RESILIENT MODULUS OF MALAYSIAN BASE AND SUBBASE PAVEMENT MATERIALS

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ABSTRACT

Pavement design approach is shifting towards analytical or mechanistic-based procedures. Resilient modulus is a fundamental parameter used in the procedure and a study was carried out to characterise the parameter for base and subbase pavement materials used in Malaysia according to the Public Works Department of Malaysia's (PWD) Specification for Road Works (JKR/SPJ/1988). This paper details the study and describes the materials tested, the methodology used and the results obtained from the study. In this study, base (Type II) and subbase (Type E) specimens of 100 mm diameter x 200 mm height were tested using the repeated load triaxial test in accordance with AASHTO T307-99. In addition, the test was carried out at different gradation compositions (but within the required gradation envelope) and moisture contents to study their effects on the resilient modulus value. From the test, the k-θ model was used to characterise the base and subbase materials. Finally, recommendations on a set of resilient modulus values for Malaysian base and subbase materials to be used for mechanistic design of flexible pavements were made, taking into account of the Malaysian environment.

Keywords: *Base and Subbase Materials, Flexible Pavement Design, Pavement Materials, Resilient Modulus*

(Note: As most of the literature reviewed used U.S. Customary Units, this article used similar units for the purpose of comparing the findings. For conversion: 1 kPa = 6.9 psi)

1 INTRODUCTION

A typical flexible pavement in Malaysia consists of asphaltic concrete wearing and binder course, crushed aggregate or wet-mix base layer and granular subbase (river/mining sand or quarry dust). In certain circumstances, particularly where the traffic loadings are high, additional bituminous macadam roadbase layer is included above the crushed aggregate/wet-mix base layer.

Current Public Works Department of Malaysia's (PWD Malaysia) Specifications for Road Works (JKR/SPJ/1988) is a "recipe-based" specification that requires flexible pavement materials to comply with the physical properties described in the specification [1], such as gradation, compaction density, CBR value and plasticity index for mix aggregates, base and subbase materials (Table 1). These properties ensure that the materials are of a specified quality but do not measure the structural properties required as input for mechanistic pavement design method.

Table 1: PWD Malaysia's requirements for subbase and base materials [1]

Requirements	Subbase	Base
Plasticity Index	≤ 6	≤ 6
Liquid Limit	≤ 25 %	-
Aggregate Crushing Value	≤ 35	≤ 30
CBR	≥ 30	≥ 30
Soundness (Sodium Sulphate)	-	≤ 12 %
Flakiness Index	-	≤ 30
Fractured Face (4.75mm sieve)	-	≥ 80 %

Resilient modulus (MR) is a fundamental parameter used in the mechanistic pavement design procedure and is defined as the ratio of deviator stress, σ_d over the recoverable strain, ε_r [2] :

$$M_R = \frac{\sigma_d}{\varepsilon_r} \tag{1}$$

A laboratory study was carried out to characterise resilient modulus for base and subbase pavement materials used in Malaysia according to PWD Malaysia's Specification for Road Works (JKR/SPJ/1988). The materials tested include base type II using crushed rock aggregates and subbase type E using quarry dust and mining sand.

The objective of the laboratory tests is to determine the values or range of values of resilient modulus for typical Malaysian flexible materials so that these can be used in routine mechanistic based flexible pavement design. Testing was carried out at different gradation compositions (but within the required gradation envelope) and moisture contents to study their effects on the resilient modulus value.

2 LITERATURE REVIEW

A The Importance of Resilient Modulus

The development of mechanistic-based pavement design procedures such as the Shell Pavement Design Manual [3] and the Asphalt Institute's Thickness Design Manual (MS-1) 9th edition [4] provide the need for the measurement of resilient modulus as input for mechanistic design of flexible pavements. In mechanistic design, flexible pavement is modeled as a multi-layered system and required inputs such as the material properties, thickness of each layer and traffic loadings. The material properties required are the elastic modulus and Poisson's ratio (usually assumed from other studies). According to Huang [2], the elastic modulus to be used is the resilient modulus.

In addition, although the AASHTO Guide for Design of Pavement Structures [5] is still empirical, the determination of layer coefficients for its design procedure requires input values of resilient modulus for subgrade, subbase and base layers. AASHTO [5] recommended direct laboratory measurement using the AASHTO Method T274-82 for subgrade and unbound granular materials (including base and subbase) and ASTM D4123-82 for asphaltic concrete and asphalt stabilised materials. Furthermore, the increasing use of performance-based specifications requires the measurement of resilient modulus of pavement materials as one of the key properties to be achieved.

B Factors Affecting the Resilient Modulus of Granular Materials

The resilient modulus of granular materials are known to be a function of factors such as stress level, density , grading, fines content, maximum grain size, aggregate type, particle shape, moisture content, stress history and number of load applications [6]. However, most researchers agreed that the most influential factors are the level of applied stress and the amount of moisture content in the material.

In a recent study by Khogali and Zeghal [7], four parameters that affect the resilient modulus were investigated, namely: deviator stress, confining pressure, moisture content and material dry density. It was found that deviator stress is the most significant factor followed by the effect of moisture content. The remaining factors appeared to have little or no effect on the resilient modulus value.

C Constitutive Models for Material Characterisation

The laboratory testing of a base or subbase material will provide data for constitutive modeling of resilient modulus behaviour over a range of applied stress. The pavement responses that are to be calculated using multilayer elastic analysis are dependent on the constitutive model selected to represent the materials' resilient modulus behaviour. Various constitutive models have been used for pavement design. The constitutive equations that have been used with varying complexities are given below:

Fine-Grained Soils – 1986/93 AASHTO Design Guide[5]:

$$M_R = K_1(\sigma_d)^{K_3} \qquad (2)$$

Coarse-Grained Soils – 1986/93 AASHTO Design Guide[5]:

$$M_R = K_1(\theta)^{K_2} \qquad (3)$$

Universal Equation (Uzan, 1985)[8]:

$$M_R = K_1 P_a \left[\frac{\theta}{P_a}\right]^{K_2} \left[\frac{\theta_d}{P_a}\right]^{K_3} \qquad (4)$$

Expanded Universal Constitutive Equation (NCHRP Project 1-28A)[9]:

$$M_R = k_1 p_a \left[\frac{\theta - 3k_4}{p_a}\right]^{k2} \left[\frac{\tau_{oct}}{p_a} + 1\right]^{k3} \qquad (5)$$

where,

$$\theta = \sigma_1 + \sigma_2 + \sigma_3$$

$$\tau_{oct} = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2}$$

where

p_a = Atmospheric pressure.
θ = Bulk stress:
σ_d = Deviator stress.
σ_1 = Major principal stress.
σ_2 = Intermediate principal stress.
σ_3 = Minor principal stress/confining pressure.
τ_{oct} = Octahedral shear stress.
k_1, k_2, k_3, k_4 = Regression constants from repeated load resilient modulus tests.

The AASHTO model for coarse-grained soils/granular materials is based on the work of Hicks [10] who studied on the factors affecting the resilient properties of granular materials. However, Von Quintus and Killingsworth [11] found that the so-called "universal constitutive model" which is based on studies made by Uzan [8] is more accurate in simulating the responses measured in the laboratory. This is because the model takes into account both the confining stress and the deviator stress, compared to the Hicks' model which only takes into account of the confining stress.

The draft AASHTO 2002 Pavement Design Guide adopted a modified version of the equation, called the "expanded universal constitutive equation" which is applicable to all types of unbound paving materials, ranging from plastic clays to clean granular bases [9]. Von Quintus and Yau[12] found good fit of the equation using data for the pavement materials obtained from the Long Term Pavement Performance (LTPP) program conducted in the United States.

This paper focused on the k-θ model because of its simplicity and its widespread use in modeling granular materials. In addition, the model is also incorporated in multilayer elastic analysis softwares presently available which is used to analyse pavement structures. Table 2 shows the k_1 and k_2 values from previous research by various investigators using the k-θ model.

Table 2: Ranges of k_1 and k_2 for untreated granular materials [2]

Reference	Material	k_1(psi)	k_2
Hicks (1970)	Partially crushed gavel, crushed rock	1600-5000	0.57–0.73
Hicks & Finn (1970)	Untreated base at San Diego Road Test	2100-5400	0.61
Allen (1973)	Gravel, crushed stone	1800-8000	0.32-0.70
Kalcheff & Hicks (1973)	Crushed stone	4000-9000	0.46-0.64
Boyce et. al (1976)	Well-grade crushed limestone	8000	0.67
Monismith & Wictzak (1980)	In-service base & subbase materials	2900-7750	0.46-0.65

3 METHODOLOGY

A Equipment

UTM-5P servo-pneumatically controlled testing machine was used for the resilient modulus testing of base and subbase materials. Real time control of the machine and the generation of the required waveform were provided by a digital signal processing unit; while a data acquisition system took all transducer readings at the same time. The signal processing unit and the data acquisition system were provided in a control and data acquisition system, which was integrated with the UTM-5P testing machine. A universal triaxial cell capable of testing 100 mm diameter x 200 mm high specimens was used for repeated load test of the base and subbase materials (Figure 1).

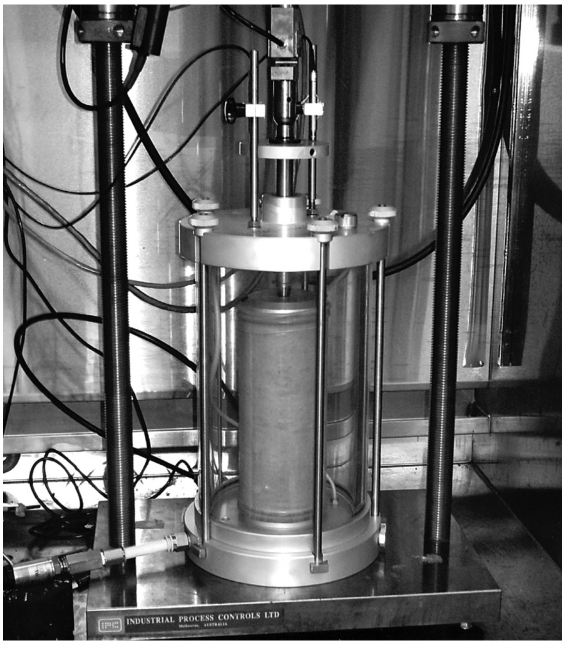

Figure 1: Repeated load triaxial cell and UTM 5-P machine

B Materials

B.1 *Base Materials*

Crushed rock aggregates were used for base type II material. The gradation in accordance to PWD Malaysia's specifications is as follows:

Table 3 : Gradation envelope for base type II [1]

BS Sieve Size (mm)	% Passing by weight
50	100
37.5	85 – 100
28	70 – 100
20	60 – 90
10	40 – 65
5	30 – 55
2	20 – 40
0.425	10 – 25
0.075	2 – 10

Three (3) specific gradation lines were set for each gradation envelope (Figure 2): (1) middle of the envelope (named Mid thereafter), (2) between middle of the envelope and the upper limit of the envelope (named Mid+25% thereafter) and (3) between middle of the envelope and the lower limit of the envelope (named Mid-25% thereafter). One (1) sample each was prepared for each gradation line.

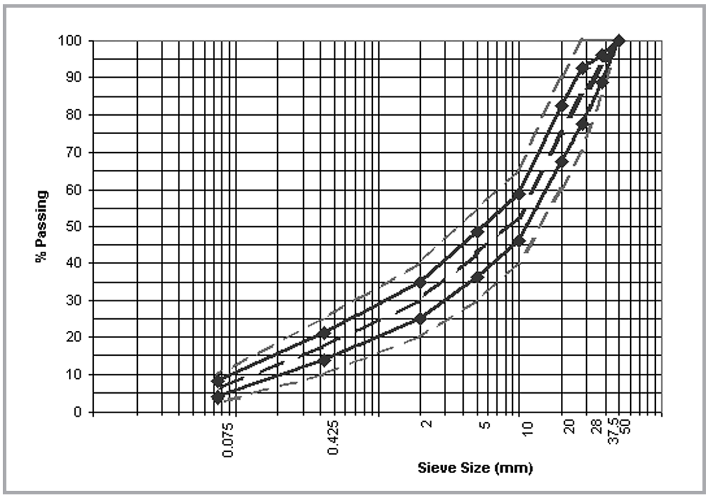

Figure 2: Gradation lines and envelope for base (Type II)

B.2 *Subbase Materials*

Mining sand and quarry dust were used for subbase materials (type E). The gradation of the subbase materials were in accordance with the gradation envelope as per PWD Malaysia's Specifications for Road Works (Table 4). Similar to base materials, three (3) specific gradation lines were set for each gradation envelope: (1) middle of the envelope (named Mid thereafter), (2) between middle of the envelope and the upper limit of the envelope (named Mid+25% thereafter) and (3) between middle of the envelope and the lower limit of the envelope (named Mid-25% thereafter). One (1) sample each was prepared for each gradation line.

Table 4: Gradation envelope for subbase type E [1]

B.S. Sieve Size	% Passing by weight
	Subbase 'E'
50.0 mm	-
25.0 mm	-
9.5 mm	100
4.75 mm	55 – 100
2.00 mm	40 – 100
425 um	20 – 50
75 um	6 – 20

C Testing Procedure

For each type of sample, the optimum moisture content was first determined using modified proctor test (4.5 kg rammer). The oven-dried sample was then prepared at three (3) different levels of moisture content by adding water to the required amount prior to compaction : optimum moisture content (OMC), OMC-2% and OMC+2%.

Each of the 100 mm diameter x 200 mm high specimen was prepared using a split sand former, using a 0.3 mm thick rubber membrane over it. The split sand former was placed above a triaxial base-plate, with a porous stone being placed on the base plate pedestal. For each specimen, a vibratory hammer was used to compact five equal layers of approximately 40 mm in thickness (Figure 3). The split sand former was then removed and another layer of rubber membrane was placed around the specimen to make it air-tight. The triaxial top cap and the porous stone was placed on the specimen; rubber O-rings were then placed around it and the bottom pedestal, prior to the placement of the specimen in the triaxial chamber. Figure 4 shows the set-up of the repeated load triaxial test for base and subbase materials [13].

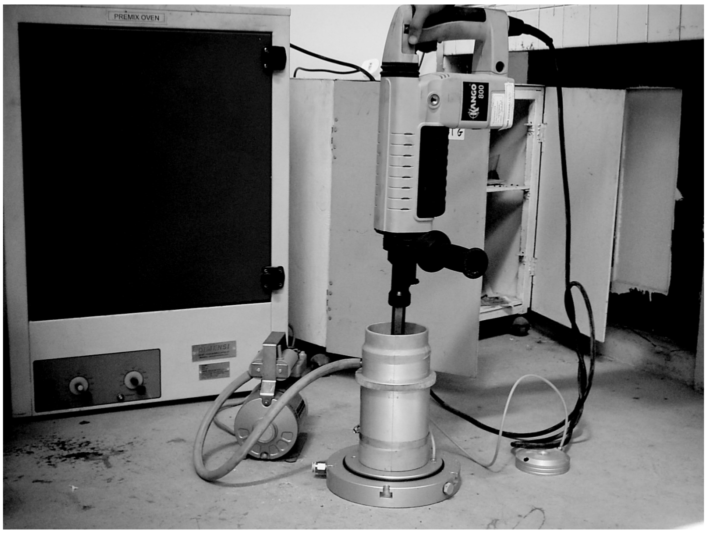

Figure 3: Compaction of samples using vibratory hammer

The specimens were tested for resilient modulus using the UTM-5P machine at the deviator stress and confining pressures as per AASHTO T307-99 test [13]. The repeated load was set at a duration of 0.1 seconds with a rest period of 0.9 seconds. Pre-conditioning of the specimen was carried out at a confining pressure of 103.4 kPa and a maximum axial stress of 103.4 kPa for 1000 repetitions for base materials and 500 repetitions for subbbase materials. Resilient modulus tests were then carried out at the required confining pressures and deviator stress (15 cycles) for 100 repetitions (Table 5). The average of the last five readings for each cycle is taken as the resilient modulus for the particular cycle.

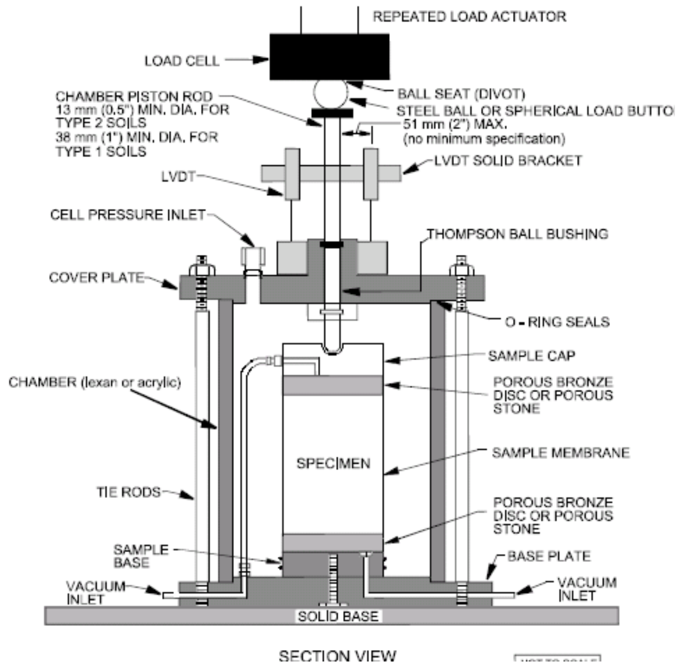

Figure 4: Set-up of the repeated load triaxial test [13]

Table 5 : Testing sequences for base/subbase materials [13]

Sequence No.	Confining Pressure, S_3		Max. Axial Stress, S_{max}		Cyclic Stress S_{cyclic}		Constant Stress 0.1 S_{max}		No. of Load Applications
	kPa	psi	kPa	psi	KPa	psi	kPa	Psi	
0	103.4	15	103.4	15	93.1	13.5	10.3	1.5	500 – 1000
1	20.7	3	20.7	3	18.6	2.7	2.1	0.3	100
2	20.7	3	41.4	6	37.3	5.4	4.1	0.6	100
3	20.7	3	62.1	9	55.9	8.1	6.2	0.9	100
4	34.5	5	34.5	5	31.0	4.5	3.5	0.5	100
5	34.5	5	68.9	10	62.0	9.0	6.9	1.0	100
6	34.5	5	103.4	15	93.1	13.5	10.3	1.5	100
7	68.9	10	68.9	10	62.0	9.0	6.9	1.0	100
8	68.9	10	137.9	20	124.1	18.0	13.8	2.0	100
9	68.9	10	206.8	30	186.1	27.0	20.7	3.0	100
10	103.4	15	68.9	10	62.0	9.0	6.9	1.0	100
11	103.4	15	103.4	15	93.1	13.5	10.3	1.5	100
12	103.4	15	206.8	30	186.1	27.0	20.7	3.0	100
13	137.9	20	103.4	15	93.1	13.5	10.3	1.5	100
14	137.9	20	137.9	20	124.1	18.0	13.8	2.0	100
15	137.9	20	275.8	40	248.2	36.0	27.6	4.0	100

The data obtained for the 15 cycles were then plotted (Figure 5) based on the following relationship for the base/subbase materials [5]:

$$M_R \text{ (psi)} = k_1(\theta)^{k_2} \quad (6)$$

where

θ = Stress invariant or Bulk stress (psi)= $(\sigma_1 + \sigma_2 + \sigma_3)$ = $(\sigma_d + 3\sigma_3)$.
σ_1 = Major principal stress (psi).
σ_2 = Intermediate principal stress (psi).
σ_3 = Minor principal stress/confining pressure (psi).
σ_d = Deviator stress (psi).
k_1, k_2 = Regression constants from repeated load resilient modulus tests.

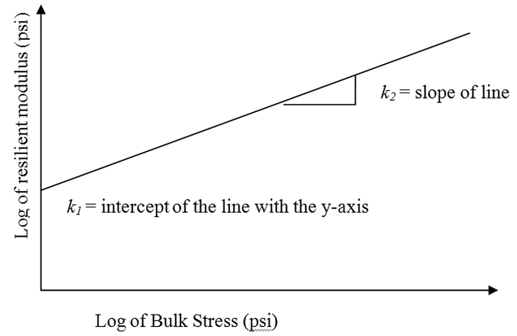

Figure 5: Plot of resilient modulus-bulk stress for base and subbase materials

4 RESULTS AND DISCUSSION

This section presents the results, analysis and discussion of the laboratory resilient modulus testing carried out on base Type II and subbase Type E (quarry dust and mining sand).

A Base Materials

The resilient modulus values obtained at various confining pressures and deviator stresses were plotted on a log-log graph and the values of k_1 and k_2 were obtained from the graph. A total of 3 specimens (Mid, Mid-25% and Mid+25%) were tested at three (3) different moisture contents (OMC, OMC-2% and OMC+2%). Figure 6 shows a typical plot of resilient modulus-stress invariant (bulk stress) relationship for base type II (mid-gradation) at the three different moisture contents. It could be seen that the lower the moisture content the higher is the k_1 value, however k_2 value increase slightly with the increase in moisture content.

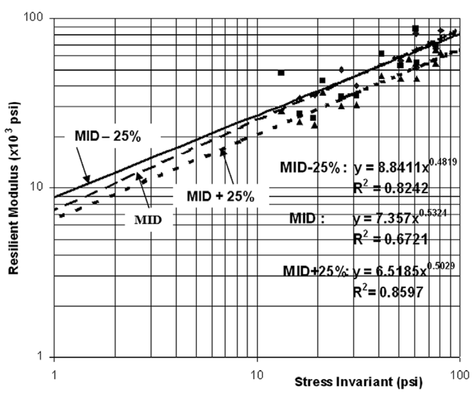

Figure 6: Resilient modulus plot for base type II (Mid-Gradation)

AASHTO T307-99 require the samples to be tested at the in-situ moisture content or OMC if the in-situ moisture content is not known/unavailable. Table 5 lists the values of k_1 and k_2 for the base materials obtained at OMC:

Table 5: Values of k_1 and k_2 for different gradations of base type II at OMC

Base Type	Moisture Content (%)	Max. Dry Density (Mg/m^3)	k_1	k_2
Mid-25%	5.40	2.342	2,831.7	0.6968
Mid	5.70	2.350	2,8114.0	0.6917
Mid+25%	6.30	2.363	2,729.7	0.6576

From the above table, it could be seen that base material with Mid-25% grading line has the highest k_1 value, which is likely due to the lower fines content (particles passing the 75um sieve) and lower moisture content which produces a much stiffer material than the base materials with higher fines content and higher moisture content. The values obtained above can be compared to the following k_1 and k_2 values that were suggested by AASHTO for base materials:

Table 6: Typical values of k_1 and k_2 for Base Materials [5]

Moisture Condition	K_1	K_2
Dry	6,000 – 10,000	0.5 – 0.7
Damp	4,000 – 6,000	0.5 – 0.7
Wet	2,000 – 4,000	0.5 – 0.7

Table 6 above suggests that k_1 values are affected by moisture content whereas k_2 values are within a range between 0.5 to 0.7. Referring to Table 5, it could be seen that most of the k_1 values obtained in the laboratory are at the lower end of the suggested range (wet moisture condition), while for k_2, most of the values are within the range of the suggested values.

It is likely that the base moisture condition is below the optimum moisture content as the current practice in Malaysia is to compact the base in dry conditions and achieve minimum 95% of the maximum dry density obtained in the laboratory modified proctor test. In addition, Bulman and Smith [14] measured subgrade moisture content under the pavement's base and subbase layers at 73 different locations in Malaysia and found that more than half of these moisture contents were equal or drier than the optimum moisture content (OMC) of the subgrade soil given by the British Standard 2.5 kg rammer compaction test. Furthermore, Croney and Bulman [15] found that there is no evidence of long-term moisture exchange with the subgrade sufficient to affect the strength of the sub-base/base layers. Therefore, it is possible that the resilient modulus at OMC-2% is more representative of the conditions achieve at site. Figure 7 below shows the resilient modulus plot for all gradations tested at OMC –2 %. Referring to Tables 6 and 7, it could be seen that the k_1 values are in the dry condition while for k_2, most of the values are within the range of the suggested values. This, however, have to be confirmed at site by measuring the in-situ moisture content of the base material in the actual pavement constructed.

Table 7: Values of k_1 and k_2 for different gradations of base type II at OMC-2%

Base Type	k_1	k_2
Mid-25%	8,841.1	0.4819
Mid	7,357.0	0.5324
Mid+25%	6,518.5	0.5028

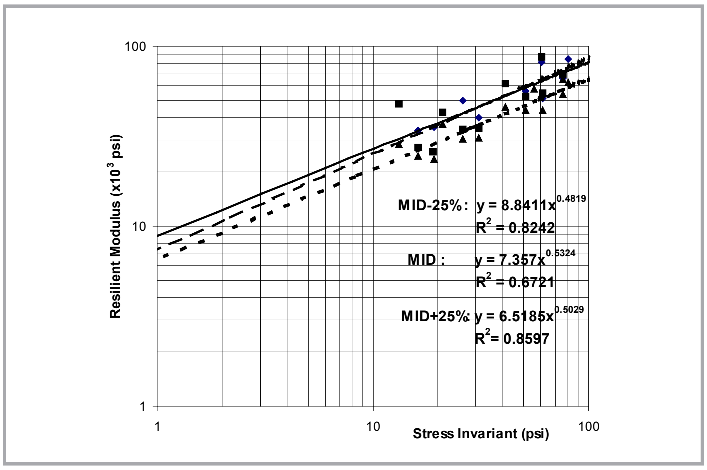

Figure 7: Resilient modulus plot for all gradations at OMC

4.1 SUBBASE MATERIALS

Figures 8 and 9 show the resilient modulus plot of subbase materials (Type E) using quarry dust and mining sand for three (3) different gradations tested at OMC. The k_1 and k_2 values obtained are summarized in Table 9 and can be compared to the following k_1 and k_2 values that were suggested by AASHTO for subbase materials:

Table 8: Typical values of k_1 and k_2 for subbase materials [5]

Moisture Condition	k_1	k_2
Dry	6,000 – 8,000	0.4 – 0.6
Damp	4,000 – 6,000	0.4 – 0.6
Wet	1,500 – 4,000	0.4 – 0.6

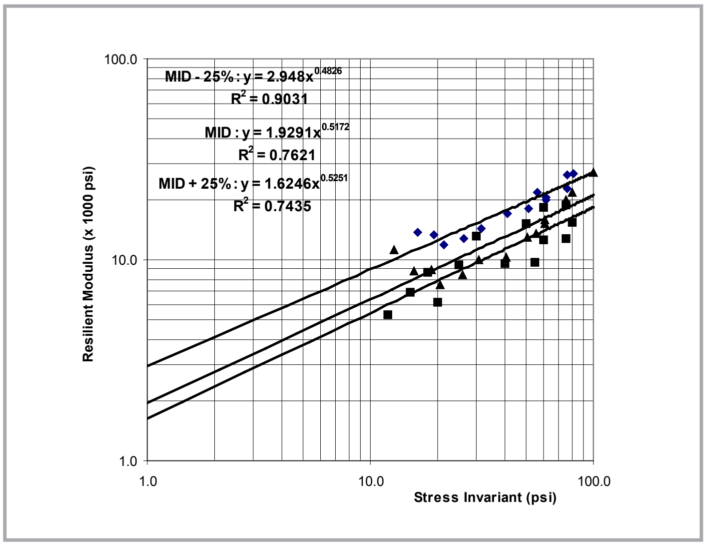

Figure 8: Resilient modulus plot for subbase type E (quarry dust) at OMC

It could be seen that by comparing Tables 7 and 9 that subbase materials have much lower k_1 values than base materials and only slight differences in k_2 values. This is possibly due to the fact that subbase materials have a smaller maximum aggregate size than base materials and also because of the higher optimum moisture content (OMC) than base materials. Gray [16] reported that the resilient modulus increased with increasing maximum particle size for aggregates with same amount of fines and similar shape of size distribution. Also, Hicks and Monismith [10], Dawson *et al*. [17] and Heydinger *et al*. [18] reported that the resilient modulus of granular materials decreases with the increase in moisture content.

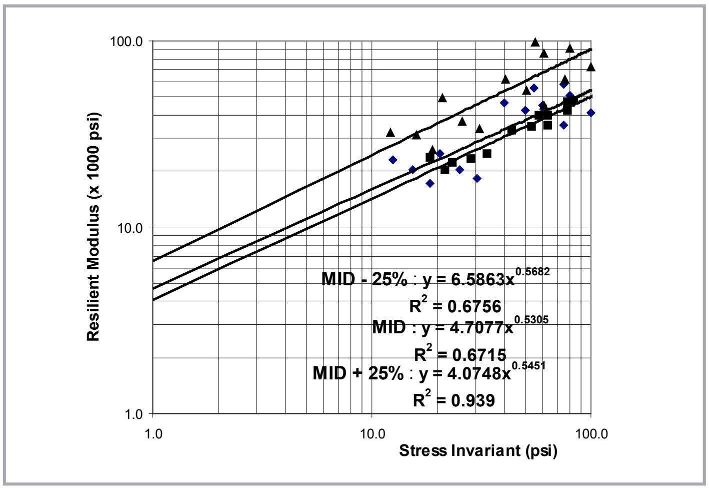

Figure 9 : Resilient Modulus plot for subbase type E (Mining Sand) at OMC

Referring to the Tables 8 and 9, it could also be seen that for quarry dust at OMC, most of the k_1 values obtained are at the lower end of the suggested range (wet moisture condition), while for k_2, the values are within the range of the suggested values. MID-25% gradation has the highest k_1 values for both quarry dust and mining sand, while MID+25% gradation has the lowest k_1 values. This suggest that the gradation with the lower fines content (% passing 75 μm) has a higher k_1 value.

Table 9: Values of k_1 and k_2 for subbase materials at OMC

Subbase Type	k_1	k_2
Quarry Dust		
Mid-25%	2,948.0	0.4826
Mid	1,929.1	0.5172
Mid+25%	1,624.6	0.5251
Mining Sand		
Mid-25%	6,586.3	0.5682
Mid	4,707.7	0.5305
Mid+25%	4,074.8	0.5451

Also, mining sand was found to have higher k_1 value than quarry dust, while k_2 value does not show any specific trend with changes in moisture content. As the k_1 value for quarry dust is low at OMC (and thus has a lower resilient modulus value), it is likely that quarry dust is unsuitable as a subbase material as it is adversely affected by an increase in moisture content. For mining sand, the OMC value gives the highest k_1 value and thus is appropriate to be tested at OMC. The reasons for this differences are possibly due to firstly, the lower moisture content and degree of saturation at OMC for mining sand and secondly, it is likely that the fines content of mining sand (below 0.075 mm) is coarser than the fines content of quarry dust, thus is less plastic and is less influenced by the increase in moisture content at OMC.

5 RESILIENT MODULUS OF BASE AND SUBBASE MATERIALS TO BE USED IN PAVEMENT DESIGN

Base and subbase materials are granular in nature and therefore the resilient modulus for granular materials is non-linear and depends on particularly the confining pressure that exist in the particular layer. To determine the resilient modulus, iterative calculations must be carried out and this is normally done using computer software that calculate the stresses using elastic layer assumptions or finite element procedures. However, AASHTO [5] provides some suggestions regarding the values to be used.

A Base Materials

The base modulus is not only a function of moisture but also the stress state which in turn, vary with the subgrade modulus and thickness of the asphaltic concrete surfacing layer. The following is recommended values by AASHTO [5] for use in design of pavements:

Table 10: Values of stress state of base recommended by AASHTO [5]

Asphalt Concrete Thickness (inches)	Subgrade Soil Resilient Modulus (psi)		
	3,000	7,500	15,000
Less than 2	20	25	30
2 - 4	10	15	20
4 - 6	5	10	15
Greater than 6	5	5	5

In Malaysia, most pavements are designed based on an assumed CBR value of 5 and asphaltic concrete thickness of between 4 -6 inches (100 -150 mm). Subgrade resilient modulus are usually calculated based on the following relationship:

$$M_R \text{ (psi)} = 1500 \times \text{CBR} \tag{7}$$

As CBR = 5, MR = 7,500 psi (51.8 MPa)
The stress state to be used is 10 psi. (0.069 MPa)
Assuming the base material to be used is from the MID gradation line (moisture content of OMC-2%), the following equation derived from the laboratory test is used:

$$M_r \text{ (psi)} = 7357\ \theta^{\,0.5324}$$

Using θ = 10 psi, M_r (psi) = $7357\ (10)^{0.5324}$
M_r (psi) = 25,067 psi.

If a factor of 1.2 is used to compensate for the reduction of resilient modulus value due to the scalping of materials larger than 25 mm in the laboratory testing (Barksdale et al. 1997), then:

$$M_R\text{(psi)} = 25{,}067 \text{ psi} \times 1.2 = 30{,}080 \text{ psi (207.6 Mpa)}$$

For Malaysian Base Type II, MID gradation line (moisture content of OMC-2%), the recommended values of resilient modulus is shown in Table 11. It should be noted that the resilient modulus is dependant on both asphaltic concrete thickness and the resilient modulus of the subgrade soil. For the same asphaltic concrete thickness, the higher the subgrade resilient modulus, the higher is the resilient modulus value of the base. On the other hand, for the same subgrade modulus value, the increase in the thickness of the asphaltic concrete will result in lower base resilient modulus value.

Table 11: Recommended values of resilient modulus (psi) for Malaysian Base Type II material (MID gradation, OMC-2%) using stress state values suggested by AASHTO [5]

Asphalt Concrete Thickness (inches)	Subgrade Soil Resilient Modulus (psi)		
	3,000 (CBR = 2)	7,500 (CBR = 5)	15,000 (CBR = 10)
Less than 2	43,500	49,000	54,000
2 - 4	30,100	37,300	43,500
4 - 6	20,800	30,100	37,300
Greater than 6	20,800	20,800	20,800

B Subbase Materials

The modulus of the subbase is dependant on the asphaltic concrete thickness and for subbase thickness between 6 and 12 inches (150 mm to 300 mm), AASHTO [5] recommended the following stress states (in psi) :

Table 12: Values of stress state of subbase recommended by AASHTO[5]

Asphalt Concrete Thickness (inches)	Stress State (psi)
less than 2	10
2 – 4	7.5
greater than 4	5

Using subbase Type E (mining sand-mid gradation) as an example, and assuming that the thickness of asphaltic concrete is greater than 4 inches (100mm) the resilient modulus is determined as follows:

$$\begin{aligned} M_R &= 4{,}707.7\ (\theta)^{\,0.5305} \\ &= 4{,}707.7\ (5)^{\,0.5305} \\ &= 11{,}056 \text{ psi (76.3 MPa)} \end{aligned}$$

The recommended values of resilient modulus for Malaysian subbase Type E, using mid-gradation line (moisture content at OMC), is shown in Table 13. It should be noted that the resilient modulus of the subbase is dependant on the asphaltic concrete thickness. The increase in the thickness of the asphaltic concrete will result in lower subbase resilient modulus value.

Table 13: Recommended values of resilient modulus (psi) for Malaysian Subbase Type E material (mid-gradation, OMC) using stress state values suggested by AASHTO [5]

Asphalt Concrete Thickness (inches)	Mining Sand (psi)	Quarry Dust (psi)
less than 2	16,000	6,300
2 – 4	13,700	5,500
greater than 4	11,100	4,400

CONCLUSION

The measurement of resilient modulus of base type II and subbase type E using quarry dust and mining sand was carried out by laboratory testing according to the procedures set out in AASHTO T307-99. For the base materials, MID-25% gradation has the highest resilient modulus value at OMC. However, comparing with values obtained by research elsewhere, it is likely that the value should be based on lower moisture content, possibly at OMC-2%. For subbase materials, mining sand gave the higher resilient modulus values than quarry dust at OMC. As subbase layer is located adjacent to the subgrade, its moisture condition is likely to be higher and possibly at the OMC. Resilient modulus values of base (Type II) and subbase (Type E) for the mid-gradation line was recommended based on the stress state values suggested AASHTO. Field verification using non-destructive techniques such as falling weight deflectometer (FWD) and the measurement of in-situ moisture content of base and subbase should be carried out to compare the values obtained in the laboratory and those measured in-situ. ■

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