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Numerical Analysis of Earth Slopes Using Finite Element Program

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ABSTRACT

The sustainability of the earth's topography is a major concern in geotechnical engineering. Nowadays there are a number of computer based geotechnical software that are used for slope stability analysis. For slopes with known geometry and soil parameters, computer based slope stability analysis is a simple task for engineers. Computational software based on limit equilibrium principle has been in practice for many years. Likewise, software based on finite element approach has become crucial tool for both researchers and professionals. The finite element is becoming well accepted, particularly the FE program Plaxis [1]. Since the finite element program utilizes stress-strain relationships, a more practical stress redistributions are computed even for a sophisticated problem. In addition, the concept of slices is not applicable in the finite element approach and there is no need for assumptions of interslice forces. Unlike the LE approaches, the shape and location of the failure surface are not assumed prior to analysis. This makes analysis of slope stability with FE methods more advantageous than LE methods. The objective of this study is to compare the applicability of the two dimensional finite element program Plaxis 2D, for the analysis of pore water pressure, deformations and slope stability, with other finite element and limit equilibrium programs.

Keywords: Slope stability, Finite element program, Water drawdown, transient saturated/unsaturated seepage, Embankment failure, Ground improvement.

1 INTRODUCTION

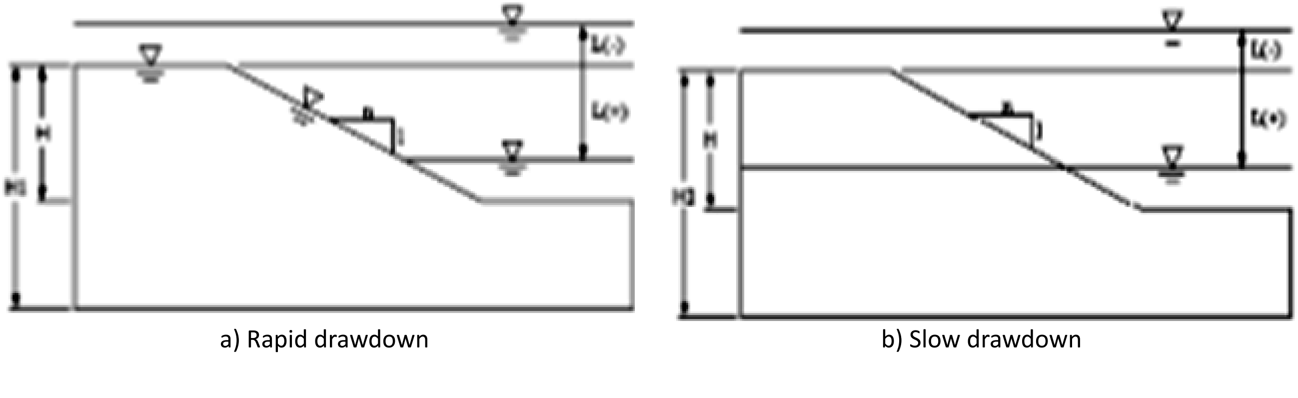
The problems related to the issues of instability of both engineered as well as natural slopes have been common problems for both researchers and professionals. Rainfall, increase in groundwater table and change in stress conditions may produce instability in construction areas. In the same way, external forces, changes in geometry and loss of shear strength may cause sudden failure in natural slopes that have been in stable condition for long time [2]. The combination of steep topography, intense rainfalls, and soil conditions are critical [3].
The provision of engineered solutions for problems of slope instability often requires having a good knowledge of investigative tools, analytical methods and stabilization measures [2]. When decisions are made to make a quantitative assessment of the safety factor is important [4]. As a result, stability analysis methods that are suitable as well as reliable have great scope and thus, they are increasingly in demand.

In Geotechnical engineering, analysis of slope instabilities is a very important field. There are several methods of analyzing slope instability problems covered in most soil mechanics textbooks. Duncan (1999) presents a detailed work on slope stability analysis by limit equilibrium methods [5]. These methods are based on static equilibrium, force equilibrium and moment equilibrium, and it requires dividing the soil mass into a number of slices. All limit equilibrium methods have different assumptions to the interslice normal and shear forces, which results the basic difference between the methods.
In recent years, finite element method, especially the FE program PLAXIS, is becoming increasingly applicable in solving slope instability problems [1]. The finite element method is based on stress-strain relationship or constitutive law. The fact that no assumption needs to be made in advance about the location or shape of failure surface, slice side forces and their directions, makes the finite element approach more advantageous over the limit equilibrium method in slope stability analysis. Unlike the LE method, extremely general critical failure mechanism can be generated and it does not have to be a simple circular or logarithmic spiral arc. The range of this method can be extended to account for the brittle soil behavior, seepage induced failures, random field soil properties and engineering interventions like soil nailing, retaining walls, geo-textiles [6].
Generally, the finite element method analyzes slope instability problems by using two major approaches. The first approach is the Gravity increase method where g is increased until the slope becomes unstable and equilibrium solutions no longer exist. The second approach is the strength reduction method which involves reducing the strength parameters c'- φ' of the slope until slope becomes unstable and equilibrium solutions, no longer exist (this method is used in this study).

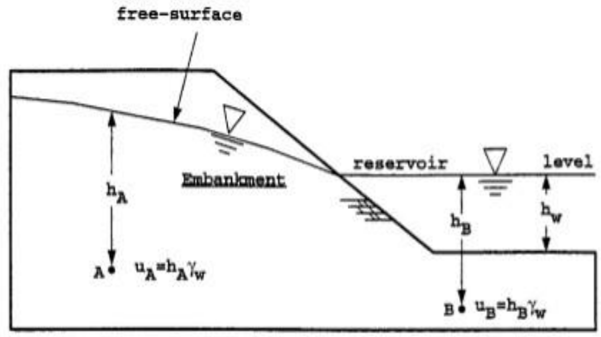
2 PLAXIS 2D SOFTWARE

Plaxis 2D is a finite element software which is intended for 2-Dimensional stability and deformation analysis in geotechnical engineering. The program allows generating finite element mesh of different sizes, which enables to find the least possible factor of safety. Various problems can be modeled based on 6 nodes or 15 node elements in plain strain or axisymmetric model. Different models are included to determine the behavior of the slope soil. Some of these models are Mohr-Coulomb model, Hardening soil model, Soft soil model, Modified Cam-Clay model, Soft soil creep model, jointed rock model, etc. The application of a particular model depends on the available soil parameters and the type of analysis to be performed. The program automatically generates standard boundary conditions during analysis. It is applicable in the analysis of many geotechnical structures like embankments, retaining walls, pile foundations, etc.
The analysis of problems using Plaxis 2D generally includes four main subroutines. These subroutines are inputs, calculation, outputs and curve plots. The program allows users to select a particular point where the load displacement curve, pore water pressure, stress path and stress-strain curves is generated at that particular point in the output subroutine. From the curve plot sub-routine, variation of pore water pressure with time, factor of safety versus displacement, etc., can be plotted.
In the following two sections, the finite element software PLAXIS 2D is used for evaluation of previous works done by both finite element (ABAQUS) and limit equilibrium (Talren-4) based software.

Section 1: Water drawdown condition near lakes, reservoirs, rivers and seas often causes instability of the bank slope. Generally, there are three modes of water drawdown conditions. These are fully slow or partial drawdown condition, fully rapid or sudden drawdown condition and transient saturated/unsaturated seepage, shown in Fig. 1. Rapid or sudden drawdown is when there is no sufficient time for the drainage of the slope soil to happen as the water level changes. Slow drawdown is when the internal segment of the free surface has reached and stabilized to the new reservoir water level. These two conditions represent the extreme cases and they are commonly adopted because of their simplicity. However, for slope stability considering practical loading such as surface water pressure and pore water pressure, these drawdown conditions are responsible for generating results that under- or over-estimate the factor of safety. Therefore, to accommodate most of the practical cases a stability analysis based on transient saturated/unsaturated seepage is required.



a) Rapid drawdown b) Slow drawdown



c) Transient seepage

Figure 1: Three drawdown conditions for slope stability analysis. [7] & [8]

In this section, a slope stability analysis under transient saturated/unsaturated seepage is performed using Plaxis 2D software. The effects of water drawdown ratio, drawdown rate and hydraulic conductivity on the slope stability are evaluated. Finally, the results are compared with the FE program Abaqus outputs used by Tingkai Nian et al. (2011).

3 METHODLOGY

Finite element analysis is performed to simulate the groundwater flow of the slope during drawdown, which is important to analyze the stability of submerged slopes under transient saturated/unsaturated seepage. Next, the effect of hydraulic conductivity on the stability of slopes is evaluated by considering three different values (k=1.0x10^{-4} cm/sec, k=1.0x10^{-5} cm/sec and k =1.0x10^{-6} cm/sec). The range of drawdown ratio (L/H) used for the analysis is 0.1 to 1. The drawdown ratio L/H is the ratio the depth by which the water falls L to the height of the slope H. The reservoir water level drops at two different drawdown rates (R=0.1 m/day and R=1 m/day).

3.1 Material Property

Material properties used by Tingkai Nian et al. (2011) are adopted for the FE analysis.

Table 1. Soil properties used in FEM analysis.

Material properties	Symbol	Value
Unit weight of soil	γ	20 kN/m^3
Cohesion	C'	1 kN/m^2
Internal angle of friction	φ'	20°
Dilatancy angle	ψ	0°
Young's Modulus	E'	10^5 kN/m^2
Poisson's ratio	ν	0.3
Void ratio	e	0.2

3.2 Plaxis 2D Model

The slope is modeled using the input module of plaxis 2D program. The geometry of the slope has slope ratio of *H: V=2:1,* [8]. A very fine mesh is generated based on 15 node elements in a plain strain model. The behavior of the slope soil is defined using Mohr-Coulomb soil model.

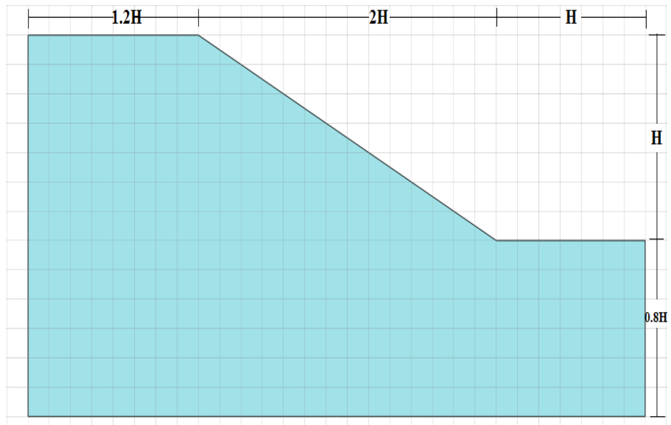
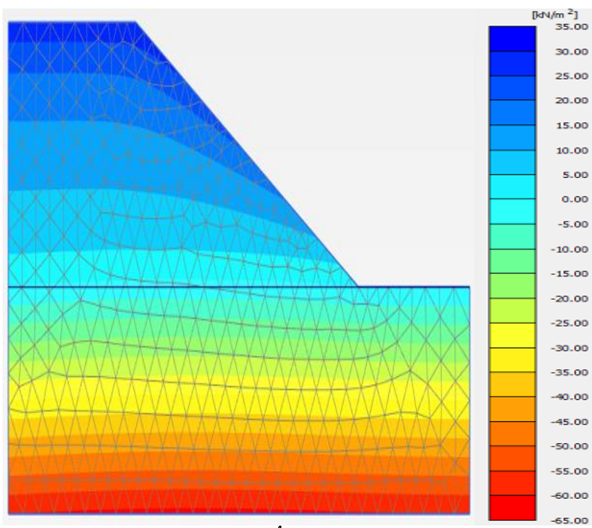
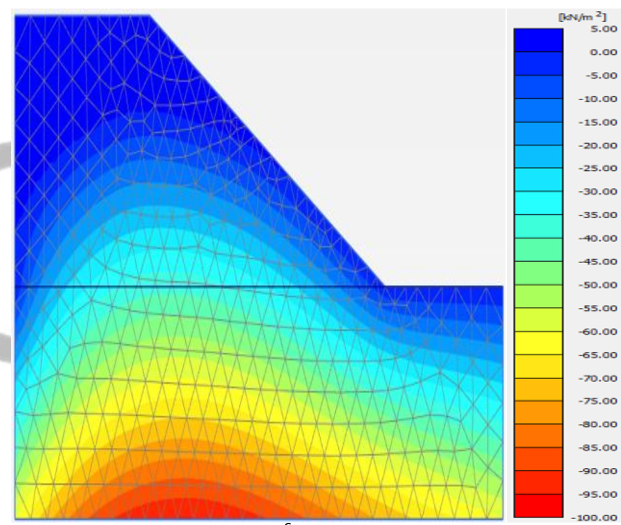


Figure 2: Plaxis 2D model and Geometry, H=7m.

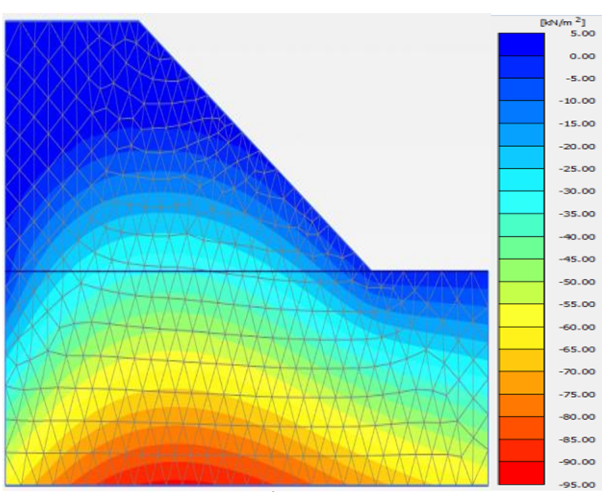
3.3 Determination of ground water flow during drawdown

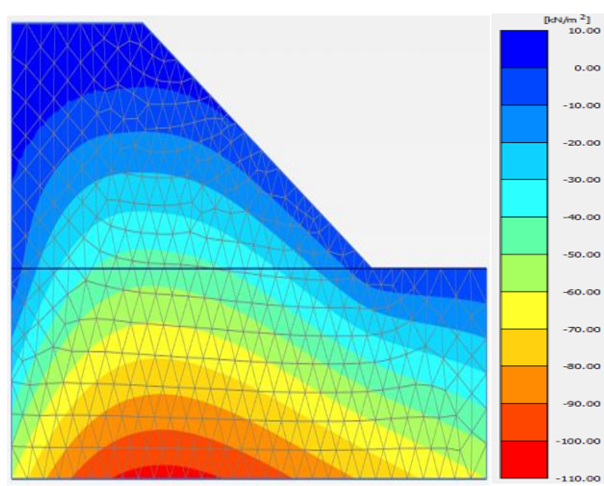
The groundwater flow of the slope following drawdown is simulated first using the finite element program Plaxis 2D. This analysis is crucial to investigate the stability of submerged slopes subjected to transient saturated/unsaturated seepage. For this analysis, two hydraulic conductivity values (k=1.0×10^{-4} and 1.0×10^{-6} cm/s), two drawdown rates (R =0.1 m/d and R =1.0 m/d) with various drawdown ratios from 0.1 to 1 are applied.





a) k =1.0×10^{-4} cm/s and R = 0.1 m/d b) k =1.0×10^{-6} cm/s and R = 0.1 m/d





c) k = 1.0×10^{-4} cm/s and R = 1 m/d d) k =1.0×10^{-6} cm/s and R = 1 m/d

Figure 3: Pore water pressure values for various hydraulic conductivity k and drawdown rates R.

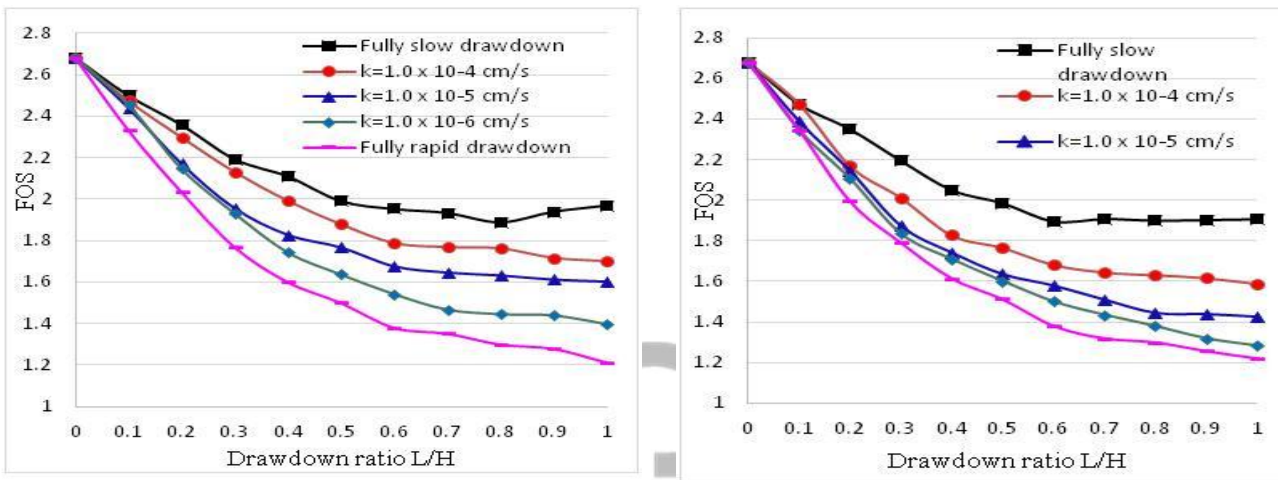
From the above figures, it can be observed that for slopes with lower hydraulic conductivity or rapid drawdown rate, the pore water pressures are higher. In addition, the extent of the pore pressure increase in low and high hydraulic conductivity is different as the drawdown rate increases from o.1 m/d to 1 m/d.

3.4 Effect of hydraulic conductivity on the slope stability

Plaxis 2D is used to study the effect of hydraulic conductivity of slope stability using three hydraulic conductivity values (k=1.0×10^{-4}, 1.0×10^{-5}, and 1.0×10^{-6} cm/s), two drawdown rates (R =0.1 m/d and R =1.0 m/d) and different drawdown ratios L/H ranging from 0.1 to 1. The factor of safety is calculated at each drawdown position. The section is divided into two parts: 1) FOS for drawdown rate R =0.1 m/day with different hydraulic conductivity and drawdown ratios, 2) FOS for drawdown rate R =1 m/day with different hydraulic conductivity and drawdown ratios.

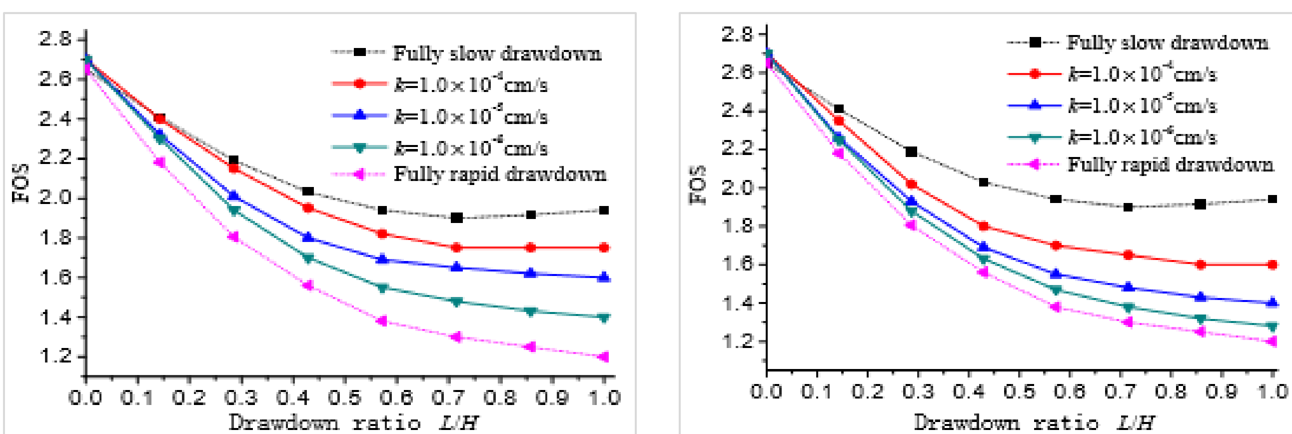
3.5 Comparison of results

The safety factor calculated using the finite element program Plaxis 2D are drawn against draw down ratios for the two drawdown rates. In addition, a comparison is made with the results from Tingkai Nian et al. (2011).



(a) Drawdown rate R=0.1 m/d (b) Drawdown rate R=1.0 m/d

Figure 4: Variation of FOS with drawdown ratio for various hydraulic conductivity k and drawdown rates R, (present study).



(a) Drawdown rate R=0.1 m/d (b) Drawdown rate R=1.0 m/d

Figure 5: Variation of FOS with drawdown ratio for various hydraulic conductivity k and drawdown rates R, [7].

3.6 DISCUSSION

In the analysis using both finite element methods, the behavior of the slope approaches that of the fully rapid drawdown condition in case of soils with low hydraulic conductivity (k=1.0x10^{-6} cm/s) and high drawdown rate (R=1 m/d), Figure 4b and Figure 5b. In addition, for the same hydraulic conductivity but slower drawdown rate (R=0.1 m/d), the slope behavior is still close to the fully rapid drawdown condition. From this, we can conclude that for soils with low permeability, hydraulic conductivity is a dominant factor compared to drawdown rate.

For the case of relatively higher hydraulic conductivity (k=1.0x10^{-4} cm/s) and slower drawdown rate (R=0.1 m/d), the computed factor of safety is closer to the fully slow drawdown case. However, for the same soil permeability and higher drawdown rate (R=1 m/d), the computed factor of safety approaches the fully rapid drawdown condition. Therefore, the slope behavior is mostly affected by drawdown rate rather than hydraulic conductivity in soils with high permeability.

3.7 Effect of drawdown rate on the slope stability

To investigate the effect of drawdown rate on factor of safety, the variation of FOS with drawdown ratio under two drawdown rates (R=0.1 m/d and 1 m/d) and two hydraulic conductivities (k=1.0x10^{-4} cm/s and 1.0x10^{-6} cm/s) is show in Figure 6.

Both FEM analysis show, the factor of safety decreases with an increase in drawdown rate regardless of the hydraulic conductivity. The factor of safety versus drawdown ratio relationship curve with drawdown rate R=0.1 and 1.0 m/day approaches the fully rapid condition under low hydraulic conductivity. On the other hand, the relationship curve approaches the fully slow drawdown condition under high hydraulic conductivity. From these, we can concluded that under the same drawdown ratio and drawdown rate, FOS with high hydraulic conductivity *k* value is higher than FOS with low *k* value.

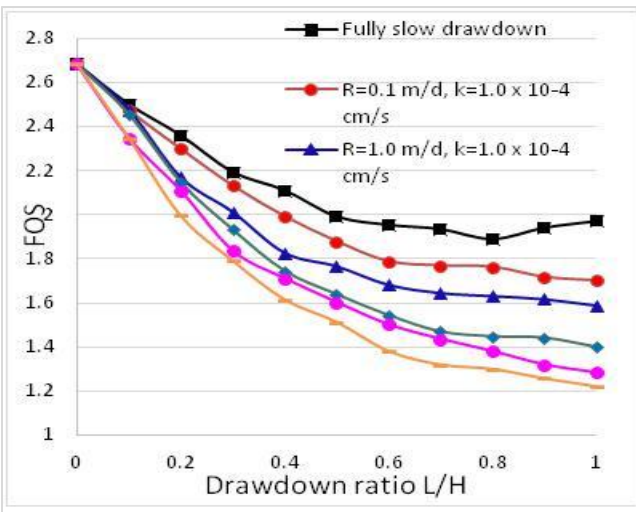


Figure 6: Variation of FOS with drawdown ratio for Various drawdown rates R and hydraulic conductivity *k*, (Present study).

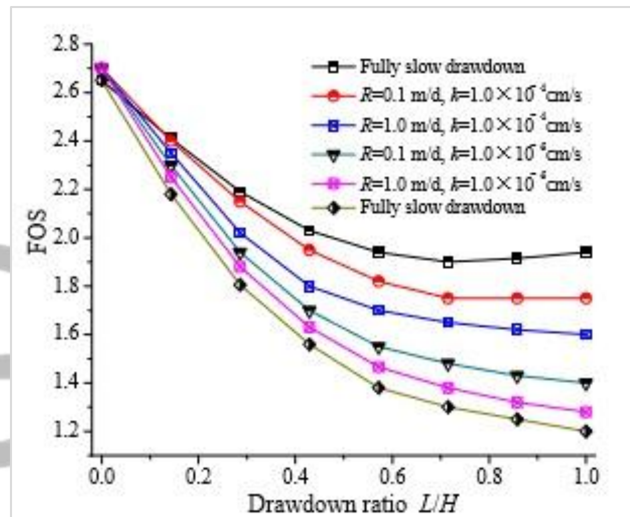


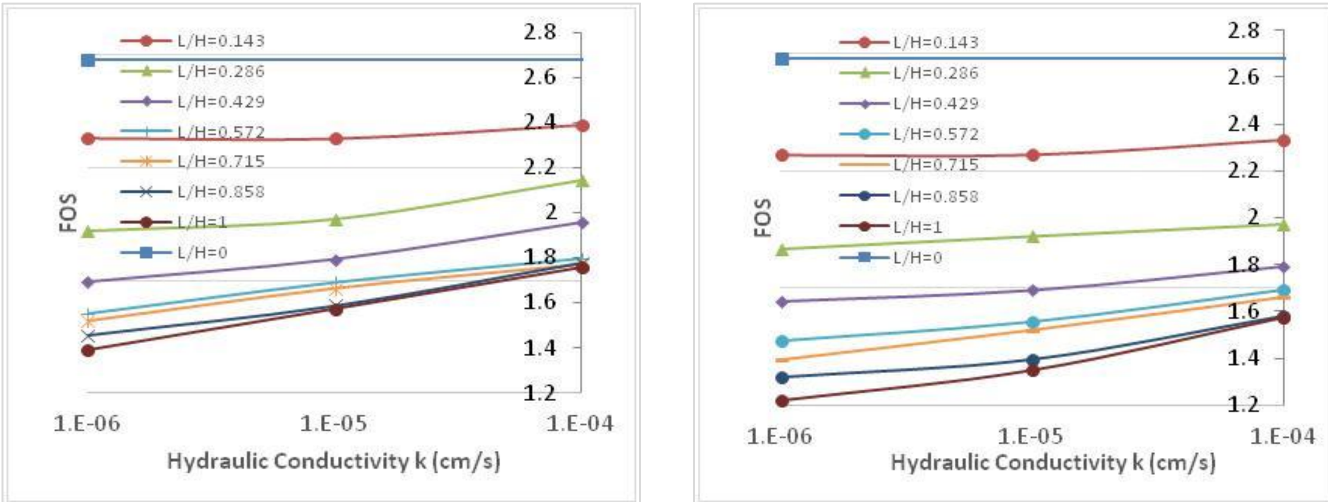
Figure 7: Variation of FOS with drawdown ratio For various drawdown rates R and hydraulic conductivity *k*, [7].

3.8 Effect of drawdown ratio on the slope stability

The following Plaxis 2D analysis result shows the effect of drawdown ratio on the factor of safety. Two hydraulic conductivity values (k=1.0×10^{-4}, 1.0×10^{-5}, and 1.0×10^{-6}cm/s), two drawdown rates (R =0.1 m/d and R =1.0 m/d) and various drawdown ratios are employed in the analysis.

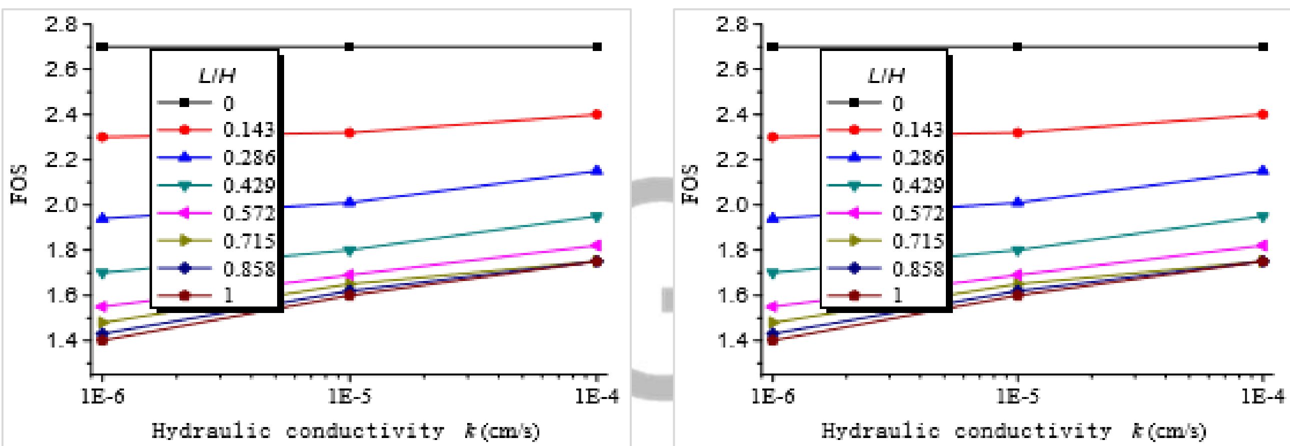
3.9 Comparison of results

The analysis shows that for small drawdown ratio, variation of factor of safety with hydraulic constant *k* is very small. On the other hand, the factor of safety shows a linear increment with hydraulic conductivity *k* as the drawdown ratio becomes greater. For a given hydraulic conductivity, the factor of safety will decrease with an increase in drawdown ratio showing maximum extent of reduction more than 50%. The evaluations done by Plaxis 2D program show similar output like the FEM program (ABAQUs) used by Tingkai Nian et al. (2011).



a) *R*=0.1 m/d b) *R*=1.0 m/d

Figure 8: Variation of FOS versus hydraulic conductivity *k* under different drawdown ratios L/H, (present study)



a) *R*=0.1 m/d b) *R*=1.0 m/d

Figure 9: Variation of FOS versus hydraulic conductivity *k* under different drawdown ratios L/H, [7].

3.10 CONCLUSIONS

The numerical analysis using plaxis 2D shows that for high hydraulic conductivity the drawdown rate has remarkable effect on the pore water pressure, for slopes under transient saturated/unsaturated seepage compared to low hydraulic conductivity. Therefore, the effect of drawdown rate in soils with low hydraulic conductivity can often be neglected for design purpose.

The factor of safety analysis using both finite element based software (PLAXIS 2D, present study and ABAQUS, Tingkai Nian et al. (2011) shows excellent agreement among the results regardless of slow, rapid drawdown or transient seepage conditions**.** Therefore, both analysis programs are reliable for slope instability problem computations.

For soils with slow hydraulic conductivity and moderately high drawdown rates, or relatively higher hydraulic conductivity and high drawdown rate, the behavior of the soil tends to approach the fully un-drained condition (fully rapid drawdown condition). On the other hand, the calculated factor of safety is higher than the fully rapid drawdown and lower than that of the fully slow drawdown condition for soils with relatively higher hydraulic conductivity and rather slow drawdown rate.

Increasing the drawdown rate causes a remarkable decrease in the factor of safety analysis regardless of the hydraulic conductivity. In addition, for small drawdown ratio the variation of factor of safety with hydraulic conductivity is very small or unremarkable. However, the factor of safety shows a linear increment with hydraulic conductivity when the drawdown ratio becomes larger. For a given hydraulic conductivity, the factor of safety will decrease with an increase in drawdown ratio showing maximum extent of reduction more than 50%.

Section 2: Juneja A. and Chatterjee D. (2013) studied the failure and settlement problem of the Nivasr Yard Embankment, located in Ratnagiri district of Maharashtra [9]. The slope stability problem was investigated using the limit equilibrium program Talren-4 (Terrasol 2005). In this section, the finite element program Plaxis 2D is used to evaluate the instability of the embankment. Later, a comparison is made between the two methods of analysis.

The Konkan Railways constructed the Nivsar Yard Embankment in 1994 and has a station located in this district. This 22m high embankment has faced failure and settlement related problems since July 2005-monsoon season. Following this period, various ground failure and settlement mitigation measures were employed. However, these measures were not sufficient enough to prevent the failure from happening again as similar failure surface reappeared during the following monsoon season. Ever since the embankment has experienced failure and settlement problem nearly every monsoon despite the various ground improvement measure taken.

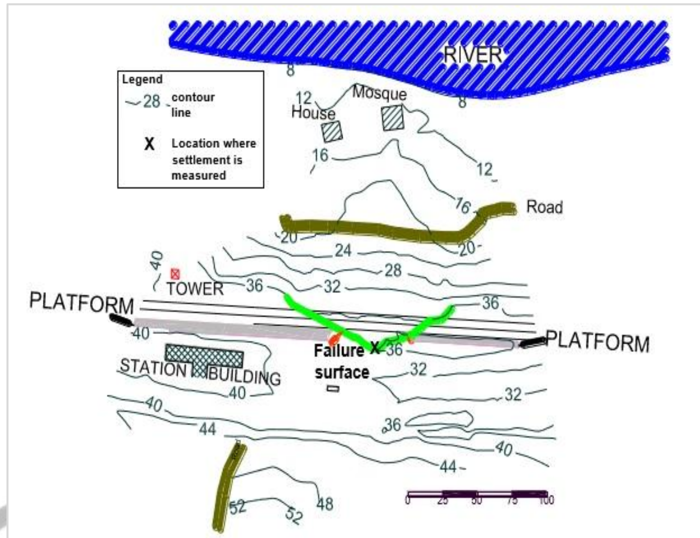


Figure 10: Failure at Nivsar Yard Embankment, [9].

The failure surface of the embankment has an inverted parabola and encloses all the tracks and platform of the Konkan Railway station, which passes through this district, shown in Figure 10. Moreover, a circular failure surface occurs and passes through the toe of the embankment terminating close to the road.

Failure to prevent the ground movement using soil nails, micropiles, relief wells, grout curtains and GI pipe drains led to the requirement of new techniques. Therefore, in 2010 the Konkan Railway shifted the rail tracks to a new rail alignment to bypass the failure surface. A significant improvement was observed on the embankment stability following this new alignment.

In this study, different models are prepared using the finite element program Plaxis 2D to study the instability of the embankment. Using 5 sections (A-A, B-B, C-C, D-D and E-E) drawn along the slope, Figure 11, the stability of the slope is calculated considering two different cases,

Case 1: stability of unreinforced slope

Case 2: stability of reinforced slope

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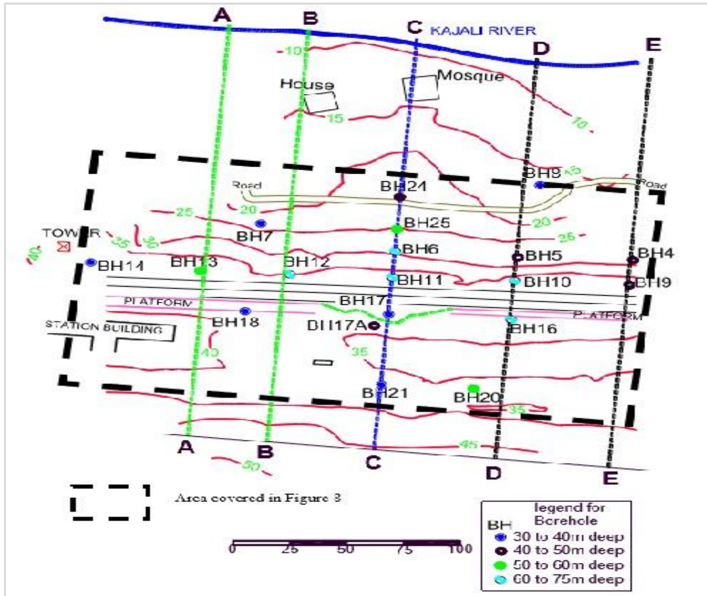


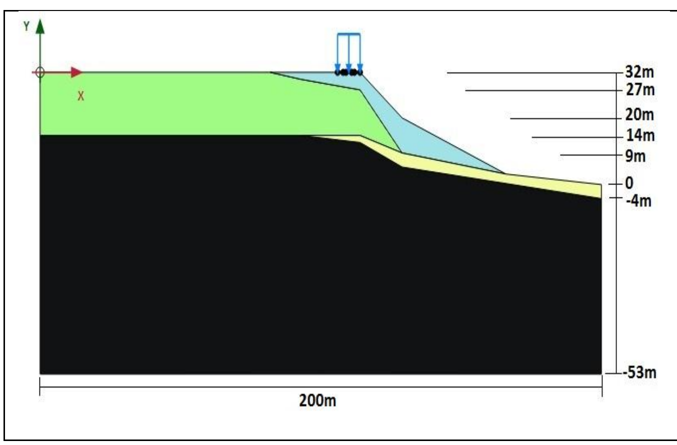
Figure 11: Borehole location along the 5 sections, [9].

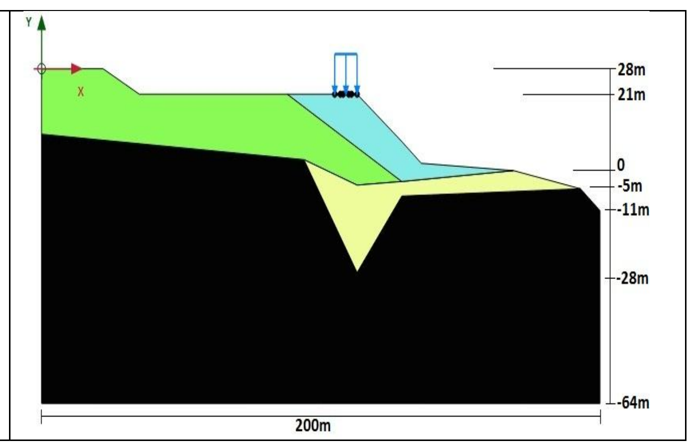
4 Methodology

Finite element analysis using Plaxis 2D software is performed to study the stability of the embankment considering the design railway loading and the water level position during the wet and dry season. In order to obtain the least possible factor of safety, a well-refined mesh is generated based on 15 node elements in a plain strain model. The behavior of the slope soil is defined using Mohr-Coulomb soil model. Standard fixity is applied for the developed Plaxis model. The groundwater flow for both dry and wet season is calculated when it reaches steady state condition. Finally, factor of safety analysis is performed and the results are compared with Juneja A. and Chatterjee D. (2013).

4.1 Plaxis 2D model

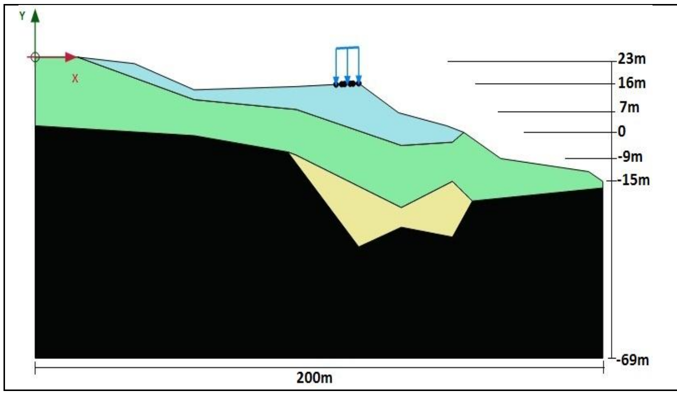
The embankment is divided into 5 cross-sections and the contour map given in Figure 11 is used to draw the subsurface profile of the site. In the Plaxis 2D analysis, similar profile of the subsurface soil is generated using same data from Juneja A. and Chatterjee D. (2013).





Section A-A

Section B-B



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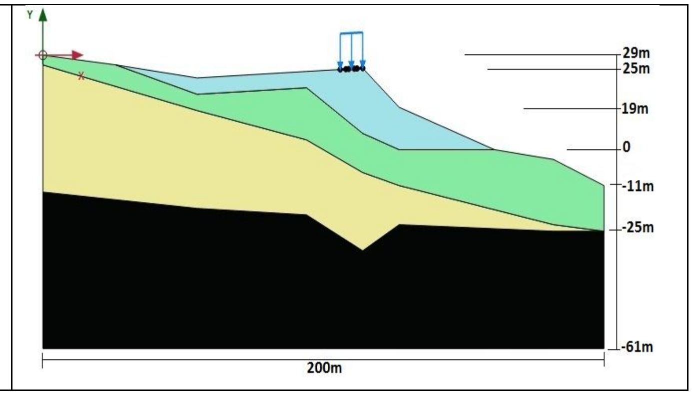
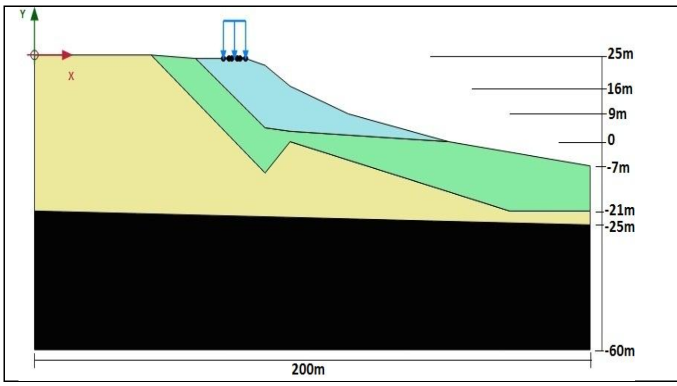


Section D-D



Section E-E

Figure 12: Soil profile at different sections (A-A to E-E).

4.2 Geotechnical and Hydrological properties

Juneja A. and Chatterjee D. (2013) collected the soil and hydrological properties from 19 boreholes drilled at the top and bottom of the embankment, Figure 11. The geotechnical and hydrological data used for the Plaxis 2D analysis are used from this reaserch paper.

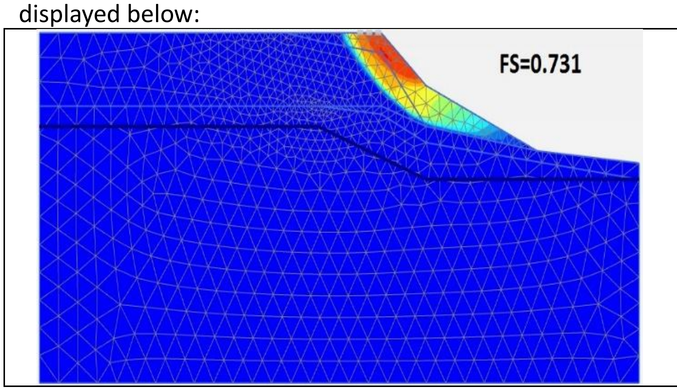
4.3 FOS calculation and comparison

Case 1: stability of unreinforced slope

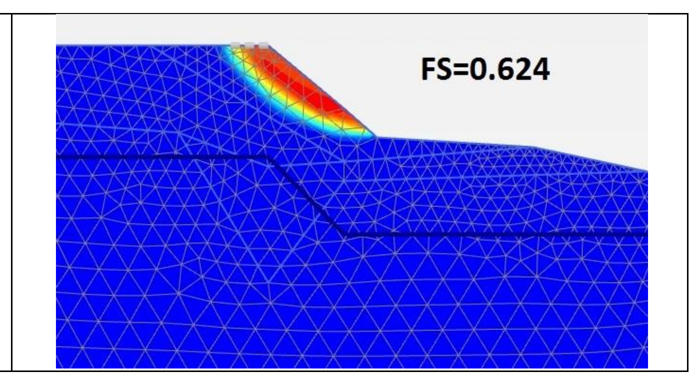
In this section, the failure of the slope in 2005 is analyzed using the Plaxis 2D software. In this analysis, a uniformly distributed live load of 125 kN/m^2 spread over 3m width at the foundation level is used for the design axel and track loads. The analysis is divided in to two parts.

Part 1- slope stability analysis during the dry season.

For these analyses, the soil parameters from Juneja A. and Chatterjee D. (2013) are utilized. The outputs results are displayed below:



Section A-A



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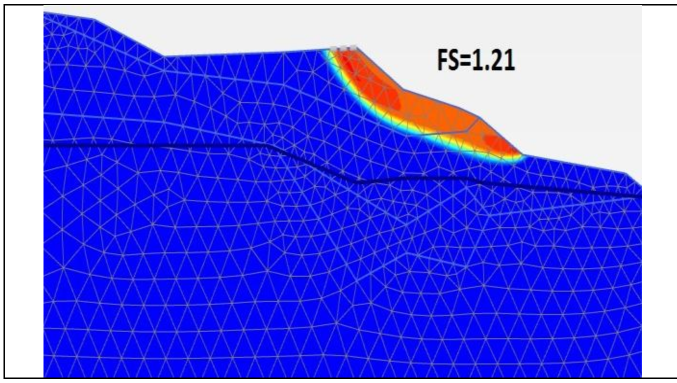

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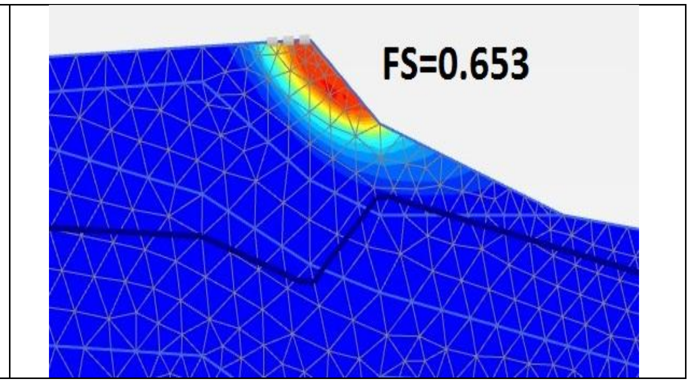

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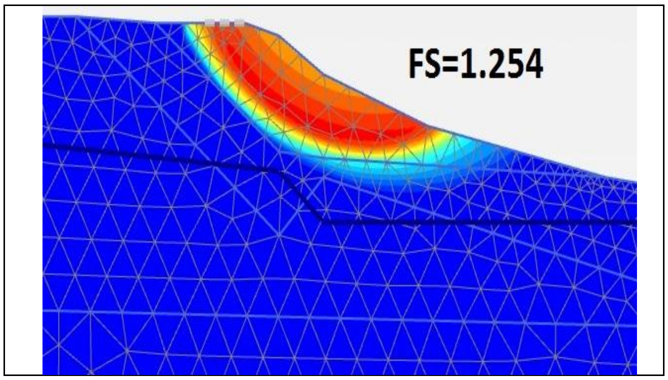

Sectioin E-E

Figure 13: Plaxis 2D results of FOS, dry season.

4.4 Discussion

The work by Juneja A. and Chaterjee D (2013) is conducted using the limit equilibruim program Talren-4. In this program, the Bishop's method of analysis is chosen for the slope stability analysis. However, the limit equilibruim method does not take into account the stress strain relationships. In order to account these relationships and compute a realistic stress distribution, Plaxis 2D is implemented and the stress strain parameters are modified to generate reasonable results.
A comparion of the factor of saftey results from the analysis methods in presented in Table 2. From the table, we can see that there is a slight difference between the factor of safety computed by the FEM and LEM program. This can show the fundamental difference in the basic principles of LE and FE methods. The LE method is based on the limit equilibruim formulations, which are dependent on static force or moment equilibrium. The FE methods is based on stress-strain relationship. The finite element analysis using Plaxis usually finds critical slip surface where the excessive strains are localised and computes the FOS by a c'-ϕ' reduction procedure for the Mohr-Coulomb model. The factor of safety is computed for each element along the CSS, in this anlysis. However, in LE analysis a single weighted average FOS is calculated. This makes the FOS calculated by the FEM more realiable than LEM method.

Table 2. Comparsion of results, dry season.

Section	Plaxis 2D results	Talren-4 results
A-A	0.731	0.77
B-B	0.624	0.69
C-C	1.21	1.37
D-D	0.653	0.75
E-E	1.254	1.43

Most of the failure surfaces obtained are circular, except section A-A and C-C., and encompasse all the rail tracks. Unlike the limit erquilibruim method where a circular slip surface is adopted, the shape and location of the failure surface is not determined prior to analysis. In addition, it observed that the ground water table is below the critical failure circle in all cases. Therefore, we can conclude that the position of the ground water table is unlikely to affect the stability of the slope during the dry season.

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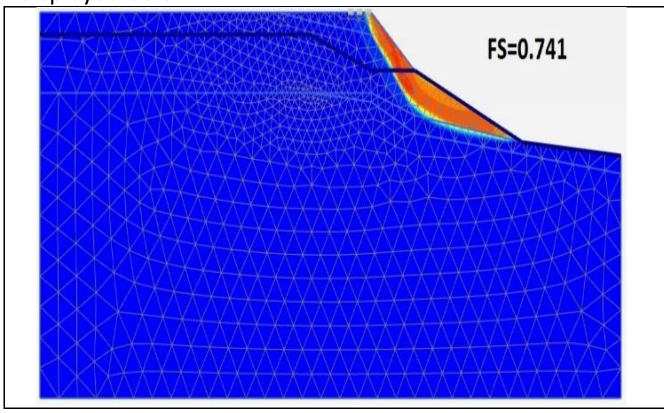
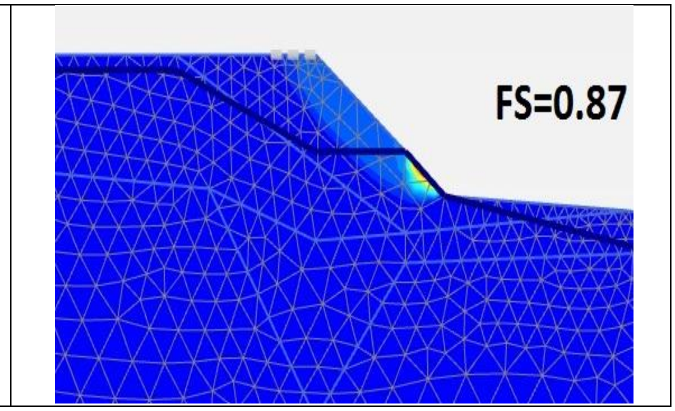
Part 2- slope stability analysis during the wet season.

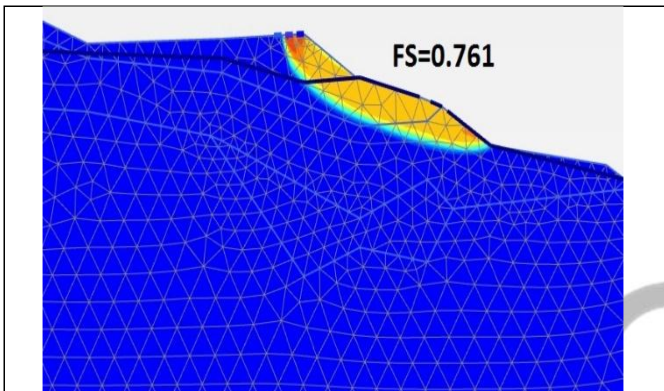
For these analyses, the soil parameters from Juneja A. and Chatterjee D. (2013) are utilized. The outputs results are displayed below:



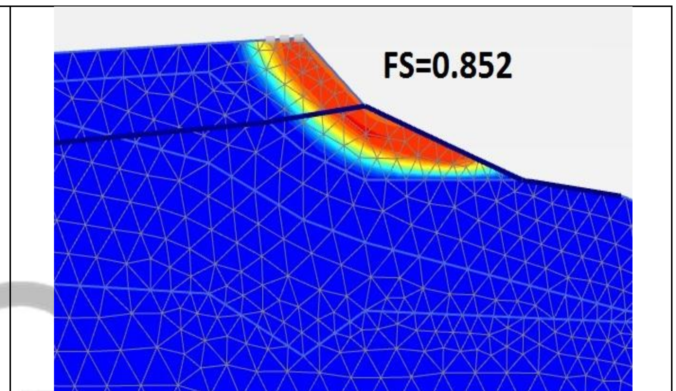
Section A-A



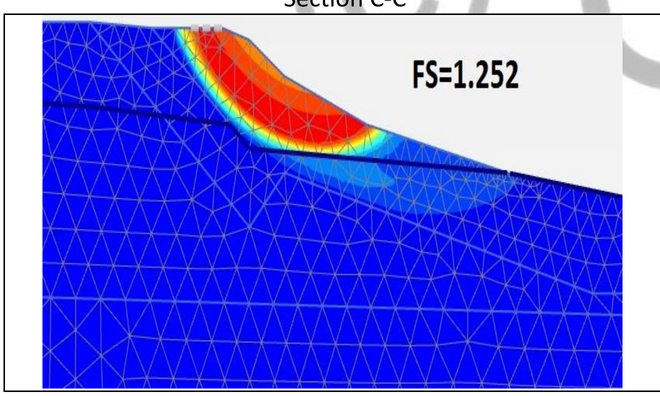
Section B-B



Section C-C



Section D-D



Section E-E

Figure 14: Plaxis 2D results of FOS, wet season.

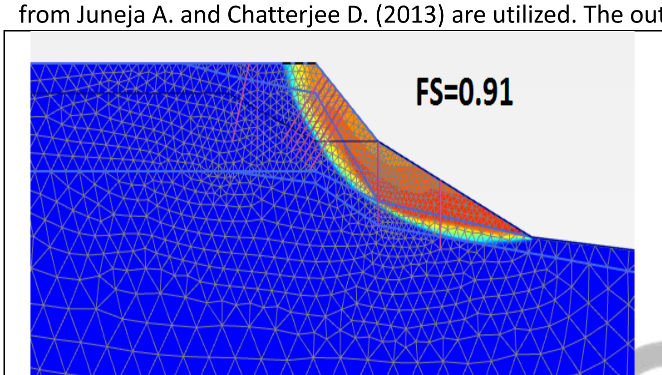
From the anlysis using both methods, we can see that the factor of safety reduces below one when the ground water level rises. In addition, the critical slip circle passes through the embankment toe, which is similar to the field observation. The depth of the critical slip circle computed using Plaxis 2D is larger than the one calculated by Talren-4.

Table 3. Comparsion of results, wet season.

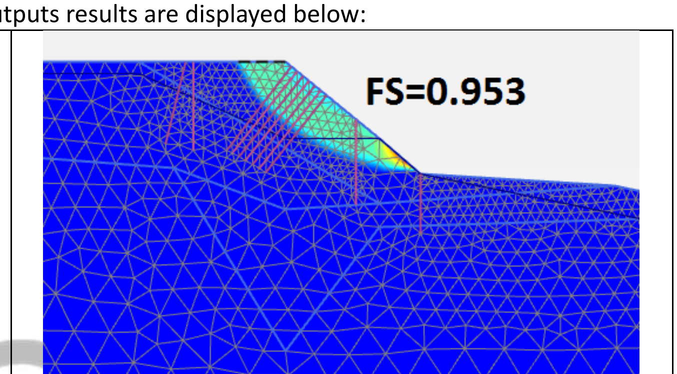
Section	Plaxis 2D results	Talren-4 results
A-A	0.741	0.73
B-B	0.87	0.91
C-C	0.761	0.87
D-D	0.852	0.84
E-E	1.252	1.25

Case 2: Stability of Reinforced Slope

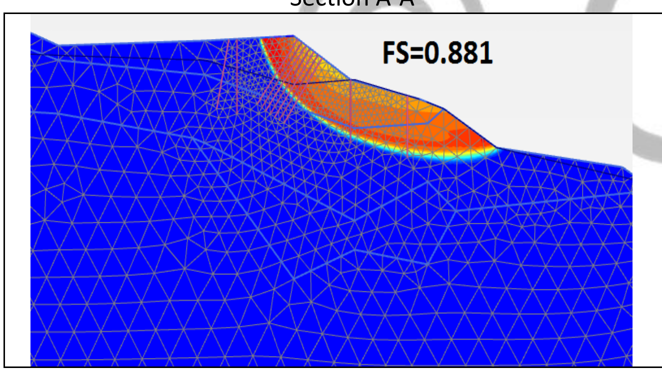
In this section, slope stability analysis of the embankment using the ground improvement (soil nails and micropiles) techniques applied in 2005 is presented. The properties of the reinforcement elements (micropiles) used for this analysis are: Young's Modulus E= 3174 kN/m^2, Unit weight γ=20 kN/m^3, Diameter D=0.8m, and Spacing $L_{spacing}$=1.5m, table 1. Similar unifromly distributed load of 125 kN/m^2 is used for the design axel and track loads. For these analyses, the soil parameters from Juneja A. and Chatterjee D. (2013) are utilized. The outputs results are displayed below:



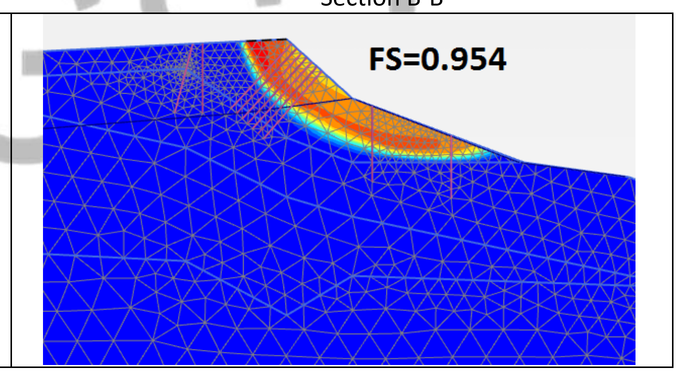
Section A-A



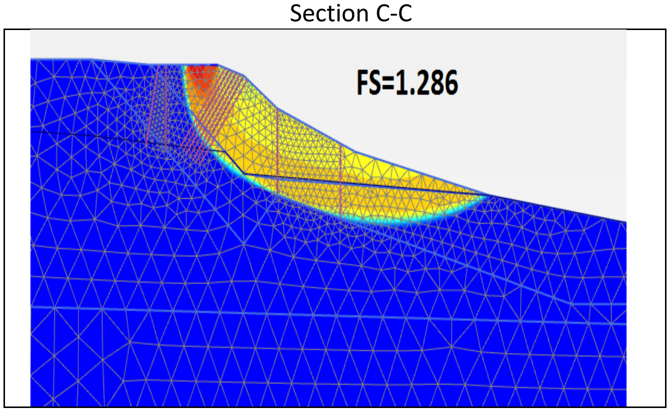
Section B-B



Section C-C



Section D-D



Section E-E

Figure 15: Plaxis 2D results for reinforced slope stability, 2005 wet season.

From both analysis, we can see that the FOS is less than one in sections A-A, C-C and D-D, FOS in section B-B is also less than according the Plaxis 2D analysis, Table 4. This indicates that the soil improvement techniques (soil nails and micropiles) employed in 2005 were not sufficient to resist the ground movement.

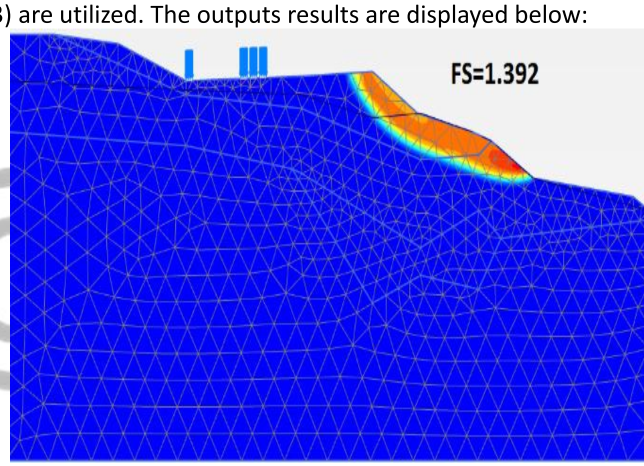
Table 4. Comparsion of results, wet season.

Section	Plaxis 2D results	Talren-4 results
A-A	0.91	0.87
B-B	0.953	1.04
C-C	0.881	0.94
D-D	0.954	0.97
E-E	1.286	1.31

According to Talren-4 outputs, the improvement measures showed insignificant influence on the shape and size of the critical slip circle. However, the plaxis 2D outputs show some improvement on the the shape and size of the failure surfaces.

4.5 Evaluation of the slope stability with new rail alignment

In 2010, the Konkan Railways changed the rail alignment, which was causing problems due to unstable ground to a new alignment. The new alignment has 3 loop-lines and 1 main-line. The analysis of factor of safety for the new alignment is done for section C-C, since this section is closer to the failure surface than the others are. Similar unifromly distributed load of 125 kN/m^2 is used for the design axel and track loads , for all the lines. For these analyses, the soil parameters from Juneja A. and Chatterjee D. (2013) are utilized. The outputs results are displayed below:



Section C-C

Fig. 16. Plaxis 2D results for section C-C, new alignment.

Both analysis show a minimum factor of safety more than 1.3 (Talren-4 result, FOS=1.46), which confirms the stability of the slope under the new alignment. However, in the Plaxis 2D analysis the depth of the slip surface is smaller and passes far away from the rail tracks. In the case of the previous calculation by Talren-4 software, the failure surface includes all the track lines. The Konkan Railway has been using this new alignment since 2011.

4.6 Conclusions

The stability analysis of the Nivsar yard embankment was carried out using Plaxis 2D. Since Plaxis software is based on stress compatibility, the soil parameters were modified to generate comparable output with the limit equilibrium program Talren-4. Minimum factor of safety is obtained from the Plaxis 2D analysis, which is compatible with the observed field condition.

Most of the failure surfaces obtained from Plaxis 2D analysis are circular, except for few sections, and encompasse all the rail tracks. Unlike the limit erquilibruim method where a circular slip surface is adopted, the shape and location of the failure surface is not determined prior to analysis.

The reinforcement provided in 2005 was not sufficient according to factor of safety results from both analyses. According to Talren-4 outputs, the improvement measures showed insignificant influence on the shape and size of the critical slip circle. However, the plaxis 2D outputs show some improvement on the the shape and size of the critical slip circle.

For the analysis considering the new rail alignment, both methods show a minimum factor of safety more than 1.3, which confirms the stability of the slope under the new alignment. In addition, Plaxis 2D generates a slip surface, which is smaller and passes far away from the rail tracks.

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REFERENCES

[1] Nordal, S. and Glaamen, M.G. (2004), "Some examples of slope stability evaluations from Norwegian geotechnical practice", Geotechnical innovations, Edited by Brinkgreve, R. B. J., Schad, H., Schweiger, H. F. and Willand, E., pp. 347-63.

[2] Abramson, L.W., Lee, T.S., Sharma, S., and Boyce, G. M. (2002). "Slope Stability Concepts. Slope Stabilisation and Stabilisation Methods". Second edition, published by John Willey & Sons, Inc., 329-461.

[3] Thielen, A., Friedel, S., Plotze, M. and Springman, S.M. (2005). "Combined approach for site investigation in terms of the analysis of rainfall induced landslides". Proceedings of the 16th Int. Conf. on Soil Mechancis and Geotechnical Engineering, Osaka Japan, p. 2591.

[4] Nash, D. (1987). "Comprehensive Review of Limit Equilibrium Methods of Stability Analysis". Slope Stability, Chapter 2. M.G. Andersen and K. S. Richards, Eds. New York, Wiley, 11-75.

[5] Duncan, J. M. (1996). "State of the Art: Limit Equilibrium and Finite Element Analysis in Slopes". Journal of Geotechnical Engineering,122 (7), 577-96.

[6] Tingkai, N., Jiang, J., Wan, S., and Luan, M. (2011). "Strength Reduction FE Analysis of the Stability of Bank Slopes Subjected to Transient Unsaturated Seepage". Electronic Journal of Geotechnical Engineering, 165-177.

[7] Lane, P.A.and Griffiths, D.V. (2000). "Assessment of Stability of Slopes under Drawdown Conditions". Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 126(5), 443-450.

[8] Juneja, A., Chatterjee, D. (2013). "Embankment Failure in Residual Soils at Nivsar, Ratnagiri". International Journal of Geoengineering Case Histories, 2(3), 229-251.