Protection & retention system of Kaliapani Chromite Mines dump using gabion wall: A case study

Smita Tung & Dola Roychowdhury
Z-Tech India, India

ABSTRACT: The chromiferous ultramafic rocks of Sukinda Valley (21 °0'-21 ° 5'N : 85 °4Y-86°0'E) of Orissa are intrusive into the Iron-Ore Supergroup at the eastern periphery of the Indian Precambrian shield. M/s Balasore Alloys Limited currently extracting Chrome Ore from its Captive Chromite OreMines covering an area of 64.463 Ha. located at Sukinda Valley, Jajpur District, Odisha by Open Cast Mining Method. Run offs from the OB dumps have the potential of polluting the water bodies. Stabilization of OB dumps is necessary to reduce the potential effect of environment. Composite reinforced soil system with gabion facia and vegetated facia meets all the demands compared to any other RS wall system to reduce the environmental effect and to encounter generation of pore water pressure effect. In the present study the OB Dump in Kaliapani Chromite Mine has to be stabilized using combination of Terramesh and Green Terramesh unit system for increased OB Dump quantity. Based on the strength reduction method using FLAC/SLOPE software it was estimated that the overall safe dump slope angle for dump-1 towards north and south side under saturated condition are 35.50 and 360 respectively. From the results of the present numerical stability analysis using MacStARS software it has been indicated that, there is a large potential for cost effectiveness in using wire mesh and grids combined.

Keywords: Chromiferous ultramafic rock, Stability, MacStARS, Terramesh, Green Terramesh, Grids, Strength eduction method, FLAC/SLOPE

1 INTRODUCTION

Sukinda valley in Jajpur district of Odisha contains about 98% of chromite reserve and it is exploited mostly by opencast mining process since 1950. There are 20 open cast and 2 underground mines in Sukinda valley. The chromite ore belt at Sukinda is spread over an area of approximately 200 sq. km. in Jajpur district and is well-known chromite hub in the world (Das et al., 2010). M/s Balasore Alloys Limited (BAL) is a modern Ferro Alloys plant capable to produce high grade Ferro Chrome of good quality.

The capacity in 2015 is of 94,800 TPA of High Carbon Ferro Chrome being expanded to capacity to 1,45,000 TPA. Opencast chromite mining generates enormous quantities of overburden (OB). Run offs from the OB dumps have the dual potential of polluting the water bodies by siltation and leaching of Cr(VI). Stabilization of OB dumps is necessary to reduce the potential effect of environment. In the present study the OB Dump in Kaliapani Chromite Mine has to be stabilized with suitable slope protection and retention system for increment of OB Dump quantity up to height 202 mRL.

1.1 *Need of study*

The study of Overburden Dump Optimization is required for increasing life of Open Cast Mines. Waste Dump-1 covers an area of 11.892 ha and has been heighten to 182 mRL as on 2015. The dump was accommodated about 25,56,845 m^3 OB, with 3 number of terraces. The height of the dump was increasedfrom existing 182 mRL to 202 mRL. Due to the limited space for Over Burden (OB) dumping area a Gabion wall from the toe of the waste Dump – 1 towards North and West was constructed for

additional quantity of OB of the Chrome Ore Production of at least 3 years life of the ongoing Opencast Mining.
Hence, the need to enhance capacity of OB dumping area within the allotted ML area, through scientific & technical study was carried out by the Z-TECH INDIA, the consultant and duly vetted by IIT, Mumbai.

Figure 1. Geographical location of Sukinda Valley

1.2 *Geographical location of study area*

The chromiferous ultramafic rocks of Sukinda Valley situated 50 km to the northwest of the Jajpur-Keonjhar Road railway station near the eastern margin of the Indian Precambrian shield and extends in the NE-SW direction across the Cuttack and Dhenkanal districts of Orissa (21°0'-21°5'N: 83°43'-86°0'E) shown in Figure 1.

1.3 *Problem specification and proposed solution*

For Retaining Structures of larger height, according to the site condition in this case, Robust and high tensile strength elements are required as reinforcement to accommodate heavy loading and also, pore water pressure. Reinforced Soil walls are speedier to construct as it is less labour intensive and also allows the usage of stones and soils for wall construction and large quantity of soil coming from cutting of mine to be used as backfill. Based on flexibility criteria Composite Soil Reinforcement System walls have the ability to absorb seismic shocks. Based on all the above criterion, Composite soil reinforcement system using GABION WALL, considered to be the best possible solution that was adopted as retaining wall for Dump-fill Stabilization. Composite reinforced soil system with gabion facia and vegetated facia meets all the demands compared to any other RS wall system to reduce the environmental effect and to encounter generation of pore water pressure problem. Sheet Drain was provided in addition to the reinforced soil system, for drainage.

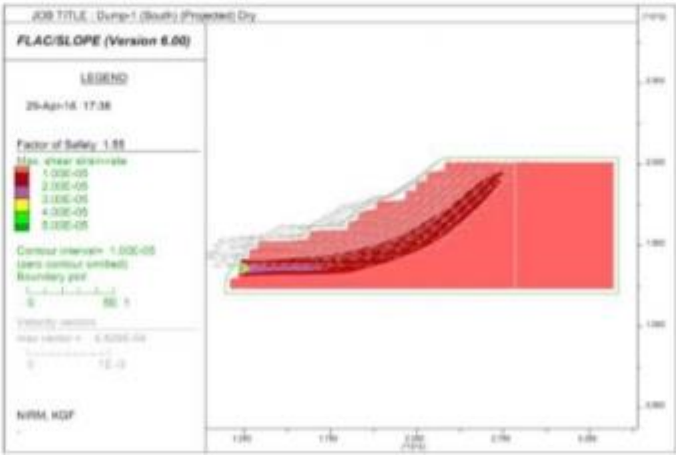
2 DESIGN MECHANISM

Terramesh is a mechanically stabilized earth system comprising of a Gabion facing with woven steel mesh or high strength geogrid soil reinforcement. The Gabion facing prevents erosion on the front face and the soil reinforcement increases the shear parameters of the backfill material. Polymeric reinforcements and steel wire mesh units in high MSE walls act as reinforcements and as stabilizing elements. ParaLink are considered to work as primary reinforcements and also for the overall and compound internal stability of the structure. Whereas the wire mesh facia units (either gabion units or wraparound green units) are considered a secondary reinforcement providing the local stability at the facing, ensuring that no local mechanism of direct sliding, pull-out or rotational failure occurs.

3 DESIGN CONSIDERATION

3.1 *Stability analysis using FLAC 2D*

Numerical analysis was carried out using strength reduction technique to estimate the stability of the dump slopes. Accordingly, the optimum dump bench parameters and overall slope angles of the, dump have been designed. For carrying out the slope stability analysis, a strength reduction method of dry and saturated slopes was adopted using the software 'FLAC/SLOPE'. In this, the factor of safety of potential failure surface is computed for different sections, and the critical failure surface was identified shown in Figure 2 and Figure 3. The analysis was carried out for the dump slopes to determine the optimum bench height and slope angle, and, also for the overall slopes to determine the ultimate dump slope angle. A factor of safety of 1.3 was considered for the long-term stability. Based on the analysis it was estimated that the overall safe dump slope angle for dump-1 towards north and south side under saturated condition are 35.5^0 and 36^0 respectively.



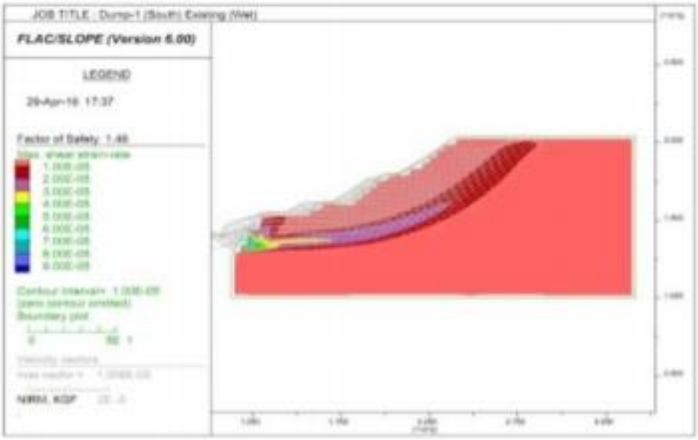


Figure 2. Stability analysis of Dump-1 in Dry condition. Figure 3. Stability analysis of Dump-1 in wet condition.

3.2 *Prosed Model of case study*

The proposed structure of the chromite mine dump slope has been shown in Figure 4. It has been shown from Figure 5 that Terramesh System Unit (TMS) height is 11.00 m and height of Green Terramesh System Unit for middle and top tier are 9.6 m and 10.4 m respectively.

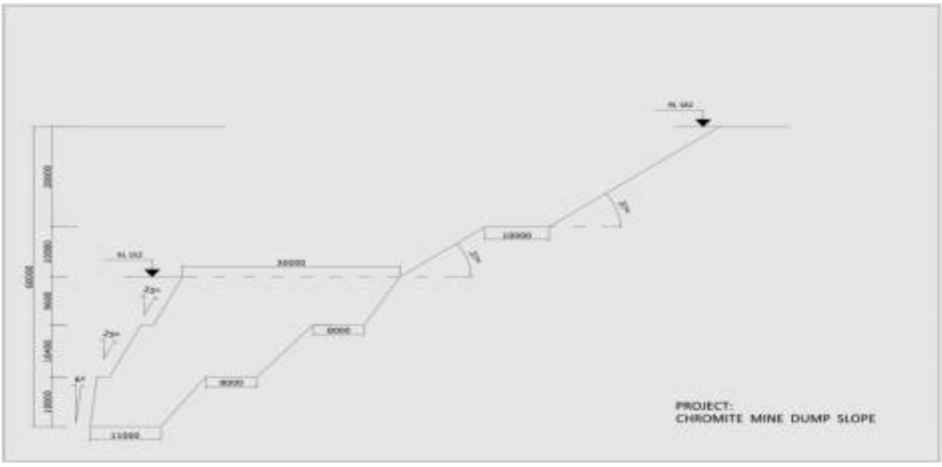


Figure 4. cross sectional details of chromite mine dump slope

3.3 *Proposed design parameter of current case study*

Laboratory testing was carried out to determine the shear parameters of the samples of different lithological units collected from the mine. Test results of Fill Soil from South Bench of mine are shown in Table 1. Live load have been taken for the current study is 22 kpa. In the present study a 30 m high dump surcharge at a distance of 15 m from the top crest of the wall have been considered at seismic condition. Seismic coefficient value for the stability analysis of the proposed study have been shown in table 2. In Table 3 properties of optimized reinforcement are listed. In particular the present study refers to "Hybrid" systems which combine planar polymeric reinforcements (ParaLink) and steel wire mesh units in order to build high MSE walls slopes.

Table 1. Soil Properties

Type of Soil	Cohesion (c) in kPa	Angle of internal friction (ϕ) in degree	Bulk unit weight (γ_{bulk}) in kN/m^3
Reinforced Fill	0	30°	19.00
Dump Fill	59	34°	19.00
In-situ Foundation soil	0	28°	19.00

Table 2. Seismic Coefficient

Zone	α_h	α_v
III	0.08	0.04

Table 3. Properties of the Used Reinforcements

Linear Composites	Tensil strengt UTS [kN/m	Breakag Safety Factor (sand)	Pull-out Safety Facto	Interaction factor reinforcement	Pullout coefficient reinforcement-sand
ParaLink 30°C - 150	150.0	1.64	1.00	0.25	0.90
ParaLink 30°C - 200	200.0	1.64	1.00	0.25	0.90
ParaLink 30°C - 300	300.0	1.52	1.00	0.27	0.90
Green Teramesh - 10/2.7 P	41.30	1.30	1.00	0.30	0.65
Terramesh System - 10/2.7P - 0.5x1.0	41.30	1.30	1.00	0.30	0.65

4 INSTALLATION OF TMS AND GTM WITH PARALINK

4.1 *Field Installation and construction sequence*

Terramesh System Unit (TMS), a meshing of 10mm×12mm zinc and PVC coated wire diameter of 2.7/3.7 mm having dimension of 1m (W)×2m (L)×0.5 m(H) with 2m wide tail end was placed one by one in the construction site have been shown in Fig. 5 to Fig. 12. In TMS unit connection with tie rod was made according to the slope angle. Placing of ParaLink, having a planar structure consisting of mono axial array of geo-synthetic strips are shown in Fig. 6. In TMS unit filled up Stone must be hard, angular to round and Size should be between 150 to 200 mm have been shown in Figure 7(a). In case of Placement of TMS unit Steel formwork is necessary to avoid bulging. Filter geotextile was placed at the end of stone filling are shown in Fig. 7(b). Horizontal drain was placed at a slope of 2% and connected with sheet drain which placed along the side slope of the OB dump. For the backfill Soil Placement over ParaLink, Particles having size more than 40 mm shall not be allowed. Backfilling of compaction was done for first layer of structural fill have been shown in Fig. 8. Mechanically hexagonal double twisted wire mesh acted as secondary reinforcement. Backfilling and compaction of Filling of the vegetative layer of TMS continued to the same steps till reaching total height of structure. After completion of stage construction of TMS, Green Terramesh unit , fabricated with polymer coated steel wire with front face having angle of 65° was installed are shown in Fig 12(a) to Fig 12(b).The good quality topsoil would be placed immediately behind the front face to promote the rapid vegetation of the slope of GTM unit.

Figure 5. Construction of foundation and compaction

Figure 6. Laying of ParaLink as soil reinforcement

(a) (b)

Figure 7. Installation of Terramesh System Unit (TMS) with ParaLink as soil reinforcement and horizontal drain a) Pictorial view b) Installation of Geotextile

Figure 8. Backfilling Process on going

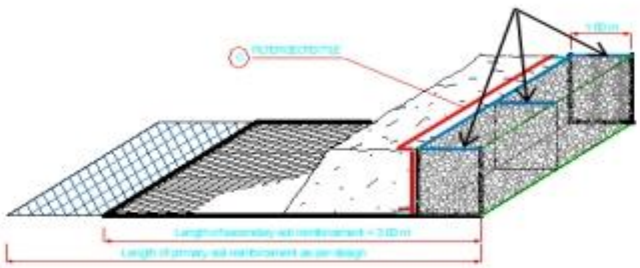
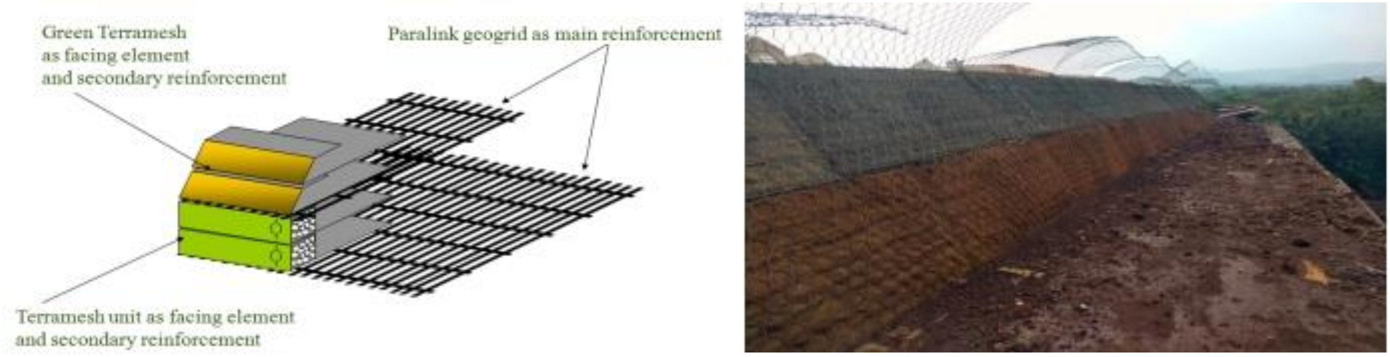


Figure 9. Completion of Stage-1of TMS unit

Figure 10. Execution of construction of second layer

Figure 11. Final stage of Terramesh System Unit



(a) (b)

Figure 12. Installation of Green Terramesh System Unit a) Pictorial view b) Actual Site Execution

4.2 *Instrumentation and monitoring of gabion retaining wall*

To monitor potential movement of MSE wall, berm and slope at different wall and slope height position deformation monitoring was installed at 15 to 30 m separation distances. Deflection was detected within expected limit of a few centimeters. After completion of structure up to full height a slope indicator was installed from the top through the layers of reinforcement and into the foundation soil. Surveying was conducted to evaluate dump soil settlement during construction when settlement plates are placed on foundation soil and properly extended through the fill. Piezometers were placed before construction on portion of wall, berm and slope which will be experienced highest load and on the toe of structure at the post construction stage. Decrease in excess pore water pressure indicate soil strength gain. Additional drainage required during increase in water level due to inadequate drainage. 5 no's of VW Piezometer was drilled for 30 m depth to monitor the water pressure and water level. Piezometer readings was taken weekly for initial 3 months, after that it was carried out in once in a fortnight and later once in a month.
During Monsoon, the reading was taken weekly basis to monitor the water pressure. The current study of construction of Hybrid MSE structures was completed on 2017.

5 NUMERICAL ANALYSIS

In the present numerical study of design of the hybrid MSE structures has been carried out using MacStARS tool according to BS 8006 code (British) standards for internal and global stability checks, while the seismic analysis has been designed according to FHWA code. The factors considered in the numerical study for designing current study of reinforced soil slopes and complex soil geometries are pore water pressure, seismic conditions, external uniform surcharges. This software is based on the rigid method, considers the possible reinforcements as concentrated forces situated at the intersection between the reinforcement and the surface itself. Numerical analyses have been done in three positions i.e. top, middle and bottom tier by application of with and without surcharge considering seismic and static condition.

6 RESULT AND DISCUSSION

Serviceability Limit State principles were applied to the design of reinforced soil structures. The design has been carried out under both static and seismic condition, adopting the pseudo static method. Reduction factors have been considered to calculate the long-term design strength of primary and secondary reinforcements from their short term ultimate tensile strength.

6.1 *Observations regarding optimization of reinforcement*

Figure. 13 represents optimized cross sectional reinforcement details of 31.0 m high OB Dump structure analyzed by numerical tool MacStARS tool.

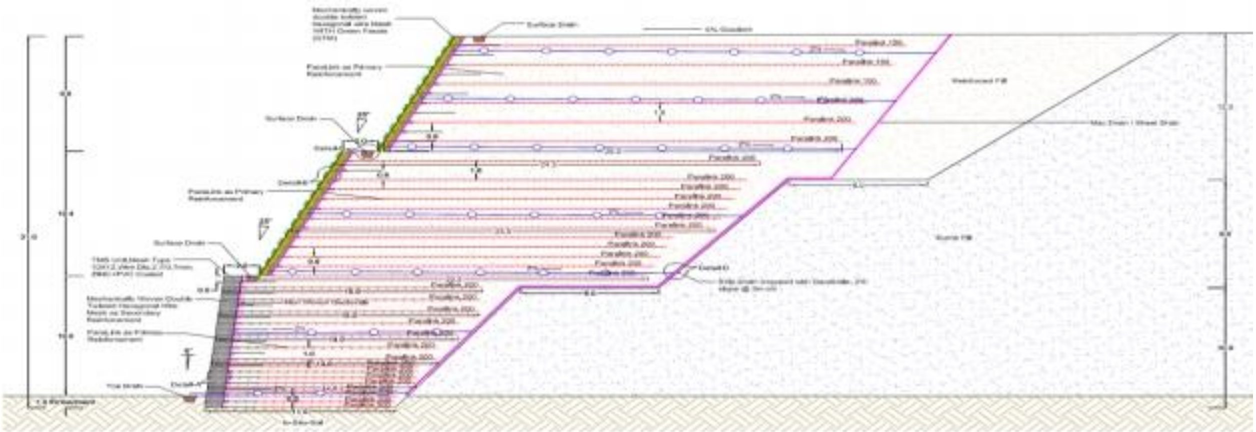


Figure 13. Typical cross-sectional reinforcement details of 31.0 m high OB Dump Structure

6.2 *Observations regarding stability analysis*

External stability has been analyzed as sliding and bearing capacity were performed as well as internal checks like reinforcement rupture and reinforcement pullout. The internal stability check has been performed with circular surfaces according to the Bishop's method for slip circle analysis shown. A typical output of MacStARS is presented in Fig. 14 where the "safety map" of the potentially sliding surfaces is shown, represented with different colors according to the values of the Factor of Safety. In Figure. 15 sliding analysis has been shown for static and seismic condition in case of bottom tier. The achieved factor of safety for global, internal and sliding stability in case of static and seismic condition with the effect of surcharge and no surcharge has been listed in Table 5.

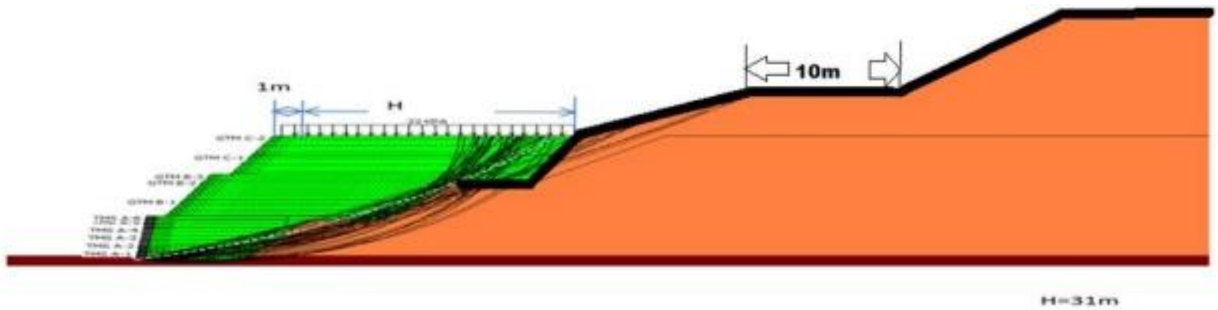
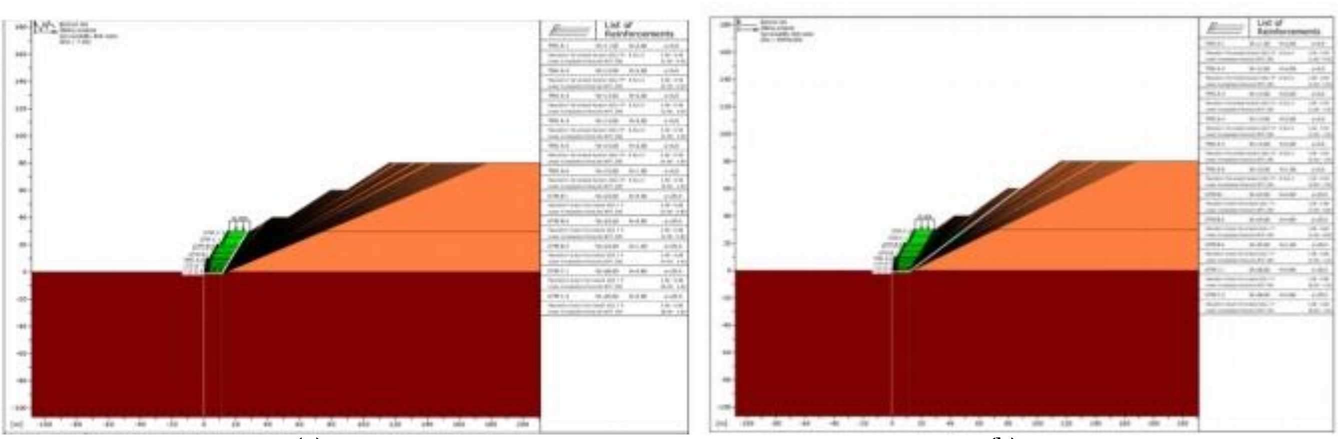


Figure 14. Typical view of Global slope stability analysis of 31.0 m high OB Dump Structure



(a) (b)

Figure 15. Sliding analysis at bottom tier a)Seismic condition b) Static condition

Table 5. Achieved Factor of Safety from Numerical Analyses

Criteria	31m high submissior (no surcharge)		31m high-with 30m higl 37° slope surcharge at 31 r distance from the crest	
	Static	Seismic	Static	Seismic
Top Tier (Internal Stability Analysis)	3.104	2.71	3.104	2.71
Top Tier (Sliding Analysis)	3.053	3.208	3.053	3.208
Middle Tier (Internal Stability Analysis)	2.235	1.785	2.171	1.795
Middle Tier (Sliding Analysis)	2.842	1.691	2.842	1.691
Bottom Tier (Internal Stability Analysis)	1.538	1.302	1.532	1.313
Bottom Tier (Sliding Analysis)	1.773	1.003	1.773	1.048
Internal-Combined (Internal Stability Analysis)	1.501	1.295	1.514	1.3
Global Stability Analysis	1.372	1.215	1.365	1.223

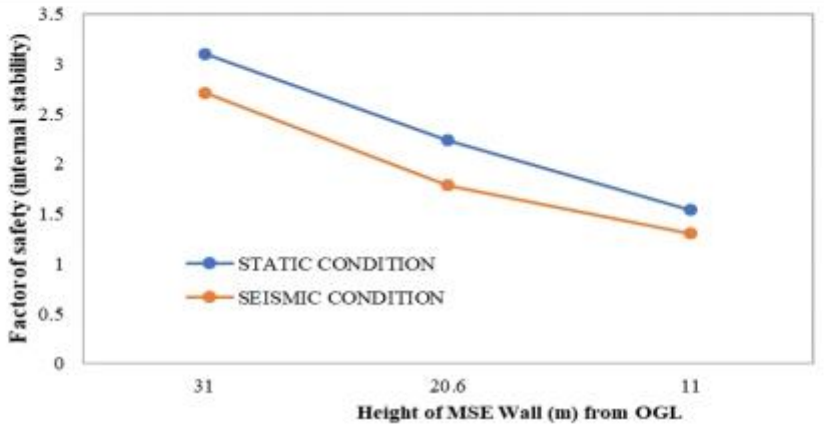


Figure. 16. Graphical representation of Factor of safety at different position of wall

It has been shown from Fig. 16 that factor of safety increases at the top tier of composite MSE wall. It has been shown that compared to static condition factor of safety reduces for seismic condition at about 12% for different position of composite MSE wall.

7 SUMMARY & CONCLUSIONS

The findings of the present study are as follows,

i) The composite structures of TMS and GTM unit have been observed to be economic in terms of reinforcement detailing and flexibility criteria with comparison to other methods.

ii) Factor of safety have been observed to be reduce for seismic condition compared to static at about 12% for different position of composite Terramesh and Green Terramesh wall system.

iii) GTM system effectively encountered collapse against pore water pressure generation and mitigation of slope erosion at facing by vegetation.

iv) The composite structures of TMS and GTM unit allow very high deformations and settlement before collapse in both static and seismic condition.

REFERENCES

Anon, 2010. FLAC slope version 6 manual. Itasca consulting group, Inc. USA. IIT-Madras Report, 2016. Report on the strength characteristics of Kaliapani Opencast mine dump samples at Kaliapani, Jajpur district, Odisha, IIT Madras.

FHWA 1997. Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines. *Federal Highway Administration, Demonstration project 82*, Washington, DC, USA.

BS: 8006 – 2010. Code of practice for strengthened / reinforced soils and other fills.

Das, A. and Mishra, S. 2010. Biodegradation of the metallic carcinogen hexavalent chromium Cr (VI) by an indigenously isolated bacterial strain. *Journal of Carcinogen*, Vol.9, No.6, pp 19-24.