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APPLICATION OF GEO-CELL TO PROTECT BURIED PIPELINE UNDER FLEXIBLE PAVEMENT: CASE STUDY IN SAMARINDA-EAST KALIMANTAN

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ABSTRACT
One of the problems in urban infrastructure development is the effectiveness of pipeline networks, which often overlook the city's layout. Buried pipes provide innovative solutions for a wide variety of processes. However, they are susceptible to alteration and damage due to repeated dynamic or static loads from the structure above the pipe. Previous studies have indicated that applying a geocell reinforcement system can reduce the deformation of the pipe compared to an unreinforced bed. This observation prompted us to conduct a numerical simulation study using Plaxis 2D to assess the behavior of buried pipelines with geocell reinforcement under various sand and local soil backfill conditions, considering the highest and normal water table levels. The pipes were buried at a depth of 200 cm with an external diameter of 120 cm. This study aims to compare stress and deformation values, provide an effective simulation through stress and deformation graphs, and determine the impact of geocell reinforcement on flexible pavement. The modeling results demonstrated that deformation and stress were significantly reduced when using sand in combination with geocells. In sand-filled soil, under both the highest and normal water table conditions, stress decreased by 0.83% and 0.22%, while deformation decreased by 18.8% and 19.3%, respectively. These results highlight the substantial reduction in stress and deformation achieved through geocell reinforcement.

Keywords:
Geocell, Buried Pipeline, Stress, Deformation, Numerical Analysis

INTRODUCTION
Karangmumus River is one of the main channels that play an important role in draining rainwater runoff from Samarinda City to the Mahakam River. Most of the Samarinda City area is within the Karangmumus Watershed, so the flooding problems that often hit the city are closely related to the condition of the river. To significantly mitigate flooding risks, the Samarinda City Government plans to build a sluice gate and pump house at the mouth of the Karangmumus River. This infrastructure aims to control water levels and maximize flood management with an adaptive design in the middle of the river and on the roadside.
However, infrastructure development in urban areas faces its own challenges, especially in city layout and protection of underground structures. Underground pipelines used in pumping systems are designed to convey water under great pressure, which can cause deformation or damage due to static and dynamic loads from the overlying structures. Traffic loads can cause deformation and cracks in pipes, pavements, and subgrade soils [1]. For this reason, geocells are used as soil reinforcements [2]. Soils reinforced with geocells can reduce the soil surface settlement and vertical diametral strains by 65% and 35%, respectively [3]. The application of geocells is also able to improve the performance of footing in terms of load-carrying capacity and stability against rotation [4], [5], [6].
To navigate these challenges, numerical simulations using the Plaxis 2D program were conducted to analyze the stresses and deformations in pipes buried underground [2], [7], [8]. This research also evaluates the effectiveness of using geocells with various local backfill soil materials and sand as a protective layer. The analysis results will demonstrate a graph of the relationship between stress and deformation from various simulation scenarios, which is expected to be the foundation for designing safer and more sustainable underground infrastructure development in Samarinda City.

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OBJECTIVES

The main objective of this research is to analyze and compare the stress and deformation behavior of buried pipeline systems reinforced with geocell under varying soil and pavement conditions. The study examines two types of soils, namely well-graded sand and local excavated backfill, applied to flexible pavement structures. Through numerical simulations using Plaxis 2D, this research aims to evaluate the effectiveness of geocell reinforcement in improving the structural performance of buried pipelines. Specifically, it aims to assess the differences in stress and deformation values before and after geocell application, identify the most effective reinforcement approach through stress-deformation graphs, and determine the overall influence of geocell reinforcement on the safety and durability of underground pipeline systems. The findings are expected to provide valuable insights for optimizing the design and planning of buried pipeline networks in urban infrastructure.

METHODOLOGY

Based on the Detailed Engineering Design (DED) planning of the Karangmumus River estuary pump house construction project located on Jl. Pangeran Suriansyah, Kel. Sungai Dama, Kec. Samarinda Ilir, Samarinda City, East Kalimantan. Considering the river's width and location, the pump house was designed next to the Karangmumus River to optimize the pump performance. The output pipe from the pump adjacent to the river must pass through the road. The pump house pipeline is buried under the road to consider social and aesthetic aspects. The type of pipe used is steel with a pressurized flow system that has a thickness of 22mm and a diameter of 1.2m. The pipe network will be under Jl. Pangeran Suriansyah for 20 meters.
In the analysis of the effect of geocell reinforcement on underground pipes, the pipe is modeled under non-flowing conditions to avoid pressure against the working load. This research considers only the stress and deformation of the effect of geocell reinforcement on the pipe. The modeling will produce a stress and deformation comparison graph for geocell reinforcement used in underground pipelines with various types of well-graded sand soil and fill soil sourced from local excavations on flexible pavements. The following is a modeling of the underground pipeline geometry using Plaxis 2D to define the performance of geocells in determining the suitable implementation for reinforcing buried pipelines underground. Figure 1 illustrates the first condition during flood water levels, while Figure 2 shows the second condition at normal water levels.

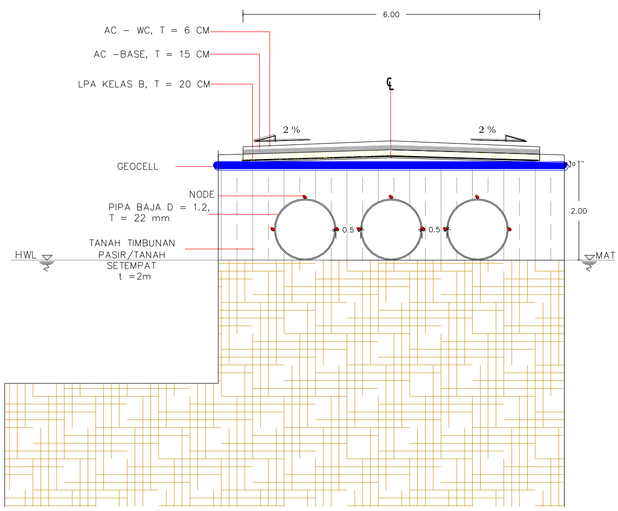

Figure 1 Modeling in PLAXIS2D of Flexible Pavement in The First Condition

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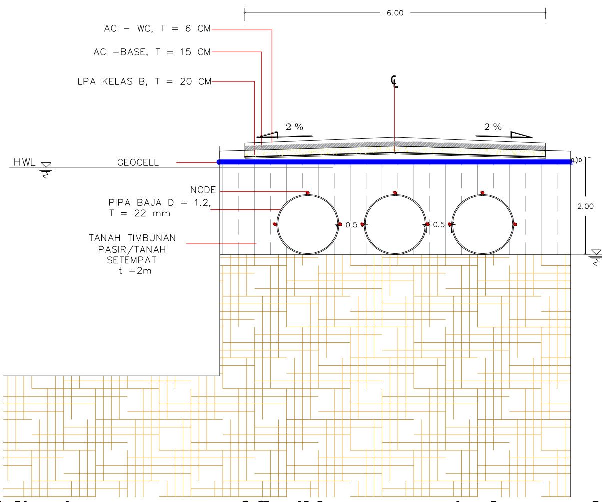

Figure 2 Modeling in PLAXIS2D of flexible pavement in the second condition

Structural analysis with the Plaxis 2D program is used calculated the amount of stress and deformation that occurs in the structure due to loads acting on the embankment structure and pavement. Based on the resulting stress and deformation values, the results of the analysis output in Plaxis 2D can be used to determine the feasibility of an underground pipeline planning design that is directly related to the structure above the pipeline. To obtain maximum results, the deformation graphs issued in the results of 2D Plaxis calculations, namely, total deformation |u|, horizontal direction deformation u_x, and vertical direction deformation u_y, and stress graphs using principal total stresses denoted by P in Plaxis 2D.

RESULTS AND DISCUSSION

Underground pipelines can change and deform due to repetitive implementation or static loads from structures above them. The addition of geocell reinforcement, the type of backfill soil, and the type of pavement play significant roles in the deformation and stresses that occur in underground pipeline planning simulations.

The planning of underground pipelines using numerical simulation consists of several steps. It involves modeling geometry in Plaxis 2D software with a flexible pavement model, examining two scenarios with and without geocells, modeling local backfill soil obtained from backfilled excavations, modeling well-graded sand backfill soil, and inputting the loading data and materials used.

In the output issued by Plaxis 2D, the total deformation |u|, horizontal direction deformation u_x and vertical direction deformation u_y can be seen. As well as a stress graph using principal total stresses denoted by P**.**

The deformation graph and stress graph are compared to the implementation load in the form of heavy equipment with a load of 140 kN, this is useful for obtaining deformation and stress results that can be seen directly step by step when the load is in the initial condition until the condition reaches the ultimate limit.

Description		Stresses		Total Deformation		Deformation Horizontal		Deformation Vertical	
		Point stresses	p [kN/m²]	node	|u| [mm]	node	u_x [mm]	node	u_y [mm]
First condition	A1	4	-7.07	8	0.232	10	-0.032	2	-0.187
	B2	4	-5.90	3	0.259	10	-0.071	11	-0.194
	A3	4	-18.90	8	0.243	10	-0.030	2	-0.187
	B4	4	-18.50	4	0.261	10	-0.058	11	-0.197

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Description		Stresses		Total Deformation		Deformation Horizontal		Deformation Vertical	
		Point stresses	p [kN/m²]	node	|u| [mm]	node	u_x [mm]	node	u_y [mm]
Second condition	A1	4	-7.55	8	0.245	10	-0.036	2	-0.193
	B2	4	-7.24	3	0.272	10	-0.078	11	-0.205
	A3	4	-18.56	8	0.254	10	-0.034	2	-0.192
	B4	4	-18.21	4	0.273	10	-0.065	11	-0.208

Table 1 Recapitulation of deformation and stress values

Description :
A1 = Flexible pavement with sand fill with geocell
B2 = Flexible pavement with sand fill without geocell
A3 = Flexible pavement with local backfill with geocell
B4 = Flexible pavement with local backfill without geocell

For example, the calculation results presented include only one variation with two different conditions to simplify the analysis and provide a more transparent interpretation of the influence of each condition on the results obtained.

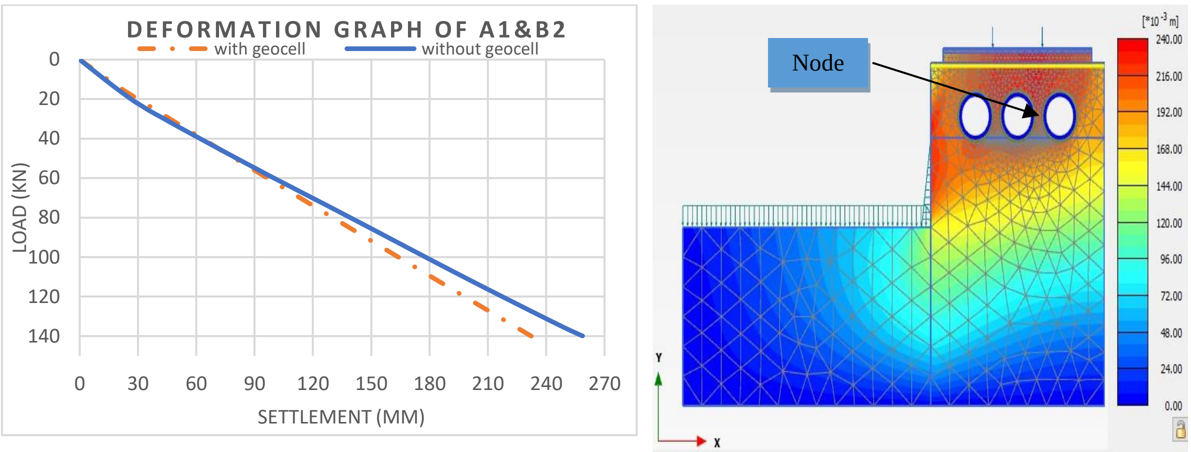

Figure 3 Deformation of flexible pavement with sand fill (A1 & B2) in First Condition at Low Water Level

According to **Figure 3**, which displays the deformation graph of flexible pavement with sand fill (A1 & B2) under the First Condition with a Low Water Level, there is a noticeable change in the deformation pattern at the significant nodes, specifically nodes 8 and 3, when both x and y are set to 10. The graph indicates that the construction with geocell reinforcement experienced a slower settlement than without geocell until it reached the ultimate condition, with a deformation of 0.232 mm. Meanwhile, the construction without geocell reinforcement continues to decline until it reaches the ultimate condition with a deformation of 0.258 mm.

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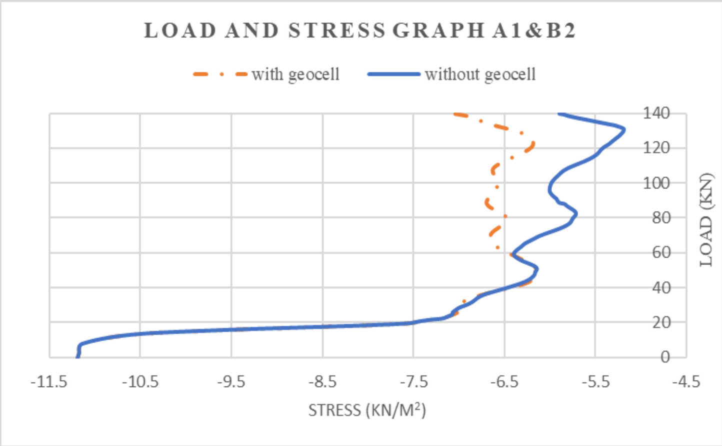

Figure 4 Stresses of flexible pavement with sand fill (A1 & B2) in First Condition at Low Water Level

Based on **Figure 4**, the stress graph shows a change in stress at node 2 with x = -7.7 and y = 21. The graph shows that the construction using geocells is -10.3 kN until the load reaches the ultimate condition when the value is -9.4 kN/m2. In contrast, those that do not use geocell reinforcement is -10.22 kN/m2 until the load reaches the ultimate condition, when the value is -12.7 kN/m2.

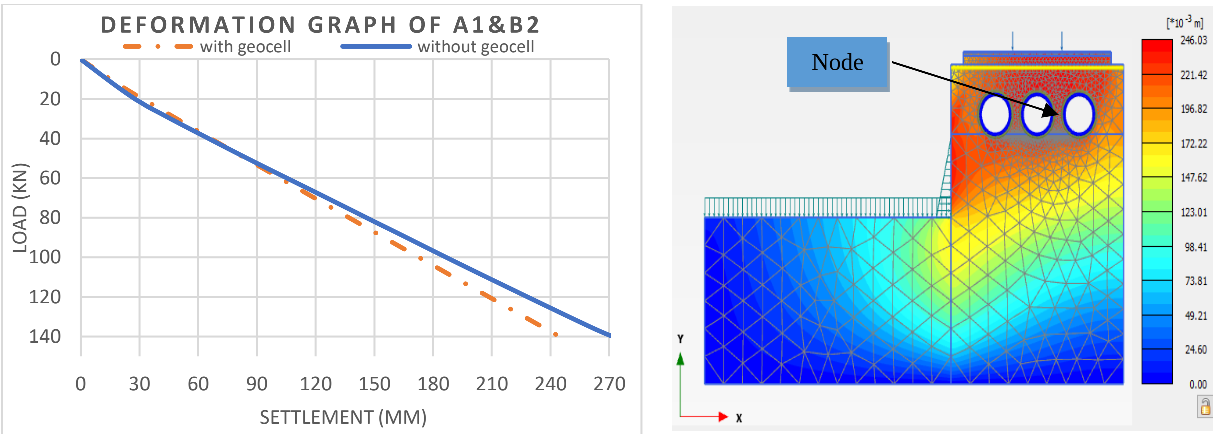

Figure 5 Deformation of flexible pavement with sand fill (A1 & B2) in Second Condition at Highest Water Level

Based on **Figure 5**, graph Deformation of flexible pavement with sand fill (A1 & B2) in second condition at highest water level shows that at the most significant nodes, namely 8 and 4 at x = 12 and y = 9, there is a change in the deformation pattern, the construction that uses geocells experiences a slow decline compared to those that do not use geocell reinforcement until it reaches the ultimate condition, a value of 244 mm is obtained. While those that do not use geocells continue to decline until the load reaches the ultimate condition, a value of 271.6 mm is obtained.

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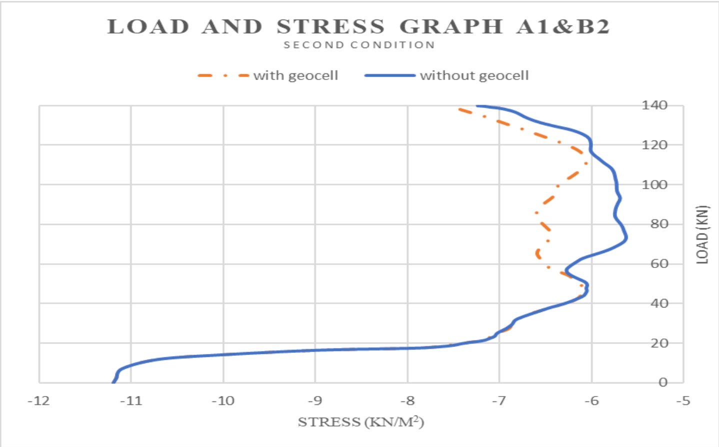

Figure 6 Stresses of flexible pavement with sand fill (A1 & B2) in Second Condition at Highest Water Level

Based on **Figure 6**, the stresses graph shows a change in stress at node 2 with x = -6.2 and y = 40. Construction using geocells at the load reached the ultimate condition and obtained a value of -7.55 kN/m2. In contrast, those not using geocell reinforcement at the load reached the ultimate condition and obtained a value of -7.23 kN/m.

In total deformation, the (+) sign is interpreted as down/down. As for horizontal, the (-) sign is interpreted as left direction, the (+) sign is interpreted as right and vertical, the (-) sign is interpreted as down/down direction, and the (+) sign is interpreted as up/up. In tension, the (-) sign is interpreted as compressive stress, and the (+) sign is interpreted as tensile stress.
For example, based on **Figures 3-6** and **Table 1**, it can be seen that in the reinforced construction that does not use geocells, the deformation pattern will be more dominant to the left than those that use geocell reinforcement, while in the reinforced construction that does not use geocells, the deformation pattern will be more dominant downward than those that use geocell reinforcement. The line graph indicates that deformation in construction structures using geocell reinforcement is distributed more uniformly compared to those that do not utilize it.
The stress distribution illustrated in the figure reveals that the stress distribution line in the construction structure shows minimal variation between the scenarios with and without geocell reinforcement.

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CONCLUSION

Based on the numerical simulation results, the use of geocell reinforcement in flexible pavement effectively reduces stress and deformation, especially in sand-filled soil. The stress reduction in sand fill soil reached 0.83% in the first condition and 0.22% in the second condition, while the deformation reduction reached 18.8% in the first and 19.3% in the second conditions. For the local fill soil, the stress reduction was 0.28% in the first and 0.24% in the second conditions, with a deformation reduction of 13.24% in the first and 13.15% in the second conditions.
An analysis of the eight modeling runs conducted with Plaxis 2D demonstrated that the use of geocells in sand-fill soil resulted in shorter deformations and lower stress levels compared to local fill soil. This suggests that geocells enhance load distribution, helping to prevent excessive stress and deformation from concentrating in one area. Thus, geocells significantly improve the performance of flexible pavements, especially when used with sand fill soils.

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