Engineering Characteristics of Collapsible Soils in Ethiopia (A Case Study around Zeway Area)

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Abstract

Under normal circumstances, collapsible soils types of unsaturated soils that can bear relatively high load without notable volumetric changes. However, when the saturation level is set to increase, they are prone to a significant and rapid decrease in volume. These soils present significant challenges to the engineering profession during construction and during the service life. Numerous soil types fall in the general category of collapsible soils, including Aeolian wind-deposited sands and/or silts such as loess, and volcanic dust deposits. Problematic soils such as expansive soils have been comprehensively studied in many researches and studies. However, the geotechnical properties and treatment methods for collapsible soils didn't get due consideration in the past in Ethiopia. Hence, this research had the aim of assessing the engineering properties of collapsible soils, through a series of field and laboratory tests, found around Zeway area by taking the Modjo-Hawassa Dual Carriageway Highway Project, Lot 3; Zeway-Arsi Negele as a case study. Experimental works conducted in the field as well as in the laboratory revealed that the study area is covered with loose deposits of sands and silts having a trace amount of clay content with small in-situ dry densities and low moisture contents. The collapse potential test results indicated that the soils in the study area exhibit moderate collapse potential.

Key Words: **Collapse Index, Collapse Potential, Collapsible Soils, Zeway, Ethiopia**

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1. Introduction

The construction of infrastructures needs comprehensive study and characterization of the geotechnical properties of the foundation soils. In this regard, it is apparent to investigate the presence of problematic soils such as expansive, dispersive and collapsible soils which pose significant problems on the construction of civil engineering infrastructures. For any project, the problematic soils and the associated problems thereof shall be investigated thoroughly during the design stage and the remedial measures in order to minimize the risks shall be properly considered.

Different studies were carried out previously on problematic expansive soils in Ethiopia and their engineering properties and the treatment methods have got proper consideration in the past. However, collapsible soils and the associated problems didn't get proper attention on previous works in the country.

Collapsible soils are soils that are strong and stable in their natural state. However, they exhibit sudden reduction in volume upon wetting, leading to significant and sudden settlements. This can yield disastrous consequences for structures built on such deposits. These types of soils can be in the form of wind-blown sands, loess or alluvial deposits and are typical in areas where the ground does not consolidate by its own weight owing to the fact that water evaporates in an accelerated manner in arid and semi-arid places (Pye, 2008). The soild particles in such soils are held by small amount of clays or other binding agents. (Samtani, 2006).

Generally, sudden volume change can occur in collapsible soils, regardless of the presence of loading, when there is a significant increment in moisture content. It is interesting to note that full saturation is not needed to induce collapsibility, which actually happens when the degree of saturation is somewhere above 50% (Abbeche, 2010). The increment of moisture content und load deteriorates the bondage between soil particles, reduces the soil suction and causes desiccation or collapse (Houston. 2001).

Although many researchers have been conducted in other countries where collapsible soils exist, such as the United States of America, China, Nigeria, South Africa etc., no satisfactory research and investigation has been made and published on collapsible soils found in our country. Many of the focus areas of the researches undertaken so far have given emphasis on expansive soils, among any other problematic soils, and less attention is given on the existence of collapsible soils.

Due to the above-mentioned reasons, there is no extensive knowledge within even the experienced engineering professionals on the methods of identification, classification and treatment of collapsible soils.

To this regard, this research work is aimed to investigate the engineering properties of collapsible soils found in the Mojo-Hawassa Design and Build Highway Project, Lot-3; Zeway-Arsi Negele Section.

2. Geological Setting

According to the project's site investigation report (SBI, 2018), the route alignment traverses through the central part of the Cenozoic rift zone where the four of main rift valley lakes, which are considered to have been once connected forming one great lake in the geologic past, namely Ziway, Langano Abijata and Shala are situated at closer distances.

The area is covered by a variety of lithologies representing bimodal volcanic rocks and volcaniclastic sedimentary

deposits. The road generally traverses through sandy silt/clay (Qld), sandy silt (Qsd) and welded tuff (Nwt) lithostratigraphic units.

Grey to grayish white and brown Sandy Silt/Clay (Qld) is the most extensive unit occupying the plain land bounded to the east and west by high rising mountains and ridge line. The unit is marked by an alternation of loose to moderately compacted volcaniclastic deposits that are of few centimeters to a meter thick.

The project area is also covered by grey to dark grey sandy silt and gravelly sand (Qsd). This unit represents loose material deposited alongside a stream channel in the northwest corner of the area and small valley in the southeast. It is composed of very loose silt and sand with various grey shades and rarely shows brown colors.

The area at the project end consists of Ignimbrite and partially to moderately welded tuff lithostratigraphic unit (Nwt) which is part of the oldest rift sequence also known as Nazreth Group.

3. Materials and Methods

Collapsible soil samples were taken by excavating two pits manually using pickaxe and shovel at stations km 93+560 and km 96+660 at the centerline of the road alignment of the Modjo-Hawassa Design and Build Highway Project, Lot-3; Zeway-Arsi Negele Section.

Table 1: Sampling Locations

Sampling Station	Easting	Northing	Depth of Sampling
93+560	465466	876494	1 m
96+660	464632	873509	1 m

In order to acquire the in-situ state of compaction, in-place density tests have been conducted inside the 1 m deep test pits by sand replacement method in accordance with AASHTO T-191 (1993).

Representative disturbed soil samples collected from the test pits were safely transported to the laboratory for testing. The laboratory testing for soil samples included moisture content, Atterberg Limits, sieve analyses, specific gravity and proctor compaction tests.

Table 2: Laboratory Tests and Standards

It. No.	Laboratory Test Type	Standard
1	Natural Moisture Content	AASHTO T-265
2	Atterberg Limits	AASHTO T89/T90
3	Grain Size Analysis	ASTM D422
4	Specific Gravity	ASTM D854-00
5	Moisture-Density Relationship	AASHTO T-180

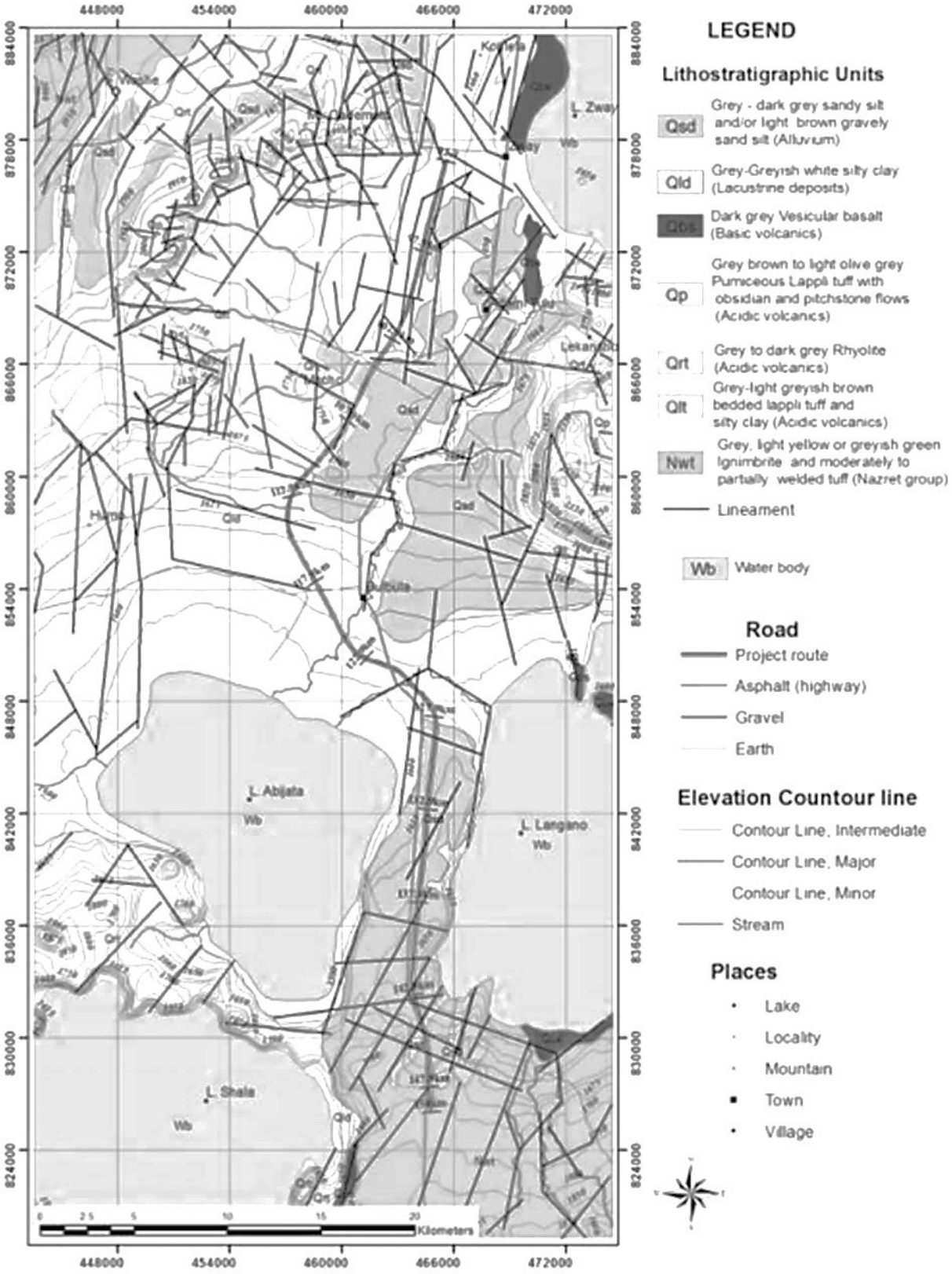


Figure 1: Geological Map of the Area (Source: Site Investigation of the project (SBI, 2018)

Further to the above-mentioned laboratory tests, as per ASTM D5333 (1993), one dimensional Oedometer test has been conducted in order to determine collapse index and potential on remolded soil samples.

The collapse index tests conducted at a stress level of 200 kPa, were carried out on two conditions. The first one is using the in-situ bulk density obtained from sand replacement method, in order to simulate the collapse of the sample at its natural moisture and density conditions. The second one is using the maximum dry density and optimum moisture content obtained from proctor compaction test, in order to observe the response of the sample when subjected to inundating water and stress at its compacted state.

The collapse potential tests were carried out based on the stress level expected to be encountered at sampling locations. The stress level to be applied in the tests was calculated by considering the overburden stress of the subgrade above the sampling point, the embankment and the pavement loads and the surcharge load from the traffic. The collapse potential test was also carried out using both bulk and maximum dry densities. All the loading schemes are shown on Table 3.

Table 3: Loading Schemes for Collapse Index/Potential Tests

Station	Adopted Standard	Stress Condition	Remolding Density	Remolding Moisture
93+560	ASTM D5333	At 200 kPa	Bulk	NMC
			MDD	OMC
		At Over Burden Stress (67 kPa)	Bulk	NMC
			MDD	OMC
96+660		At 200 kPa	Bulk	NMC
			MDD	OMC
		At Over Burden Stress (75 kPa)	Bulk	NMC
			MDD	OMC

4. Results

The in-situ bulk density characteristics of the subgrade at the sampling locations were investigated by carrying out density tests. In addition, the natural moisture contents of the soil samples were determined as per AASHTO T-265. These moisture content values were used in order to calculate the field dry densities.

Table 4: Field Density Test Results

Station	Bulk Density (g/cc)	NMC (%)	Dry Density (g/cc)
93+560	1.24	17.27	1.06
96+660	1.18	20.92	0.98

Specific gravity tests were conducted on the samples collected from both test pits. The specific gravities of the samples are 2.51 and 2.56 for test pits located at km 93+560 and km 96+660 respectively.

Wet sieve and Hydrometer analysis tests were conducted to determine the percentage of different grain sizes contained within a soil. Wet sieve analysis was performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method was used to determine the distribution of the finer particles. The test results show that percentage passing sieve no. 200 are 62% and 64.6% for samples collected from test pits at km 93+560 and km 96+660 respectively. The soils are also classified as A4(6) and A4(7), in their respective order as per AASHTO soil classification system. In addition, both soils are categorized as ML (low plastic silt) based on the soil classification system.

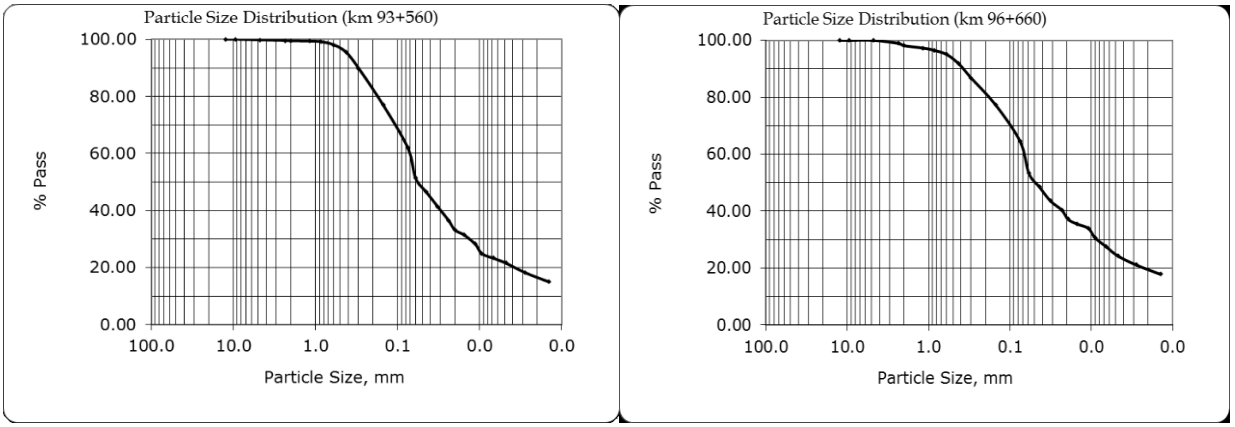


Figure 2: Particle Size Distribution Curves

Table 5: Soil Type Composition as per MIT Classification System

Station	Gravel % (>2.0mm)	Sand % (2.0mm-0.06mm)	Silt% (0.06mm-0.002mm)	Clay %(<0.002mm)	Remark
93+560	0.53	48.0	34.72	16.7	Silty Sand Soil
96+660	1.85	44.8	33.82	19.5	Silty Sand Soil

Atterberg limits were determined from the soil samples in order to investigate for better understanding the plasticity and elasticity natures.

Table 6: Atterberg Limits

Station	Liquid Limit (LL), %	Plastic Limit (PL), %	Plasticity Index (PI)
93+560	30	27	3
96+660	28	26	2

Modified Proctor tests were conducted on the collected soil samples to determine the relationship between the moisture content and dry densities. Furthermore, the degrees of compaction of the soils have been included by making comparison to the in-situ bulk density obtained from sand replacement method and the maximum dry densities.

Table 7: Proctor Compaction Test Results

Station	In-situ Dry Densities (g/cc)	MDD (g/cc)	OMC (%)	Degree of Compaction (%)
93+560	1.06	1.38	24.40	76.81
96+660	0.98	1.24	26.20	79.03

The first attempt towards investigating the collapse property of the soil under investigation was concentrated in determining the collapse index at a stress level of 200 kPa, as per recommendation on ASTM D5333 (1993), at their in-situ bulk Densities and natural moisture contents. Then, the collapse indices were also determined at the samples' maximum dry densities and optimum moisture contents.

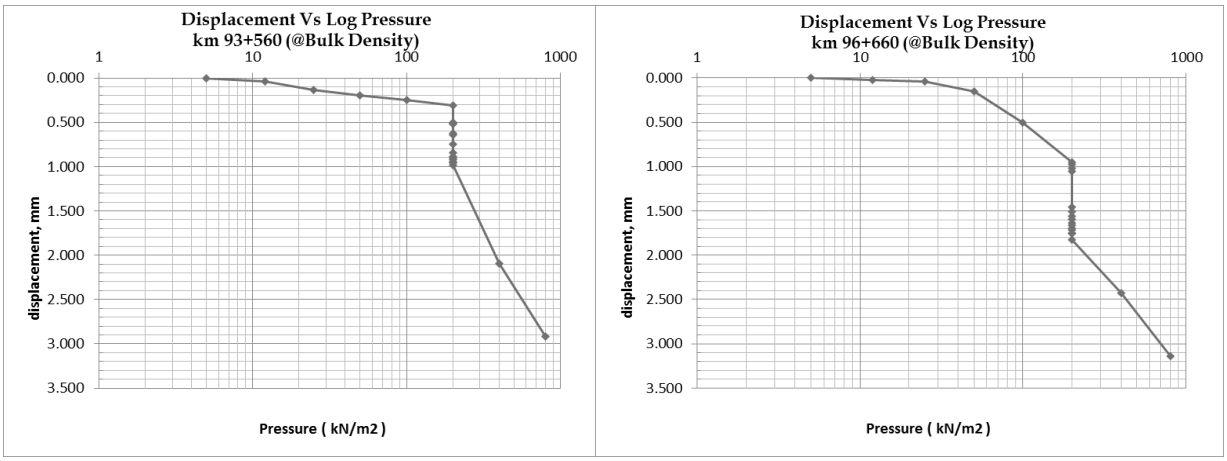


Figure 3: Collapse Indices at Bulk Densities

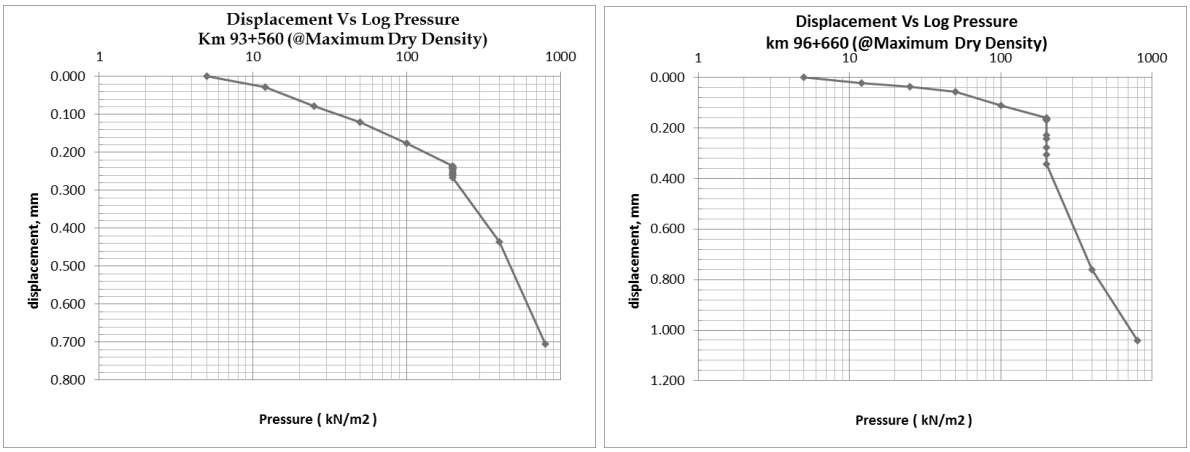


Figure 4: Collapse Indices at Maximum Dry Densities

The obtained test results were checked against the collapse severity as specified by ASTM D5333 (1993).

Table 8: Collapse Index Test Results

Station	Remolding State	Density (g/cc)	Collapse Index Value (%)	Rating as per ASTM D5333
93+560	Bulk	1.24	3.35	Moderate
	MDD	1.38	0.15	Slight
96+660	Bulk	1.18	4.37	Moderate
	MDD	1.24	0.91	Slight

The samples were again tested by subjecting them to the actual anticipated stress level to obtain the collapse potential values. The test results of the collapse potential values are as shown below.

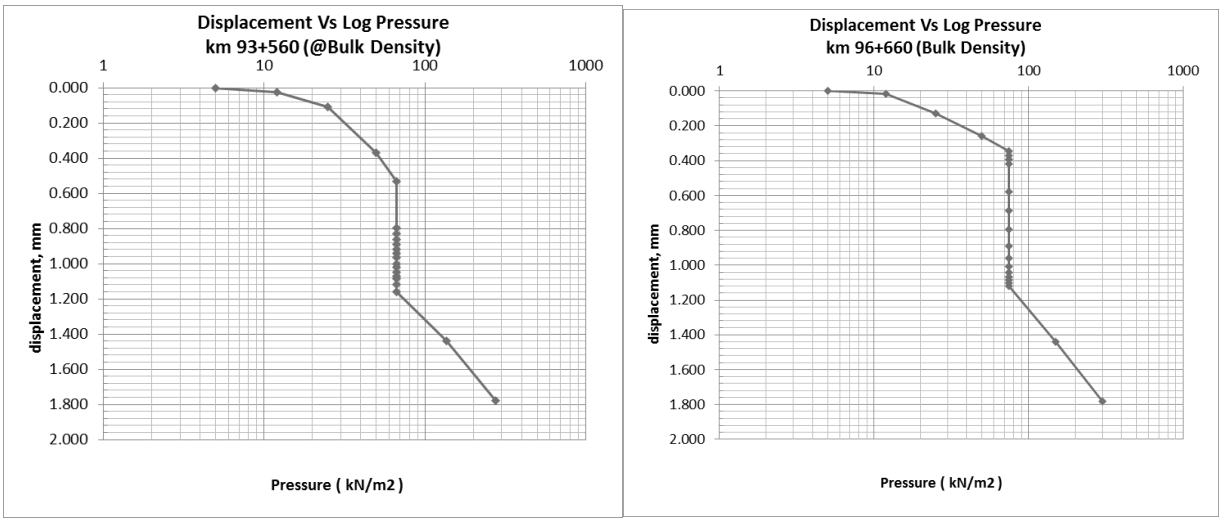


Figure 5: Collapse Potentials at Bulk Densities

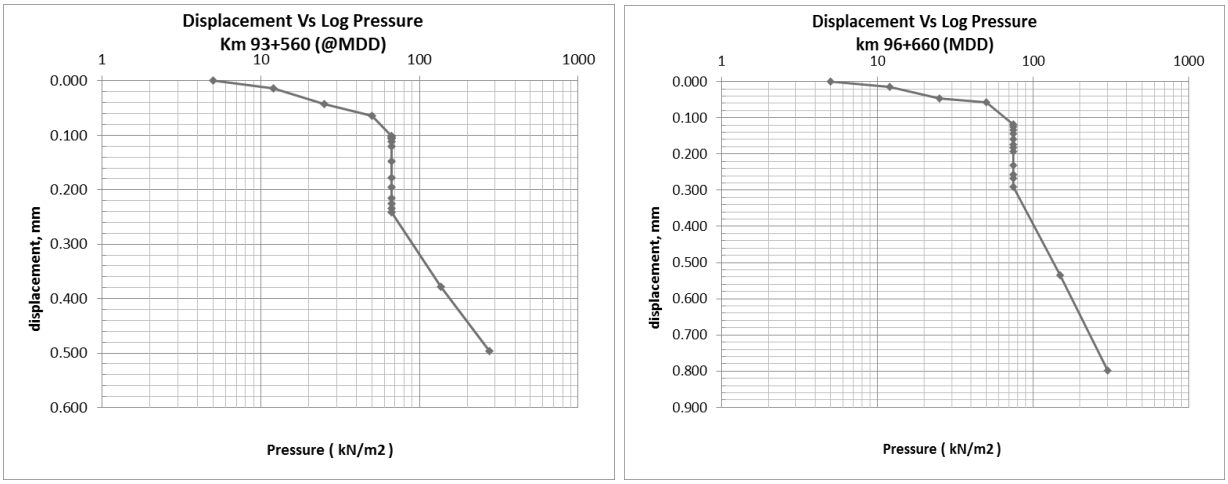


Figure 6: Collapse Potentials at Maximum Dry Densities

The obtained test results were checked against the collapse severity as specified by ASTM D5333 (1993).

Table 9: Collapse Potential Test Results

Station	Remolding State	Density (g/cc)	Collapse Potential Value (%)	Rating as per ASTM D5333
93+560	Bulk	1.24	3.14	Moderate
	MDD	1.38	0.70	Slight
96+660	Bulk	1.18	3.87	Moderate
	MDD	1.24	0.86	Slight

5. Discussions

The subgrade soils have very low bulk as well as dry densities. Both densities from the two test pits are below the suggested margins of Clevenger for collapse vulnerability-1.28 g/cc, which indicate that the soil is susceptible to significant settlement (Al-Rawas, 2000).

Similarly, based on ERA's 2013 Geotechnical Design Manual, the densities are below 1.6 g/cc, which makes them, as per the manual, prone to collapse (ERA, 2013).

T.W. Lambe and R. V. Whitman (1969) has presented typical specific gravity values for different soil mineral types. Based on the typical values, it can be implied that the soil samples are most likely made up of potassium feldspars. Feldspars, are known to be a major constituent of sand and silt fractions of soils (Makenzie, 1975). Therefore, it can be concluded that the obtained specific gravity values of the soil samples show that they possess sandy and silty natures.

As discussed in many literature, including ERA's 2013 Site Investigation Manual, collapsible soils mainly consist of sands and silts with a trace amount of clay content.

The same trend has been observed in the particle size analysis of both samples.

Using dry density values from field tests and Atterberg limits, it can be observed that for both stations, the soils fall under the "potentially metastable" portion of the plot suggested originally by Bell and Bruyn (Al-Rawas, 2000).

In the collapse potential tests, the collapse property of the specimen when compacted at their maximum dry densities have significantly improved. This will lead us to a conclusion that the nature of collapsible soils can be highly improved by compaction.

As compared to the collapse indices obtained from the specimen subjected to a stress level of 200 kPa, the collapse potentials obtained at a lower stress level are lesser. This can be an indication that the stress level does affect the obtained collapse property and that a higher stress level means a higher collapse index/potential.

Suggested Remedial Measures

There are numerous possible alternatives of improving the properties of collapsible soils. They mainly focus on either avoiding collapse triggering mechanisms (like using geotextile as a drainage filter to prohibit water reaching to the collapsible soils), or inducing collapse prior to construction (like pre-wetting and surcharging) or heavy

compaction or using grouting and blending techniques.

The selection of the treatment method mainly depends on the type of the structure. Alternative treatment options recommended for highway subgrade may not be suitable for treating collapsible ground below bridge or building foundations.

For example, solutions like grouting, or pre-wetting and surcharging are more relevant to foundations, since foundations occupy a small amount of area. In addition, the solution of precluding the presence of water, like using geotextile membranes, is almost impractical, as discussed on ERA's 2013 Geotechnical Design Manual.

Furthermore, blending the collapsible soils with selected material may not be the best solution as the collapsible soils by their nature, except for their looseness, do not pose a serious problem and have a high strength; and hence, can be an excellent subgrade, if properly compacted.

Therefore, considering the moderate nature of the collapse potential of the area based on the findings of the study and the characteristics of the project, alternative solutions involving compaction like excavation and re-compaction, high energy impact compaction and rapid impact compaction are recommended.

6. Conclusions

From the different field and laboratory tests carried out for the study area, it can be concluded that:-

- Field dry density tests indicate that the subgrade sols in the study area are naturally found in a very loose state.
- The classifications of the soils based on AASHTO classification indicate the project subgrade comprises soils with AASHTO group A4.
- One dimensional collapse potential tests done for the samples remolded at their bulk densities and subjected to stress level of 200 kPa as well as to in-situ stress levels anticipated at site have shown that the samples are moderately collapsible as per ASTM classification.
- One dimensional collapse potential tests done for the samples remolded at their maximum dry densities and subjected to stress level of 200 kPa as well as to in-situ stress levels anticipated at site has shown that the samples are slightly collapsible as per ASTM classification.
- One-dimensional Oedometer test results obtained at the same density but at different stress levels revealed that the magnitude of the loading stress level had an effect on the collapse potential of the samples. A higher stress level resulted in a higher collapse index/potential.
- Observing the collapse potential test results for samples remolded at their bulk and maximum dry densities, it was learnt that the collapse nature of the samples can be highly enhanced by improving their densities.

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