AN EXPERIMENTAL STUDY ON STABILITY ANALYSIS OF A HIGHWAY CUT ADJACENT TO NH-66 IN BHATKAL USING PLAXIS-2D

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Introduction:

A highway cut situated near a nursing home and adjacent to NH-66 is considered for the present study. This cut has a height of 8m, makes an angle of 75o with respect to horizontal. The entire slope is comprising of homogenous Shedi strata which is found to be problematic in the coastal region due to its expansive and shrinkage nature. Shedi soil, is also known as Lithomargic clay, has higher permeability. The Lithomargic clay (Shedi soil) is expansive and has a greater affinity towards water. During the monsoon, the Shedi soil comes into contact with water it expands and behaves as a liquid by losing its strength. During summer, it shrinks by losing the water. This property of expansion and shrinkage causes serious problems like the formation of potholes, dilation problems, etc in the cement constructed over this soil. Shedi soil is highly porous but hard and strong. The soil contains mainly quartz and kaolinite which increases the expansion characteristics of the soil. The soil is also not easily compactable. The highway cut considered for the stability analysis is situated at about 49.26m from Nishath Nursing Home and 30.86m from the existing NH-66. The traffic volume on this National Highway is found to be 122563 PCU/day. The alignment of the new lane of NH66 is proposed to be at a distance of 2m from the Toe portion of the cut. There are a few residential buildings and a sports club run by Rotary Club, Bhatkal situated on the crest of the slope. By considering the following aspects the significance of the present work can be understood:

1. The Shedi soil found in the crest portion.
2. Vicinity of the slope to the hospital building and NH66.
3. Existence of the structures above the crest of the slope.

Objectives:

This entire work is planned to take an account of slope failures and slope stabilization methods for the slope situated at Bhatkal adjacent to NH-66 opposite Nishanth Hospital. Based on field conditions and availability of materials to stabilize the slope, the following objectives are considered:

1. To analyze the stability of the slope provided with benching.
2. To analyze the slope stabilized by providing retaining wall.
3. To analyze the slope stabilized by soil nailing technique.
4. To determine the safest distance for any construction over the crest of slope.

Methodology:

The entire study was planned in two phases. In the first phase, it was planned to collect data (slope geometry and other site details) from the said location, and in the second phase it was planned to carry out numerical modeling using the finite element software “Plaxis-2D”.

The various activities involved in these phases are as follows:

Phase-1: It includes the following objectives

1. To determine the Existing slope angle.
2. To determine the Height of the slope and other geometrical properties of the slope.
3. To study existing terrain/geological conditions.
4. To determine the geotechnical properties of soil.

Phase-2: It includes the following objectives

1. To carry out Finite element modeling using Plaxis 2D Software and to perform numerical analysis by treating the slope with benching, retaining walls, and soil nailing.
2. To determine the Factor of safety corresponding to various slope stabilization methods considered in the present study.
3. To compare the feasibility of different techniques used for the stabilization of slopes.
4. To determine the safe horizontal distance from the crest of the slope for any construction to take place in the future at said location.

Shedi soil was collected from the study area particularly from the face and toe portions as per IS: 2720 (Part XXIX) using Core Cutter. The following properties were determined by conducting various tests as per relevant IS Codes.

Table 1: Geotechnical Properties of Shedi Soil

Sl.No	Parameters	Value	IS Code
1	**Grain Size Distribution**		IS: 2720 (Part IV)
	(a) Gravel (%)	3.83	
	(b) Sand (%)	38.42	
	(c) Silt + Clay (%)	57.75	
	(d) Coefficient of uniformity, Cu	2.15	
	(e) Coefficient of curvature, Cc	1.044	
2	**Specific Gravity**	2.15	IS: 2720 (Part III)
3	**Atterberg's Limits**		IS: 2720 (Part V)
	(a) Liquid limit (%)	45	
	(b) Plastic limit (%)	38	
	(c) Plasticity Index (%)	7	
4	Field Moisture content (%)	11.6	IS 2720 (Part – 2)
5	Unconfined Compressive Strength, (kN/m^2)	50.28	IS: 2720 (Part X)
	Young's Modulus E (kN/m^2)	1277	
6	Coefficient of Permeability, K (m/day)	0.366	IS: 2720 (Part XVII)
7	**Shear Strength Parameters**		IS: 2720 (Part XIII) (Direct Shear test)
	(a) Cohesion (kPa)	25.95	
	(b) Angle of Internal Friction	41.1°	
8	**In-situ Density by Core Cutter Method**		IS: 2720 (Part XXIX)
	Bulk Density (kN/m^3)	17.90	
	Dry Density (kN/m^3)	16.04	
9	**Swelling Characteristics**		IS: 2720 (Part XL)
	(a) Free swell index (%)	30	
	(b) Swell potential	Moderate	

After obtaining the geotechnical properties of soil, the analysis of the stability of the slope by adopting different stabilization methods was carried out.

In benching, numerical analyses are performed on the slope provided with different bench configurations by varying the slope angle, height of the bench, and number of benches.

In retaining wall, a retaining wall A was designed, and analysis was made by varying the geometry of the backfill such as sloping backfill, backfill with a single bench, two benches, and three benches to find the most suitable backfill condition based on the factor of safety. Then, analysis was done by designing and using retaining wall B for the most suitable backfill condition.

In soil Nailing, The FOS of the slope treated with soil nails is determined by varying the length of soil nails, spacing between the nails, and their inclination with respect to the ground (nail angle).

Conclusion:

Benching

The FOS calculated using Plaxis-2D for slope with different bench configurations is mentioned in the Table 2 below.

Table 2: Variation of FOS with respect to different bench geometries.

Slope Angle	No. of Benches	Height of the Benches(m)	Factor of safety
75°	4	2.2	3.472
75°	3	2.94	3.273
75°	2	4.4	2.904
65°	3	2.94	3.531
65°	2	4.4	3.217
55°	2	4.4	3.548

The result obtained from the analysis states that the FOS decreases with an increase in both the slope angle and height of the bench. In both these cases, the variation is almost linear.

Retaining Wall

The factors of safety determined from the analysis are mentioned in Table 3 below.

Table 3: Variation of FOS with respect to backfill conditions

Sl.no	Condition of Backfill	FOS
1	Sloping Backfill	1.508
2	Backfill bench with 1 Step	0.625
3	Backfill bench with 2 steps	1.441
4	Backfill bench with 3 steps	1.529

From the numerical analysis, it is observed that increasing the number of benches increases the factor of safety in the presence of a retaining wall.

An analysis was carried out by comparing the deformation behavior of the retaining walls of both designs A and B with the backfill modelled with three-step benching as it gives the highest factor of safety among the other conditions.

The FOS determined for slopes provided with the retaining wall of different designs is shown in the table 4.

Table 4: FOS corresponding to different retaining wall designs

Sl.no	Design	Factor of Safety
1	Design A	1.852
2	Design B	1.529

Thus, it can be seen that the heavier the retaining wall is used, the higher the value of the safety factor.

Soil Nailing

The FOS of the slope treated with soil nails is determined by varying the length of soil nails, spacing between the nails, and their inclination with respect to the ground (nail angle). The variation in the factor of safety is shown in the Table 5 below.

Table 5: FOS with respect to different nail length, nail angles,and spacing

Length of nail (m)	Spacing (m)	Nail angle (˚)						
		0	10	20	30	40	50	60
4	1	1.342	1.356	1.384	1.395	1.42	1.48	1.523
	2	1.338	1.342	1.369	1.38	1.403	1.469	1.514
	3	1.306	1.334	1.35	1.375	1.39	1.443	1.5
6	1	1.35	1.358	1.391	1.405	1.457	1.498	1.53
	2	1.348	1.349	1.373	1.392	1.429	1.479	1.526
	3	1.339	1.346	1.359	1.387	1.415	1.456	1.51
8	1	1.365	1.379	1.398	1.41	1.468	1.5	1.542
	2	1.359	1.368	1.379	1.407	1.459	1.486	1.539
	3	1.344	1.354	1.361	1.398	1.425	1.471	1.52

From the table 5, it is evident that the FOS increases as the nail angle and length of the nail increases and FOS decreases as the spacing between the nails decreases. An array of soil nails of length 8m spaced at 1m apart center to center with an inclination of 60˚ exhibits higher FOS i.e. 1.542.

Safe Horizontal Distance for Future Constructions

Benching

Since, it is observed that the factor of safety for the slope with a bench height of 4.4 m and bench angle of 55˚is higher compared to all other bench geometries, the same is adopted to determine the safe horizontal distance for future constructional activities. To interpret the safest distance from the crest of the slope for future construction, numerical analysis was carried out by varying the horizontal distance of the load 5kN/m from the crest. The values of FOS determined by varying distances of structural load from the crest are presented in the table 6 below.

Table 6: Variation of FOS with respect to distance from the crest of the slope

Distance from the crest of the Slope (m)	**FOS**
2	3.643
4	3.764
6	3.81
8	3.804
10	3.814

The analysis of the FOS values at different distances from the crest of the slope reveals that the stability of the slope is relatively consistent within the range of distances considered.

Retaining wall

Since, it is observed that factor of safety for Retaining wall A is higher than B, retaining wall A is adopted to determine the safe horizontal distance for future constructional activities.

Table 7: Variation of FOS with respect to distance from the crest of the slope.

Distance from the crest of the slope (m)	**FOS**
2	1.804
4	1.721
6	1.771
8	1.902

From the analysis, the distance of 8m from the crest of the slope provides the highest factor of safety of 1.902.

Soil Nailing

Since, it is observed that the factor of safety for the slope provided with soil nails with length of 8m and inclined at an angle of 60˚ is higher compared to all other nail configurations, the same is adopted to determine the safe horizontal distance for future constructional activities.

The FOS by varying the distance of the structural load from the crest is mentioned in the Table 8 below.

Table 8: Variation in FOS for the distance from the crest for a nail angle of 60˚

Distance from the Crest of the Slope	FOS
2	1.53
4	1.537
6	1.54
8	1.549

Considering the FOS values for the 60° nail angle, the best suitable distance from the crest of the slope is 8 meters. At this distance, the slope exhibits the highest factor of safety of 1.568, indicating the greatest stability and resistance to potential failure.

The following conclusions are drawn from the present numerical analysis of the slope situated near NH-66 in Bhatkal:

1. Slope provided with a bench height of 4.4 m, inclined at 55˚ having a FOS of 3.548 proves to be the most stable slope geometry.
2. Retaining wall A with three benched backfill having FOS 1.852 provides better resistance against slope failure.
3. An array of soil nails of length 8m spaced at 1m centre to center with an inclination of 60˚ exhibits higher FOS i.e. 1.542.

4. Among all the slope stabilization methods discussed in this numerical study, slope stabilization by providing benching proves to be the most feasible practical solution against slope failure.
5. For future construction, it can be concluded that a horizontal distance of 6m from the crest of the slope is sufficient for the slope provided with benching. Similarly, a horizontal distance of 8m from the crest of the slope is sufficient for the slope provided with a retaining wall as well as the slope treated with Soil nails.

Scope for future work:

- The same slope can be analyzed numerically by subjecting it to the seismic load.
- The same numerical analysis can also be extended for excessive rainfall conditions with water table fluctuations.
- The same slope can also be analyzed numerically by other finite element software packages like Geoslope, FLAC, etc.
- In addition to the software packages, same slope can also be analysed by using graphical solutions like Swedish circle method, Bishop's simplified method, and also by using Taylor's stability number.
- Morphological study can be undertaken to interpret the exact behavior of the slope under the applied load.