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Slope Stability Analysis by GeoSlope

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Abstract
The present study is concerning to the stability analysis done for the dump slope of WCL Makardhokara-2 open cast mine in Umred, District Nagpur, Maharashtra, India. In this area dump failures are reported due to the improper geometry of the dumps. Slope stability analysis by seven finite slope stability methods namely Morgenstern price method, Spencer method, Sarma method, Bishop method, Janbu method and ordinary method is done using GeoSlope software for the dump slope in Makardhokara site. At the obtained results are compared and presented.

Keywords
Geoslope, Slope Stability, Soil Nail, Finite Slope, Factor of Safety

Introduction

Slopes can be natural or man-made. These may be above ground level as embankments or below ground level as cuttings. Earth slopes are formed for railway embankments, earth dams, canal banks, levees, and at many other locations. Instability related issues in engineered as well as natural slopes are common challenges to both researchers and professionals. Instability may result due to rainfall, increase in groundwater table and change in stress conditions. Similarly, natural slopes that have been stable for many years may suddenly fail due to changes in geometry, external forces and loss of shear strength.

In addition, the long-term stability is also associated with the weathering and chemical influences that may decrease the shear strength. In such circumstances, the evaluation of slope stability conditions becomes a primary concern. When a mass of soil has an inclined surface the potential of slope to slide from higher level to lower level always exist. The primary aim of slope stability analyses is to contribute to the safe and economic design of excavation, embankment and earth dams. [1-7]

To do the stability analysis of finite slopes, different approaches are available such as Morgenstern price method, Spencer method, Sarma method, Bishop method, Janbu method and ordinary method based on limit equilibrium approach.[8]

In this paper, stability analysis is carriedout for a dump slope in WCL Makardhokara-2 open cast mine, Umred. This region is very prone to instability as area is covered by black cotton soil up to the depth of 20 m. In this area dump failures are reported due to improper geometry of the dump. At the site location, the main constraint was related to availability of the land for dump. The available land is 40 m and height of dump is 17.5 m (Figure 1) due to presence of railway track. Analysis of the problem is done by all the above mentioned methods with and without reinforcement using GeoSlope software and results are discussed here.

Slope Stability Analysis

Slope stability analysis is performed to assess the safe design of human-made or natural slopes (e.g. embankments, road cuts, open-pit mining, excavations, landfills etc.) and the equilibrium conditions. Slope stability is the resistance of inclined surface to failure by sliding or collapsing. The main objectives of slope stability analysis are finding endangered areas, investigation of potential failure mechanisms, and determination of the slope sensitivity to different triggering mechanisms, designing of optimal slopes with regard to safety, reliability and economics, designing possible remedial measures. Some of the typical methods used for analysis of finite slopes are used and discussed in brief. Following methods of finite slope stability analysis are used in the present study.

- Morgenstern-Price method
- Spencer Method
- Bishop Method
- Janbu Method
- Ordinary Slices Method
- Sarma Method

GeoSlope Software

GeoSlope[12] is modern limit equilibrium software useful to handle complexity within an analysis. It is now possible to deal with complex stratigraphy, highly irregular pore-water pressure conditions, and various linear and nonlinear shear strength models, almost any kind of slip surface shape, concentrated loads, and structural reinforcement. Limit equilibrium formulations based on the method of slices are also being applied more and more to the stability analysis of structures such as tie-back walls, nail or fabric reinforced slopes, and even the sliding stability of structures subjected to high horizontal loading arising, for example, from ice flows.

Stability Analysis of Dump Slope

Dump slope in WCL Makardhokara-2 open cast mine, Umred is analysed for both conditions i.e. unreinforced and reinforced (by soil nailing & ground anchor techniques) by all above mentioned methods of finite stability analysis. Due to presence of railway tract, main constraint was related to availability of the space for the dump (40 m wide) and dump height is restricted to 17.5 m as seen from Figure 1.

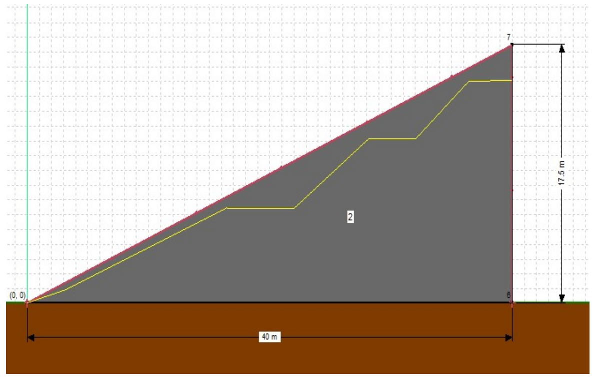

Figure 1: Field Dimensions

In the beginning, stability analysis is done for unreinforced section by varying the slope angles and geometry (Figure 2) to achieve FOS for the slope greater than 1.5. Table 1 shows the FOS computed by various methods for different slope angles. In general it is observed that, the unreinforced slope is not stable as the computed FOS is less than 1.5.

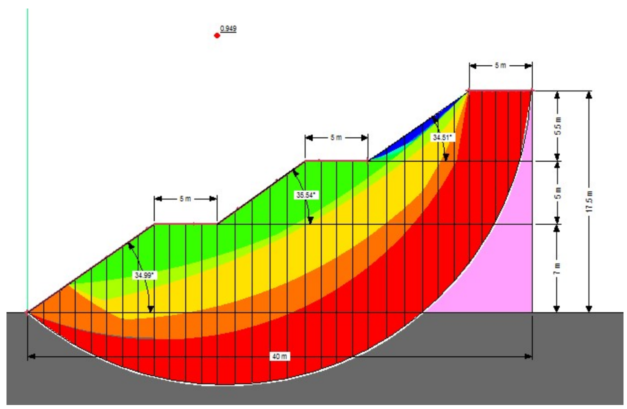

Figure 2: Field Dimensions

Slope Inclination (in °)	Factor of Safety (FOS)					
	Morgestern Price	Spencer	Sarma	Bishop	Janbu	Ordinary
45	1.033	1.032	1.031	1.033	0.994	1.017
40	1.062	1.063	1.062	1.063	1.022	1.046
35	1.132	1.131	1.131	1.132	1.079	1.116
30	1.272	1.272	1.272	1.272	1.191	1.252
27	1.380	1.386	1.383	1.386	1.288	1.365
25	1.576	1.583	1.583	1.584	1.554	1.560

Table 1: FOS Comparison

Methodology for Soil Stabilization

Soil nailing as an effective stabilization technique for the slopes, excavations, rail or road embankments, tunnels and retaining walls wherein, passive reinforcement is done by the insertion of slender elements (normally steel reinforcing bars) called soil nails. The reinforcement is installed horizontally or gently inclined parallel to the direction of tensile strain so that it develops maximum tensile force. The function of soil nailing is to strengthen or stabilize the existing steep slopes and excavations as construction proceeds from the top to bottom. Soil nails develops their reinforcing action through soil-nail interaction due to the ground deformation which results in development of tensile forces in soil nail. The major part of resistances comes from development of axial force which is basically a tension force. Conventionally, shear and bending have been assumed to provide little contribution in providing resistance [8-13]. The effect of soil nailing is to improve the stability of slope or excavation through;

a) Increasing the normal force on shear plane and hence increase the shear resistance along slip plane in friction soil.
b) Reducing the driving force along slip plane both in friction and cohesive soil.

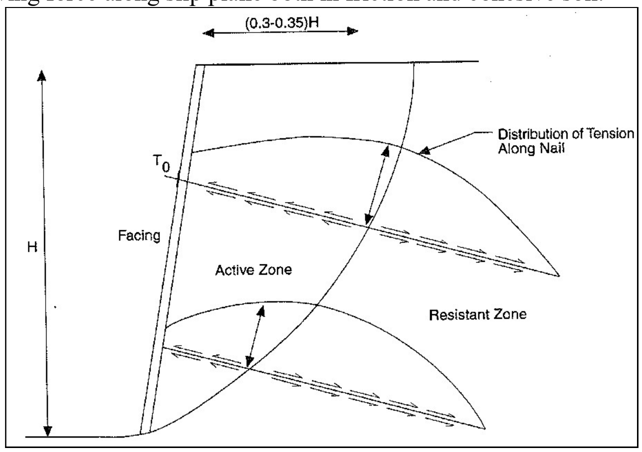

Figure 3: Conceptual Soils Nail Behaviour (Byrne et al., 1998)

The soil nail system can be divided into active and passive region as shown in the Figure 3. During the slope failure, active region tends to deform which results in an axial displacement along soil nails which are placed across the slip plane. This results in the development of tensile forces in soil nail in the passive zone which resists the deformation of active zone. This tension force results in increment of the normal force coming on slip plane and reduces the driving shear force. The soil nails are embedded in passive region through which it resists the pull-out of nail from slope through friction between nails and soil. Based on the above two mechanisms, the required amount of nail length should be placed in resistive zone. In addition, the combined effect of nail head strength and tension force generated in active zone must be adequate to provide the required nail tension at the slip surface [9]. In the present study using this technique of Soil Nailing analysis is done on GeoSlope software for the following three conditions and only static analysis is done i.e. no consideration of dynamic forces and their effects on factor of safety;

i. Variation in the diameter of the soil nail between 16 to 30 mm
ii. Variation in centre to centre spacing between soils nailing from 1m to 3m.
iii. Variation in the nail length from 1m to 3m.

Discussion

Slope stability analysis is done for the above mentioned three variation and following observations are made from the results observed on GeoSlope.

i. Effect of Variations in Diameter of Soil Nail

When the diameter of the soil nailed varied from 16 mm to 30 mm diameter, it is observed that, with the increase in diameter of nail, the FOS increases as indicated from the Table 2. However, no significant improvement in the FOS is seen for the nail diameter 20 mm and above.

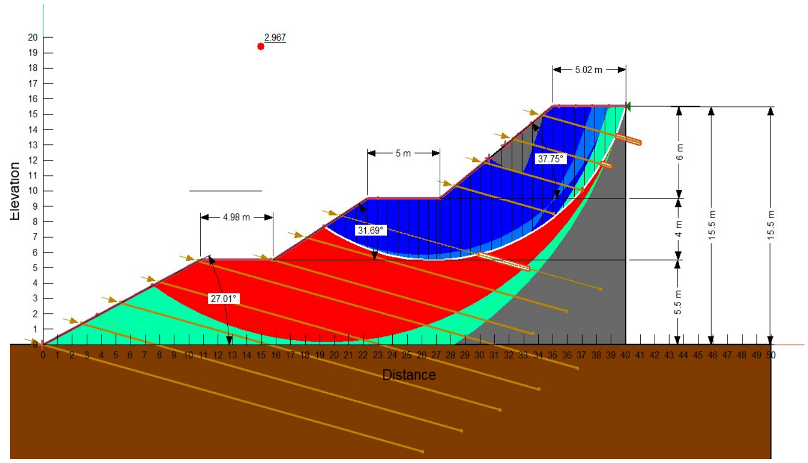

Figure 4: A 27° Inclined Dump Slope Reinforced with 16 mm Diameter Soil Nail

Diameter Of soil nail (in mm)	Factor of Safety (FOS)					
	Morgestern Price	Spencer	Sarma	Bishop	Janbu	Ordinary
16	2.131	1.882	2.219	1.983	2.127	2.129
18	2.197	1.929	2.195	2.993	2.193	2.195
20	2.206	1.946	2.204	2.003	2.204	2.202
22	2.208	1.951	2.206	2.005	2.204	2.206
24	2.210	1.956	2.208	2.009	2.207	2.208
26	2.212	1.961	2.211	2.005	2.209	2.211
28	2.215	1.966	2.213	2.006	2.211	2.213
30	2.217	1.971	2.215	2.006	2.214	2.216

Table 2: FOS for Varying Soil Nail Diameter

ii. Effect of Variation in Spacing

When the spacing between the nails is varied, it is observed that, the value of FOS reduces (in all methods) as seen from the results tabulated in Table 3. This indicates, centre to centre spacing (lateral) can be increased up to 2.5 m from economy point of view and beyond which overall stability affects.

Centre to centre Spacing (in m)	Factor of Safety (FOS)					
	Morgestern Price	Spencer	Sarma	Bishop	Janbu	Ordinary
1.00	3.076	4.292	4.290	3.075	3.440	2.424
1.25	2.607	3.292	3.291	2.606	2.743	2.186
1.50	2.476	2.605	2.592	2.476	2.231	2.146
1.75	2.270	2.28	2.269	2.276	2.025	2.167
2.00	2.224	2.218	2.216	2.219	1.976	2.007
2.25	2.100	2.100	2.098	2.101	1.876	1.919
2.50	2.094	2.106	2.099	2.106	1.867	1.916
2.75	1.895	1.904	1.898	1.904	1.726	1.768
3.00	1.786	1.794	1.789	1.795	1.618	1.700

Table 3: FOS for Varying C/C Spacing between Soil Nails

iii. Effect of Soil Nail Length

To understand the effect of length of soil nail beyond the potential plane of failure in the given condition, lengths were varied from 0.25 m to 2.0 m beyond failure plane and analysis was done. An observation tabulated in the Table 4 reflects an overall increase in the FOS with increase in soil nail length beyond failure plane. This is due to development of more resistance in the passive zone.

Soil Nail Length (in m)	Factor of Safety (FOS)					
	Morgestern Price	Spencer	Sarma	Bishop	Janbu	Ordinary
0.25	2.168	2.673	2.272	2.166	2.65	2.645
0.50	2.733	2.791	2.362	2.207	2.761	2.762
0.75	2.858	2.914	2.459	2.224	2.883	2.889
1.00	2.995	3.048	2.565	2.243	3.025	3.027
1.25	3.144	3.195	2.68	2.292	3.161	3.178
1.50	3.309	3.356	2.805	2.388	3.32	3.345
1.75	3.439	3.442	2.938	2.355	3.438	3.439
2.00	3.490	3.492	3.062	2.415	3.488	3.489
2.25	3.524	3.526	3.104	2.477	3.522	3.523
2.50	3.553	3.555	3.133	2.55	3.559	3.553
2.75	3.576	3.578	3.157	2.739	3.574	3576
3.00	3.576	3.578	3157	2.739	3.574	3.576

Table 4: FOS for Varying Lengths of Soil Nails

Conclusions

Present study is a GeoSlope software based stability analysis of the dump slope in WCL Makardhokara-2 site in static condition only. On basis of observations, following conclusions are made;

- With the increase in the slope angle, the slope stability gets affected. In such cases, an external technique of stabilization is needed to keep the slope stable.
- With soil nailing technique, slopes can be stabilized effectively.
- With varying soil nail diameter FOS doesn't affect much however, nail spacing has its effect on the FOS of the slope.

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