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Stability Modeling of Groyne-Type Structure with Embankment in Pelangai River, Pesisir Selatan Regency, West Sumatra

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ABSTRACT

Erosion is one of the exogenic processes that commonly occur around river dynamics. Intensive erosion occurs at the riverbank area, which has the potential to cause the slope on that side to collapse. Therefore, a groyne-type structure is required to prevent this from happening. A groyne-type structure is planned to reduce the impact of erosion in the Pelangai River with embankment. This research aims to determine the stability of the groyne with embankment design using Plaxis 2D software. Plaxis 2D modeling uses soil input parameters based on CPT, SPT, and groyne structure with approximation parameters. The modeling results show that with the addition of groyne, embankment and traffic load, the safety number drops from 1.906 to 1.241. This figure does not meet the safe number limit according to SNI Geotechnical 8460 of 2017, which requires a minimum safe number of 1.25. In addition, the addition of groyne, embankment, and traffic load resulted in soil settlement of up to 6.3 cm, which is still considered safe.

1. Introduction

Erosion is one of the exogenic processes that commonly occur around river dynamic. This process impacts changes in river morphology that affect the stability of the riverbank area [1]. Intensive erosion occurs in the area of the river bank, which has the potential to cause the slope on that side to collapse. Therefore, a groyne-type structure is needed to prevent this from happening. Sandbars significantly influence riverbank stability and the effectiveness of riverbank protection structures [2]. The location of groyne-type structures affects how well they reduce erosion along the river. The study specifically highlights the significance of comprehending morphological dynamics. It proposes that groynes can be strategically placed to lower significant erosion risks and enhance riverbank protection, especially in locations prone to erosion [3]. In braided rivers, installing groynes is a common way to stop riverbank erosion. It is essential to evaluate the stability of the groynes and their effects on the surrounding environment because of the braided river's unpredictable behavior and the critical climate [4].

Some factors influence the stability of groyne such as: scour depth, flow conditions, sediment load and bed aggradation, hydraulic conductivity, and water level fluctuation [5][6][7]. Slope stability with changes in groundwater level rise showed that the safety factor value decreased as the groundwater level rose [8]. This condition is reached when the water table reaches the most crucial landslide plane. Geotechnical factors such as shear strength, plasticity index, and particle size are crucial when evaluating bank stability. These characteristics are frequently included in numerical models to forecast stability and erosion. Using PLAXIS 2D to evaluate riverbank stability and deformation patterns has proven successful. For example, PLAXIS 2D was used to investigate the use of geogrid for slope protection on Majuli Island, demonstrating increased stability and decreased deformation [9]. Comparative tests between PLAXIS and other software tools, such as Geostudio [10], have demonstrated that PLAXIS predicts the safety factor for erosion protection structures or slope stability more accurately.

The failure of a riverbank protection system along the Pasak River in Thailand was examined using PLAXIS 2D. In order to improve stability, the study suggested a new reinforced retaining wall structure and determined that seepage forces and soil erosion were the primary sources of instability [11]. Similarly, PLAXIS 2D's usefulness in retrofitting and enhancing safety elements was demonstrated in Jakarta when it examined and reinforced a sheet pile that had collapsed on the Ciliwung Lama riverfront [12]. Groyne-type structures have been modeled to evaluate their efficacy in rerouting flow and halting erosion in the context of riverbank protection. The best groyne configurations to successfully reduce erosion hazards can be found using numerical simulations with programs like Plaxis [3].

2. Method

2.1 Research Location and Data

The research location is at latitude -1.7779452 and longitude 100.7824222, precisely in the Pelangai River area, Pesisir Selatan Regency, West Sumatra. This location is about 151 km to the southwest of Padang City. Figure 1 shows the condition of the study area and the layout of several cross sections. Based on the regional geologic map, the study site is located on alluvial deposits of Quaternary age with silt, sand, and gravel soil composition [13]. Based on the results of field tests and with the help of the geological map of the area, which states that there is a layer of rock at the test site composed of sand and clay layers, this is quite relevant to the investigation results obtained.

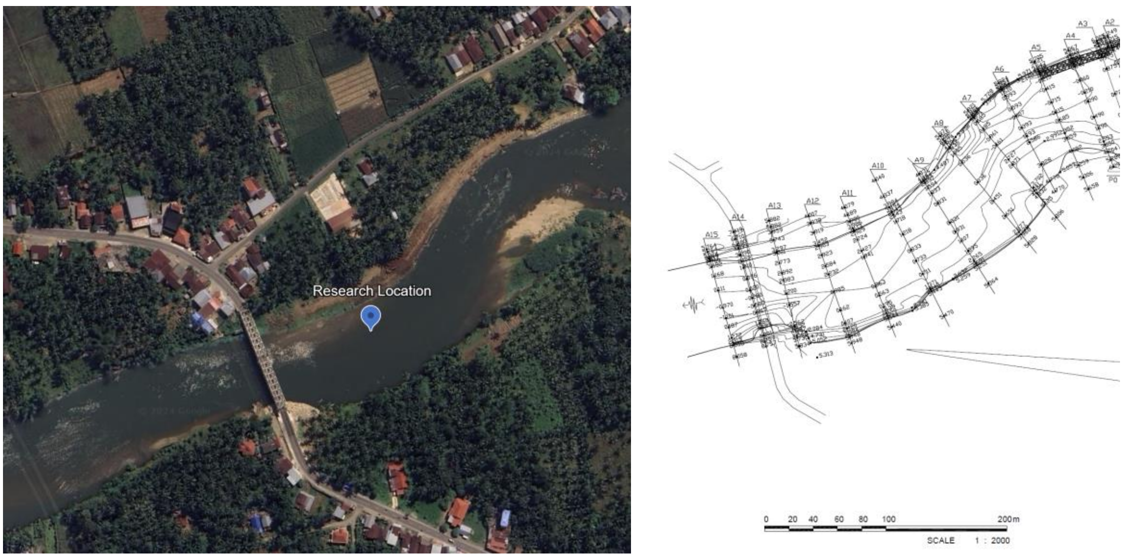


Fig 1. Research Location and layout of several cross sections
Source: Google earth and project report

Fig 2. Soil investigation (CPT and SPT) locations
Source: Project report

Figure 2 shows the location of the CPT and SPT testing point. There are three CPT testing points and four SPT testing points. In this study, cross section A10 was selected as the research area due to its proximity to the CPT-1 and BH-2 SPT testing point. From the results of CPT testing conducted by CPT-1, it was carried out to a depth of 6.2 m from the surface because the reading of the conus resistance had reached a value of 250 kg/cm^2. Information related to soil behavior at the testing point is dominated by clay soil types, which means that in the interpretation carried out, the soil has a dominant behavior of clay soil. In the BH-2 test, it is known that the soil's surface is clay soil with medium plasticity. Sandy soil with loose-medium density is at a depth of 1.00 m to 3.00. Depth 3.00 m to 5.30 is gravelly sand soil with medium density. Sandy soil with medium density is at 5.30 m to 5.70 m depth. At a depth of 5.70 m to 7.50 m is sandy silt soil with loose density and low plasticity. A layer of clay with medium-high plasticity is at a depth of 7.50 m to 10.00 m. At a depth of 10.00 m to 12.00 m is sandy soil with loose density. At a depth of 12.00 m to 13.00 m is sandy, silty soil with very loose density. At a depth of 13.00 m -14.00 m is sand soil with loose density - sedan. It is continued to a depth of 15.00 m in the form of a layer of very loose - medium-density silty sand.

2.2 Cross-Section and Modeling

In 2D Plaxis modeling, the cross-section data is the primary data to determine the model's geometry. Figure 3 shows cross-section A10 as the basis for modeling. Cross section A10 stretches northwest-southeast for 126.57 m. Based on the cross-section, the highest elevation of the original ground soil is 5.47 m above sea level, and the lowest elevation is the riverbed at 0.711 m above sea level.

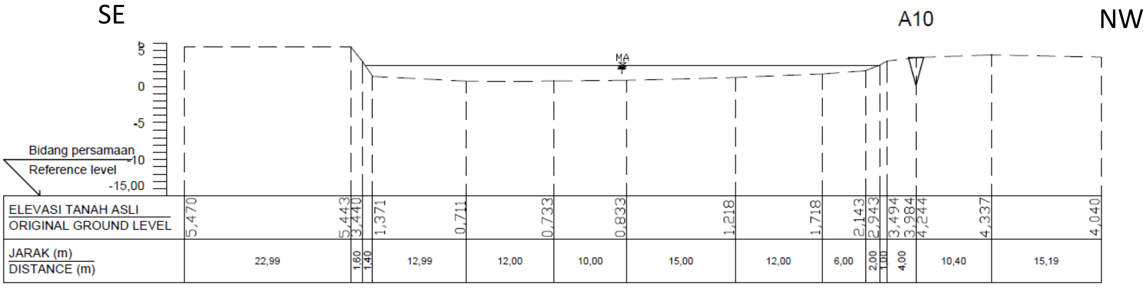


Fig 3. Cross-section
Source: Project report

The geometry of the model in Plaxis 2D uses the boundary approach of the half-embankment geometry of plain-strain model on homogeneous soil, as shown in Figure 4 [14]. Assuming the height of the embankment is H, the lower limit for the homogeneous soil model is 5H. The model's boundary is at least 3L from the toe of the embankment, where L is the width of the half-embankment. The boundary conditions of the left and right parts of the model are no deformation in the horizontal direction or denoted as $u = 0$. As for the boundary conditions at the bottom of the model, there is no deformation in the vertical or horizontal direction or marked with $u = v = 0$. So, the geometry of Plaxis 2D modeling can be seen in Figure 5.

The geometry of the Plaxis model is designed to represent the various components involved in the analysis, which include the soil layers, groyne, and embankment. In addition to these structural elements, a uniform load of 10 kPa is applied to simulate the effects of vehicle traffic on the slope. This load is intended to represent the pressure exerted by the weight of vehicles moving across the embankment, and its impact on the system's overall stability is a critical factor in the analysis.

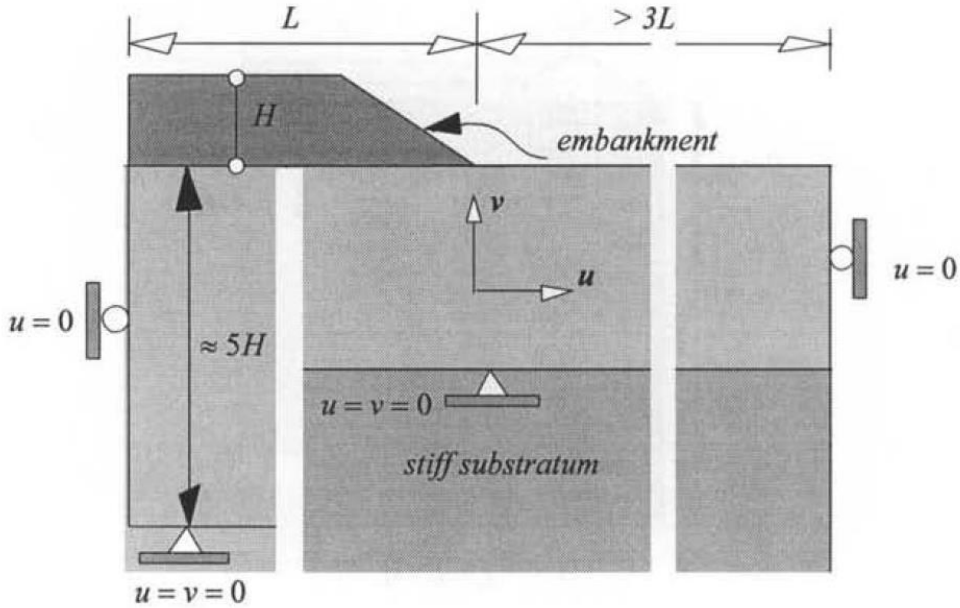


Fig 4. Boundary condition of model
Source: Azizi, 2000

The soil profile within the model is divided into six distinct layers, each with its material properties that influence the behavior of the slope. These layers are designated CL-1, CL-2, SP-1, SP-2, SP-3, and SM, each representing different types of soil or sediment encountered in the field. CL layers typically represent clayey soils with low permeability, while SP layers correspond to sand and gravel, which may have different strength and compaction characteristics. SM refers to silty soils, which exhibit intermediate behavior between clay and sand. The specific characteristics of each soil layer, such as cohesion, friction angle, and density, are crucial for determining how the soil will respond to external forces, including the added groyne and embankment structures.

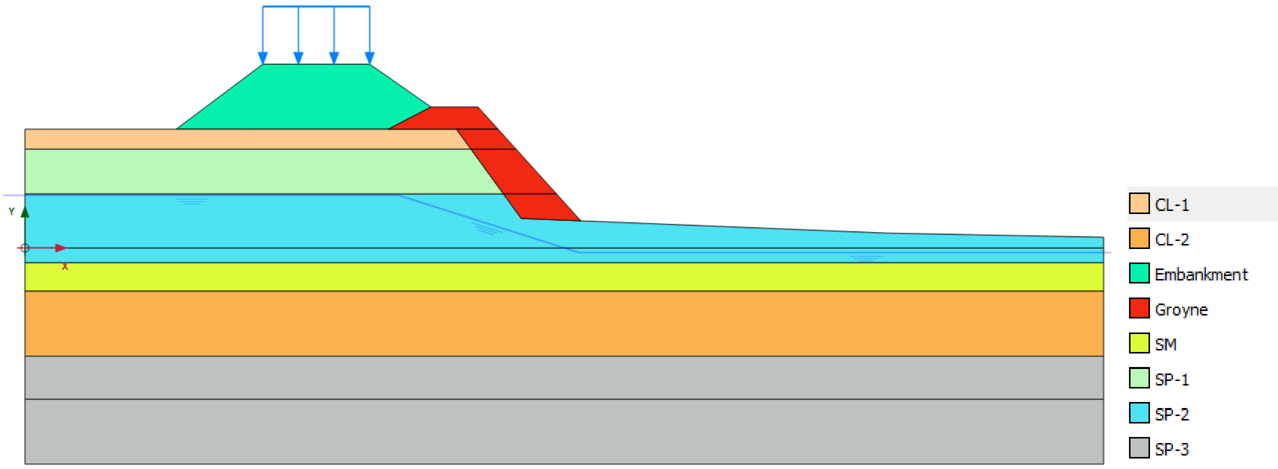


Fig 5. Plaxis model
Source: Plaxis

Table 1 provides a detailed list of input values for the soil, groyne, and embankment parameters. These values are primarily based on field data collected from site investigations, ensuring that the model accurately reflects the real-world conditions of the project area. In cases where direct field measurements were unavailable or insufficient, some parameters were derived using correlation values from established soil mechanics literature or similar projects. This approach ensures that all relevant factors are incorporated into the model, providing a comprehensive understanding of how the slope will behave under various loading conditions. These parameter inputs are critical for ensuring the reliability and accuracy of the Plaxis model in predicting the stability of the slope under specified conditions.

Table 1 Parameter Input

No.	Parameter Input	Soil						Groyne	Embankment
		CL-1	CL-2	SP-1	SP-2	SP-3	SM		
1	Material Model	MC	MC	MC	MC	MC	MC	LE	MC
2	Drainage type	U	U	D	D	D	D	-	D
3	γ_{unsat} (kN/m^3)	16	18	17.44	17.54	17.91	17.74	22	18
4	γ_{sat} (kN/m^3)	16	18	18.44	18.54	18.91	18.74	22	19
5	$E_u (kN/m^2)$	6250	6000	10720	18380	6894	3830	200000	50000
6	ν_u	0.49	0.49	0.33	0.35	0.35	0.35		0.39
7	$c_u (kN/m^2)$*	25	24	5	10	2	5		66
8	ϕ'**	-	-	27.96	31.97	25.39	22.75	-	10

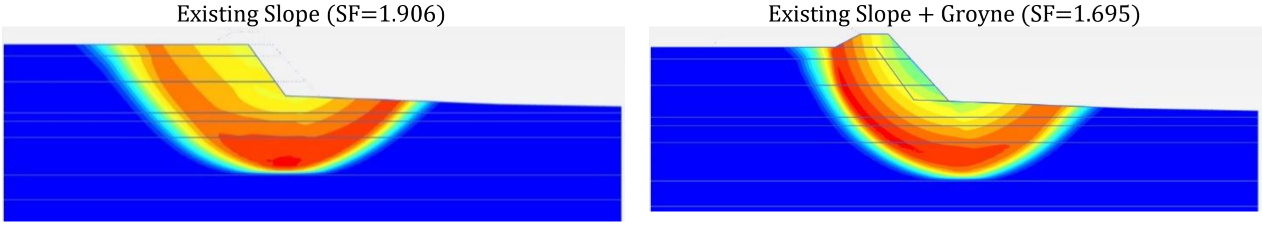
*Terzaghi and Peck, 1967
**DeMello, 1971

Source: Field and correlation data

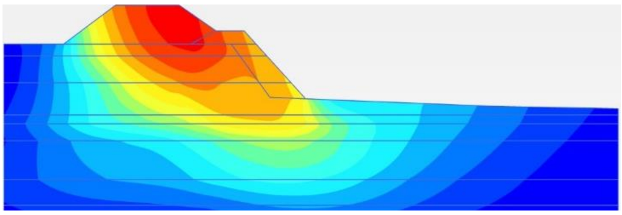
3. Result and Discussion

The calculation of model stability is conducted by the construction stages that were defined earlier in order to assess the feasibility and safety of slope structures under varying conditions (illustrated in Figure 6). This modeling approach involves a step-by-step analysis of four distinct construction stages, each representing a different development and testing phase.

Existing Slope (SF=1.906) Existing Slope + Groyne (SF=1.695)



Existing Slope + Groyne + Embankment (SF=1.285)



Existing Slope + Groyne + Embankment + Traffic Load (SF=1.241)

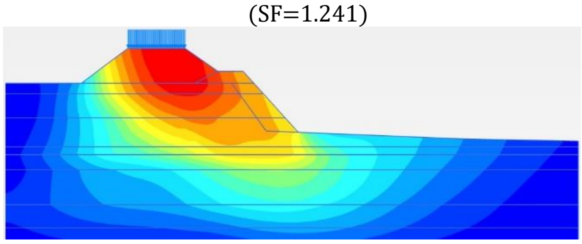
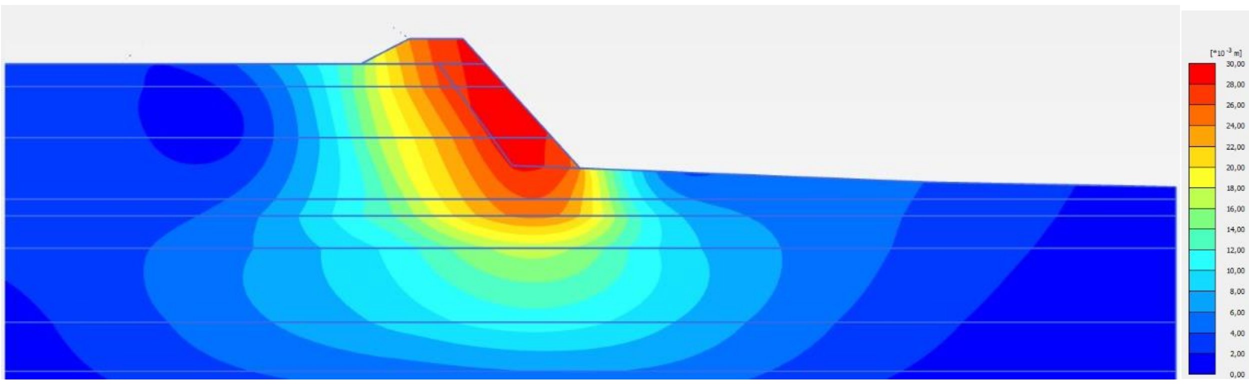


Fig 6. Changes in safety numbers at each stage of construction
Source: Plaxis

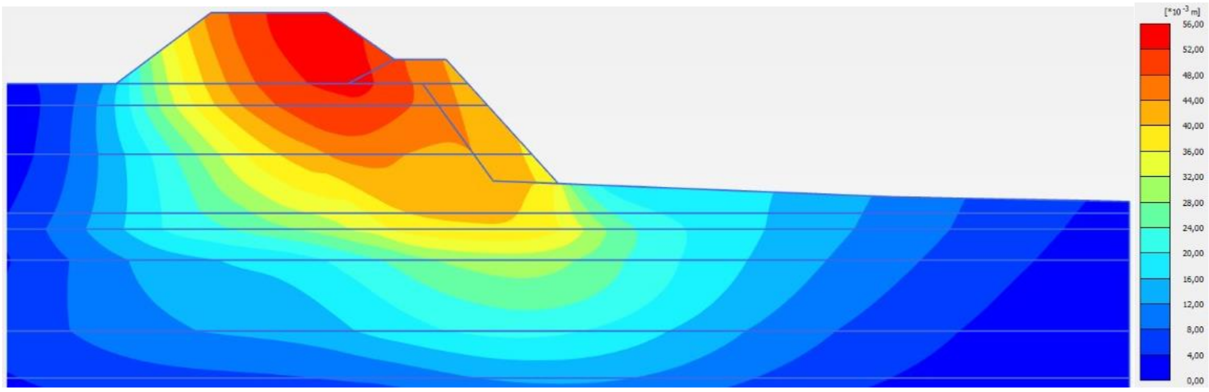
The first stage involves evaluating the stability of the existing slope, where the slope's initial condition is analyzed without any added structures or external loads. This provides a baseline measurement of its natural stability. In the second stage, a groyne structure is introduced to assess its influence on the slope's stability. Groyne structures are commonly used to manage water flow and can significantly affect the slope's integrity by reducing erosion and destabilizing forces. In the third stage, the addition of a road embankment is considered. This embankment, which supports road construction, adds extra weight and pressure to the slope, which can alter its stability. The final stage examines the slope with all previous additions—the groyne, road embankment, and the introduction of traffic load. The added load from traffic increases the external forces acting on the slope, further challenging its stability.

The results from the modeling analysis show a clear progression of stability changes: for the existing slope, the stability number is 1.906, indicating a relatively safe condition. However, after adding the groyne structure, the stability number decreases to 1.695, suggesting a slight reduction in safety. When the road embankment is added, the stability number decreases to 1.285, reflecting the increased load from the embankment. Finally, with the introduction of traffic load, the stability number drops to 1.241 which mean not required the limit of safety number according to SNI 8460 2017[15], indicating a significant reduction in slope safety due to the combined effects of additional structures and external loads. These results highlight the importance of considering all factors, including structural additions and traffic loads, when evaluating the long-term stability of slopes.

Existing Slope + Groyne (Settlement: 3.4 cm)



Existing Slope + Groyne + Embankment (Settlement: 5.8 cm)



Existing Slope + Groyne + Embankment + Traffic Load (Settlement: 6.3 cm)

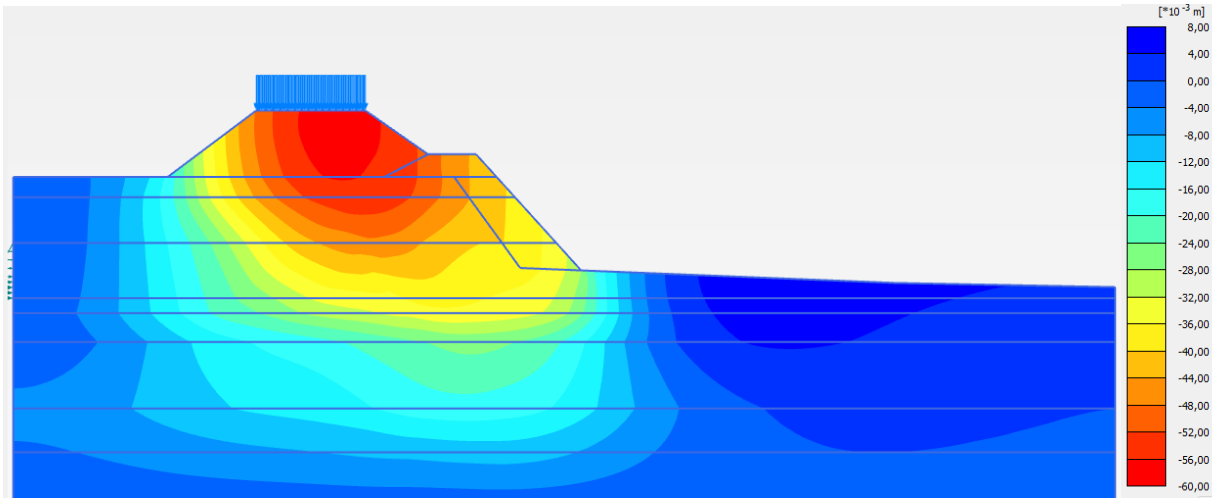


Fig 7. Settlement at each stage of construction

In addition to assessing the stability of the soil, a complete simulation utilizing the Plaxis model was employed to investigate the ground settlement. This model helped predict the behavior of the ground under different construction phases. Following the initial phase, which comprised adding a groyne structure to the existing soil, 3.4 cm of subsidence was noted, per the simulation results. Although the purpose of this groyne was to stabilize the area and change the water flow, it also somewhat settled the nearby soil. Following this, a road embankment was constructed behind the groyne, further contributing to the settlement and increasing the subsidence to 5.8 cm. The embankment added weight to the soil, causing further compression and settlement. Finally, when a traffic load was applied to the road embankment, the settlement increased even more, reaching a total of 6.3 cm. This last increase in subsidence was anticipated as the traffic load put a great deal of strain on the soil structure, further compressing it. The Plaxis model shed important light on how various construction phases added up and how the ground behaved overall under different stresses.

4. Conclusion

The stability and general behavior of the soil are greatly impacted by the addition of groyne and embankment constructions. The safety factor, which gauges the soil's resistance to failure, is among the most noticeable outcomes. The safety factor shows how safe the soil is from possible collapse or instability. In this case, the safety factor decreases from 1.906 to 1.241 when the groyne and embankment components are added. This decline suggests that the soil is becoming less stable due to the added weight and changed soil dynamics caused by these structures. A lower safety factor indicates a higher likelihood of soil failure, requiring additional measures to ensure stability in the long term.

Furthermore, the addition of the groyne and embankment structures causes observable modifications in the settling behavior of the soil. Initially, a subsidence of 3.4 cm is observed after the groyne is added to the existing soil. This settlement amount increases to 5.8 cm when the embankment is constructed behind the groyne, indicating that the added weight from the embankment further compresses the soil. Finally, with the application of traffic loads on the embankment, the settlement reaches 6.3 cm. When taken as a whole, the decline in safety factors and the rise in settlement emphasize how crucial it is to carefully oversee the design and construction of groyne and embankment structures in order to preserve the soil's stability.

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