# Effect of Slope Stability on Stabilized Soil due to Earthquake Loads using GeoStudio

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**Abstract –** ***Black cotton soil found in many central parts of India and Karnataka poses several serious problems for civil engineers in the buildings, roads, slopes, retaining structures, etc. This paper evaluates the possible use of Granulated Blast Furnace Slag (GBS) to stabilize Black Cotton Soil (BCS). The soil sample collected from Kadur, Chikmanglur District of Karnataka was classified as highly compressible clay(CH) as per Indian Standard Classification System (ISCS). In this investigation, the response of slopes made of GBS stabilized BCS under dynamic loading was studied using finite element method. The slope was assumed to be constructed with BCS stabilized with (GBS) along with small amounts of lime viz, 1, 2 and 4 % and for a slope of 15m height. These soil mass along with the slope was subjected to an amplitude of 0.1g which was equivalent to highest earthquake in the region as per past earthquake records. The stability of slope was analysed and factor of safety was determined. Factor of safety obtained for unstabilized soil slope is compared with stabilized soil slope. It was observed that the stabilized soil performs better under seismic condition when compared to unstabilized soil slope.***

**Key Words:** *Slope stability, Black cotton Soil, GBS, Factor of Safety, Dynamic Analysis.*

## 1.INTRODUCTION

In India, expansive soils are usually called Black Cotton soil (BCS). These soils show high strength under dry condition (in summer), but undergoes rapid reduction in strength when it is saturated (during monsoon). The properties of BCS can be enhanced by blending it with industrial wastes like Fly Ash, GBS, GGBS, Rice Husk Ash, etc. GBS, which is a slag material of sand-sized particles, is one such material which is used to enhance the strength of BCS. It is not only useful in enhancing the strength of the soil, but is also a very useful way of disposing industrial waste and makes the stabilization process more eco-friendly.

Slopes are one of the main Civil Engineering components in embankments and earth dams. Stability of these man-made slopes is of great importance. The stability or potential to withstand the movement of soil is mainly measured by its shear strength. There are many causes for the failure of slopes. Earthquake is one of these main causes.

Earthquake is one of the most devastating forms of natural disaster. It causes a lot of damage to life and property. It is a result of sudden release of energy from earth's crust which creates seismic waves. Liquefaction is also one of the effects of earthquake where in the soil loses its strength and transforms from solid to liquid state. This effect leads to sinking of soil and collapse of structures. Inertia forces which are induced in the slope due to earthquake results in the displacement of the soil. When this displacement exceeds certain limit the slope is said to have failed, because the factor of safety drops below unity during earthquake. In order to mitigate this failure, it is tried to stabilize the BCS using GBS and lime so that it may be used in constructing the slopes which would be more strong.

## 2. MATERIALS AND METHOD

2.1 Location of Material.

The BC soil sample used for this study was collected from Kadur, Chikmaglur District of Karnataka at a depth of 1m below ground level. The GBS sample used for this study was procured from Jindal Steel Plant, Bellary in Karnataka.

2.2 Testing method

Properties of BCS and GBS were determined as per Indian Standard code and are tabulated in Table 1. The soil obtained from the site was carefully pulverized with rammer to break lumps. It was then oven dried and mixed in different proportions with GBS and lime. The different proportions tested for are tabulated in Table 2. Laboratory tests were performed on these proportions to determine their strength parameters.

**Table 1: Properties of soil and GBS**

| Properties | BCS | GBS |
|---|---|---|
| Liquid limit (%) | 61 | NA |
| Plastic limit (%) | 23.2 | NA |
| Shrinkage limit (%) | 14.43 | NA- |
| Specific gravity | 2.668 | 2.525 |
| Maximum Dry Density (kN/m$^3$) | 15.4 | 13.6 |
| Optimum Moisture Content (%) | 21.5 | 15.2 |
| CBR value (soaked) (%) | 0.11 | NA |
| CBR value (unsoaked) (%) | 1.58 | NA |
| 28$^{th}$ day UCC strength (kPa) | 122 | NA |
| Indian Standard Soil Classification | CH | ML |
| Cohesion (kPa) | 90 | 0 |
| Angle of internal friction (°) | 26 | 36 |

**Table 2: Combinations of additives with soil**

| Sl. No. | BCS (%) | GBS(%) | LIME(%) |
|---|---|---|---|
| 1 | 100 | 10 | 0 |
| 2 | 100 | 10 | 1 |
| 3 | 100 | 10 | 2 |
| 4 | 100 | 10 | 4 |

## 3. RESULTS AND DISCUSSION

### 3.1 Compaction properties

Compaction properties for the blended mixes were determined as per mini compaction test proposed by Sreedharan and Sivapullaiah (2005). The MDD decreased on addition of GBS and lime whereas OMC increased for the same. As lime needs water for chemical reactions and becomes stronger, the OMC increased because the presence of optimum content of water for lime provides more strength.

### 3.2 Shear strength

Direct shear tests were conducted as per IS 2720 (Part 13) – 1986. These experiments were used to determine the shear strength of the soil in terms of C and Phi.(Vide table 3) Samples of various mixes were prepared with maximum dry density in the laboratory and tested.

**Table 3: Direct shear test results**

| PROPORTIONS | DENSITY in (kN/m$^3$) | C in (kPa) | Phi in (degrees) |
|---|---|---|---|
| 100 % BCS | 15.08 | 90 | 25.5 |
| BCS + 10% GBS | 14.27 | 82 | 28.5 |
| BCS + 1% LIME + 10% GBS | 14.27 | 76 | 31 |
| BCS + 2% LIME + 10% GBS | 14.27 | 70 | 35 |
| BCS + 4% LIME + 10% GBS | 14.27 | 63 | 40.5 |

## 4. ANALYSIS OF SLOPE STABILITY

Geo Studio includes elementary features of SLOPE/W, SEEP/W, SIGMA/W, QUAKE/W, TEMP/W, CTRAN/W, AIR/W, and VADOSE/W for solving slope stablity and other related geotechnical analysis. In the present study two features were primarily used to study the stability, namely, SLOPE/W which gives the stability of the slope and QUAKE/W which performs earthquake analysis of the soil

## 5. RESULTS AND DISCUSSION

The static and dynamic factors of safety have been given in Tables 4 to 8. For a slope of 1:1, from Table 4, it was observed that addition of 10% GBS reduced the dynamic factor of safety but the addition of 1% Lime increased the factor of safety and on further addition of lime, the factor of safety reduced compared to 1% but was found to be higher than plain BCS. From this, it was understood that the addition of 10%GBS and 1% lime gives us the highest dynamic factor of safety. It was also seen that 10 % GBS and 1 % lime was found to give the highest dynamic factor of safety only for slope angles of 1:1 and 1:0.9. From Table 6, Table 7 and Table 8, the results show that the factor of safety increased on addition of lime and it is seen that the highest factor of safety is obtained for 10% GBS and 4% lime.

After finalizing the geometry and obtaining material properties, the slope was modelled in Geostudio SLOPE/W by keeping the height constant at 15m and the slope angles were varied using slope angles 45°, 48°, 51°, 55° and 61°. Fig 1, shows the analytical model for 45°. The other slope angles were also modelled similarly. SLOPE/W gives us the static factor of safety of the slope as shown in Fig 2. Using the same geometry and properties, the same model was run in QUAKE/W to analyze the same slope for seismic load. The seismic file is then imported to SLOPE/W and the dynamic factor of safety was determined using Newmarks' Deformation. Fig. 3 shows the slip surface for the seismic load. Similarly, the slope and properties were modelled and analysed for all the proportions shown in Table 3.

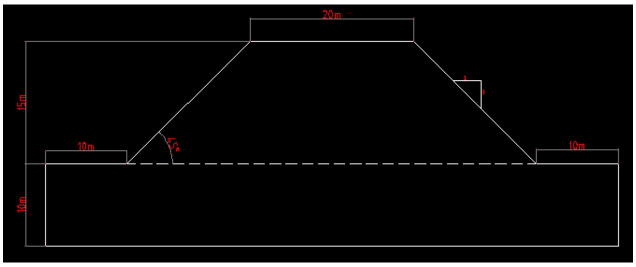


**Fig -1 Geometry of slope**

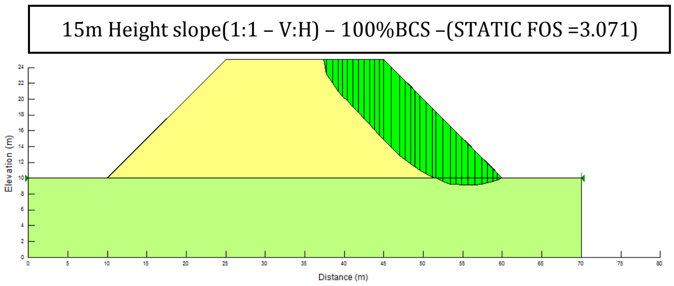


**Fig -2 Critical slip surface of 100%BCS slope for static load**

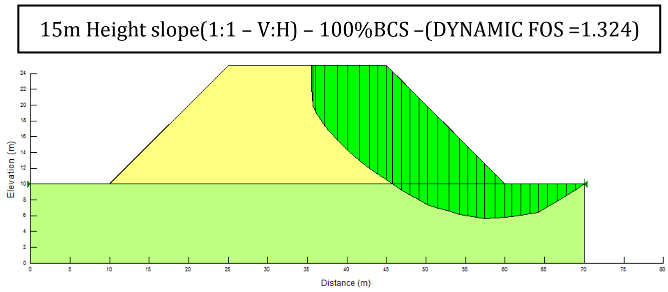


**Fig -3 Critical slip surface of 100%BCS slope for dynamic load**

**Table 4: Factor of Safety for slope angle 45°**

| 15 m Ht embankment | (1:1) V:H | |
|---|---|---|
| | **FACTOR OF SAFETY** | |
| | Static | Dynamic |
| 100 % BCS | 3.07 | 1.34 |
| BCS + 10% GBS | 3.14 | 1.31 |
| BCS + 1% LIME + 10% GBS | 3.14 | 1.54 |
| BCS + 2% LIME + 10% GBS | 3.15 | 1.50 |
| BCS + 4% LIME + 10% GBS | 3.20 | 1.47 |

**Table 5: Factor of Safety for slope angle 48°**

| 15 m Ht embankment | (1V : 0.9 H) | |
|---|---|---|
| | **FACTOR OF SAFETY** | |
| | Static | Dynamic |
| 100 % BCS | 2.30 | 1.32 |
| BCS + 10% GBS | 3.02 | 1.41 |
| BCS + 1% LIME + 10% GBS | 3.10 | 1.42 |
| BCS + 2% LIME + 10% GBS | 3.10 | 1.38 |
| BCS + 4% LIME + 10% GBS | 3.16 | 1.35 |

**Table 6: Factor of Safety for slope angle 51°**

| 5 m Ht embankment | (1 V : 0.8 H) | |
|---|---|---|
| | **FACTOR OF SAFETY** | |
| | Static | Dynamic |
| 100 % BCS | 2.99 | 1.36 |
| BCS + 10% GBS | 2.96 | 1.33 |
| BCS + 1% LIME + 10% GBS | 2.87 | 1.45 |
| BCS + 2% LIME + 10% GBS | 2.93 | 1.41 |
| BCS + 4% LIME + 10% GBS | 2.88 | 1.52 |

**Table 7: Factor of Safety for 55°**

| 15 m Ht embankment | (1 V : 0.7 H) | |
|---|---|---|
| | **FACTOR OF SAFETY** | |
| | Static | Dynamic |
| 100 % BCS | 2.88 | 1.51 |
| BCS + 10% GBS | 2.88 | 1.46 |
| BCS + 1% LIME + 10% GBS | 2.83 | 1.48 |
| BCS + 2% LIME + 10% GBS | 2.83 | 1.44 |
| BCS + 4% LIME + 10% GBS | 2.80 | 1.74 |

**Table 8: Factor of Safety for slope angle 61°**

| 15 m Ht embankment | (1V: 0.5H) | |
|---|---|---|
| | **FACTOR OF SAFETY** | |
| | Static | Dynamic |
| 100 % BCS | 2.75 | 1.77 |
| BCS + 10% GBS | 2.84 | 1.76 |
| BCS + 1% LIME + 10% GBS | 2.81 | 1.69 |
| BCS + 2% LIME + 10% GBS | 2.77 | 1.69 |
| BCS + 4% LIME + 10% GBS | 2.76 | 1.89 |

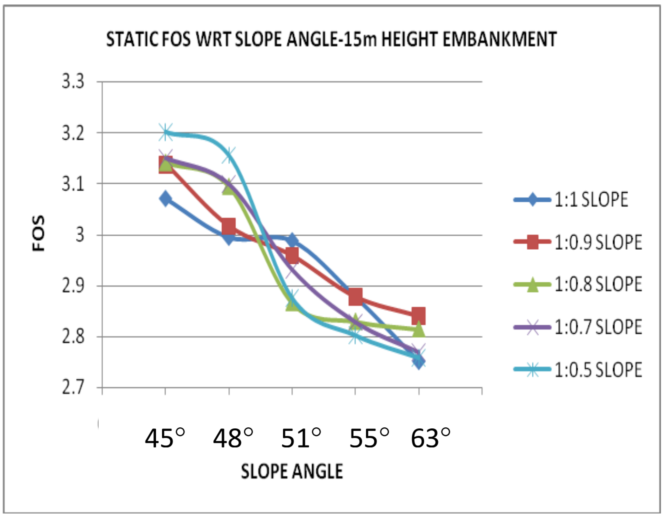


Fig 1: Static FOS for various Slope Angles

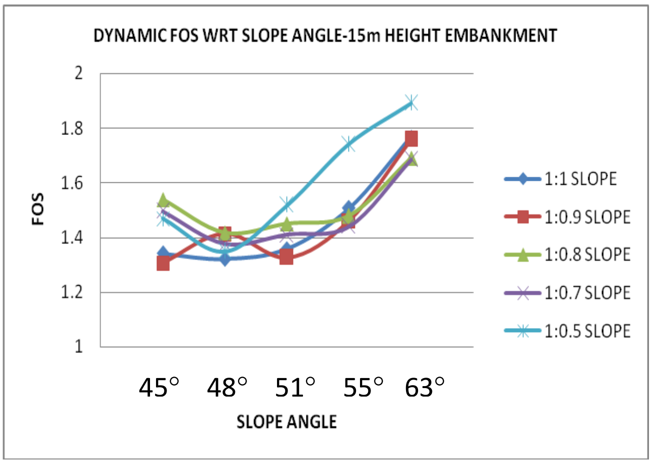


Fig 2: Dynamic FOS for various Slope Angles

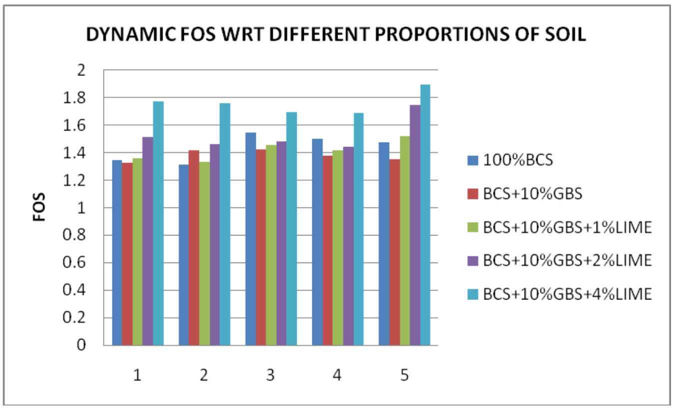


Fig 3: Dynamic FOS for Varying Proportions

## 6. CONCLUSIONS

The following conclusions was drawn from the results of the slope stability analyses.

- The static factor of safety increases as the percentage of lime increases, it was seen that for a slope of 1:1, the static factor safety increased by 2.18% when compared to BCS, on addition of 10% GBS.
- On further addition of 1% lime and 10% GBS, the static factor of safety was 2.32% higher than that for BCS.
- While for 2% and 4% lime, there was an increase of 2.57% and 4.23% compared to BCS respectively.
- The dynamic factor of safety for stabilized soil is higher when lime and GBS were added.
- It was observed for a slope of 1:1, the dynamic factor of safety for 10% GBS decreased by 2.67% when compared to 100% BCS, while 1% lime +10% BCS gave an increase of FOS by 14.68% when compared to 100% BCS.
- Also the FOS for 2% lime and 4% lime was found to be higher by 11.55% and 9.46% respectively when compared to 100%BCS.
- An optimum percentage of lime is obtained as the slop angle is varied, for slope of 1:1 and 1:0.9, the optimum percentage of lime was 1% + 10% GBS. While for the other slopes, the optimum percentage lime was found to be 4% lime.
- Also it was observed that the dynamic factor of safety increased as the slope angle increased. This was because as the slope increased, the mass of the soil in the slope reduced hence there was an increase of factor of safety.

## REFERENCES


1. **G Sridevi and A Sreerama Rao(2011**), Utilization Of GBS In Road Sub-Base, Proceedings of Indian Geotechnical Conference, December 15-17,2011, Kochi (Paper No. H-076)
2. **Laxmikant Yadu, and R K Tripathi (2013)**, "Stabilization Of Soft Soil With Granulated Blast Furnace Slag And Flyash" ,International Journal of Research in Engineering and Technology. ISSN:2319-1163.
3. **Huy Thanh Pham , Htet Zaw Oo, Cheng Jing,( 2013 )** "Stability Of Slope And Seepage Analysis In Earth Dam Using Numerical Finite Element Model", Study of Civil Enginreering and Architecture (SCEA) Volume 2 Issue 4, December 2013.
4. **Stability Modelling With SLOPE/W 2007** Version, An Engineering Methodology, Third Edition, March 2008, GEO-SLOPE International Ltd.
5. **Dynamic Modelling With QUAKE/W 2007** Version, An Engineering Methodology, Third Editioni, March 2008, GEO-SLOPE International Ltd.
6. **Indian Standard Codes IS:2720**


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