AN INVESTIGATION ON MINE OVERBURDEN DUMP SLOPE STABILITY

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Abstract -*In the present study, an attempt has been made to evaluate the safety and stability of mine overburden dump slopes. The influence of addition of geogrids, on the overall stability of the slope has been further discussed. Influence of additional parameters, such as slope height, number of geogrids and their numbers, on the overall stability, has been assessed by performing a rigorous parametric investigations. Upper bound finite element limit analysis technique has been used to obtain the factor of safety of the slopes. The samples are collected from several different overburden slopes, located in the Dhanbad district of India. The basic engineering parameters are evaluated in the laboratory and are further used for numerical modelling. Based on the results obtained, the significance of addition of geogrids, to enhance the stability of mine overburden dump slopes, has been established. Furthermore, the optimum numbers of geogrids, as well as the optimum spacing of the geogrids are also obtained. The present study would be highly beneficial for practicing civil engineers, designing the mine overburden slopes in coal rich regions, such as Dhanbad.*

Key Words: Overburden dump (OB), slope stability, finite element limit analysis, OptumG2

1. INTRODUCTION

Due to global increase in the demand of power, coal producing companies are under tremendous pressure to produce large amount of coal. In the last few decades, the urban population has increased substantially and thus the demand for power has increased. Although, use of the renewable energy sources are increasing with each passing day, still, coal is going to be the chief source of power for the next few decades (Anand and Sarkar 2020). In India, Dhanbad city is also known as the coal capital of India due to the large reserves of coal. In Dhanbad, often open pit mining is carried out for efficient mining operation and due to high availability of coals.

However, in this process of open pit mining, a large volume of overburden dump materials are generated. These overburden dump materials are often disposed off in nearby locations under the action of gravity. The height of the mine overburden dump slopes may even reach up to a height of 80m. Under these circumstances, a rigorous safety evaluation of these mine overburden dump slopes are essential, as the failure of these overburden dump slopes, may often be catastrophic.

In the present study, the mine overburden dump slope materials have been collected from several different locations of the Dhanbad region. The basic characterization studies are carried out in the geotechnical engineering laboratory of BIT Sindri, Dhanbad. The engineering parameters of the materials are evaluated and the properties obtained, are then further used to evaluate the safety of the slope.

Furthermore, the influence of addition of geogrids, on the overall improvement of the stability of the dump slope has been further established. For this, different number of geogrids and their relative significance in improving the stability of the slopes are evaluated. Furthermore, the optimum spacing of the geogrid, at which the factor of safety of the slope is highest, has been obtained.

The influence of height of slope, on the overall factor of safety, has been further evaluated. It has been found that with inclusion of geogrids, the height of the slope of the mine overburden slope may be increased without compromising the safety of the slope.

1.1 Location and geology of study area

Materials from mines OB dumps were obtained from two separate locations of Bastacolla mines, Dhanbad. Bastacolla areas are located on eastern edge of Jharia coalfield having areas around 1637.64 hectares, producing 42.80 lakh tons of coal in 2019-2020. The geographic location of mines sites are indicated in the figure 1

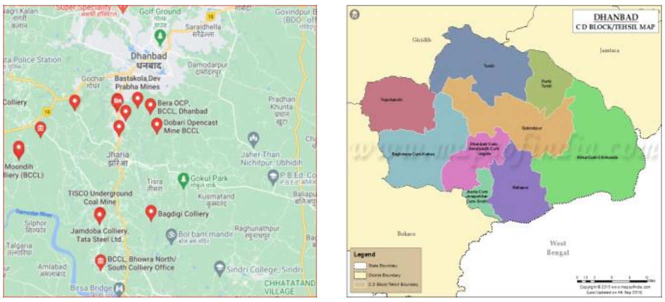

Fig. 1: Location of Dhanbad mines (sources: googlemap, maps of India)

2. Laboratory Investigation

For estimating the slope stability of mine OB dump specific gravity, bulk unit weight, dry unit weight, cohesion and friction angle of sample are important.

2.1 Specific gravity

The specific gravity of OB dump materials was determined in the laboratory according to IS 2720 recommendations (part III).

Table -1: Specific gravity of samples

Sl. No.	Location	G_s
1	Bastacolla mines 1	2.26
2	Bastacolla mines 2	2.33

The minimum value (2.26) of specific gravity was observed at Bastacolla mines 1
The value (2.33) of specific gravity was found in Bastacolla mines 2. The high bulk density values in Bastacolla mines 2 sites due to presence of movement of heavy earth moving machineries (HEMMs) and less amount of grass cover on dump materials.

2.2 Sieve analysis

Grain size distribution analyses of the sample were obtained based on dry sieve.
In the sampling sites percentage of sand fraction was found to be higher. More than 50% of sample passes through 4.75 mm sieve and % fineness (% faction which pass through 75 µ sieve) was less than 5%, this indicate poor quality for plant growth. Due to higher amount of sand particles in the overburden samples would allow water to move into dump materials by infiltration process.

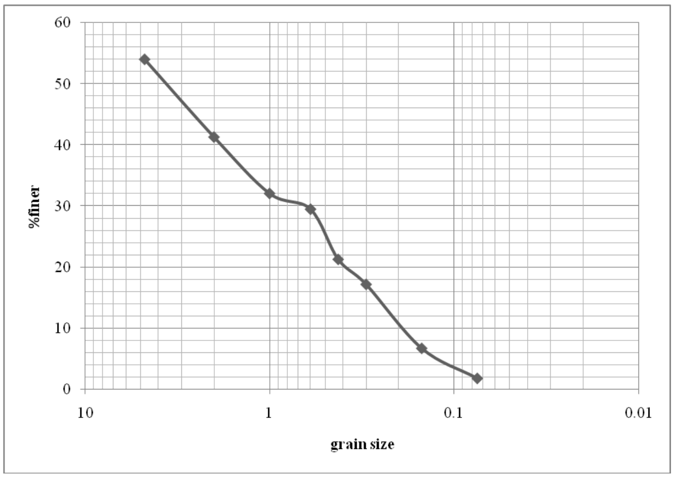

Fig. 2. Grain size distribution curve of mine ob dump

2.3 Compaction characteristics

When it comes to geomechanics problems like bearing capacity assessment and slope stability evaluation, compaction characteristics of a geomaterial are quite significant. The compaction characteristics of mine OB dump trash collected from various places are discussed in this section. The IS light compaction test, as recommended by IS 2720, was used to obtain the compaction curves for waste materials obtained for each location (Part VII).

Table -2: MDD and OMC for different OB dump materials

Location	MDD(gm/cc)	OMC (%)
BT1	1.98	13.87
BT2	1.76	12.46

2.4 Shear behaviour

The shear strength of the mine overburden dump slopes were evaluated by performing the direct shear test in the laboratory. The cohesion and angle of friction angle values were obtained and the results are shown in table 3.

Table 3: Shear strength paraments obtained for OB dump materials

Location	C(kN/m^2)	Φ°
BT1	1.954	33°
BT2	2.136	36.56°

3. Numerical analysis

Numerical analysis is the branch of mathematics and computer science that create, analyzes and implements algorithms for numerical solution of problems in continuous mathematics. These problems usually arise in the practical application of algebra, geometry, calculus and involve constantly changing variables. In recent decades, numerical methods have become increasingly important in practical geotechnical engineering, and numerical methods have become a widely accepted standard geotechnical planning tool in geotechnical engineering.
For stability of OB dump slope analysis we are using OPTUM G2. Factors of safety are calculated in OPTUM G2 utilizing strength reduction finite element limit analysis (SR-FELA). SR-FELA not only has fast computation speeds, but it also allows you to determine upper and lower bounds on the genuine factor of safety. In reality, this means that the true factor of safety can be determined in a fraction of a second within a minimal gap.(www.optumce.com).

3.1 Numerical simulation of dump slope

In this study, the factor of safety (FOS) obtained based on the finite element analysis using optum G2 software on two different OB dump samples. Property use by optum G2 to determine the FOS of OB dump is dry density, saturated density, cohesion, and friction angle of the sample. The numerical analysis has been done considering the gravity load only. Deterministic analysis of OB dump considers under various geometrical conditions such as slope angle (β), height of slope (H), and under the influence of number of geogrids layers (N).

The dump slope angles are varied from 25° to 40° keeping height of 30 m and FOS has been evaluated. Then dump slope height is varied from 10 m to 80 m keeping slope angle to be constant at 30° and FOS has been evaluated. And in third case, influences of number of layers of geogrid are analysis for checking FOS improvement at dump height at 80 m and slope angle of 30°.

4. Results and Discussions

4.1 Influence of slope angle, (β)

The current study additionally considers the effect of slope angle on slope FOS. The current research focuses on four different slope angles between 25 and 40 degrees (25°, 30°, 35°, and 40°). The slope angles used in this study are well within the range of slope angles that can be used for building an OB dump slope.

Table 4. FOS of samples at different angles

Angle	BT1	BT2
25^0	1.532	1.760
30^0	1.259	1.447
35^0	1.058	1.215
40^0	0.900	1.033

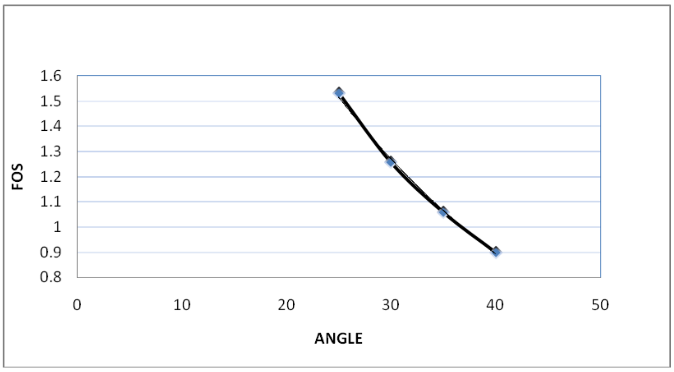

Fig. 2: FOS of BT1 sample at different angle

From graph, FOS varies almost non-linearly with increase in the slope angle. For OB dump sample BT1 at slope angle 40^0 slopes becomes substantially unstable as value reduces less 1 and in OB sample BT2 FOS is almost equal to 1. All the analysis has been performed under dry slope. So, under partial saturated state, the actual FOS may be higher. As angle changes from 25^0 to 40^0, percentage reduction of 42.13% has been obtained.

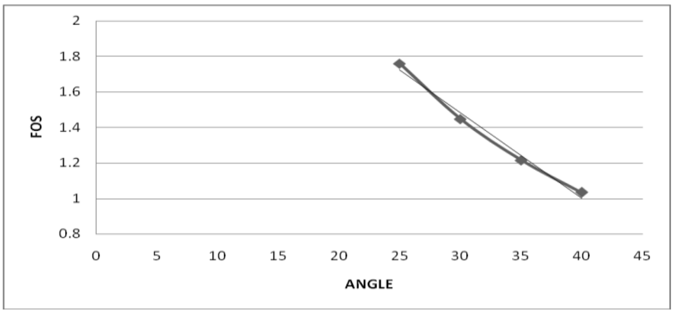

Fig. 3: FOS of BT2 sample at different angle

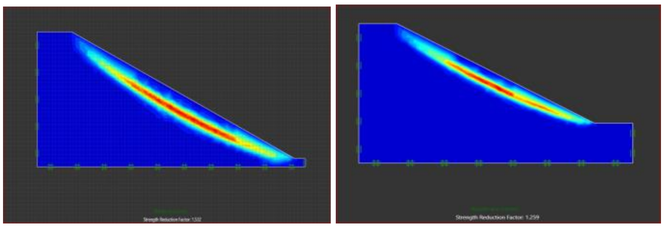

Fig -4: shear dissipation contours obtained for slope 25^0 and 30^0 at BT1 sample

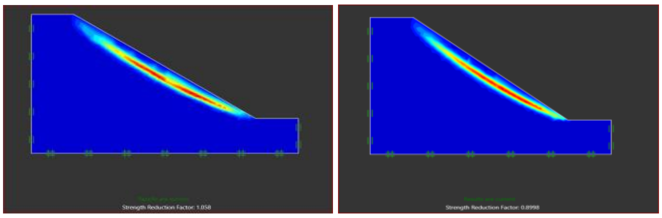

Fig -5: shear dissipation contours obtained for 35^0 and 40^0 at BT1 sample

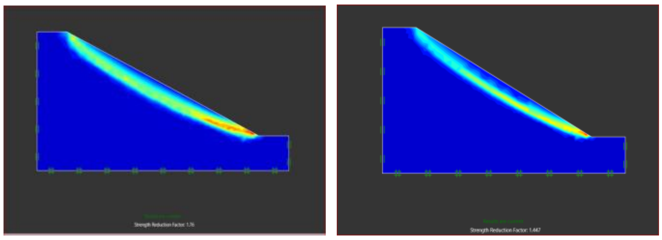

Fig -6: total dissipation contours obtained on slope 25^0 and 30^0 at BT2 sample

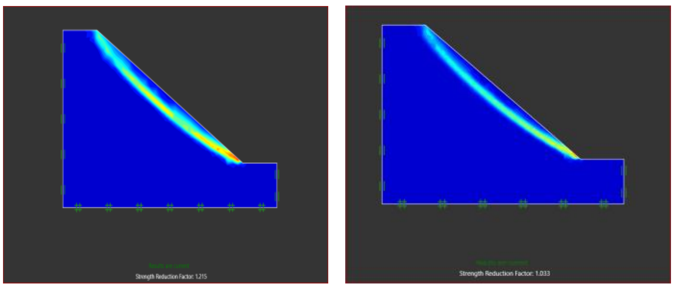

Fig -7: total dissipation contours obtained on slope 35^0 and 40^0 at BT2 sample

4.2 Influence of slope Height (H)

It has known that stability of slope is affected by the height of slope. A parametric study has been carried out to know the influence of height of slope on overall FOS of slope. The angle of slope has been kept constant at β= 30^0, while studying the impact of H on FOS of slope. For the parametric analysis, 8 different slope height (10m, 20m, 30m, 40m, 50m, 60m, 70m, 80m) has been assumed.

Table 5: FOS of sample BT1 and BT2 at different height

Height	BT1	BT2
10m	1.391	1.601
20m	1.299	1.492
30m	1.259	1.447
40m	1.237	1.418
50m	1.224	1.403
60m	1.212	1.392
70m	1.203	1.381
80m	1.197	1.372

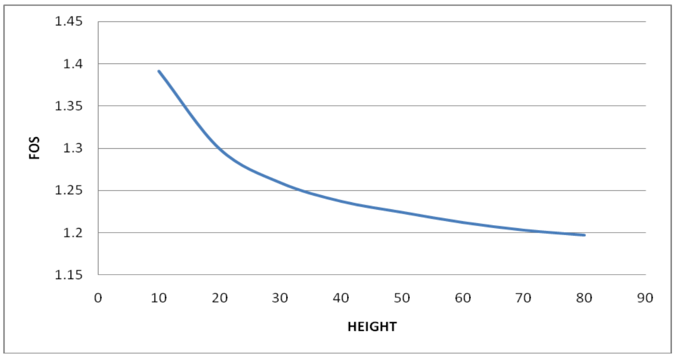

Fig. 8: FOS with height of slope (H) of sample BT1

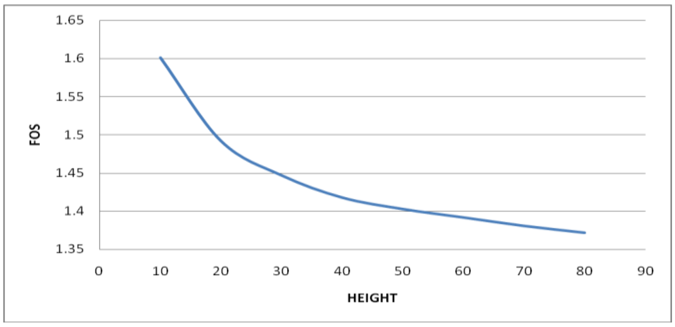

Fig. 9: FOS with height of slope (H) of sample BT2

From the table 5 it has been seen that with increase in height of slope (H), FOS reduces non-linearly. Slope stability reduces with increases of height of slope and reaches to critically safe at height of 80m. With increase in height of slope from 10m to 30m, FOS reduces to 9.48%. With increase of height 10m to 50m, FOS reduces to 12%. And with increase of height from 10m to 80m the FOS reduces to 13.94%. Therefore FOS of dump slope is less sensitive towards variation of height of slope (H) when compared to slope angle (β). However FOS has been carried out on dry sample, so additional stability of slope would be gain with dampness and vegetation.

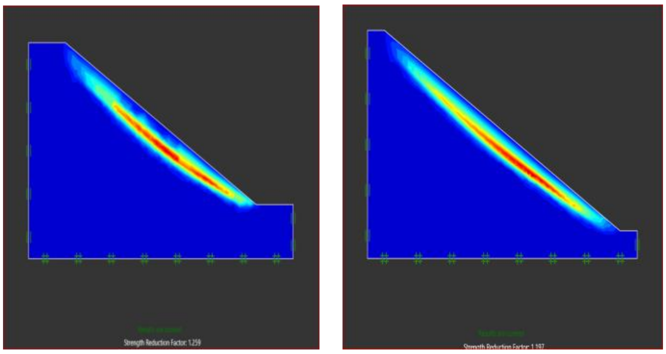

Fig –10: shear dissipation contours obtained for slopes of height 30 m and 80 m of BT1 sample

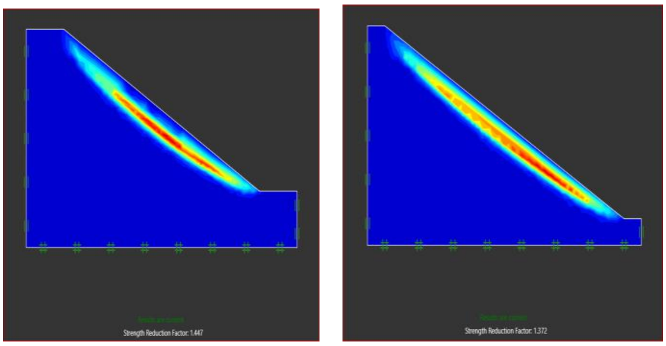

Fig -11: shear dissipation contours obtained for slopes of height 30 m and 80 m of BT2 sample

4.3 Influence of multi Layers (N) of geogrid

Geosynthetics, such as geogrids are usually added as a tensile resistant element and it enhances the shear strength of the soil slope substantially. Geogrids are artificial polymeric materials and addition of geogrids in artificial slope may impart substantial strength to the soil geogrid composites.
Reinforcement of soil imparts tensile strength to OB dump and thereby increases the factor of safety of the slope. Reinforced use geogrids is very effective technique. In these section different layer of geogrids influence are determine on OB dump soil and influence of multi layers of geogrids are studied. For the study, the number of geogrids layers are consider are N= 1 to 15. Maximum numbers of geogrids

provided would be 15 as with increase numbers of geogrids would increase the cost the project.

Table 6: FOS of sample BT1 and BT2 at different layers of geogrids

Number of geogrid layer	BT1	BT2
1	1.205	1.380
2	1.208	1.386
3	1.215	1.389
4	1.215	1.392
5	1.217	1.397
6	1.219	1.401
7	1.223	1.402
8	1.224	1.405
9	1.230	1.407
10	1.230	1.409
11	1.230	1.410
12	1.228	1.410
13	1.232	1.407
14	1.229	1.410
15	1.233	1.415

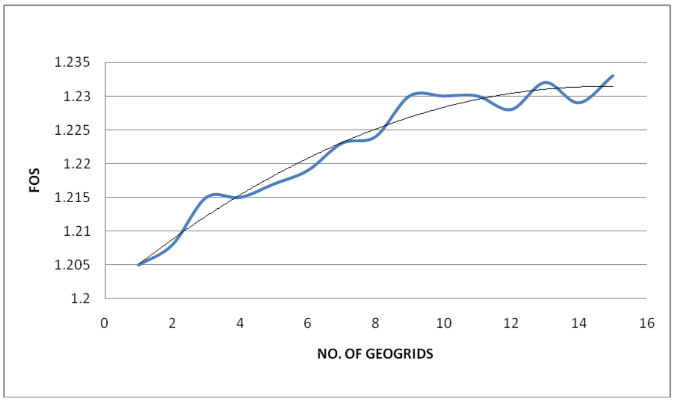

Fig. 12: variation of FOS of mine OB dump BT1 slope with number of geogrid layers (N)

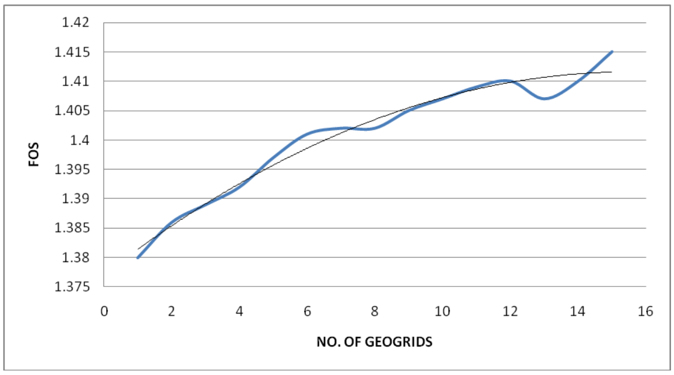

Fig. 13: Variation of FOS of mine OB dump BT2 slope with number of geogrid layers (N)

Base on the results, it could be stated the there is no notable increase of FOS of OB dump slopes. It has been noted that in OB sample BT1 the FOS remain constant on 3 and 4 multi layers geogrids and FOS after 7 geogrids remains ineffective as it does not show any greater improvement on slope stability.

On sample BT2 geogrids shows slight improvement of FOS up to 7 multi layers geogrids after that it remain constant and decrease of FOS on 10 and 13 geogrids. Therefore, project budget does not permit to provide larger number of geogrids layer, in those case an optimum 6-7 number of geogrids layers may be provided.

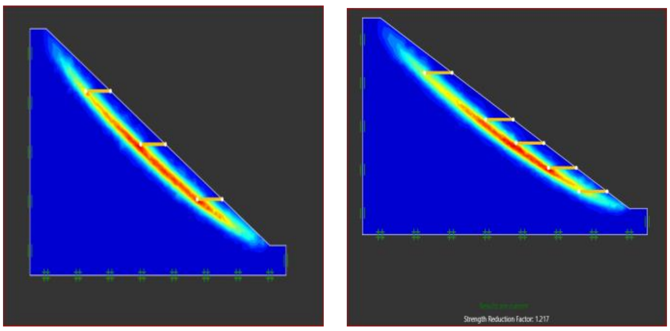

Fig -14: Influence of multi layers geogrids on stability of OB dump slope N=3 and N=5 of BT1

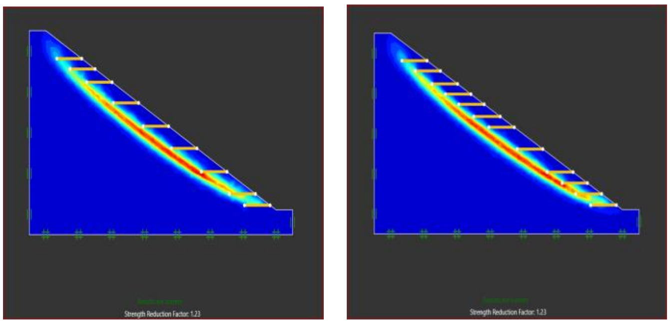

Fig -15: Influence of multi layers geogrids on stability of OB dump slope N=9 & N=12 of BT1

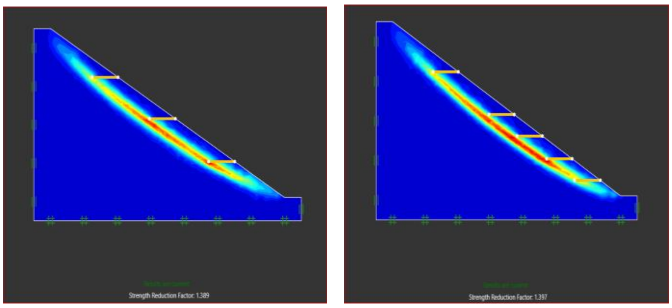

Fig -16: Influence of multi layers geogrids on stability of OB dump slope N=3 and N=5 at BT2

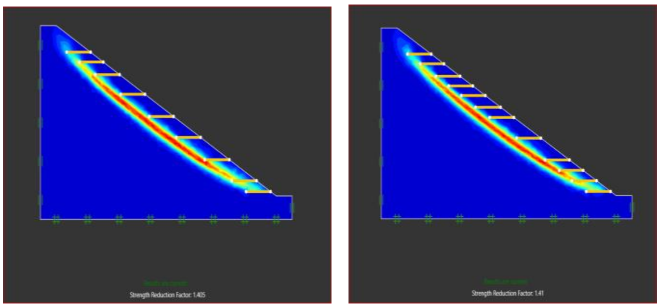

Fig -17: Influence of multi layers geogrids on stability of OB dump slope N=9 and 12 at BT2

5. CONCLUSIONS

In this study, the safety parameters of the OB dump slope of two mine samples are examined in depth. Geotechnical parameters were obtained through laboratory studies C_{BT1}= 1.954 kN/m^2 and C_{BT2}= 2.136 kN/m^2 and friction and friction angle of OB dump BT1 and BT2 are 33° and 36.6°. These properties, then were use in OPTUM G2 software for slope stability analysis and three different parameter and their influence (slope angle, height of slope and multi layers of geogrids) were studied.

Slope stability analysis of different angle of slope (β) was done at a constant height of 30m. The FOS of OB dump slope reduces significantly with increase of angle from 25^0 to 40^0. For OB dump sample BT1 at slope angle 40^0 slopes becomes substantially unstable as value reduces less 1 and in OB sample BT2 FOS is almost equal to 1. As slope angle changes from 25^0 to 40^0, percentage reduction of 42.13% has been obtained.

Slope stability analysis at different height of slope (H) were done at constant angle of 30^0 on heights of 10m, 20m, 30m, 40m, 50m, 60m, 70m and 80m. With increase in height of slope from 10m to 30m, FOS reduces to 9.48%. With increase of height 10m to 50m, FOS reduces to 12%. And with increase of height from 10m to 80m the FOS reduces to 13.94%. Therefore FOS of dump slope is less sensitive towards variation of height of slope (H) when compared to slope angle (β). FOS of OB dump was founded to greater than 1 at height of slope (H) is 80m. BT1 FOS at 80m was found to be 1.197 and BT2 FOS at 80m was found to be 1.372.

Slope stability analysis after providing multi layers of geogrids (N) in order to improve FOS of OB dump slope was done by keeping constant angle of slope to 30^0 and constant height to be 80m. Base on the results, it could be stated the there is no notable increase of FOS of OB dump slopes. On sample BT1 FOS of OB shows improvement on 1, 2 and 3 geogrids layers but at 4th geogrid layer sample FOS remain constant. Then improvement is been noted on 5th, 6th and 7th geogrids layers but after that FOS of OB sample BT1 remains almost constant and decrease at 10th geogrids layer. On sample BT2, FOS of OB dump slope increase with geogrids layers up to 7th geogrids layers but at 8th geogrid layers it remains constant. There is no notable improvement of FOS of OB dump slope with increase of geogrid layers (N). Therefore, project budget does not permit to provide larger number of geogrids layer, in those case an optimum 6-7 number of geogrids layers may be provided.

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