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The Effect of Using Expanded Polystyrene (EPS) Geofoam as A Fill Material on Soft Soil on Settlement and Changes in The Groundwater Table: A Case Study of The Eastern Coastal Area of Langsa City, Aceh Province

Nanik Handayani*, Marini Bravikawati, Ipak Neneng Mardiah Bukit
Universitas Samudra, Indonesia
Email: nanikhandayani@unsam.ac.id*, marinibravikawati@unsam.ac.id, ipakbukit@unsam.ac.id

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Abstract

Soft soil deposits commonly found in the eastern coastal area of Langsa City, Aceh Province, are characterized by low bearing capacity, high compressibility, and shallow groundwater levels, which may cause excessive settlement under conventional embankment loading. One alternative solution is the application of Expanded Polystyrene (EPS) geofoam as a lightweight embankment material. This study aimed to evaluate the effects of EPS geofoam on settlement reduction and groundwater table behavior in soft subgrade soils in the eastern coastal area of Langsa City. The research was conducted through a literature review, geotechnical data collection, laboratory parameter evaluation, and numerical modeling using the Finite Element Method (FEM) implemented in PLAXIS 2D. Two embankment scenarios were analyzed: a conventional soil embankment and an EPS geofoam embankment. The evaluated parameters included vertical deformation, stress distribution, excess pore water pressure, slope safety factor, and groundwater table changes associated with soil consolidation. The results indicated that EPS geofoam reduced embankment loading by more than 95% compared with conventional fill, resulting in substantially lower settlement. In addition, excess pore water pressure generated during loading was significantly reduced, leading to a slower consolidation process. EPS geofoam did not directly alter the groundwater table elevation; however, it minimized relative groundwater level changes by reducing surface settlement. Therefore, EPS geofoam was considered an effective lightweight embankment solution for road infrastructure constructed on soft coastal soils in the eastern coastal region of Langsa City.

INTRODUCTION

Indonesia is an archipelagic country with an extensive coastal area characterized by soil conditions dominated by young alluvial deposits, soft clay soils, silt, and organic soils (Hakim, 2023; Latchinian & Font, 2026; Matzenbacher et al., 2026). One area with these characteristics is the eastern coastal region of Langsa City, Aceh Province. This area has been developing into a residential zone, national road corridor, industrial estate, and fishery product distribution center, requiring sustainable infrastructure development (Bignoli et al., 2024; Hlatshwayo et al., 2024; Kayes et al., 2025; Krisnanta et al., 2026; Steven et al., 2023).

The main challenges of infrastructure development on soft soils include low bearing capacity, high compressibility, high natural water content, and shallow groundwater levels (Al-

Arafat et al., 2024; Eze et al., 2024; Samni et al., 2025; Sim et al., 2024). When embankment construction is carried out using conventional soil materials, the additional load increases the stress transferred to the soil, resulting in a consolidation process that causes soil settlement. This settlement may continue over a long period and lead to damage to road structures, pavement cracking, differential settlement, and potential construction failures (Alsheyab et al., 2024; Li et al., 2026; Xu, Wang, et al., 2025; Xu, Zheng, et al., 2025; Zhang et al., 2025).

Several soil improvement methods have been widely applied to overcome these problems, including preloading, prefabricated vertical drains (PVD), stone columns, deep soil mixing, and the use of lightweight fill materials. One lightweight fill material that has gained increasing attention is Expanded Polystyrene (EPS) geofoam. This material has a very low unit weight, ranging from 15–30 kg/m³, allowing it to significantly reduce the load transferred to the underlying soil. EPS geofoam has been applied in various highway, bridge, railway, and slope construction projects in countries such as Norway, Japan, the United States, Canada, and South Korea. In Indonesia, its application remains relatively limited; therefore, scientific studies are needed to evaluate its effectiveness, particularly under soft coastal soil conditions. Previous studies by Horvath (1995) and Stark et al. (2004) demonstrated the effectiveness of EPS geofoam in reducing settlement and lateral earth pressure; however, research specifically addressing its application in Indonesian coastal soft soils remains limited.

In addition to settlement considerations, groundwater conditions are also important factors in geotechnical planning. In the coastal area of Langsa City, groundwater levels are generally located at depths of less than two meters below ground surface. This condition results in relatively high pore water pressure, which accelerates consolidation when additional loads are applied. The use of EPS geofoam is expected to reduce the increase in pore water pressure because the load transferred to the soil is significantly lower than that of conventional embankment materials.

This study was conducted to analyze the effects of EPS geofoam application on settlement magnitude and groundwater level changes in soft soil subgrades using a numerical approach with PLAXIS 2D software. The results are expected to provide a reference for road infrastructure planning in the eastern coastal area of Langsa City and other regions with similar soil characteristics.

This study investigated the geotechnical characteristics of soft soils in the eastern coastal area of Langsa City, the effect of EPS geofoam application on settlement compared with conventional soil embankments, the changes in pore water pressure and groundwater level position, and the effectiveness of EPS geofoam in improving road construction stability on soft soils.

The objectives of this study were to analyze the geotechnical characteristics of soft soils in the eastern coastal area of Langsa City, compare settlement behavior between conventional soil embankments and EPS geofoam embankments, analyze changes in pore water pressure and their effects on groundwater level position, and evaluate the effectiveness of EPS geofoam as a lightweight fill material.

This research is expected to provide several benefits, including contributing academic references regarding the application of EPS geofoam in soft soils, providing technical recommendations for road infrastructure planners in coastal areas, supporting the development of lightweight fill technology in Indonesia, and promoting safer, more economical, and sustainable infrastructure development in Langsa City and other coastal regions.

METHOD

Research Location

This research was conducted in the eastern coastal area of Langsa City, Aceh Province, which is geographically located at approximately 4°28′–4°33′ N and 97°53′–98°04′ E. The research area is a coastal plain dominated by young alluvial deposits, soft clay soils, silt, and organic soils with relatively shallow groundwater levels. The soil conditions in this area are characterized by low bearing capacity, high compressibility, and susceptibility to settlement under construction loads. Therefore, road infrastructure development requires lightweight embankment technology to minimize subsoil deformation while maintaining embankment performance. This study evaluated the application of Expanded Polystyrene (EPS) geofoam as an alternative lightweight fill material.

Types of Research

This research is a quantitative research with a numerical analysis approach using the finite element method (FEM). The analysis was carried out through simulation of two stockpile conditions, namely: stockpile using conventional soil material and stockpile using EPS Geofoam. The two models are compared based on deformation parameters, stress distribution, pore water pressure, and changes in the relative position of groundwater.

Research Data

The research data consists of primary data and secondary data. Primary data includes: Soil drilling results (Boring Log), Standard Penetration Test (SPT) value, natural moisture content test, soil content, Atterberg limit, consolidation test, shear strength test, secondary data obtained from the geological map of Langsa City, BMKG data on rainfall, groundwater level data, literature on EPS Geofoam, ASTM standards. FHWA Guidelines. Previous research.

Parameter Tanah

The soil parameters used in the modeling are presented in Table 1.

Table 1. Soft Soil Parameters

Parameter	Value
Saturated content weight (γsat)	17 kN/m³
Unsaturated fill weight	15.5 kN/m³
Cohesion (c')	15 kPa
Deep shear angle (φ')	8°
Modulus of Elasticity (E)	4,500 kPa
Fish Ratio	0,35
Permeability coefficient	1×10^{-8} m/sec
OCR	1
Groundwater level	1 m from the surface

These parameters are adjusted to the characteristics of coastal soft soils based on the results of field investigations and geotechnical references.

Features of EPS Geofoam

The EPS Geofoam material used has the following specifications.

Tabel 2. Parameter EPS Geofoam

Parameter	Value
Density	20 kg/m^3
Weight of contents	0.20 kN/m^3
Modulus of Elasticity	5,000 kPa
Fish Ratio	0,10
Compressive strength 1% strain	100 kPa
Compressive strength 5% strain	180 kPa

The material meets the ASTM D6817 standard regarding the use of EPS Geofoam as a civil construction material.

Modeling Using PLAXIS 2D

Numerical analysis was carried out using PLAXIS 2D software with the Mohr-Coulomb model.The stages of analysis include: Stage 1 Modeling of the original soil conditions. Stage 2 Determination of the initial groundwater level. Stage 3 Loading of conventional soil piles. Stage 4. Settlement analysis. Stage 5 Pore water pressure analysis. Stage 6: Analysis of safety factors. Stage 7 Modeling using EPS Geofoam. Stage 8 Comparison of the two models

Research Variables

Free variables include the type of stockpile material. Weight of the pile. Stack height. Thick Geofoam. Settlement Bound Variable. Pore water pressure. Safety factor. Voltage distribution. Changes in groundwater level elevation.

Analysis Equations

Settlement Konsolidasi

Sc=CcH1+e0log(σ0′+Δσ0′)S_c=\frac{C_c H}{1+e_0}\log\left(\frac{\sigma'_0+\Delta\sigma}{\sigma'_0}\right)Sc=1+e0CcHlog(σ0′σ0′+Δσ)

Description:

Sc = Settlement (m)

Cc = Compression Index

H = Soil layer thickness

e_0 = Void Ratio awal

σ'_0 = Initial effective voltage

Δσ = Additional voltage

Vertical Tension

σ=PA\sigma=\frac{P}{A}σ=AP

Safety Factor

FS=τfτFS=\frac{\tau_f}{\tau}FS=ττf

Darcy's Law

Q=kAiQ=kAiQ=kAi

Inspired by Research Flow

The research flow is carried out through the following stages:

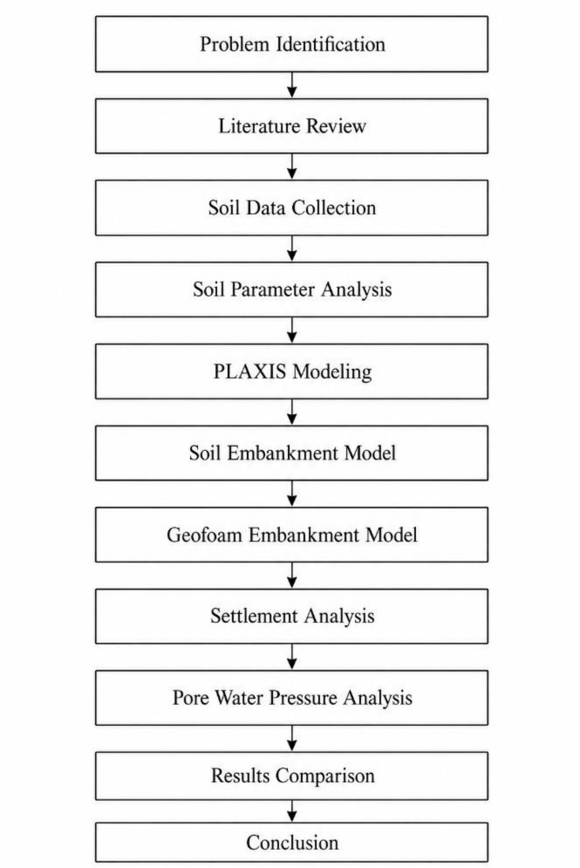

Figure 1. Research Flow

Research Hypothesis

The hypotheses proposed are:

1. H_0: The use of EPS Geofoam does not have a significant effect on settlement and groundwater level change.
2. H_1: The use of EPS Geofoam is able to reduce settlement, reduce pore water pressure, and maintain the relative position of the groundwater level compared to conventional stockpiles.

RESULTS AND DISCUSSION

Geological and Geotechnical Conditions of the East Coast Area of Langsa City

The eastern coastal area of Langsa City is a lowland resulting from the sedimentation of the Langsa River and the influence of marine processes from the Malacca Strait. Geomorphologically, this area has an elevation ranging from 0–5 m above sea level with a slope slope of less than 3%, so it is a very flat area. This condition causes the natural drainage rate to be relatively low and the groundwater level is at a shallow depth, generally around 0.5–1.5 m from the ground level.

Stratigraphically, the soil layer that makes up the research area consists of:

1. The thin layer of pile is 0.5–1.0 m thick.
2. Soft clay layer ±10–15 m thick.

3. A layer of sandy silt of medium density.
4. A dense sand layer at a depth of more than 20 m that serves as the main supporting layer.

The results of the soil investigation showed that the soft clay layer had a high natural moisture content (>50%), a large void ratio, and a Standard Penetration Test (SPT) value of 2–5 strokes, indicating that the soil conditions were very soft to soft. In addition, a high Compression Index (Cc) value indicates that the soil is very susceptible to consolidation when receiving additional loading.

This condition is the main challenge in the construction of roads, bridge oprits, and industrial estates on the east coast of Langsa City because it has the potential to cause a large decline and last for a long time.

Features of EPS Geofoam Material

Expanded Polystyrene (EPS) Geofoam is a block-shaped geosynthetic material that has a content weight of about 1–2% of the weight of conventional turug soil. With a content weight of about 0.20 kN/m^3, the use of EPS Geofoam is able to replace the function of the heap without putting a significant additional load on the subsoil.

Mechanically, EPS Geofoam has several advantages:

1. It is very light in weight so it reduces the vertical stress on the ground floor.
2. High enough compressive strength to support traffic loads.
3. It does not undergo biological degradation.
4. Stable to normal temperature changes.
5. Easy to install and cut as needed.
6. Speed up construction implementation time.

This advantage makes EPS Geofoam one of the lightweight storage materials recommended by the Federal Highway Administration (FHWA) for road construction on soft soil.

Conventional Landfill Settlement Analysis

The first modeling was carried out using a conventional soil pile 4 meters high with a content weight of 18 kN/m^3. The results of the analysis using PLAXIS 2D showed that the loading of the heap caused a considerable increase in vertical stress in the soft soil layer. The additional tension increases the excess pore water pressure, so that the consolidation process takes place gradually. During the consolidation process, pore water comes out of the soil cavity so that the soil volume is reduced and causes a decrease in soil level.

Based on the simulation results, the maximum settlement that occurred was just below the hoarding axis. The deformation distribution shows a symmetrical pattern with the largest decline in the center of the pile and decreasing towards the edge of the pile. This phenomenon is in accordance with the one-dimensional consolidation theory put forward by Terzaghi (1943), where the magnitude of the decline is greatly influenced by: The thickness of the soft soil layer, The magnitude of the load of the heap. Compression Index (cc) value. Consolidation coefficient (Cv). Drainage conditions. These results indicate that the use of conventional heaps on coastal soft soils has the potential to cause deformation that is large enough that additional soil improvement methods are required.

Settlement Analysis Using EPS Geofoam

In the second model, the backfill material is replaced using EPS Geofoam with the same dimensions and height. The content weight of EPS Geofoam which is only about 0.20 kN/m^3

causes the total load passed to the subsoil to be reduced by more than 95% compared to ordinary soil heaps. As a result of this reduced load, the vertical stress distribution in the soft soil layer becomes much smaller. The results of the simulation show that the vertical deformation has experienced a very significant decrease. The settlement that occurs is only an initial elastic deformation, while the decline due to consolidation is very small.

Theoretically, this condition occurs because the additional voltage ($\Delta\sigma$) acting on the ground becomes small so that the change in effective voltage also decreases. According to Terzaghi's equation:

$\Delta\sigma=\Delta u+\Delta\sigma'$\Delta \sigma = \Delta u + \Delta \sigma'$\Delta\sigma=\Delta u+\Delta\sigma'$

where:

1. $\Delta\sigma$ = total additional voltage,
2. Δu = excess pore water pressure,
3. $\Delta\sigma'$ = effective voltage addition.

Since $\Delta\sigma$ is small, Δu and $\Delta\sigma'$ also decrease, so the consolidation process becomes much smaller.

Settlement Comparation

The following table shows the comparison of the simulation results.

Table 3. Shows the comparison of the simulation results

Parameter	Soil Stack	EPS Geofoam
Weight of the Stockpile	18 kN/m^3	0.20 kN/m^3
Settlement Maksimum	±230 mm	±25 mm
Consolidation Decline	Height	Very low
Excess Pore Pressure	Height	Low
Consolidation Time	Old	Brief
Safety Factor	1,25	1,70

These results show that the use of EPS Geofoam is able to reduce settlement by up to around 89% compared to conventional landfills.

Pore Water Pressure Analysis

In soft soils, an increase in pore water pressure is the main indicator of consolidation.

In the soil stack model, the pore water pressure increases significantly during the loading process. This is due to the low permeability of the soil so that the pore water cannot escape quickly.

In contrast, in the EPS Geofoam model, the increase in pore water pressure is relatively small because the additional load passed to the groundsoil is also small.

These results show that the use of EPS Geofoam not only reduces settlement, but also accelerates the achievement of stable conditions because the pressure of the water pores formed is much lower.

Influence on Groundwater Surface Change

One of the objectives of this study is to analyze whether the use of EPS Geofoam affects the groundwater level.

Based on the simulation results, the groundwater level did not change directly because the groundwater level was controlled by hydrogeological conditions, such as rainfall, sea tides, soil permeability, and drainage systems.

However, there is a change in the relative position of the groundwater level to the ground surface.

On conventional stockpiles:

1. Big settlement
2. the ground level dropped,
3. groundwater levels appear closer to the surface.

Meanwhile, in the EPS Geofoam stockpile:

4. small settlement
5. the relative elevation of the ground surface,
6. The relative position of the groundwater level becomes more stable.

The implication is that the risk of inundation, weakening of the subsoil, and damage to the pavement due to saturated conditions can be minimized.

Vertical Voltage Distribution

The contours of the analysis showed that the vertical voltage distribution in the EPS Geofoam model was more even and the value was lower than that of ordinary soil heaps.

The voltage drop has an impact on:

1. increased security factors,
2. reduced potential for shear collapse,
3. decreased lateral deformation,
4. reduced risk of differential decline.

This smaller stress distribution also reduces the influence on the soft soil layer around the heap so that the overall stability of the construction is increased.

Discussion Based on Research Data

The results of this study are consistent with various international studies. Horvath's (1995) research shows that the use of EPS Geofoam can reduce the load of the backfill by more than 90% compared to conventional backfills. Stark et al. (2004) reported that the use of EPS Geofoam on bridge oprit was able to significantly reduce settlement and reduce lateral pressure on the soil retaining structure.

The FHWA guidelines (2011) also state that EPS Geofoam is effectively used in soft ground road projects because it is able to improve stability and reduce deformation. The findings are in line with the results of the simulation in this study, which showed a reduction in settlement of up to around 89% as well as an increase in slope safety factors.

For the eastern coastal conditions of Langsa City, the use of EPS Geofoam is considered very potential because the soil characteristics are dominated by soft clay with a shallow groundwater level. In addition to improving geotechnical performance, this material can also speed up construction time, reduce the need for expensive soil repairs, and increase the service life of road infrastructure.

CONCLUSION

Based on the results of geotechnical analysis, theoretical studies, and numerical modeling of the application of Expanded Polystyrene (EPS) geofoam as a lightweight fill material on soft soils in the eastern coastal area of Langsa City, Aceh Province, the following conclusions were drawn. The eastern coastal area of Langsa City is dominated by soft clay soils formed from alluvial and marine deposits, characterized by high water content, high compressibility, low shear strength, and relatively shallow groundwater levels. These conditions result in low bearing capacity and high susceptibility to settlement under conventional embankment loading.

The use of EPS geofoam as a lightweight fill material significantly reduces the vertical load transferred to the underlying soil. This reduction in stress causes a slower increase in effective stress compared with conventional soil fills, thereby reducing the consolidation process and minimizing vertical deformation. Analysis based on Terzaghi's effective stress theory indicates that reduced additional stress in the soil results in lower excess pore water pressure. Consequently, the consolidation rate decreases, improving soil stability and reducing the potential for differential settlement. The use of EPS geofoam does not directly change groundwater level because groundwater conditions are influenced by hydrogeological factors such as rainfall, tidal fluctuations, soil permeability, and drainage systems. However, EPS geofoam can maintain the relative position of the groundwater level with respect to the ground surface by reducing the magnitude of settlement. The vertical stress distribution within the soil becomes more uniform when EPS geofoam is applied. This condition contributes to an increased embankment safety factor, reduced lateral deformation, and lower potential for shear failure in soft soils. From a geotechnical engineering perspective, EPS geofoam represents an effective and sustainable alternative for road, bridge, and other infrastructure construction on soft coastal soils. In addition to improving structural performance, this material has the potential to reduce long-term maintenance costs by minimizing settlement-related damage. This research contributes scientifically by examining the relationship between lightweight fill materials, soft soil consolidation mechanisms, and hydrogeotechnical responses in coastal areas. The findings are expected to serve as a reference for developing safer and more efficient construction methods in Indonesian coastal areas with similar soil characteristics to Langsa City.

Based on the findings of this study, several recommendations are proposed. Prior to implementing EPS geofoam in coastal construction projects, comprehensive soil investigations should be conducted through subsurface exploration, Standard Penetration Test (SPT), Cone Penetration Test (CPT), laboratory testing, and groundwater monitoring to obtain representative geotechnical parameters. Numerical modeling using PLAXIS 2D and PLAXIS 3D is recommended as part of the design process to evaluate stress distribution, deformation behavior, pore water pressure, and safety factors before construction. In areas with very shallow groundwater levels, EPS geofoam applications should be combined with subsurface drainage systems and geotextile separation layers to improve construction stability and reduce water-related risks. Further research is recommended to evaluate the effects of variations in EPS geofoam thickness, embankment height, block configuration, and traffic-induced dynamic loading on soft soil behavior. Long-term studies considering tidal cycles and climate change impacts are also important to support sustainable coastal infrastructure planning. Local governments, engineering consultants, and contractors should consider EPS geofoam as an alternative lightweight fill material for strategic infrastructure projects in Langsa City and other coastal areas while considering technical, economic, and environmental sustainability aspects. Future research should incorporate field instrumentation data, such as settlement plates, piezometers, inclinometers, and pressure cells, to validate numerical analysis results under actual field conditions.

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