3rd International Conference on New Developments in Soil Mechanics and Geotechnical Engineering,
28-30 June 2012, Near East University, Nicosia, North Cyprus

Evaluation of resilient modulus properties of Iraqi soil using standard laboratory test for load cyclic triaxial strength

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KEYWORDS: Resilient modulus, cyclic loads, subgade, triaxial strength

ABSTRACT**:** Resilient Modulus (M_r) was adopted by (AASHTO, 1986) as the principal soil property contributing to the design of flexible pavements. It can consider that resilient modulus (M_r) is a key value in pavement design. The present study uses the standard laboratory test for load cyclic Triaxial strength to evaluate the resilient modulus and liquefaction condition of some Baghdad soils. It is well-known that the Performance of resilient modulus tests are difficult, expensive and time consuming and hence there has been an interest in adopting mathematical model that satisfactorily predicts resilient modulus values without the necessity of a laboratory test. In this paper, the neural network approach to develop a model that can be used to predict resilient modulus values for Baghdad soils was adopted. The model uses the results of routine laboratory tests. The results shows that soil brought from Baghdad City exhibited the resilient modulus (M_r) of pavement subgrade soils which has been adopted for the purpose of designing flexible roadway pavement systems, values ranging from 40 MPa to about 100MPa. Based on ASTM subgrade resilient modulus criterion, the A-7-5 and A-6 untreated subgrade soil would be classified as fair to poor (unacceptable as a competent subgrade).It is concluded that Baghdad soils mathematical model need to have some modification to be done on the OSU models to provide a good estimation of M_r predicted from general routine test results.

1 INTRODUCTION

Resilient Modulus M_r can be more simply described as the unloaded phase of the stress-strain slope developed during the impulse loading that occurs as vehicles pass over the pavement; it is a key value in pavement design. M_r is numerically equal to the ratio of the deviator stress to the resilient or recoverable strain after large number of load cycles $M_r = \sigma_d / \varepsilon_r$. Performance of resilient modulus tests is difficult, expensive and time consuming and the current standards for resilient modulus testing are AASHTO T292-00 and T307-99 for soils and ASTM D 4123 for asphalt. Trying to minimize the effects of these shortcomings, and hence many researchers were developing a mathematical model that satisfactorily predicts resilient modulus values without the necessity of a laboratory test. It is very important for a mathematical model to accommodate new data as it becomes available. George 2004, Kim 2004 and Rodgers 2006, used an existing models to study significantly overestimated the M_r of a cohesive soil, the proposed model predictions are close to the experimental values and are in most cases a slight underestimation.

Several researchers(Thomson and Robnett1976, Pezo and Hudson 1994, Mohammad, et al.1999,Kim 1999, Masada and Sargand2002, Huang2001,Butalia, et al. 2003, Kim 2004, George 2004 and Rodgers 2006) has been studies evaluated the characteristics of M_r for cohesive soils in association with the stress state and engineering properties, and developed procedures for estimating M_r. The results of these studies show that M_r of cohesive soils depends on deviator stress, confining stress, water content, and degree of saturation, plasticity index, unconfined compressive strength, freeze-thaw action, and pore water pressure.

2 PURPOSES OF THE STUDY

The main purpose of this research is to find direct and accurate values of the Resilient Modulus using standard cyclic Triaxial test available in the laboratories of soil mechanics in the Department of Civil Engineering at the Ohio State University, the United States to assist highways designer in Iraq to put this parameter into consideration for city of Baghdad as a parameter in the design of roads ,highways and airports, as well as to find out whether these types of soil affected by liquefaction condition at selected densities ,confining pressure and cyclic stress ratio.

3 TESTING PROCEDURE

Since AASHTO first proposed T274-82 as the testing procedure for determining M_r of soils, three additional modifications, AASHTO T292-91, and T294-94, and T307-99, have been introduced. Table 1 lists the dynamic waveform, and load and cycle duration of each testing procedure.

Table 1 Comparison of resilient modulus test procedures

Testing Procedure	Wave Type	Load Duration (Sec.)	Cyclic Duration (Sec.)	σ_d (kPa)	σ_3 (kPa)	Number of Cycles
T274-82	Sine, Haversine, Rectangular Triangular	0.1	1.0 to 3.0	7	41, 21, 0	200
				14	41, 21, 0	200
				28	41, 21, 0	200
				55	41, 21, 0	200
				69	41, 21, 0	200
T292-91	Rectangular Triangular	0.1 to 1.0	1.0 to 3.0	21, 34, 48, 69, 103	21	50
T294-94	Haversine	0.1	1.0	14, 28, 41, 55, 69	41	100
				14, 28, 41, 55, 69	21	100
				14, 28, 41, 55, 69	0	100
T307-99	Haversine	0.1	1.0 to 3.0	14, 28, 41, 55, 69	41	100
				14, 28, 41, 55, 69	28	100
				14, 28, 41, 55, 69	14	100

4 SAMPLE COLLECTIONS

Representative Cohesive soil samples that are used in pavement subgrade from four sites distributed throughout Baghdad City in Republic of Iraq were collected from a depth of about (0.50to1.5) m. from ground surface elevation to represent Al.Baladiat Site (BB1), Zaiona (BZ1), Al.Kazalia (BK1) and Al.Mansour (BM1).

Laboratory tests were performed on the samples to determine their basic engineering properties. M_r and liquefaction Tests were conducted on soil samples at three different moisture contents which are dry of optimum(DOP), optimum(OPT), and wet of optimum(WOP).

5 BASIC ENGINEERING PROPERTIES TESTING AND RESULTS

Laboratory tests were conducted on the four soil samples to determine their basic engineering properties. All soil collected samples were transported to the Soil Mechanics Laboratory in Civil, Environmental and Geodetic Engineering Department at The Ohio State University. The samples were oven-dried at 60 °C, for 24 hours and then air-dried in the laboratory. All dried soil samples were thoroughly pulverized.

According to Unified Soil Classification system in ASTM D2487-93 and Soil Classification system in AASHTO M145-91.Table 2 shows Classification and Engineering Properties of each location. According USCS, the soils were found to be classified as CL (low plasticity clay) for BB1, BZ1, BM1 and Bk1. Atterberg limit tests were performed in accordance with AASHTO T89-96, and T90-96 testing procedures. The liquid limit of A-6 location ranged about 38, and that of A-7-5 locations were much higher (40 to 49). The plasticity index of A-6 group ranged about 17 while it shows higher for A-7-5 which was above 20. Sieve analyses and hydrometer tests were conducted in accordance with AASHTO T88-97. As shown in Table 4, all soil of A-7-5 had approximately highest percent of Clay (generally ranging from 40% to 50%). The A-6 soil had Clay ranging between 25% and 30%. The A-7-5 soil had the lowest amount of sand. Standard Proctor compaction tests were conducted on each soil sample in accordance with procedure A in AASHTO T99-97 testing methods as shown in figure 1.

Table 2 Classification and Engineering Properties of each location

Soil Location	**Soil Type**		**Gs**	**Liquid Limit LL**	**Plastic Limit PL**	**PI**	**Passing #200 Finer**	**Sand %**	**Silt %**	**Clay %**	**O.M.C %**	**Max. Dry Density kN/m^3**	**TSS %**
	AASHTO	**USCS**											
BB1	**A-6**	**CL**	**2.67**	**38.32**	**20.38**	**17.94**	**78.92**	**24**	**49**	**27**	**16.96**	**16.81**	**11.2**
BZ1	**A-7-5**	**CL**	**2.69**	**44.46**	**21.15**	**23.31**	**82.17**	**17**	**37**	**46**	**17.45**	**16.67**	**9.95**
BM1	**A-7-5**	**CL**	**2.68**	**46.41**	**21,04**	**25.37**	**84.26**	**21**	**38**	**41**	**17.21**	**16.23**	**8.51**
BK1	**A-7-5**	**CL**	**2.70**	**45.78**	**18.52**	**26.89**	**88.49**	**19**	**39**	**42**	**17.76**	**15.78**	**10.8**

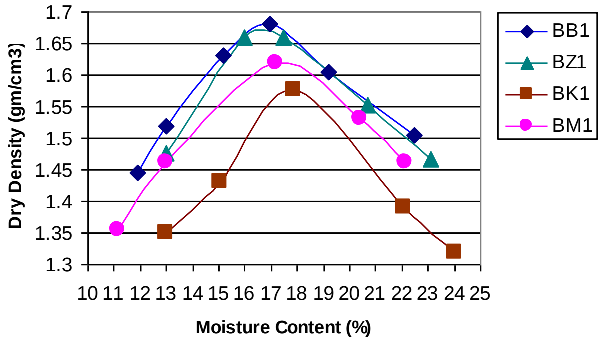

Fig.(1) Moisture Content Vs. Dry Density For each location (BB1,BZ1,BK1 & BM1)

Unconfined compressive strength tests were conducted immediately after sample compaction in accordance with AASHTO T208-96 testing procedures. The unconfined compressive strength tests were conducted on each soil sample at three different moisture contents. As shown in Table 3, the three different moisture contents were dry of optimum moisture content (DOP), optimum moisture content (OPT), and wet of optimum moisture content (WOP).

In general, the dry of optimum samples exhibited the highest unconfined compressive strength values. The measured strength values typically decreased with increasing sample moisture content.

Table 3 Compaction and Unconfined Compressive Strength Test Results

Soil Type	BB1			BZ1			BM1			BK1		
Soil Condition	DOP	OPT	WOP	DOP	OPT	WOP	DOP	OPT	WOP	DOP	OPT	WOP

Unconfined Compression Strength (kPa)	156	139	126	192	176	138	189	169	135	176	162	132

Soil sample for unconfined compression tests was compacted at desired dry, optimum and wet density and moisture content (-2, 0, +2 from optimum) % respectively. it is quite obvious that A-7-5 soil shows good ability to withstand higher stress before failure than A-6 soil. Clearly, saturation adversely affects the unconfined compressive strength of soils compacted at optimum moisture content.

7 RESILIENT MODULUS TESTING AND RESULTS

The major components of M_r testing as performed in the Soil Mechanics Laboratory at The Ohio State University are shown in Figure 2. The specified load was applied by a loading system manufactured by MTS.

The Triaxial pressure chamber (see Figure 3) was modified to include a load cell to measure axial load, an LVDT to measure axial displacement. The LVDT was mounted on the external steel rod in the top cover of the triaxial pressure chamber.

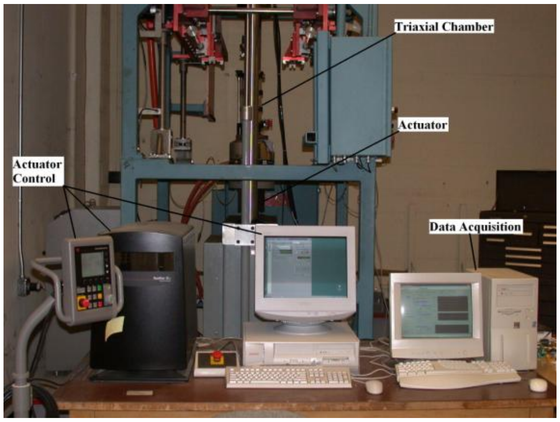

Figure 2 M_r Testing System

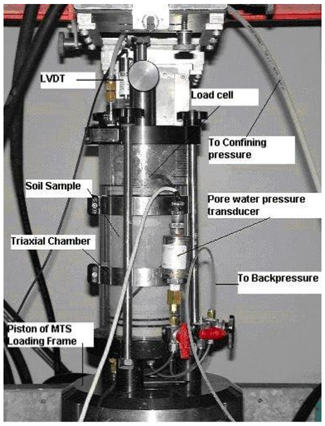

Figure 3 Triaxial Cells for M_r Test

The soil specimens for M_r Tests had a diameter of about 71.4 mm and height of about 152.4 mm. The samples were compacted according to required moisture content and dry unit weight.AASHTO T294-94 testing procedure was adopted to carry out Mr Test. This was for unsaturated soil samples, which were compacted at three different moisture contents, Dry, Optimum, and Wet. During these tests, the bottom drainage valves were open and no pore pressures were measured.

Figures 4, 5,6and 16 show typical results of M_r test on BB1, BZ1, BM1 and BK1 at DOP, OPT and WOP for whole samples. Figures 15, 16 and 16 illustrate the effects of varying deviator stresses and Resilient Modulus Values at different moisture contents.

As shown in Figures 4, 5, 6, and 16, M_r at constant confining stress gradually decreased with an increase in deviator stress. In many cases, the decreasing rate at the low deviator stress was more pronounced than that at high deviator stress. This nonlinear trend of M_r to deviator stress is similar to observations of other researchers (Seed, et al. (1962), Fredlund, et al. (1977), Woolstrum (1990), Drumm, et al. (1990), Li and Selig (1994), Pezo and Hudson (1994), Lee et al. (1995), Mohammad, et al. (1999), Kim (1999), Huang (2001), Masada and Sargand (2002)) and Kim (2006). M_r increased with an increase in confining stress. As mentioned previously, it is noted that M_r is closely related to the moisture content in soils. M_r of the soil samples decreased with an increase in moisture content. Kim 2004 and Rodgers 2006 confirmed the same results.

8 MODEL VERIFICATION

The present study uses the neural network approach to develop a model that can be used to predict resilient modulus values for Baghdad Soils and can easily accommodate new data as this becomes available. The model uses the results of commonly performed laboratory tests like water content, Atterberg limits, soil classification and unconfined compressive strength to predict M_r. The network was trained using all laboratory test results performed in the Soil Mechanics Laboratory of The Ohio State University for A-6 and A-7-5 Baghdad soils and the Neural Network Math Works Toolbox.

It is believed that M_r of a cohesive soil is dependent upon its moisture content. To study this phenomenon for the proposed constitutive model, the predicted and measured M_r at various moisture contents (dry of optimum, optimum, and wet of optimum) were investigated. Figures 17, 18, and 19 show comparison of the measured M_r with the predicted M_r for BB1, BZ1, BM1 and BK1 soils, respectively. Comparisons of the measured M_r with the predicted values were carried out using percent error and multiple correlation coefficients, R^2.

To prove the capability of the network, M_r predicted values for Baghdad soils were compared with its corresponding M_r measured as illustrated and explained in Figures 17, 18 and 19. It can be observed that as the sample moisture content increases, M_r predicted by the model reduces significantly and is generally close to the experimentally measured M_r, irrespective of the sample moisture content. It can be observed that as the sample moisture content increases, M_r predicted by the model reduces significantly and is generally close to the experimentally measured M_r, irrespective of the sample moisture content. this model was performed previously by Kim (2004) and Rodgers (2006)

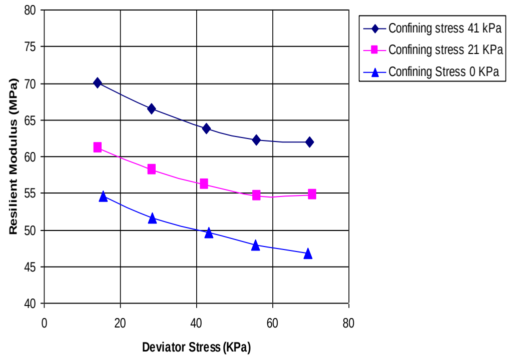

Fig. (4) Resilient Modulus From Mr laboratory test For BB1 Location (DOP)

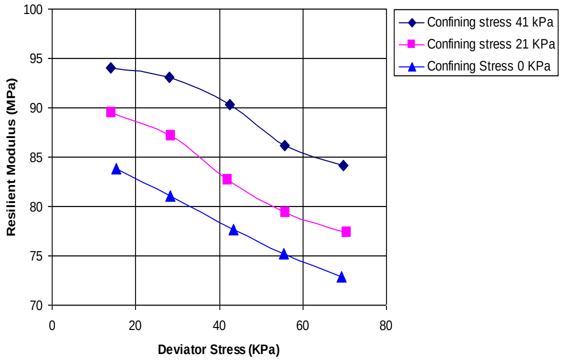

Fig. (5) Resilient Modulus From Mr laboratory test For BZ1 Location (DOP)

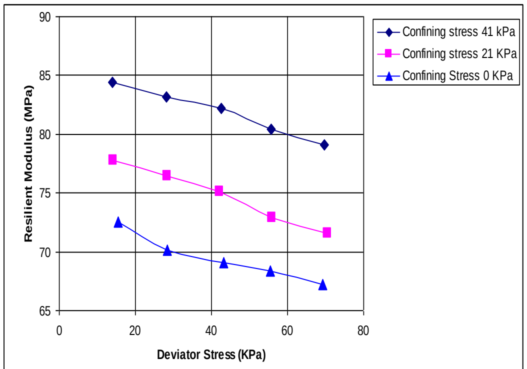

Fig. (6) Resilient Modulus From Mr laboratory test For BM1 Location (DOP)

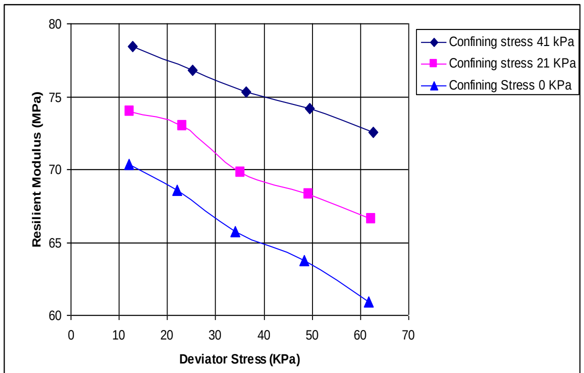

Fig. (7) Resilient Modulus From Mr laboratory test For BZ1 Location (OPT)

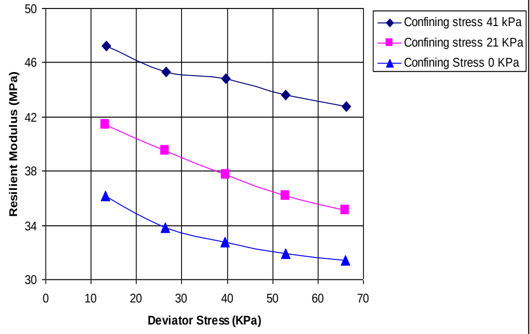

Fig. (8) Resilient Modulus From Mr laboratory test For BB1 Location (OPT)

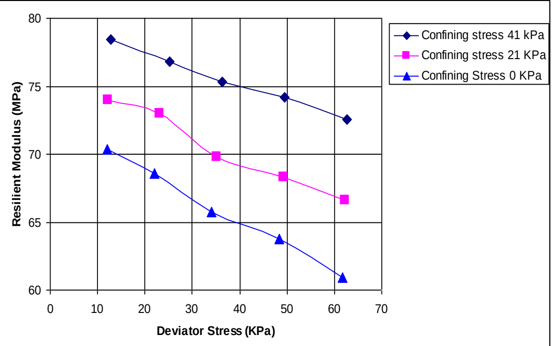

Fig. (9) Resilient Modulus From Mr laboratory test For BZ1 Location (OPT)

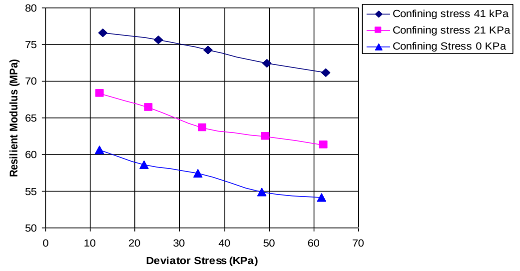

Fig. (10) Resilient Modulus From Mr laboratory test For BM1 Location (OPT)

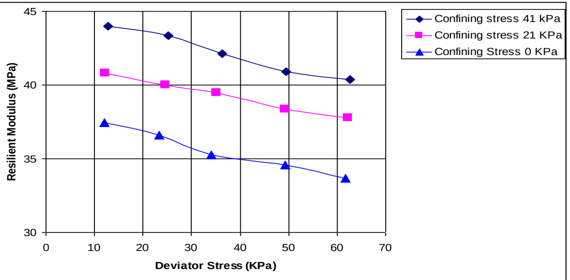

Fig. (11) Resilient Modulus From Mr laboratory test For BK1 Location (OPT)

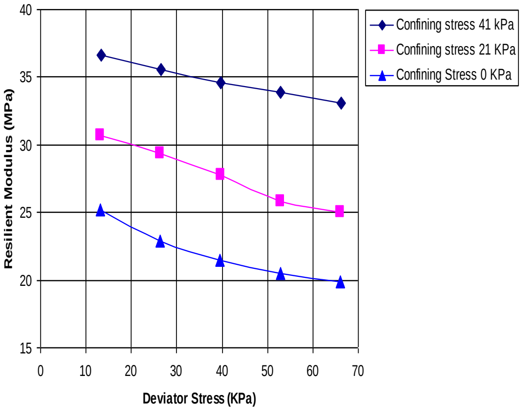

Fig. (12) Resilient Modulus From Mr laboratory test For BB1 Location (WOP)

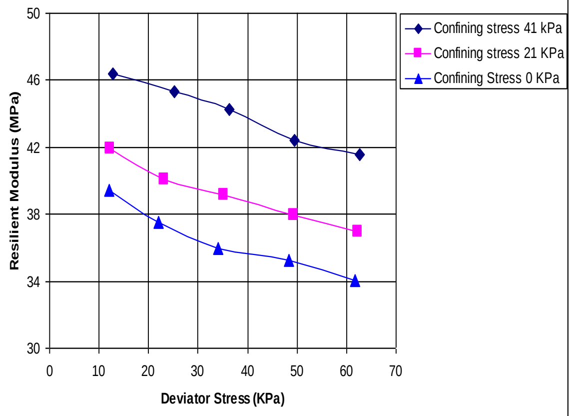

Fig. (12) Resilient Modulus From Mr laboratory test For BZ1 Location (WOP)

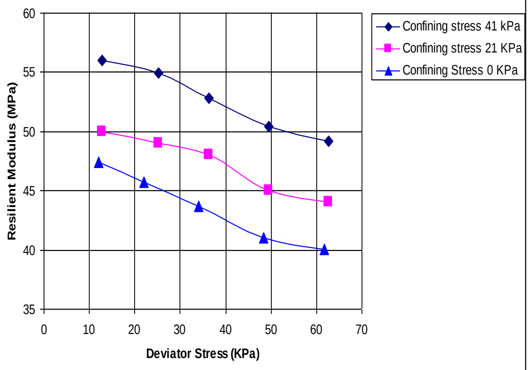

Fig. (13) Resilient Modulus From Mr laboratory test For BM1 Location (WOP)

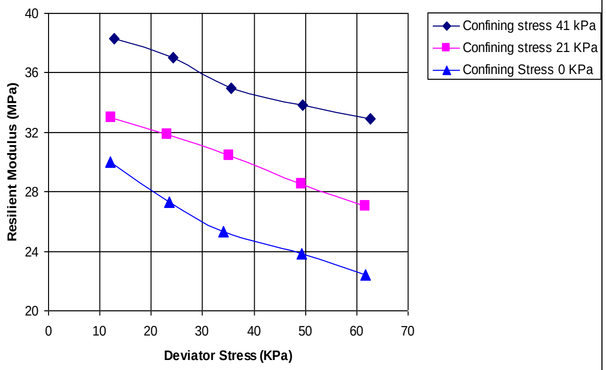

Fig. (14) Resilient Modulus From Mr laboratory test For BK1 Location (WOP)

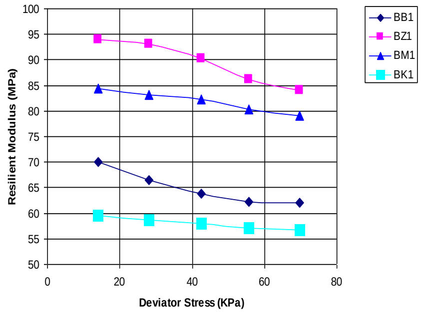

Fig. (15) Resilient Modulus From Mr laboratory test For BB1,BZ1, BM1 Location (DOP) at Confining Pressure 41kPa

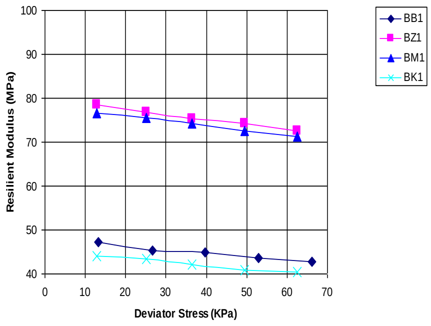

Fig. (16) Resilient Modulus From Mr laboratory test For BB1,BZ1, BM1 Location (OPT) at Confining Pressure 41kPa

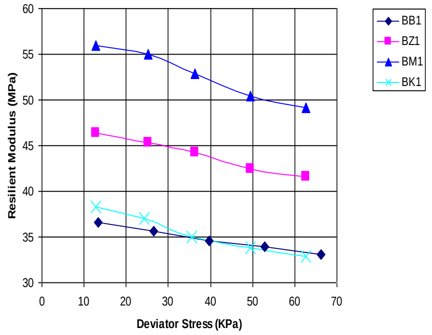

Fig. (17) Resilient Modulus From Mr laboratory test For BB1,BZ1, BM1 Location (WOP) at Confining Pressure 41kPa

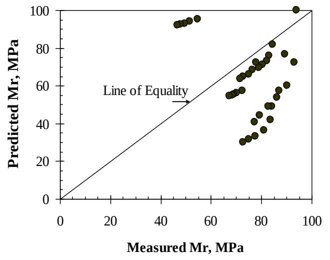

Fig.(18) Measured and predicted Resilient Modolus for all soils at DOP

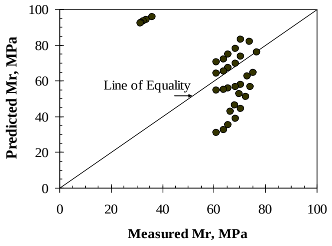

Fig.(18) Measured and predicted Resilient Modolus for all soils at OPT

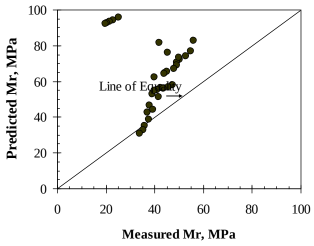

Fig.(19) Measured and predicted Resilient Modolus for all soils at WOP

Table 6 Summary of liquefaction test results on soil samples at WOP

10 CONCLUSSION AND RECOMMENDATION

Evaluation of Baghdad Soil brought from four locations was well studied to evaluate the resilient modulus and the following conclusions were drawn:

1. The results of all experimental programs show the real need in evaluating the resilient modulus by adopting laboratory methodology.
2. A total collapse of the pavement structure can occur due to large plastic deformations arising in the subgrade soil due to extremely heavy traffic loads.
3. it is noted that M_r is closely related to the moisture content in soils. M_r of the soil samples decreased with an increase in moisture content

4. Resilient modulus (M_r) of pavement subgrade soils has been adopted by the American Association of State Highway and Transportation Officials (AASHTO) for the purpose of designing flexible roadway pavement systems for Baghdad City.
5. For natural soils of Baghdad city, all samples exhibited resilient modulus values ranging from 40 MPa to about 100MPa. Based on ASTM subgrade resilient modulus criterion, the A-7-5 and A-6 untreated subgrade soil would be classified as fair to poor (unacceptable as a competent subgrade)(from a resilient modulus criterion perspective).
6. the results of predicted Mr Value were very close to the measured value. This validates the applicability of the OSU model to Baghdad cohesive soils.
7. It is recommended to make some modifications on OSU model to be used to predict values of resilient modulus for location in Baghdad City .

ACKNOWLEDGEMENT

The authors would like to thank of Civil, Environmental and Geodetic Engineering Department at Ohio State University, especially for Professor Dr.William Wolfe, Dr.Butalia and the Engineers Nate & Brian their contribution to this research.

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