Slope Stability Analysis for High Embankment with Metacomputing Technique "A Case Study of NATRAX High Speed Track"

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Abstract **-** In the present study an attempt has been made for find out the reason of slope failure on the basis of site investigations, experimental and design analysis to provide the standard geotechnical properties of materials with the suitable side slope. Some geotechnical characteristics of soil as Grain size, Optimum moisture content and Cohesive strength has been taken in consideration to design and construct the high embankment up to 20m. The optimization of side slope with required factor of safety as per IRC guideline has been also attempted in the present study. Treatment of embankment slopes for erosion control is considered to prevent from damage due erosion from rain and wind.

Key words **-** *Stability analysis, Geotechnical property improvement, Advance methods.*

I. INTRODUCTION

The evolution of slope stability analysis in geotechnical engineering has followed closely the developments in soil and rock mechanics as a whole. Slopes either occur naturally or are constructed by humans. Slope stability problems have been faced throughout history when men or nature has disrupted the delicate balance of natural soil slopes. Furthermore, the increasing demand for engineered cut and fill slopes on construction projects has only increased the need to understand analytical methods, investigative tools, and stabilization methods to solve slope stability problems. A case study carried out for NATRAX High Speed Track, Pithampur in Dhar District, about 45km from Indore, MP India. The proposed embankment will be the oval High Speed Track for vehicle testing purpose, at which the vehicle with speed up to 350 km/hr will be tested.

About the site

NATRAX (National Automotive Test Track) is a up leading test centre of NATRIP (National Automotive Testing and R&D Infrastructure Project). NATRAX will be the world class automotive proving ground set up on 4123 acres with digital testing infrastructure capable of sensing fine nuance of an automobile. The proving ground will have all verities of structure types to test vehicles against varying terrains and stringencies. The heart of the proving ground will be oval High Speed Track which is 13.28 km in length where vehicle with natural speed up to 350 kmph would be tested. A large part of test load relating to speed, noise, vibration, handling, stability etc. is expected to shift to India from abroad once this infrastructure is complete. Once ready, it will be world's largest providing ground.

NATRAX will be the CoE for vehicle dynamic. NATRiP has planned an expenditure of Rs 900 carores to create world-class facilities at NATRAX

Need for present study

The project has to recognize a need for consistent understanding and application of slope stability analysis for construction and remediation projects across the India and abroad. These analysis are generally carried out at the beginning, and sometimes throughout the life, of projects during planning, design, construction, improvement, rehabilitation, and maintenance. Planners, engineers, geologists, contractors, technicians, and maintenance workers become involved in this process. This body of information encompasses general slope stability concepts, engineering geology principles, groundwater conditions, geologic site explorations, soil and rock testing and interpretation, slope stability concepts, stabilization methods, instrumentation and monitoring, design documents, and construction inspection.

Objective of the study

- Identification of significant parameter those affect the system.

- To establish a simplified method of monitoring the performance of system to avoid the practical complexity.
- To improve the cohesion of soil with respective angle of internal friction (Ø) as required condition.
- To develop an appropriate system by using advance method with enhancing accuracy.

Scope of the study

With the present study it is possible to remove the geotechnical deficiencies in the existing ground set-up. High embankment (up to 20m) has been design with proper and safe side slope, optimization of slope with necessary safety factor has been kept in mind to enhance the proper land use. Safety provisions are considered for road users. Treatment of embankment slopes for erosion control is considered to prevent from damage due erosion from rain and wind. Drainage from road and side slopes is also considered to prevent damage in rainy seasons.

II. COMPUTER PROGRAMS

For more sophisticated analysis and complex slope, soil, and loading conditions, computer programs are generally used to perform the computations. Computer programs are available that can handle a wide variety of slope geometries, soil stratigraphies, soil shear strength, pore water pressure conditions, external loads, and internal soil reinforcement. Most programs also have capabilities for automatically searching for the most critical slip surface with the lowest factor of safety and can handle slip surfaces of both circular and noncircular shapes. Most programs also have graphics capabilities for displaying the input data and the results of the slope stability computations.

Types of computer programs

Two types of computer programs are available for slope stability analysis: The first type of computer program allows the user to specify as input data the slope geometry, soil properties, pore water pressure conditions, external loads, and soil reinforcement, and computes a factor of safety for the prescribed set of conditions. These programs are referred to as *analysis programs*. They represent the more general type of slope stability computer program and are almost always based on one or more of the procedures of slices.

The second type of computer program is the *design program*. These programs are intended to determine what slope conditions are required to provide one or more factors of safety that the user specifies. Many of the computer programs used for reinforced slopes and other types of reinforced soil structures such as soil nailed walls are of this type. These programs allow the user to specify as input data general information about the slope geometry, such as slope height and external loads, along with the soil properties.

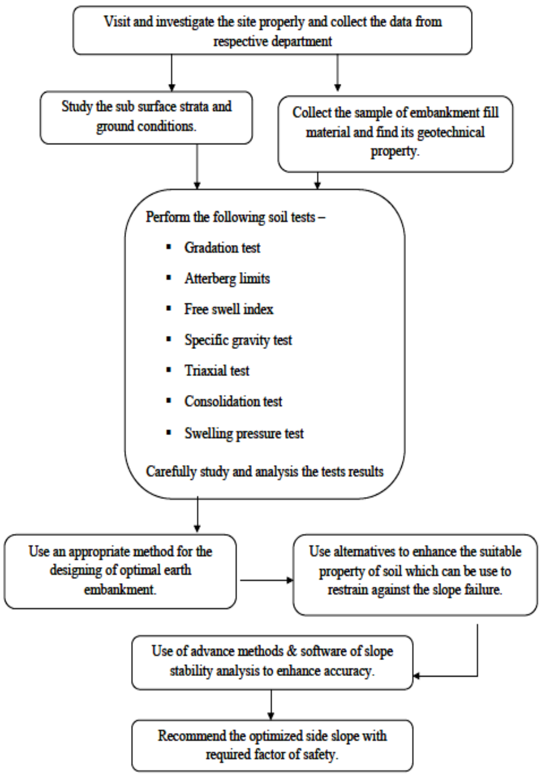
Different methods for computing factor of safety

Different methods of stability analysis indicating equilibrium conditions, forces and factor of safety considered. Almost all computer programs employ one or more schemes for searching for a critical slip surface with the minimum factor of safety

S. No	Methods	Moment Equilibrium	Force Equilibrium	Inter Slice Normal ces	Inter Slice Shear Forces	Moment Factor of safety	Force Factor Of Safety	Inter Slice Force Function
1	Fellenius, Swedish circle or ordinary Method (1936)	Yes	No	No	No	Yes	No	No
2	Bishop Simplified method (1955)	Yes	No	Yes	No	Yes	No	No
3	Janbu Simplified method (1954)	No	Yes	Yes	No	No	Yes	No
4	Morgenster n -Price method (1965)	Yes	Yes	Yes	Yes	Yes	Yes	Const ant Half -Sine

III. METHODOLOGY

The study has been carried out by collecting information of project site from Rites Ltd. and study the re-usability of the excavated material. Laboratory investigation of sub surface material and embankment fill materials have been collected from site. The conventional Limit Equilibrium method is used to analyze the high embankment slope stability. Program Geo-Studio (SLOPE/W) is formulated in terms of moment and force equilibrium factor of safety equations. Analysis provides a factor of safety, defined as a ratio of available shear resistance (capacity) to that required for equilibrium.



IV.TESTS AND SIMULATION RESULTS

4.1 Test results of Excavated Fill Materials collected from site.

Sr. No.	Sample	Proctor Compaction Test		Grain Size Analysis				Triaxial Compaction Quick Test	
		OMC %	MDD gm/cc	Gravel %	Sand %	Silt %	Clay %	C kg/cm^2	Ø^0
1	Fill material I	6	1.82	23.21	24.51	41.82	10.46	0.07	15
2	Fill material II	16	1.8	18.64	17.96	42.48	20.92	0.7	7
3	Fill material III	22	1.87	34.81	39.59	21.76	3.84	0.7	10
4	Fill material IV	9	1.94	69.71	12.53	16.33	1.42		
5	Fill material V	22	1.27	32.43	60.79	5.36	1.42		
6	Fill material VI	10	1.79	61.86	32.2	5.69	0.24		
7	Fill material VII	21	1.83	46.84	26.23	16.56	10.37	0.82	13

The tests mentioned above has been done for different types of material to enhance the check the geotechnical suitability of the material for high embankment side slope with required factor of safety. The excavated material has been collected from site perform the tests to ensure that whether this material is suitable for embankment fill or not, the test results are shown in table 4.1. The results of Borrowed Fill Materials collected from local area near site are shown in table 4.2.

Gravel and sand contain of some material is much higher that so that the triaxial test not possible for that kind of materials, to overcome from this problem it is possible to processing the soil in terms of altering its grain size distribution.

Some modifications have been done with the materials by mechanical blending to perform the triaxial test and can find out the cohesive strength of material. The test results of the altered grain size distribution of the soil samples are shown in table 4.3.

4.2 Test results of Borrowed Fill Materials collected from site

Sr. No.	Sample	Proctor Compaction Test		Grain Size Analysis				Triaxial Compaction Quick Test	
		OMC %	MDD gm/cc	Gravel %	Sand %	Silt %	Clay %	C kg/cm^2	Ø^0
8	Yeloowish Murrum	17	1.66	9	40	30	21	0.26	20
9	Brownish Murrum	14	1.9	40	41	19		0.21	32
10	SM	20	1.76	3	58	29		0.13	36
11	Silt Clay CH	26	1.62	1	11	48	40	0.69	10
12	Silt Clay CH	25	1.62	6	9	41	44	0.66	10
13	Silty Sand SP	8	1.81	0	98	2			
14	Sandy Gravel GP	7	2.2	95	1	4			

The materials with some grain size alteration (table 4.3) have been denoted by the coding as Fill material V with Gravel 20% (FV g20%) is denoted by M1, Fill Material V with Gravel 30% (FV g30%) is denoted by M2, Fill Material V with Gravel 40% (FV g40%) is denoted by M3, Fill Material V with Gravel 50% (FV g50%) is denoted by M4. Similarly some borrowed materials ware mixed together with some particular fixed percentage (as shown in Table 4.3) to check the change of geotechnical property of the materials, as the borrowed material 14 (Sandy Gravel GP) 60% and borrowed material 11 (Silt Clay CH) 40% is coded by M5, the same materials ware again altered with various percentage mix to verify the effect of gravel and silt quantity variations. The borrowed material 14 (Sandy Gravel GP) 40% and borrowed material 11 (Silt Clay CH) 60% is denoted by M6, again the borrowed material 13 (Sandy Gravel GP) and borrowed material 11 (Silt Clay CH) is added in same quantity (50% + 50%) which is coded by M7. Then the four borrowed materials 11, 12, 13, 14 were mixed together with same quantity i.e. 25% of all four materials, which is denoted by M8. All these materials test results is shown in Table 4.3.

4.3 Test results of Borrowed Fill Materials collected from site with some grain size alteration

Sr. No.	Sample	Proctor Compaction Test		Grain Size Analysis				Triaxial Compaction Quick Test	
		OMC %	MDD gm/cc	Gravel %	Sand %	Silt %	Clay %	C kg/cm^2	Ø^0
1	F V (g20%)	18	1.79	21.87	31.32	41.95	4.86	0.74	14
2	F V (g30%)	17	1.84	30.79	28.98	37.09	3.14	0.7	15
3	F V (g40%)	16	1.88	40.83	20.97	36.76	1.44	0.64	16
4	F V (g50%)	14	1.9	50.12	15.61	32.82	1.45	0.6	16
5	F14+F11 (60%+40%)	18	1.86	48.14	20.43	15.13	16.3	0.82	10
6	F14 + F11 (40%+60%)	19	1.88	38.23	6.13	31.14	24.5	0.84	8
7	F14 + F11 (50%+50%)	18	1.85	45.43	7.12	26.71	20.74	0.83	11
8	F11+F12+ F13+F14 (All 25%)	17	1.8	26.33	30.15	39.52	4	0.79	15

V. ANALYSIS AND FINDINGS

The analysis of collected data and test results will serve to identify the deficiencies in slope stability for high embankment and suggest for overcoming the deficiencies.

The conventional limit equilibrium methods investigate the equilibrium of the soil mass tending to slide down under the influence of gravity. Transitional or rotational movement is considered on assumed or known potential slip surface below soil mass. All methods are based on comparison of forces (moments or stresses) resisting instability of the mass and those that causing instability (disturbing forces). Two-dimensional sections are analyzed assuming plain strain conditions. These methods assume that the shear strengths of the materials along the potential failure surface are governed by linear (*Mohr-Coulomb*) or non-linear relationships between shear strength and the normal stress on the failure surface. Analysis provides a factor of safety, defined as a ratio of available shear resistance (capacity) to that required for equilibrium.

Functional slope design considers calculation with the critical slip surface where is the lowest value of factor of safety. Locating failure surface can be made with the help of computer programs using search optimization techniques. Program **SLOPE/W** is formulated in terms of moment and force equilibrium factor of safety equations. Limit equilibrium methods include *Morgenstern-Price*, *Spencer*, *Bishop*, *Ordinary*, *Janbu* etc. This program allows integration with other applications.

Analysis modeling

Modeling of the continuum is suitable for the analysis of soil slopes, massive intact rock or heavily jointed rock masses. This approach includes the finite difference and finite element methods that discretize the whole mass to finite number of elements with the help of generated mesh. Various types of models ware analyse for different soil properties and heights of embankment with their respective side slope. These models are analysed on axis symmetry geometry.

The typical cross sections of the embankment of 20m height with side slope of 1:2 without any berm is shown in figure 5.1.

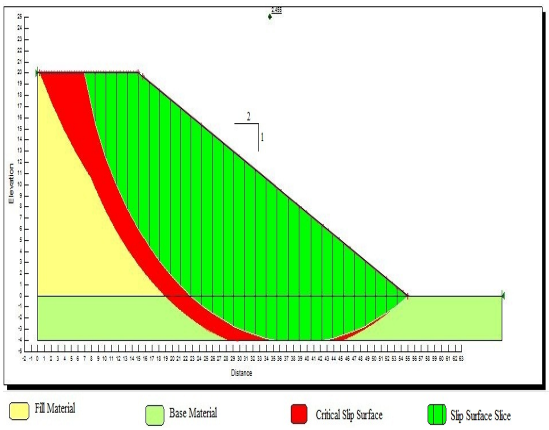


Fig. 5.1 : Typical cross sections of the embankment of 20m height with side slope of 1:2

The above cross section of the embankment defines different type of materials by different colours. Red colour shows the critical slip surfaces or the critical area. The hatched area shows the slice which divides the potential sliding soil mass into sections, the calculation of forces on slice will estimate the total sliding soil mass.

Table 5.3 : Stability Analysis by SLOPE/W for Excavated Fill Materials at side slope of 1:1.7

S no.	Embankment Height (m)	Side Slope	Material properties				Factor of Safety (calculated by different methods)			
			Material Index	Fill Material						
				γ kN/m³	C kN/m²	Ø⁰	Ordin-ary	Bisho-ps	Janbu	M. P.
1	20	1:1.75	F I	17	123	4	2.618	2.664	2.659	2.665
2	20	1:1.75	F II	15	68	7	2.121	2.141	2.066	2.418
3	20	1:1.75	F III	16	68	10	2.22	2.288	2.175	2.302
4	20	1:1.75	F VII	17	80	13	2.277	2.368	2.245	2.377

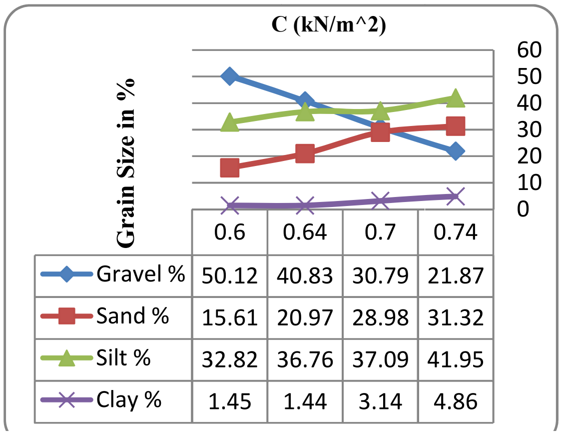
Table 5.2: Stability Analysis by SLOPE/W for Excavated Fill Materials at side slope of 1:2

5	20	1:2	F I	17	123	4	2.605	2.679	2.627	2.674
6	20	1:2	F II	15	68	7	2.246	2.185	2.168	2.305
7	20	1:2	F III	16	68	10	2.304	2.334	2.263	2.405
8	20	1:2	F VII	17	80	13	2.303	2.428	2.259	2.237

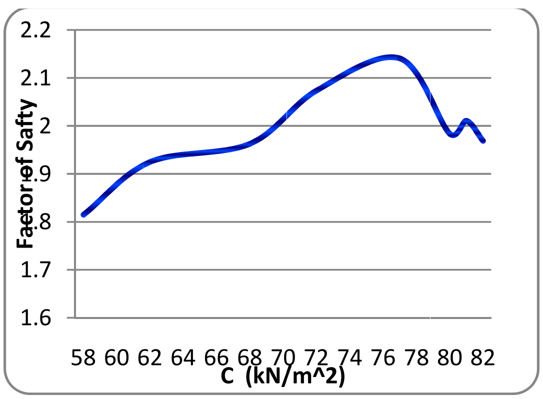
Table 5.3: Stability Analysis by SLOPE/W for Borrowed Fill Materials collected from site with some modifications

S no.	Embankment Height (m)	Side Slope	Material properties				Factor of Safety (calculated by different methods)			
			Material Index	Fill Material						
				γ kN/m³	C kN/m²	Ø⁰	Ordin-ary	Bisho-ps	Janbu	M. P.
1	20	1:1.75	M 1	14	72	14	2.003	2.074	2.02	2.074
2	20	1:1.75	M 2	15	68	15	1.883	1.963	1.886	1.96
3	20	1:1.75	M 3	15	62	16	1.838	1.925	1.837	1.922
4	20	1:1.75	M 4	16	58	16	1.723	1.815	1.714	1.81
5	20	1:1.75	M 5	15	80	10	1.929	1.984	1.952	1.958
6	20	1:1.75	M 6	15	82	8	1.92	1.969	1.946	1.971
7	20	1:1.75	M 7	15	81	11	1.954	2.011	1.986	2.012
8	20	1:1.75	M 8	14	77	15	2.07	2.141	2.098	2.14

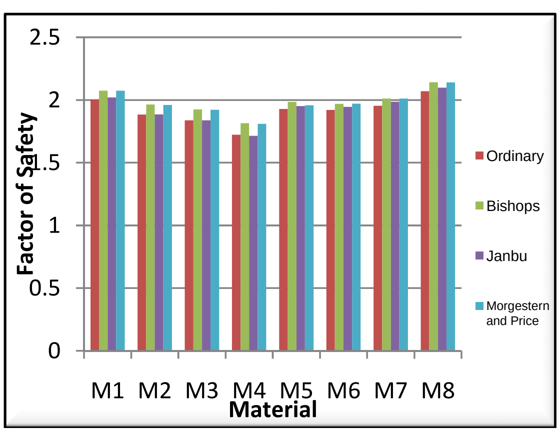
Effect of Grain size on Cohesion



Factor of Safety V/s Cohesion of soil of side slope 1:1.75



Factor of safety of modified material by different methods



VI. CONCLUSION AND RECOMMENDATION

The selection of slope stability methods is critical since the accuracy of the analysis results depends on the mechanics of the failure. Based on the field observations, theoretical analysis and experimental study following points are concluded:

1. The Ordinary Swedish Circle Method always estimate lower factor of safety compared to other three methods like Bishop's Simplified Method, Janbu Method and Morgenstern and Price Method.
2. For embankment of height up-to 20m, the material should be homogeneous and well compacted, it should be ensure that the water content of the embankment material should be within the specific limit and that is uniformly distributed throughout the soil prior the rolling.
3. For safe embankment side slope the cohesion (C) of the soil or the fill material should be 72 – 80 kN/m^2 and the angle of internal friction (Ø) should be 15^0 – 20^0.
4. Processing the soil in terms of altering its grain size distribution is rarely possible but in some critical cases mechanical blending procedure can be adopt to achieve the geotechnical property of the soil regarding withstanding the side slope.
5. Normally 40% – 45% of Gravel, 15% - 20% of Sand, 30% - 35% of Silt and 1% - 5% of Clay is suitable for fill material of 20m high embankment with the side slope of 1:1.75 to 1:2.
6. Treatment of embankment for erosion control shall be done by stone pitching from top of embankment.

REFERENCE

[1] Werneck, L. G. M., Lacerda A. W., and Ramalho-Ortigao J.A., (1983). "Embankment failure on clay near Rio de Janeiro." Journal of Geotechnical Engineering, vol.109(11),1460-1479.

[2] Wu, H.T., Randolph, W.B., and Huang C.S., (1993). "Stability of shale embankments." Journal of Geotechnical Engineering, vol. 119(1), 127-146.

[3] Manzari M.T., and Nour M.A., (2000). "Significance of soil dilatancy in slope stability analysis." Journal of Geotechnical and Geoenvironmental Engineering, vol. 126(1), 75-80.

[4] Zaretskii, Yu.k., (2001). "Provision for slope and embankment stability." Journal of soil

Mechanics and Foundation Engineering, vol. 38(6), 2-6.

[5] Ashford, S.A., and Sitar, N., (2002). "Simplified method for evaluating seismic stability of steep slopes." Journal of Geotechnical and Geoenvironmental Engineering, vol. 128(2), 119-128.

[6] Irsyam,M., Susila,E., and Himawan,A., (2006). "Slope failure of an embankment on clay shale at Km 97+500 of the Cipularang toll road and the selected solution." Int. Conf., on Geotechnical Engineering, Ground Improvement and Geosynthetics 2006, HSEP Bangkok, Thailand.

[7] Sinha, B.N. (2007). "Advance methods of Slope-Stability Analysis for Economical Design of Earth Embankment." IRC Journal, vol. 68(3), 201-222.

[8] Batog, A., and Stilger-Szydlo, E., (2009). "New Approach to Assessment of road embankment Stability." Studia Geotechnica et Mechanica, vol. 31(3) 27-46.

[9] Saha, S., (2009). "Control of landslide hazards through Slope Stability Analysis – Case Studies." IRC Journal, vol. 37(12), 23-31.

[10] Behera, J., (2009). "Slope SStabilization in hill roads using Bio-Engineering works: A case study of Mizoram state road projects." IRC Journal, vol. 37(10), 31-37.

[11] Zhang, J., Tang W.H., and Zhang, L.M., (2010) "Efficient probabilistic Back-Analysis of Slope Stability model parameters." Journal of Geotechnical and Geoenvironmental Engineering, vol.136(1), 99-109.

[12] Collins, B.D., and Sitar, N., (2011). "Stability of steep slopes in Cemented Sands." Journal of Geotechnical and Geoenvironmental Engineering, vol.137(1), 43-51.

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