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WATER RETENTION AND SWELLING CHARACTERISTICS OF DIATOMACEOUS EARTH TREATED EXPANSIVE SOIL

*Alemshet Bekele Tadesse[1], Yoshinori Fukubayashi[1], Atsushi Koyama[2], and Daisuke Suetsugu[3]

[*1] Interdisciplinary Graduate School of Agri. and Eng., University of Miyazaki, Japan
[1,2,3] Faculty of Engineering, University of Miyazaki, Japan

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ABSTRACT: Expansive soils pose significant challenges to highway embankments due to their high swell-shrink potential, which is exacerbated by desiccation cracking. While diatomaceous earth (DE) has shown promise in mitigating these issues, the underlying mechanism in expansive soils remains poorly understood. This study investigates the mechanism of diatomaceous earth (DE) addition in improving the behavior of expansive soils by examining soil-water retention and swell characteristics. The filter paper method was employed to assess soil water retention, while a one-dimensional swell compression test assessed swelling potential and swell pressure. Results indicate that adding 10%DE_{SF} in mass enhances water retention capacity and air entry suction, thereby improving the soil structure and reducing desiccation cracking. Furthermore, the swell potential and swell pressure of the expansive soil were significantly reduced, highlighting the effectiveness of DE treatment in mitigating soil expansion. These findings contribute to a better understanding of the role of DE in expansive soil stabilization. However, future research should focus on detailed microstructural analysis to explain the mechanisms at the particle level and field-scale validation to ensure practical applicability.

Keywords: Expansive Soil, Cracking, Diatomaceous Earth, Soil water retention Curve, Swell potential

1. INTRODUCTION

Expansive soils pose significant challenges in highway embankment construction due to their tendency to undergo substantial volume changes with fluctuations in moisture content. These soils swell up on absorbing water and shrink when they dry, primarily due to the presence of clay minerals such as montmorillonite, which readily absorb and release water [1–3]. This swell-shrink behavior leads to poor strength, high compressibility, and instability, making them unsuitable for road subgrade and embankment applications.

Various soil stabilization techniques have been implemented to address these challenges, including mechanical compaction, chemical stabilization, material replacement, and route realignment. Chemical stabilizers such as cement, lime, fly ash, slag, and fibers [4–7] have been demonstrated to be effective in enhancing the engineering properties of expansive soils. Also, a study on the soil water characteristic curve (SWCC) and one-dimensional deformation characteristics of fiber-reinforced lime-blended expansive soil found that a significant change in the shape of SWCC has a marginal effect on the swell potential as well [8]. However, Ethiopia has an increasing demand for sustainable, locally sourced alternatives.

Diatomaceous earth (DE), a naturally occurring siliceous material, has emerged as a potential stabilizer due to its high silica content and water absorbency properties. Ethiopia possesses an estimated 45.1 million tons of DE across five regions, with deposits containing over 80% silica and more than 3% alumina [9]. Despite its abundance, DE remains underutilized in construction applications.

Recent studies suggest that Yanaizu Expansive soil (YES) treated at 10%DE_{SF} mitigates cracking, as shown in Fig. 1, but further investigation is needed to understand the mechanism [10,11]. Introducing diatomaceous earth (DE) to expansive soils offers a new approach to geotechnical engineering. DE's properties, including high porosity, a large surface area, and pozzolanic reactivity[12], may help mitigate these soils' swelling and shrinkage behavior. DE is not commonly utilized as an additive for the stabilization of expansive soils; however, its high silica content renders it particularly advantageous for this study. This method presents a sustainable and potentially more effective alternative to traditional stabilization techniques.

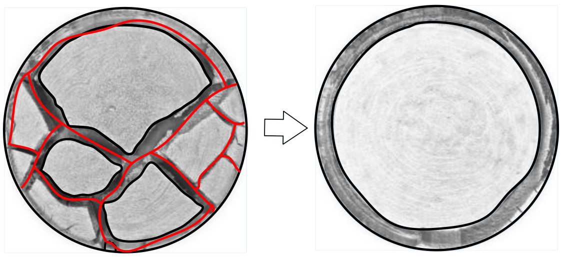

Fig. 1. Desiccation cracking condition change of untreated YES to treated specimen condition of YES+10%DE_{SF} [10]

Cracks significantly influence the behavior of expansive subgrade soils by acting as conduits for water infiltration during periods of saturation, facilitating deeper moisture penetration compared to less cracked soils. This process increases the depth of the "active zone," the layer of soil that undergoes volumetric changes due to moisture fluctuations. A deeper active zone is associated with larger swell-shrink cycles, which can lead to greater ground movement and potential damage to structures, including pavements and foundations[13].

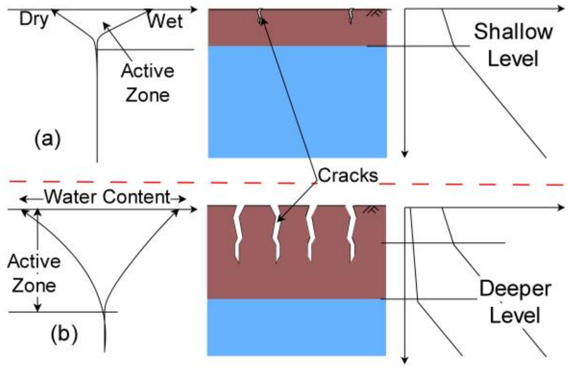

Fig. 2 Moisture Fluctuation in Active Zone of Subgrade Soil

Fig. 2 (b) illustrates that deeper cracks are associated with significant moisture fluctuations and extensive cracking, allowing for greater moisture penetration. In contrast, the shallower cracks depicted in Fig. 2 (a) indicate reduced cracking, which corresponds to shallower active zones. By minimizing cracking in expansive subgrade soils, stability is enhanced as water infiltration into the upper soil layers is limited, thus decreasing the depth of the active zone. A shallower active zone results in less swell-shrink cycling, which in turn reduces ground movement and differential settlement, ultimately improving subgrade stability and the performance of structures built on it. Effective management of cracking helps control water ingress and limits problematic volumetric changes, thereby stabilizing expansive subgrade soils.

This study explores the effect of DE treatment on the hydro-mechanical behavior of expansive soils by analyzing the soil-water retention curve, swell potential, and swell pressure. By examining these key parameters, the research aims to provide insights into how DE enhances soil stability and minimizes shrinkage effects, contributing to more sustainable geotechnical engineering practices.

2. RESEARCH SIGNIFICANCE

This research addresses the significant issue of cracking in highway subgrade constructed from expansive soils by examining the stabilizing effects of Diatomaceous Earth (DE). We present a comprehensive analysis of how the incorporation of DE enhances soil properties, particularly by improving water retention and increasing air entry suction, significantly reducing crack development. This study uniquely quantifies DE's effectiveness in lowering both swelling potential and swell pressure, providing new insights into stabilizing expansive soils. Our findings propose a novel stabilization methodology that aims to prevent crack propagation by controlling water retention characteristics, thereby optimizing the soil's strength potential at lower moisture contents near its plastic limit.

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Yanaizu Expansive Soil (YES)

The expansive soil used in this study was collected from a landslide-prone area in Yanaizu, Fukushima Prefecture, Japan, where a retaining wall was constructed for slope remediation. To ensure consistency in sample preparation, non-soil impurities were carefully removed. The soil was then air-dried, pulverized with a rubber hammer, and sieved through a 2mm aperture sieve.

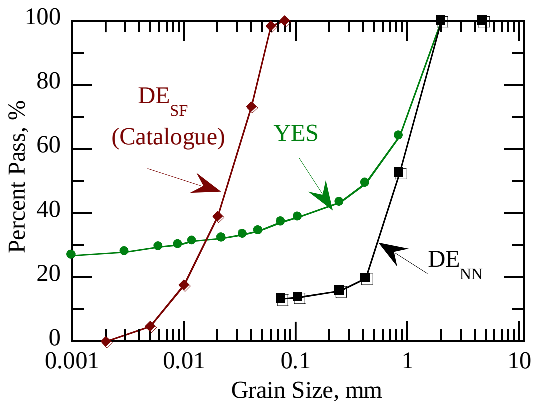

Fig. 3 Grain Size distribution of YES, DE_{SF}, and DE_{NN}

Table 1. Physical Properties of Yanaizu Expansive Soil

Physical Properties	Value
Liquid limit, ωL (%)	134.3
Plastic limit, ωP (%)	42.3
Plastic Index, PI (%)	92
Unified Soil Classification System	CH
Specific Gravity	2.72
Color	Light Green
Optimum Moisture Content, ω_{Opt} (%)	41
Maximum Dry Density, ρ_{dry} (g/cm^3)	1.151

The fraction passing the 2mm as shown in Fig. 3 for the YES, $DE_{SF,}$ and DE_{NN} was stored in a sealed container. Table 1 summarizes the soil's physical properties, classifying YES as exhibiting very high expansion potential due to its plastic index, with XRD analysis confirming montmorillonite as the predominant clay mineral, as shown in Fig. 4. Table 2 details the chemical composition of Yanaizu Expansive soil (YES), DE_{SF}, and DE_{NN} obtained via energy dispersive X-ray spectroscopy (EDX).

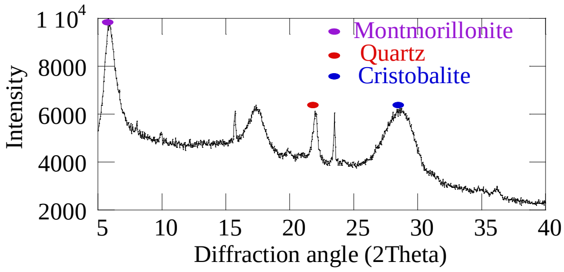

Fig. 4 X-Ray diffractogram of YES

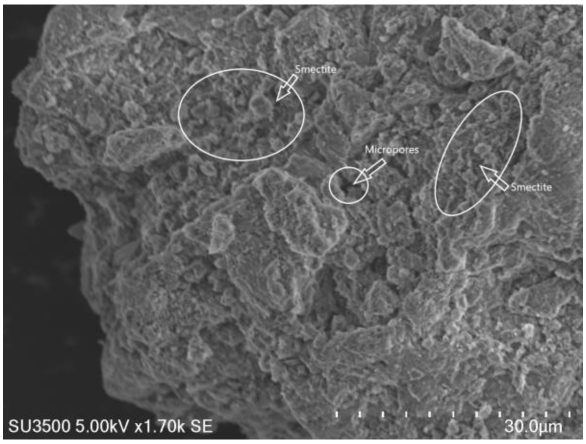

Fig. 5 SEM of YES

The scanning electron micrograph in

Fig. 5 illustrates the surface morphology of YES expansive soil, which is characterized by a dense, aggregated structure primarily composed of smectite clay minerals. These minerals have a platy arrangement that forms a complex matrix. This structure promotes close particle-to-particle contact, increasing the potential for swelling. Unevenly distributed micropores enhance the soil's porosity, resulting in a high specific surface area and indicating the soil's capacity for moisture interaction.

Table 2. Chemical composition of YES, DE_{SF}, and DE_{NN}

%Oxides	YES	DE_{SF}	DE_{NN}
SiO_2	65.73	86.41	94.74
Al_2O_3	13.63	8.63	2.51
Fe_2O_3	11.22	2.10	0.50
CaO	0.98	0.56	0.64
MgO	2.91	0.81	0.90
K_2O	3.14	0.49	0.27
Na_2O	1.63	1.00	0.47
LOI	6.59	11.9	6.67

3.1.2 Diatomaceous Earth (DE)

Diatomaceous earth (DE), or diatomite, is a light sedimentary rock that occurs naturally and contains about 80 to 90% silica [14–16]. DE is characterized by its high surface area, high porosity, and low density [17]. It is commonly used as a filter aid for water, liquors, alcoholic beverages, oils, chemicals, construction materials, and pharmaceuticals [14,18].

As shown in Table 2, both calcined and non-calcined DE exhibit high silica content and noticeable alumina levels. Calcined diatomaceous earth (DE_{SF}) has a particle size of less than 60µm, while non-calcined diatomaceous earth (DE_{NN}) is below 2mm. The difference in grain size is assumed to influence the swelling potential and pressure of expansive soil through physical resistance.

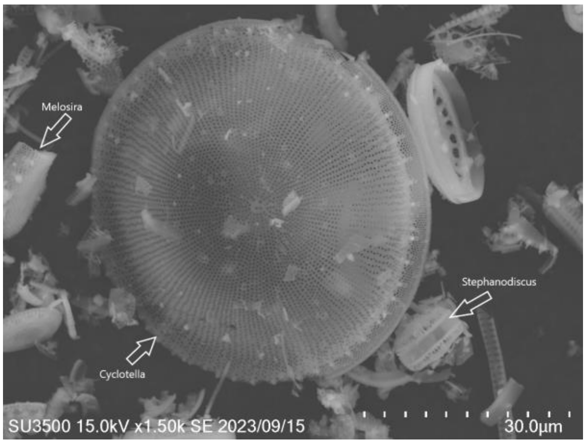

Fig. 6 SEM images of DE_{SF}

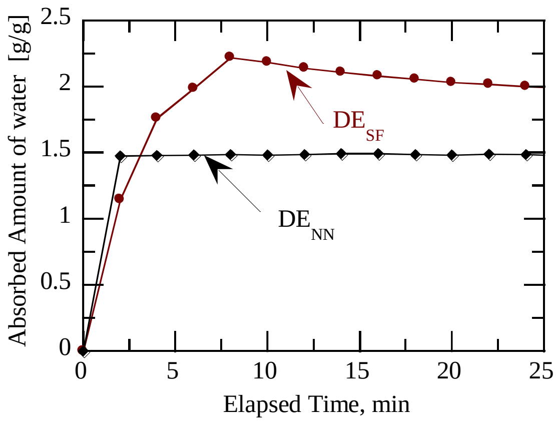

Fig. 7 Water Absorption of DE_{SF} and DE_{NN}

Since silica is the main component of DE and contains micropores, it is assumed that it will absorb moisture. Commercial diatomaceous earth was obtained from Showa Chemical Industry Co., Ltd, Oita, Japan.

Fig. 6 and Fig. 7 present the SEM image of DE_{SF}, illustrating the micropores and the water absorption results for both DE_{SF} and DE_{NN}.

The water absorption test results, shown in Fig. 7, demonstrate that the calcined and finer diatomaceous earth (DE_{SF}) exhibits a significantly higher water retention capacity, absorbing approximately two grams of water per gram of its weight. In contrast, the coarser non-calcined diatomaceous earth (DE_{NN}), as shown in Fig. 3, absorbs around 1.5 grams of water per gram of its weight. This discrepancy highlights the influence of particle size and calcination on absorption potential, with finer and thermally treated DE exhibiting hygroscopic properties.

Two distinct DE grain sizes were utilized: a non-calcined (DE_{NN}) with a particle size of 2 mm and a calcined (DE_{SF}) with particle sizes of 60 µm and smaller.

3.2 Sample Preparations and Mixing Proportions

3.2.1 Sample Preparations

The soil sample preparation procedure follows the filter paper technique (FPT) soil suction measurement as referenced in [19]. Soil specimens were prepared at standard compaction energy to ensure consistency in testing. Nine moisture levels, as shown in Table 4, ranging from 25% to 65% in 5 increments, were considered. Two cylindrical specimens (6cm diameter, 2cm height) were prepared and sealed for each moisture level to prevent moisture loss. The specimens were then conditioned at room temperature to achieve moisture equilibrium before conducting the filter paper method for soil water retention analysis.

Similarly, soil specimens were prepared following ASTM D4546 Method C, ensuring standard compaction energy for consistency. Two diatomaceous earth (DE) grain sizes and moisture levels were considered, as detailed in

Table 3. The expansive soil was mixed with DE based on its dry mass, thoroughly blended, and compacted. The specimens were then carefully conditioned to achieve uniform moisture distribution before conducting swell potential and swell pressure tests.

3.2.2 Mixing Proportions

A control sample of 100% Yanaizu expansive soil was prepared by adding 5% and 10% diatomaceous earth by dry mass. These proportions were selected to examine the incremental effects of diatomaceous earth on the modified expansive soil's soil water retention curve (SWRC), swell potential, and swell pressure properties.

The mixtures for swell potential and swell pressure test were examined at two moisture levels to examine the wet conditions (i.e., twice the OMC of YES) and at the OMC of the untreated soil.

Table 3 presents the proportions of the soil mixtures and their corresponding moisture (ω) levels analyzed in this study. The soil mixtures were examined at an optimum moisture content (OMC) of 41% and approximately twice the OMC, around 80%. Additionally, the mixtures were assessed using two different grain sizes of the additives.

Table 3 Soil Mix proportions for swell test

Mix Group	DE_{SF} Mixes		DE_{NN} Mixes	
Designation	DE [%]	ω [%]	DE [%]	ω [%]
YES	0	41	0	41, 80
YES + 5%DE	5	41	5	41, 80
YES + 10%DE	10	41	10	41, 80

Table 4 Moisture levels considered for the FPT test

Moisture Levels, %	YES	YES + 5%DE	YES + 10%DE
25	√	√	√
30	√	√	√
35	√	√	√
40	√	√	√
45	√	√	√
50	√	√	√
55	√	√	√
60	√	√	√
65	√	√	√

3.3 Experimental Procedures

3.3.1 Soil water retention curve (SWRC) measurement

When dealing with expansive soils that exhibit a wide range of suction, the filter paper technique is highly useful. Considering the factors and referring to the various methods outlined in the reference [20]. The filter paper method is both economical and capable of capturing a broad range of suction; therefore, it is employed in this study.

To measure soil potential (suction) using this method, we employ the ASTM D-5298 Standard Test Method outlined in [19]. Two samples, each sized 60cm in diameter and 20cm in height, were prepared at different moisture levels. They were compacted using standard compaction and extruded using a 60cm diameter oedometer ring.

Subsequently, two standard specimens measuring 20mm in height and 60 mm in diameter were prepared. The matric suction testing procedure involves placing a 5.5cm Whatman No.42 standard filter paper, sized 5.5cm, between two 6cm larger protective (Advantec) filter papers. The assembled filter papers are then sandwiched into the soil sample, ensuring close contact with the soil sample.

Samples were placed in an ice chest within a controlled environment for a 10-day equilibrium period. The standard filter papers were removed and placed in an oven to determine the filter paper moisture content (ω_f). Subsequently, relevant calibration equations, as cited in [21,22], were used to ascertain the matric suction (ψ) of the soil samples.

The volumetric moisture content for each specimen is determined, and the SWRC is plotted using the online tool SWRC Fit [23]. This program performs nonlinear fitting of the SWRC with parameters of suction (ψ) and volumetric moisture content (θ). Input data is organized as measured pairs (suction (ψ), volumetric moisture content(θ)). The SWRC prediction models developed by Van-Genuchten, as presented in Eq. (1), are employed.

Equation (1 represents the Van-Genuchten SWRC model, which is utilized for predicting the measured experimental data.

$$\theta(\psi) = (\theta_s - \theta_r)\left(\frac{1}{1 + (\alpha\psi)^n}\right)^m \quad (1)$$

Where θs is saturated volumetric moisture content (cm^3/cm^3) and θr is residual volumetric moisture content, ψ is matric suction (kPa), α, n, and m are curve fitting parameters.

3.3.2 Swell Potential and Swell Pressure Test Using Modified Oedometer Apparatus

This study utilized a consolidometer apparatus to perform the swell-consolidation test, integrating ASTM D4546 (Method C) and JGS0411(Test method for one-dimensional consolidation properties of soils using incremental loading) shown in Fig. 8. A linear variable differential transducer (LVDT) was mounted on the load cap to precisely monitor specimen height changes during swelling induced by water infiltration and subsequent consolidation.

The specimens were fully inundated with water and allowed to swell until equilibrium was reached, defined as the point where the LVDT recorded no height change for over 48 hours. Once the swelling phase concluded, the compression started at 19.2kPa for 24 hours. The loading was subsequently doubled daily until the specimen's height dropped below its original level, enabling the determination of swelling pressure - maximum force per unit area required to prevent volume increase in the swelling soil. A swelling pressure below 20kPa is generally considered negligible.

The swell potential reflects the soil's volumetric change for a given final water content and loading condition. The swell potential and swell pressure measurements test conducted as per ASTM D4546 utilized the modified oedometer equipment setup shown in Fig. 8. For a given elapsed swelling time, vertical axial swelling is determined using Eq. (2).

$$\boldsymbol{\varepsilon_a(t)}(\%) = \frac{\boldsymbol{\Delta H(t)}}{\boldsymbol{H_0}}\boldsymbol{x100} \quad (2)$$

Where $\varepsilon_a(t)$ is axial swelling over the elapsed time, $\Delta H(t)$ is the change in specimen height over the elapsed time, and H_o is the initial height of the soil specimen.

Fig. 8 Swell potential and swell pressure test of soil Specimens

4. EXPERIMENTAL RESULTS

4.1 Effect of Diatomaceous Earth on Soil-Water Retention

The typical drying path of the SWRC is schematically illustrated in Fig. 9, coupled with the phase change during drying. The soil water retention curves (SWRC) of Diatomaceous earth-treated 5% and 10% Yanaizu expansive soil are presented in Fig. 10. The dry density of the tested specimens ranges from $1g/cm^3$ to $1.2g/cm^3$. Fig. 10 indicates a modification in the SWRC, with the addition of Diatomaceous earth, resulting in a curve that more closely resembles that of sandy materials, as referenced from the SWRC fit database (https://seki.webmasters.gr.jp/swrc/).

Based on the available experimental data, the predicted fitting line for YES demonstrates an acceptable statistical correlation. However, obtaining experimental results for YES at matric suction values lower than the air entry point is challenging. Consequently, the fitting curve exhibits an unrealistically high volumetric moisture content (VMC) of 0.87, while the VMC at saturation for YES from the experimental data is approximately 0.6. To address this issue, the fitting curve for YES has been modified as shown in purple. The fitting lines for the 5% DE_{SF} and 10%DE_{SF} mixtures are reasonable, with statistical indices indicating a better fit than the other models, while VMC at saturation remains around 0.6.

Referring to Fig. 9 and the modified soil water retention curve (SWRC), the air entry suction values are compared in Fig. 13. The air entry suction values are as follows: YES = 100kPa, 5% DE_{SF} = 60kPa, and 10% DE_{SF} = 150kPa. While the air entry suction values for YES and 5% DE_{SF} do not show improvement, the 10% DE_{SF} mixture exhibits a notable increase. Based on the cracking study discussed in [10]. The 10% DE_{SF} mixture substantially reduces desiccation cracking, whereas the 5% DE_{SF} mixture has a smaller effect.

Fig. 10 illustrates the enhanced water retention capacity of diatomaceous (DE_{SF})-treated Yanaizu expansive soil, correlating with reduced desiccation shrinkage. This improvement might arise from DE_{SF}-induced micropore structure refinement and surface charge modification, amplifying capillary forces. Fig. 13 highlights the elevated air entry value (AEV), indicating superior resistance to air intrusion under applied suction.

The increased AEV reflects optimized pore geometry and interparticle matric potential gradients, which stabilize soil saturation during hydraulic cycling, mitigating crack propagation in unsaturated conditions.

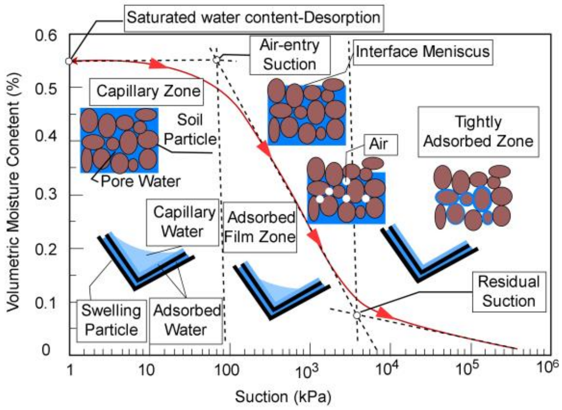

Fig. 9 Typical drying path soil water retention curve

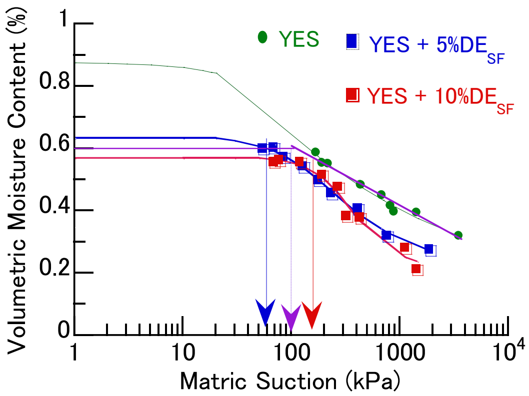

Fig. 10 SWRC curves of YES and DE_{SF} Treated YES

The soil-water retention curve (SWRC) prediction for untreated expansive soil (YES), as shown in Fig. 10, appears unrealistic at full saturation due to the material's inherent behavior distorting water retention estimation. We compare the predicted SWRC of untreated expansive soil (YES) in green with a more accurate curve in purple, highlighting discrepancies. At 10% DE_{SF}, a significant increase in air entry suction is observed as shown in Fig. 13, indicating improved water retention characteristics. This improvement mitigates desiccation cracking by reducing rapid moisture loss and stabilizing soil structure. These findings demonstrate that 10%DE_{SF} modification effectively enhances the performance of expansive soil under varying conditions.

The soil water retention curve (SWRC) is well-fitted to the experimental data obtained from the laboratory testing, demonstrating a strong correlation between measured and predicted values. However, for the untreated expansive soils (YES) case, data is unavailable at lower moisture content, unlike the other treated samples. As a result, the volumetric moisture content (VMC) at saturation is presented as illustrated in Fig. 10. The statistical evaluation parameters further validate the accuracy of the curve fitting, confirming that the van Genuchten model provides a reliable representation of the soil water retention behavior.

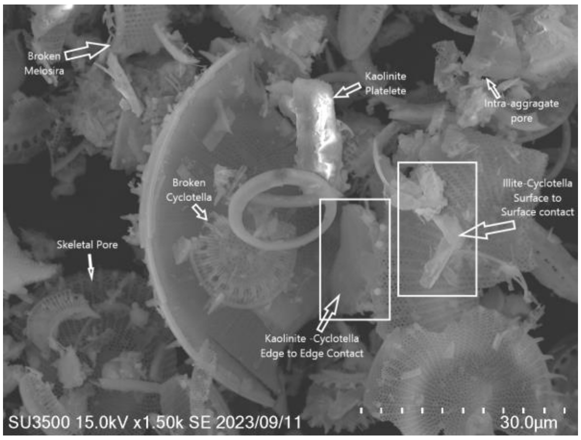

Fig. 11. SEM image of YES+5%DE_{SF}

The scanning electron micrograph (SEM) in

Fig. 11 reveals a complex microstructure of a YES+5%DE_{SF} mixture, characterized by fragmented diatom frustules, including broken Melosira and Cyclotella with skeletal pores. These frustules are interspersed with clay minerals, such as kaolinite platelets observed in edge-to-edge contact with Cyclotella and illite, showing surface-to-surface interaction. Collectively, these components contribute to intra-aggregate porosity.

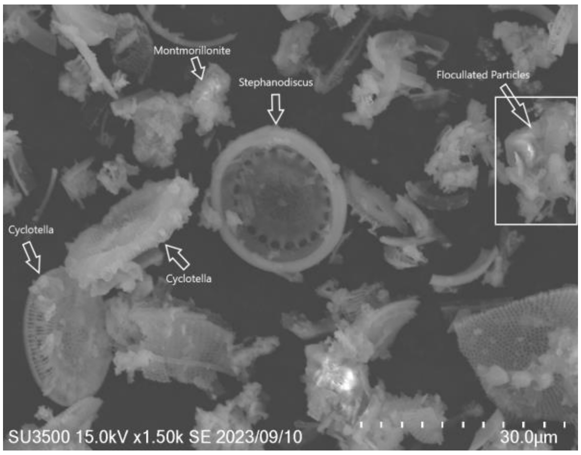

Fig. 12. SEM image of YES+10%DE_{SF}

Fig. 12 reveals an SEM image of the microstructural arrangement of YES expansive soil incorporated with a 10% DE_{SF} additive, showcasing a heterogeneous composition of montmorillonite clay interspersed with diatomaceous remnants from Stephanodiscus and Cyclotella species. Flocculated components indicate aggregation within the soil matrix. The 30.0 µm scale bar provides essential dimensional context for evaluating the influence of the DE_{SF} additive on the expansive behavior of the soil.

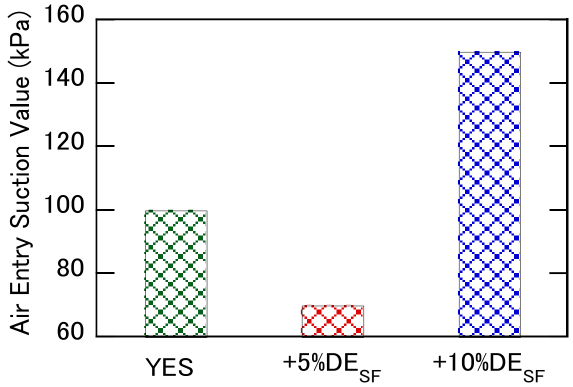

Fig. 13 Air Entry Suction Value of DE_{SF} treated YES

4.2 Effect of Diatomaceous Earth on Swell Potential and Swell Pressure

The swell potential and swell pressure of diatomaceous earth treated YES mixture were examined at two moisture levels, specifically at the optimum moisture content (OMC=41%) and approximately twice the OMC=80 %, to simulate both the initial optimum conditions and scenarios of excessive wetness.

4.2.1 Effect of DE on Vertical Swell Potential of YES at 41% and 80% Initial Moisture

The swell-time characteristics play a crucial role in defining the swelling rate in expansive soils, providing insights into how the soil expansion progresses over time. Understanding the swell-time relationship helps determine the maximum swell by analyzing the trend over time. Fig. 14 illustrates the axial vertical displacement swell-time curve for Yanaizu expansive soil treated with different percentages of DE.

Fig. 15 illustrates a relationship between the vertical swell behavior of Yanaizu soil and varying proportions of diatomaceous (DE) under controlled moisture conditions. Notably, the addition of 10% uncalcined diatomaceous earth (DE_{NN}), results in a substantial decrease in swell strain. This pronounced reduction is primarily attributed to the high porosity and silica rich composition of DE_{NN}., which influences the soils microstructure. These properties act to suppress clay particle expansion by disrupting interlayer hydration mechanisms and modifying the chemical characteristics of the pore fluid. Consequently, the expansive nature of the soil is significantly mitigated, especially near moisture content levels where swelling is severe.

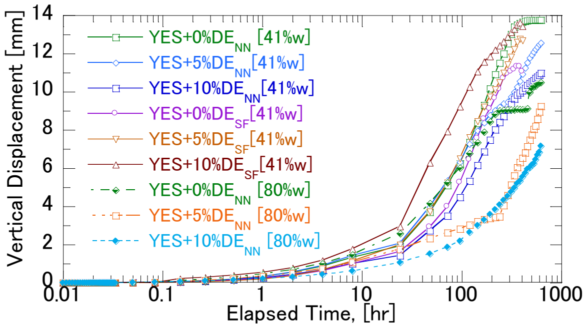

Fig. 14 Swell potential- elapsed time curves for YES, YES+DE_{SF}, YES+DE_{NN} blended specimens

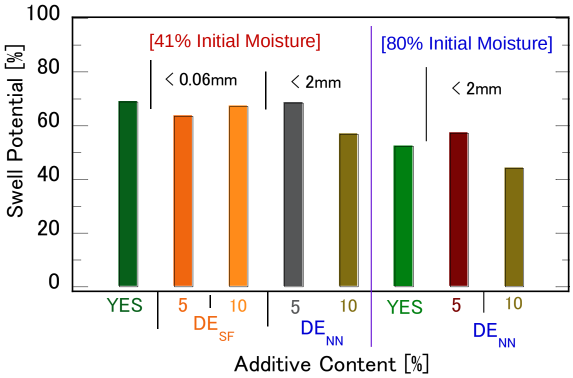

Fig. 15 Swelling Potential Result of YES, YES+DE_{SF}, and YES+DE_{NN}, mixtures

4.2.2 Effect of Diatomaceous Earth on Swell Pressure

The swelling pressure values were determined based on the compression deformation at which the soil samples regained their original height following successive compression cycles. Fig. 16 provides a representative illustration of the swelling pressure determination process for each specimen. As depicted in Fig. 17, the addition of diatomaceous earth (DE) led to a noticeable reduction in swelling pressure. This reduction can be attributed to the soil stabilization effect induced by the action of DE, which modifies the soil's microstructure and reduces its expansive behavior.

5. DISCUSSION

5.1 Improvement of Soil Water Retention

The addition of calcined diatomaceous earth (DE_{SF}) to expansive soil significantly enhances its water retention capacity, complementing its previously established role in mitigating desiccation cracking. This study elucidates the mechanistic link between DE's intrinsic properties and soil hydro-regulation. The calcined DE's porous microstructure, characterized by high surface area and micro-voids, acts as a moisture reservoir, adsorbing and storing water within the soil matrix. Concurrently, its hydrophilic surface chemistry, driven by hydroxyl (-OH) groups formed during calcination, promotes strong hydrogen bonding with water molecules, increasing their retention even under evaporative stress.

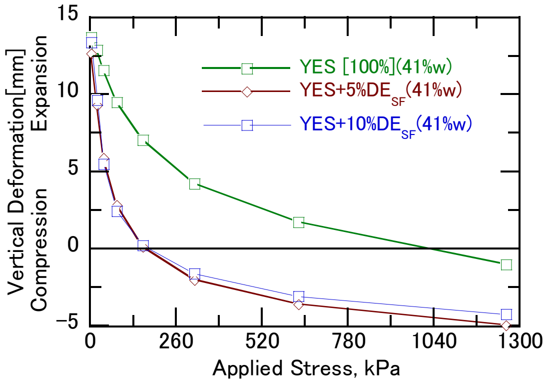

Fig. 16 Swelling Pressure determination of YES+DE$_{SF}$ blended Specimens at 41% initial moisture content

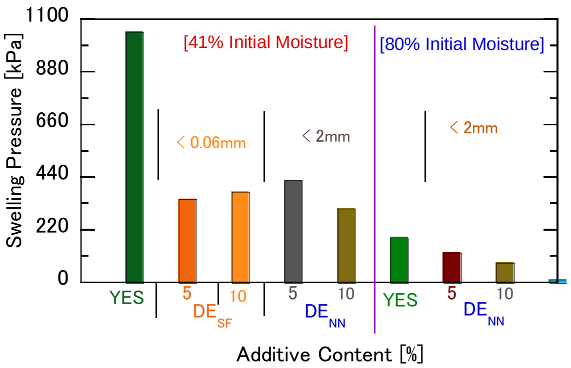

Fig. 17 Swelling Pressure Result of YES, YES+DE$_{SF}$, YES+DE$_{NN}$, and YES+DE$_{SF}$ mixtures

By prolonging moisture availability, DE-treated soils exhibit delayed hydraulic hysteresis, which reduces abrupt volumetric changes during drying cycles. This dual-action physical storage and chemical binding of water diminishes the development of tensile stresses that drive crack propagation in expansive clays. The improved water retention also stabilizes the soil's interparticle forces, curbing shrinkage-swelling behavior.

These findings highlight DE’s potential as a sustainable soil additive for highway embankments in arid or variable climates. Future work should explore the interplay between DE dosage, soil mineralogy, and long-term performance under cyclic environmental conditions to optimize its application in highway embankment construction.

5.2 Swell Potential and Swell Pressure Changes

In addition to the use of calcined DE, non-calcined granular DE was utilized to evaluate the physical resistance and assess its effect on the swell potential and swell pressure. The influence of DE content, grain size, and initial moisture content on the swell potential of blended specimens is illustrated in Fig. 15. As shown, the swell potential decreases with increasing additive content. However, the observed decrement is not substantial enough to be considered effective for field applications.

Despite variations in swell behavior among specimens, the rate of swelling differs significantly. Specimens tested at an initial moisture content of 41% with finer DE required 408 hours to reach maximum swell potential, whereas those treated with coarser DE took 864 hours. Notably, DE$_{SF}$-treated specimens swelled 2.12 times faster than DE$_{NN}$-treated specimens.

Additionally, specimens prepared at a higher moisture content of 80% exhibited slower swelling compared to those at the optimum moisture content. DE$_{NN}$-treated specimens at the optimum moisture content reached optimum swell 1.17 times faster than those with 80% moisture content. Furthermore, when the De additive content was 10% and the grain size was <2mm, the swelling process appeared to be more gradual.

Applying DE in expansive soils resulted in a marginal reduction in swell potential. This behavior can be attributed to DE's role in altering the soil's ability to absorb water and undergo volumetric expansion. The DE particles will fill the void spaces within the soil matrix, enhancing structural stability, promoting a more uniform stress distribution, and ultimately reducing swelling pressure.

6. CONCLUSIONS

This study builds on prior findings demonstrating that calcined diatomaceous earth (DE$_{SF}$) additive mitigates desiccation cracking in expansive soils by investigating the underlying mechanisms through soil-water retention behavior and swelling potential/pressure. The enhanced soil-water retention curve (SWRC) of DE$_{SF}$-treated soils reveals two critical outcomes: (1) 10%DE$_{SF}$ significantly improves moisture retention capacity by altering the pore structure, which delays water release during drying cycles, and (2) it elevates air entry, the threshold suction at which air begins displacing pore water. This dual effect stabilizes the soil matrix, suppressing crack initiation by maintaining interparticle cohesion under evaporative stress.

Furthermore, the use of larger-grained uncalcined diatomaceous earth (DE$_{NN}$) in this study introduced distinct physical advantages. The coarser DE particles reduced intergranular friction, creating a more stable skeletal framework that limits clay particle rearrangement during swelling. Experimental results confirmed that soils treated with larger DE exhibited reduced swell potential and swell pressure. This is attributed to the reduction of expansion clay minerals and the partial replacement of fines with non-swelling

DE particles, which restrict moisture uptake and redistribute swelling stresses.

While these findings underscore the effectiveness of DE_{SF} in treating expansive soils, further research is recommended to refine its application. Specifically, the interplay between larger DE-gran size and SWRC behavior warrants detailed microstructural analysis to quantify the pore-size distribution and DE-clay interactions. Also, the modification effect of water retention and volume change by adding DE, which leads to crack reduction, requires characterization regarding the relationship with the mixing ratio. Additionally, long-term cyclic wetting-drying tests under field-simulated conditions are crucial for assessing durability.

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