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Retaining Structures in Slope Stabilization: A Comparative Analysis on Safety and Cost Effectiveness

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ABSTRACT

This study aims to investigate the safety and cost-effectiveness of different retaining structures, namely gravity stone walls, reinforced concrete cantilever walls, and pile shoring systems, in the stabilization of slopes with varying excavation depths. A parametric model was developed and analyzed using PLAXIS 2D (based on the finite element method) and İstCAD software (based on limit equilibrium principles in accordance with the Turkish Seismic Code, TBDY-2018). The results revealed that gravity stone walls are the most economical solution for excavation depths up to 5 meters. For intermediate depths (5–9 meters), cantilever retaining walls offer a more feasible and structurally efficient alternative. ıt shows that beyond 9 meters, traditional retaining systems become insufficient in terms of both stability and displacement limits, necessitating the use of pile shoring systems. The study provides a comparative assessment of these solutions, considering safety factors, lateral displacements, construction costs, and field applicability. These findings offer practical guidance for engineers in selecting optimal stabilization strategies under varying project constraints.

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1. Introduction

Rapid urbanization driven by global population growth has led to a significant increase in the demand for residential and infrastructural development, particularly in geologically challenging terrains such as slopes. In many countries characterized by rugged topography, this demand has resulted in the expansion of settlements onto unstable slopes, thereby escalating the risk of geotechnical hazards such as landslides. Consequently, various construction activities, including residential buildings, industrial facilities, dams, and transportation infrastructure, have increasingly encroached upon geotechnically sensitive areas. As a result of the increase in construction on the slopes, an increase in the danger and risk of landslides has also been observed. Several human-induced factors contribute to slope instability in such areas, including excavations, steepened slopes, accumulation of excavation waste, construction of tall buildings, increased pore water pressure due to inadequate drainage, and damage to natural

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vegetation. In addition, natural disasters such as earthquakes and volcanic activity serve as major triggers for landslide events in slope regions. Another problem of the issue is that landslide and/or landslide risk areas are given construction permits without sufficient research due to political and financial situations or public insistence. The increase in landslides in Turkey and the world shows the importance of the issue and the necessity of increasing studies by benefiting from current approaches in slope stabilization methods [1]. Landslide events that occur every year in Turkey cause serious loss of life and property, and this situation requires more research on the prevention and management of landslides [2].

Turkey's geographical and geological characteristics, including active fault lines, steep topography, and irregular rainfall patterns, render it particularly susceptible to landslides. When all these reasons come together, slope failures are inevitable and sometimes life and property security are under threat. When looking at the statistics of natural disasters in Turkey, losses caused by landslides are second after earthquakes [2], [3]. It is extremely important to conduct risk and priority analyses of landslides that occur due to these adverse morphological, topographic, geological and meteorological conditions and to establish permanent security in problematic slopes [4], [5], [6].

Various engineering techniques have been developed to mitigate slope instability, ranging from traditional retaining walls to advanced reinforcement systems [7], [8], [9], [10], [11]. In the context of slope stability analysis, both Limit Equilibrium Methods (LEM) and Finite Element Methods (FEM) are widely used to evaluate the effectiveness of various reinforcement techniques, including the use of anti-slip piles [12], [13], [14], [15]. The Limit Equilibrium Method remains a widely accepted approach due to its simplicity and ease of application. The method allows calculating the factor of safety against sliding by analyzing the surfaces of possible failures within the slope. However, LEMs have limitations, especially in their inability to account for complex interactions between the soil and structural elements such as piles, which can significantly affect stability [16]. Some studies in the literature highlight the advantages of integrating finite element analysis with limit equilibrium methods to increase the accuracy of slope stability assessments [16], [17]. Furthermore, recent studies emphasize that 3D finite element methods provide a more detailed understanding of the behavior of pile-reinforced slopes, as they can model the complex interactions between soil and reinforcement structures [9], [18].

Within the scope of this study, a model slope geometry was defined for conducting slope stability analyses. The soil profile and material model parameters were kept constant across all simulations to ensure consistency. Three types of retaining structures, gravity stone walls, reinforced concrete cantilever walls, and pile shoring systems, were designed for varying excavation heights and analyzed through multiple iterations. Numerical simulations were performed using PLAXIS, a finite element-based software commonly employed in geotechnical engineering. Following these analyses, structural stability checks, reinforced concrete design, and quantity estimations were carried out using İstCAD, in accordance with the Turkish Building Earthquake Code (TBDY-2018). Additionally, overall structural safety was assessed via equivalent static limit equilibrium analyses based on the slice method, also implemented in İstCAD. The resulting safety factors were then compared with those obtained from PLAXIS simulations to evaluate consistency and reliability between the two approaches.

2. Material Method

2.1. Model Slope and Engineering Properties

To evaluate the performance of gravity stone walls, reinforced concrete cantilever retaining walls, and pile shoring systems used in stabilizing problematic slopes, a representative model slope was created using PLAXIS software. Figure 1a presents the geometry and coordinates of the modeled slope, while Table 1 summarizes the associated soil properties and engineering parameters. Prior to excavation, slope stability analyses were conducted in PLAXIS. The factor of safety was calculated as 2.255 under static conditions (Figure 1b) and 1.479 under seismic loading using pseudo-static analysis (Figure 1c).

Table 1.
Soil material and engineering properties of the model slope.

Material Model	**Drainage Condition**	γ_{unsat} **kN/m^3**	γ_{sat} **kN/m^3**	**Effective Elasticity Modulus, E' (kPa)**	**Effective Poisson's Ratio, ν'**	**Effective Cohesion, c' (kPa)**	**Effective Internal Friction Angle, ϕ'**	**Dilatation Angle, Ψ**	**Horizontal/Vertical Permeability Coefficient, kx,ky (m/day)**
MC	Drained	16,50	18,50	20.000	0,35	7	31^o	1^o	0,0001

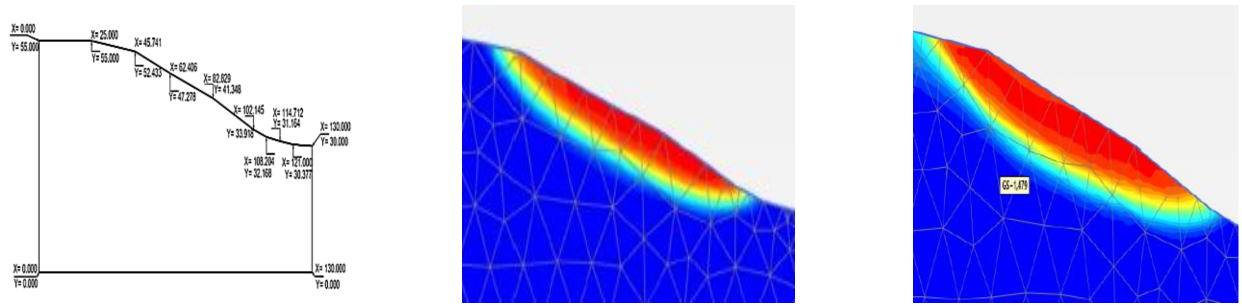


Figure 1. a. Model slope geometry and coordinates. b. Slope safety factor for static condition before excavation. c. Slope safety factor for seismic condition before excavation

In the model slope analyses, the soil profile and strength parameters were kept constant. An external load of 75 kN/m was entered for a length of 17 m starting from 5 m from the edge of the slope at the top. In order to obtain a flat area on a parcel with a sloping surface, different bearing structures were designed for the situations that occurred by advancing with 2 m gradual excavations from the two area of the model slope. The material from the excavation was used in the backfill.

3. The Research Findings and Discussion

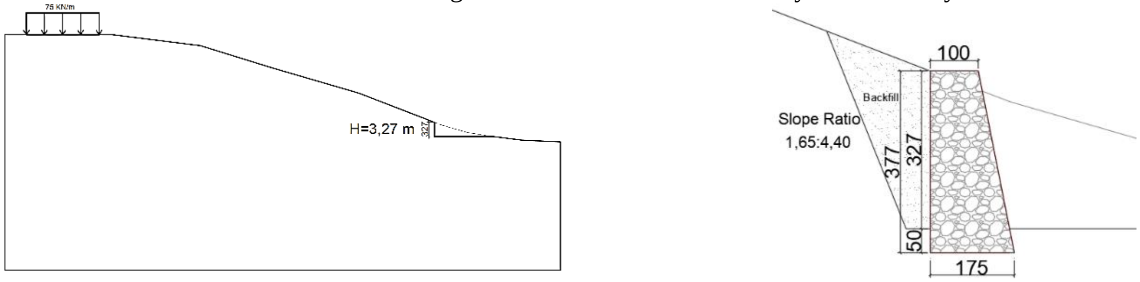
3.1. Slope Stability Analyses and Engineering Interpretations

Slope stabilization represents a critical and complex challenge in contemporary geotechnical engineering. In particular, excavation activities in sloped terrains necessitate the use of reliable and sustainable structural systems to prevent slope failure and mitigate associated risks. Various stabilization techniques have been developed to address this issue, among which gravity retaining walls, reinforced concrete cantilever walls, and pile shoring systems are commonly employed [19], [20], [21], [22]. TBDY-2018 Stability of Slopes Under Earthquake Effects regulations 16.13.7 states that "Slope stability control under earthquake effect can be done by equivalent static limit balance analyses, finite element method or dynamic behavior analyses to be performed in the time domain". In this study, slope analyses were performed using the pseudo-static analysis method in the Plaxis 2D software based on the finite element method.

In this study, a comprehensive slope stability analysis was conducted using a model slope subjected to six successive excavation stages. Each stage resulted in a reduction in overall stability, necessitating the implementation of appropriate retaining structures. Gravity retaining walls, reinforced concrete cantilever walls, and pile shoring systems were designed for different excavation depths, and their performance was comparatively assessed in terms of both structural stability and construction cost. In the simulations, stability was restored at each excavation depth using the aforementioned systems. These solutions were systematically evaluated to identify the most efficient method for each case. While literature provides a general guideline for pseudo-static slope stability analyses, it does not define a universally accepted value for the horizontal seismic coefficient. Based on a review of related studies [13], the horizontal coefficient (kh) is typically selected within the range of 0.10–0.20. In this study, a value of kh = 0.15g was adopted for seismic loading scenarios. Structural stability checks for gravity and cantilever walls were carried out using the İstCAD software, following the requirements of the Turkish Building Earthquake Code (TBDY-2018). These checks included sliding, overturning, and bearing capacity, along with reinforced concrete design and quantity estimations.

First of all, excavation was started by making a slope ratio of 1.65:4.10 on the model slope (Figure 2 a). It was seen that the slope safety number was 1.086 for the post-excavation situation (Figure 2b). In order to keep the slope safe, a stone wall with a base of 175 cm, a top of 100 cm wide and a height of 377 cm was modeled (Figure 2 a) and a slope analysis was performed by backfilling behind the wall (Figure 2 c). As a result of the analysis, the safety number of the slope was 1.769 for the static situation (Figure 3.7) and 1.281 for the earthquake situation (Figure 2 d). Analyses were made to ensure the stability of the slope with a reinforced concrete cantilever retaining wall for this excavation height, and it was revealed that stability could be achieved with a retaining wall with a foundation width of 200 cm, a body height of 327 cm, and a total wall height of 357 cm (Figure 3).

The model slope toe area was planned to open a flat area and continued from the same level with excavations up to 5.00 m, and its stability was disrupted due to the increasing excavation height, and the slope was made safe again by designing a stone wall and a cantilever retaining wall as a support structure that can safely hold the slope. The analyses show that the slope will be stable with a stone wall of 262 cm, a top of 125 cm wide, a height of 550 cm (Figure 4) and a reinforced concrete cantilever retaining wall with a foundation width of 350 cm, a body height of 500 cm, and a total wall height of 540 cm (Figure 5), and shoring was not needed for this height of excavation in terms of both stability and economy.



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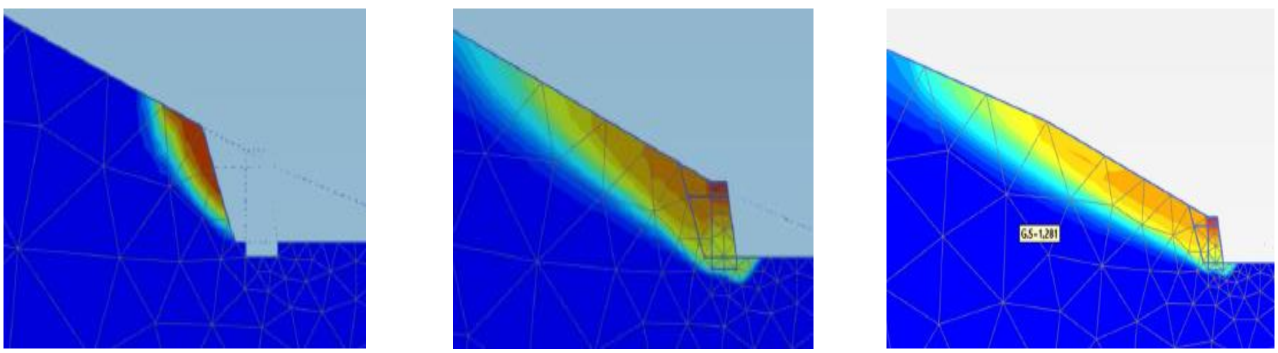
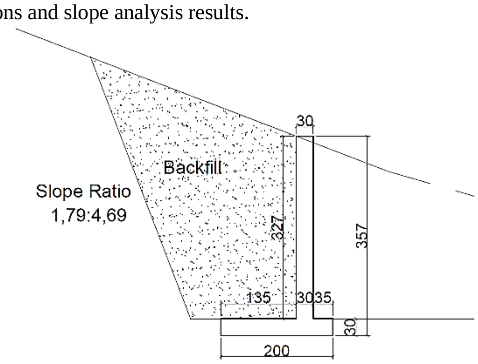


b. Slope analysis for post-excavation situation

c. H= 3.77 m Safety factor for the static case in the solution with the stone wall.

d. H= 3.77 m Safety factor for the seismic case in the solution with stone wall.

Figure 2. H= 3.77 m gravity stone wall dimensions and slope analysis results.



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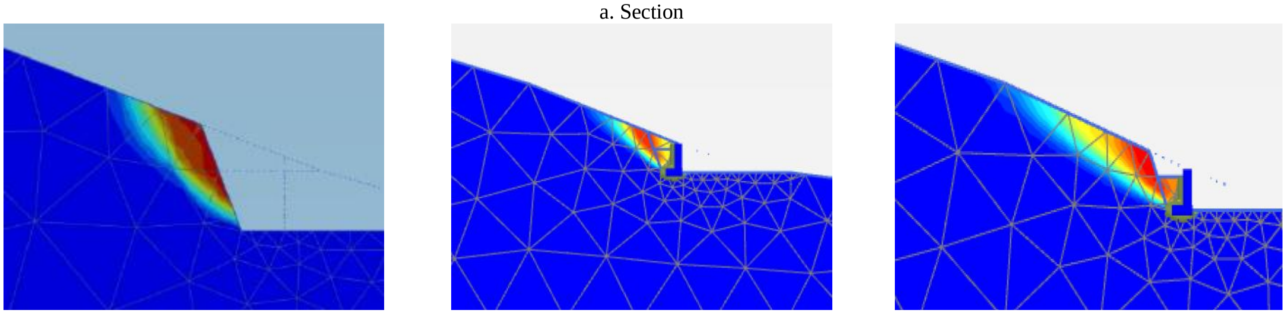
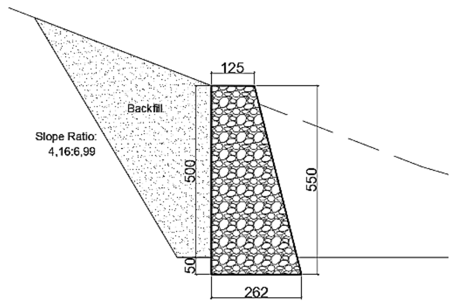


b. Slope analysis for post-excavation situation.

c. H= 3.57m Solution with cantilever retaining wall and full backfill.

d. H= 3.57m Solution with cantilever retaining wall and gradual backfill.

Figure 3. H= 3.57 m cantilever retaining wall dimensions and slope analysis results.



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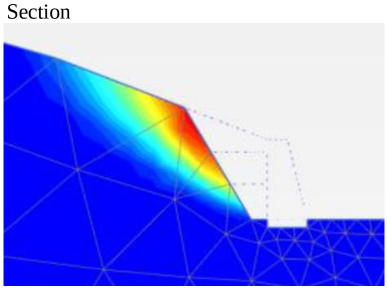
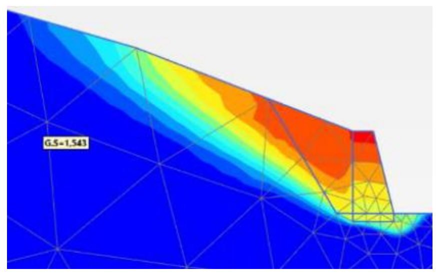
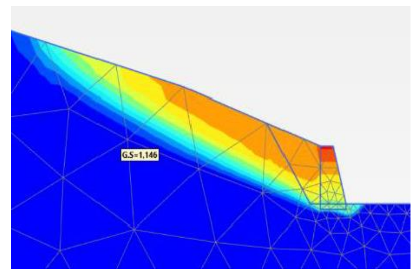




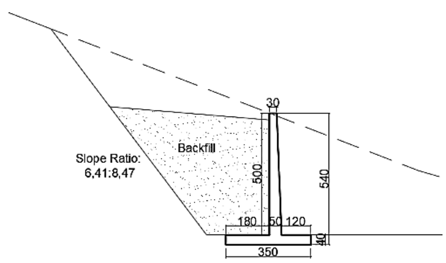


b. Slope analysis for post-excavation situation

c. Static case slope stability analysis in solution with H= 5.50 m stone wall.

d. Slope stability analysis for earthquake case in solution with H= 5.50 m stone wall.

Figure 4. H= 5.50 m gravity stone wall dimensions and slope analysis results.



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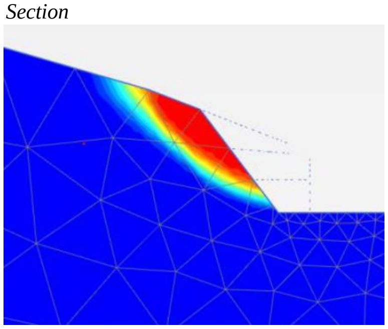
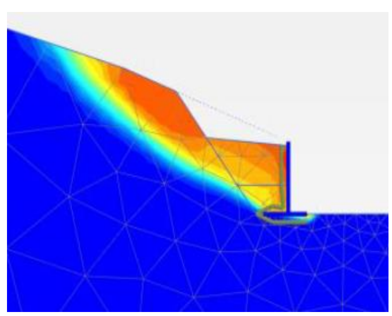
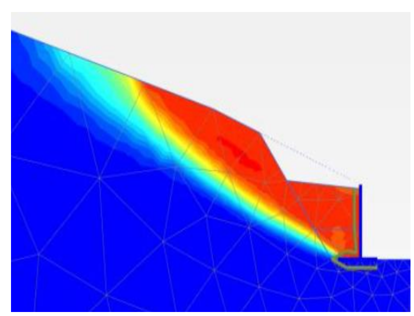






b. Slope analysis for post-excavation situation

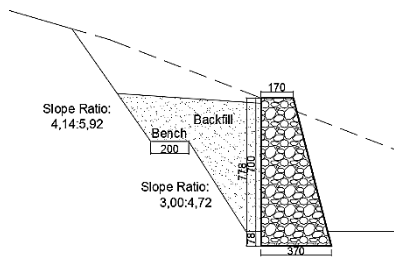
c. Static state slope analysis in solution with H= 5.40m console wall.

d. Slope analysis of earthquake case in solution with H= 5.40 m console wall.

Figure 5. H= 5.40 m cantilever retaining wall dimensions and slope analysis results.

In order to open a flat area in the toe area of the slope, the stone wall and the console retaining wall were first examined as the support structure that could safely hold the 7.00 m vertical height with the excavations planned and continuing from the same level (Figure 6a, 7a). As seen in Figure 6a, 7a, the slope was graded with a 3.00:4.72 excavation, 2 m berm in between, and a 4.14:5.92 excavation. It was observed that the slope safety number for the post-excavation situation was 1.022 (Figure 6b, 7b). When the entire backfill was filled at the natural angle of the slope, sufficient safety could not be provided in the static and seismic situations. Sufficient stability was provided in the solution created by making a step in the backfill by adding the stability-enhancing effect of the slope stepping (Figure 6c, 6d, 7c, 7d).

In order to open a flat area in the toe area of the slope, primarily the stone wall, cantilever retaining wall and pile shoring system were examined for the problems encountered in the application with the increasing height, safety and cost comparisons as a retaining structure that can safely hold the 9.00 m vertical height with the excavations continuing from the same level (Figures 8a, 9a, 10a, 11a). It was observed that the slope safety number was 1.05 for the situation after the excavation (Figures 8b, 9b). As a result of the solutions made with the stone wall and cantilever retaining wall by grading the backfill, a sufficient safety situation was reached (8c, 8d, 9c, 9d). An evaluation was made with Ø80 cm diameter tangential pile shoring for the same height (Figure 10b), it exceeded the sufficient safety number (Figure 10c) but the maximum value of pile lateral displacement was exceeded (Figure 10d). For this reason, for the same excavation height, a solution was made again for the Ø100 cm diameter tangential pile shoring system (Figure 11a), and the lateral displacement and safety factor values in Figures 11 c and 11 d were found to be within the acceptable range.



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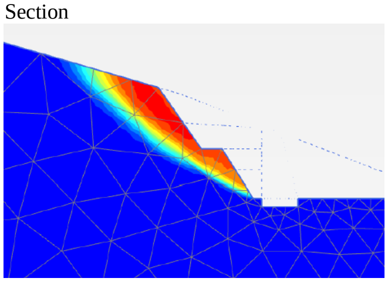
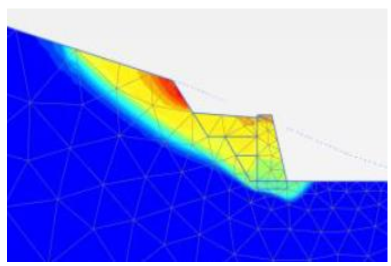
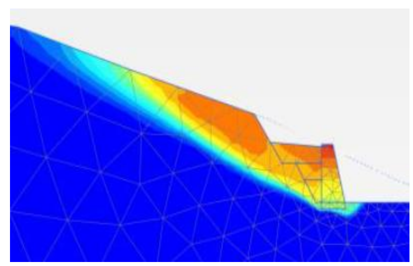


b. Slope analysis for post-excavation situation

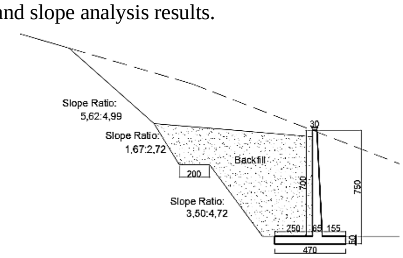


c. Static case slope stability analysis in solution with H= 7.78 m stone wall.



d. Slope stability analysis for earthquake case in solution with stone wall at H= 7.78 m.

Figure 6. H= 7.78 m gravity stone wall dimensions and slope analysis results.



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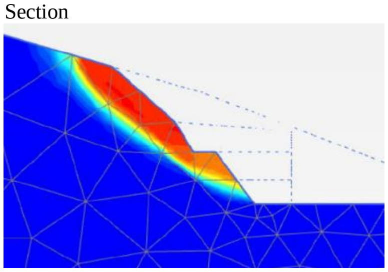
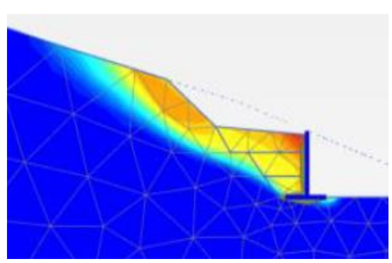
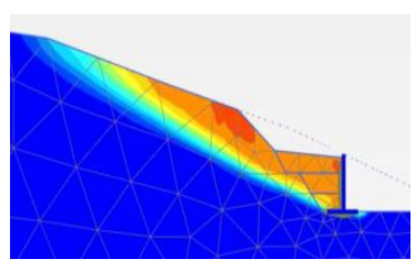


b. Slope analysis for post-excavation situation

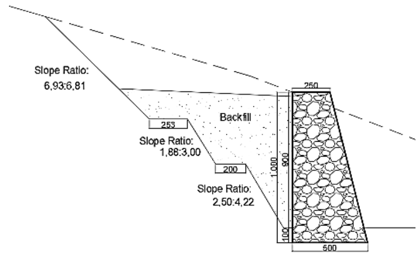


c. Static case slope analysis in solution with H= 7.50m console wall.



d. Seismic case slope analysis in solution with H=7,50m console wall

Figure 7. H= 7.50 m cantilever retaining wall dimensions and slope analysis results.



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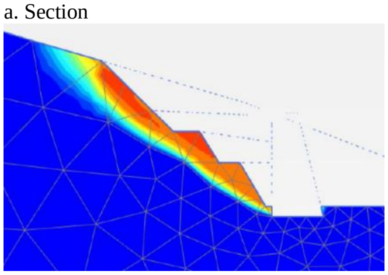
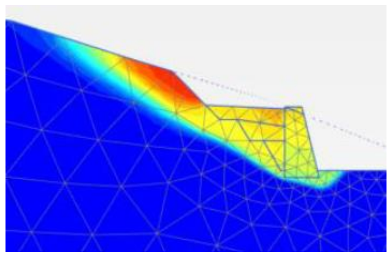
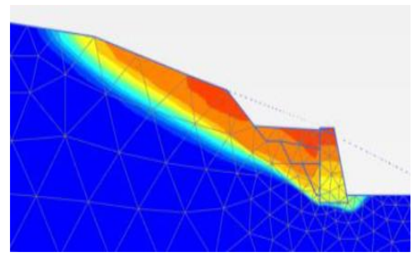


b. Slope analysis for post-excavation situation

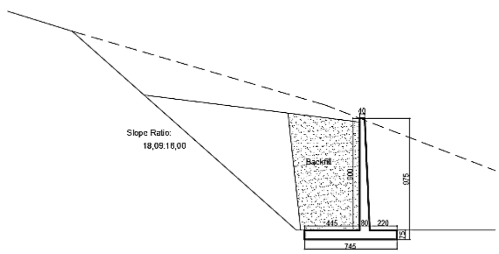


c. Static case slope stability analysis in solution with H= 10.00 m stone wall.



d. Slope stability analysis in earthquake case with H= 10.00 m stone wall solution.

Figure 8. H= 10.00 m gravity stone wall dimensions and slope analysis results.



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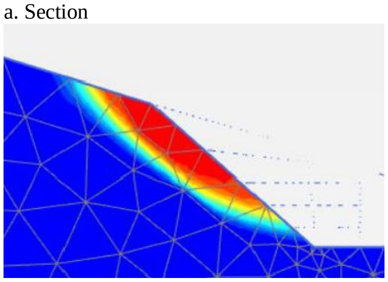
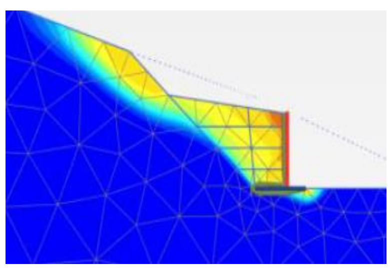
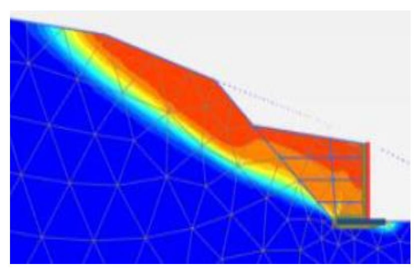


b. Slope analysis for post-excavation situation

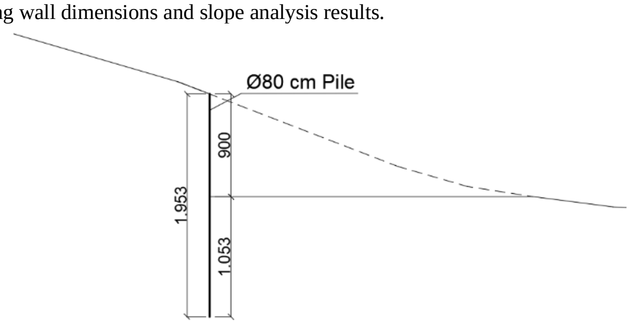


c. Static case slope analysis in solution with H= 9.90 m console wall.



d. H= 9.90 m Seismic situation slope analysis in solution with console wall.

Figure 9. H = 9.90 m cantilever retaining wall dimensions and slope analysis results.



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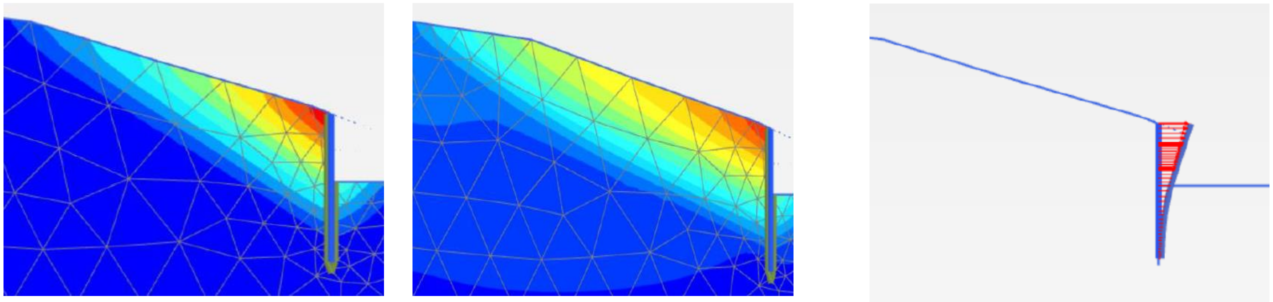
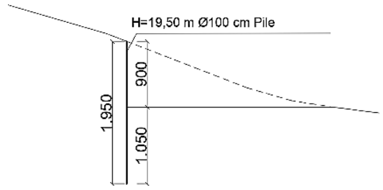


b. H= 19.50 m. Ø 80 cm tangent pile static condition slope analysis.

c. H= 19.50 m Ø 80 cm tangent pile earthquake case slope analysis.

d. Lateral displacements in pile element in Plaxis software.

Figure 10. H=19.50 m Ø 80 cm tangent pile dimensions and slope analysis results.



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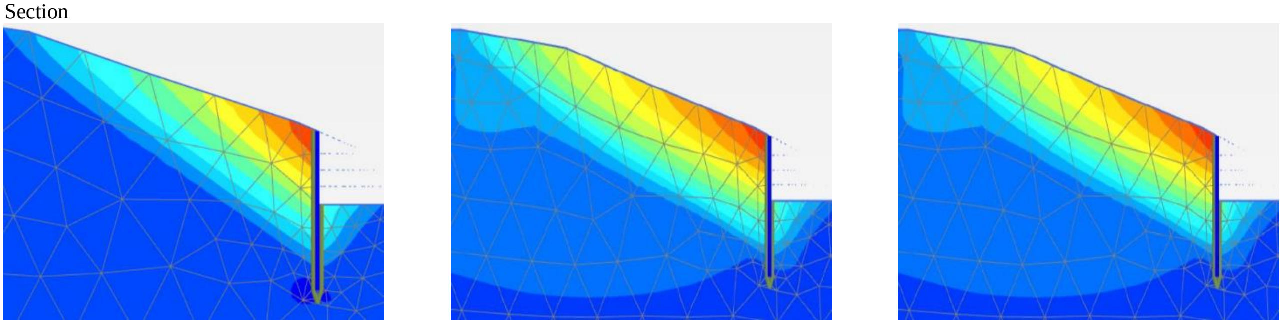
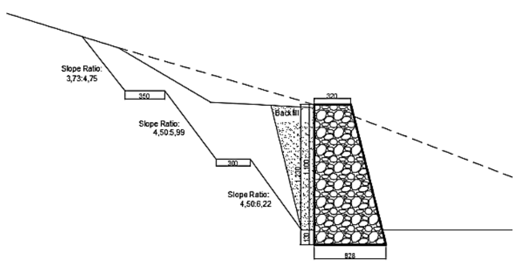


b. H= 19.50 m Ø100 cm tangent pile static condition slope analysis.

c. H= 19.50 m Ø100 cm tangent pile earthquake case slope analysis

d. Figure 11. H=19.50 m Ø 100 cm tangent pile dimensions and slope analysis results.

Figure 11. H=19.50 m Ø 100 cm tangent pile dimensions and slope analysis results.



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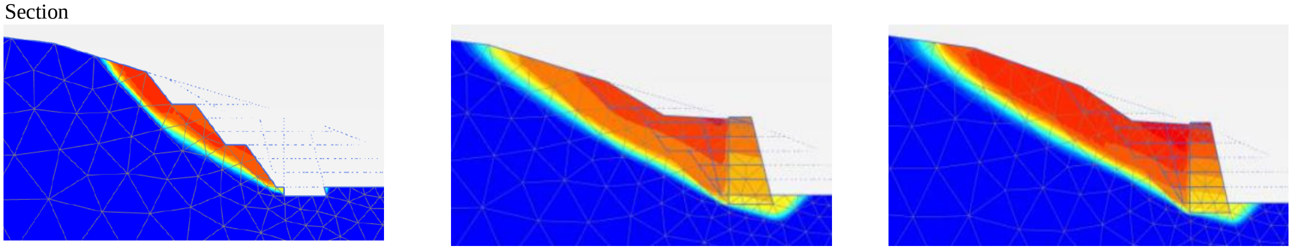


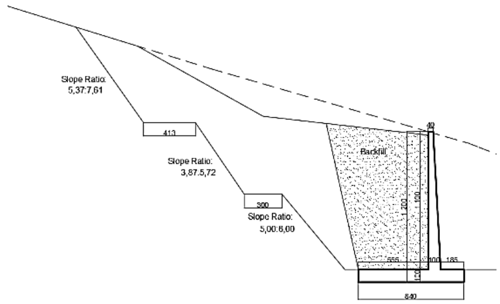
b. Slope analysis for post-excavation situation.

c. Static case slope stability analysis in solution with H= 12.30 m stone wall.

d. Slope stability analysis for earthquake case in solution with stone wall at H= 12.30 m.

Figure 12. H= 12.30 m gravity retaining wall dimensions and slope analysis results.

At the same level, the excavation depth was increased to 11 m and a solution was achieved with stone wall, console retaining wall and pile shoring system (Ø 100 cm tangential pile size) (Figures 12a, 13a, 14a, 15a). As a result of the analyses, sufficient stability could not be provided for the determined solution systems (12 b,c, 13c,d, 14 c,d). However, when the pile diameter was increased to Ø 120 cm (Figure 15b) for the same excavation height, the stability conditions were provided (Figures 15c, 15d).



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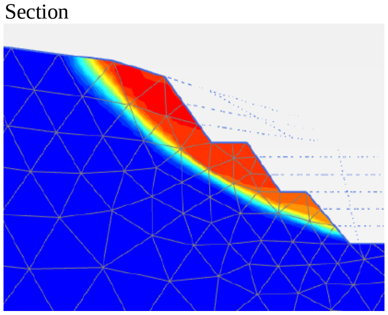
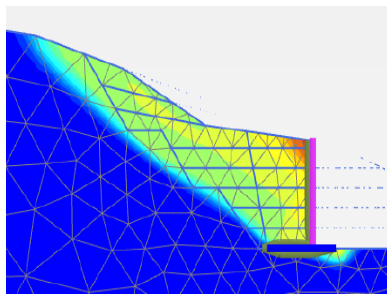

b. Slope analysis for post-excavation situation


c. Static state slope analysis in solution with H= 12.00 m console wall.

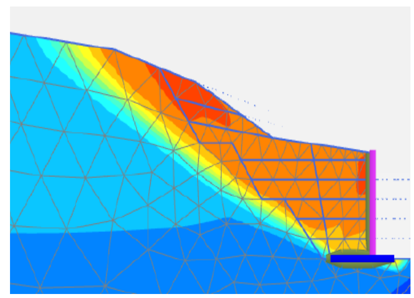
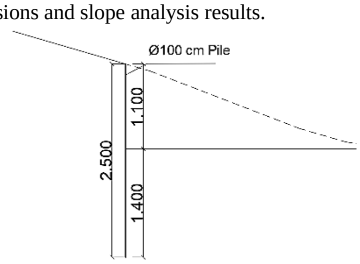
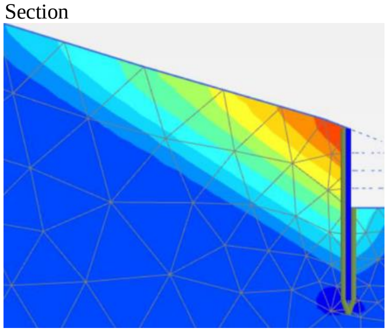
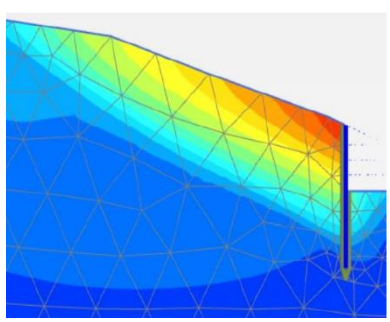

d. H= 12.00 m Seismic case slope analysis in solution with console wall.

Figure 13. H= 12.00 m cantilever retaining wall dimensions and slope analysis results.



a. Section


b. H= 25 m Ø100 cm Tangential pile plaxis static condition slope analysis.


c. H= 25 m. Ø100 cm Tangential pile plaxis analysis earthquake condition slope analysis.

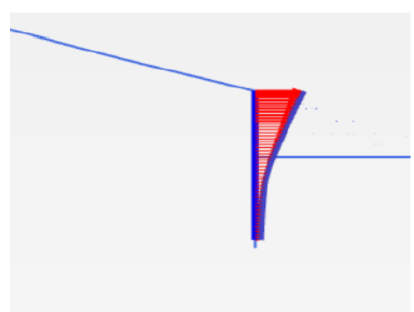
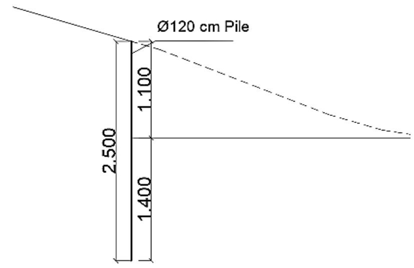
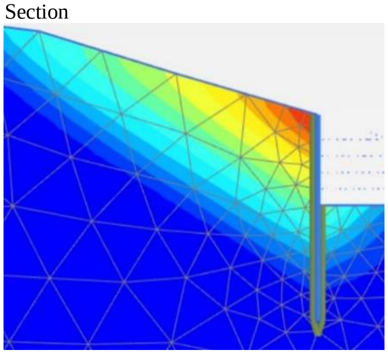
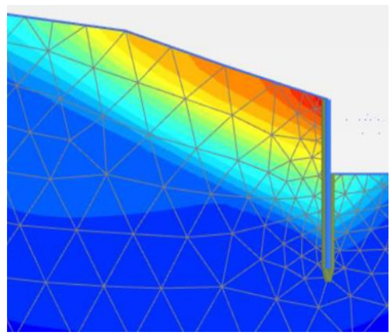

d. H= 25 m. Ø100 cm Tangential pile lateral displacements.

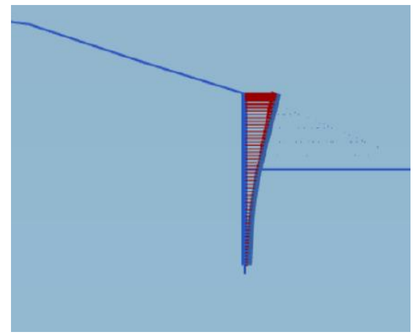
Figure 14. H=25.00 m Ø 100 cm tangent pile dimensions and slope analysis results.



a. Section





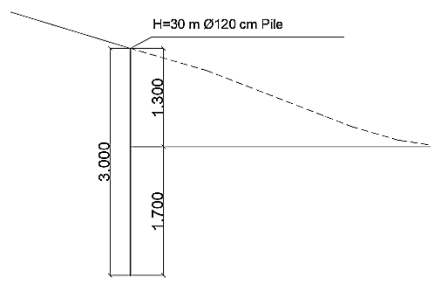


b. H= 25 m. Ø120 cm Tangential pile plaxis slope analysis for static condition.

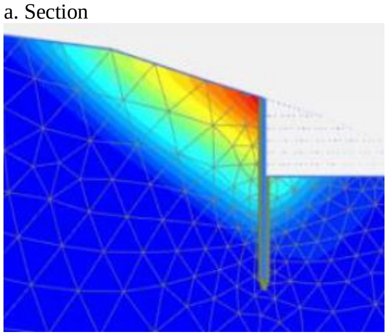
c. H= 25 m. Ø120 cm Tangential pile plaxis slope analysis for earthquake condition.

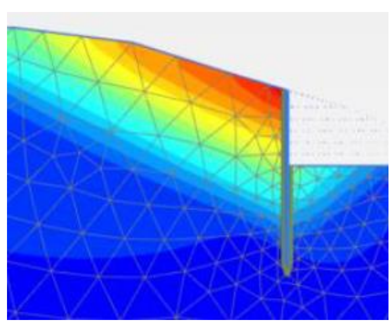
d. H= 25 m Ø120 cm Tangential pile lateral displacements.

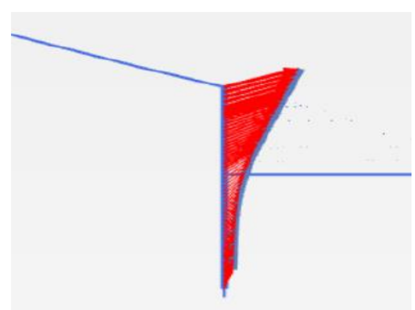
Figure 15. H=25.00 m Ø 120 cm tangent pile dimensions and slope analysis results.



a. Section







b. H= 30 m. Ø120 cm Tangential pile plaxis static condition slope analysis.

c. H= 30 m. Ø120 cm Tangential pile plaxis earthquake case slope analysis.

d. H= 30 m Ø120 cm Tangential pile lateral displacements.

Figure 16. H=30.00 m Ø 120 cm tangent pile dimensions and slope analysis results.

When the analysis was performed with the Ø120 cm diameter tangential pile shoring system (Figure 16a) as the support structure that can safely hold the vertical height of 13.00 m with the excavations continuing from the same level, the sufficient conditions could not be provided (16b, 16c, 16d). Therefore, it is necessary to examine the anchored bored pile or other prevention methods as the support structure for the excavation slope at this height.

The slope safety numbers and maximum lateral displacements of pile elements obtained from the analyses obtained from Plaxis 2D and istCAD software are given in Table 2. According to these results, it is seen that the static condition slope safety numbers are close to each other, and in the earthquake condition, the limit balance method slope safety numbers are slightly higher than the finite element method. In Project-10, while the limit balance analysis slope safety number for the Ø100 tangent pile is not sufficient for the static condition with 1.04, the safety number for the earthquake condition is a high value of 2.58. The inadequacy of the static safety number is due to the insufficient pile anchorage length in the calculation of the istCAD program. Here, the deformation calculations of the Plaxis software based on the finite element method are taken into account.

The comparison of the cost analyses of the projects is given in Table 2. When the stone and console retaining wall costs are compared; it is seen that stone walls up to 5 m in height are economical. Stone wall manufacturing is easy and fast with construction machinery. Due to their cost-effectiveness, ease of construction, and minimal technical requirements, gravity stone retaining walls are commonly preferred for slope stabilization projects involving excavation depths of up to 5 meters. Their widespread use in low-height slope applications is supported by various field investigations and numerical modeling studies, which demonstrate that such walls provide adequate stability against sliding and overturning while requiring relatively simple construction methods and materials. Furthermore, in comparison with reinforced concrete retaining structures, gravity stone walls offer faster installation, reduced labor demands, and lower material costs, particularly in rural or low-traffic areas where heavy equipment access and aesthetic integration with the environment are important considerations [23], [24]. Furthermore, even at a height of 9 meters, gravity stone walls have been found to be approximately 10% more cost-effective than cantilever retaining walls. However, despite their technical feasibility at this height, their use becomes less practical due to the significantly larger foundation footprint they require. This spatial demand often conflicts with boundary constraints in densely developed or restricted parcels, thereby limiting their application in such environments [25].

Cantilever retaining walls ranging from 5 to 9 meters in height are generally considered both cost-effective and structurally functional for moderate slope stabilization needs [26]. However, as wall height increases, construction becomes significantly more complex, leading to extended project durations and increased labor intensity [27]. Taller cantilever walls typically require dense reinforcement detailing, extensive scaffolding, and complex formwork systems to ensure structural integrity [28], [29]. Furthermore, these systems demand large-scale excavation for foundation construction, which can pose challenges in urban environments, such as permit restrictions along adjacent properties or road frontages. Excessive excavation may also compromise the stability of the slope during construction by reducing passive earth pressures and disturbing the equilibrium of the slope mass, thereby increasing the risk of localized failure. In contrast, pile-supported retaining systems do not necessitate extensive excavation, and the slope’s factor of safety typically remains unaffected during installation, making them a more stable alternative for deeper cuts[29], [30].

The bored pile shoring system offers advantages such as accelerated construction timelines and ease of implementation within restricted property boundaries. However, the cost efficiency of such systems becomes a critical consideration. For instance, a Ø100 cm tangent pile with a length of 19.50 meters, designed for a 9-meter excavation depth, incurs approximately 32% higher costs compared to a 10-meter-high cantilever retaining wall. This underscores the importance of performing a cost-benefit analysis when selecting retaining systems for deep excavations [31]. At greater slope heights, specifically around 11 to 12 meters, conventional solutions such as gravity stone walls and cantilever reinforced concrete walls begin to exhibit limitations in terms of structural performance and stability. Merely increasing the wall dimensions or concrete strength is insufficient to achieve the required safety criteria. While slope stability analyses for Ø100 cm tangent piles at these depths indicate acceptable safety factors, the lateral displacement values surpass permissible thresholds [32], [33].

To address this issue, a Ø120 cm tangent pile configuration was employed. Although this system meets the required safety factor for slopes up to 13 meters, it still exhibits lateral displacements exceeding allowable limits. Even with modifications such as increased pile length and enhanced concrete quality, displacement control remains inadequate. Consequently, alternative solutions such as anchored bored pile systems or other advanced stabilization techniques should be considered for excavation slopes at this depth to ensure both structural integrity and serviceability.

4. RESULTS

According to the data obtained as a result of the two-dimensional analyses carried out within the scope of the study, the following conclusions were reached;

Slope gravity retaining walls up to 5 meters can be preferred due to their economy and easy construction. Since the manufacturing of weight retaining walls in the range of 5-9 m is difficult, cantilever retaining walls are considered more suitable in terms of cost and functionality. Using Ø100 cm tangent piles for 9 m excavation height brings 32% higher cost compared to 10 m cantilever retaining wall. While stability problems were observed in

Table 2.
Slope numbers of finite elements and limit equilibrium methods

Supporting Structure Information				Slope Safety Number				Maximum Lateral Displacement	Construction Cost (TL)	Difference Ratio (%)
Excavation Height (m)	Project No	Supporting Structure	Supporting Structure Height (m).	Finite Elements Analysis		Limit Balance Analysis -				
				Statik Situation	Pseudo Static	Statik Situation	Pseudo Static			
3,27	Project-1	Stone Wall	3,77	1,769	1,281	1,76	1,62	---	139.925,15	34,26%
	Project-2	Cantilever Retaining	3,57	1,615	1,188	1,84	1,66	---	187.869,47	
5	Project-3	Stone Wall	5,5	1,54	1,142	1,63	1,44	---	283.558,80	33,13%
	Project-4	Cantilever Retaining	5,4	1,541	1,107	1,65	1,48	---	377.499,55	
7	Project-5	Stone Wall	7,78	1,554	1,124	1,58	1,44	---	609.041,78	12,09%
	Project-6	Cantilever Retaining	7,5	1,513	1,107	1,55	1,36	---	682.656,33	
9	Project-7	Stone Wall	10	1,606	1,14	1,63	1,46	---	1.148.363,60	10,31%
	Project-8	Cantilever Retaining	9,9	1,512	1,1	1,67	1,46	---	1.266.705,57	
	Project-9	Ø80 Tangent Pile	19,5	1,507	1,173	2,77	2,32	94	---	
	Project-10	Ø100 Tangent Pile	19,5	1,515	1,183	1,04	2,58	76,68	1.677.304,59	
11	Project-11	Stone Wall	12,3	1,526	1,092	1,53	1,35	---		32,41%
	Project-12	Cantilever Retaining	12	1,379	1,01	1,59	1,37	---	---	
	Project-13	Ø100 Tangent Pile	25	1,536	1,195	---	---	132,6	---	
	Project-14	Ø120 Tangent Pile	25	1,536	1,192	3,03	2,49	10,51	2.288.559,50	
13	Project-15	Ø120 Tangent Pile	30	1,526	1,205	---	---	193,8	---	

stone and cantilever retaining walls with a height of 11-12 meters, the use of Ø100 cm tangent piles was insufficient in terms of lateral displacement and in this case, Ø120 cm diameter piles were applied as a solution. Even for 13 meters height, the lateral displacement of Ø120 cm cantilever piles remained above the limit values and it became necessary to evaluate alternative stability measures such as anchored bored piles at this height. In this context, it is of great importance to select the optimum bearing structure by considering stability, cost and construction difficulties for each slope height.

Within the scope of the excavation works, stone wall, cantilever retaining wall and pile retaining systems were analyzed for different excavation depths and slope slopes. While stone wall and cantilever retaining wall solutions provided sufficient stability in the first stages, pile retaining systems were needed in terms of slope safety with the increase in excavation depth. Stability was provided with stone wall for excavations up to 5.00 m, and for excavations up to 7.00 m, the excavation was graded and the safety factor was brought to acceptable levels with the combination of stone wall and cantilever retaining wall. As a result of the analyses made with stone wall and retaining wall for the excavation height of 9.00 m, it was seen that stability could be provided. However, in the analyses made at the excavation depth of 11 m, it was determined that the stone wall and retaining wall solutions were insufficient and the pile retaining system was switched to. In the solution made with Ø100 cm diameter piles, the lateral displacement limit values 32% were exceeded, therefore it was determined that the stability conditions were provided with Ø120 cm diameter piles. However, it was observed that sufficient stability conditions could not be provided in the analyses made with the Ø120 cm diameter tangential pile shoring system as a support structure that could safely hold the 13.00 m vertical height with the excavations continuing from the same level. Therefore, it was revealed that anchored bored pile systems or other prevention methods should be examined for the excavation slope at this height. As a result, it was determined that stone wall and retaining wall solutions were sufficient for certain excavation depths, but in case of exceeding certain limits, it was necessary to switch to pile shoring system and to anchored pile systems at greater depths, and the most suitable engineering solution was presented by taking into account safety and economic factors.

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