

Evaluation of resilient modulus and unconfined compressive strength of subgrade

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Abstract. Subgrade soil is the important material as the foundation for supporting the pavement layers and the repeated load of vehicle traffic. To characterize the stiffness and strength behavior of subgrade due to traffic loading in structural pavement design can be determined by resilient modulus and unconfined compressive strength test. In this study, laboratory test of resilient modulus and unconfined compressive strength used to investigate (1) the effect of moisture content of the changes of stiffness and strength characteristics, (2) the correlation between the resilient modulus and elasticity modulus. The soil sample prepared at five type of compacted soils, at the dry side (OMC-20%OMC and OMC-10%OMC), OMC and at the wet side (OMC+10%OMC and OMC+20%OMC) . The result shows the moisture content has a significant effect on cohesive soil, the resilient modulus, modulus elasticity and stress value increase with the increase of moisture content until reaching the optimum moisture content (OMC) and then decrease with the increase of moisture content on the wet side of OMC point. By comparing both resilient modulus and unconfined compressive strength result from ANOVA statistics analysis can be concluded that there is no difference in stiffness between resilient modulus and modulus elasticity methods.

1 Introduction

Resilient modulus (M_R) is a measure of subgrade material stiffness while the modulus of elasticity (E) is a parameter that used to measure material or the resistance of material to elastic deformation when load is applied. Resilient modulus (M_R) is stress divided by strain for rapidly applied loads and modulus of elasticity is stress divided by strain for a slowly applied load. Resilient modulus (M_R) requires input for determining the stress, strains deflection in pavement design. Modulus of elasticity can be deformed for any solid material and representation of the stress strain ratio. The ability of materials to return to its original shape after release the stress applied is called stiffness. Stiffness is also the degree to which an object resists its deformation in applied load.

Soil is a material that influences by moisture content, soil texture, density, and strength. The performance of the pavement is influenced by the characteristics of the soil subgrade [1]. Subgrade may consist of natural soil, either cut or fill which supports the pavement systems [2]. Subgrade is close to the soil surface, the conditions will always be effected by changes in climate [3]. It causes water levels fluctuate so that will effect to the soil strength and stiffness especially on clay soil. Subgrade can significantly affected by variation of moisture content. In a few decades, some researchers have studied the influence of moisture content on resilient modulus of subgrade soils [4,5,6,7]. The moisture content of subgrade soils is one of the most important variable to

predict the resilient modulus (M_R) value [8,9]. The resilient modulus increases due to increasing moisture content until it reaches the optimum moisture content, and the increase of water content next will cause a decrease on the resilient modulus [3,4,9].

The objective of this research is to show the effect of moisture content of subgrade and the correlation between the resilient modulus value and elasticity modulus from the unconfined compressive strength test. Several researchers have also been done regarding the relationship between resilient modulus (M_R) and unconfined compressive strength (UCS), either to estimate the resilient modulus (M_R) value based on the UCS test or to see the interaction between resilient modulus and unconfined compressive strength value [10-13].

The resilient modulus is a stress-strain relationship and can be defined as the ratio of axial deviator stress to recoverable axial strain. The resilient modulus (M_R) was calculated from the load and deformation using the following equation:

$$M_R = \sigma_d / \epsilon_r \quad (1)$$

Where

M_R is resilient modulus

σ_d is axial deviator stress

ϵ_r is recoverable (resilient) strain.

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Fig. 1 shows the illustration of behavior of permanent strain resilient modulus under repeated load [13].

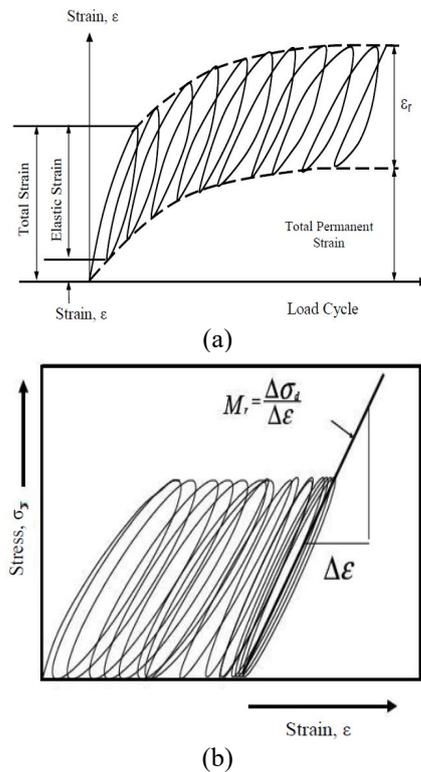


Fig. 1. (a) Behavior of specimen under repeated load and (b) Resilient modulus

Modulus of elasticity (E) of a material can be defined as the ratio between stress ($\Delta\sigma$) and strain ($\Delta\epsilon$) that occur to the soil due to loading, or can be formulated as below.

$$E = \Delta\sigma / \Delta\epsilon \quad (2)$$

Where

- E is modulus elasticity
- $\Delta\sigma$ is stress
- $\Delta\epsilon$ is strain

Each type of soil has a different modulus of elasticity, its depending on the type of soil, besides external factors such as compaction and moisture content also affects the value of the modulus of soil elasticity.

2 Materials and methods

2.1 Materials

The soil subgrade sample taken from the Research Centre of Soft Soils Universiti Tun Hussein Onn Malaysia (RECESS, UTHM) at a depth of 2 meters. The physical properties were determined using atterberg limits, specific gravity, sieve analysis, standard proctor test. The standard proctor compaction test is used to determine the maximum dry density (MDD) and optimum moisture content (OMC) based on guidelines

of BS (1993) part 4. Table 1, shows the summary of the soil properties data of the clay soil.

Table 1. Data properties of clay soil [14]

Soil Properties	Value
Natural moisture content (%)	92.88
Atterberg limit :	
Liquid limit (%)	55.54
Plastic limit (%)	24.58
Plasticity index (%)	30.96
Specific gravity	2.61
Particles:	
Gravel fraction, percent retained above sieve 4,75 mm (%)	0
Coarse fraction, percent retained above sieve 0.075 mm (%)	5.87
Fine fraction, percent passing sieve 0.075mm (%)	94.13
USCS / AASHTO Classification	CH / A-7-6
Optimum Moisture Content (OMC) (%)	28%
Maximum Dry Density (MDD) gr/cm ³	1.84

The compaction curve shows that the dry density increase as the increase of moisture content after it achieved the optimum moisture content, the dry density will decrease as the increase of the moisture content increase. Maximum dry density (MDD) obtained at 1.84 g/cm³ and optimum moisture content (OMC) at 28%.

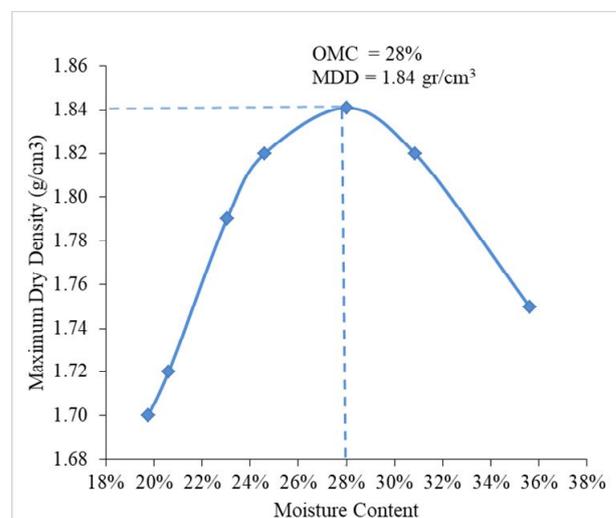


Fig. 2. Compaction curve for clay soil

2.2 Methods

The resilient modulus test was done on fine materials as per the standard of AASHTO T.307, the soil samples tested using the machine Load Trac II (Geocomp). According to the standard, the soil sample was classified as type II (fine grained). The soil samples dimension for tested of 50 mm diameter and height of 100 mm.



Fig. 3. GEOTEC fully automated resilient modulus machine

The resilient modulus test is conducted in 15 sequences that consist of two phases. The first phase, the test began with a conditioning phase (sequence 0) which consists of applying 500-1000 repetitions of the load and further followed by the second phase (sequence 1 until 15), which the specimen is submitted to cycle loading that consists of applying 100 repetitions of load. The cyclic axial stress using a haversine-shape that consists of a 0.1 second load pulse, then followed by a 0.9 second rest period. Table 2 shows the testing sequence that applied.

Table 2. Testing sequence for subgrade soil (Type II) [15]

Sequence No.	Confining Pressure (σ_3)	Deviator Stress (σ_d)	Load repetition
	kPa	kPa	
Cond	41.4	27.6	500-1000
1		13.8	100
2		27.6	100
3	41.4	41.4	100
4		55.2	100
5		68.9	100
6		13.8	100
7		27.6	100
8	27.6	41.4	100
9		55.2	100
10		68.9	100
11		13.8	100
12		27.6	100
13	13.8	41.4	100
14		55.2	100
15		68.9	100

The unconfined compression strength test is used to measure the shearing resistance of cohesive soils which may be undisturbed or remolded specimens. An axial

load is applied using either strain-control or stress-control condition. The unconfined compressive strength is defined as the maximum unit stress obtained within the first 20% strain. The UCS test performed on a cylindrical sample having a ratio of height to diameter is 2:1, this research used a soil sample dimension with a diameter of 38 mm and a height of 76 mm.



Fig.4. The unconfined compressive strength test machine

3 Result and discussions

3.1. Resilient modulus and unconfined compressive strength test result

Each sample has been compacted at five different moisture contents for resilient modulus (M_R) test and unconfined compressive strength (UCS) test.

Table 3. Moisture content for soil testing

Moisture Condition	Target moisture content (%)	Moisture content of M_R test (%)	Moisture content of UCS test (%)
OMC-20%*(OMC)	22.4	21.87	20.90
OMC-10%*(OMC)	25.2	24.65	25.08
OMC	28	27.85	27.87
OMC+10%*(OMC)	30.8	30.23	30.54
OMC+20%*(OMC)	33.6	33.34	33.55

Table 4, shows the result of resilient modulus for 15 sequences from five various of moisture content. The result of resilient modulus at optimum moisture content (OMC) have higher values than other moisture content at dry side and wet side of OMC.

Table 5, shows the mean of resilient modulus and UCS test results for each moisture content. Fig. 5 and 6, shows the trend of the curve of M_R versus q_u and M_R versus elasticity modulus has a similar curve as OMC-MDD curve. It can be explained that when the soil sample is not at the OMC point (at the dry side and wet side), the dry density of soil is lower than maximum dry density condition. It causes the resilient modulus also have the lower value than at the OMC point. The addition of more water to soil can produce its saturation and it's very difficult to compact, also if compacted soil at low moisture content.

Table 4. Resilient modulus at various of moisture content

Stress			Resilient modulus (Mpa)				
σ_3 (kPa)	σ_d (kPa)	θ (kPa)	OMC - 20%OMC	OMC - 10%OMC	OMC	OMC + 10%OMC	OMC + 20%OMC
41.40	13.80	138.00	192.25	225.67	245.51	263.73	182.53
41.40	27.60	151.80	175.44	218.21	279.33	244.13	168.01
41.40	41.40	165.60	163.56	207.28	261.39	213.67	161.07
41.40	55.20	179.40	158.50	195.07	246.35	200.60	139.04
41.40	68.90	193.10	143.80	181.13	251.37	205.97	122.45
27.60	13.80	96.60	137.15	195.95	231.81	195.00	151.14
27.60	27.60	110.40	133.90	202.50	229.81	167.00	141.26
27.60	41.40	124.20	126.08	182.15	214.44	167.00	130.56
27.60	55.20	138.00	126.00	156.90	239.66	156.00	131.66
27.60	68.90	151.70	122.29	151.89	232.98	139.00	120.35
13.40	13.80	54.00	129.46	170.70	239.27	143.11	147.89
13.40	27.60	67.80	131.78	167.76	212.25	124.91	145.56
13.40	41.40	81.60	129.35	156.77	209.00	130.92	145.36
13.40	55.20	95.40	127.50	143.98	212.19	128.99	126.10
13.40	68.90	109.10	120.53	129.58	210.56	127.78	124.38

Table 5. Mean of M_R versus UCS test result

	OMC- 20% OMC	OMC- 10% OMC	OMC	OMC+ 10% OMC	OMC+ 20% OMC
Mean M_R (MPa)	141.17	153.76	234.39	173.85	142.49
Stress (kPa)	189.68	249.74	253.53	220.97	183.34
E (kPa)	143	183	236	179	145

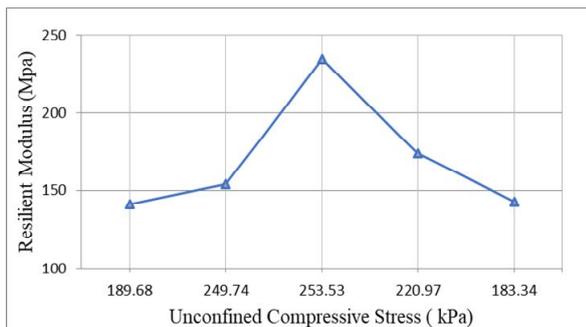


Fig. 5. M_R versus q_u at various moisture content

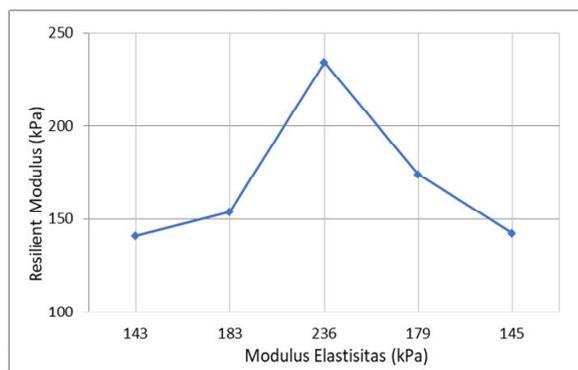


Fig. 6. M_R versus E at various moisture content

From the M_R and E curve of five different moisture content shows that the maximum stress reached at the optimum moisture content (OMC), the same as the curve of M_R and q_u this is because at OMC condition, maximum dry density is at the highest point.

Table 6. The percentage changes of value M_R , q_u and E

M_R	ΔM_R	E	ΔE	q_u	Δq_u
141.17	39.77%	143	39.41%	189.68	25.19%
179.04	23.61%	183	22.46%	249.74	1.49%
234.39	0.00%	236	0.00%	253.53	0.00%
173.85	25.83%	179	24.15%	220.97	14.74%
142.49	39.21%	145	38.56%	183.34	27.68%

Table 6, shows the percentages of changes of resilient modulus (M_R) and modulus elasticity (E) from the dry side to OMC and wet side to OMC have a value that almost close to the same, but different with the stress (q_u) result. It is because the resilient modulus and modulus elasticity is the same parameter to measure the stiffness parameter, although it has the differences of procedure of testing whereas stress (q_u) is strength parameter.

3.3. M_R and E correlation

Statistical analysis is used to compare groups means. ANOVA (analysis of variance) was used in this research where the effect of moisture content was used as the basis for analysis the resilient modulus (M_R) and modulus elasticity (E) values. The effect is considered statically significant for p-value of less than 0.05 and insignificant for p-value greater than 0.05. This value means significant level provides 95% confidence result and only 5% probability of committing.

Table 7. Anova

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4463.206	1	4463.206	3.580587	0.095097	5.317655
Within Groups	9972.009	8	1246.501			
Total	14435.21	9				

The ANOVA table above shows the value of p value is greater than 0.05 (alpha), then the decision to accept H_0 means there is no difference in the average of each group. Besides, it can be seen by comparing the value of F (3.5805) with F crit (5.3176). It can be seen that F is smaller than F crit, then the same decision is received H_0 . So it can be concluded that there is no difference in stiffness between resilient modulus and modulus elasticity methods.

4 Conclusion

The value of resilient modulus, modulus elasticity and also the stress, increased with an increasing of moisture content until it reaches the optimum moisture content, the increase of water content next will cause a decrease on resilient modulus, modulus elasticity and stress. Moisture content has a significant effect on cohesive soil type on the dry-wet conditions, this causes the decrease of resilient modulus, modulus elasticity and stress. Resilient modulus of subgrade is one of the key material properties that is required for pavement design and analysis. Cyclic repeated load that is used on the resilient

modulus test is used to simulate the traffic load condition. Modulus elasticity from UCS test also can be used to evaluate the stiffness of subgrade. The resilient modulus of subgrade is not strength but stiffness where a subgrade can support a high amount of load applied with very slight deformation.

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