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Assessment of the potential of using blackstrap molasses as a soil stabilizer for small earthfill dam embankment

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ABSTRACT

This research aimed to assess ability of blackstrap molasses to stabilize silt clay soil for use as inner core in earth dam embankment. Specifically, this research examined the effect of adding blackstrap molasses to silt clay soil in terms of consolidated-undrained triaxial test, soil permeability and compaction. The study used blackstrap molasses with a density of 1.4 g cm^{-3} and viscosity of 2.9 x 10^{-6} m^2 sec^{-1} for soil stabilization. Molasses can improve the adherence between soil particles and, thus, enable formation of a strong interparticle bond that enhances the stability of the stabilized soil.

By adding 6.5% of molasses to soil sample, cohesion of soil was increased from 6.0 to 43.8 kN/m^3, while decreasing friction angle of soil from 22.1° to 8.6°. Additionally, maximum dry density of soil was increased from 18.5 to 19.40 kN/m^7 while bulk density of soil increased from 20.72 to 21.34 kN/m^3. Also, optimum moisture content of soil decreased from 12.0% to 10.0% at 6.5% molasses content. The permeability of the soil decreased from 6.062 x 10^{-5} to 2.413 x 10^{-5} mm sec^{-1} with increase of molasses up to 6%. Results showed that, stabilization of silt clay soil with molasses, increased strength properties of soil, and therefore, molasses can be used as stabilizing agent for silt clay soil. It is recommended that, further studies be conducted to determine duration molasses as stabilizing agent will last in the soil while maintaining the same strength. Also field trials would be necessary to assess the performance of soil stabilized with molasses.

Key words: Soil stabilization, silt clay soil, molasses, soil properties

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1.0 INTRODUCTION

1.1 Background

Water is essential for all living organisms i.e. human beings, animals and vegetation [8]. The majority of the populations in the semi-arid areas depend on agriculture and pastoralism for survival. It is therefore important that adequate supply of water to be developed to sustain all life. Water scarcity is experienced in many places and sectors in Tanzania due to unreliable rainfall. The recent droughts 2011/12 and associated crop failures have led to severe hunger in many places in Tanzania that has forced the government to organize food aid to the people [7]. However, irrigation sector found to be the only solution to combat drought caused by climatic change. In order to achieve food self-sufficiency to all, the government is now struggling to invest more in rainwater harvesting technology such as construction of small, medium and big earthfill dams for purpose of collecting run-off water for irrigation and domestic purpose. However, construction of dams found to be difficult to some identified potential areas due to lack of suitable soil for dam embankment construction. This research aimed to stabilize silt clay soil using blackstrap molasses to assess potential of molasses as a soil stabilizer. Specifically, this research examined the effect of adding molasses to silt clay soil in terms of consolidated-undrained triaxial test, soil permeability and compaction.

2.0 MATERIALS AND METHODS

2.1 Study area

The study was conducted at Goweko village (Fig.1). The village is located on the South – Eastern part of Uyui District, Tabora Region - Tanzania. The village is about 60km from Tabora Municipal Centre. The study area is located at Goweko Mlimani – Sub village on the northern part of Goweko village Centre. This area was chosen because of the following reasons:

- Catchment of study area is big to discharge enough water needed for irrigated agriculture.
- Length of designed dam embankment is only 730m and maximum dam height is 12.05m while estimated total reservoir capacity is 4,940,000.00m^3 at full supply level.
- Potential area suitable for irrigated agriculture is more than 400ha of paddy.

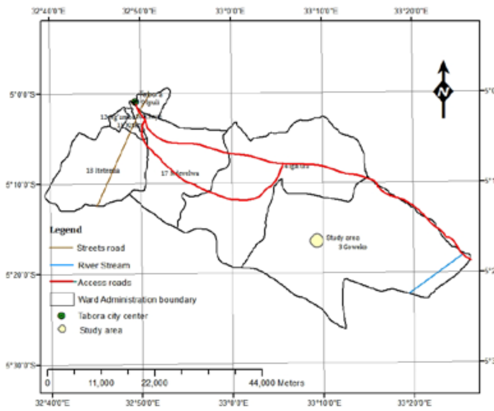


Figure 1 : Map of study area - Uyui District - Tabora region

2.2 Characteristics of soil at the study area

Silty Clay soil was brought from Goweko representing a widely spread typical soil in the study area. The soil samples were taken at a depth of about 1.5 – 2.5 m below the top surface. These samples were found to be loose silty clay. The properties of the soil and the results of the consistency limits are given in Table 1 while the classification of the soil is given in Figure 2. The soil lies above the A-line (as shown in Fig. 2), thus the soil is classified as Silt Clay (CL - ML) soil according to the unified soil classification system [6]

TABLE 1: PROPERTIES OF THE SOIL USED IN THIS STUDY

Sample	Moisture Content %	Bulk density (kN/m^3)	Atterberg Limits			Void ratio (e)	Specific Gravity (Gs)
			LL	PL	PI		
Silt Clay soil	8.66	16.74	32.3	26.0	6.3	0.66	2.61

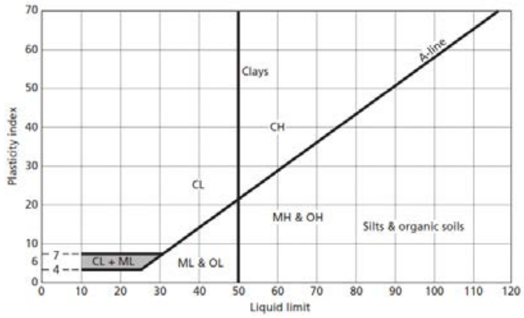


Figure 2: Plasticity Chart: British system (BS 1377-2:1990)

2.3 Soil Sampling and Research Design

Soil sample was randomly taken at depth of about 2.5m from the open pit having cross-section of 1.5m x 1.5m within the proposed borrow pit site. Disturbed soil sample was collected using a backhoe and spade while undisturbed soil sample was collected using cylindrical sampler. In the laboratory, soil was treated with molasses by adding 5%, 5.5% 6.0%, 6.5%, 7.0% and 7.5% to soil sample [9].

2.4 Laboratory analysis

A series of laboratory experiments and data analysis was carried out on disturbed and undisturbed soil sample before and after adding and varying amount of molasses to check effect of adding molasses to the soil. Silt clay soil was treated with molasses by adding 5%, 5.5% 6.0%, 6.5%, 7.0% and 7.5% to soil sample [9]. From these mixing techniques protocol for stabilizing silt clay soil using molasses was developed. All experiments and data analysis were done in accordance with British Standard (BS) for soil testing [5].

2.5 Consolidated-undrained triaxial test

In order to examine the strength behavior of stabilized soil in detail, a series of consolidated-undrained (CU) triaxial tests with pore pressure measurements was conducted. The laboratory test was very important because it allowed assessment of the suitability of stabilized soil as material for dam embankment construction to be carried out. During laboratory test, the axial load was increased by applying a constant rate of strain until specimen fail, normally within a period of 5-15 minutes, confining pressures were also varied from 0 to 150 kPa. Experiment setup and data analysis were done in accordance with British Standard [2] for soil testing.

2.5.1 Specimen Preparation

Consolidated-undrained triaxial test was conducted on untreated soils as well as molasses treated soils. The dry soil material was mixed with 5-7.5% by weight of molasses thoroughly until a uniform color observed, untreated and treated soil was then prepared at optimum water content and maximum dry density. Later, soil samples were molded in a special cylindrical mold having 70mm internal diameter and 140mm height. Each soil sample was compacted in three equal layers to achieve target density. It must be noted that each sample in this part of the study was prepared similar to triaxial specimens.

2.5.2 Data analysis

The following steps were used for data analysis:

1) To calculate axial strain. $\varepsilon = \dfrac{\Delta L}{L}$,
   where :
   ΔL (mm) = Vertical deformation of the specimen, L (mm) = Original length of specimen and
   $\varepsilon = \text{Axial strain}$

2) To calculate vertical load on the specimen.

3) To calculate corrected area of the specimen A_c (mm^2), where $A_c = \dfrac{A_0}{1-\varepsilon}$
   and A_0 (mm^2) = Initial cross-sectional area i.e. $A_o = \pi * \dfrac{D^2}{4}$
   Where D (mm) = Diameter of mould

4) To calculate the stress σ (kN/m^2) on the specimen. Where
   $\sigma = \dfrac{\text{Axial Load (N)}}{A_c}$
5) To plot σ (kN/m^2) versus axial strain separately for three tests.
6) To plot deviator stress σ_d against ε_a for three tests in the same plot.
7) To plot Mohr circle based on measured deviator stress σ_1 and σ_3 at failure.
8) To make a straight line, which is a tangent to all Mohr's circles. This gives cohesion C(kN/m^2) and angle of internal friction ($ø^0$)

2.6 Soil permeability test

2.6.1 Falling head permeability test

The falling head permeability test is a common laboratory testing method used to determine the permeability of fine grained soils with intermediate and low permeability such as silts and clays. This testing method can be applied to disturbed and undisturbed soil sample. In order to investigate the effect of adding molasses to soil permeability, a series of laboratory permeability tests on non-stabilized and stabilized soils was conducted according to British Standard [3].

2.6.2 Steps used for soil testing in the laboratory

1) Permeameter cell was filled with soil compacted at optimum moisture content and maximum dry density in three layers.
2) Filter paper was placed on both sides of permeameter cell and porous stone on bottom of permeameter cell.
3) Manometer tubes were connected, but valves kept closed.
4) Air was removed from soil sample for 15 minutes through inlet tube located at top of permeameter cell.
5) Test was run and readings taken i.e. h_1 & h_2, and time taken to reach h_2
6) Then, soil sample was thoroughly mixed after adding 5% of molasses to total weight of soil, permeameter cell was filled with soil compacted at optimum moisture content and maximum dry density in three layers, step 1-5 was repeated to soil treated by adding 5.5% 6.0%, 6.5%, 7.0% and 7.5% of molasses to soil sample.

2.6.3 Data Analysis

Data was analyzed using the following equation

$$K = \frac{aL}{At} \ln\left[\frac{h_1}{h_2}\right]$$ Where;

K: Coefficient of permeability (mm/sec)
A: Cross section area of permeameter cell (mm^2)
a: Cross section area of the standing pipe (mm^2)
L: Length of sample (mm)
T: Time duration (sec.)
h_1: Initial head of soil sample (cm)
h_2: Final head of soil sample (cm)

2.7 Compaction test

The modified proctor compaction test was carried out to determine the moisture content-dry density relationship according to British Standard [1]. Soil sample was treated with molasses at different percentage i.e. 5.0%, 5.5%, 6.0% 6.5%, 7.0% and 7.5% in order to investigate the effect of adding molasses on optimum water content and maximum dry density of the selected soils. The soil was compacted into 9.56 x 10^{-4}m³ molds in 5 equal layers.

2.8 Bulk density of soil

Bulk density of a soil is an essential parameter in most of geotechnical engineering analysis, e.g. stability of slopes, consolidation settlement, earth pressure and bearing capacity analysis.
In order to investigate the effect of adding molasses on bulk density of soil a series of laboratory tests on non-stabilized and stabilized soils was conducted according to British Standard [1],[4].

2.8.1 Data analysis

After having maximum dry density and optimum moisture content of soil treated with molasses at 5.0%, 5.5%, 6.0% 6.5%, 7.0% and 7.5% from compaction test, bulk density of soil was analyzed from the following equation.

$$\text{MDD}\,(\text{kN/m}^3) = \left[\frac{\text{Bulk density of soil}\,(\text{kN/m}^3)}{(1+\text{OMC})}\right]$$

Where,
MDD = Maximum dry density of soil
OMC = Optimum moisture content of soil in percentage

3.0 RESULTS AND DISCUSSION

3.1 Consolidated-Undrained triaxial test

Figures 3 to 9 show effective Mohr circles for non-treated and treated soil samples with different percentage of molasses. Results of the effect of adding molasses on cohesion and friction angle of Silt Clay soil are as shown in Figure 10. It can be observed that molasses treatment leads to significant increase in strength of soil especially for molasses contents greater than 5%. At 6.5%, molasses content exhibited greater strength compared with other percentage of molasses treatment in soil samples. This occurred due to decrease of soil void ratio, as a result of soil particles improvement which subsequently led to higher maximum dry density and greater soil strength.

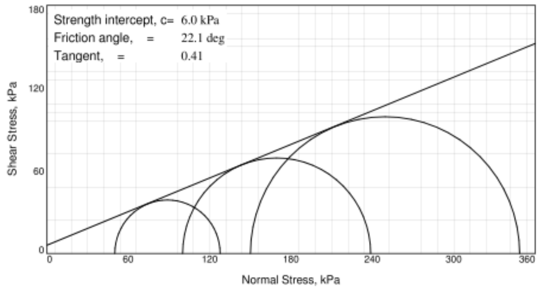


Figure 3: Mohr circle for untreated soil with molasses as stabilizer

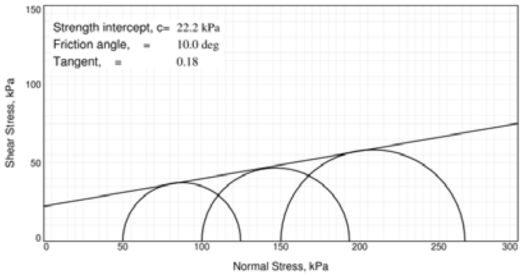


Figure 4: Mohr circle for 5% molasses added to soil sample

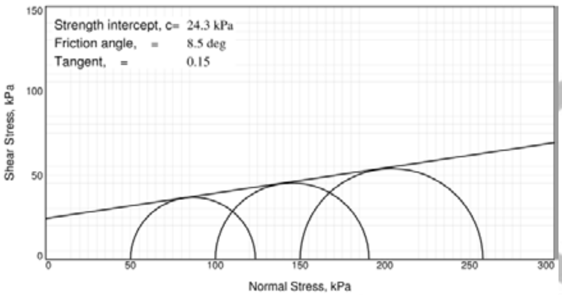


Figure 5: Mohr circle for 5.5% molasses added to soil sample

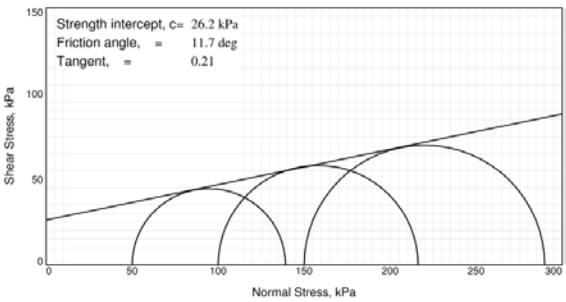


Figure 6: Mohr circle for 6.0% molasses added to soil sample

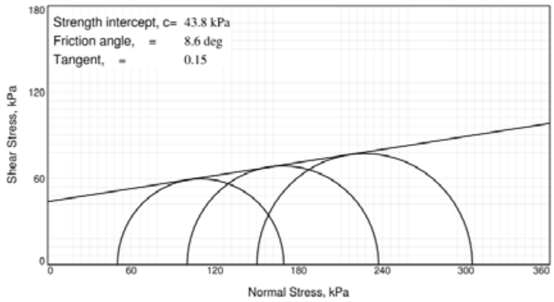


Figure 7: Mohr circle for 6.5% molasses added to soil sample

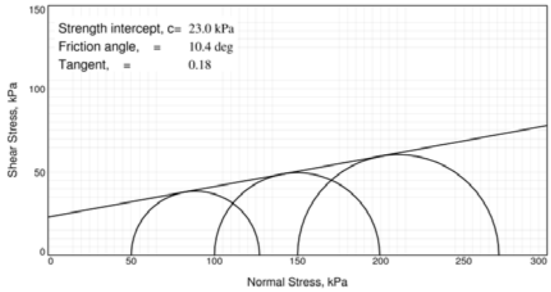


Figure 8: Mohr circle for 7.0% molasses added to soil sample

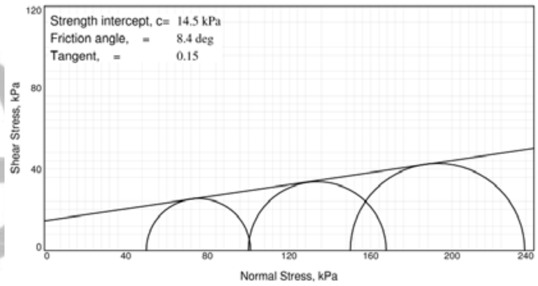


Figure 9: Mohr circle for 7.5% molasses added to soil sample

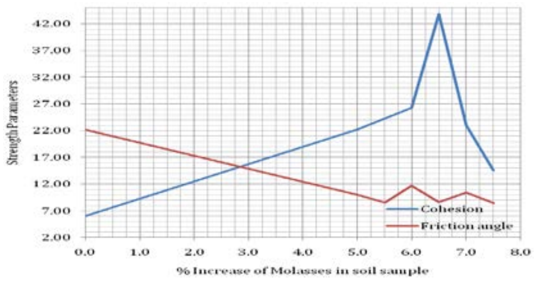


Figure 10: Effect of molasses treatment on cohesion and friction angle of the soils

A summary of strength parameters for consolidated – undrained triaxial test used for silt clay soil is given in Table 2. It can be seen that addition of small percentages of molasses to soil sample led to significant improvement in cohesion and friction angle of silt clay soil. It can also be seen that, Silt Clay soil attain maximum strength at 6.5% molasses treatment.

TABLE 2: STRENGTH PARAMETERS FOR CONSOLIDATED - UNDRAINED TRIAXIAL TEST FOR SILT CLAY SOIL

% increase of molasses in soil sample	0.0	5.0	5.5	6.0	6.5	7.0	7.5
Cohesion (C) kN/m^2	6.0	22.2	24.3	26.2	43.8	23.0	14.5
Friction angle (ϕ^0)	22.1	10.0	8.50	11.7	8.60	10.4	8.40
Tan(ϕ)	0.41	0.18	0.15	0.21	0.15	0.18	0.15

3.2 Soil permeability test

The falling head permeability was performed to determine effect of adding different percentage of molasses to soil particles. Seven specimens were created in a permeameter cell at maximum dry density and optimum moisture content. Results of soil permeability as it was determined from falling head permeameter are as shown in Figure 11. It can be seen that, by adding small percentages of molasses to soil sample led to major improvement in particles of silt clay soil. It can also be seen that, silt clay soils attained minimum permeability at 6.0% molasses treatment. Therefore, as molasses content increased in soil sample, permeability of soil decreased. Table 3 show a typical permeability values in soils [10].

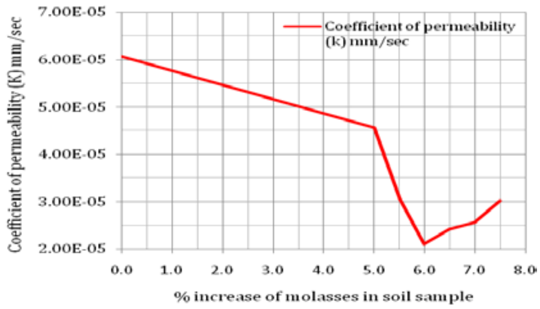
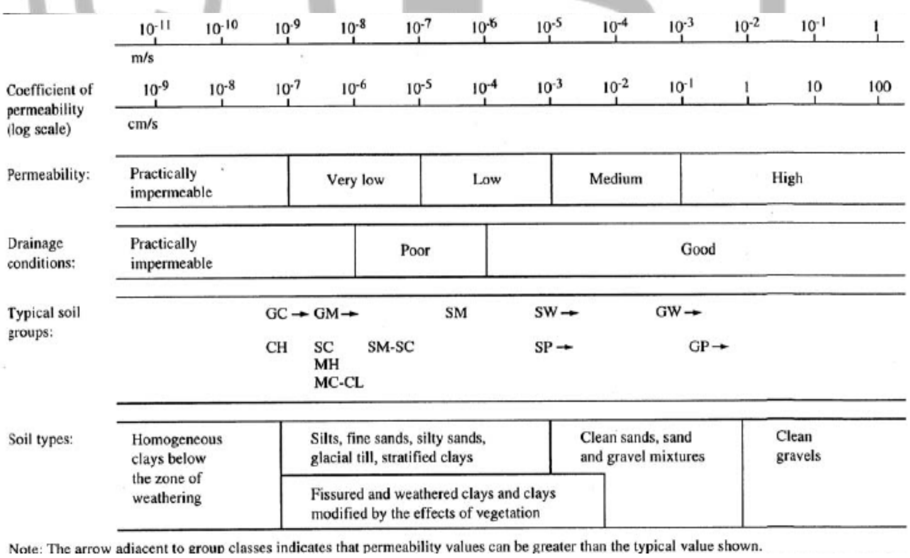


Figure 11: Effect of molasses treatment on permeability of Silt Clay soil

TABLE 3: TYPICAL PERMEABILITY VALUES IN SOILS (CARTER, M AND BENTLEY, S. 1991)



3.3 Compaction characteristics

The effect of molasses treatment on optimum water content, bulk density and maximum dry density of soils were determined from modified compaction tests and results are as shown in Figures 12 and figure 13. It can be observed that, as molasses content increased, optimum water content decreased where as maximum dry density and bulk density of soil increased.

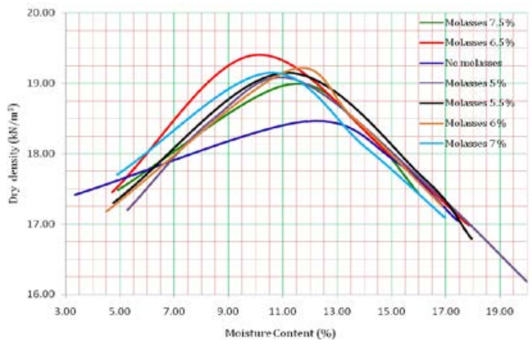


Figure 12: Effect of adding molasses on moisture content and maximum dry density of soil

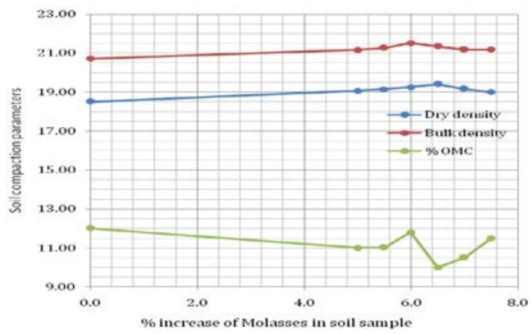


Figure 13: Effect of molasses treatment on optimum moisture content, bulk density and maximum dry density of the soils.

3.4 Bulk density of soil

Results of bulk density of soil derived from soil modified by adding 5.0%, 5.5%, 6.0% 6.5%, 7.0% and 7.5% of molasses treatment are as shown in figure 14. It can be observed that, as molasses content increased, maximum dry density of soil increased from 18.5kN/m³ to 19.40kN/m³ also, bulk density of soil increased from 20.72kN/m³ to 21.3kN/m³.

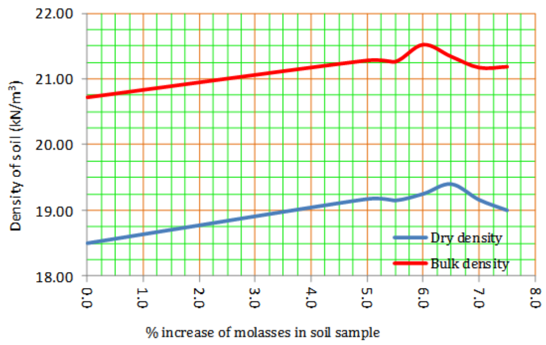


Figure 14: Effect of adding molasses on maximum dry density and bulk density of soil

4.0 CONCLUSIONS

Laboratory experiment of these study revealed that, by adding 6.5% of molasses to silt clay soil, cohesion was increased from 6.0 to 43.8 kN/m³, while decreasing friction angle of soil from 22.1⁰ to 8.6⁰. Additionally, maximum dry density of soil was increased from 18.5 to 19.40 kN/m³ while bulk density of soil increased from 20.72 to 21.34 kN/m³. Also, optimum moisture content of soil decreased from 12.0% to 10.0% at 6.5% molasses content. The permeability of the soil decreased from 6.062 x 10^{-5} to 2.413 x 10^{-5} mm sec^{-1} with increase of molasses up to 6%. Results showed that, stabilization of silt clay soil with molasses, increased strength properties of soil, and therefore, molasses can be used as stabilizing agent for silt clay soil.

4.1 Recommendations for future work

The following recommendations are made for future research:

- Further studies are recommended to determine duration molasses as stabilizing agent will last in soil while maintaining the same strength
- Field trials would also be necessary to assess the performance of soil stabilized with molasses.

5.0 ACKNOWLEDGEMENT

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6.0 Conflicts of Interest

The authors declare that there is no conflicts of interest regarding the publication of this paper.

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