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Stability Analysis of Road Embankment with Various Fill Materials

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ABSTRACT

Evaluation of the stability analysis for road embankment is not only a problem but also a challenge for Geotechnical Engineering. In manmade slope, the problem of choosing soil is an important role for stability condition. The main purpose of this study is to determine the stability of road fill embankment according to the factor of safety and deformation. In this study, the stability of slope was modelled in scenarios (different fills, different inclination and various level of water table). Finite Element Method by Plaxis-2D was used in numerical analysis of slope. The results of this study showed the suitability of fill soil in embankment construction according to the comparative study of deformations, factor of safety. In collected fill soils, Clayey sand (fill 2) is most suitable for road fill embankment.

Keywords :- Stability, deformations, factor of safety, excess pore pressure, fill soils.

I. INTRODUCTION

Stability analysis is an important role not only in the construction of transportation facilities such as highways, railroads, and canals; but also the development of natural resources such as surface mining, refuse disposal, and earth dams; as well as many other human activities involving building construction and excavation. Failures of slope in these applications may be caused by movements within the human created cut or fill, in the natural slope, or a combination of both. In manmade slope, properties of subsoil and fill soils are greatly effected on stability. In this research, it is presented the numerical simulation analysis on the stability of road fill embankment by using locally fill materials.

Especially in Ayeyarwady delta region, many failures of road embankment can be occurred such as settlement of embankment, sliding failure of road embankment and collaspe slope due to the erosion by rain or water. According to the previous research, one of the reasons for these failure is usage of poor materials as fill [1]. The present work is focused on investigation the behavior of locally fill material when it used in road fill embankment by using Plaxis program in slope stability analysis.

II. LITERATURE REVIEW

Stability calculation is performed to assess the safe design of human-made or natural slopes like embankments and respectively the equilibrium conditions. The term stability analysis can be explained as the resistance of inclined surface to failure by sliding or collapsing. Before 1970, stability analysis was accomplished through hand calculation. Today there are many useful analysis softwares for engineers. Geo5 and Geostudio software are based on the traditional limit equilibrium method. Plaxis software is a computational analysis to newer numerical solutions such as finite element method. The main problem with limit equilibrium method (LEM) is disregarding stress-strain behavior of the soil in calculation but can provide an estimation of FS. On the other hand, Finite Element Method (FEM) uses stress-strain behavior of the soil and removes the assumptions applied in LEM. It is well established to predict material behavior of the ground, water and structures better than LEM (Heibaum et al.2009) [2].

A. Review of Slope Stability Analysis

Embankments over 10 feet in height or any embankment on soft soils, or those comprised of lightweight fill require more in depth stability analyses, as do any embankments with side slope inclinations steeper than 1V: 2H. Moreover, any fill placed near or against a bridge abutment or foundation, or that can impact a nearby buried or above ground structure, will likewise require stability analyses.

Highway embankments should have a minimm factor of safety of 1.25. When repairing an embankment slide or slipout, and a minimum factor of safety can be considered as 1.15. Bridge approach embankments supporting or potentially impacting structures should have a minimum factor of safety of 1.5. The allowable deformation for embankment is not over 200 mm [3].

Geotechnical engineers widely used Plaxis software, a FEM software in stability analysis problem related to rocks and soil. The Technical University of Delft firstly developed Plaxis Software in 1987 to analyze soft soils of the low lands of Holland[9]. In stability analysis, Plaxis software can be effectively used and also in the investigation of soil-settlement. Mohr-Coulomb iterative solution and phi-c reduction procedure for calculation of safety factor.

The factor of safety FS in Plaxis is defined as:

 $FS = (c + \sigma n \tan \phi) / c_R \tan \phi_R$

Where, σ ń is effective normal stress acting on a plane c and ϕ are the input cohesion and angle of internal friction and c_R and ϕ_R are a reduced cohesion and reduced angle of internal

friction calculated in the program as product of the input values and a multiplier. It is used in the above equation to give the factor of safety on an element by element basis [5].

III. NUMERICAL SIMULATION FOR MODELING

The crest width of embankment is 12 m and height of embankment is 5m. Different slope inclinations (1V:1.5H), (1V:2H) and (1V:2.5H) are considered in modeling. And 15 nodes plain-strain elements have been considered in this analysis with Mohr-Coulomb model. The coarseness factor for mesh generation is used as medium.

A. Geotechnical Properties of Subsoils

The subsoil samples were collected from the river embankment of Ngawun at PanTawGyi bank. According to the undisturbed samples, the subsoil of the proposed embankment is consisted of cohesive and cohesionless soils are interbedded. But the thickness of sand layer is about 1.27 cm. It is difficult to collect the actual thin layer of soil. The samples were tested in laboratory as ASTM and AASHTO Standards as follows; Specific gravity(ASTM D 854, AASHTO T100), Grain- size distribution(ASTM D 2487, AASHTO M145), Atterberg's limits (ASTM D 4318, AASHTO T89 and 90), and Unconfined Compression Strength (UCS)(ASTM D 2166-85), Permeability (ASTM D 2434) and Tri- axial test (ASTM D 2850). Soil testing will be carried out with restricted condition. Accurate information of the ground is difficult to know. It is required to recognize the possible errors of soil exploration data. The properties of subsoils are shown in Table I.

B. Geotechnical Properties of Fill Soils

Different fill soils were collected from Pathein- Monywa Highway Road* (between 76/0 to 78/6 miles). The samples were tested in laboratory as ASTM and AASHTO Standards as follows; Specific gravity, Grain- size distribution, Atterberg's limits, and Unconfined Compression Strength (UCS), California Bearing Ratio (CBR), Permeability and Triaxial test same as subsoil. The properties of fill soils are shown in Table II.

TABLE I PHYSICAL PROPERTIES OF SUBSOILS

Property	operty Subsoils				
	Layer 1	Layer 2	Layer 3		
Gs	2.58	2.62	2.56		
LL (%)	36	31	43		
PL (%)	26	24	25		
OMC (%)	14	12	16		
MDD (kN/m ³)	17.67	18.47	17.02		
Soil Class (USCS)	Silty clay with sand (CL)	Silty clay (CL)	Lean clay (CL)		
Рнуз	TABLE I SICAL PROPERTIES	II S OF FILL SOILS			
Property Subsoils					

	Layer 1	Layer 2	Layer 3
Gs	2.59	2.56	2.49
LL (%)	61	36	47
PL (%)	26	24	27
OMC (%)	22	17	16
MDD (kN/m ³)	17.06	15.79	16.57
Soil Class (USCS)	Fat clay with sand (CH)	Clayey sand (SC)	Clayey sand with gravel (SC)

C. Modeling of Road Embankment

In this study, the embankment is 5 m. height and 12 m width. Berms are considered in each side of slope and width of berms is 2m. Considering the height of embankment is not variable. The subsoil layers are considered in 10 m depth .

Thickness of soil layers are as followed:

Top fill layer = 2m, Second fill layer = 3m

Subsoil Layer 1 = 3m

Subsoil Layer 2 = 3m

Subsoil Layer 3 = 4m

1) *Mesh Generation:* In Plaxis software, the geometry of the modelling embankment is required to mesh with finite element mesh generator. In this study, the input of global coarseness is considered as medium.

2) **Calculation:** In this study, the calculation for consolidation of embankment construction is considered 5 days to 200 days with the effect of ϕ - c reduction of the embankment. Calculation consists of the following steps:

- Apply in a stage construction first step with 3m height of fill layer, in 5 days ;
- Consolidation period is considered 200 days to allow the excess pore pressure to dissipate;
- Apply the second step in a stage construction with 2m height of fill is overlie the first fill layer, also in 5 days;
- For long-term consideration, estimated the deformation for 1 year, two years to until 30 years.
- And then consider the minimum pore pressure in loading input.

D. Input Parameters for Plaxis Software

The required input parameters for Plaxis Software are listed in Table III. The main input parameters in Mohr-Coulomb model are unit weight of soil, cohesion, angle of internal friction, young modulus of soil, coefficient of permeability and poisson ratio.

TABLE III
INPUT PARAMETERS FOR PLAXIS SOFTWARE

	Layer	Layer	Layer	Fill 1	Fill 2	Fill 3
	1	2	3			

γ_{sat} (kN/m ³)	21.29	22.03	20.59	19.76	20.43	20.17
γ_{dry} (kN/m ³)	17.67	18.47	17.02	17.06	15.79	16.57
E (kN/m ²)	5000	4800	4000	5000	10500	6000
K (m/day)	4.4 x 10 ⁻⁴	3.4 x 10 ⁻⁴	4.4 x 10 ⁻⁴	6.2 x 10 ⁻⁵	1.7 x 10 ⁻⁴	2.1 x 10 ⁻⁴
c (kN/m ²)	33	28	44	32	37	34
φ (degree)	12	25	14	12	21	29
ν	0.35	0.35	0.35	0.35	0.3	0.3

IV. RESULTS AND DISCUSSION

The result of stability analysis for approach road embankment using Plaxis 2D is summarized the values of stability factor and displacement according to the FEM models.

A. Deformation of the Embankment

In this study, water table is considered as four conditions: (1) without water table, (2) water table at base of embankment, (3) at second fill layer and (4) at top of fill layer. The variation of water table is considered and the deformations of the road embankment are shown in Fig. 1. to Fig. 12.

For without water table condition, the deformations of embankment is evaluated as shown in Fig. 1, Fig. 2 and Fig. 3. For water table at the base of embankment, the deformations is shown in Fig. 4, Fig. 5 and Fig.6. In Fig. 7., Fig. 8. and Fig. 9. are shown the deformations when the water table is at second fill layer. Also Fig. 10., Fig. 11. and Fig. 12. are shown the deformations of road embankment when the water table is reached at the top of embankment. For each case, using fill 2 is sastisfied because of the smallest values of deformation may be occurred.



Fig. 1. Vertical deformation for embankment, 1V:1.5H (without Water Table)



Fig. 2. Vertical deformation for embankment, 1V:2H (without Water Table)



Fig. 3. Vertical deformation for embankment, 1V:2.5H (without Water Table)





Fig.5. Vertical deformation for embankment, 1V:2H (at base)























Fig. 11. Vertical deformation for embankment, 1V:2H (at top fill layer)

In long-term consideration, using fill 2 is acceptable because of the smaller value of deformation. If fill 1 is used the deformation of embankment will be above 200 mm after two years the end of construction.

B. Factor of Safety

Variation in slope inclination is effect on the factor of safety for road embankment is shown in Figure 13, 14 and 15. Condition of water table is considered without water table (without), at the base of embankment (at base), at the second fill layer (at second layer) and at the top layer of embankment (at top fill layer).

According to the results, when the slope inclination is steeper the value of factor of safety will be decreased.



Fig. 13. Factor of Safety for embankment, 1V:1.5H

From the above figure 13. All the factor of safety are above 1.5 for slope inclination is 1V:1.5H. The smallest value is 2.6.The largest value is 3.6. In 1V:1.5H, there is slightly effect on factor of safety due to varying water table.



Fig. 14. Factor of Safety for embankment, 1V:2H

From the above figure 14. All the factor of safety are above 1.5 for slope inclination is 1V:2H. The smallest value is 2.9. In 1V:2H, there is slightly effect on factor of safety due to varying water table. When water table is at the top of embankment, factor of safety for fill 2 is highest. Embankment built with fill 2 is the most stable and safest.



Fig. 15. Factor of Safety for embankment, 1V:2.5H

From the above figure 15. All the factor of safety are above 1.5 for slope inclination is 1V:2.5H. The smallest value is 2.88.The largest value is 4.7. In 1V:2.5H, there is slightly effect on factor of safety due to varying water table except the water table is top of embankment. In that condition, using fill 2 can give the highest factor of safety and using fill 1 can give the smallest value.

C. Excess Pore Pressure and Consolidation Time

If the soil has a low coefficient of permeability require a longer time to disperse the porewater pressure. As the same way, the soil has a large coefficient of permeability requires less time to disperse the pore water pressure. This time is called fully consolidated time [7].

. In this study, fill 1 is less permeability and poor drainage than the other fills. So, it is required more time to reach a fully consolidated state. If the excess pore pressure is changed, the condition of the road fill embankment is not stable.

According to the results, required consolidation time for fill 1 is 13122 days, for fill 2 is 1444 days and for fill 3 is 5865 days. Excess pore pressure of each fill for long-term consideration is shown in following figures.



Fig. 16. Excess pore pressure at 1V:1.5H (without water table)

The highest excess pore pressure occurs under the embankment center. According to the results, the maximum excess pore pressure can be occurred during construction and then it may decrease with time. In this analysis, excess pore pressure with different fill soils are expressed in long-term consideration.



Fig. 17. Excess pore pressure at 1V:2H (without water table)









Fig. 22. Excess pore pressure at 1V:1.5H (water table at second fill layer)









Fig. 21. Excess pore pressure at 1V:2.5H (water table at base)













Fig. 26. Excess pore pressure at 1V:2H (water table at top fill layer)

In general, the soil particles are finer, the larger the saturation capillary head, and hence the higher the negative pore pressure. In Fig. 16. to Fig. 27., the excess pore pressure is shown according to the long-term consideration such as 1 year to 30 years. According to the results, excess pore pressure for fill 2 and fill 3 may lead to zero after one year from end of construction. But excess pore pressure for fill 1 is lead to zero between ten to twenty years after construction. Therefore, using fill 1 in road embankment construction is not suitable for long-term consideration.

V. CONCLUSIONS

In this study, it is observed that all of numerical analysis for road fill embankment in short term stability is acceptable and safe. And decrease of slope inclination is lead to increase the stability factor. Higher stability factor is occurred in 1V:2.5H slope. But it may cause the covering of the largest area of the ground as the disadvantage. Fill 2 is the best condition for safe according to the factor of safety values.

According to the numerical results by using Plaxis 2D, it is less the deformation changes in 1V:2H slope with water table at the base of embankment. For a homogeneous embankment, using fill 1 and fill 3 are stable even the fluctuation of water table. Fill 2 is suitable for all case according to the deformation results. Therefore, it has a tremendous effect on the slope stability. The volume and shear strength of soil will change due to increase in pore pressure when the desaturated soil is wetted. So, prediction results are required to shown with excess pore pressure and long-term deformation. The maximum excess pore pressure is occurred 5 days during construction. And then the value of excess pore pressure may lead to zero and it mean that the soil is to be fully consolidated state. According to the results, using fill 2 is suitable for embankment construction because of its consolidation time is less than the others. This time are decreased when the water table is rise.

VI. RECOMMENDATIONS

In this study, the stability analysis is evaluated by Plaxis 2D. The following are recommended for further study.

- 1. In this research, Plaxis 2D is used. The update version Plaxis 2018 should be used in next study.
- 2. The deformation of road embankment should be compared by using experimental results and software results.
- 3. Europe 7 code for embankments design should be considered to anlyze the stability of slope.
- 4. it can be analyzed by using Limit Equilibrium Method (LEM) and then results can be compared.
- 5. For further study, suitable model such as Hardening-Soil Model (HS) should be considered in Plaxis program.

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