Stability Analysis of Embankment Slope Reinforced with Bi-Axial Geogrid

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Abstract: Embankments and manmade excavations are frequently used engineering structures to facilitate construction of earth dams, roads, railways, river training works, mining excavations, landscape engineering and landfills. Retaining the man-made slope is always a problem in geotechnical engineering and solution to this problem keeps evolving with advancement in technology. The study of slope stability is considered to be very important, because this helps in avoiding damages to structures and saving in cost as well, also this supports the understanding of slope failure mechanism and exploring ground improvement techniques. Methods used for slope stabilization are flattening of the slopes, constructing of earth retaining structures and ground improvement methods like foundation grouting, inserting micro piles, reinforcement with geosynthetics products, mechanical and chemical stabilization. The present study discusses about the slope stability problem of switchyard area in one of the hydroelectric project. The issues faced during design of embankment for switchyard are (i) Embankment base is on weathered poor quality rock, (ii) heavy load from switchyard machinery and (iii) limited space. To address these issues, analysis with bi-axial geogrid as soil reinforcement is adopted to design the slope, by analyzing for all the expected loading conditions and meeting minimum factor of safety criteria. The results of comparative stability analysis carried out using slope stability SLIDE software, for six different loading conditions, without soil reinforcement and with soil reinforcement, are presented in this paper.

Index Terms: **Embankment, Slopes, Reinforcement, Geogrid**

1. INTRODUCTION

Switchyard is an important structure in hydroelectric project and its purpose is to link the power generating units with the transmission line system. It is mostly an assemblage of transformer, switches, power circuits, breakers, and auxiliary equipment which are used to collect power from the generators at the hydro power plant and distribute to the transmission lines at a load point.

In this particular project the switchyard structure is proposed over an embankment which is resting on weathered poor quality rock. The heavy load from electrical instruments resting over the embankment expected to apply a uniformly distributed load of 10 kN/m^2. Further, the switchyard is proposed on the bank of tailrace channel, which constrained the space required for flatter slope, hence side slope is proposed as 1V:1.6H. The project location is also in the high seismic zone and hence horizontal seismic coefficient of $0.19\alpha_h$ is considered in the analysis. Various methods available for embankment slope stabilization are flattening slopes, construction of earth retaining structures and ground improvement methods like foundation grouting, inserting micro piles, reinforcement with geosynthetics products, mechanical and chemical stabilization. From the above methods, soil reinforcement with extruded bi-axial geogrid as geosynthetics product is considered in design analysis of backfilled embankment. The application of various geosynthetics products in modern geotechnical engineering is for reinforcement, filtration, drainage, separation, moisture barrier, protection, cushion etc and combination thereof to enhance its engineering performance.

The American Society for Testing and Materials defines Geosynthetics (D4439) as "a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering related material as an integral part of a man-made project, structure, or system". In this study extruded bi-axial geogrid characterized by a tensile resistance of 40 kN/m in both longitudinal and cross direction, made up of polypropylene material is considered in analysis for soil reinforcement of the switchyard embankment. Bi-axial geogrid act as a tensile element when placed within a flexible unbound base to increase the bearing capacity, thus improving performance with a reduced structural section. Geogrid provides three main functions which makes it suitable for reinforcement work i.e., 1) Interlocking of soil/aggregate particles within their aperture opening to facilitate lateral confinement 2) Better distribution of load to the foundation 3) By virtue of its tensile characteristic it resists stresses and induce tension membrane effect.

2. STABILITY ANALYSIS OF EMBANKMENT SLOPE

The switchyard embankment is analyzed for six different loading conditions, without soil reinforcement and with soil reinforcement using limit equilibrium method with the aid of slope stability SLIDE software. The shear strength parameters i.e., cohesion 'c' and angle of internal friction 'ϕ' obtained from laboratory work with Mohr-Coulomb principle are the input value in failure analysis. The failure is analyzed using Morgenstern – Price method. In this method the equilibrium conditions are satisfied considering overall moment, individual slice moment, vertical and horizontal force. Analysis using Morgenstern – Price method is being preferably considered for arriving at factor of safety.

Shear strength parameters obtained from laboratory work with Mohr-Coulomb principle are specified in the SLIDE software. The Mohr-Coulomb failure theory is a valuable tool in calculation of the shear strength parameters of soil. According to Mohr, the failure is caused by a critical combination of the normal and shear stress. Figure 1 shows the Mohr's graphical representation of stresses when a soil element is subjected to principal stresses (σ_1 and σ_3).

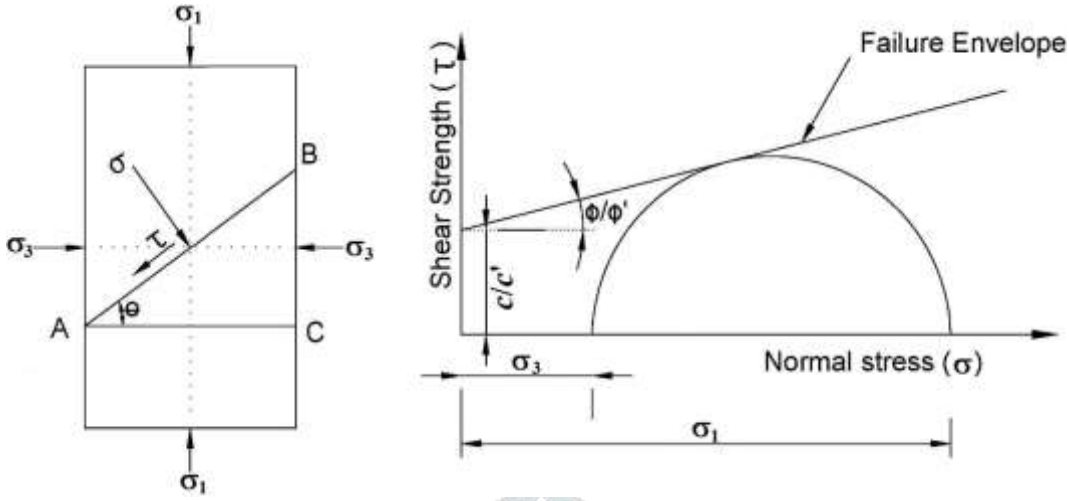


Fig. 1. Mohr's graphical representation of stresses

Mohr-Coulomb failure envelope is represented by a straight line. It represents shearing resistance of soil, linearly related with 'σ'. Here 'c', equals to the intercept on τ-axis and 'ϕ' is the angle which the envelope makes with the σ -axis.

$$\text{Total shear strength, } \tau = c + \sigma \tan\phi$$

$$\text{Effective shear strength, } \tau' = c' + \sigma' \tan\phi'$$

Where,
c/c′ = Cohesion for total and effective stress
ϕ/ϕ′= Angle of internal friction for total and effective stress
σ_3 = Minor principle stress
σ_1 = Major principle stress

The backfill and foundation materials are free drained materials, hence effective shear strength parameters c′ and ϕ′ are considered in the design. The slope failure happens at any point of time, when the stresses generated during application of external applied load and overlying soil load touches the failure envelope. The embankment section shall be designed such that the stresses lies below the failure envelope, which makes the structure stable. The factor of safety calculated in circular arc analysis is the ratio of stabilizing force to the destabilizing force. Slope stability SLIDE software quickly searches for the most critical failure surfaces within a fill embankment. Stability of slope is checked for six different loading conditions to satisfy the minimum factor of safety criteria.

3. GEOMETRY OF THE EMBANKMENT

The geometry of the embankment slope and section considered in this analysis are shown in Fig. 2. The backfilled material is placed over 10 m high poor quality weathered bed rock. Below the weathered bed rock, good quality bedrock exists and the same is having considerably good strength, hence that portion is not considered in the analysis / design. The switchyard is proposed to be constructed on the bank of tailrace channel. Bed level of the tailrace channel is at EL 0.0 m. Normal water level (N.W.L) during running of the entire machine is at EL 3.5 m and maximum water level (M.W.L) during high flood level is considered at EL 4.0 m. The 2.0 m intermediate bench is kept at an elevation of 5.0 m. The top elevation of the switchyard is at EL13.0 m height. As the switchyard is considered on the bank of tailrace channel, it constrains the space required for flatter slope, hence side slope of 1V:1.6 H for the backfill, is kept same as that of slope of weathered rock.

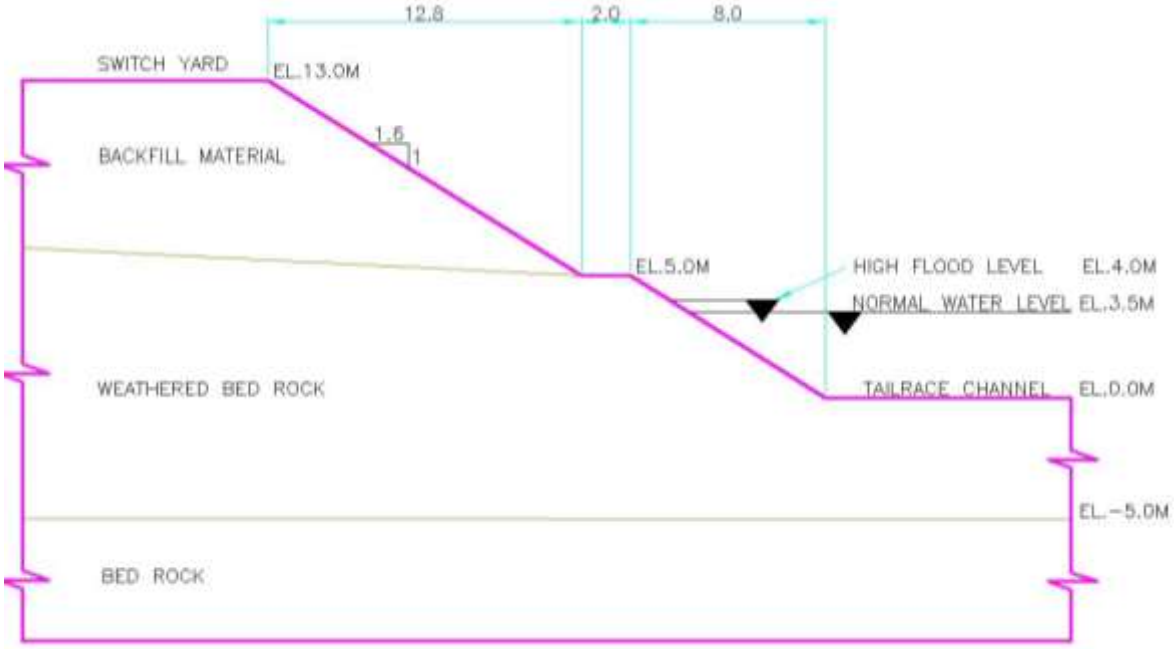


Fig. 2. Geometry of the embankment

4. MATERIALS PROPERTIES

Properties of earth materials (i.e., backfill material and weathered bed rock) and bi-axial geogrid are presented in Table 1 and Table 2 respectively. Since embankment is part of the tailrace channel and exists on the same side, water flowing in the channel may saturate the embankment. Hence, depending on the level of water, the unit weight of the materials may vary. Interface adhesion between backfill material and bi-axial geogrid is considered zero in analysis.

Table 1. Properties of backfill and weathered bed rock materials

Sr. no.	Materials	Unit weight, γ (kN/m^3)	Saturated unit weight, γ_{Sat} (kN/m^3)	Cohesion, c' (kN/m^2)	Friction angle, ϕ' (°)
1	Backfill material	20	20.6	22	23.1
2	Weathered bed rock	20	21	25	16

Table 2. Properties of bi-axial geogrid

Sr. no.	Material	Interface adhesion, c'_a (kN/m^2)	Interface friction angle, δ' (°)	Tensile strength (kN/m)
1	Bi-axial geogrid	0	22.05	40

5. LOADING CONDITIONS

All the possible loads acting on the embankment and their combinations are shown below. As the proposed construction of the switch yard and machinery apply a load of 10 kN/m^2 at the top level (EL13 m). Machinery dead load is not considered on loading condition 1 and 5. The water level on the tailrace channel varies seasonally; this is considered in the loading condition 2 and 3. Rapid drawdown of water level is expected during the immediate shutdown of the power house unit. At this condition the water level in the tail race channel (downstream side) decreases at faster rate than pore water pressure can dissipate, this case is considered in loading condition 4. The project is located in high seismicity zone and the seismic load is accordingly considered in loading condition 5 and 6.

1) L.C -1 (End of construction)
   Ground water and pore water pressure on the whole embankment is not present.
2) L.C - 2 (Long term stability)
   There is presence of tailrace water up to normal water level and ground water level also increases consequently (N.W.L is at 3.5m).
3) L.C - 3 (Unusual condition)
   During flood time the water level may rise up to maximum water level (M.W.L considered is at 4.0 m).
4) L.C - 4 (Rapid drawdown)

Rapid drawn down condition generally take place due to the immediate shutdown of the power house units. At this condition the water level in the tail race channel (downstream side) decreases at faster rate than pore water pressure can dissipate (water level is reduced from N.W.L 3.5 m to 0 m).

5) L.C - 5 (LC-1 + EQ)
Due to high seismic zone, horizontal seismic coefficient of $0.19\alpha_h$ is considered in analysis after the end of construction (LC -1 + Earthquake load).

6) L.C - 6 (LC-2 + EQ)
Due to high seismic zone, horizontal seismic coefficient of $0.19\alpha_h$ is considered in analysis for normal water level flowing in tailrace channel (LC-2 + Earthquake load).

Note: Loading Condition (L.C), Normal Water Level (N.W.L), Maximum Water Level (M.W.L), Earthquake Load (EQ).

6. ANALYSIS AND RESULTS

The bi-axial geogrid as reinforcement material is modelled horizontally inside the backfill embankment (8.0 m height) in seven different layers as shown in Fig. 3. Four numbers of 17 m long bi-axial geogrids are positioned at bottom part and three numbers of 14 m long bi-axial geogrids are positioned at top part of embankment. The spacing of 1.15 m at equal distance is considered between each layers. The stability analysis is carried out for all the possible six different loading conditions. The outcome of stability analysis of embankment slope, without reinforcement and with bi-axial geogrid as reinforcement are shown in Fig. 4 and Fig. 5 respectively. The comparative result of stability analysis are presented in Table 3.

The stability analysis result shows that without reinforcement, the switchyard embankment slope is not sufficient to satisfy the minimum factor of safety requirement for the loading case of L.C-2 (Long term stability), L.C-4 (Rapid drawdown) and L.C-6 (LC-2 + EQ). This necessitates further strengthening to meet the minimum desired factor of safety. Embankment modelled with the bi-axial geogrid as soil reinforcement, establishes sufficient factor of safety requirement in all the loading conditions. Without any reinforcement, factor of safety varies from 0.944 to 1.50. After considering the bi-axial geogrid as soil reinforcement in design, the factor of safety increases and varies from 1.008 to 1.602. When modelled with bi-axial geogrid as reinforcement, the percentage increase in factor of safety is between 6.63 % to 9.75 % presented in Table 3.

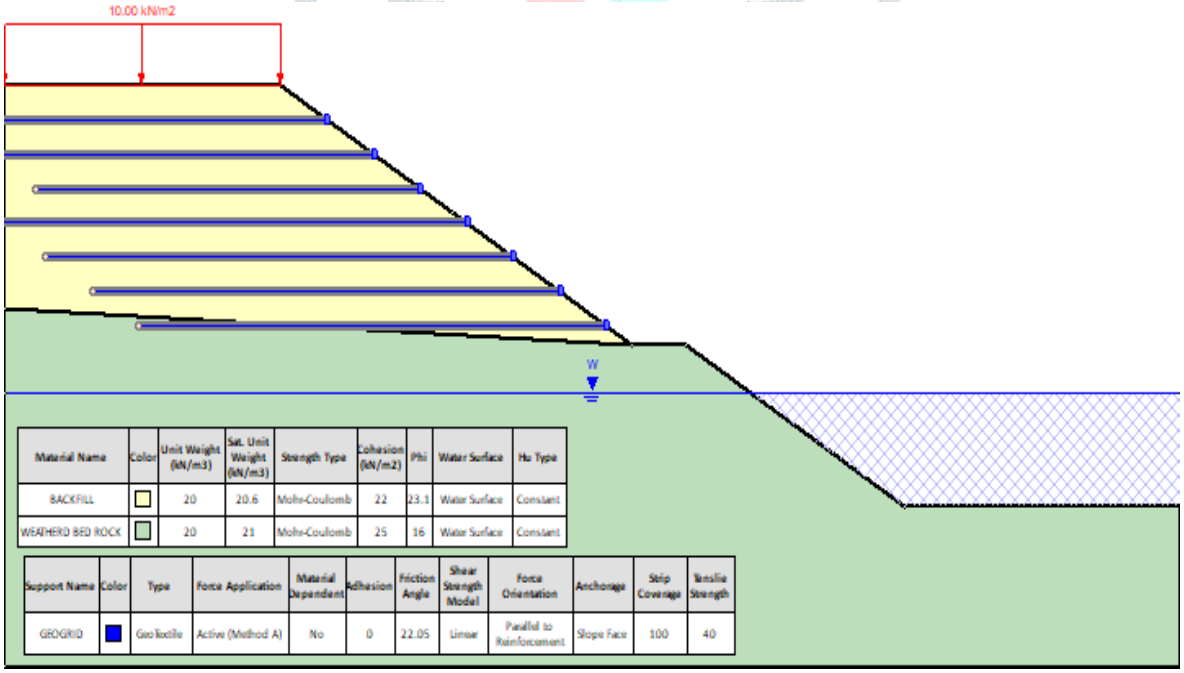
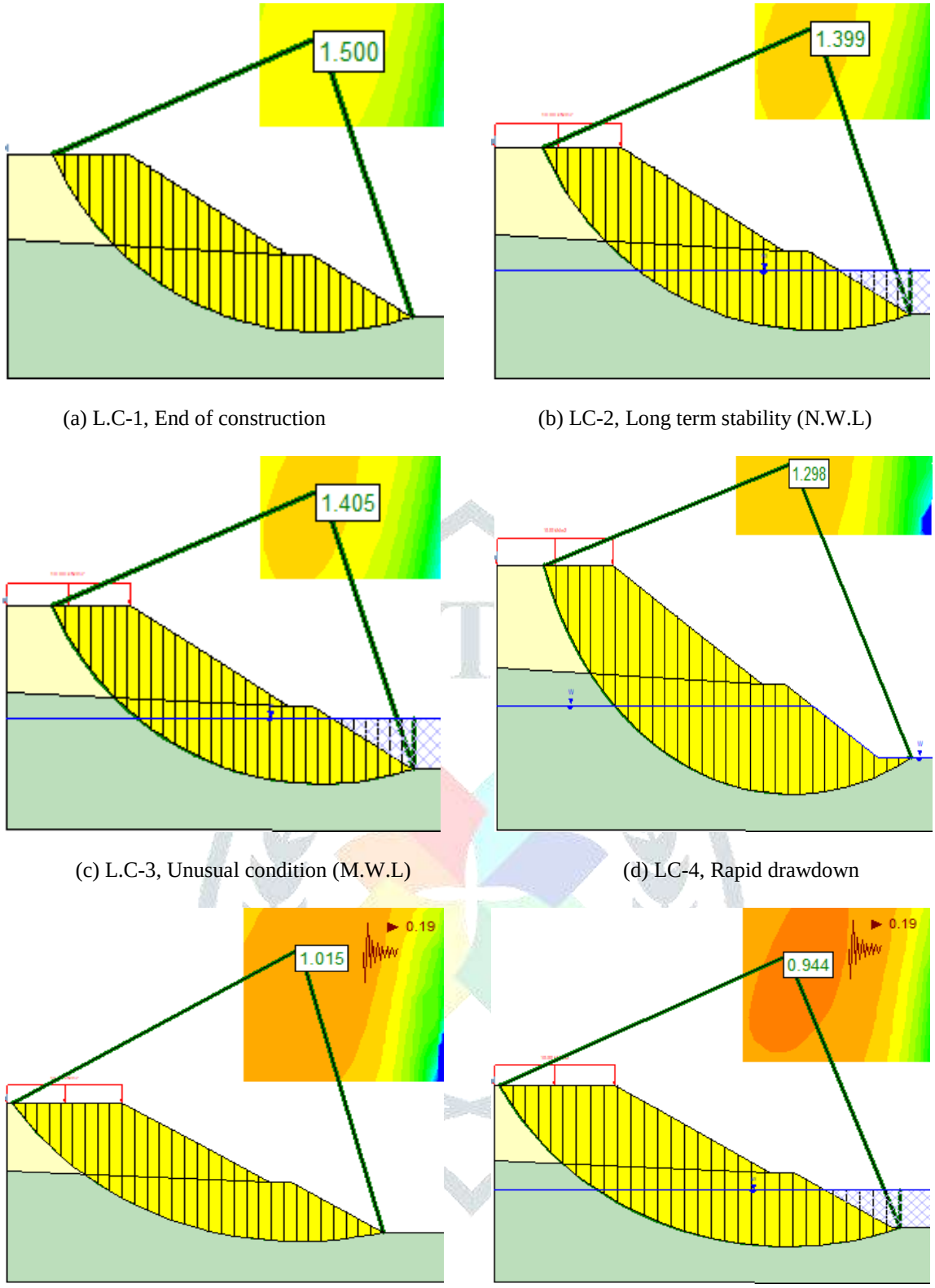


Fig. 3. Embankment reinforced with bi-axial geogrid



(a) L.C-1, End of construction

(b) LC-2, Long term stability (N.W.L)

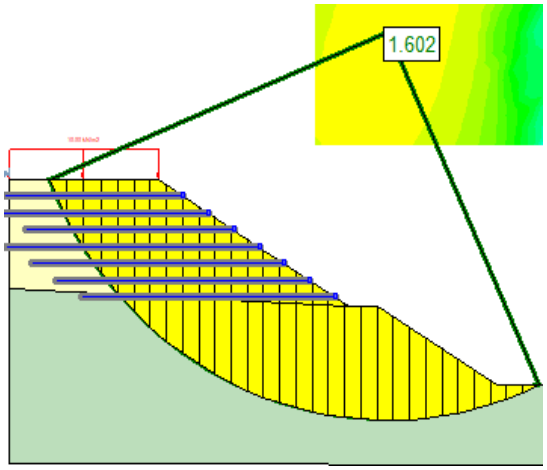
(c) L.C-3, Unusual condition (M.W.L)

(d) LC-4, Rapid drawdown

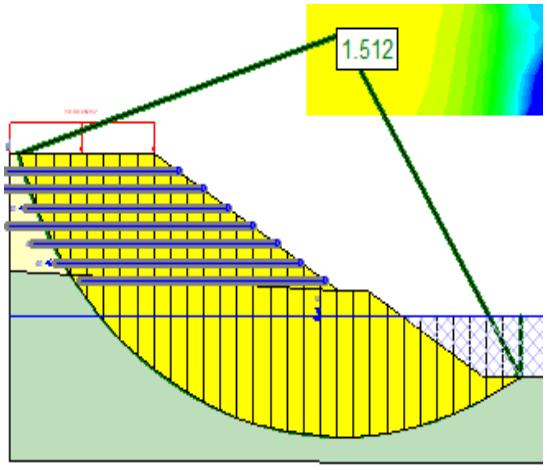
(e) L.C-5 (LC-1 + EQ)

(f) LC-6 (LC-2 + EQ)

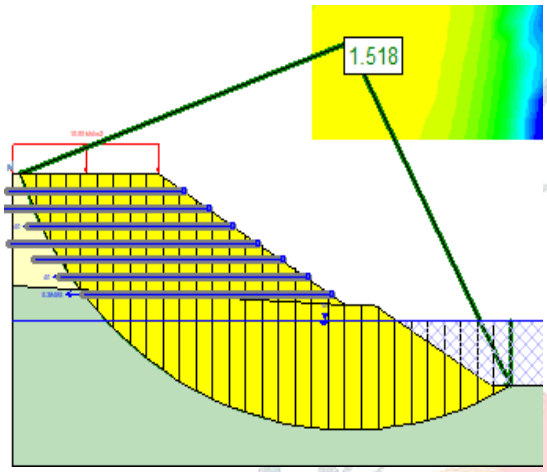
Fig. 4. Stability analysis results without reinforcement



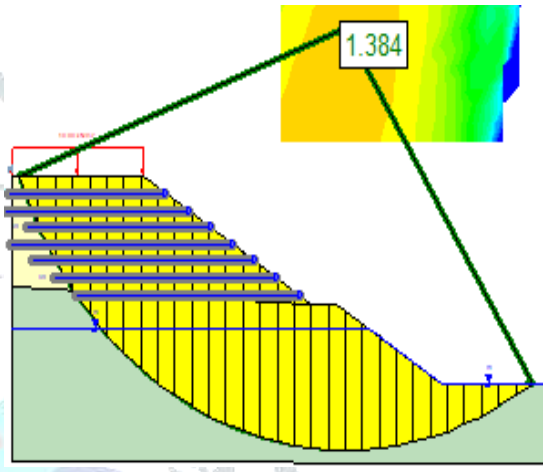
(a) L.C-1, End of construction



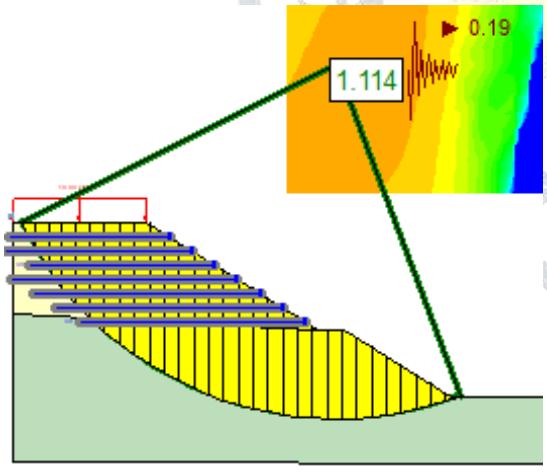
(b) LC-2, Long term stability (N.W.L)



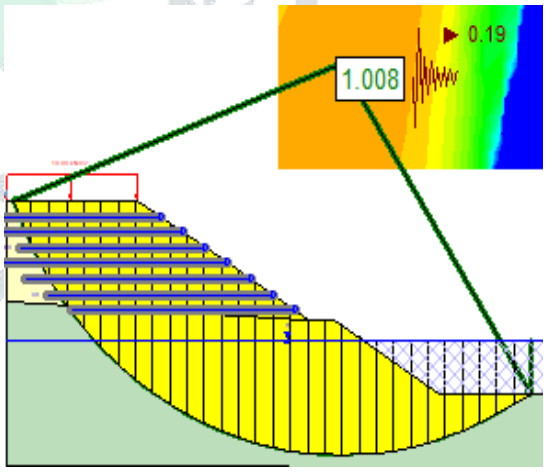
(c) L.C-3, Unusual condition (M.W.L)



(d) LC-4, Rapid drawdown



(e) L.C-5 (LC-1 + EQ)



(f) LC-6 (LC-2 + EQ)

Fig. 5. Stability analysis results with bi-axial geogrid as reinforcement

Table 3. Comparative results of stability analysis

Sr. no.	Loading conditions	Factor of safety (F.S)			Percentage increase in F.S (%)
		Without Reinforcement	With bi-axial geogrid as reinforcement	Minimum desired F.S	
a	L.C-1 (End of construction)	1.500	1.602	1.3	6.80
b	L.C-2 (Long term stability), N.W.L	1.399	1.512	1.5	8.08
c	L.C-3 (Unusual condition), M.W.L	1.405	1.518	1.4	8.04
d	L.C-4 (Rapid drawdown)	1.298	1.384	1.3	6.63
e	L.C-5 (LC-1 + EQ)	1.015	1.114	1.0	9.75
f	L.C-6 (LC-2 + EQ)	0.944	1.008	1.0	6.78

7. CONCLUSIONS

The stability analysis shows that without reinforcement, embankment slope does not satisfy minimum factor of safety criteria in loading condition of L.C-2 (Long term stability, N.W.L), L.C-4 (Rapid drawdown) and L.C-6 (LC-2 + EQ). Due to space constraint, slope of 1V:1.6H cannot be flattened. Embankment modelled with the bi-axial geogrid as soil reinforcement, establishes sufficient factor of safety requirement in all the six different loading conditions. It is concluded that even in the weak foundation with heavy external load, bi-axial geogrid as soil reinforcement can be a fruitful solution in strengthening the embankment having steep slopes.

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