Determination of Effect of Moisture Content and Density on Shear Strength Parameters and Slope Stability of Highly Plastic Silt Embankment Soil (the Case of Wozeka-Gidole Road)

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Abstract— *Moisture content is one of the most crucial factors influencing soil strength. This paper deals with the effect of moisture content and density on the shear strength parameters of WOZEKA-GIDOLE road elastic silt (expansive) embankment soil under dry, wet (partially saturated), OMC and saturated conditions in relation to slope stability analysis. The wide distribution of expansive soil in Ethiopia creates problems in many field of construction such as excavation, slope stability and foundation in understanding their engineering characteristics especially the behavioral changes in dry and saturation condition. In this study, samples were collected from a slope construction road site in WOZEKA-GIDOLE, southern Ethiopia. At a constant grading of a soil its effect on strength, swelling pressure and index properties value has been undertaken, as soils are to be used for making road pavement, embankments. The stability of an embankment will greatly be influence by the shear parameters which are depend upon the degree of compaction. So soil specimen were compacted in the laboratory and the optimum moisture content and dry densities were identified. After compaction soil was tested at the dry side of optimum water content at w = 5%, partially saturate of the optimum at 10%, at 15% OMC and at 20% saturation condition at 1.3 gm/cm^3, 1.4 gm/cm^3 and 1.55 gm/cm^3(MDD) dry densities. Parameters of shear strength (C) and (ϕ) were obtained from triaxial shear test (UU) and shows the compacted elastic silt soil behaves like a granular soil on the dry side of optimum water content (5% and 10%) and a reduction in angle of friction and an increase in cohesion are observed as the compaction water contents approach the optimum value. Cohesion shows a slight increase as moisture content increases whereas friction angle highly decreases with increasing moisture content at constant density. The shear strength parameters were used for stability analysis with software GEOSLOPE/W 2018 with Limit equilibrium based methods to calculate the factor of safety (FOS) and locate critical failure arc. The slope stability analysis of elastic silt soil has been done and is used in under different conditions to evaluate slope stability. Analysis of embankment at different heights of the slope with Morgenstern-Price's analysis method. In the present study varying the density and moisture has been affect the properties of expansive soil namely elastic silt soil. Finally constant grading of soil is a technique for modification the geotechnical properties and improving slope stability of embankment and increasing the dry density and decreasing height of embankment, the undrained shear parameters (C & Φ) are improved.*

Key words— Cohesion, Elastic silt, Factor of safety, Friction Angle, Geo-slope/W, Limit equilibrium, Moisture Content

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1 INTRODUCTION

In the planning, design, construction, and maintenance of engineered structures, the engineer must be cognizant of potential problems that might be associated with the stability of man-made and natural slopes when they are subjected to saturated condition. Expansive soils have become notorious as a result of the numerous foundation, slope stability, excavation and embankment failure problems with which they are often associated. Most of these problems resulted from the change of moisture content and densities. The wide distribution of expansive soil (Elastic silt) in Ethiopia and their interaction with water creates problems in many field of construction such as excavation, slope stability and foundation [6-8].

Water in soil acts both as a lubricant and as a binding agent among the soil particulate materials, thereby influencing the structural stability and strength of soil [18-21].Moisture content is known as one of the most important factors lowering the strength of soils. A small increase in the moisture content may lead to a marked reduction in strength and deformability [27-30]. The variation of moisture in soils may be developed most likely from climate change, has great adverse impact on quality and performance of structures constructed on it. Since, increase in moisture content in substructure material decreases the engineering quality of soil; like load bearing capacity. Study in basic engineering properties such as the grain size distributions, swelling index, durability, consistency and shear strength parameters (cohesion c and friction angle ϕ) is important to understand the behavior for expansive soil and avoid the inherence of problems when they interact with moisture [26-28].

Usually the laboratory specimen, which are used to determine shear strength of the soil are prepared at moisture content and dry density same as in the field conditions. Shear strength of soils which contain fine materials are highly affected by variation moisture conditions. Fine particles of silt and clay form structural connections with sand particles, so when the soil dried out the strength of these connections increased [27-28].

Thus, this research is carried out to determine the effect of moisture content and density to the shear strength parameters (c and ϕ) and slope stability of expansive soil (Elastic silt) embankment road at Wozeka-Gidole, southern Ethiopia. The author made an investigation on slope models developed under varying compacted density and optimum moisture content (OMC) condition at different embankment heights. In this regard using Geo-slope (2018) software several models have been analyzed with Morgenstern-Price's analysis method. The result revealed moisture content and density have correlation with slope geometry, soil index and strength properties of expansive soil (Elastic silt).

2 MATERIALS AND METHODS

2.1 Study Area location and description

The Wozeka-Gidole road project is situated in the south west of Arba Minch town. The road project crosses a sharp faulted escarpment of Gidole Mountain. The project starts at about 539 km far from Addis Ababa (capital city of Ethiopia) and ends at 573km and the profile of the slope is taken at 5^0 39'00.97''N and $37^0$22'03.29''E. At the elevation of 2081m amsl and it is part of the Arba Minch-Jinka surface treatment road project which is located in the Southern Nations, Nationalities and Peoples Regional State (SNNPRS) in Arba Minch area and Derashe Woreda. Figure 2.1 shows the location of the project.

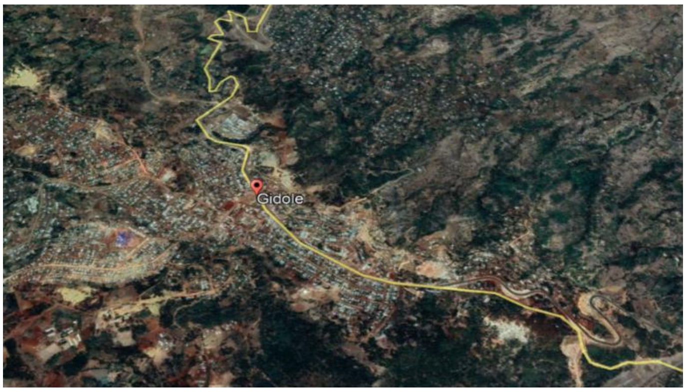


Figure 2.1: Location of the project site

2.1.1 Description of the Embankment section

Wozeka-Gidole road project has a total length of 33.9km and the pavement is Double Bituminous Surface Treatment (DBST) standard. The carriageway is 6.7m and 1.5m shoulder width in both sides in flat to rolling terrain, Section of embankment fill places where the road bed require continuous terrain with in short distance between them.[9-10]

The geometry of the embankment fill and slope shows a 36m high fill comprises face of fill with 2:1 slope. As illustrated on the figure below the total length of 98.92m and section of the road almost in danger of failure at side of embankment portion.

Figure 2.1: portion of embankment project site

2.2 Methodology

There are three different activities that were applied for this experimental work: pre-field work, field work and post field work. Each of the three steps comprises different activities.

The main activities in the pre-field work were literature review and field preparation. During the field work stage, visual identification of embankment section around Wozeka- Gidole road and soil sampling (disturbed and undisturbed), at the depth of 0.5-1m at different part of the fill section were collected. During post field work, laboratory test for collected samples were conducted and the tests were performed as well as final research work was conducted. The objective of the study is to observe the variation in shear parameters (C,Φ), for expansive soil by varying its dry density and moisture content. For the research work the soil samples were obtained from the Gidole-Wozeka embankment road section and divided in equal parts for grading. Due to the homogenous nature of the embankment, grading was more or less constant for all parts so an average grading pattern was found.

A series of laboratory tests were conducted both index properties and strength properties tests: particle grain analysis, Atterberg limit test, compaction test, free swell index, triaxial shear test (UU), CBR, specific gravity, and moisture contents were conducted. To mention some of the test procedures: :[1-5 & 11-14]

Particle Size Distribution (ASTM D 422-63)

Approximately 500 grams of dry soil was placed in water which had a specified quantity of dispersing agent, for a minimum period of 18 hours for deflocculates the soil particles. The sample was then washed through a sieve with progressively smaller screen sizes (Sieve No. 200) to determine the percentage of sand-sized particles in the specimens. A hydrometer analysis was also performed on the soil content passing sieve No. 200 to measure the amount of silt and clay size particles.

Atterberg Limits (ASTM D 4318-00)

Casagrande device was used to determine the liquid limit of each soil using the material passing through a 425 μm (No. 40) sieve and soaked for 16hr-24hrs to enable the water for permeating through soil. The plastic limit of each soil was determined by using soil passing through a 425μm sieve and rolling 3-mm diameter threads of soil until they began to crack. The plasticity index was then computed for each soil based on the values obtained for liquid and plastic limit. The liquid limit and plasticity index were then used to classify each soil as per AASHTO and USCS.

Free swell index

Approximately 10 grams of dry soil material passing through a 425 μm (No. 40) was poured into each of the two graduate cylinders of 100ml of kerosene and distilled water. The entrapped air was removed by gentle shaking the cylinders and stirring the contents with a glass rod. Both samples were then allowed to settle in the bottom of cylinders. Sufficient time which was not less than 24 hours was allowed for soil sample to attain equilibrium state of volume without any further change in the volume of the soils. Record the final volume of the soils in each of the cylinders.

Compaction proctor test (ASTM 1557)

All Modified Proctor Compaction tests were performed in accordance with the standard (ASTM 1557). In the Modified Proctor procedure, soil is compacted in a standard cylindrical mold. Two different size molds are used depending upon the gradation of the soil. The molds have diameters of either 6 or 4 inches. The mold have corresponding volumes of 1/30 ft3 and 1/13.33 ft3. By referring the ASTM-1557 standard Modified Proctor Compaction test was conducted in 4-inchs (101.6mm) diameter mold by 45cm hammer height with 25 blows.

Soil samples were subjected to proctor compaction testing to determine the maximum dry density and optimum moisture content of the soil. The moisture contents and dry densities were used in preparing samples for triaxial shear tests (UU) and were maintained varying at dry, partially saturated, optimum and fully saturated moisture content for each mixture, to get different shear strength parameters.

Triaxial shear test

For the purpose of this study 12 specimen were sheared. A detailed study of shear strength characteristics of expansive soils is being carried out in the laboratory using triaxial shear apparatus. For verification, more samples were sheared for Unconsolidated Undrained (UU) tests and compared with when samples were dry, partially saturated and fully saturated. Both compacted and undisturbed samples were used but to minimize uncertainties from protruded expansive soils, mostly selected and samples compacted to standard proctor are used. For each tests, the soil behavior including the influence of moisture, densities with the shear strength parameters were evaluated and discussed.

Classification (ASTM D 2487-00)

Each soil was classified using the Unified Soil Classification System (USCS) and AASHTO classification system depending on Atterberg limit and grain size distribution result. Using the particle size distribution and the Atterberg limits, the USCS and AASHTO designates a two letter symbol and a group name for each soils. All classifications provided in this research are based on the laboratory testing-based procedure.

Stability analysis procedure

Parameters of shear strength and unit weight of the soil were used as input parameters for the software GEO-slope W/2018. Mentioned software divides the shear plane into 30 slices with minimum shear surface depth of 0.1 m and FOS tolerance 0,001. Number of points on the slip surface starting at 4 and ending at 8 with maximum number of iterations of 2000. Morgenstern's-price method were used for calculation of FOS. The height for stability analysis of embankment fill was established at 7m, 14m, 21m and 27m with inclination was set on 2H:1V.

3 RESULTS AND DISCUSSION

3.1 Index laboratory test results and discussion

The basic properties and classification of the soil sample collected was summarized in give table 3.1 for sample according to laboratory result and constant grading. From soil samples collected along the road more than 75.47% were fine grained soil passing through sieve No. 200 (0.075mm opening) as obtained from wet sieve grain size analysis performed to identify the amount of silt and clay pass sieve No.200 (0.075mm opening). From this grain size analysis 42.5% of clay soil particle is recorded form laboratory activity of hydrometer method. The Atterberg limit result shows that all representative soil samples have plasticity index of 26.68% which represent high plastic or high clay content. Therefore based on AASHTO and USCS soil classification systems, all representative sample falls under classes of soil material types which is high plastic silty soil (MH) under group index of A-7 5(25.62) which indicates the rating of subgrade fair to poor quality. Under average conditions of good drainage and thorough compaction, the supporting value of a material may be assumed as an inverse ratio to its group index, i.e. a group index of 0 indicates a "good" subgrade material and a group index of 20 or more indicates a poor subgrade material as outlined in the ERA Site Investigation Manual-2002. From the finding of this research soil classification according to AASHTO classification system, Wozeka-Gidole road embankment soil classified as A-7-5 under group index of 25.62 which is indicated as poor subgrade soil.

Atterberg limits (Plastic limit "PL", Liquid limit "LL", and Plasticity index "PI") play an important role in soil identification and classification. To achieve this objective, Atterberg limits test (including PL, LL, and PI) and grain size distribution system was performed on natural soils according to consistency test of ASTM T 88.

After constant grading and classification of soil particles, soils retained on particular sieve were kept in separate bottles for mixing the required properties for conducting the test on a varying dry density required proportion of water was added to the soil mass for making a soil paste and samples were prepared for conducting the desired tests. After obtaining the required shear parameters for a constant dry density on a constant moisture content, the same set of tests were conducted on another samples prepared at same dry density but another moisture content. In this way the required set of experiments were conducted. The following dry density and moisture content values were adopted.

- Dry Density: - 1.3gm/cm3, 1.4gm/cm3, 1.5gm/cm3 and 1.55(i.e. MDD)
- Moisture Content: - 5%,10%, 15% and 20% (OMC=15%)

Constant grading results of the tested soil samples	**TP-all**
percentage of passing 2mm sieve size (No.10)	97.024
Percentage of passing 4.75mm sieve size (No.4)	99.596
Percentage of passing 0.075mm (No.200)	75.474
Gravel	0.404
Sand	24.12
Silt	32.974
Clay	42.5
Characteristics of Soil pass Sieve No.40	
Liquid Limit	76.36
Plasticity Index	26.8145
Classification According AASHTO systems	A-7-5
Free swelling index	74%
Specific gravity	2.72
Compaction Parameters	
OMC	15%
MDD (gm/cm3)	15.5
Group Index	25.62
According to USCS System	MH

Table 3-1 Classification table of Wozeka-Gidole embankment

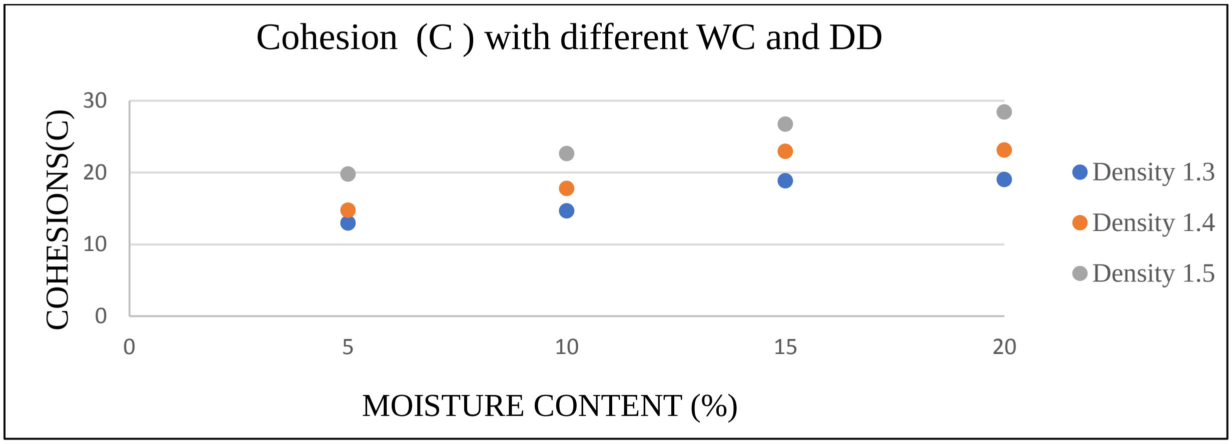
This indicates that the lower values of density are the result of more finer (clay and silt) soil with having low bearing capacity whereas the higher values of density are for granular soil materials; which are suitable for subgrade material to withstand traffic loading. The reverse is true for OMC. Table3.1 presents the overall classification of the soil of Wozeka-Gidole embankment road after constant grading of the tested sample.

3.2 Shear test results

The shear parameters C and Φ were determined by conducting quick Triaxial compression test of UU test for different density and moisture content. Table 3.2 shows results of cohesion (c) and friction angle (ϕ) for each varying water content and dry densities. Values of cohesion increases as the moisture content increases at constant dry density but after OMC the increment of cohesive strength is minimal. Angle of internal friction decreases as the moisture content increases and drastically lower at fully saturated moisture level. Meanwhile both cohesion and angle of internal friction increases with increasing density at constant moisture content. As illustrated on the table below the degree of cohesion increment at constant density but varying moisture content is 46.9% at 1.3gm/cm^3, 56.96% at 1.4gm/cm^3 and 43.65% at MDD. Whereas angle of internal friction decreases as 13.49%, 14.97% and 34.66% at constant density but varying moisture content. Fig.3.2 displays development of cohesion and angle of internal friction for each varying moisture content and densities.

Sample no.	Dry unit weight (gm/cm^3)	Moisture content (%)	Cohesion (C)	Angle of internal friction (Φ)
1	1.3	5	12.95	16.31
2		10	14.66	10.29
3		15	18.81	5.54
4		20	19.03	2.20
5	1.4	5	14.73	17.44
6		10	17.78	11.30
7		15	22.94	6.65
8		20	23.12	2.61
9	1.55	5	19.77	19.04
10		10	22.60	14.11
11		15	26.71	9.31
12		20	28.40	6.60

Table 3-2 Cohesion and angle of internal friction for each varying water contents and densities



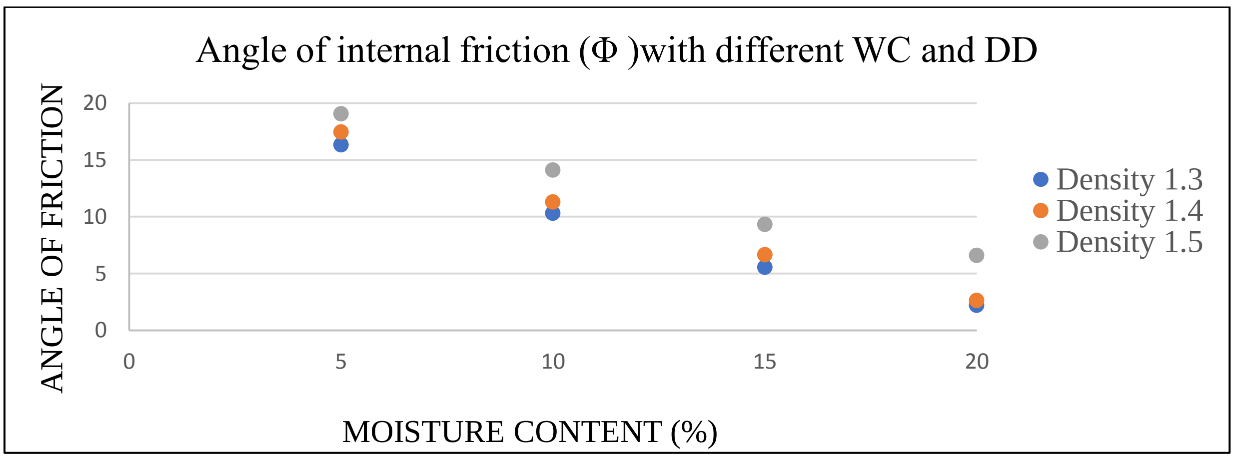


Figure 3.1 values of cohesion (C) and Angle of internal friction (Φ) for each of the water contents and densities

3.3 Slope stability analysis

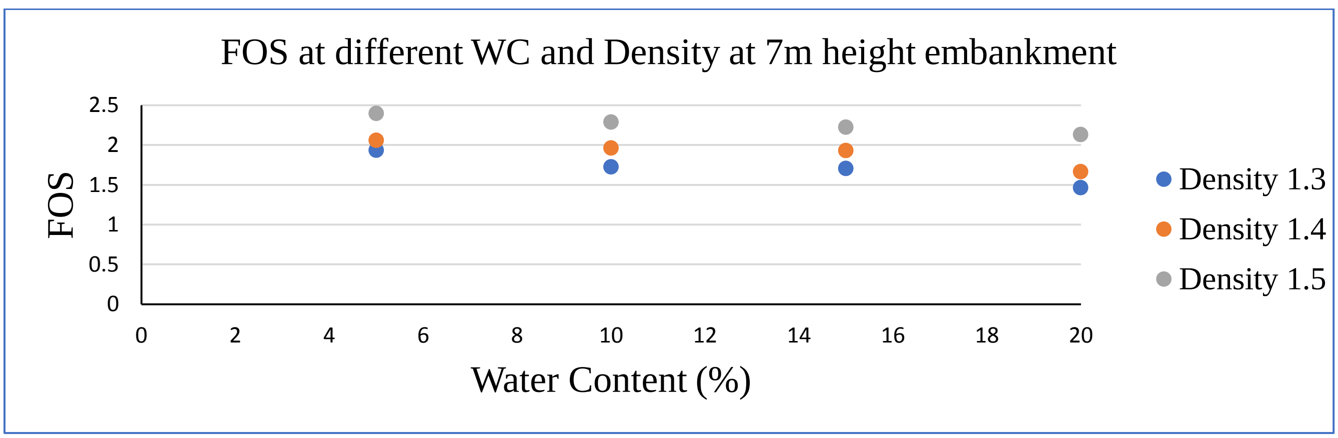
The Geo-Slope/2018 was used for studying models characteristics and finding critical failure surface with factor of safety. Slope models were created at the soils angle of friction (Φ), unit weight and cohesion (C) at different height of embankment. In application of the Geo-slope/2018 software, 48 slope models geometry were prepared on dry, partially saturated, optimum moisture content and fully saturated condition of soil. Morgenstern's-price method with limit equilibrium was used to solve slope problem, find critical slip surface, calculate and show reduction of Factor of Safety at varying moisture content and height of embankment.

Sample no	**Height of Embankment (M)**	**Dry soil Condition**		**Partially saturated condition**		**OMC condition**		**Fully saturated condition**	
		Density	FOS	Density	FOS	Density	FOS	Density	FOS
1	7	1.3	1.935	1.3	1.727	1.3	1.707	1.3	1.465
2		1.4	2.058	1.4	1.962	1.4	1.929	1.4	1.664

3		1.5	2.396	1.5	2.287	1.5	2.223	1.5	2.131
4	14	1.3	1.367	1.3	1.137	1.3	1.037	1.3	0.832
5		1.4	1.457	1.4	1.267	1.4	1.199	1.4	0.947
6		1.5	1.671	1.5	1.517	1.5	1.402	1.5	1.287
7	21	1.3	1.166	1.3	0.927	1.3	0.803	1.3	0.616
8		1.4	1.245	1.4	1.031	1.4	0.931	1.4	0.702
9		1.5	1.417	1.5	1.243	1.5	1.103	1.5	0.993
10	27	1.3	1.072	1.3	0.828	1.3	0.696	1.3	0.515
11		1.4	1.145	1.4	0.921	1.4	0.809	1.4	0.589
12		1.5	1.298	1.5	1.116	1.5	0.965	1.5	0.859

Table 3-3 FOS analysis results for each varying water contents and densities

Factor of Safety in Short-Term Analysis i.e. Homogeneous Embankments at different heights on varying moisture content and different density shown on the figures below.



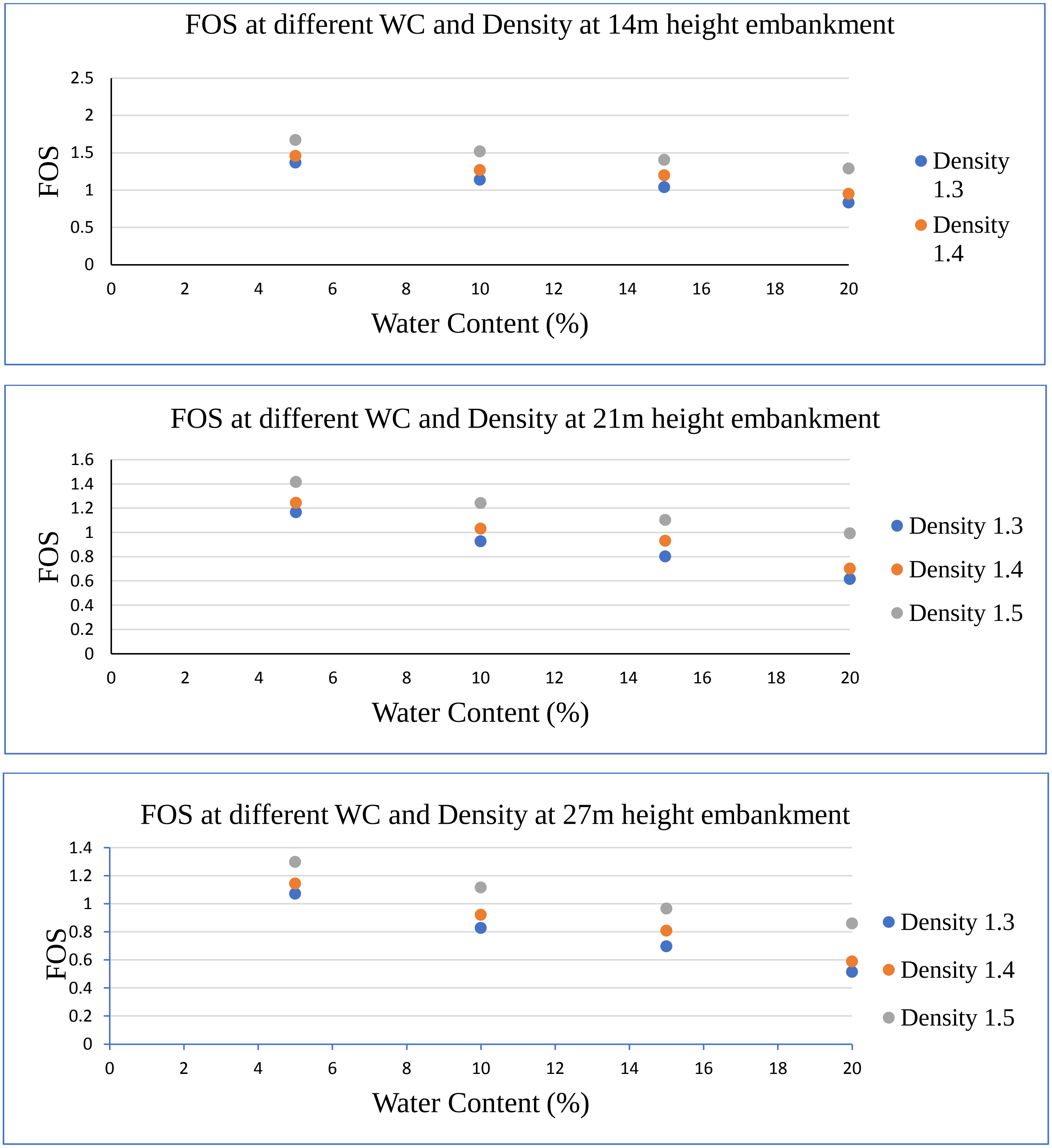


Figure 3.2 values of FOS for each of the water contents and densities

3.3.1 Stability analyses results at different height of a homogenous embankment

This section presents the results of the short-term analyses performed on the homogenous embankments built with elastic silt (expansive) soils using GEO-SLOPE/2018 software. For each height of the embankment a figure demonstration were prepared to show the critical failure arc and factor of safety variation at dry condition and OMC during maximum compaction (MDD).

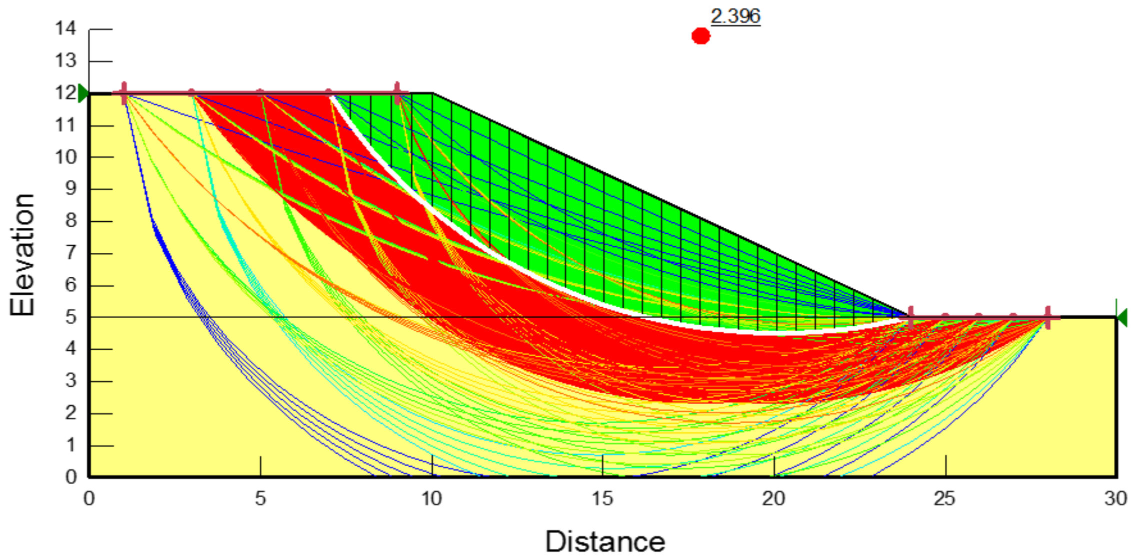


Figure 3.3 Critical Failure Arc in Short-Term Analysis at dry moisture condition (Homogeneous Embankment; Height 7m)

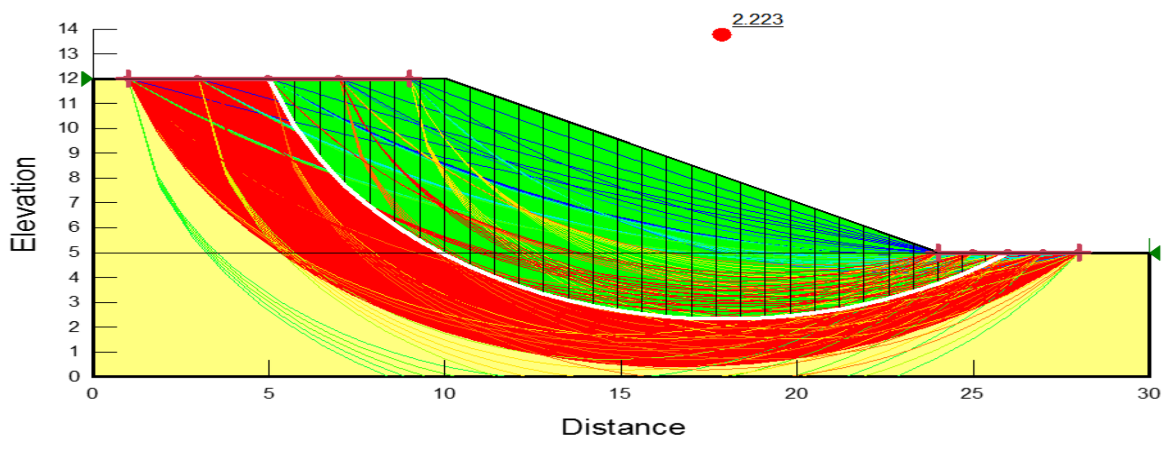


Figure 3.4 Critical Failure Arc in Short-Term Analysis at OMC condition (Homogeneous Embankment; Height 7m)

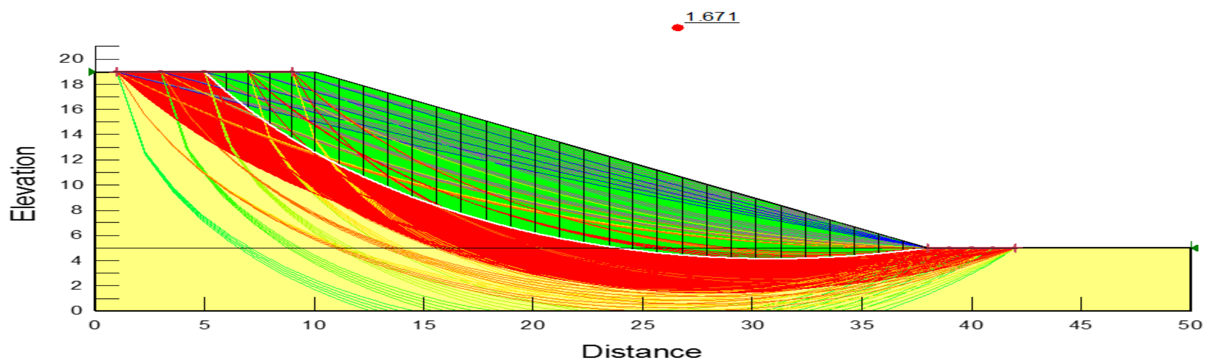


Figure 3.5 Critical Failure Arc in Short-Term Analysis at Dry condition (Homogeneous Embankment; Height 14 m)

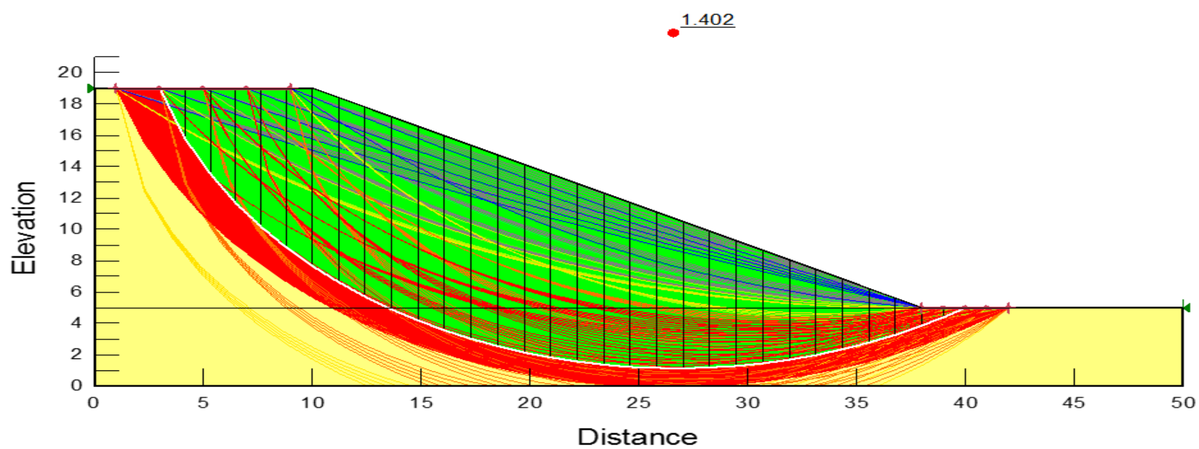


Figure 3.6 Critical Failure Arc in Short-Term Analysis at OMC condition (Homogeneous Embankment; Height 14m)

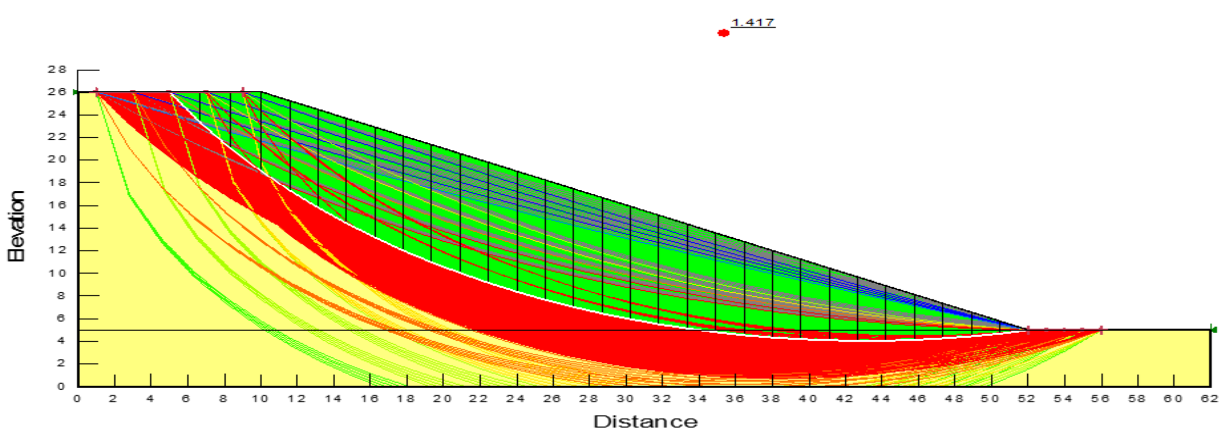


Figure 3.7 Critical Failure Arc in Short-Term Analysis at Dry condition (Homogeneous Embankment; Height 21m)

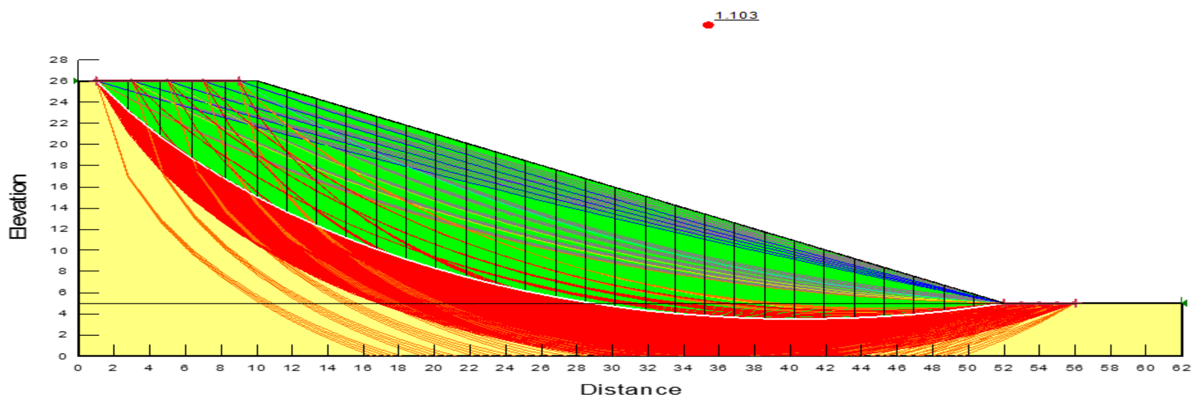


Figure 3.8 Critical Failure Arc in Short-Term Analysis at OMC condition (Homogeneous Embankment; Height 21m)

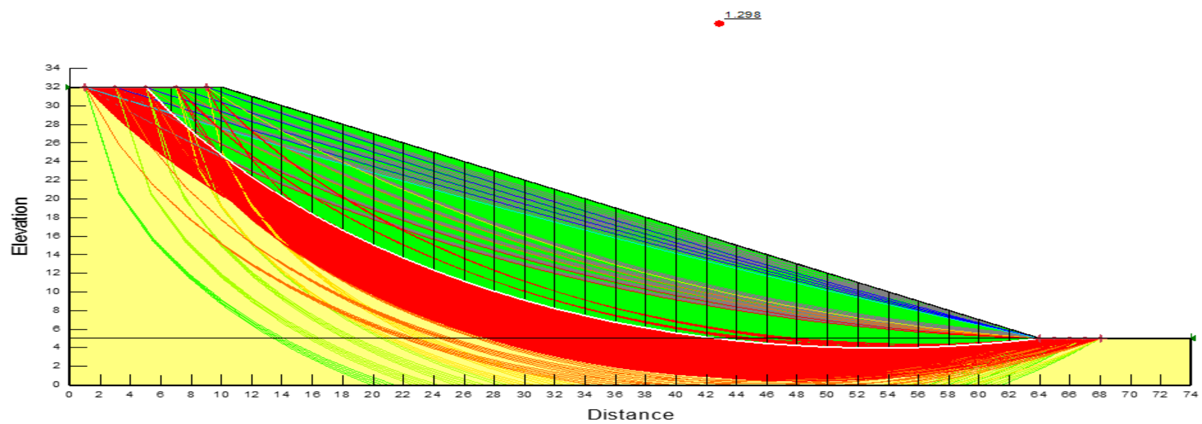


Figure 3.9 Critical Failure Arc in Short-Term Analysis at Dry condition (Homogeneous Embankment; Height 27m)

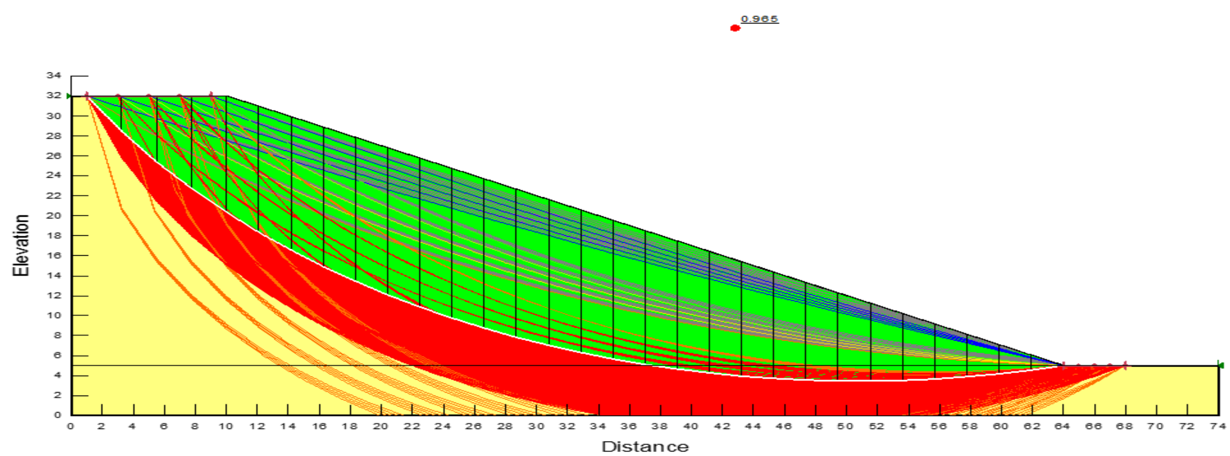


Figure 3.10 Critical Failure Arc in Short-Term Analysis at OMC condition (Homogeneous Embankment; Height 27m)

4 CONCLUSIONS

Slope failure along highways are often repaired or reconstructed using locally available soils (Wozeka-Gidole embankment) that can contain significant amount of fines (clay and silt) due to high cost of producing and transporting free draining coarse-grained materials. The present study show the embankment section contains high amount of clay (42.5%) and silt (32.97%) also classified as elastic silt according to USCS as discussed in chapter 3. One main concern in using soils with considerable amount of fines (clay and silt) which is > 15-30% in embankment fills is that their strength, stability and performance are suspectable to variation in their moisture content. According to [15-19] overall shear strength decreases with increasing moisture content, both the friction angle and the cohesion decrease when saturated. Results of presented study showed, the compacted elastic silt soil behaves like a granular soil on the dry side of optimum water content (5% and 10%) and a reduction in angle of friction and an increase in cohesion are observed as the compaction water contents approach the optimum value.

More over Cohesion increases with increasing dry densities and also slightly increases as moisture content heading towards the OMC and saturation condition. Whereas angle of internal friction shows a drastic reduction towards to saturation condition (20%) at lower density of 85% compaction value but kept relatively good value at OMC condition (15%) at higher density more than 98% compaction value.

The instability of the embankment is depend on slope geometric property, shear parameter and climatic condition of the area. Recently, it has been observed that sudden slope failure of most fine material slopes occurs in regions with repeated rainfall. Gidole town is known to have more precipitation and low temperature, hence the moisture fluctuation and its effect on the slope were expected particularly during rainy seasons. As the result of slope stability analysis indicate FOS increases with increasing density at constant moisture content and height of embankment. But FOS decreases with increasing moisture content at constant dry density and height of embankment. Finally FOS decreases with increasing height of embankment at constant moisture content and dry densities. It was indicated that the FOS greatly reduced < 1 as the moisture content nears to saturation and as the height of the embankment increases. So it is suggested to reduce the height of the embankment, make the slope flatter and if possible to use stabilization technique (geo-synthetic) at different layer of the embankment section. Even if most previous studies and application of geo-synthetic stabilization are confined to non-cohesive soils, few research efforts have been indicated to the feasibility and benefits of geo-synthetic reinforcement on cohesive soils including cost, availability and technology [22-24]. This study also provides a basis for future research on the behavior between slope made of cohesive fine soils and its stabilization techniques.

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