

Compressibility Behaviour of Soft Clay Treated by Combination between Sodium Silicate and Biomass Silica Probase Stabilizer

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Abstract

A chemically altered technique called soil stabilisation with additives can be utilised to strengthen soils with poor engineering qualities. The treatment of problematic soils, non-traditional additions such as ionic, enzymes, salts, polymers, and tree resins are frequently employed. Two types of non-traditional stabilizers a powder stabiliser (biomass silica) and a liquid stabiliser (sodium silicate) based on sodium silicate were mixed with soft soil to determine the stabilisation mechanism and performance. The engineering qualities of the stabilised soil were evaluated using a macro-structural research that included consolidation, direct shear, and consolidation tests, unconfined compression strength tests, and compaction tests. A number of physical model tests were also used to assess the performance of treated laterite backfills stabilised with the chosen additives. The laboratory tests showed that the addition of 9 % as the optimum amount of both additives increased more than 80% of compressive strength after 7 and 28 days of curing periods while the consolidation settlement had been effectively reduced. The micro-structural analysis showed that the stabilisation process changed the laterite soil's porosity network. The newly created substances, known as sodium aluminosilicate hydrate gel-like product for samples treated with sodium silicate and calcium aluminate hydrate cementitious material for samples treated with biomass silica, had filled the pores of the soil. Hence, the stabilization mechanism of two selected non-traditional additives was by cationic exchange and physical bonding. The results of the physical model tests revealed that, after just seven days of curing, the stabilised backfill soil's ultimate bearing capacity improved significantly and its settling decreased in comparison to untreated backfill soft soil.

1. Introduction

The structural problems of road construction in Batu Pahat, emphasizing the need for safe, convenient, and comfortable roads. One of the key factors affecting road construction is the condition of the subgrade and subsoil. The quality of pore water pressure, soil bearing capacity, soil pressure, and water content are critical to maintaining safe and stable road construction. The study identified problems such as low shear strength, high

compressibility, and high water table in Batu Pahat soil. Shear strength is an important property to evaluate the bearing capacity of foundations and stability of retaining walls and embankments. To ensure the strength and stiffness of the soil during construction, soil stabilization is essential, for which various traditional and non-traditional additives can be used. The study presented the use of the products biomass silica and sodium silicate to improve soil strength. The presence of high compressibility in fine-grained soils and the effects of a high water table on soil moisture were also discussed [2].

Road construction activities can lead to sediment deposition in streams, damaging water resources and aquatic life. Revegetation measures can reduce sediment input from slope cuts and fills, but road surfaces and ditches continue to contribute significantly to sediment in streams. Accurate prediction of sediment input from existing road networks is critical, and sediment prediction models based on empirical relationships have been developed for this purpose. To determine the optimal combination of probase stabilizers sodium silicate and biomass silica and evaluate their effects on atterberg limits in the soft clay of Batu Pahat. Chemical additives for soil stabilization have gained attention as an effective method for improving soil strength and resilience. However, the proprietary nature of these chemical products makes it difficult to fully understand their stabilization mechanisms and predict their performance [3].

In the last 5 years, there has been a significant increase in residential and commercial development in Batu Pahat, resulting in soft clay development. This type of clay, known as Batu Pahat Soft Clay (BPSC), is characterized by a plasticity index (PI) between 36% and 46%. A higher PI indicates a greater potential for problems such as cracking, structural deformation of pavement layers and surface deformation and subgrade of roads. The plasticity index value indicates a very high potential for volume change, which can lead to ground movement and damage to buildings. In addition, BPSC exhibits low strength, high compressibility, and reduced engineering properties, including permeability and compactness [4].

After construction, BPSC experiences a high settlement rate, which affects the strength and workability of structures and shortens their service life. Soft clay soils are known for their low strength and high compressibility, which can vary due to different sedimentation processes and environments. The engineering properties of clay soils, such as void ratio, water content, particle size distribution, compressibility, permeability, and strength, can exhibit significant variations. These variations further contribute to the challenges of working with soft clay soils and make them less suitable for construction purposes [5].

To address these issues, it is critical for engineers to stabilize the existing soil before beginning construction. Appropriate soil stabilization techniques can improve the suitability of the soil as a road base and increase the overall quality of road construction. By reducing settlement, improving strength, and reducing compressibility, soil stabilization plays an important role in ensuring the long-term stability and durability of infrastructure built on soft clay soils in Batu Pahat.

2. Literature Review

2.1 Soft Clay

Characteristics commonly associated with soft soils include limited shear strength, high compressibility, and restricted permeability. In Malaysia, these soft soils fall into the category of Quaternary sediments, composed of materials like alluvium and organic deposits such as peat. When undertaking construction in such areas, various engineering issues may arise, including slope instability, a decrease in bearing capacity, or excessive settling. It has been reported that the shear strength of the soil is below 40 kPa, and it can be physically deformed with light finger pressure. Inadequate bearing capacity, excessive post-construction settling, and instability during excavation and slope formation represent the primary challenges in working with these deposits. Theoretically, the subsidence issues resulting from applied stresses are often referred to as settlement problems. Moreover, when the groundwater levels are high, some of the fill material may experience buoyancy, leading to changes in the structural system's geometry and impacting the soil's stability [6].

2.2 Sodium Silicate Liquid Soil Stabilizer

The naturally occurring organic bi-sulphate arises from the combination of buffer acid and organic sulphur within the creation of liquid soil stabilizer known as sodium silicate. This product's origin is entirely natural. In instances where unpaved roads fail to satisfy the required sealing criteria, sodium silicate, commonly referred to as such, presents itself as one of the several available methods for achieving stabilization. Despite the ongoing investigation into the impacts of non-traditional stabilizers on the geotechnical attributes of tropical soils, the intricate structural characteristics of these alternative soil additives, especially sodium silicate, remain insufficiently explored. The predominant application of sodium silicate lies in the stabilization of rugged terrains, enabling their utilization in constructing more durable roadways and bridges. Moreover, it serves to enhance soil integrity while concurrently reducing the plastic index. This particular additive encompasses a novel composition that boasts cost efficiency compared to established construction materials [7].

2.3 Biomass Silica Powder Soil Stabilizer

A groundbreaking achievement in biotechnology, known as Probase biomass silica Soil Hardener, generates "synthetic laterite" by utilizing waste biomass silica material. The current research investigates the efficacy of biomass silica, a novel calcium-based powdered additive derived from waste biomass silica, for enhancing the stability of tropical waste laterite soils. On a larger scale, alterations in soil strength due to the application of this additive were evaluated through a series of unconfined compressive strength (UCS) tests. The results of these UCS tests revealed that the incorporation of biomass silica powder had a significant stabilizing impact on the laterite soil, leading to a fivefold increase in UCS value following a curing period of seven days. On a more detailed level, the introduction of biomass silica triggers a weathering process in the clay minerals, causing shifts in the intensity of the mineral peaks detected in the XRD spectrum after the stabilized soil undergoes weathering. This study affirms the potential of biomass silica as a viable alternative to traditional stabilizers for construction projects involving tropical waste soils [8].

2.4 Theory of Consolidation

Soil consolidation is the phenomenon wherein the volume of soil experiences a reduction. This occurs as a response to the application of stress on the soil, compelling its particles to aggregate more closely. In scenarios involving soil saturated with water, this compression leads to the expulsion of water from the soil. Diverse techniques can be employed to anticipate the extent of consolidation. Subsequent to the withdrawal of stress from the compacted soil, there is a rebound effect where the soil restores some of the volume that was lost during the consolidation procedure [9]. The maximum stress applied in this context is termed the preconsolidation stress. Additionally, consolidation denotes a gradual contraction observed in fully saturated soils possessing minimal permeability due to shifts in effective stress [10]. This change might be attributed to the partial drainage of pore water, a progression that persists until the surplus pore water pressure, established by the augmented total stress, is entirely dissipated [11].

2.5 The Oedometer Test

The evaluation of soil properties during consolidation or one-dimensional swelling can be achieved through the utilization of the oedometer test. In this test, a soil sample takes the form of a disc, positioned within a metal ring and positioned between two permeable stones. The upper permeable stone, which can move slightly within the ring, is situated beneath a metal loading cap capable of exerting pressure on the specimen. The degree of specimen compression under applied pressure is quantified using either a dial gauge or an electronic displacement transducer that operates on the loading cap. Typically, each pressure level is sustained for a duration of 24 hours (though in certain cases, it might extend to 48 hours), with compression measurements taken at suitable intervals during this timeframe. Once the dissipation of excess pore water pressure is complete at the end of the consolidation period, the total applied stress becomes equivalent to the effective vertical stress within the specimen. The findings are graphically represented by plotting the final specimen thickness or void ratio for each incremental period against the corresponding effective stress value [11].

3. Methodology

In the pursuit of enhancing the compressibility of pliable clay, experimentation with sodium silicate and biomass silica-based stabilizers is conducted within the controlled settings of UTHM's laboratory and the Soft Clay Research Center (RECESS). The chosen stabilizers encompass liquid sodium silicate and powdered biomass silica. For the precise representation of soft clay, samples are acquired from a depth of 1.5 meters at RECESS UTHM. The characterization of the clay's physical traits entails subjecting it to Atterberg's 5 limit tests and the conventional Proctor test. Meanwhile, the soil's compressibility is gauged through an oedometer test, accounting for the specific mixture proportion of the stabilizers employed.

The crux of this inquiry revolves around the physical attributes and consolidation dynamics of pliable clay situated in Batu Pahat. Through Atterberg's limit and Proctor tests, the clay's intrinsic properties are deduced. This exploration is centered on the mitigation of settlement within the pliable clay, achieved by treating it with a blend of sodium silicate and biomass silica. Here, the interplay between biomass silica content and the duration of curing takes center stage in reducing settlement. Moreover, a decline in void ratio is anticipated as the ratio of biomass silica is augmented, effectively bridging the voids amid clay particles. The envisaged outcomes of this study offer valuable insights and alternative methodologies to road engineers and contractors engaged in the conception and realization of roadways, especially pertaining to the reinforcement of road substrates.

The prime concentration of this research lies in identifying the optimal blend ratio of sodium silicate and biomass silica for the specific pliable soil in question. The quest is to strike a balance in the concoction that can effectively treat the pliable soil while maintaining cost-efficiency. The overarching objective centers on the

scrutiny of the physical properties of soft clay and the assessment of its compressibility behavior under the influence of the assessment stabilizers, namely sodium silicate and biomass silica.

The approach employed in this study involves the utilization of the conventional oedometer test, which entails using a consolidation cell for saturated soil. The oedometer test apparatus typically comprises specimens with dimensions of 75 mm in diameter and 20 mm in thickness. The preparation of the sample's dry density involves employing 90% of the Optimum Moisture Content (OMC) on the wet side and 90% of the Maximum Dry Density (MDD) of the native soils. Subsequently, the sample's uniform mass is compacted within the ring. After being reconfigured, the specimen is securely enveloped in plastic sheets to counteract moisture loss through surface evaporation. This encapsulated specimen is then subjected to curing at room temperature (20°C) for durations of 7 and 28 days.

In order to establish the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for specimen preparation, a Compaction test is administered. To ensure precision in the results and to acquire averaged values, three samples are prepared using the same mixture. The specimens are formulated with varying proportions of sodium silicate (liquid) and biomass silica (powder) probase stabilizer, and they undergo distinct curing periods (7 and 28 days). Specifically, the combinations 3%L + 6%P, 3%L + 9%P, and 3%L + 12%P are considered. In this context, 'L' signifies the liquid sodium silicate stabilizer, while 'P' signifies the powder form of biomass silica stabilizer. The observation of vertical compression induced by each applied load is carried out at periodic intervals, typically spanning up to 24 hours. Loading conditions of 25 kPa, 50 kPa, 100 kPa, 200 kPa, 400 kPa, and 800 kPa are employed, while unloading conditions involve 400 kPa and 200 kPa. Fig. 1 illustrates the methodology's sequence as depicted in the flow chart.

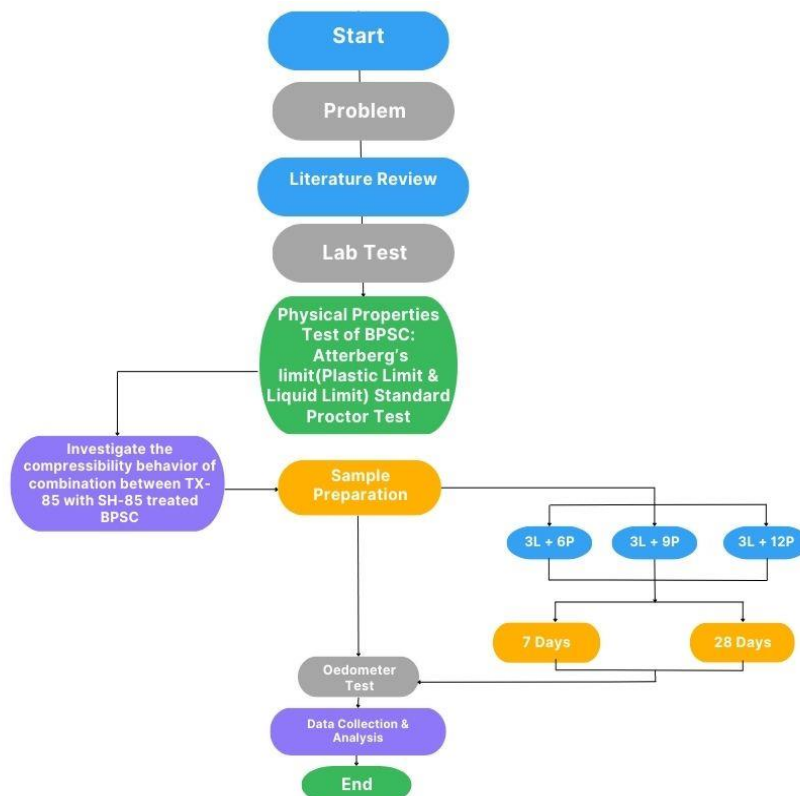


Fig. 1 Flow chart for methodology.

4. Results and Discussion

The characteristics of Batu Pahat Soft Clay (BPSC) were assessed through the employment of the Atterberg limit examination. The findings indicate that the liquid limit stands at 71%, and concurrently, the plastic limit registers at 26.40%. By deducting the plastic limit from the liquid limit, the plastic index is computed at 44.60%. This substantial plasticity index classifies BPSC as a type of plastic clay, rendering it amenable for blending alongside sodium silicate and biomass silica. In its liquid state, BPSC manifests an elevated liquid limit, causing the clay to adopt an exceedingly soft and adhesive consistency while relinquishing its structure.

In the context of soil compaction, as per the standard Proctor test, mechanical compression is applied to the soil particles to augment the dry weight. In the case of BPSC, the maximum dry density (MDD) gauges at 1520 kg/m³, while the optimum moisture content (OMC) corresponds to 23%. These parameters, pertaining to

maximum dry density and optimum moisture content, align with the permissible spectrum for Batu Pahat Soft Clay. This alignment is depicted in Table 1, which outlines the physical attributes of BPSC.

Table 1 *Physical Properties of Batu Pahat Soft Clay*

Physical Properties	Value
Liquid Limit,LL (%)	71
Plastic Limit,PL (%)	26.4
Plasticity Index,PI (%)	44.6
Specific Gravity,SG	2.66
Maximum Dry Density,MDD (kg/m ³)	1520
Optimum Moisture Content,OMC (%)	23

Fig. 2 and 3 depict the outcomes arising from the amalgamation of sodium silicate and biomass silica in altering the compression characteristics of both untreated and treated BPSC, across diverse curing time ratios. Evident from the illustrations is the decline in void volume as the combined proportions of sodium silicate and biomass silica grow, along with extended curing durations. This reduction in void volume signifies an enhancement in soil compactness. The experimental findings underscore that the bonding influence on treated BPSC remains limited when employing lower quantities of biomass silica. This infers that a certain measure of biomass silica is necessary to facilitate complete interaction and the creation of principal and secondary cohesive elements between biomass silica and BPSC. The escalation in apparent pressure before solidification is traceable to the structural alterations evident in the treated BPSC particles.

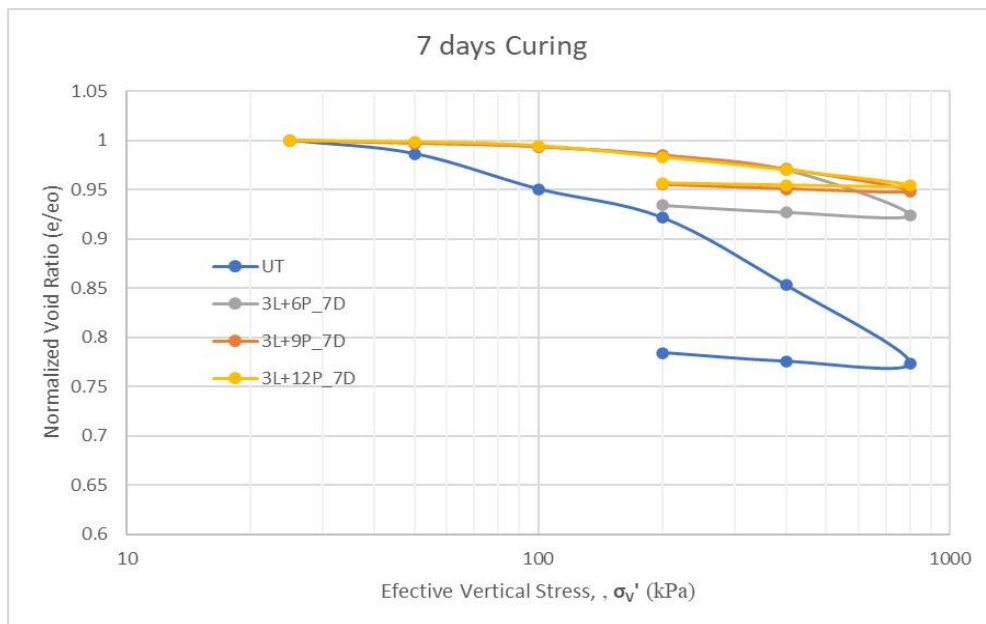


Fig. 2 *The impacts of the combination of sodium silicate and biomass silica on the compression curves of treated BPSC over a 7-day period*

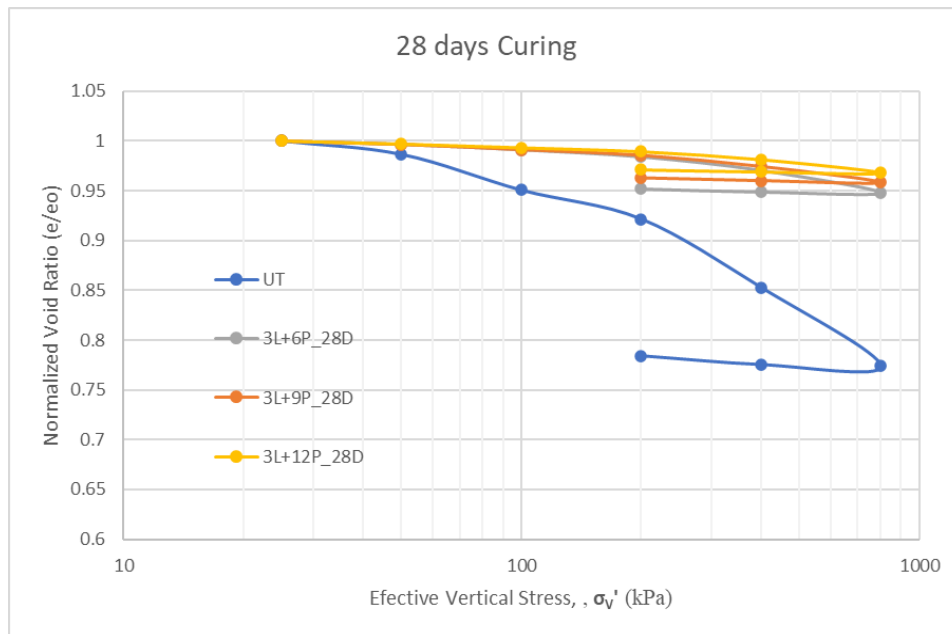


Fig. 3 The impacts of the combination of sodium silicate and biomass silica on the compression curves of treated BPSC over a 28-day period

When subjected to consolidation pressures lower than the apparent preconsolidation pressure (reflecting overconsolidation), an augmented amalgamation of sodium silicate and biomass silica leads to a reduction in void volume within the treated samples. Conversely, an opposing pattern emerges for consolidation pressures surpassing the apparent preconsolidation pressure (denoting underconsolidation). It is noteworthy that the alteration in void volume within the pressure range preceding the apparent preconsolidation pressure remains slight due to the overconsolidated state of the soil.

The compressive index (C_c) serves as a representation of the consolidation conduct of treated Batu Pahat Soft Clays (BPSC), while the swelling index (C_s) delineates the swelling conduct of BPSCs following treatment with a fusion of sodium silicate and biomass silica. It's essential to highlight that the determination of C_c and C_s values was predicated on the initial loadings captured within the e -log curve ($\sigma' v$). As the combination ratio of sodium silicate and biomass silica augments, the C_c value undergoes reduction. Moreover, the treated BPSC showcases notably diminished C_c values relative to the untreated clay soil. At the 7-day juncture, C_c treated ranges from 0.042 to 0.089, while at the 28-day mark, it varies from 0.031 to 0.052. By comparison, the untreated clay soil features C_c untreated at 0.2199. This consistent pattern highlights the heightened compressibility of the treated soil compared to the initial state. Notably, under elevated pressures (beyond the apparent preconsolidation stress), the treated samples manifest the anticipated consolidation behavior, indicating an increased C_c . Incorporated in Figure 4 is an illustration elucidating the impact of the mixture, displaying a diminished compression index towards the end of the 7-day curing period. This manifests as an elevation of 41.57% (3L+6P), 26.47% (3L+9P), and 26.19% (3L+9P) in comparison to the 28-day curing phase.

Fig. 5 unveils the ramifications of distinct amalgamations of biomass silica and sodium silicate content in tandem with curing time on the swelling index. The treated Batu Pahat soft clay exhibits substantially diminished swelling index values vis-à-vis the untreated clay, manifesting reductions of 61.78% (3L+6P), 57.96% (3L+9P), and 26.19% (3L+12P). This bespeaks a relatively restricted swelling behavior consistent with a markedly overconsolidated natural soil. The swelling curves of the treated clay exhibit a gradual wane as the proportion of the sodium silicate and biomass silica combination rises. Furthermore, the swelling index for the 7-day curing period surpasses that of the 28-day counterpart, indicating a significant resistance to plastic deformation within the soil fabric.

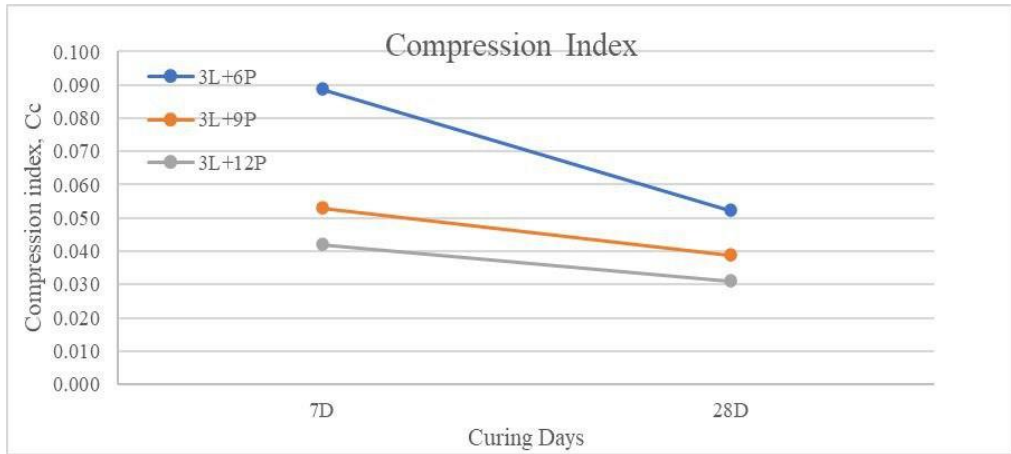


Fig 4 The impact of sodium silicate with biomass silica content and curing time on the treated BPSC compression index

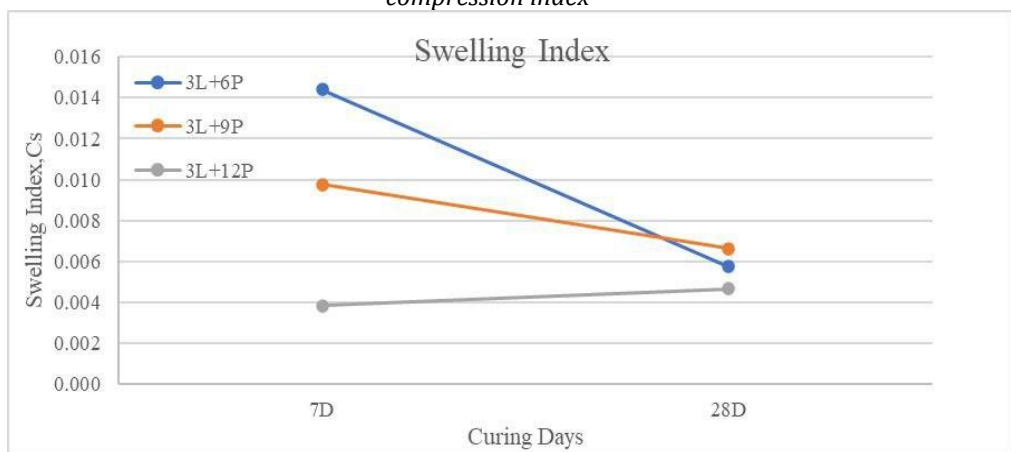
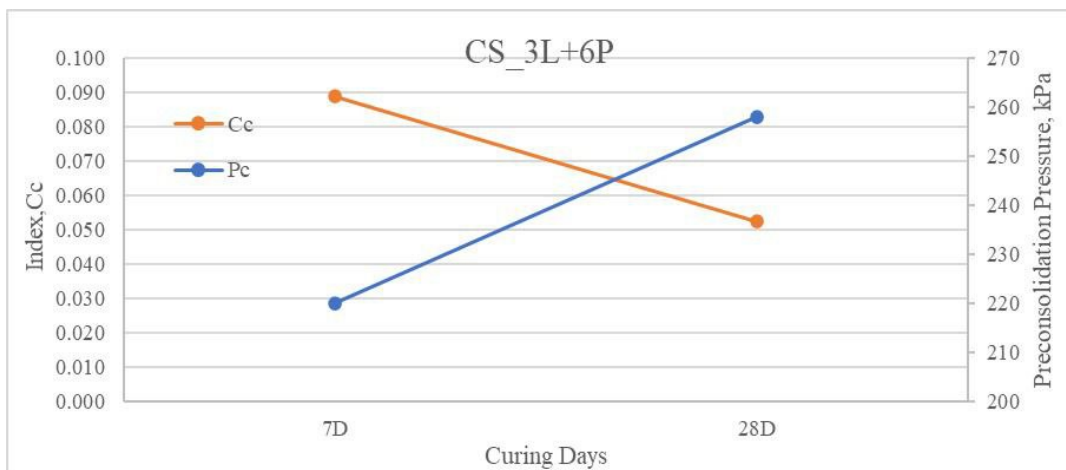


Fig. 5 The influence of sodium silicate with biomass silica value and curing time on the swelling index of treated BPSC

Illustrations in Fig. 6(a), (b), and (c) showcase the correlation between the pre-consolidation pressure (P_c) and the compression index (C_c) across different biomass silica percentages within distinct compositions. The data delineate a reduction in the compression index as the preconsolidation pressure escalates, pointing to reduced compressibility consequent to heightened past vertical stress on the soil.



(a)

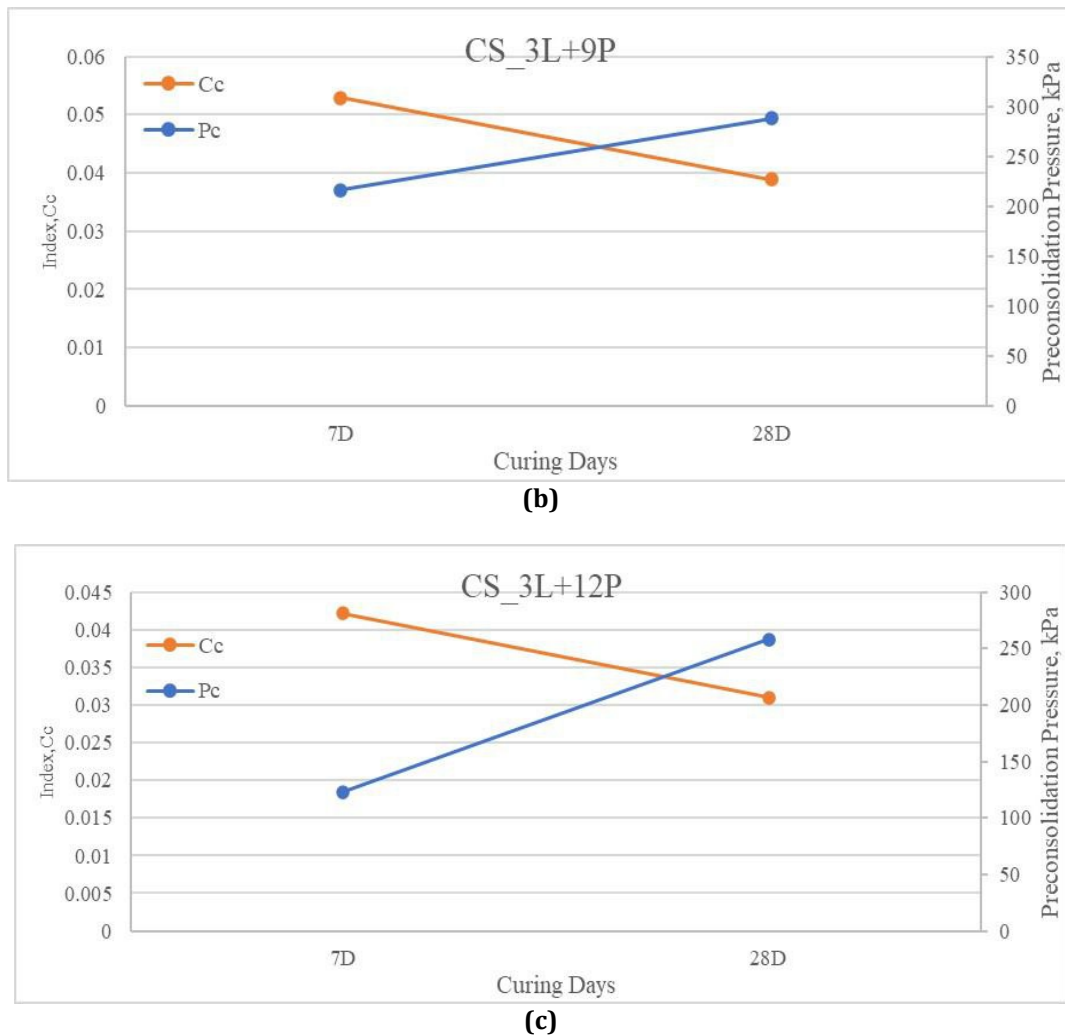


Fig. 6 Relationship between P_c and C_c (a) for 3L+6P at various biomass silica percentages, (b) for 3L+9P at various biomass silica percentages, and (c) for 3L+12P at various biomass silica percentages

5. Conclusion

Based on the outcomes of this investigation, the incorporation of sodium silicate and biomass silica into Batu Pahat soft clay can potentially influence its attributes and robustness. As the amalgamation of sodium silicate and biomass silica increases, along with the duration of curing, noteworthy enhancements in apparent consolidation pressure are accompanied by corresponding declines in the apparent compression index, as evidenced by the oedometer consolidation test. The treated clay exhibits an exceptionally firm swelling behavior, resulting in an exceedingly diminished swelling index. Moreover, the sample's void fraction displays a decrease, particularly with the elevation of biomass silica content, especially at the proportions of 6% (12 grams of biomass silica), 9% (18 grams of biomass silica), and 12% (24 grams of biomass silica).

Furthermore, the values attributed to the swelling index and compression index stand as indicative markers of soil compressibility. These values diminish proportionally to the increase in the percentage of sodium silicate in conjunction with biomass silica. The compression index exhibits a decline with heightened pre-consolidation pressure (P_c) due to the soil's prior exposure to sustained elevated vertical stresses. This antecedent history results in the compression index's reduction. The findings of this study cater to the requisites of those engaged in the road design and construction domain. Moreover, the intent is to offer road engineers and contractors innovative avenues for reinforcing road subgrades.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Nursyazwiy Wafiy Mohd Noh, Irfan Fauzan Ahmad Nor Faizal, Muhamad Arshad Aidid Mohd Azlan @ Atan; **data collection:** Nursyazwiy Wafiy Mohd Noh, Irfan Fauzan Ahmad Nor Faizal, Muhamad Arshad Aidid Mohd Azlan @ Atan; **analysis and interpretation of results:** Nursyazwiy Wafiy Mohd Noh, Irfan Fauzan Ahmad Nor Faizal, Muhamad Arshad Aidid Mohd Azlan @ Atan; **draft manuscript preparation:** Nursyazwiy Wafiy Mohd Noh, Irfan Fauzan Ahmad Nor Faizal, Muhamad Arshad Aidid Mohd Azlan @ Atan; All authors reviewed the results and approved the final version of the manuscript.*

References

- [1] A. N. Shukri, S. A. A. Tajudin & A. H. M. Nor, "Determination of Unconfined Compressive Strength and Atterberg Limit of Soft Clay by Stabilizing with Sodium Silicate and Biomass Silica in Batu Pahat," *Journal of Sustainable Underground Exploration*, vol.1, no.1, Dec, 2021. [Online]. Available: <https://publisher.uthm.edu.my/ojs/index.php/j-sue/article/view/10423>. [Accessed September 15,2024].
- [2] A.M. Nor, F. Pakir, A. Arifin & M.E. Sanik, "Stabilization of Batu Pahat soft clay by combination between TX-85 and SH-85 stabilizers," *Journal of Advanced Research in Materials Science*, vol. 14, no. 1, 2015.
- [3] N. Latifi, A. Marto & A. Eisazadeh, "Structural characteristics of laterite soil treated by SH-85 and TX-85 (non-traditional) stabilizers," *EJGE*, vol. 18, no. 1707-18, 2013.
- [4] M. M. M. Idrus, J. S. M. Singh, A. L. A. Musbah & D. C. Wijeyesekera, "Investigation of Stabilised Batu Pahat Soft Soil Pertaining on its CBR and Permeability Properties for Road Construction," *IOP Conference Series: Materials Science and Engineering*, vol. 136, no.1, 2016. [Online]. Available: <https://doi.org/10.1088/1757-899X/136/1/012026>. [Accessed September 15,2024].
- [5] A. J. L. M. Siang & M. A. A. Izzudini, "The Behaviour of Remolded Batu Pahat Soft Clay with Different OCR Values under Cyclic Loading," *In MATEC Web of Conferences*, vol. 103, no. 07004, 2017. [Online]. Available: <https://doi.org/10.1051/mateconf/201710307004>. [Accessed September 15,2024].
- [6] N. O. Mohamad, C. E. Razali, A. A. A. Hadi, P. P. Som, B. C. Eng, M. B. Rusli & F. R. Mohamad, "Challenges in Construction over Soft Soil - Case Studies in Malaysia," *IOP Conference Series: Materials Science and Engineering*, vol. 136, no.1, 2016. [Online]. Available: <https://doi.org/10.1088/1757-899X/136/1/012002>. [Accessed September 15,2024].
- [7] N. Latifi, A. Eisazadeh & A. Marto, "Strength behavior and microstructural characteristics of tropical laterite soil treated with sodium silicate-based liquid stabilizer," *Environmental earth sciences*, vol. 72, no. 91-98, 2014. [Online]. Available: <https://doi.org/10.1007/s12665-013-2939-1>. [Accessed September 15,2024].
- [8] N. Latifi, A. Eisazadeh, A. Marto & C. L. Meehan, "Tropical residual soil stabilization: A powder form material for increasing soil strength," *Construction and Building Materials*, vol.147, no. 827-836, 2017. [Online]. Available: <https://doi.org/10.1016/j.CONBUILDMAT.2017.04.115>. [Accessed September 15,2024].
- [9] P. Lokkas, I. Chouliaras, T. Chrisanidis, D. Christodoulou, E. Papadimitriou & E. Paschalis, "Historical background and evolution of Soil Mechanics," *Wseas Transactions on Advances In Engineering Education*, vol. 18, no.96-113, 2021. [Online]. Available: <https://doi.org/10.37394/232010.2021.18.10>. [Accessed September 15,2024].
- [10] A. Mohammed, R. A. Hummadi & Y. I. Mawlood, "Predicting the chemical and mechanical properties of gypseous soils using different simulation technics," *Acta Geotechnica*, vol. 17, no.4, April, 2022. [Online]. Available: <https://doi.org/10.1007/s11440-021-01304-8>. [Accessed September 15,2024].
- [11] W.H. Craig & K. Chua, "Deep penetration of spud-can foundations on sand and clay," *Géotechnique*, vol. 40, no. 4, December, 1990. [Online]. Available: <https://doi.org/10.1680/geot.1990.40.4.541>. [Accessed September 15,2024].