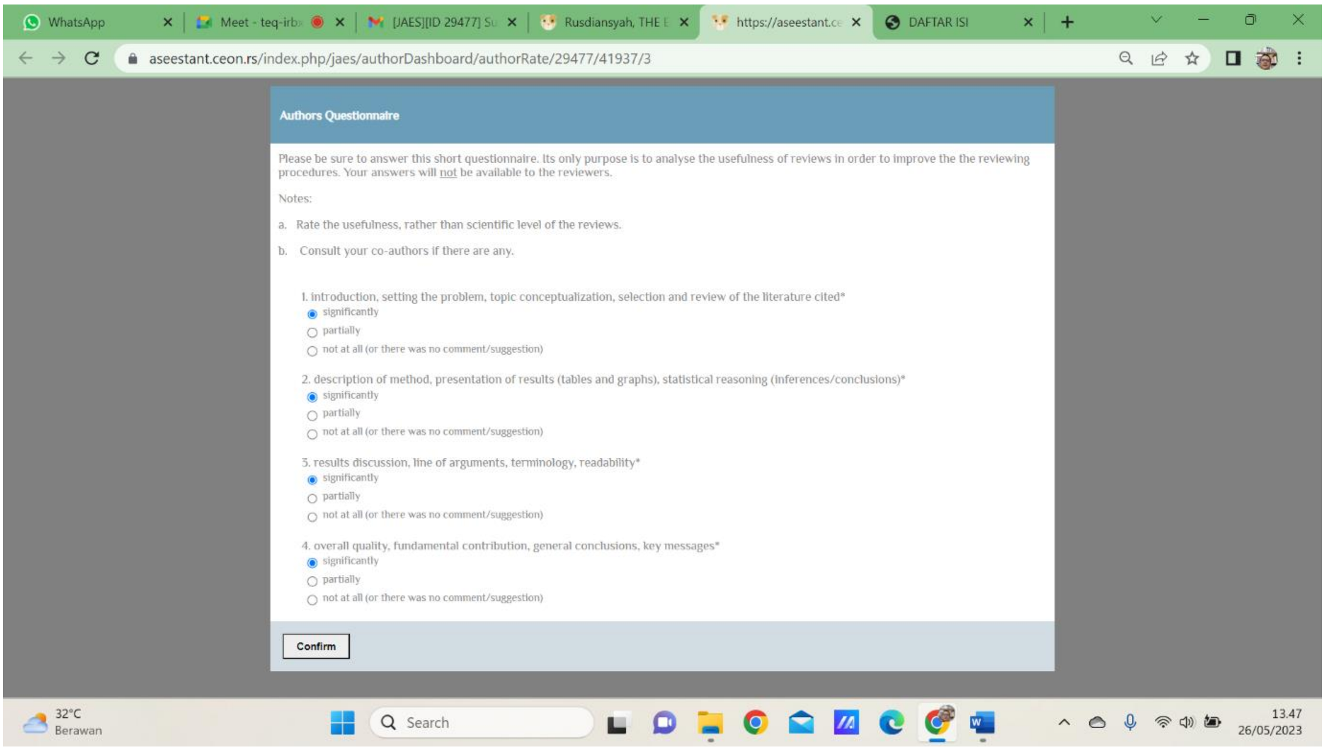
It is my pleasure to inform you that your paper entitled THE EFFECT OF TEMPERATURE ON THE ENGINEERING PROPERTIES CONSOLIDATION BEHAVIORS OF SOFT SOIL is accepted for publication in our journal Journal of Applied Engineering Science.

With kindly regards,

Prof. Dr Gradimir Danon
Editor in Chief
gdanon@iipp.rs

Journal of Applied Engineering Science - JAES www.engineeringscience.rs

Ovaj mejl je poslat sa sistemskog naloga. Ako želite da odgovorite na njega, molimo Vas da koristite sledeću adresu e-pošte:
This e-mail is sent from system account. To reply, please use the following e-mail address:
"Prof. Dr Gradimir Danon"
gdanon@iipp.rs



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Authors Questionnaire

Please be sure to answer this short questionnaire. Its only purpose is to analyse the usefulness of reviews in order to improve the the reviewing procedures. Your answers will not be available to the reviewers.

Notes:

a. Rate the usefulness, rather than scientific level of the reviews.

b. Consult your co-authors if there are any.

1. introduction, setting the problem, topic conceptualization, selection and review of the literature cited*
- (•) significantly
- ( ) partially
- ( ) not at all (or there was no comment/suggestion)

2. description of method, presentation of results (tables and graphs), statistical reasoning (inferences/conclusions)*
- (•) significantly
- ( ) partially
- ( ) not at all (or there was no comment/suggestion)

3. results discussion, line of arguments, terminology, readability*
- (•) significantly
- ( ) partially
- ( ) not at all (or there was no comment/suggestion)

4. overall quality, fundamental contribution, general conclusions, key messages*
- (•) significantly
- ( ) partially
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[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.

ACKNOWLEDGEMENT

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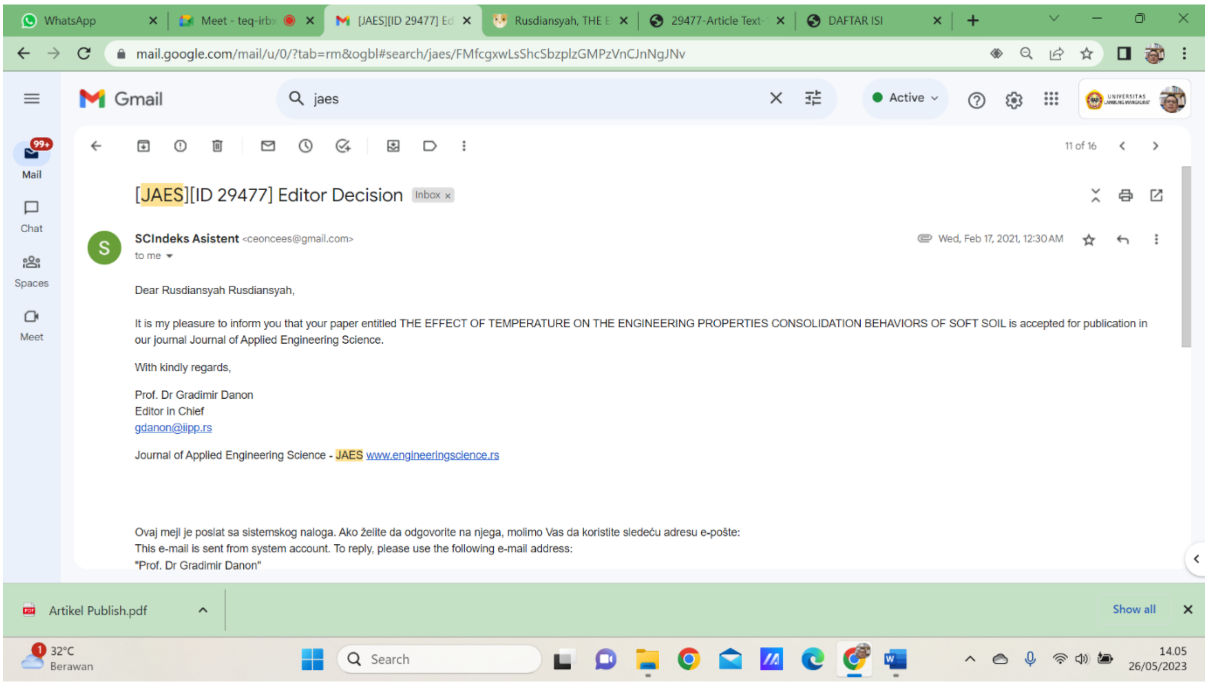

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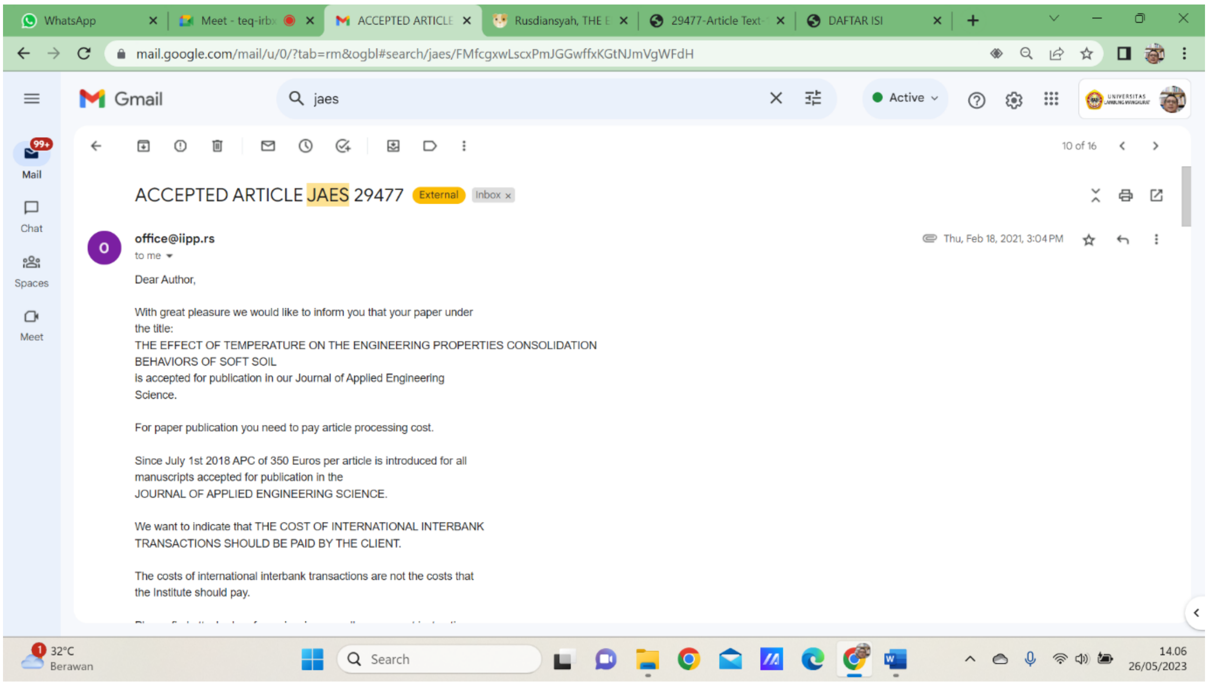
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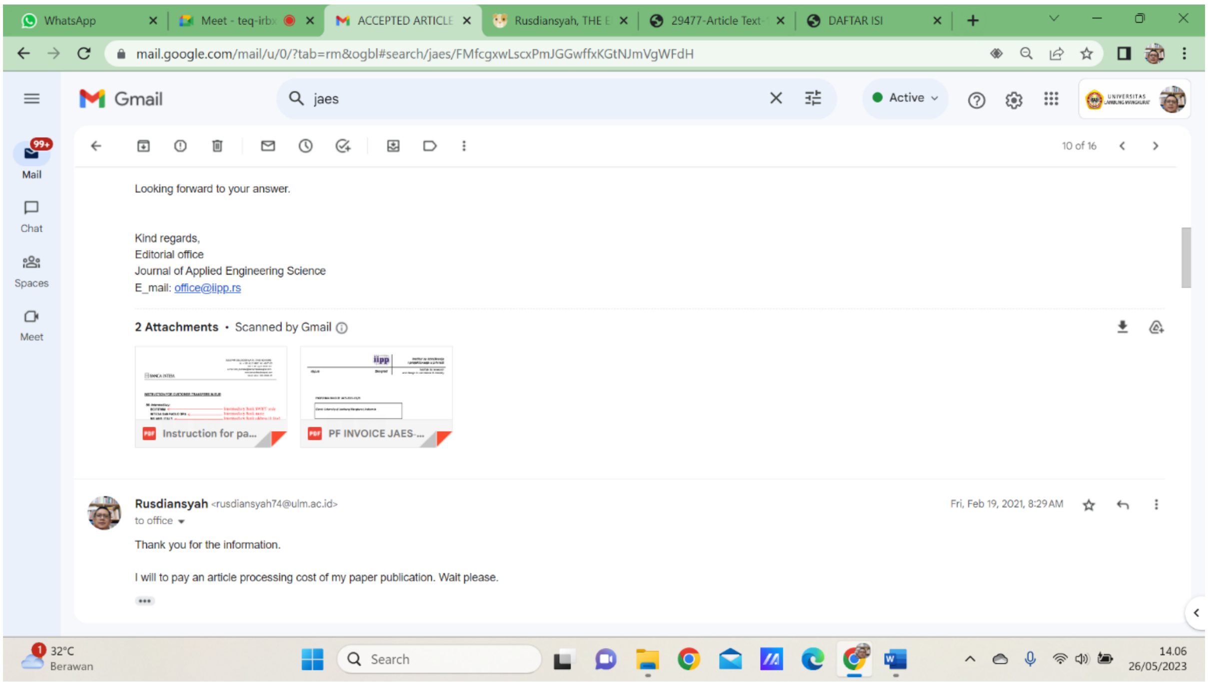
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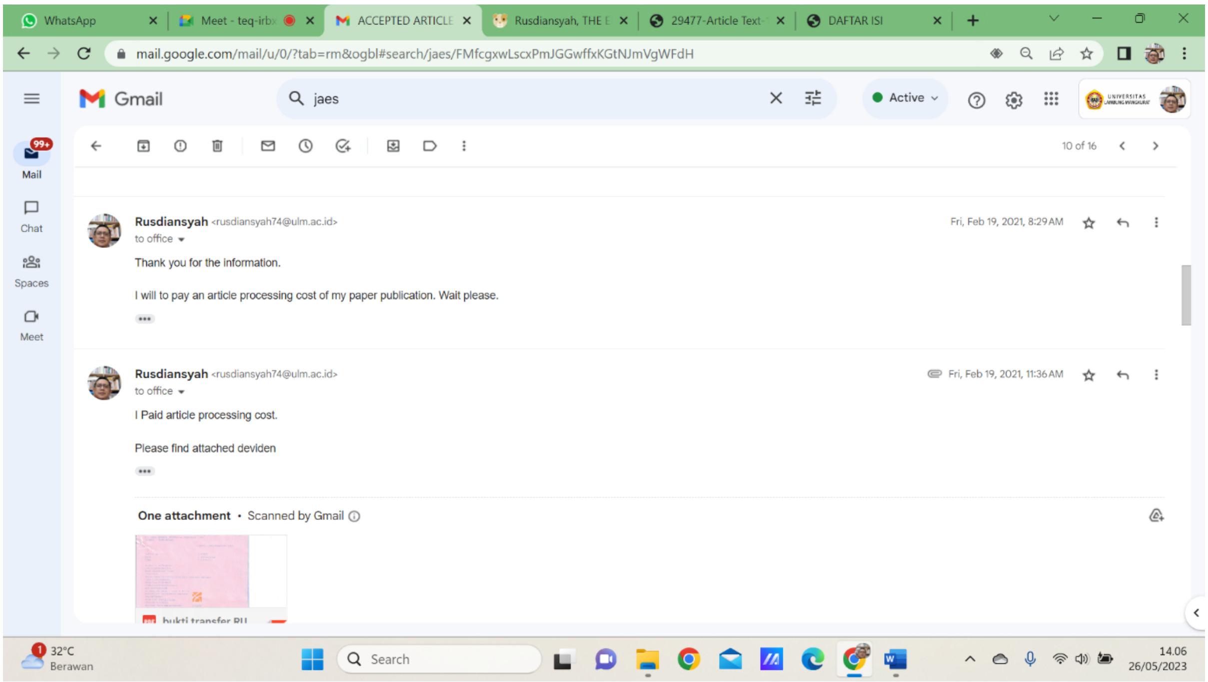

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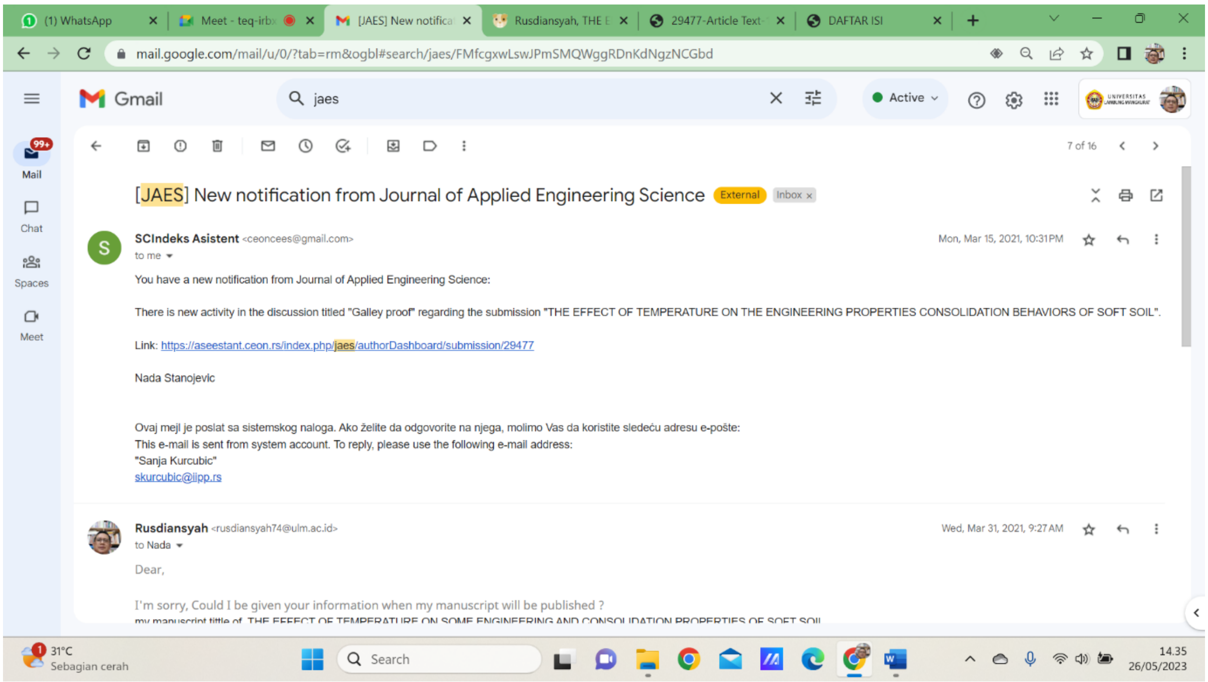

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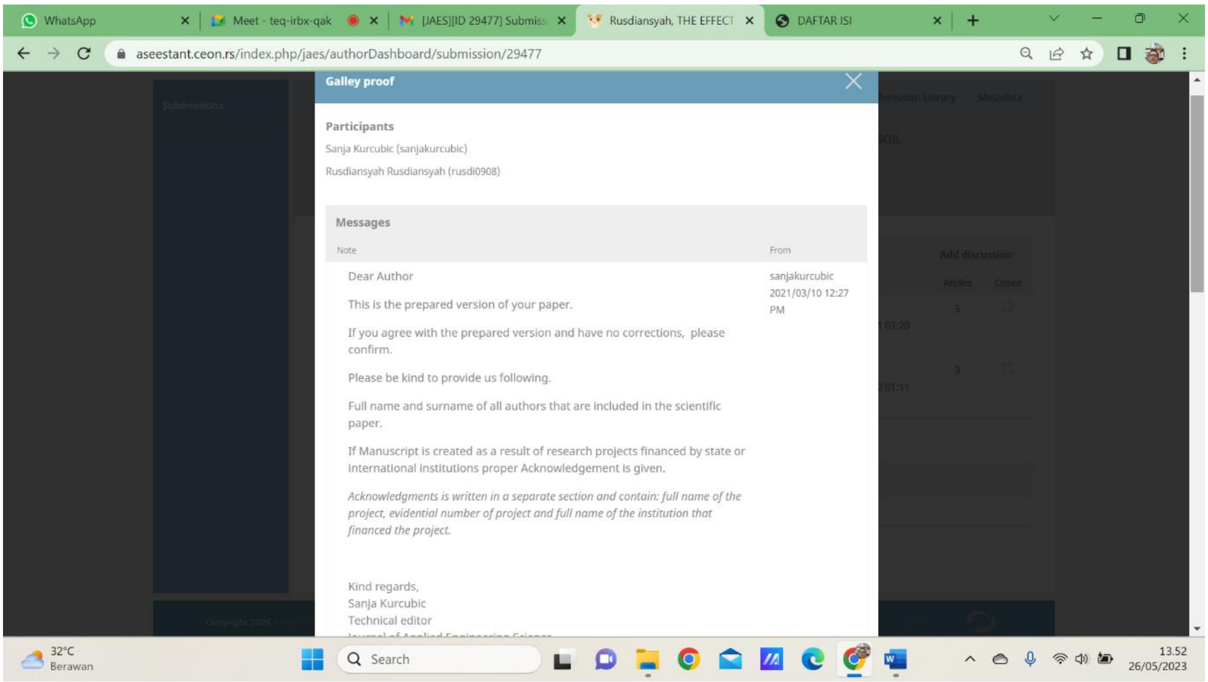
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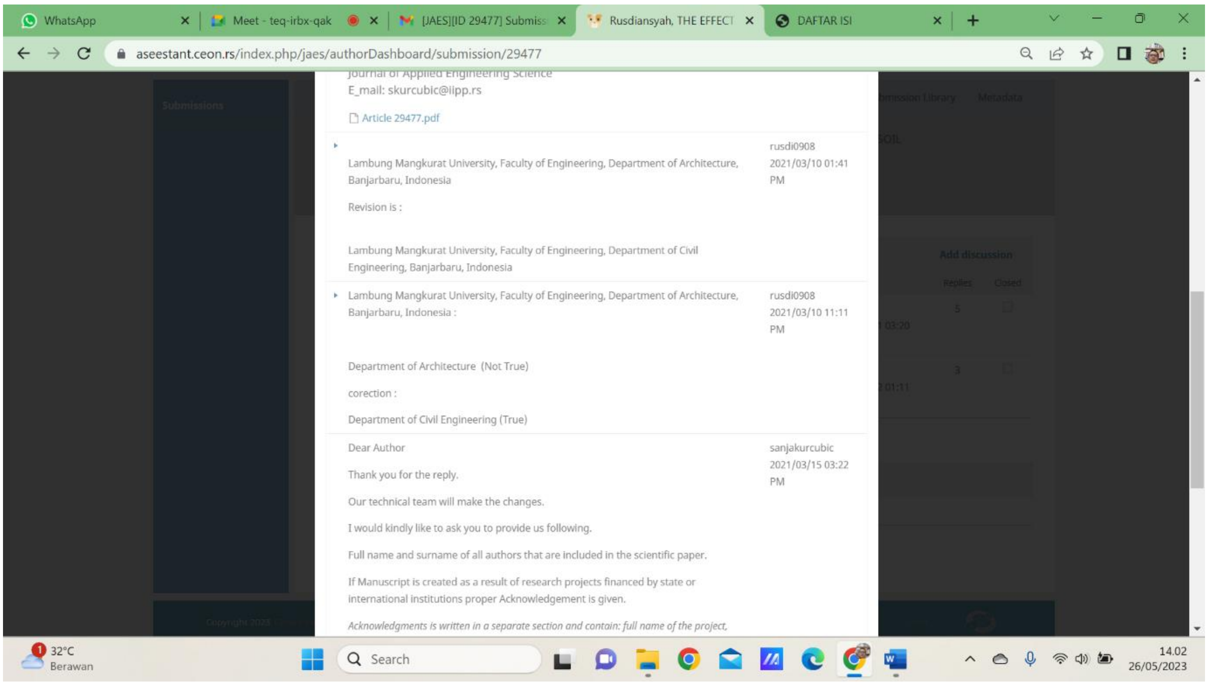
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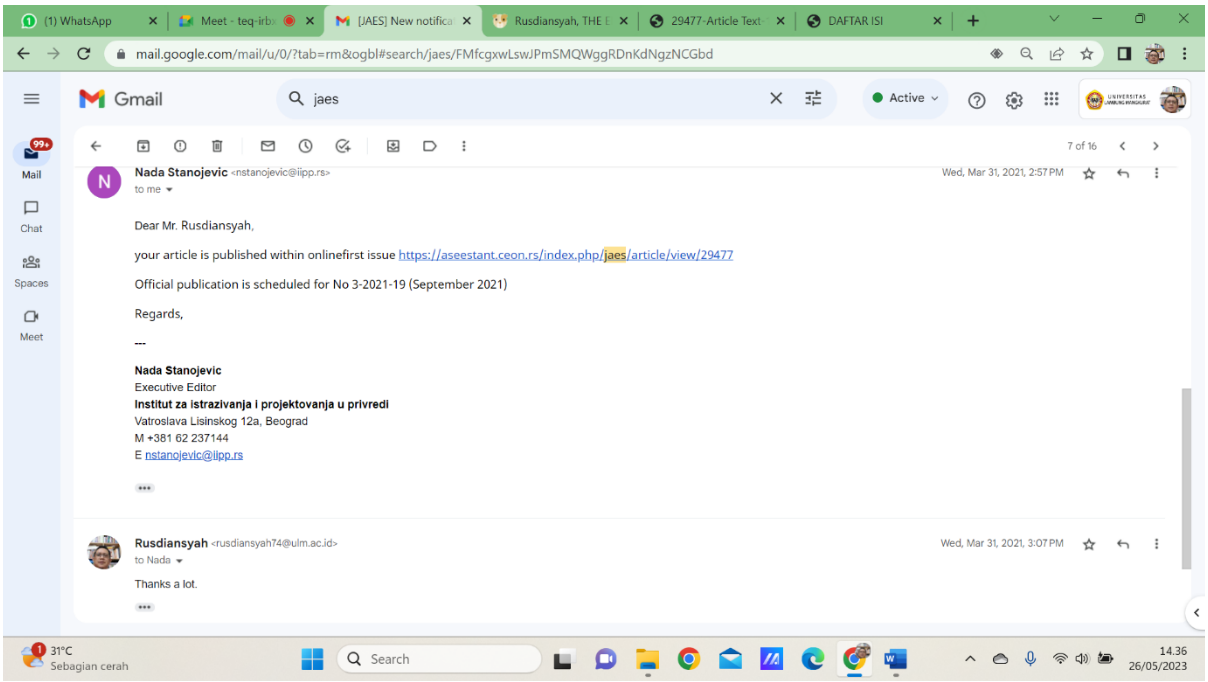

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