Comparative Assessment of Shear Strength under Static Loading for Asphalt Stabilized Soil

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Abstract: ***The main purpose of this research is to assess the impact of asphalt stabilization on the variation in the shear resistance of subgrade soil under static loading.The impact of two testing techniques (double punch) on cylindrical specimen of100mm diameter and 63mm thickness and (single punch) on cylindrical specimen of 152mm diameter and 127mm thickness has been verified on shearstrength using incremental static loading. The testing program for this paper is concerned with the determination of shear stress property of natural and asphalt stabilized subgrade soil under the static loading.The study found that increasing asphalt content above the optimum has a positive impact on single punch test. The percentage of variance relative to natural (untreated soil) is equal to (107, 164, and 261) and (94, 163, and 312) at (2.5 and 5) mm penetration respectively for fluid content equal to (15.5, 16, and 16.5) % correspondingly.Shear strength increases as fluid content increases for single punch test, while it decreases as fluid content increases for the double punch test.At 15.5% fluid content, single punch test shows higher shear strength by 128% than that of double punch test. Such variation increases by (278 and 853) % with the increments of fluid content.***

Keywords: Granular soil, Liquid asphalt, shear strength, Double punch, CBR

1. Introduction

The subgrade soil quality that usually utilized in construction of roads are categorized into main five categories (hard, very stiff, stiff, medium, and soft) relying on the value of shear strength[1]. In addition, it may be categorized into five categories (excellent, good, fair, poor, and very poor) depending on the value of California bearing ratio, CBR, [2]. Finally, if the soil had shear strength or CBR values which is note adequate for the design loading; therefore, the soil should be stabilized.Soil stabilization is the mechanism of mixing soil with other material to improve soil properties. This process may contain mixing of additives that may develop the gradation texture or as binder for cementation of the soil[3]. The subgrade layer of pavement structure should be capable to resist tensile stresses, shear failure and have sufficient stiffness to prevent and resist pavement deformation.Available fill materials may not meet these necessities and may need development of their engineering properties. Therefore, soil stabilization with liquid asphalt could be an alternative to increase soil adhesion, waterproofing properties, and stability which are preferred for embankment construction objectives[4].An experimental study on combined stabilization (lime with liquid asphalt) was conducted by [5]. California Bearing Ratio test, CBR, has been carried out during the study. It was found that the values of CBR increases by 52% after stabilization. A comprehensive experimental study on anasphalt stabilization was conducted by [6]. The study concluded that asphalt stabilization is mainly used with non- cohesive granular soil where the asphalt offers cohesive properties soil while increasing its strength and resistance to the water effect. A comprehensive study has been carried out by [7] forassessing the differences in asphalt content for several soil engineering properties. The methodology of the study stated that a typical subgrade used for embankment construction that has been approved by Mayoralty of Baghdad was stabilized by liquid asphalt. The study found, cohesion, *C*, and angle of internal frication (ϕ) of asphalt stabilized soil was increased with increasing asphalt content up to optimum of *6%*, after this percentage the soil mechanical properties start to decease. *C* was increased by 175% *and* 615% at soaked and dry condition respectively, while (ϕ) was changed by 214% *and* 39.6% at soaked and dry condition.Selection of asphalt grade and type depend on five considerations which affect the selection of the grade and category for a specific use: environmental conditions, available equipment, method of construction, loading, and soil characteristics. Available equipment and technique of construction will principally determine the form of asphalt (emulsion, cutback) to be utilized, [8]. The matching grade, with setting characteristics and viscosity, will be affected by the sum of fine particles and the gradation in the aggregate soil features, the climatic conditions through and after construction, the category of mixing equipment, and the number of loads estimated on the pavement, [9].

The compressibility features of asphalt stabilized mixturewas assessed usingconsolidation tests which has been carried out through thestudy by [10] for treated soil with several percentages of asphalt. The results show that adding of 7% asphalt is well pronounced in reduction of voids ratio. At dry test, (10, 20, and 30) cycles of (freezing-thawing), the compression index decreases by (35, 39, and 48) % respectively. Whereas the compression index increases by (32, 107, and 93) at soaked test with the same cycles above. The aim of this work is to assess the variation in shear strength of asphalt stabilized soil when implementing two testing techniques, the single and the double punching shear test under static loading.

2. Liquid Asphalt

In Iraq, cut-back asphalt and emulsion are the most commonly used bindersfor soil stabilization. Cut-back asphalt with medium curing form usually have saybolt-fural viscosities in the domain between 3–30 sec at 25°C. This type of liquid asphalt is appropriate for soil stabilization since it reflects the climatic circumstances of humidity and high temperature for seven months in a year[10].

Lower grads of cut-back asphalt hold supplementary solvent and cure more slowly. Therefore, asphalt cut-back (MC-30) had low viscosity which is reflected appropriate for improved coating and mixing of soil particles and improved compaction. The features of medium curing cut-back (MC-30) Produced at AL-Dora refinery, Baghdad, Iraq, are in accordance to (ASTM D-2027)[11].

Table 1shows MC-30 properties which was obtained from Al-Dora refinery.

Table 1: Medium curing cut-back asphalt properties (as per Al-Dora refinery).

Grade	MC-30
Viscosity (cst) @60 °C	30-60
Flash point (C.O.C) °C (min)	38
Water% V (max)	0.2
Distillation Test to 360 °C	
Distillate %V of Toat Distilled:	
To 225°C (max)	25
To 260° C (max)	40-70
To 315° C (max)	75-93
Test on Residue from Distillation	
Penetration @ 25°C (100g, 5sec, 0.1mm)	120-250
Ductility @ 25 °C (cm)(min)	100
Solubility in *Trichloro* ethylene %*wt* (min)	99.0

3. Granular Soil

The proposed soil that has been used in this research was taken from Al-Taji, which is about 25 km to the north of Baghdad, Iraq. A scraper has been used to eliminate the 30 cm from top of the soil that contains plant roots. Additionally, the soil was taken from a depth about $(0.5 - 0.1)\,m$ and it has been stocked in plastic bags then transported to laboratory. Table 2 illustrated the chemical composition of the natural soil.

Table 2: Chemical composition of the natural soil

Chemical composition	Test result
$Total\ soluble\ salt\ (T.S.S)$	1.31%
$Sulfur\ Trioxide\ (SO_3)$	0.712%
$Calcium\ Carbonate\ (CaCO_3)$	1.111%
$Potential\ of\ Hydrogen\ (pH\ value)$	10.03
$Calcium\ sulphate\ (Total\ CaSO_4)$	1.069%

Soil classification has been conducted according unified classification system as mention in Table 3. Soil grain size distribution has been conducted according to (ASTM D 1140-2000).Finally, hydrometer test was conducted according to (ASTM D422-2002). The grain size distribution of the tested soil is shown inFigure 1.The proposed soil compaction properties were established using modified compaction test.

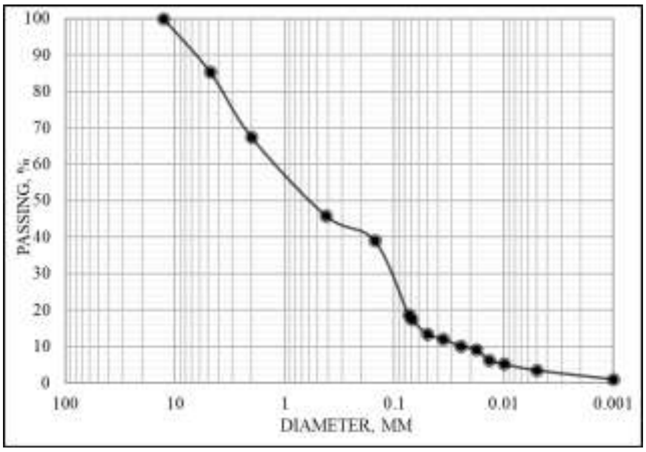

Figure 1: Grain Size Distribution

The test was performed according to (ASTM D1557-2000). The relation between moisture content and dry density of the soil is illustrated inFigure 2.

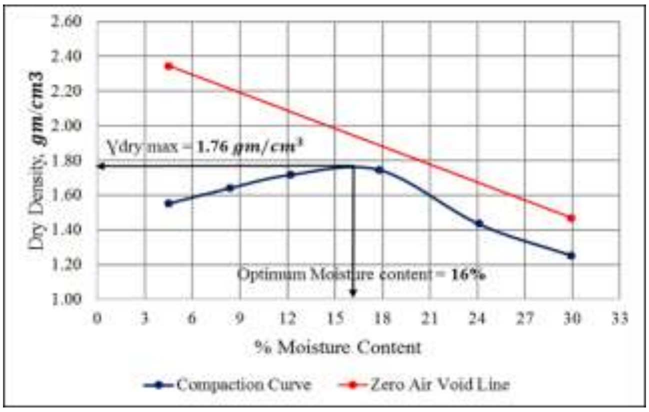

Figure 2: Modified proctor compaction test

According to (ASTM D 3080-98), the test has been conducted to obtain the parameters of proposed soil shear strength $(\emptyset\ and\ C)$ at un-soaked condition. According to (ASTM D2166) the unconfined compression test has been implemented. Table 3 summarizes the overall properties of the soil that has been used in this research.

4. Assessments of Shear Properties Under Static Load

The main purpose of this assessment is to evaluate the shear properties of asphalt stabilized soil mixture under static load. Two test techniques have been implemented in this stage. Single Punching shear test using California bearing ratio test specimens, and double punching test under static load using Marshall Size specimens.

A. Double punch shear test specimen preparation

Specimens of 100mm diameter and 63mm thickness have been prepared for this test using the homogenous and free from lumps soil passing from sieve No.4. The soil that has been used in test was dried at oven temperature (around$100\,^{\circ}C$) until it reaches constant weight. The optimum fluid content used was (6% cutback asphalt +10% water) and γ_{dmax} of soil ($17.6\,KN/m^3$) that has been designated for sample preparation. Further percentage of fluid content (±0.5%) in soil-asphalt mixture has been carried out through this test (15.5, 16, and 16.5) %. The water has been added to the soil by hand for four minutes till the water diffuse through the mixture to guarantee the mixture consistency.

Table 3: Proposed soil physical properties

Physical properties	Test result
Specific Gravity	2.62
Atterberg Limits: -	
LL %	23
PL %	Non-Plastic
PI %	Non-Plastic
Modified Compaction Properties: -	
γ_{dmax}	1.76
ω_{opt} %	16
AASHTO classification system	A3
ASTM classification system	SP
D_{10}	0.025
D_{30}	0.1
D_{60}	1.5
Coefficient of curvature (C_c)	60
Coefficient of uniformly (C_u)	0.26
Strength parameters (Direct Shear Test) (un-Soaked Condition)	
Cohesion (C) kPa	41
Angle of internal friction (Ø)	29.2°
Undrained shear strength (Unconfined compression test)	
(S_U) kPa	50

Then, cut-back asphalt was added to wet soil and blended by scrub the mixture by hand for five minutes until the soil-asphalt mixture had a homogenous property beside an appropriate covering particle of soil with asphalt. The soil-asphalt mixture has been permitted for aeration for 2 hours at laboratory temperature (20 ± 3 °C). In the bottom of the mold the filter paper was positioned. Finally, the mixture after aeration has been placed in model in addition, it has been statically compacted to the target maximum dry density. Then, the samples were taken out from the mold, and subjected to curing at room temperature for 8 days. The practice and process of the sample preparation and Versa tester machine are revealed in figure 3.

Figure 3: Preparation of asphalt stabilized specimen

B.Testing specimens for Double Punching Shear

Figure 4. Showsthe test setup for double punch shear strength.

Each specimen wasconditioned at laboratory temperature of($20 \pm 4\,^{\circ}C$) for around (30) minutes, then it has been centered on the horizontal diametrical plane between two identical steel punches which have diameter of 25.4mm and height equal to 50 mm. Perpendicular compression has been loaded with rate equal 50.7 mm/min (2 inch / min). The compression machine used in this test is versa tester machine and the load was applied till the reading of dial-gage achieved the ultimate load resistance and thesample failed. This procedure was established at the Arizona University and cited by [12]. Finally, this test has been described by several researchers [13, 14, and 15].

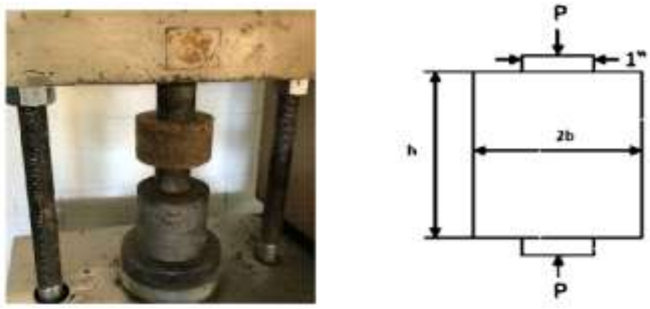

Figure 4: Geometry of the sample for double punch test

Shear stress (double punching) can be calculated by the following equation (1): -

$$\sigma_\tau = p/\pi(1.2bh - a^2) \qquad \textbf{Eq. 1}$$

Where b = radius of specimen,
p= maximum load, kN
a = radius of punch,
h = height of specimen,
σ_τ= punching stress, kPa.

Figure 5 exhibit Stress variations for several cutback asphalt contents. Six specimens have been tested in duplicate with three fluid content (15.5, 16, and 16.5) % and the average values were considered for analysis. The results showed that decreasing the fluid content in mixture leads to an increase in the value of the punching shear stress. Therefore, the highest bond action between soil particle and cutback asphalt is at fluid content equal to 15.5%. Thus, the optimum asphalt content for this test is lesser than 6%. Finally, the results show that when increasing the asphalt content,it shows negative impact on punching shear. The failure mode of specimens with fluid content of 16% is illustrated inFigure .

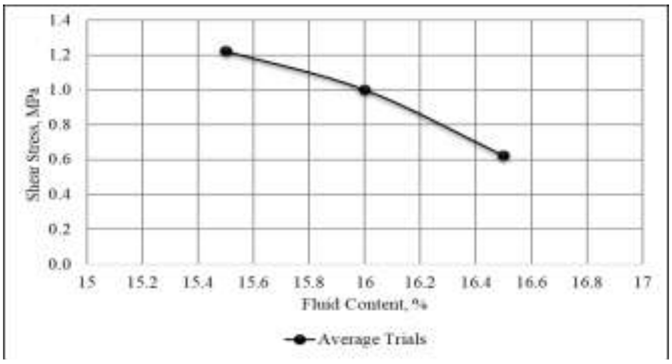

Figure 5: Fluid content versus stress relationship

Figure 6: The failure mode at fluid content equal to 16%

C. Single Punching Shear Test

The California Bearing Ratio, CBR, test has been carried out to assess the shear strength properties under static load. Four specimens have been tested with three fluid content (15.5, 16, and 16.5) %. Specimens of natural soil before stabilization have also been prepared and tested. Every specimen has been tested from top and bottom to verify the impact of exposure of specimen surface to curing. Also, the average between top and bottom has been considered in the calculations. Figure 7 shows the CBR test assembly.

Figure 7: CBR test assembly

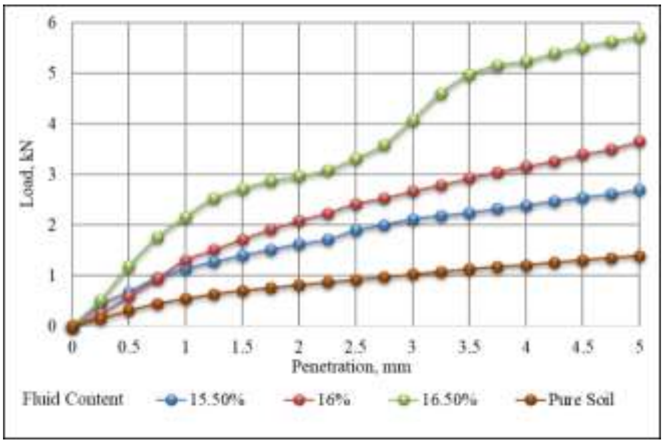

Figure 8: Load penetration curve for several fluid contents

Figure below shows the load-penetration curve that was obtained from this test for (15.5, 16, and 16.5) % of fluid content and also for pure soil respectively.From test results, it may be observed that the maximum resistance for single punching shear is obtained for 16.5% fluid content.

Finally, percentage of variance relative to natural soil can be observed inFigure Similar work was reported by [16].

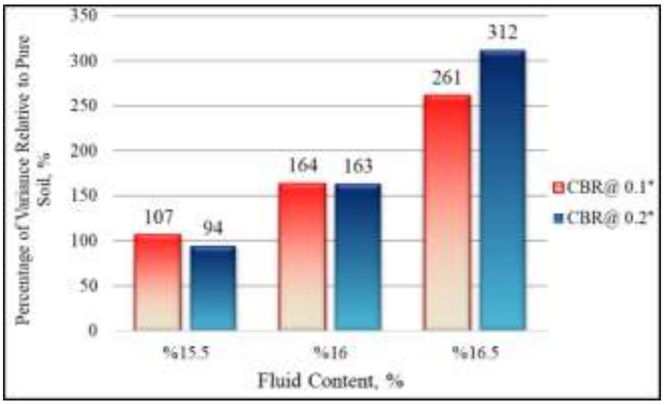

Figure 9: Percentage of variance relative to natural (untreated) soil

5. Results and Discussion

For all results in the figures, it can be noticed that there is an increase in CBR values as compared with natural (untreated) soil. This can be referred to the increase in mechanical strength of soil when using cutback asphalt as an additive material in soil. Also, it may be impliedthat the asphalt increases the cohesion of the soil-asphalt mixture. The 16.5% fluid content exhibits the highest load and maximum resistance to penetration compared to other percentages. The results of CBR showed that as the fluid content increasing it leads to increment in the percentage of CBR. The penetration curve increases gradually at the initial loading steps up to penetration equal to 2.45 mm, at that point the rate starts sudden increases (especially at 16.5% fluid content) with added extra loading for all specimens that have been tested. Such findings agrees well with [14] work.Figure 3 illustrated specimen failure mode.

(a) Specimen Under Test | (b) Specimen at the End of Test

Figure 3: CBR specimen under testing

Figure 11 exhibit the variation of shear stress between single punch (CBR) Specimen and double punch tested specimens. It can be noted that at 15.5% fluid content, single punch test shows higher shear strength by 128% than that of double punch test. Such variation increases by (278 and 853) % with the increments of fluid content. On the other hand, shear strength increases as fluid content increases for single punch test. This may be attributed to the confined nature of the specimen, load application mode from top, and restriction to

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lateral deformation. Higher asphalt content will furnish good bond of soil particles and exhibit higher shear resistance.

However, the shear stress decreases as fluid content increases for the double punch test, this could be attributed to the unconfined nature of the specimen in the test as well as the size of the specimen. The asphalt content will sustain the load and exhibit a stiff behavior at lower asphalt content, while higher asphalt content will exhibit lower stiffness and lower shear resistance.

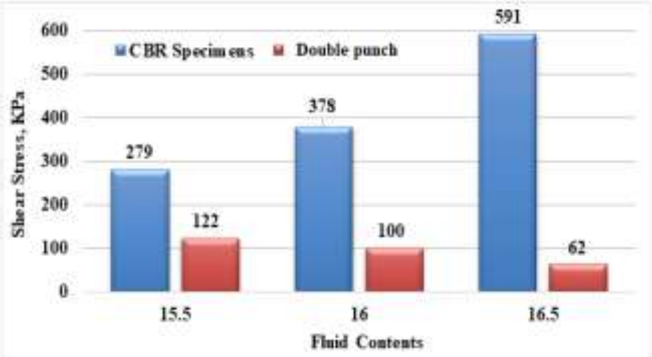

Figure 11: Variation of shear stress between single and double punch test

6. Conclusion

1) From double punching shear test, the highest bond action between soil particle and cutback asphalt is at fluid content equal to 15.5%. Further increment of the asphalt content shows negative impact on double punching shear strength.
2) From single punching shear test (CBR size specimens), it has been found that increasing asphalt content above the optimum has a positive impact on CBR. The percentage of variance relative to natural (untreated soil) is equal to (107, 164, and 261) and (94, 163, and 312) at (2.5 and 5) mm penetration respectively for fluid content equal to (15.5, 16, and 16.5) % correspondingly.
3) Shear strength increases as fluid content increases for single punch test,while it decreases as fluid content increases for the double punch test.
4) At 15.5% fluid content, single punch test shows higher shear strength by 128% than that of double punch test. Such variation increases by (278 and 853) % with the increments of fluid content.

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