Proceedings of the 9th International Conference on Civil Structural and Transportation Engineering (ICCSTE 2024)
Chestnut Conference Centre - University of Toronto, Toronto, Canada – June 13-15, 2024
Paper No. 255
DOI: 10.11159/iccste24.255

Case Slope Stability Planning and Structural Strengthening of Fuel Storage Tanks in Kalimantan, Indonesia

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Abstract **-** The slope stability planning for manufacturing fuel storage tanks in Kalimantan, Indonesia, involves various crucial steps. It begins with a comprehensive understanding of soil characteristics, including its type, pressure tolerance, and considerations for the surrounding environment. Material selection, structural design, and adherence to safety standards are paramount in ensuring the construction's safety and resilience against landslides and environmental damage. A notable challenge arises from a steep excavation slope, particularly at an elevation of +8.00 in the tank area. To mitigate risks, meticulous planning for retaining walls and similar structures becomes necessary to ensure the tank's construction and operation remain undisturbed. The research primarily analyses the slope stability between zones A and B, particularly on the western side with an elevation of +35 meters. Findings reveal that the existing conditions fail to meet the minimum safety factor requirements, indicating potential instability when applied to operational loads. Zones A and B exhibit safety factors below 1.50, suggesting a heightened risk of collapse under load. The study proposes a comprehensive reinforcement plan encompassing various stages to address these concerns. These include Soldier Pile 1 Construction, Soil Nailing, Slope Excavation at +8.0 meters, L-shape wall Construction, and considerations for Operational Loads and Earthquake Conditions (Pseudostatic). Detailed analyses of maximum bending moment and maximum deflection inform the selection and design of reinforcement components. Components such as Soldier Piles, L-shape walls, and Soil Nailing are carefully evaluated for their moment capacity and short-term and long-term deflection characteristics to meet safety requirements. Overall, the safety factor, maximum bending moment, and maximum lateral deflection values fall within acceptable short and long-term limits.

Keywords**:** Slope Stability, Safety Factor, Maximum Bending Moment, Maximum Deflection

1. Introduction

Slope stability planning involves steps to understand the type of soil, the pressure to be withstood, the surrounding environment, material selection, structural design, and the standards used [1] [2]. The aim is to determine a slope safety design that is safe and efficient in preventing landslides and damage to the environment [3] in the construction work of a Fuel Storage Tank in Kalimantan, Indonesia, which is at an Elevation of +8.00 (Fame Tank), +35.00 (Gasoline Tank), and +45.00 (Fame / Diesel Tank). Where in the tank at an elevation of +8.00, there is an excavation slope that is quite high, so it is necessary to plan retaining walls and the like so that the construction of the tank at an elevation of +8.00 can operate and not be disturbed. The analysis was carried out in two review sections, Zone A and Zone B. In each zone, the slope stability is analyzed based on the existing conditions and the conditions of the reinforcement plan. The existing condition does not meet the minimum safety factor value required when operational loads occur (SF < 1.5) in both Zone A and Zone B analysis, so the slope is less stable or has the potential to collapse when the load at an elevation of +35 m is operational. Therefore, it is necessary to strengthen this area.

Figure 1. 1 Location

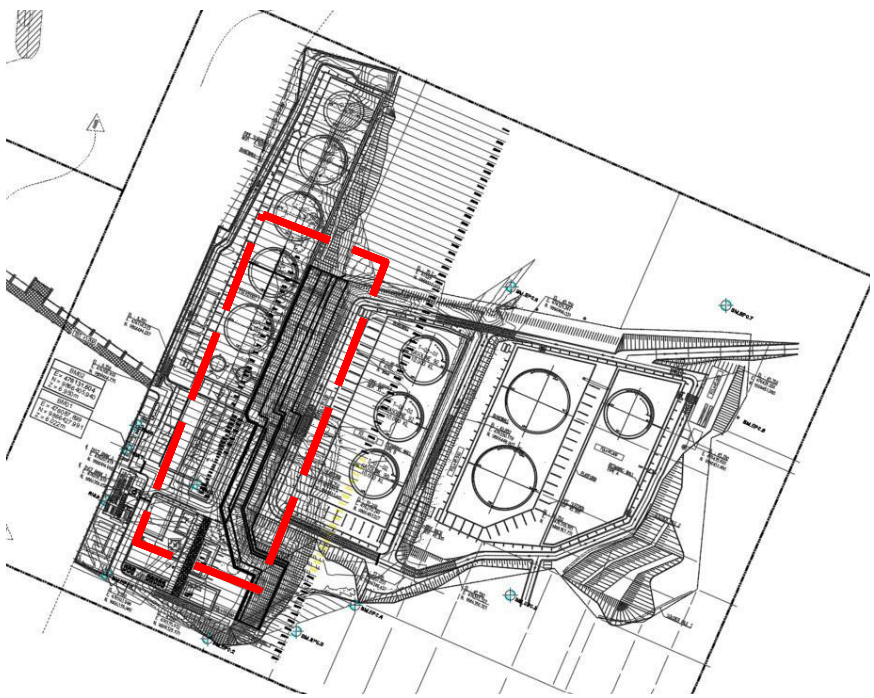

Figure 1. 2 Site Plan Land Preparation Plan

2. Review of Slope Stability Design Analysis

This slope stability planning report reviews two conditions: (1) Short-term Term Conditions using Total parameters with Undrained conditions and (2) Long Term Conditions using Effective parameters with Drain conditions. Global Stability Safety Factor has a safety number used as the minimum design limit in the Stability Analysis of the West Side Retaining Wall referring to SNI Geotechnical 8460:2017 as in the following table [4]:

Table 1. 1 Value of safety factor for soil slopes

Costs and consequences of slope failure	The level of uncertainty of the analysis conditions	
	Low	High b
The repair costs are worth the additional costs of designing more conservative slopes	1.25	1.5
The repair costs outweigh the additional costs of designing more conservative slopes	1.5	2.0 or more
The level of uncertainty in the analysis conditions is categorized as low, if the geological conditions can be understood, the soil conditions are uniform, the soil investigation is consistent, complete and logical to the conditions in the field. The level of uncertainty in the analysis conditions is categorized as high, if the geological conditions are very complex, soil conditions vary, and soil investigations are inconsistent and unreliable.		

In this planning, the stability of the retaining wall is analyzed for two conditions, namely short-term conditions (undrained) and long-term conditions (drained), so that the planner takes the safety factor values as follows:

Table 1. 2 Safety factor (SF) values used

Conditions reviewed	**SF Desain**
Construction Phase	1.25
Long-Term (Drained)	1.50
Short Term (Undrained)	1.50
Earthquake Conditions (Pseudostatic)	1.10

3. Methods for Improvement

The proposed strengthening recommendations for the stability of embankment slopes divided based on zoning, which has divided into Zone A and Zone B. Recommendations for strengthening Zone A and Zone B using strengthening structural components include (1) Soldier Pile D1200, with a concrete quality of 30 Mpa and an embedded length of 30 m (from the existing ground surface); (2) Soil Nailing D29, with primary reinforcement D29, main bone length is 12 m and 8 m; and concrete grouting quality 21 Mpa; (3) L-shape Wall, with a wall thickness of 400 mm and concrete quality of 30 Mpa.

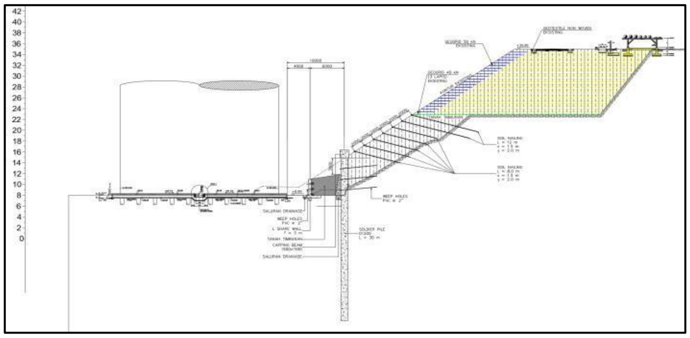

Figure A. Zone A Slope Strengthening Plan

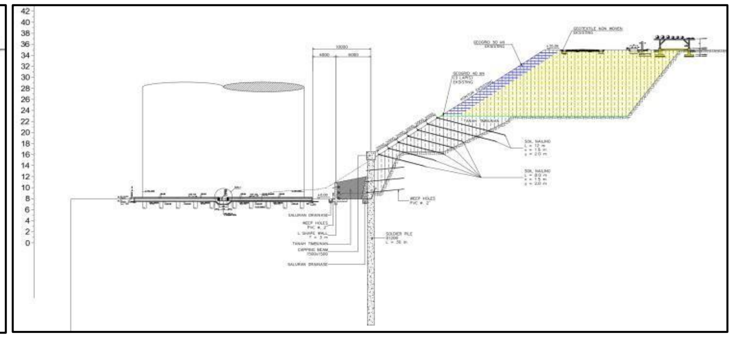

Figure B. Zone B Slope Strengthening Plan

The slope stability modeling analysis criteria for technical justification analysis of landslides on the slopes of the western side of Kalimantan, Indonesia, are as follows: (1) Modeling analysis looks at long-term and short-term conditions; (2) The land data parameters used are following the respective Zoning divisions; (3) The embankment data parameters used refer to Quarry 7 data; (4) Material input using Hardening Soil (HS) model material; (5) Input Drainage type in Short Term conditions using Undrained (B); (6) Input drainage type in long-term conditions uses a Drain.

The construction stages used to analyze slope stability in Zone A and Zone B are as follows: (1) Soldier pile construction; (2) Installing soil nailing; (3) Digging the slope up to +8.00 m; (4) L shape wall construction; (5) Operational expenses; (6) Earthquake conditions (pseudo-static).

3. Result and Discussion

3.1 Analysis of Recommendations for Strengthening Zone A Slope Stability

The analysis output shows the stress distribution that occurs, safety factor, lateral deflection, and maximum bending moment based on the construction phase reviewed and long-term and short-term conditions, which can be seen as follows

Table 3.1 Safety Factor Output Control for Zone A Slope Strengthening

SLOPE STABILITY OUTPUT CONTROL - ZONE A								
Stage Construction			**SF Short Term**			**SF Long Term**		
			SF	**SF min.**	**Check**	**SF**	**SF min.**	**Check**
Slope Strengthening Analysis	Stage 1	Soldier Pile Construction	1.405	1.25	**OK**	1.721	1.25	**OK**
	Stage 2	Soil Nailing	1.714	1.50	**OK**	2.165	1.50	**OK**
	Stage 3	Excavation Slope +8.0 m	1.702	1.50	**OK**	2.102	1.50	**OK**
	Stage 4	L-Shape Wall Construction	1.696	1.50	**OK**	2.149	1.50	**OK**
	Stage 5	Operational Expenses	1.577	1.50	**OK**	2.091	1.50	**OK**
	Stage 6	Earthquake Conditions	1.383	1.10	**OK**	1.781	1.10	**OK**

Table 3.2 Bending Moment Output Controls for Zone A Slope Strengthening

MAXIMUM OUTPUT BENDING MOMENT CONTROL – ZONE A						
No.	Reinforcement Structure	Capacity Moment	Short Term		Long Term	
			M_{Total}	Check	M_{Total}	Check
		kN.m	kN.m		kN.m	
1	Soldier Pile D1200	3728.38	1851.60	**OK**	2092.80	**OK**
2	L - Shape Wall	1262.91	34.62	**OK**	63.77	**OK**
3	Soil Nailing D29	1.21	0.79	**OK**	0.43	**OK**

Tabel 3.3 Maximum Lateral Deflection Output - Zone A

MAXIMUM LATERAL DEFLECTION OUTPUT - ZONE A							
No.	Reinforcement Structure	$H_{freestanding}$	Permit Deflection	Short Term		Long Term	
				Deflection	Check	Deflection	Check
		mm	mm	mm		mm	
1	Soldier Pile D1200	6800	34.00	12.5	**OK**	14.29	**OK**
2	L - Shape Wall	3000	15.00	8.806	**OK**	4.43	**OK**

3.2. Zone B Slope Stability Analysis (Reinforcement Recommendations)

The analysis output shows the distribution of stresses that occur, safety factors, lateral deflections, and maximum bending moments based on the construction stages reviewed and long-term and short-term conditions, which can be seen as follows:

Table 3.4 Safety Factor Output Control for Zone B Slope Strengthening

KONTROL OUTPUT STABILITAS LERENG - ZONA B								
Stage Construction			SF Short Term			SF Long Term		
			SF	SF min.	Check	SF	SF min.	Check
Slope Strengthening Analysis	Stage 1	Soldier Pile Construction	1.365	1.25	**OK**	1.689	1.25	**OK**
	Stage 2	Soil Nailing	1.737	1.50	**OK**	2.166	1.50	**OK**
	Stage 3	Excavation Slope +8.0 m	1.728	1.50	**OK**	2.135	1.50	**OK**
	Stage 4	L-Shape Wall Construction	1.733	1.50	**OK**	2.162	1.50	**OK**
	Stage 5	Operational Expenses	1.612	1.50	**OK**	2.096	1.50	**OK**
	Stage 6	Earthquake Conditions	1.383	1.10	**OK**	1.785	1.10	**OK**

Table 3.5 Maximum Deflection Output Control for Zone B Slope Strengthening

MAXIMUM LATERAL DEFLECTION OUTPUT - ZONE B							
No.	Stage Construction	Hfreestanding	Permit Deflection	Short Term		Long Term	
				Deflection	Check	Deflection	Check
		mm	mm	mm		mm	
1	Soldier Pile D1200	6800	34.00	15.89	OK	10.57	OK
2	L - Shape Wall	3000	15.00	10.03	OK	6.09	OK

Table 3.6 Bending Moment Output Controls for Zone B Slope Strengthening

MAXIMUM OUTPUT BENDING MOMENT CONTROL - ZONE B						
No.	Stage Construction	Capacity Moment	Short Term		Long Term	
			M_{Total}	Check	M_{Total}	Check
		kN.m	kN.m		kN.m	
1	Soldier Pile D1200	3728.38	2140.80	OK	2300.40	OK
2	L - Shape Wall	1262.91	34.24	OK	37.60	OK
3	Soil Nailing D29	1.21	1.20	OK	0.48	OK

4. Conclusion

From the stability analysis of the slope reinforcement in Zone A, which is reviewed based on the safety factor values, the maximum bending moment and lateral deflection are still within the allowable safe limits in long-term and long-term conditions. The stability analysis of the slope reinforcement in Zone B is reviewed based on the safety factor values, maximum bending moment, and maximum lateral deflection, which are still within the allowable safe limits in both short and long-term conditions. The slope stability strengthening plan in each planned zone is designed safely.

The author can suggest the addition of granular/gravel material behind the soldier pile as a material that can drain the groundwater stored behind the soldier pile wall. A good drainage system is needed so that water from high to low elevations does not flow wildly, which can result in erosion or landslides on the slope surface. The weep holes should be used in retaining walls and drainage channels.

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