DYNAMIC SLOPE STABILITY ANALYSIS OF BLACK COTTON SOIL STABILIZED WITH GGBS AND LIME

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Abstract

The engineering properties of Black Cotton Soil (BC Soil) improve when it is stabilized with Ground Granulated Blast Furnace Slag (GGBS) and Lime. Engineering properties such as Maximum Dry Density (MDD), Optimum Moisture Content (OMC), Free swell index and unconfined compression strength were determined using various percentages of lime activated GGBS while stabilizing BC Soil. Static shear strength of stabilized mixes wasmeasured using Unconfined Compressive tests and Dynamic shear modulus (G_{max}) was determined using Nondestructive testing technique i.e. passing primary wave though the specimen and measuring its velocity. Using the experimental data, a dam slope with height 15m is modeled in GEOSTUDIO software package and Dam's dynamic stability is analyzed for various trial mixes.

Keywords: *Black Cotton Soil, GGBS, Dynamic analysis of Slopes, GEOSTUDIO, Free swell.*

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1. INTRODUCTION

Black cotton soil is a clayey soil,grayish or black in color, highly expansive and compressive in nature. BCSoil has low shrinkage limit and high optimum moisture content. BC Soil poses many problems to engineers due to its peculiar character; it undergoes volume changes with the seasons as moisture content in the soil changes. Due to the major presence of montmorillonite clay mineral, it swells and shrinks alternatively with every wet and dry cycle and also it has low shear strength and high plasticity index.

Ground granulated blast furnace slag is a refined form of blast furnace slag which is the by-product of the steel industry. It is a pozzalonic material, i.e. it has inherent cementitious properties which have to be activated. According to K V Manjunath et al.[6] (2012)addition of GGBS and lime reduces the swelling, increases the shrinkage limit and shear strength of BCSoil. Anil Kumar Sharma et al.[1] conducted that experiments on expansive soil and found that GGBS decreases the free swelling of expansive soil. According to Dr. D D Higgins[4] (2005) that GGBS increases the resistance to Sulphate expansion. Gyanen Takhelmayum et al.[5] (2013) stated that MDD increases because of formation C-S-H which fills the pore spaces.

For civil engineers, designing embankments with BC Soil is very difficult in earthquake prone areas; so it necessitates stabilization of BC Soil to achieve improved dynamic properties. An attempt has been made by stabilizing BC Soil with Lime and GGBS in this work.

2. MATERIALS USED

1. **Black Cotton soil:** The BC Soil was procured from Kadur in Karnataka. The soil was collected from a depth of 1m below ground level. The properties of Black Cotton soil used in this study are listed in the table 1.

Table 1 Properties of Black Cotton Soil

Specific gravity	2.659
Liquid limit	60%
Plastic limit	37.5%
Plasticity index	22.5%
Shrinkage limit	-
Max. dry density	1.56g/cc
Optimum moisture content	26%
Shear strength	116.45 kPa
Free swell index	60%
Shear strength	116kPa

2. **Ground Granular Blast Furnace(GGBS):** GGBS was procured from Jindal Steels, Bellary. The properties of GGBS used are listed in Table 2.

Table 2 Properties of GGBS

Specific gravity	2.874
Liquid limit	34.5%
Plastic limit	-
Plasticity index	-
Shrinkage limit	34.43%
Max. dry density	1.632g/cc
Optimum moisture content	21.7%

3. **Lime:** Commercially availablehydrated lime (CaOH) was used here.

3. METHODOLOGY AND MODELING IN GEOSTUDIO

Unconfined compressive testing is used to find out static shear strength and conducted as per IS 2720(part-10) and free swell index test as per IS2720 (part-40).Free swell index is calculated using following formula i.e.

Free swell index= ((Volume of soil in water)-(Volume of soil in kerosene))/(Volume of soil in kerosene).

G_{max} i.e. dynamic shear modulus determined by passing Primary Elastic wave through specimen and measuring its velocity; following formulae are used.

$$V_p=L/T$$

$$E= (\rho\ (1+\mu)\ (1-2\mu)*V_p^2)/\ (1-\mu)$$

$$G_{max}= E/\ (2(1+\mu))$$

$$V_s^2= (G/\rho)$$

Where, E is dynamic Young's modulus, G_{max} is dynamic shear modulus, μ is Poisson's ratio, V_p and V_s are primary and secondary wave velocities respectively.

A dam of 15m height is modeled. It is subjected to El-Centro earthquake and 14m water head in reservoir is considered. Figure 1 and 2 shows the models considered in study.

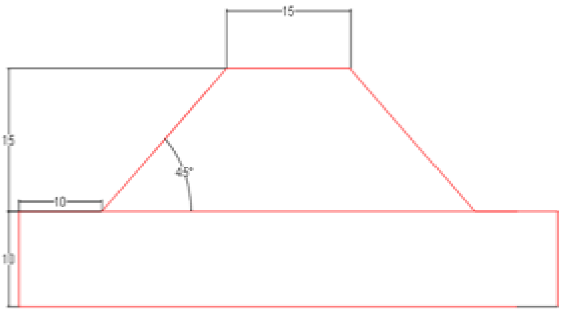


Fig1 Slope of 45 degree inclination and 15m height

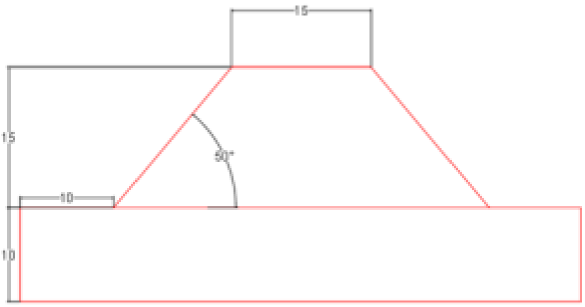


Fig2 slope of 50 degree inclination and 15m height

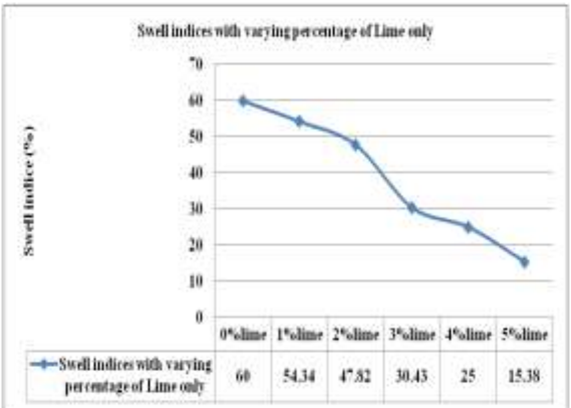
Assumptions made in GEOSTUDIO stability analysis.
1. Materials are considered as linear elastic in static analysis.
2. Dynamic shear modulus of foundation i.e. 100%BCSoil assumed to be 5000KPa.
3. Damping taken is 10%.
4. Poisson's ratio taken is 0.334.

4. RESULTS AND DISCUSSIONS

4.1 Free Swell Index Test

Free swell index reduces with the addition of GGBS and lime also. Graph 1 and 2 variation of swell indices with addition of GGBS and lime respectively.

Graph 1 swell indices of varying percentage of GGBS only



Graph 2 Swell indices of varying percentage of lime only

4.2 Maximum Dry Density(MDD) and (OMC)

MDD increases and OMC decreases with addition of GGBS. Table 2 shows variation of MDD and OMC with addition of GGBS.

Table 1 MDD and OMC variation with addition of GGBS

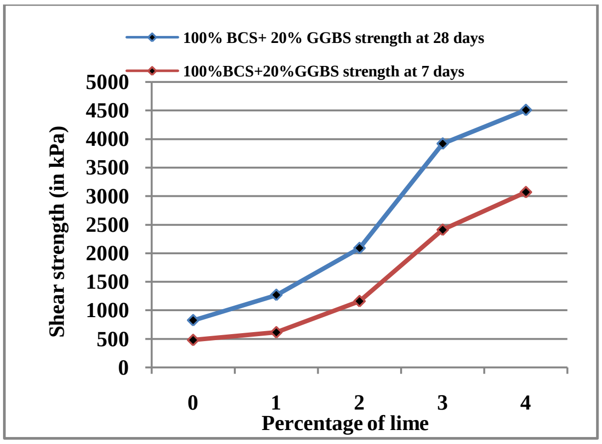
MIXES	MDD(g/cc)	OMC(%)
100%BCS	1.56	26
100%BCS+15%GGBS	1.64	24
100%BCS+20%GGBS	1.64	23
100%BCS+25% GGBS	1.67	22
100%BCS+30%GGBS	1.69	21
100%BCS+35%GGBS	1.73	21
100%BCS+40%GGBS	1.73	19
100%BCS+45%GGBS	1.77	19

4.3 UCC Test Results

Addition of GGBS and lime increases shear strength significantly. It is observed that strength at 7 days is about half of 28 days strength for 20%GGBS with varying percentages of lime. Similarly, strength at 7 days is about $1/3^{rd}$ of 28 days strength for 25% GGBS with varying percentages of lime.

Table 2 UCC strength of BCS+20%GGBS with varying percentage of lime

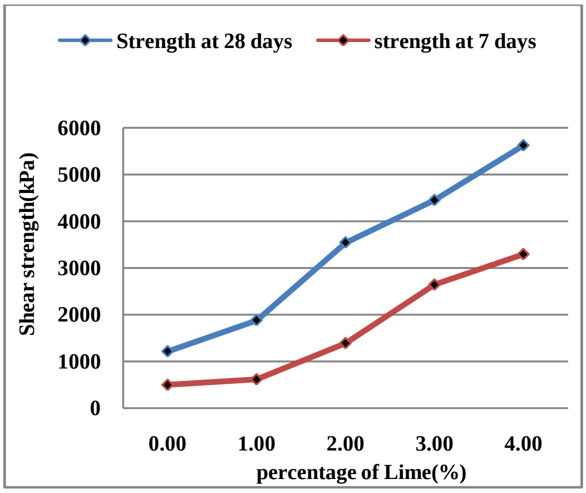
Combination	28 days UCC strength(kPa)	7 days UCC strength (kPa)
BCS+20% GGBS+0% lime	825.18	482.74
BCS + 20% GGBS + 1 % lime	1268.64	617.17
BCS + 20% GGBS + 2 % lime	2088.33	1161.66
BCS + 20% GGBS + 3 % lime	3916.63	2409.52
BCS + 20% GGBS + 4 % lime	4505.08	3066.51



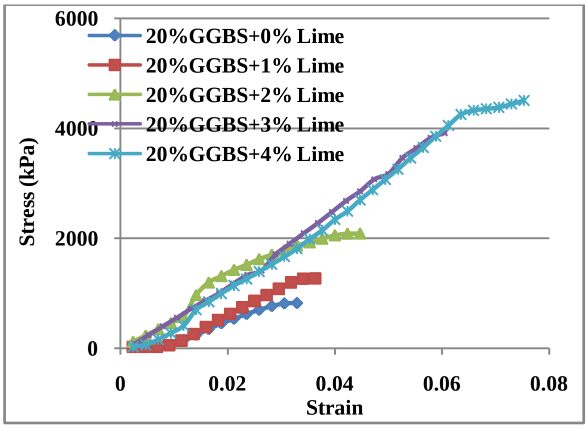
Graph 3 UCC strength of BCS+20%GGBS with varying percentage of lime

Table 3 UCC strength of BCS+25%GGBS with varying percentage of lime

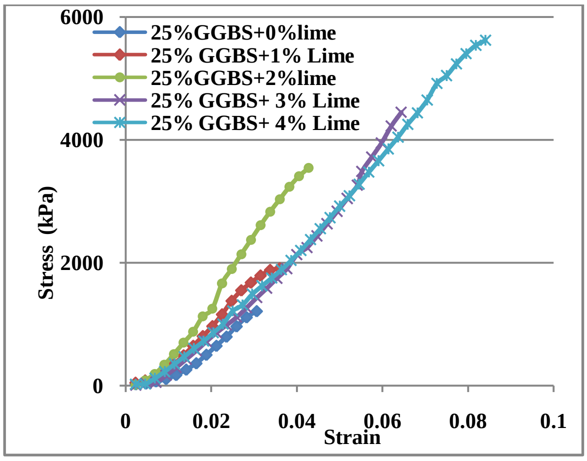
Combination	28 days UCC strength (kPa)	7 days UCC strength (kPa)
BCS + 25% GGBS + 0 % lime	1213.22	498.21
BCS + 25% GGBS + 1 % lime	1880.72	617.17
BCS + 25% GGBS + % lime	3543.63	1392.15
BCS + 25% GGBS + 3 % lime	4451	2643.49
BCS + 25% GGBS + 4 % lime	5623.37	3295.86



Graph 4 UCC strength of BCS+25%GGBS with varying percentage of lime



Graph 5 Static stress strain graph of UCC test for BCS+20%GGBS with varying percentages of lime at 28 days



Graph 6 Static stress strain graph of UCC test for BCS+25%GGBS with the varying percentages of lime at 28 days

4.4 Dynamic Shear Modulus Calculation

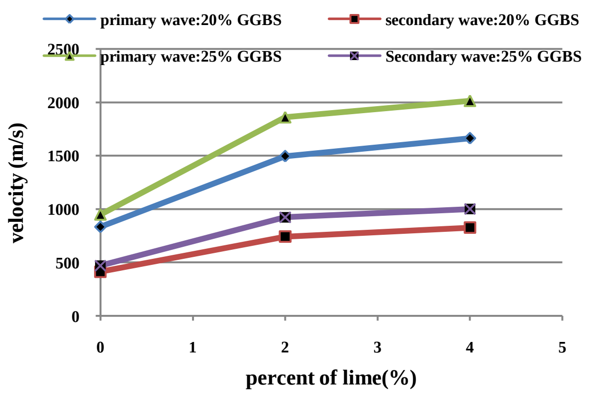
It is observed that shear modulus increases with increase in the percentages of GGBS and lime even though the density variation between all trial mixes is very less. Hence, stabilization also increases the dynamic properties as shown in the tables 5 & 6 and graphs 7 & 8 below

Table 4 Dynamic properties of BCS+20% GGBS with varying percentages of lime

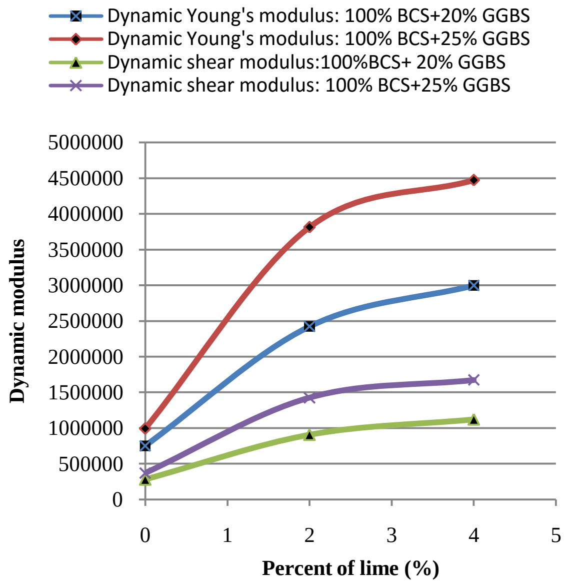
Trial mixes	20%GGBS +0%lime	20%GGB S+2%lime	20%GGB S+4%lime
Travel time (s)	0.00009	0.0000575	0.0000505
Length (m)	0.075	0.086	0.084
Primary wave velocity (m/s)	833.33	1495.65	1663.36
Poison's ratio	0.336	0.336	0.336
Density (g/cc)	1.64	1.64	1.64
Young's modulus (kPa)	751611.78	2421125.4	2994552
Dynamic shear modulus (kPa)	281291.83	906109.8	1120715.6
Shear wave velocity(m/s)	414.15	743.30	826.65

Table 5 Dynamic properties of BCS+25% GGBS with varying percentages of lime

Trial mixes	25%GGBS +0%lime	25%GGBS +2%lime	25%GGB S+4%lime
Travel time (seconds)	9.06E-05	4.41E-05	4.42E-05
Length (m)	0.086	0.082	0.089
Primary wave velocity (m/s)	949.22	1859.41	2013.57
poison's ratio	0.336	0.336	0.336
Density (g/cc)	1.67	1.67	1.67
Young's modulus (kPa)	993045.6	3810476	4468525
Dynamic shear modulus (kPa)	371648.8	1426076	1672352
Shear wave velocity (m/s)	471.75	924.09	1000.70



Graph 7 velocity of waves in stabilized mixes of 20%GGBS and 25%GGBS with varying percentage of lime



Graph 8 Dynamic Young's modulus and shear modulus of stabilized mixes

4.5 Analysis Results

Factor of safety increases for rich mixes but amplification of Acceleration at crest does not vary muchthis is because of height and unit weight of all mixes do not differ much. Stabilization also decreases acceleration amplification and displacements when compared with only BCSoil mix as shown in the below table 7 & 8.

It is observed that critical slip surface entry and exit remains almost same in all stabilized mix cases but the slip circle length for 50^{o} inclined slope is longer than 45^{o} inclined slope. Slip circles were drawn in figure 3 to 8.

It is observed that 50^{o} inclined slope gets more Acceleration time history response than 45^{o} inclined slope. Stabilized soil gets lesser Acceleration response than no stabilized soil. Responses for few mixes plotted in graph 10 to 13.

It is observed that strains due dynamic loading reduced enormously in stabilized mixes.

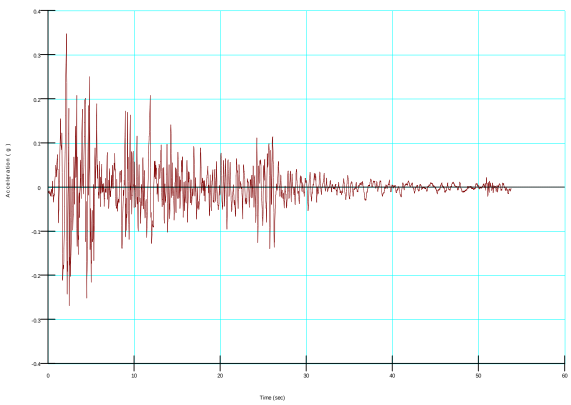
Table 6 Factor of safety and dynamic acceleration amplification for 45 degree inclination slope

Trial mix	Inclination	Dynamic factor of safety	Acceleration Amplification at 2.12s
100% BCS	45^{o}	1.458	2.5992
BCS + 20% GGBS + 0% lime	45^{o}	3.974	1.963631
BCS + 20% GGBS + 2% lime	45^{o}	8.513	1.954515
BCS + 20% GGBS + 2% lime	45^{o}	17.293	1.953919
BCS + 25% GGBS+ 0% lime	45^{o}	5.285	1.955619

BCS + 25% GGBS+ 2% lime	45^o	13.561	1.949611
BCS + 25% GGBS+ 4% lime	45^o	20.952	1.949611

Table 7 Factor of safety and dynamic acceleration amplification for 50 degree inclination slope

Trial mix	Inclination	Dynamic factor of safety	Acceleration Amplification at 2.12s
100 BCS	50^o	1.065	2.389727
BCS + 20% GGBS + 0% lime	50^o	4.017	2.11934
BCS + 20% GGBS + 2% lime	50^o	8.544	2.113893
BCS + 20% GGBS + 2% lime	50^o	17.291	2.113793
BCS + 25% GGBS+ 0% lime	50^o	6.265	2.106694
BCS + 25% GGBS+ 2% lime	50^o	13.56	1.949809
BCS + 25% GGBS+ 4% lime	50^o	18.451	1.736298



Graph 9 Input Time history of El-Centro earthquake

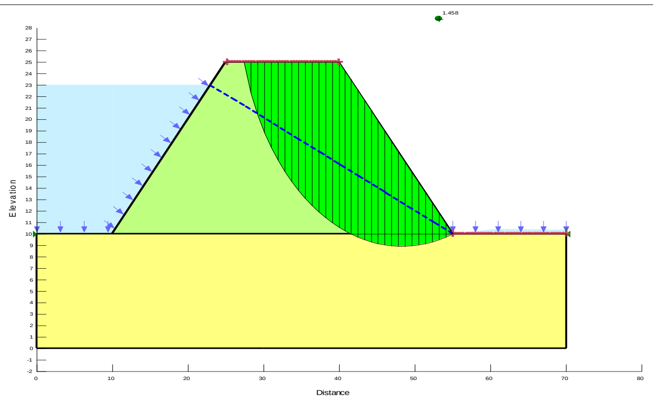


Fig3 100% BCS, i=45^o: Critical slip surface

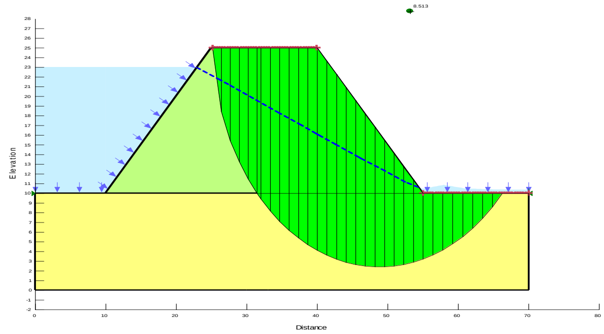


Fig4 BCS+20% GGBS+2% lime, i=45^o: Critical slip surface

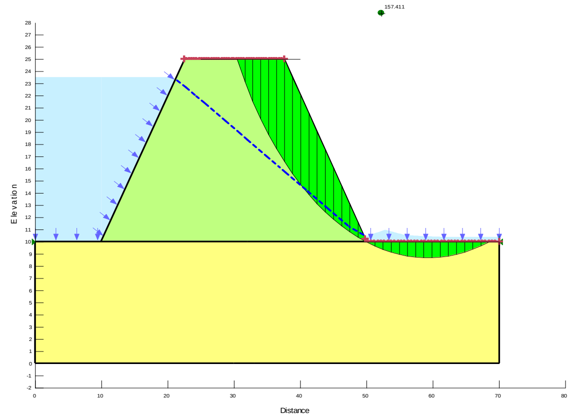


Fig6 100% BCS, i=50^o: Critical slip surface

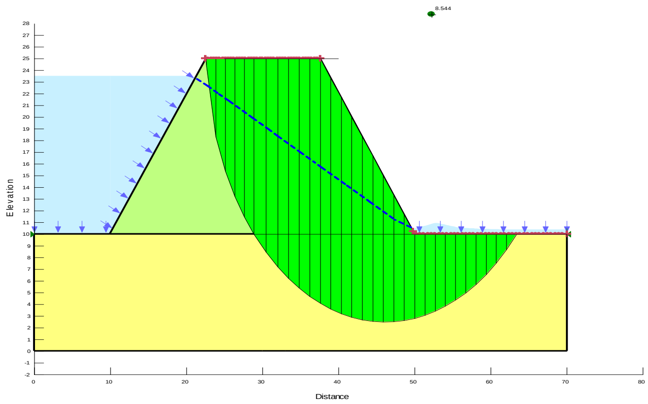
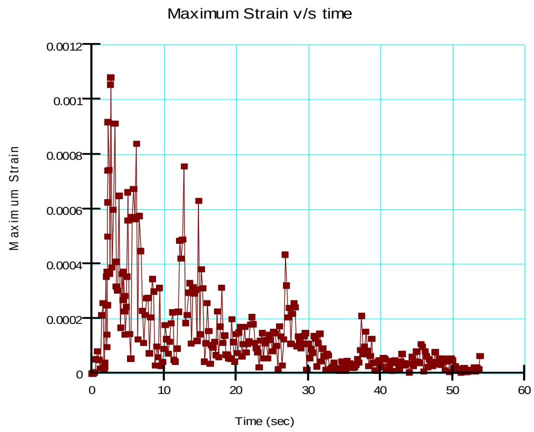
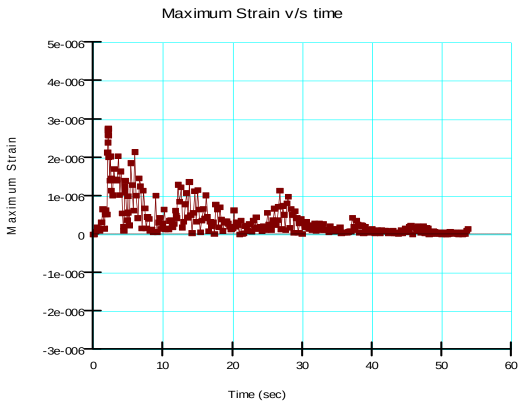


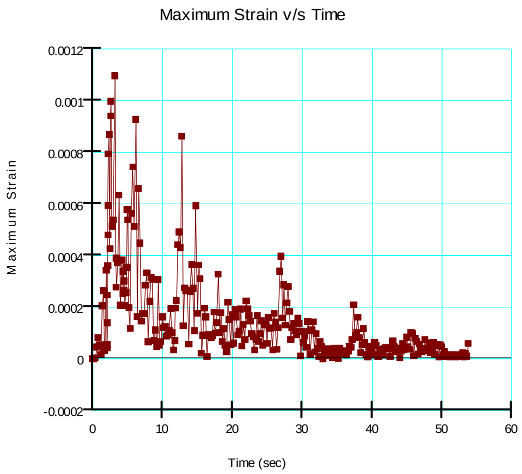
Fig7 BCS+20% GGBS+2% lime, i=50^o: Critical slip surface



Graph 10 Maximum Strain v/s time for 100%BCS only; i=45 degree at crest



Graph 11 Maximum Strain v/s time for BCS+25%GGBS+4%Lime; i=45 degree at crest



Graph 12 Maximum Strain v/s time for 100%BCS only; i=50 degree at crest

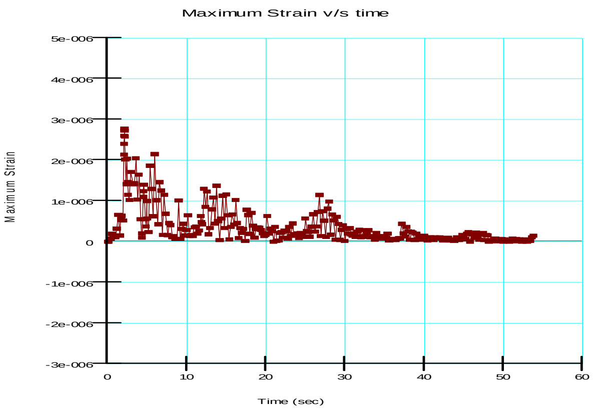
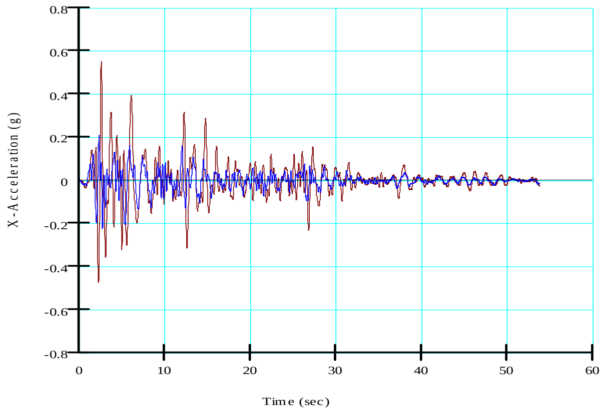
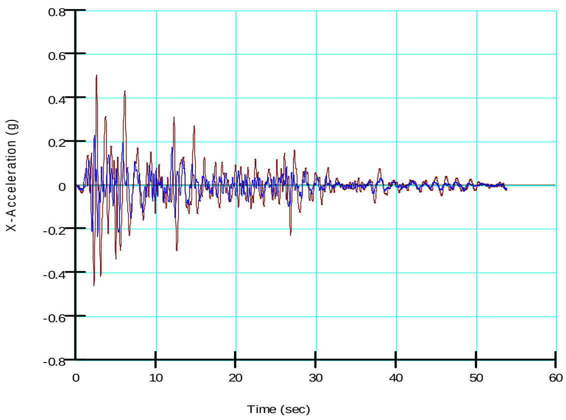


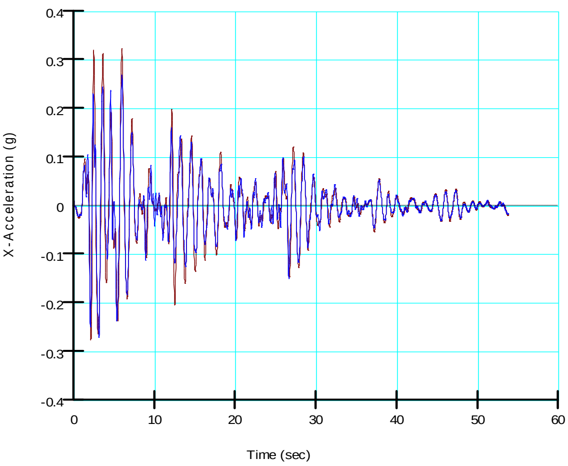
Fig8 Maximum Strain v/s time for BCS+25%GBBS+4%Lime only; i=50 degree at crest



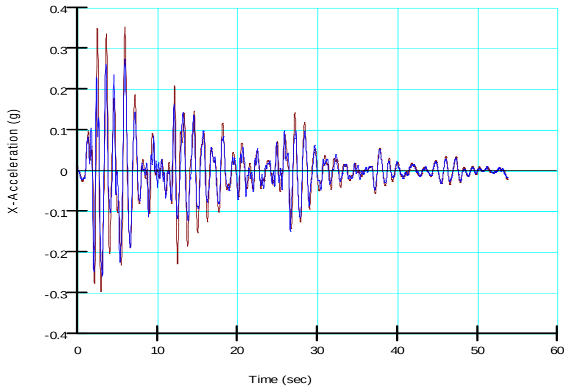
Graph 13 Acceleration time history plot at crest (black line) and at base (blue line) of 100%BCS with 45 degree inclination.



Graph 14 Acceleration time history plot at crest (black line) and at base (blue line) for100%BCS with 50 degree inclination.



Graph 15 Acceleration time history plot at crest (black line) and at base (blue line) for BCS+20%GGBS+2%lime with 45 degree inclination



Graph 16 Acceleration time history plot at crest (black line) and at base (blue line) for BCS+20%GGBS+2%lime with 50 degree inclination

5. CONCLUSION

Addition of GGBS to BCS increases MDD; reduces the OMC and decreases Free swell index. When BCSoilis stabilized with GGBS and Lime, its static and dynamic properties improves drastically.

Dynamic factor of safety increases with stabilized mixes. As inclination of slope increases Acceleration response at the crest increases.

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