Assessment of shear strength for liner cover layers at different environmental exposures

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ABSTRACT

Cover liners are the top layers placed when the closure of a landfill is decided. The top layers are normally subjected to the direct influence of moisture, temperature changes, and erosion. It is suggested to assess the shear strength of clay liners using a dynamic cone penetrometer as a quick tool for assessment. The areas indicating poor shear strength are assessed for the dry density and moisture influence on the compressibility and shear strength parameters. The dynamic probe was found to give reliable results for bentonite sand mixtures. Zones for moisture content were established to reflect the bilinear cone penetration and moisture content trends. The laboratory fall cone tests were conducted to verify the trends of penetration and influence of dry density in zones of relatively dry moisture content within the wet of optimum side of the compaction curve. The laboratory test results were assessed and recommendations to improve the shear strength evaluation using dynamic cone penetrometer are presented.

Keywords: shear strength, cone penetrometer, liners, sand-clay mixtures

1 INTRODUCTION

The assessment of the cover layers of sand-clay liners generally placed on top of landfills concerning shear strength and support of traffic is an essential measure. This will help designers to decide on possible facilities that can be supported by these layers. The field density tests conducted at the time of construction can be subjected to serious changes due to the swelling nature of the material. The expansion will cause the density and shear strength to drop significantly when wetting occurs due to environmental conditions or wetting arising due to capillary water. The suggested quick and economical test for assessment can be the dynamic field penetrometer. This test can be performed periodically and can provide useful information and guidance on whether treatment or over-layers are required.

The fall cone test procedure specified in ISO 17892–6 with a cone of 30º or equivalent is generally used in practice. The mass of the cone is 80 grams. This method is not different from that specified in BS 1377. Undrained shear strength, Su, in kPa was obtained by using Hansbo's [1] formula:

$$Su = k\,(m.g/d^2) \qquad (1)$$

k the cone coefficient is taken as 0.8 for the cone size and geometry used in this study, g is the acceleration of gravity (m/s^2) and d the cone penetration depth measured in mm. Recent works of Canelas et al, 2018 to link the fall cone results to direct shear strength indicated poor correlations and they attributed that to the complexity and factors affecting the direct shear tests. They highlighted and specifically mentioned moisture content. Higher water content indicated more variations.

Hiroyuki et al (2012) showed from a comparison study that the shear strength obtained by fall cone tests is as much as 10 times larger than that obtained from field vane tests.

The ultimate goal of this work is to enable using of field dynamic cones in the assessment of bentonite sand liners concerning shear strength. Erroneous data of field shear strength tests are often reported and are not likely reflecting true measurements. The fall cone method proved to be efficient in determining the shearing strength of saturated and nearly saturated uniform soils. As the material used in clay sand liners is uniform and does not include gravel or boulders the assessment using the cone penetration method can be ideal. The recent development in field cone penetrometers are now capable of measuring pore water pressure and can easily be fitted with sensors to determine moisture content and salinity and other parameters. This high tech equipment may be expensive if the purpose is only the survey of shear strength of a liner layer.

The introduction of sand to clay reduces the index properties of the mixture. Tan et al, 1994 introduced fall cone penetration reduction curves for liquid limit for variable sand content in a bentonite sand mixture. The liquid limit drops from above 400 to less than 100 for 20% sand content. For more than 80 % sand content a liquid limit of less than 30 can be obtained. The influence of dry density on the cone penetrometer is utilized by Presti et al (2018) to assess compaction in levees. They claimed that developed simple tool can work for the assessment of the degree of compaction in compacted, partially saturated, fine-grained soils. However, the works conducted did not specify the level of partial saturation. This is the greyest area where many researchers avoid going into its details. The soil-water characteristic curve studies (SWCCs) are the closest approach towards reliable assessment. Presti et al, 2018 stated that the tip resistance depends on the dry density and water content for a given soil. Likos, and Jaafar, 2014 pinpointed a significant factor that is very much related to cone penetration. This is the soil water retention characteristics. They defined zones that vary from nearly dry to saturated. According to the suction stress concept, effective stress (σ´) is given as:

$$\sigma' = \sigma - u_w \quad (2)$$

where σ is total stress and u_w is pore-water pressure. Matric suction is given as uw $-u_a$ where u_a pore-air pressure.

As the main purpose of this work is to provide an assessment tool that is simple, quick and yet reliable for surveying clay-sand mixture layers, it was decided to construct a simple dynamic probe to be used in penetrating clay-sand mixtures. The results can be viewed based on the fall cone behavior when applied to clay-sand mixtures of variable dry density and moisture content. The cone penetration within the partially saturated zone can be divided into two zones. The first can be called saturated and close to the saturated zone and the other can be referred to as a partially saturated zone. These two states are common in practice and known to be influenced by environmental exposure. The fall cone penetration is known to be linear for variable moisture content in saturated and close to the saturation zone (Zone 1) and non-linear in the partially saturated zone (Zone 2). Variable compaction energy was applied at different moisture content were studied and compared to the soil-water characteristic curves.

2 MATERIALS

2.1 SAND

The sand used in this research was poorly graded natural sand with a maximum grain size of 1 mm and fines content of less than 5%. The specific gravity was 2.65. This type of sand is used in the sand- bentonite mixtures for investigating the penetration of the dynamic probe and the laboratory fall cone.

2.2 BENTONITE:

The bentonite used in this study is commercial bentonite OCMA grade supplied by the arabian minerals & chemical co. Ltd in Saudi Arabia. The liquid limit of the bentonite was measured as 316 and the plastic limit as 62. Typical chemical analysis of OCMA grade bentonite manufactured in the gulf region are presented in Table 1:

Table 1. Chemical composition of OCMA grade bentonite.

SiO_2 (%)	Al_2O_3 (%)	FeO_3 (%)	Na_2O (%)	MgO (%)	Ca O (%)	TiO_2 (%)	K_2O (%)	L.O.I (%)
55.2	17.0 %	2.9	1.9	4.6	0.9	<0.01	0.1	16.7

Source Ore- Arabian Gulf Region-OCMA Grade (1998)

3 TEST METHODS AND PROCEDURES

3.1 The dynamic field penetrometer

A penetration probe 224 mm in length and 20 mm in outer diameter was made of steel. A welded or threaded flange was fitted to the top of the probe to transmit hammering energy. The bottom of the probe is fitted with a 20 mm dia cone of 60 degrees angle. A falling head 3 kg hammer is attached to the top of the probe. A measuring dial gauge is attached.

The probe could be advanced using a quasi-static system but a dynamic method was chosen because it is simpler to use on-site and does not require sophisticated strain control equipment.

The test method is quite simple. The probe is placed on the surface of the soil to be tested. The hammer is allowed to fall freely over 20 cm distance and hit the top of the probe. The distance penetrated for every 10 blows is recorded. The penetration can be given in mm or cm per blow. The value for every 10 blows can be used for comparison.

3.2 The fall cone penetrometer

The penetrometer apparatus described by the British Standard (BS 1377: Part 2:1990:4.3) and complying with the requirements of BS 2000 Part 49 was used as a basic device in this study.

The sample preparation method is very crucial to this test. To produce a homogeneous paste the bentonite and the fine sand are thoroughly mixed using two palette knives for at least 10 minutes following the British standard. A portion of the mixed soil is pushed into a 50mm diameter ring of 20 to 50 mm height or a standard cup taking care not to trap air. The cone is placed just in touch with the surface of the sample and then released to fall under its weight for 5 seconds. The difference between the initial reading of the dial gauge before and after penetration is recorded to the nearest 0.1 mm.

The approach adopted as seen from above is similar to that of liquid limit determination. Feng (2000, 2004) found that a preparation technique using specimen rings instead of cups is faster and easier. He also concluded that the use of rings would reduce the chance of trapping air in the specimen. This is found to give the same results as for the standard cup.

The test procedure is exactly as explained above for the determination of the liquid limit using the fall cone method. The data is presented similarly. The test measures the penetration in mm at different moisture contents. This relationship can be presented in a semi-log format. The trend of the curve can be used for comparison with curves of other materials.

3.3 Standard Proctor for liner material.

The clay sand mixture material was tested for compaction using the standard proctor test. The procedure explained in ASTM D 698 was followed. The maximum dry density for the mixture 5% bentonite and 95% sand was reported as 1.70 gm/cubic centimeter at optimum moisture content of 14%. Results are presented as part of Fig. 6 labeled as energy one (E1).

3.4 The soil water characteristics curve

ASTM D6836 (2002), Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using a Hanging Column, Pressure Extractor, Chilled Mirror was used for the clay-sand mixture with 5% bentonite content. Only the pressure plate method was conducted.

4 TEST RESULTS AND DISCUSSION

The dynamic field penetrometer used in this study for bentonite sand mixture is presented to show the consistency of the field. The tests were carried out on mixtures with 40% bentonite and 60% sand. For a given dry density and constant moisture content, the number of blows is proportional to the penetration. A linear relationship is observed excluding the first 10 blows. The initial zone of the curve is influenced by the status of contact between the cone and the soil in addition to the initial expansion derived by advancing the cone. The first 10 blows of the 3 kg dynamic hammer falling over 224 mm are not informative and may not be taken into account. Figures 2 and 3 present typical cone penetration versus the number of hammer blows. Infield explorations it is expected that the moisture level is about the same or varying within a small range. The comparison of penetration measured can identify the density profile of the surveyed area.

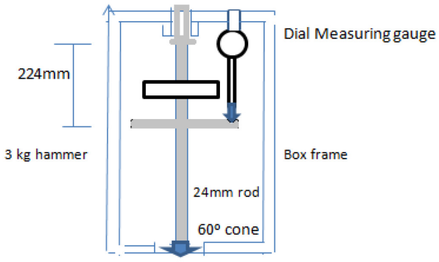

Fig. 1. Typical Dynamic cone penetrometer

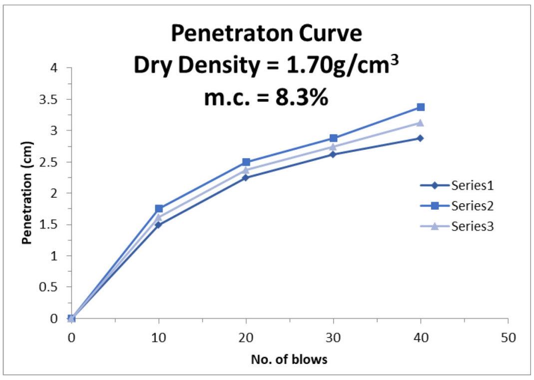

Fig. 2. Dynamic probe penetration for γd of 17 kN/m^3 and m.c. 0f 8.3%.

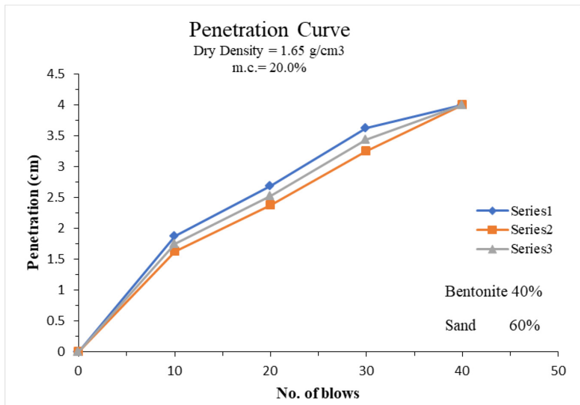

Fig. 3. Dynamic probe penetration for γd of 16.5 kN/m3 and m.c. 0f 20%.

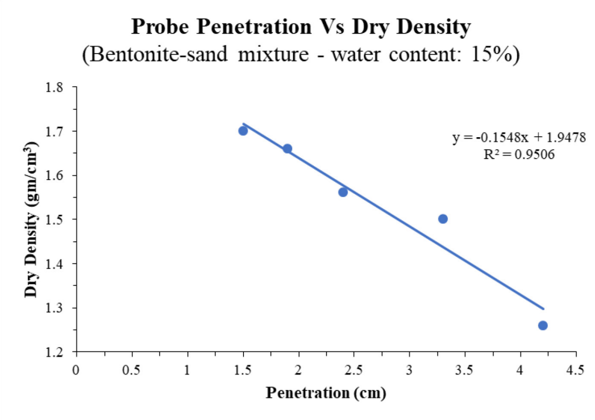

Fig. 4. Probe penetration versus dry density.

Penetration can be confidently expressed in terms of dry density using the dynamic probe as shown in figure 4.

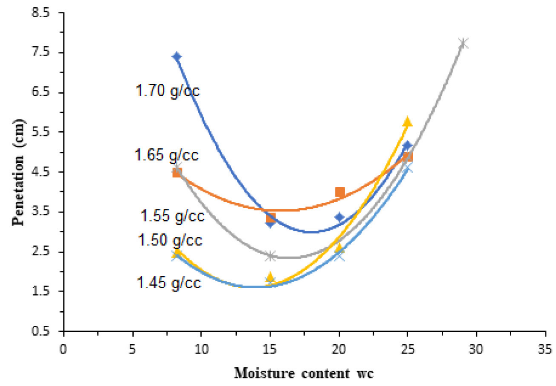

Fig. 5. Probe penetration versus moisture content.

For variable moisture content and the same dry density, the profile of penetration is a curve with a minimum value at certain moisture content. This can be called optimum moisture content linked to minimum cone penetration. When considering moisture content within the wet of optimum zone we can observe that curves for all densities converge towards a single line. This line is curvilinear with two different zones. The first part is curved and the second is linear. For simplicity, a bilinear may be assumed. The zone from optimum moisture content towards the turning point close to saturation (TP) can be referred to as Zone 2. Zone 1 is from TP towards full saturation. Zone 1 is not influenced by the dry density.

For zone 2, it can be observed that the penetrometer can not be dealt with directly without considering density influence and other parameters. To assess these samples compacted at lower proctor energy levels were considered for selected four moisture content values. The fall cone tests were conducted in the laboratory for another sand bentonite mix with 95% sand and 5% bentonite. The low bentonite content was considered to simulate practice for the liner industry which considers low bentonite content for cover layers.

Compaction energy levels applied to the bentonite sand mixture of 5% clay and 95% sand are 250, 300, 400, 500 and 600 KJ/m^3. These energies produced dry density values lower than dry density obtained in the standard proctor test for moisture content values of 14, 18, 22 and 25.5% moisture content.

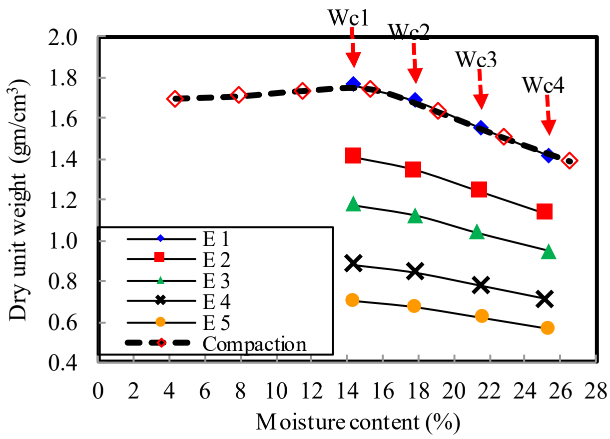

Fig. 6. Compaction curve of soil used and the variation of dry unit weight with moisture contents

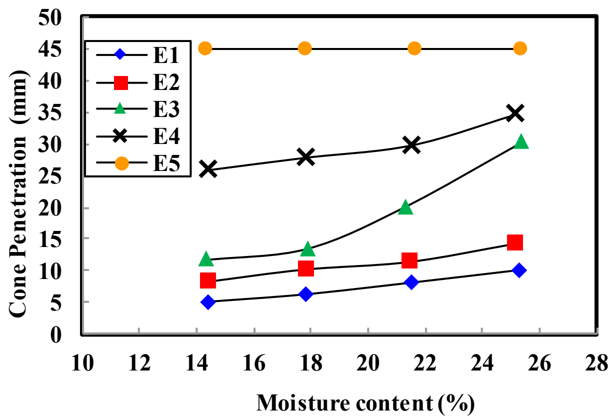

Fig. 7. Cone penetration vs. moisture contents.

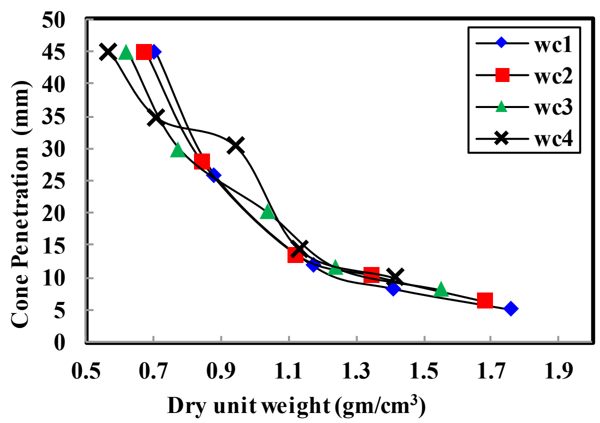

Fig. 8. Cone penetration vs. dry unit weight.

The fall cone penetration for the bentonite sand mixtures within Zone 2 range expressed in terms of compaction energy are presented in Fig 7 and cone penetration expressed in terms of dry density are shown in Fig. 8. The penetration is excessive for energy level E5 and dry density lower than 0.8 gm/cm3 . In figure 8 we can see that cone penetration can be expressed in a bilinear function where a turning point (TP) occurring at a dry density of 1.1 gm. For a given dry density the cone penetration is reduced by reducing the moisture content. The linear relationship is getting curvilinear at certain moisture content. For Energy level 3 we can see a sharp turn at 18% moisture content. For the high density levels the turning point is expected below 14% moisture content. The undrained shear strength can be computed using an appropriate cone factor for the laboratory fall cone or the dynamic probe (Hansbu formula). It worth selecting the density level to obtain a reliable shear strength value.

Figures 9 and 10 presents computed shear strength for the fall cone penetration and the dynamic probe penetration.

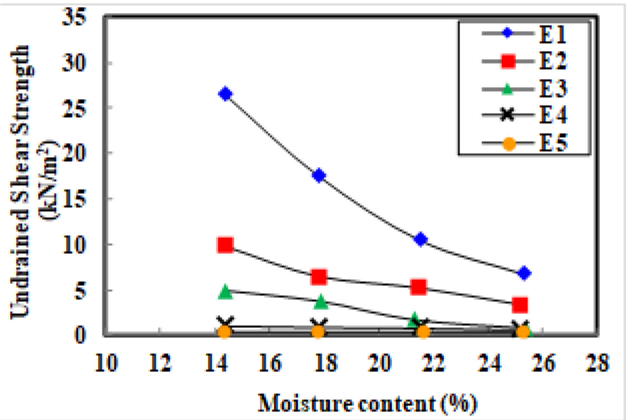

Fig. 9 Undrained shear strength by fall cone vs. moisture contents

The soil water characteristics curves conducted for the samples of variable compaction energy indicated a similar trend as the soil is density is varied.

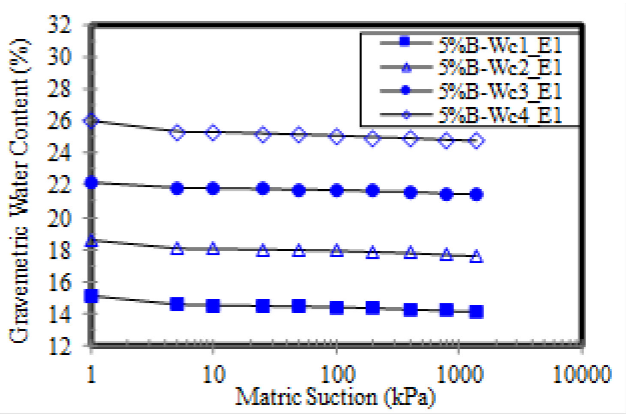

Fig.10. Soil water characteristic curves for Sand + 5% Bentonite mixture under different moisture contents

The suction is generally low when the moisture content is high. Suction tests were repeated for the same compaction energy with different initial gravimetric water content. The matric suction is low for near saturation moisture content and increases with a minor drop in water content. When correlating shear strength to low suction values it is advised to consider good simulation to natural conditions. Likos et al (2010) suggested a modified direct shear testing apparatus to suit low suction and stress.

Measurements of moisture along with cone penetration are recommended for all site surveying utilizing dynamic probes.

5 CONCLUSIONS

The first 10 blows of 3 kg dynamic hammer falling over 224 mm are not informative and may not be taken into account when assigning field density or shear strength using a dynamic cone. Penetration versus dry density is a curvilinear function for both dry and wet of the optimum part of the curve. The cone penetrometer over the full range of moisture for typical bentonite sand mixtures is a parabola curve with a minimum penetration value occurring at optimum moisture content. When considering moisture content within the wet of optimum zone we can observe that curves for all densities converge towards a single line. This line is curvilinear with two different zones. The first part is curved and the second is linear. For simplicity, a bilinear state may be assumed. The zone from optimum moisture content towards the turning point close to saturation (TP) can be referred to as Zone 2. Zone 1 is from TP towards full saturation. Zone 1 is not influenced by the dry density. This zoning must be established before surveying sites using dynamic cone penetrometers. Layers subjected to different compaction energies can produce variable cone penetrations. When surveying a site with moisture drier than an established turning point the effect of dry density must be taken into account. The computed undrained shear strength drops with the increase of moisture content. The shear strength is not a linear function for dense and well-compacted bentonite sand mixtures. For all dynamic cone penetrometer, it suggested establishing the turning point dividing two zones of penetration data. Measurements of moisture along with penetration are recommended for site surveys utilizing dynamic probes. The matric suction is low for near saturation moisture content and increases with a minor drop in water content.

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DATA AVAILABILITY STATEMENT

All data related to this manuscript is available.

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