# Stability Analysis of Embankment on Stabilized Expansive Soil

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**Abstract.** In India Black cotton soil forms to be major soil deposits. They have been found to be most problematic from engineering considerations since they exhibit swelling and shrinking when exposed to changes in moisture content. Vitrified Tile Sludge (VTS) is a waste material obtained during tile production and can be efficient in stabilizing embankments, soft soils, highway subgrade and other geotechnical application areas. High embankment slope has been stabilized using VTS as stabilizer. VTS was mixed by dry weight to soil with varying percentages of 0, 10, 20, 30 and 40% for conducting index properties, compaction characteristics, permeability, shear strength, consolidation and California Bearing Ratio tests. The experimental results indicate that the optimum VTS content was found to be 30%. The slope stability analysis was carried out for un-stabilized and stabilized embankment using Geo-Studio software. Slope stability is analyzed for the high embankment of stabilized black cotton soil by taking its characteristics as input such as Cohesion (c), Angle of Internal Friction (ϕ) and maximum dry unit weight. The Factor of Safety of stabilized soil is more than minimum value as prescribed in IRC: 75-2015.

**Keywords:** Vitrified Tile Sludge, Black cotton soil, Slope stability.

## 1 Introduction

More than 90% of Indian road network including flexible pavement rests on soil subgrade. The performance of pavement mainly depends on subgrade and design procedures depend on stiffness and strength of pavement subgrade. Pavement resting on problematic soil such as expansive, soft soil and collapsible subgrade leads to complete or partial failure of pavements, in such cases lots of maintenance required due to repeated failures. That's why pavement structures should have subgrade of suitable engineering properties in order to increase service life and to minimize the thickness of flexible pavement structure. This can be acquired by stabilization of expansive soil or replacement of weak clay with good soil [1]. Vitrified Tile Sludge (VTS) is the industrial waste generated from crushing of vitrified tiles in aqueous medium. The large quantity of the accumulated waste is dumped and left on costly land and causing wastage of good cultivated land. VTS has potential for use in Highway embankment, Subgrade & Subbase layer in combination with problematic soils. This leads to significant reduction in compressibility of expansive black cotton soil treated with VTS [2]. VTS affects the environment adversely and cause problem to society. If we use these materials in the road sector it may solve above problem and also reduce the cost of road material and convert waste into wealth. Several studies have been done on the stabilization of problematic soil using various industrial waste [3, 4, 5, 6, 7, 8, 9]. This paper discusses the physical and geotechnical properties of VTS mixed with Black cotton soil. Various tests were conducted on the VTS mixed with Black cotton soil with varying percentages. Slope stability analysis was done for stabilized embankment using SLOPE/W Geo-Studio software.

## 2 Materials and Experiments

Expansive Black cotton soil sample has been collected from Hiriyuru, Chitradurga district and Vitrified Tile Sludge from H R Johnson Tile Limited, Kunigal, Tumakuru district, Karnataka respectively. The grain size distribution of the soil sample was evaluated as per IS 2720- Part IV (1985). The black cotton soil contains 18% sand, 63% silt and 19% clay particles. The geotechnical properties of the BC soil, VTS are shown in Table-1. The chemical composition of VTS is shown in Table-2. The sample has been prepared by mixing VTS and soil in the proportion of 0, 10, 20, 30 and 40% to evaluate the index properties, compaction test, strength characteristics and CBR etc. The tests were conducted according to Indian Standard specifications. Slope stability of the un-stabilized and stabilized slopes has been carried out using Geo-Studio software.

**Table 1.**Geotechnical Properties of Material.

| Engineering property | Laboratory Test Results | |
|---|---|---|
| | BC Soil | VTS |
| Specific gravity | 2.69 | 2.52 |
| Grain Size Analysis | | |
| Sand, % | 18 | 97 |
| Silt, % | 63 | 3 |
| Clay, % | 19 | |
| Liquid Limit, % | 53 | - |
| Plastic Limit, % | 21 | - |
| Plasticity Index | 28 | - |
| Shrinkage Limit, % | 8 | - |
| IS classification | CH | SW |
| MDD, kN/m$^3$ | 17.63 | - |
| OMC | 17 | - |
| Free Swell Index | 37 | - |

**Table 2.**Chemical composition of VTS

| Constituents | Values |
|---|---|
| $SiO_2$, % | 30.48 |
| $Al_2O_3$, % | 5.15 |
| $Fe_2O_3$, % | 4.86 |
| CaO, % | 22.12 |
| MgO, % | 8.1 |
| $K_2O$, % | 1.53 |
| $Na_2O$, % | 0.42 |

## 3 Stability Analysis Using Software

Stability analysis of embankment was carried out by using Geo-Studio software. Geo-Studio software includes the elementary features of SLOPE/W, SEEP/W, SIGMA/W, QUAKE/W, TEMP/W, CTRAN/W, etc. for analyzing the slope stability and other related geotechnical analysis. In the present investigation, we have used SLOPE/W-Bishop's method, which gives the stability of the slope.

## 4 Geometry of Embankment

The stability analyses of embankment stabilized at optimum percentage VTS was carried out. A 15m high Embankment with Berm for MJB-Ch. 2+087 for existing SH-33&3 from Malavalli to Pavagada, Karnataka (See Fig.1). As per IRC: 75 2015, High embankments are those exceeding 6m in height, embankment of any height less than 6m founded soft/compressible and /or loose strata.

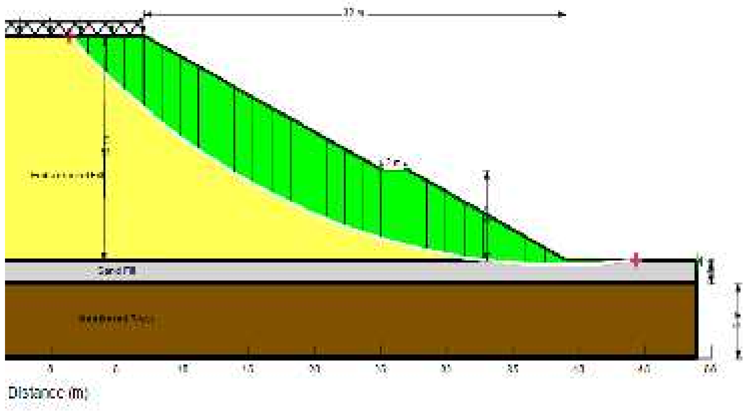


**Fig.1.** Geometry of embankment

# 5 Results and Discussions

## 5.1 Index Properties

Liquid limit, plastic limit and free swell index tests were carried out for the different percentages of BC soil mixed with VTS. Table-3 shows the results of all samples. From Table-3, it can be observed that with the increase in percentage addition of VTS to BC soil, plasticity index decreases.

**Table 3.**Index properties of soil-VTS mixtures.

| VTS (%) | Liquid limit, % | Plastic limit, % | Plasticity Index |
|---|---|---|---|
| 0 | 51 | 23 | 28 |
| 10 | 45 | 21 | 24 |
| 20 | 44 | 20 | 24 |
| 30 | 42 | 19 | 23 |
| 40 | 40 | 18 | 22 |

## 5.2 Compaction characteristics

Modified Proctor tests were conducted on different percentages of VTS mixed with BC soil. Table-4 shows the variation of Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). It was found that, with the addition of VTS, the MDD increases whereas the OMC decreases. The attraction of water molecules decrease with the addition of VTS to soil hence the decrease in OMC was observed [10]. The decrease in MDD is due to lesser content of sand size particle in the VTS as compared to the BC soil.

**Table 4.**Strength properties of soil-VTS mixtures.

| VTS (%) | MDD, kN/m$^2$ | OMC, % | c, kN/m$^2$ | $\phi$, degree | Permeability, X $10^{-4}$ cm/sec | Soaked CBR (%) |
|---|---|---|---|---|---|---|
| 0 | 17.63 | 17 | 80 | 13 | 0.03 | 2.29 |
| 10 | 18.024 | 15.1 | 60 | 18 | 0.3 | 7.38 |
| 20 | 18.78 | 14.53 | 40 | 21 | 1.1 | 9 |
| 30 | 19.5 | 14.04 | 25 | 23 | 4.74 | 10 |
| 40 | 19.94 | 13.48 | 30 | 19 | 5.48 | 9.03 |

## 5.3 Permeability test

Permeability tests were conducted on different percentages of VTS mixed with BC soil and presented in Table-4. The specimens were prepared by using static compaction method at their respective OMC and MDU. After ensuring full saturation the specimens were tested to determine their coefficients of permeability using falling head permeability apparatus. The results show that with the addition of VTS the permeability increases. This property of adding VTS to BC soil demonstrates to be more efficient in order to have adequate drainage in high embankments.

## 5.4 Unconfined Compression Strength Test

Unconfined compression testing was carried out on soaked and unsoaked specimens to determine the Unconfined Compressive Strengths (UCS) of BC soil mixed with VTS. Cylindrical specimens with a diameter of 38 mm and a height of 76 mm were prepared by compacting the mixture at their respective OMC and MDU. The UCS tests were conducted for curing stage of 0, 3, 7, 14 and 28 days in desiccators. In following curing stage, cured specimens are soaked for 1 day. Specimens are soaked by submerging them in container filled with water like top of specimen is 1cm beneath height of water. Soaked specimens are kept in air for drying about 1hr and the specimens were subjected to gradually increasing uniaxial load in unconfined compression apparatus. From these tests, it was observed that both soaked and unsoaked UCS increased with the increase in curing period upto 30% VTS and after that the strength decreases. The results are tabulated in Table 5.

**Table 5.**Unconfined compression strength characteristics.

| Test Condition | Curing Period (days) | VTS (%) | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 10 | 20 | 30 | 40 |
| Soaked | 3 | 9.87 | 15.64 | 28.32 | 31.28 | 25.42 |
| | 7 | 9.62 | 27.97 | 36.31 | 41.26 | 31.66 |
| | 14 | 8.13 | 34.73 | 48.56 | 54.09 | 44.91 |
| | 28 | 8.08 | 43.93 | 56.03 | 61.57 | 57.41 |
| Unsoaked | 3 | 113.67 | 129.26 | 219.19 | 236.32 | 177.5 |
| | 7 | 112.36 | 144.54 | 262.28 | 282.65 | 247.75 |
| | 14 | 111.58 | 165.02 | 272.11 | 298.12 | 264.99 |
| | 28 | 112.12 | 180.86 | 293.19 | 310.22 | 282.58 |

## 5.5 Static Triaxial Test

Triaxial tests were conducted on different percentages of VTS mixed with BC soil to determine the cohesion and angle of internal friction. Cylindrical specimens with a diameter of 38 mm and a height of 76 mm were prepared by compacting the mixture at their respective OMC and MDU and subjected to unconsolidated undrained triaxial tests at varying confining pressure of 50, 100 and 200kPa. From the results, it is observed that, with the increase in the percentage of VTS upto 30%, cohesion decreases whereas the frictional angle increases. The increase in frictional angle may be due to the increase in silt size particle [11]. The results are presented in Table-4.

### 5.6 California Bearing Ratio (CBR) Test

California Bearing Ratio (CBR) tests were conducted on both soaked and unsoaked condition for different percentages of VTS mixed with BC soil. CBR Specimens were prepared by compacting the mixture at their respective OMC and MDU. The soaked CBR test results are presented in Table-4. The results show that with the addition of VTS upto 30% the CBR increases and then decreases for both soaked and unsoaked condition (results not presented). This shows the increase in stabilized CBR value is due to the frictional resistance between the particles with addition of VTS.

### 5.7 Consolidation Test

Consolidation test was carried out on remoulded specimen with 30% VTS mixed with BC soil in an Oedometer under double drainage condition. The $C_c$ value for BC soil of 0% VTS content was 0.31. It reduced to 0.19 by 30% optimum VTS content addition (see Fig. 2). The consolidation settlement ($S_c$) for BC soil of 0% VTS content was 0.812 mm and with the addition of 30% optimum VTS content, $S_c$ decreased to 0.532 mm. This is because of the development of cementation of interparticle bonds that enhance the strength as well as decrease the compressibility.

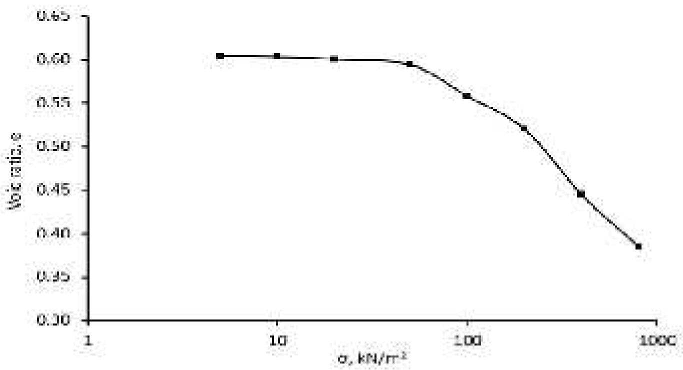


**Fig. 2. e-log p curve for 30% VTS mixed with BC soil**.

### 5.8 Stability Analysis of Embankment

The stability analysis has been carried out by Bishop's method on un-stabilized and stabilized slopes using Geo-Studio software. The sand fill has been modelled as Mohr-Coulomb having the properties unit weight = 18kN/$m^3$, cohesion = 5.4 kPa and $\phi$ = 32°. The critical slip surface and FOS for un-stabilized and stabilized embankment (See Figs. 3 and 4). It can be clearly observed that the stability analysis of stabilized embankment and un-stabilized embankment has the factor of safety more than minimum value 1.25 as per IRC: 75 specifications. Since un-stabilized embankment is of fully black cotton soil which cannot be considered for practical purpose considering the other strength and index properties, so the stabilized embankment with factor of safety 2.786 is considered and is safe as per IRC: 75-2015

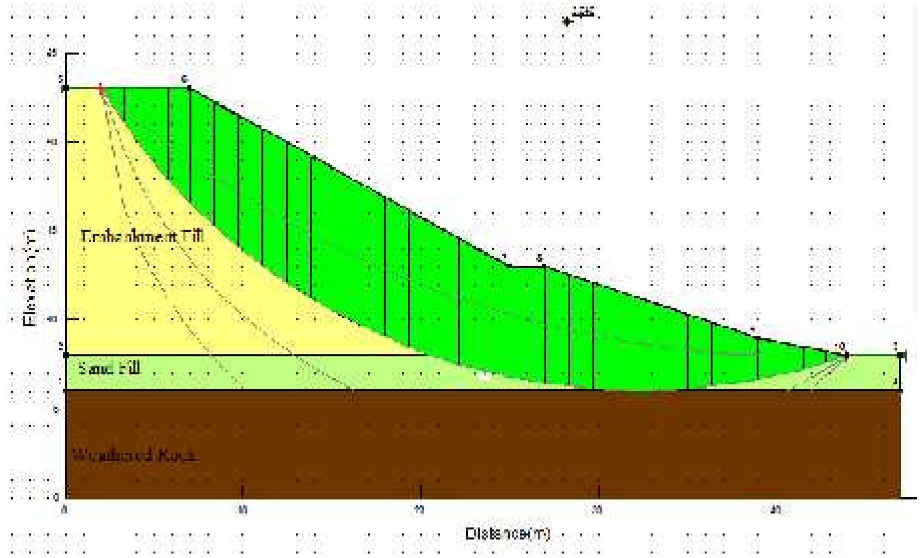


**Fig. 3** Critical slip surface and FOS for Un-Stabilized Embankment

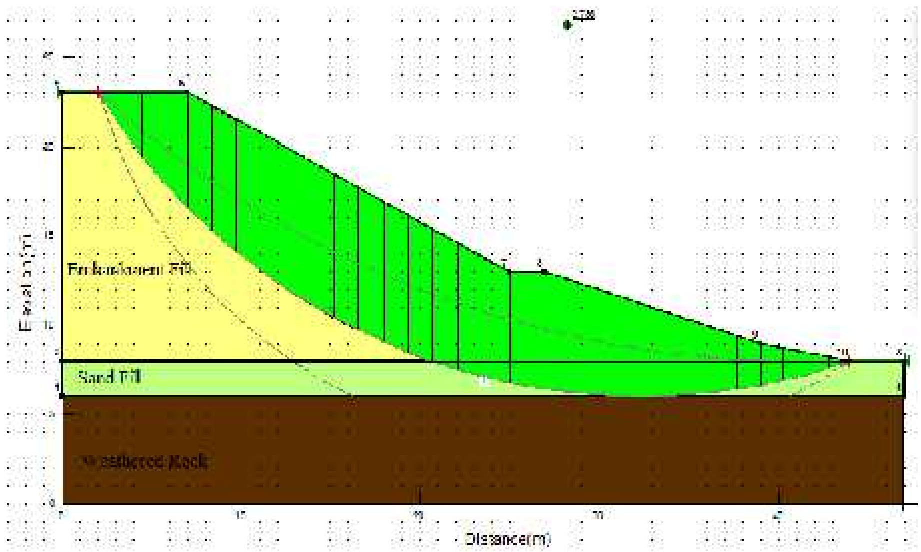


**Fig. 4** Critical slip surface and FOS for Stabilized Embankment

## 6 CONCLUSIONS

Based on the test results and numerical modelling following conclusions has been made

- Addition of varied VTS content has improved the properties of the Black cotton soil. Soaked UCS increased with the increase in curing period upto 30% VTS and after that, the strength decreases. Therefore, replacement of Vitrified Tile Sludge by 30% is found to be optimum.
- The MDD increases and OMC decreases with varying VTS content of 0 to 40 %. Similarly, CBR increases with increase in VTS till optimum content.
- The findings indicate that the permeability increases with the addition of VTS. This property of adding VTS to BC soil proves to be more effective for proper drainage in high embankments.
- Cohesion value decreases with the increase in the percentage of VTS upto 30% whereas the frictional angle increases.
- Addition of 30% VTS showed decrease in consolidation settlement (Sc) when compared with 0% VTS. This is due to the growth of interparticle bond cementation, which increases strength and reduces compressibility
- Since un-stabilized embankment consists of completely black cotton soil which cannot be regarded for practical purposes in view of the other strength and index characteristics, the stabilized embankment with safety factor 2.786 is therefore regarded and is secure as per IRC: 75-2015

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