ISSN 2229-5518

Numerical Study of Embankment Sliding on Soft Soil Using Finite Element Method

Audosira Noah [1]
Civil Engineering Faculty, Department of Geotechnical Engineering, Parahyangan Catholic University, Indonesia

Abstract—Embankments work may face a problem if it stands on relatively soft soil layer. Failure of embankment induced by soft soil layer may result in a sliding of the embankment itself. When a sliding happened, the geotehcnical engineer need to redesign the embankment so the project can keep advancing. In this scientific study, the author will conduct a back analysis using Soft Soil with Creep soil modeling on PLAXIS 2D program to determine the residual parameters on the sliding plane which occur in the field and redesign the embankment with improvement.

Keywords — Back analysis, embankment on soft soil, PLAXIS 2D, sliding.

1 Introduction

EMBANKMENT and excavation are the dominant work for construction project particularly for a toll road project. Embankment work may face a problem if it's built on top of soft soil surface. Some characteristic of soft soil are high compressibility and a relatively low undrained shear strength, this nature may result in a failure of sliding for embankment which stand atop of soft soil surface layer.

When a sliding happened at embankment, the geotechnical engineer in charge have to redesign the embankment with some improvement. This need to be done to make sure the embankment will satisfy its required performance and to account for residual soil parameter on sliding plane.

The data used for this paper is a certain project which topography consist of paddy field and plantation area with soft clay soil layer on the surface. Sliding failure has occurs at the embankment in one of the site embankment area.

In this paper, author will do a back analysis on the sliding failure with PLAXIS 2D program to determine the residual parameter of the sliding plane and redesign the embankment with some soil improvement.

2 Problem Review

The case being reviewed is a sliding of embankment atop of soft soil surface. The data gathered are secondary data from the project report of in-situ testing and laboratorium testing for undisturbed soil sample from boring test.

The topography of the area consist of mainly paddy field and plantation area which contain deep soft soil layer at the surface. From the geology map, it can be determined that the site area located at aluvium soil (Qa) deposit which contains gravel, pebble, clay, mud, and organic fragments.

The embankment build gradually with timeframe of 1 meter per 20 day, this is including the time needed for compaction of embankment. The sliding happened around 2 months after the end of construction.

The problem being reviewed are determination of soil residual parameter at sliding plane and the redesign of embankment after sliding occurs.

3 Soil Data

Soil data for this analysis obtained from 2 kind of test :

1. In-situ test / field investigation
2. Laboratory test

In-situ tests carried out at project area are boring test with SPT test, CPT, CPTu/piezocone, and DMT. For laboratory test, the tests carried out are index properties test (to determine natural water content, bulk density, specific gravity, and atterberg limit), grain size analysis, triaxial unconsolidated undrained test, and one dimensional consolidation test.

Based on the boring test, the depth of soft soil layer on this area is 12 meter which classified into silty clay soil. Soil profile obtained from boring test can be seen on Table 1.

TABLE 1
Soil Profile from Boring Test

Depth	Soil Description	NSPT (blows / 30 cm)
0.0 - 6.0	Silty clay, light grey, with a trace of sand, soft to medium density	1 - 6
6.0 - 12.0	Silty clay, dark brown, with some of organic wood, soft to medium density	2 - 6
12.0 - 23.0	Silty clay, grey to dark grey, with a trace of sand, high plasticity, medium to stiff consistency	6 - 10
23.0 - 27.5	Sand, dark grey, fine to coarse grained, uncemented, medium to dense density	29 - 41
27.5 - 32.0	Silty clay, dark grey, with trace of sand, high plasticity, stiff consistency	9 - 14
32.0 - 35.0	Sand, dark grey, with a trace of angular gravel, uncemented, very dense	50
35.0 - 40.0	Silty clay, dark grey, with a trace of little sand, high plasticity, stiff consistency	9 - 10

[1] *Audosira Noah is currently pursuing masters degree program in geotechnical engineering in Parahyangan Catholic University, Indonesia.*
E-mail: audosiranoah.s@gmail.com

And the result for undisturbed sample laboratorium test can be seen on Table 2.

TABLE 2
RESULT OF LABORATORY TESTS

Sample No.			1	2
Sample Depth, m			3.50 - 4.00	9.50 - 10.00
Specific Gravity, Gs			2.52	2.27
Liquid Limit (LL)			101.88	184.25
Plastic Limit (PL)			42.6	102.27
Index Plasticity (IP)			59.2	61.99
Wet Density, gr/cm³			1.7	1.25
Dry Density, gr/cm³			1.11	0.56
Natural Water Content, %			52.45	185.74
Void Ratio			1.28	3.05
USCS Classification			CH	MH
Visual Soil Description			Silty Clay Light Grey	Silty Clay Dark Brown
Grain Size Test	% Gravel		0	2.63
	% Coarse Sand		0.12	7.05
	% Medium Sand		1.29	1.1
	% Fine Sand		2.1	0.78
	% Silt & Clay		90.48	88.52
Shear Stength Test	Triaxial UU	Cohesion kg/cm²	0.4	0.1
		Angle of Int. Friction, (deg)	4.9	4.3
Consolidation Test	Comrpession Index, Cc		0.506	1.533
	Preconsolidation Pressure, Pc' (kg/cm²)		1.2	0.7
	Swelling Pressure, Ps (kg/cm²)		0.019	-
	Coefficient of Swelling, Cs		0.132	0.313
	Swelling (%)		2.745	0.385
	Coefficient of Rebound, Cr		0.168	1.052

Soil parameter for analysis can be determined from both in-situ and laboratory tests data. The process of determining the data will be explained at Section 5.

4 ANALYSIS USING PLAXIS 2D

4.1 Geometry Modeling

Based on soil profile from boring test (see Table 1), soil stratigraphy for geometry modeling can be determined into 3 layer. For this analysis, the layers will be divided into Silty Clay 1, Silty Clay 2, and Silty Clay 3. The depth of each layer can be seen at Fig. 1. The height of embankment for design is 6 meter with slope 1 : 1.5 (V : H).

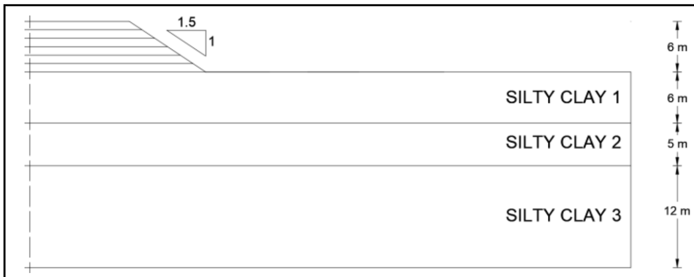

Fig. 1. Soil profile model for analysis

The next step for geometry modeling is determining the sliding plane which occurs at site. Visual observation on site and instrumentation such as inclinometer reading can determined the curve of sliding plane. After observation, it is discovered that there is a crack in the middle of embankment and heaving at 28 meter from embankment feet, thus the start and end point of sliding plane can be determined. Also inclinometer reading show that the significant horizontal movement of soil stop at the bottom of second layer (Silty Clay 2). Sliding plane modeled by creating a thin layer for about 0.5 meter and enveloped by interface to make sure the mesh disconnected when sliding occurs. But it is important to remember that R_{inter} for each layer need to be set to 1.0 so we can determine the residual parameter solely using φ_r (residual angle of friction) from thin layer parameter of sliding plane.

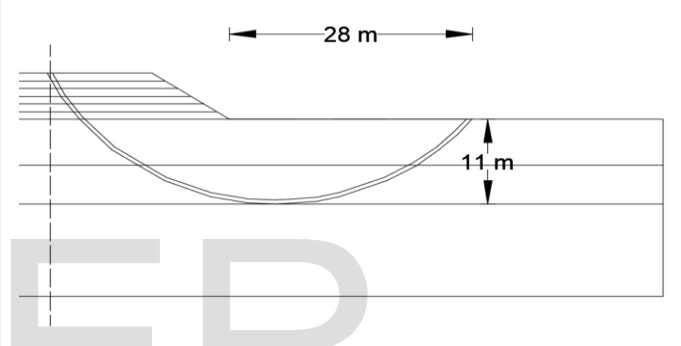

Fig. 2. Predetermined sliding plane model

For initial design, the improvement used is a geotextile woven at the feet and 2 meter above the feet of embankment. Tensile strength design for geotextile is 110 kN/m and strain assumption of 2%.

Improvement for redesign also need to be modeled before calculation begin. Improvement option for this case are addition of counterweight berm with 3 meter height and replacement of surface layer with 1.5 meter depth.

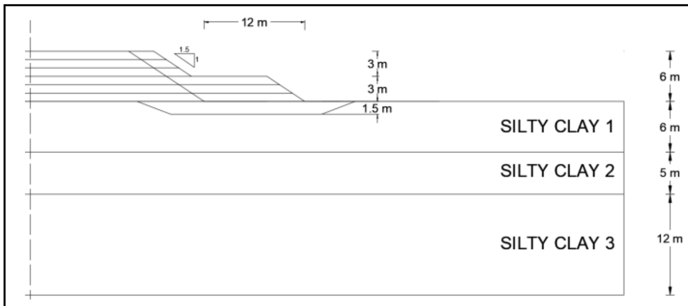

Fig. 3. Improvement model after sliding occurs

Geometry model used for this analysis can be seen on Fig.4.

4.2 Soil Model and Parameter

For this analysis, soft soil layers will be modeled using soft soil with creep model to take into account the effect of time in calculation. The rest of the soil will be modeled using mohr -

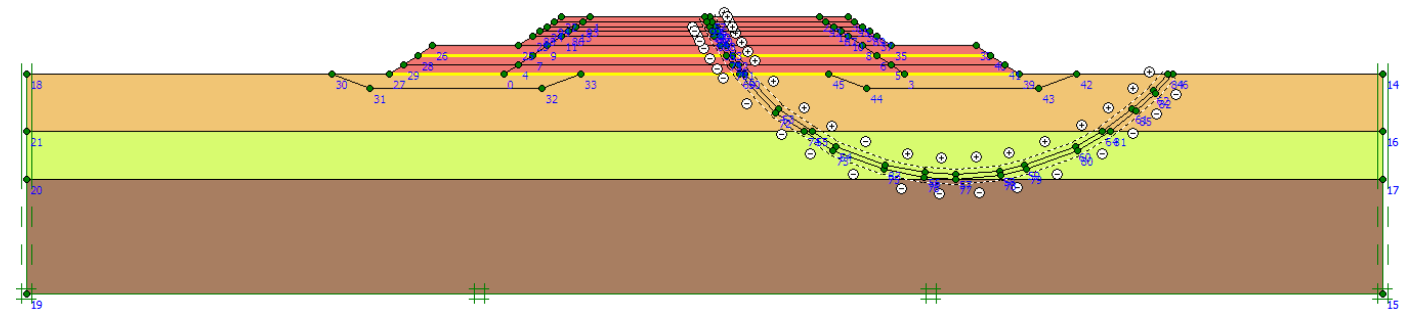

Fig. 4. Geometry model for analysis

TABLE 3
SOIL PARAMETER FOR ANALYSIS

Layer	*Material Set*		*General Properties*		*Permeability*		*Strength*		*Stiffness*				
	Model	*Type*	γ_{unsat} [kN/m³]	γ_{sat} [kN/m³]	k_x [m/day]	k_y [m/day]	c_{ref} [kN/m²]	φ [°]	E_{ref} [kN/m²]	υ	λ*	κ*	μ*
Embankment	*Mohr-Coulumb*	*Undrained*	16.5	19.9	8.64E-03	8.64E-03	5	24	5600	0.3	-	-	-
Silty Clay 1	*Soft Soil w/ Creep*	*Undrained*	17	17	8.64E-03	4.32E-03	4	26	-	-	0.096	0.050	0.0048
Silty Clay 2	*Soft Soil w/ Creep*	*Undrained*	13.5	13.5	8.64E-03	4.32E-03	1.2	24	-	-	0.164	0.074	0.0082
Silty Clay 3	*Mohr-Coulumb*	*Undrained*	16	17	8.64E-03	8.64E-03	3	29	3500	0.35	-	-	-
Replacement	*Mohr-Coulumb*	*Undrained*	16.5	19.9	8.64E-03	8.64E-03	50	0	9300	0.3	-	-	-
Sliding Plane	*Mohr-Coulumb*	*Drained*	15	15	0.00E+00	0.00E+00	0.1	9	100	0.3	-	-	-

coulomb model.

Parameters for each layer of soil can be determined by empiric correlation or formula from existing data. Table 3 contain the parameter for calculation.

4.3 Calculation Phase

The phase for analysis can be divided into 2 phase, stage construction (before and after sliding) and safety factor calculation. Table 4 define each phase and time interval between each phase while Table 5 show the safety factor calculation phase for each comstruction stage.

The work that included in embankment redesign phase are the cutting of embankment as deep as 3 meter and gradually increasing the embankment height until it reach design height which is 6 meter, replacement also done after the cutting of embankment, and the construction of counterweight berm to increase the safety factor of embankment.

After sliding occurs, the sliding plane thin layer and interface that enveloped said layer need to be kept active to calculate the safety factor of embankment after improvement while taking residual parameter of sliding plane into account.

TABLE 4
STAGE CONSTRUCTION PHASE

Phase No.	Identification	Analysis Type	Day(s) Interval	Days
0	Initial Phase	Consolidation	0	0
1	Embankment 1 m	Consolidation	20	20
2	Embankment 2 m	Consolidation	20	40
3	Embankment 3 m	Consolidation	20	60
4	Embankment 4 m	Consolidation	20	80
5	Embankment 5 m	Consolidation	20	100
6	Embankment 6 m	Consolidation	20	120
7	Consolidation 1 month	Consolidation	30	150
8	Consolidation 2 months	Consolidation	30	180
9	Sliding Plane Activation	Plastic	0	180
10	Embankment Redesign	Consolidation	60	240
11	Consolidation 3.5 months	Consolidation	108	348
12	Consolidation 5 months	Consolidation	156	504
13	Consolidation 8 months	Consolidation	245	749

ISSN 2229-5518

TABLE 5
SAFETY FACTOR CALCULATION

Phase No.	Identification	Analysis Type
13	SF Embankment 1 m	Phi/c Reduction
14	SF Embankment 2 m	Phi/c Reduction
15	SF Embankment 3 m	Phi/c Reduction
16	SF Embankment 4 m	Phi/c Reduction
17	SF Embankment 5 m	Phi/c Reduction
18	SF Embankment 6 m	Phi/c Reduction
19	SF Consolidation 1 month	Phi/c Reduction
20	SF Sliding	Phi/c Reduction
21	SF Embankment Redesign	Phi/c Reduction
22	SF Consolidation 3.5 months	Phi/c Reduction
23	SF Consolidation 5 months	Phi/c Reduction
24	SF Consolidation 8 months	Phi/c Reduction

4.4 Calculation Output

For back analysis method, the main point is to determine the residual parameter of soil when sliding occurs. To determine the correct residual parameter (in this case φ_r), the safety factor reached at sliding phase must have a value ≈ 1.0. The output of safety factor for sliding phase for φ_r = 9° shows the value of 1.033 which is close to 1.0, then it can be determined that the value φ_r = 9° may represent the residual parameter on site for sliding plane thin layer after sliding occurs.

For design improvement after sliding, there is a requirement for safety factor that need to be fulfilled.

- Safety factor for short term condition (end of construction after redesign) must have a value > 1.2.
- Safety factor for long term condition (after dissipation process almost complete) must have a value > 1.5.

Safety factor obtained from this analysis shows that both condition are fulfilled where the safety factor value for short term condition is 1.54 and 1.82 for 8 months after end of construction after improvement.

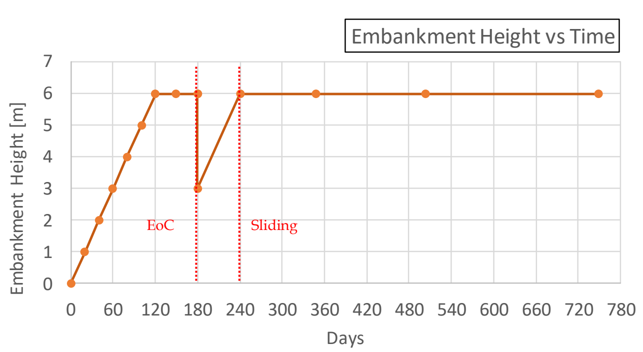

Fig. 5. Graph of embankment height vs time

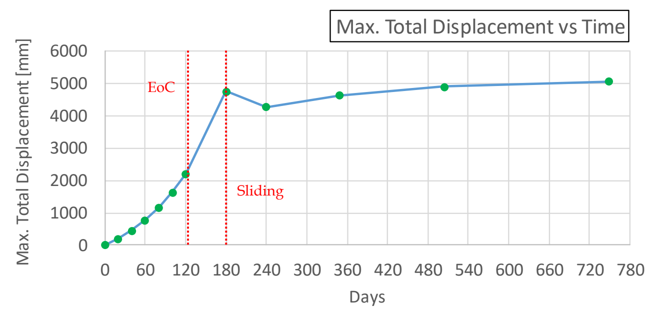

Fig. 6. Graph of maximum total displacement vs time

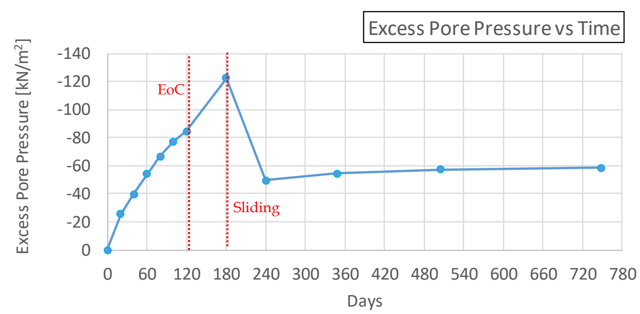

Fig. 7. Graph of excess pore pressure vs time

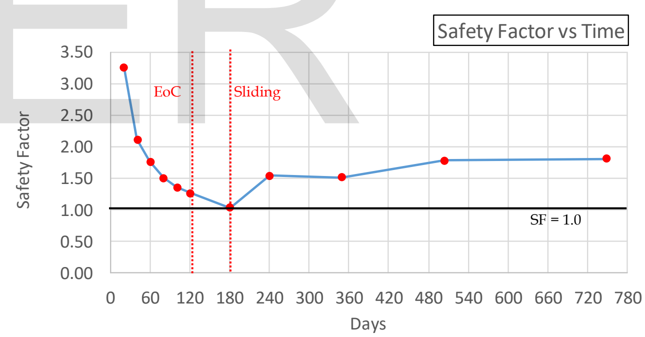

Fig. 8. Graph of safety factor vs time

5 CONCLUSION

There are 2 conclusions for this research, which is:

1. Back analysis shows that residual parameter value φ_r = 9° may represent the real condition on site when sliding occurs. This can be concluded because the safety factor reached at sliding phase = 1.033 ≈ 1.0. Then, this residual parameter can be used as reference to calculate the performance of embankment after redesign / improvements are applied.
2. The improvements applied after sliding which include replacement of soft soil on surface for 1.5 meter and counterweight berm per 3 meter are effective. This can be concluded from the safety factor value reached at end of construction which is 1.51 > 1.2 and at 8 months

ISSN 2229-5518

after end of construction which is 1.82 > 1.5. Safety factor at 8 months after end of construction is deemed sufficient for long term condition because there is no significant additional load after this phase, which mean the safety factor will continue to increase over time.

Further study might be needed to determine as to what phenomenon may cause the drop of safety factor of embankment from end of construction before sliding until the sliding occurs.

REFERENCES

[1] Das, Braja M., 2008. Advanced Soil Mechanics. New York: Taylor & Francis Group.

[2] Das, Braja M., Yani Sianipar (Ed.), 1993. *Mekanika Tanah (Prinsip-prinsip Rekayasa Geoteknik)*. Jakarta: Penerbit Erlangga.

[3] Duncan, J. Michael, Stephen G. Wright, Thomas L. Brandon, 2014. Soil Strength and Slope Stability Second Edition. New Jersey: John Wiley & Sons , Inc.

[4] Rahardjo, Paulus P., 2008. *Penyelidikan Geoteknik dengan Uji In-situ*. Bandung: Geotechnical Engineering Center, *Universitas Katolik Parahyangan*.

[5] SNI 8460 : 2017, *Persyaratan Perancangan Geoteknik*, *Badan Standardisasi Nasional*.

[6] PLAXIS Material Models Manual 2019. https://www.plaxis.com › plaxis_download=2D-3-Material-Models