Assessment of Resilient Behavior of Asphalt Stabilized Soil

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Abstract:

The resilient behavior of asphalt stabilized soil under repeated loading in terms of the change in the potential of deformation and shear failure was investigated in this work. Asphalt stabilized soil specimens of 100mm diameter and 70mm height and 152mm diameter with 127mm height have been prepared in the laboratory and compacted to a target density at optimum asphalt requirement and at 0.5% of asphalt above and below the optimum. Specimens were tested for deformation and resilient modulus under repeated shear stress. The deformation of the specimens has been captured along the load repetition process with the aid of linear variable differential transformer (LVDT) under controlled stress and environmental conditions in the pneumatic repeated load system (PRLS) until failure. For large size specimens tested under single punch shear stress, the resilient deformation decreases by (70, 51, and 47) % as compared with pure soil at fluid content equals to (15.5, 16, and 16.5) % respectively after 1200 load repetitions. For small size specimens tested under double punching shear test after thirty and eight days curing, the resilient modulus increased by (442, 362, and 216) % for fluid content equals to (15.5, 16, and 16.5) % respectively after load repetitions equal to 1200. Data of the two testing techniques regarding resilient deformation rate under single and double punching shear stress was analyzed and compared. It was concluded that eight days curing and double punch shear testing are reported as the optimum time and test technique for enhancing proper resilient modulus. Asphalt stabilization exhibit positive impact on resilient modulus, it increases Mr by a range of (600, 700, and 100) % for double punch at 30 and 8 days curing and single punch at 8 days curing after the addition of cutback asphalt as compared with natural soil.

Keywords:

Cutback Asphalt, Punching, Shear, Stabilization, Resilient, Deformation

1. Introduction

For road subgrade, it is essential that the soil must have sufficient resistance to horizontal displacement under wheel load excitation, and a soil that has such resistance is supposed to be stable, [1]. Well-compacted and well-graded soils are logically stable and commonly do not exhibit need for treatment. However, if the grading is deficient, it might generally be improved by mixing it with another binding material, [2]. The subgrade layer 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, [3]. 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]. Mechanical and Chemical treatment of a mass of soil may be required to develop the durability and shear strength for inclusion in a pavement structure, [5]. Soil stabilization with the usage of binder materials in weak soils can develop its geotechnical properties such as durability, strength, permeability, and compressibility, [6]. Soil stabilization with liquid asphalt is considered as a sustainable step towards roadway construction on problematic subgrade soil, there are no requirements to import good quality materials or to implement energy consumption, but to mix the readily available soil with liquid asphalt through the cold mix technique, [7]. Liquid asphalt stabilized soil may be an alternative approach to increase the stability and prevent shear failure, [8]. A comprehensive study on asphalt stabilization has been carried out by, [9]. A typical subgrade used for embankment construction that has been approved Mayoralty of Baghdad was implemented. The study found that 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 $615\%\ and\ 175\%$ at soaked at dry and soaked condition respectively, while (ϕ) was changed by $214\%\ and\ 39.6\%$ at soaked and dry condition. The asphalt binder associates the cohesive soil property and binds the soil elements by the thin film of asphalt. It also presents some flexible property and presents the elasticity action against deformation under repeated loading, [10]. An experimental study was conducted by [11] on soil stabilization and CBR test has been implemented. It has been found the CBR increases by 40% as compared with pure soil. Furthermore, the deformation decreases by 69% when the soil asphalt stabilization has been performed. [12] Studied the deformation of asphalt stabilized embankment model under cyclic loading. It was stated that the action of soil under cyclic loading is further complex than the static load; the difficulties ascend when an accurate simulation of field circumstances is essential to be studied. It was stated by [13] that the most main characteristic of the flexible behavior of the mass of soil is that regardless how many reiterations of load are applied to it, must afford the stresses that set up in the mass of soil do not exceed the yield stresses. Therefore, the soil does not come to be permanently deformed and get back to its original form when the load is removed directly. Under static state it is rare that any soil performs reasonably in this way. The two-principle load related to distresses with flexible pavements is fatigue and rutting cracking. All the mentioned factors produce reduction in the life of the pavement and cause pavement failure, [14]. The rate of rise in the shear properties of the untreated soil is severe at the early times of load up to 2 mm of lateral movement, whereas adding of asphalt emulsion presents a mild increase in the shear properties up to 2.5 mm of lateral displacement for soaked and dry conditions. Preparation of 17% of emulsion has improved the shear strength properties by (12 and 14) folds. In addition, the cohesion increased by (9 and 30) in the soaked and dry test conditions respectively, relative to untreated soil, [1]. The aim of this work is to evaluate the resilient properties of asphalt stabilized soil under repeated load. The testing techniques have been used to calculate the deformation of soil-asphalt mixture till its reach fatigue failure. Several percentage of fluid content has been implemented. Comparison between specimens has been carried out. Pneumatic repeated load system has been used to test stabilized soil and to calculate the deformation because of punching shear load with several percentage of asphalt content to get the relations among the number of repetitions with the deformation.

2. Materials and Methods

2.1 Liquid Asphalt

Asphalt cut-back MC-30 was implemented, it has 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, [15]. Table 1 shows MC-30 properties which was obtained from Al-Dora refinery.

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

Test	**Result**
Grade	MC−30
Viscosity (cst.) @ 60 ℃	30-60
Flash point (Cleveland open cup) ℃ (minimum)	38
Water % by volume (max)	0.2
Distillation test to 360 ℃, %Volume of total distillate: To 225 ℃ (maximum) To 260 ℃ (maximum) To 315 ℃ (maximum)	25 40-60 75-93
Test on residue from distillation	
Penetration @ 25 ℃ (100gm, 5 sec., 0.1 mm)	120-250
Ductility @ 25 ℃ (cm)	100
Solubility in Tricolor ethylene % weight (minimum)	990

2.2. Granular soil

The soil that has been used in this research was taken from Al-Taji, which is 25 km to the north of Baghdad, Iraq. The top soil of 30 cm thickness has been removed. 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 results**
Total soluble salts (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 to the unified classification system. Soil grain size distribution has been conducted according to ASTM D 1140, [15]. Finally, hydrometer test was conducted according to ASTM D422, [15]. The grain size distribution of the tested soil is shown in Figure 1. The soil compaction properties were established using modified compaction test. The test was performed according to ASTM D1557, [15]**.** The relation between moisture content and dry density of the soil is illustrated in Figure 2.

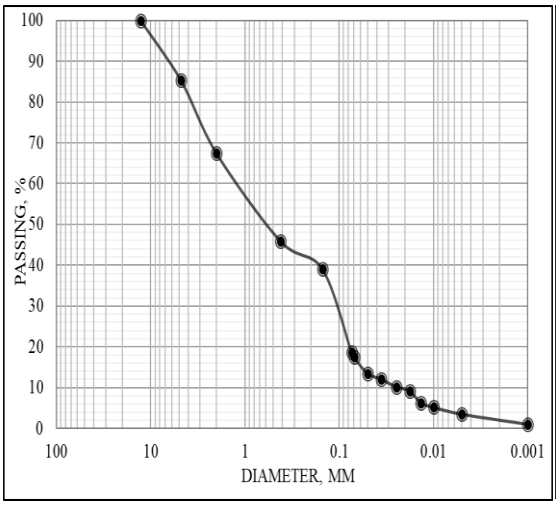

Figure 1. *Grain Size Distribution*

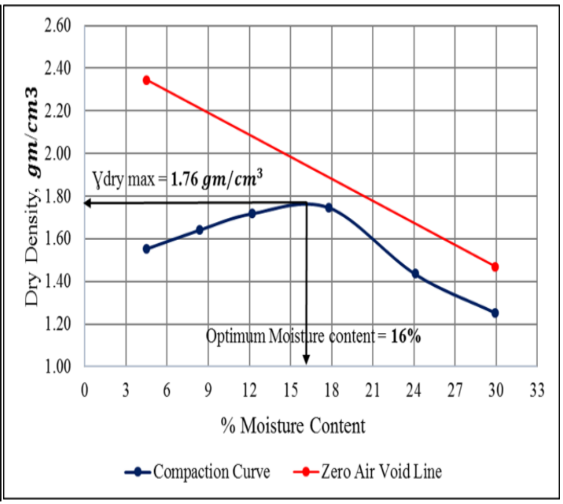

Figure 2. *Modified proctor compaction test*

According to ASTM D 3080, [15], the test has been conducted to obtain the parameters of soil shear strength ($\emptyset$ and C) at un-soaked condition. According to ASTM D2166, [15], the unconfined compression test has been implemented. Table 3 summarizes the overall properties of the soil that has been used in this research.

***Table 3**. Proposed soil physical properties*

Physical properties	Test result
Specific Gravity	2.62
Atterberg Limits: - LL % PL % PI %	23 Non-Plastic Non-Plastic
Modified Compaction Properties: - γ_{dmax} (gm/cm^3) $\omega_{opt\%}$ (%)	1.76 16
AASHTO classification system	A3
ASTM classification system	SP
D_{10} D_{60} D_{30} Coefficient of curvature (C_c) Coefficient of uniformly (C_u)	0.025 0.1 1.5 60 0.26
Strength parameters (Direct Shear Test) (un-Soaked Condition) Cohesion (C) kPa Angle of internal frication ($\emptyset$)	41 29.2
Undrained shear strength (Unconfined compression test) (S_U) kPa	50
Shear strength using unconsolidated undrained (UU) Triaxial test (kPa)	54

2.3. Preparing the Specimens

Two sizes of specimens have been prepared. Specimens of 100mm diameter and 70mm height and 152mm diameter with 127mm height have been prepared in the laboratory and compacted to a target density of 1.76 gm/cm^3 and optimum asphalt requirement and at 0.5% of asphalt above and below the optimum. The soil was oven dried at (100 °C) till it reach a constant weight then cooled at room temperature of 25 °C. Soil was sieved through sieve No. 4. Specimens were prepared for each fluid content percentage as well as for the pure soil. Based on the target maximum dry density and the mold volume, the total mass of the soil-asphalt mixture required to prepare the samples have been achieved. The essential distilled water percentage was mixed by hand till the soil mixture became homogenous. At that moment, the essential asphalt percentage has been added and mixed for 5 minutes till the asphalt soil mixture become consistent and all the particles were coated with asphalt. The mixture was spread into big dishes (for each specimen) then left 2 hours for aeration. The mixture was placed inside the mold and compacted. Finally, the specimens have been left for curing at 20 °C for seven days. Figure 3 shows part of the small size specimens that have been used in the test.

Figure 3. *Specimens for double punching shear repeated load test.*

2.4. Specimens Testing

The pneumatic repeated load system, PRLS has been used for the test. Repeated Uniaxial compressive loading has been applied. The load excitation function is a rectangular wave with steady frequency equal to (1) cycles per second (10) Hz as shown in Figure 4.

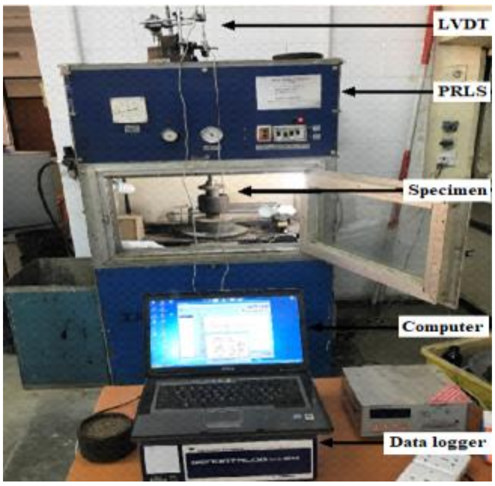

Figure 4. *Test setup using the PRLS*

A maximum load pulse time is (0.1) sec. and (0.9) sec. is the rest period used over the interval of test. Specimens have been placed in test chamber at laboratory temperature of 25 ˚C. Before starting test, the dial gauge has been set to zero and the pressure actuator has been regulated to the specific pressure level up to (55.16 kPa).

LVDT has been used to measure the deformation every second (every cycle) till the test is complete. The test tim**e** period for each specimen is (30) minute. After completing the test, the recording has been terminated, and the specimen was removed from the chamber of test. For the large size specimens (in the CBR mold), the repeated single punch shear test was conducted on the specimen from top and bottom and the average value was considered for analysis as recommended by [11]. On the other hand, the small size specimen (in the Marshal mold) was subjected to repeated double punch shear test. Figure 5 shows a close view of both specimen sizes under test setup.

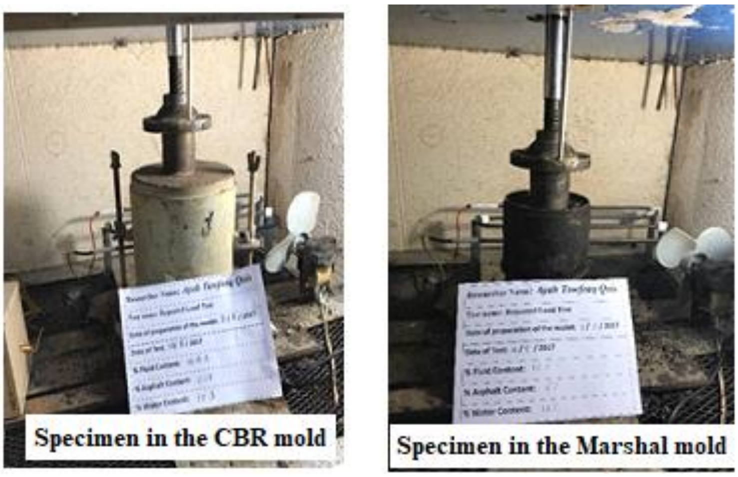

Figure 5. *Both specimen sizes under test setup*

3. Results and Discussion

The resilient modules, Mr. is a dynamic test response defined as the ratio the repeated axial stress to the revocable axial strain ε_r. Mr reflects the material nonlinearity of asphalt stabilized soil. Using a regression analysis for power mathematical model.

The resilient strain is a function calculated based on the resilient deformation obtained under constant stress load repetitions. Thus, the equation is illustrated as follows:

$$\varepsilon_r = \frac{rd}{h} \quad (1)$$

Where

ε_r is the resilient strain

rd is the resilient displacement and h is the specimen's height.

$$\text{Mr} = \frac{\sigma}{\varepsilon_r} \quad (2)$$

Where

σ is Applied stress

ε_r = Resilient strain.

According to [16], the power regression model is recommended to be used for the calculation of resilient modulus. Therefore, the model adopted for this study is based on the following equation

$$\varepsilon_r = aN^b \quad (1)$$

Where a and b is the equation constants (intercept and slope) respectively. In addition, a represents resilient strain at $N = 1$ and b is the rate of change in resilient strain as a function from N in log-log scale. Finally, N represents the no. of repetitions in a certain pressure conditions.

3.1. Double punch shear test

Figure 6 shows the relation between resilient strain against number of load cycles under constant applied stress (55.16 kPa) for double punching shear test after 30 days curing period. It can be noticed that the intercept decreases after implication of liquid asphalt while the slope increases as compared to pure soil condition. This behavior may be attributed to the increase in cohesion between soil particles due to adhesion between soil particles and asphalt in addition to the particle interlock due to the gradation of the soil. The intercept (a) represents the permanent strain at N=1, where N is the number of the load cycles. The higher the value of intercept, the larger the strain and hence the larger the potential for permanent deformation as mentioned in the literature, [2]. While slope (b) represents the rate of change in the permanent strain as a function of the change in loading cycles (N) in the log-log scale, high slope values for a mix indicate an increase in the material deformation rate hence less resistance against rutting. A mix with a low slope value is preferable as it prevents the occurrence of the rutting distress mechanism at a slower rate, [10]. The intercept decreases by (85, 86 and 83) % for (15.5, 16, and 16.5) % asphalt content respectively as compared to the natural soil condition. On the other hand, the slope increases by (175, 278, and 424) % for (15.5, 16, and 16.5) % asphalt content respectively as compared to the natural soil condition.

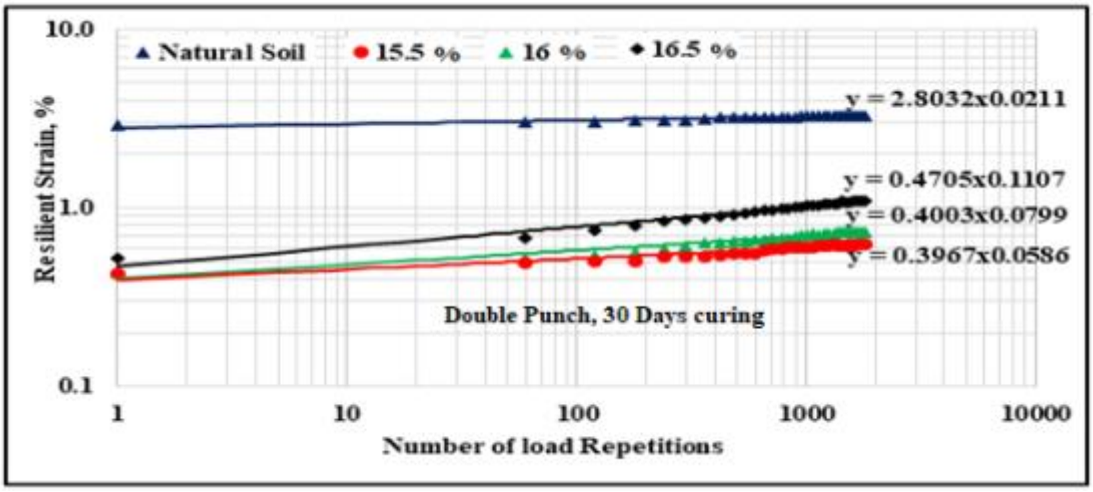

Figure 6. *Resilient strain behavior for double punching shear test*

Table 4 presents the resilient modulus Mr as calculated from the mathematical models. It can be observed that Mr decreases as the load repetitions increases which indicate the start of failure. Implementation of cutback asphalt had a positive impact on Mr, it increases by a range of six folds after the addition of asphalt.

Table 4. *Resilient modulus under double punch shear after 30 days of curing period*

No. of Blows	Mr (MPa) for Several Fluid Content, %			
N	Untreated Soil	15.5%	16%	16.5
1	19.7	139.1	137.9	117.3
1200	17.0	91.8	78.3	53.5
1800	16.8	89.7	75.8	51.2

The percent variance of Mr of asphalt stabilized soil as related to natural soil is presented in Figure 7. It can be observed that 15.5 % fluid content is the optimum from the Mr point of view after 30 days of curing period.

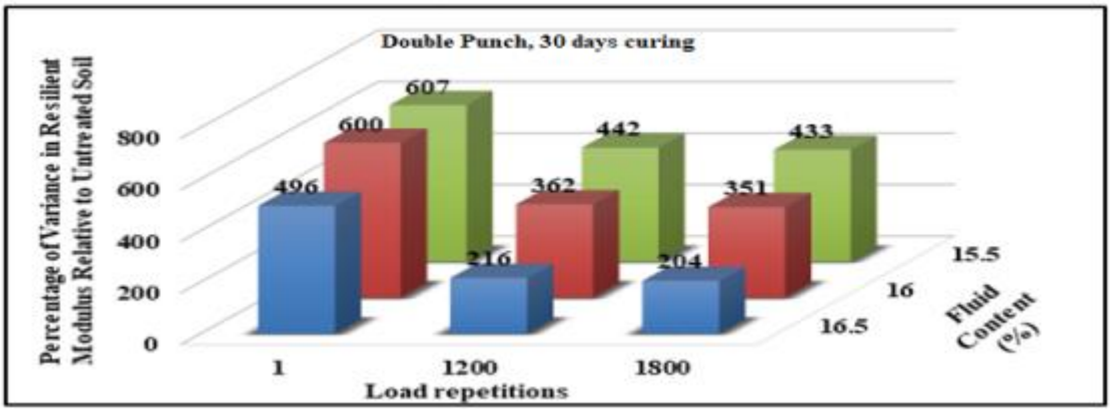

Figure 7. *Change in resilient modulus for several fluid content under double punch*

3.2. Influence of curing period on Mr under double punch shear stress

Figure 8 shows the relation between resilient strain versus number of loading cycles for double punching shear test on specimens after 8 days curing. Similar behavior of reduced intercept values and increased slope could be detected. The intercept decreases by (88, 87 and 71) % for (15.5, 16, and 16.5) % asphalt content respectively as compared to the natural soil condition. On the other hand, the slope increases by (277, 336, and 58) % for (15.5, 16, and 16.5) % asphalt content respectively as compared to the natural soil condition.

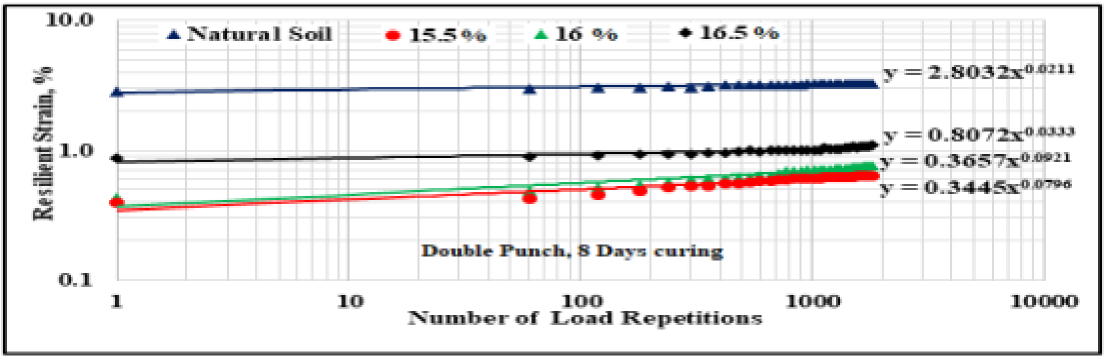

Figure 8. *Resilient strain versus number of load repetitions relation*

Table 5 presents the resilient modulus Mr as calculated from the mathematical models. It can be observed that Mr decreases as the load repetitions increases which indicate the start of failure. Implementation of cutback asphalt had a positive impact on Mr, it increases by a range of seven folds after the addition of asphalt.

Table 5 *Resilient modulus under double punch shear after 8 days of curing period*

No. of Blows	Mr (MPa) for Several Fluid Content, %			
N	Untreated Soil	15.5%	16%	16.5%
1	19.7	160.2	150.9	68.4
1200	17.0	91.1	78.6	54
1800	16.8	88.2	75.6	53.3

The percent variance of Mr of asphalt stabilized soil as related to natural soil is presented in Figure 9. It can be observed that 15.5 % fluid content is also the optimum from the Mr point of view after 8 days of curing period. The impact of increasing the curing period from 8 to 30 days is not significant. Eight days curing is the optimum time for enhancing proper resilient modulus.

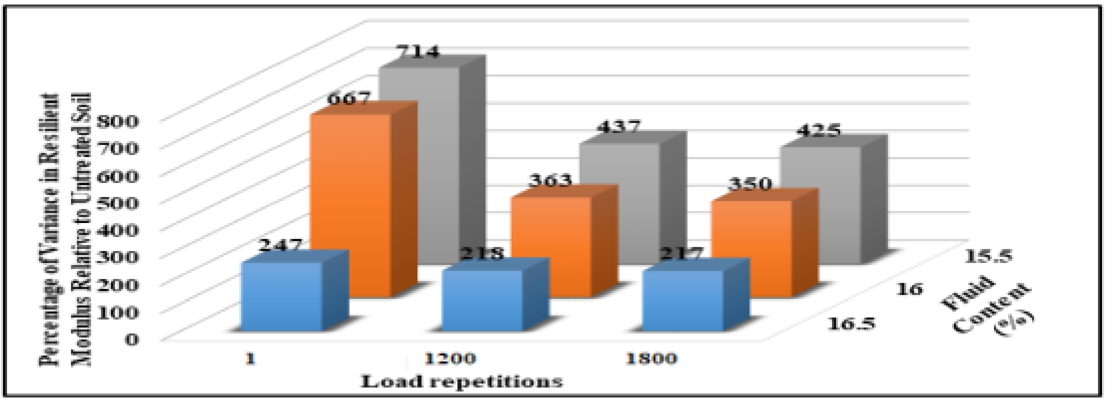

Figure 9. *Change in resilient modulus for several fluid content under double punch*

3.3. Single Punching Shear test after 8 days of Curing period

Figure 10 shows the relation between resilient strains versus number of loading cycles for single punching shear test on specimens after 8 days curing. Similar behavior of reduced intercept values and increased slope could be detected. The intercept decreases by (68, 62 and 29) % for (15.5, 16, and 16.5) % asphalt content respectively as compared to the natural soil condition. On the other hand, the slope increases by (4, 41.5, and 41) % for (15.5, 16, and 16.5) % asphalt content respectively as compared to the natural soil condition.

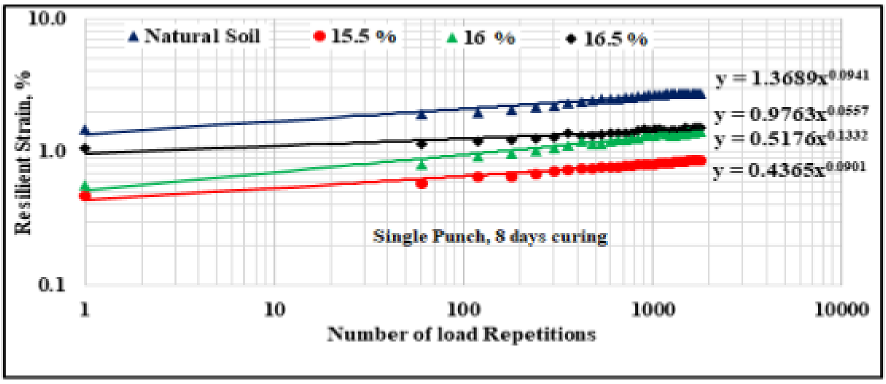

Figure 10. *Resilient strain versus number of load repetitions for single punching shear*

Table 6 presents the resilient modulus Mr as calculated from the mathematical models. It can be observed that Mr decreases as the load repetitions increases which indicate the start of failure. Implementation of cutback asphalt had a positive impact on Mr, it increases by a range of two folds after the addition of asphalt. The single punch shear exhibit 100 % higher Mr after one load repetition as compared to double punch while no significant difference is detected at higher load repetition.

Table 6. *Resilient modulus under single punch shear after 8 days of curing period*

No. of Blows	**Mr (MPa) for Several Fluid Content, %**			
N	Untreated Soil	15.5%	16%	16.5%
1	40.3	126.5	106.6	56.5
1200	20.7	66.8	41.5	38.1
1800	19.9	64.4	39.3	37.2

The percent variance of Mr of asphalt stabilized soil as related to natural soil is presented in Figure 11. It can be observed that 15.5 % fluid content is also the optimum from the Mr point of view after 8 days of curing period.

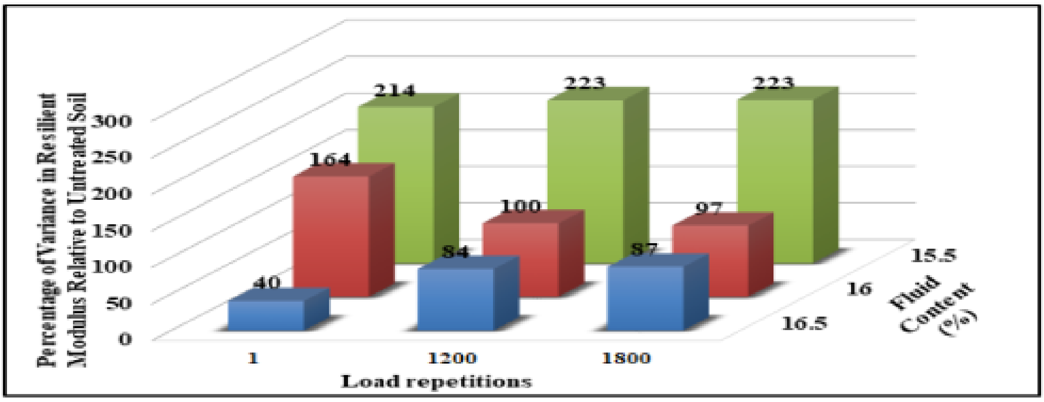

Figure 11. *Change in resilient modulus for several fluid content under single punch*

Figure 12 summarizes the impact of fluid content and testing mode on the resilient modulus of asphalt stabilized soil.

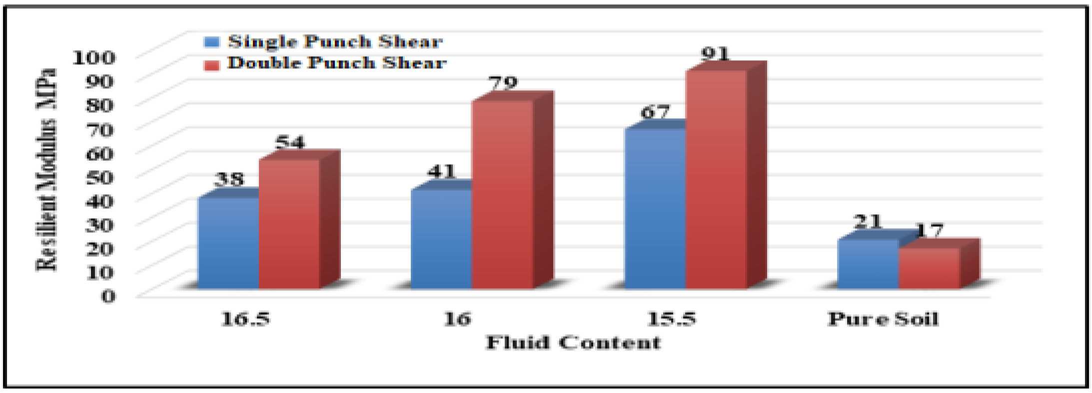

Figure 12. *Comparison between single and double punch shear*

It can be observed that for pure soil specimens, the single punch shear exhibit higher Mr as compared to double punch shear condition. On the other hand, the double punch shear test exhibit higher Mr values as compared to single punch shear condition, Mr. also decreases as asphalt content increases. It was felt that the loading of specimen from top and bottom at the same time as the case of double punch and the restricted thickness of the specimen may restrict the rolling process of soil particles over each other which is further restricted by the asphalt film surrounding each soil particle. This could restrict the deformation of the specimen in the vertical and horizontal directions and create high resilient modulus as compared to the case of single punch shear test.

Figure 13 shows resilient displacement under single punch shear stress after 8 days of curing, it can be observed that the resilient strain decreases by 71% as compared to that of natural soil, while Figure 14 exhibit that the reduction in the resilient deformation is 81 % under double punch shear after 8 days curing when compared to natural soil at 15.5 % fluid content.

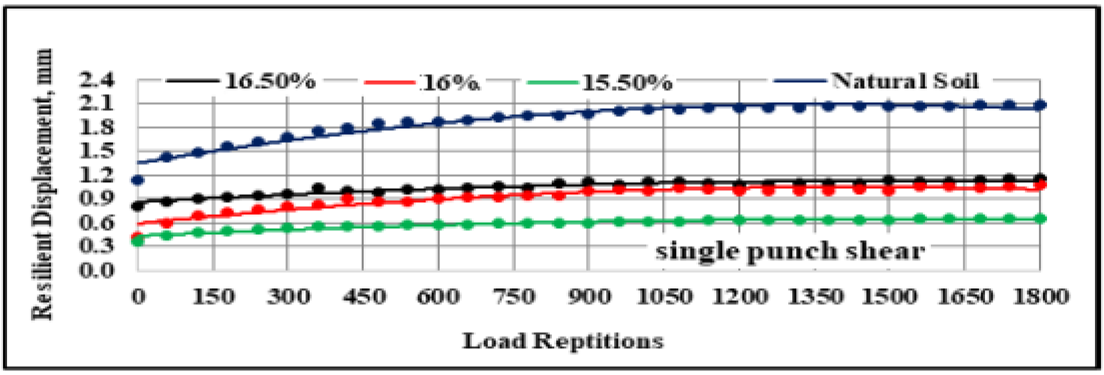

Figure 13. *Variation of resilient displacement under single punch shear stress*

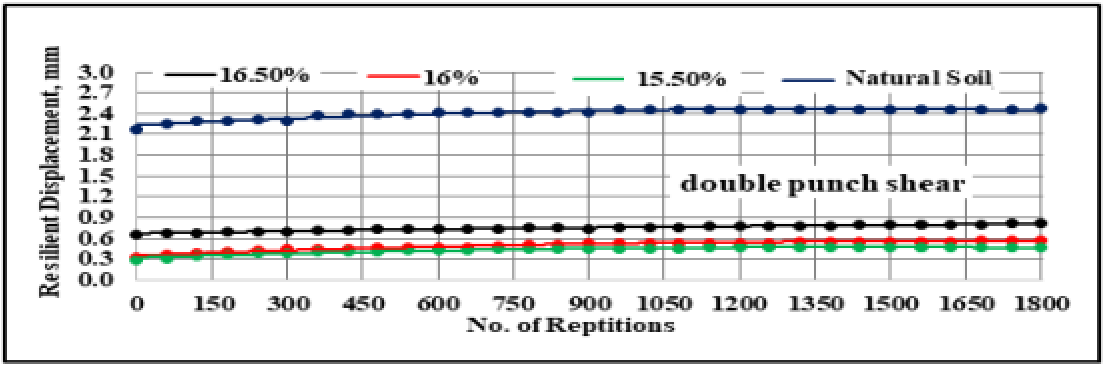

Figure 14. *Variation of resilient displacement under double punch shear stress*

4. Conclusions

Based on the limited testing program, the following conclusions may be drawn:

1- The intercept decreases by (85, 86 and 83) %, while the slope increases by (175, 278, and 424) % for (15.5, 16, and 16.5) % asphalt content respectively as compared to the natural soil condition under double punch shear stress after 30 days curing.

2- The intercept decreases by (88, 87 and 71) %, while the slope increases by (277, 336, and 58) % for (15.5, 16, and 16.5) % asphalt content respectively as compared to the natural soil condition under double punch shear stress after 8 days curing.

3- The intercept decreases by (68, 62 and 29) %, while the slope increases by (4, 41.5, and 41) % for (15.5, 16, and 16.5) % asphalt content respectively as compared to the natural soil condition under single punch shear stress after 8 days curing.

4- Asphalt stabilization exhibit positive impact on resilient modulus, it increases Mr by a range of (600, 700, and 100) % for double punch at 30 and 8 days curing and single punch at 8 days curing after the addition of cutback asphalt.

5- When comparing between single and double punching shear, the crucial enhancement for Mr goes for double punching shear. Eight days curing is the optimum time for enhancing proper resilient modulus.

6- The resilient deformation has been improved by (71 and 81) % under single and double punch shear respectively after 8 days curing.

References

[1] Sarsam S., Al Saidi A., Al Taie A. Assessment of shear and compressibility properties of asphalt stabilized collapsible soil. Applied Research Journal Vol.2, Issue, 12, December, 2016, pp.481-487.

[2] Sarsam S. and Mohsen A. Influence of Additives and Durability Cycles on the Resilient Modulus of Asphalt Stabilized Soil. Journal of Geotechnical Engineering. 2017; 4(2): 32–39p.

[3] Sarsam S.I, Tawfeaq K A. Assessing the variation in shear properties of asphalt stabilized soil using three testing techniques. International Journal of Engineering Papers, IJEP October 2017; 2(2): 1–12.

[4] Sarsam S.I., Husain A., Almas S. Assessing the variation in cutback asphalt requirement for various geotechnical properties of asphalt stabilized soil. Journal of geotechnical engineering, STM Journals, Vol.2, Issue 3. 2015, (P17-29).

[5] Jones, D., Rahim, A., Saadeh, S., & Harvey, J. Guidelines for the Stabilization of Subgrade Soils in California. California: 2010, Pavement Research Centre, University of California.

[6] Makusa, G. P. Soil Stabilization Method and Materials. 2012, Lule åUniversity of Technology.

[7] Sarsam S., Al Saidi A., Al Taie A. Influence of Combined Stabilization on the Structural Properties of Subgrade Soil. Journal of Geotechnical Engineering, Volume 4, Issue 1, 2017, P13-24. STM Journals.

[8] Sarsam S. I. Kais A. T. Comparative Assessment of Shear Strength under Static Loading for Asphalt Stabilized Soil. International Journal of Science and Research (IJSR), 2017, Volume 6 Issue 11, November.

[9] Sarsam S., Al Saidi A., Jasim A. Monitoring of the Compressibility Characteristics of Asphalt Stabilized Subgrade. International Journal of Scientific Research in Knowledge, 5(1), 2017, pp. 011-019.

[10] Sarsam S. and Barakhas. Assessing the Structural Properties of Asphalt Stabilized Subgrade Soil. International Journal of Scientific Research in Knowledge, IJSRK 3(9), 2015, pp. 0227-240.

[11] Saad Sarsam. A study on California bearing ratio test for Asphaltic soils”. Indian Highways IRC 1986, Vol. 14 No.9. India.

[12] Sarsam, S. I., Alsaidi, A. A., & Alzobaie, O. M. Impact of Asphalt Stabilization on Deformation Behavior of Reinforced Soil Embankment Model under Cyclic Loading. Journal of Engineering Geology and Hydrogeology.2014, JEGH 2014, 2(4):46-53. Sciknow publication Ltd. USA.

[13] TRRL. Soil Mechanics for Road Engineers. London: 1974, Her Majesty's Stationery Office HMSO. London.

[14] Kulkarni, A. Analysis of Response of Pavements subjected to Dynamics loading. International Journal of Innovations in Engineering and Technology, 2016. (IJIET).

[15] American Society for Testing and Materials, ASTM- 2009. Road and Paving Material, Vehicle-Pavement System, Annual Book of ASTM Standards, Vol.04.03.

[16] Yoder & Witczak. Principles of pavement design. 1975, John Willy and sons.