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Using Marshall test to assess asphalt-concrete modulus for mixes used in Kuwait

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ABSTRACT

The structural (thickness) design of asphalt pavement layers is a function of many factors, one of the most important of which is the stiffness of the asphalt mix. In Kuwait, the structural design of pavements is performed using assumed values for stiffness that may not represent the actual stiffness of the used material. Stiffness modulus testing is time and effort consuming and requires skilled labour and special equipment. Therefore, it is not performed on a routine basis to check the stiffness of the asphalt-concrete mixes in Kuwait. This study was performed to establish a relationship between the stiffness (represented by the resilient modulus) and the Marshall test parameters obtained from the Marshall mix design procedure which is the standard used in Kuwait to design asphalt-concrete paving mixes. The Marshall parameters considered in this study are stability/flow ration and the Marshall Index, which represents the slope of the straight portion of the load-deformation curve obtained during Marshall testing.

Regression analysis demonstrated good correlation between stiffness and stability/flow ratio at 60°C at various loading frequencies. The resulting model showed a linear relationship between the two parameters that are independent of the mix type.

Keywords: Asphalt concrete; Kuwait; Marshall test; MATTA; stiffness modulus.

INTRODUCTION

Background

Asphalt concrete durability is an important criterion to ensure that a pavement layer maintains its desired properties. With time, asphalt pavement becomes dense and failure may occur due to changes in the aggregate, permanent deformation, cracking, or bleeding of asphalt, among other changes. One way to

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minimize such failure is to select the best mix properties. Asphalt mix design is performed to select the best blend of aggregate and optimum binder content. The standard method of Marshall mix design is used in Kuwait (MPW 1987a).

In Kuwait, asphalt mixtures are divided into three main types depending on their specific use. A base course mise of a large aggregate size up to 37.5 mm is placed directly on the subgrade. It is characterized by low asphalt content due to large size aggregates. The second mix type is the binder course mix, which serves as an intermediate layer between the surface and the underlying layers. It consists of large aggregate sizes up to 25 mm with low bitumen content. The third type of asphalt mixes is the surface course mix, which is a surface layer designed to have sufficient stability and durability to carry the expected traffic loads, sufficient skid resistance, and resistance to changes in weather conditions. This type of mix contains the highest bitumen content and smaller sizes of aggregate that provide a smooth and dense surface. A fourth type of surface mix, called open-graded friction course (OGFC) may be used to increase surface skid resistance and to provide a free-draining layer for the surface water to seep to the edges of the pavement. It also contains a relatively high bitumen content mixed with small size aggregates (MPW 1987a).

Resilient modulus is an important design parameter in flexible pavement design. The 1986 AASHTO guide for design of pavement structures incorporated the resilient modulus into design procedures (Little *et al.* 1992). Apart from design, the stiffness modulus is also a key parameter in the evaluation of pavements (Thom *et al.* 1977).

The indirect tensile test (ITT) has been identified as an economical and practical means of measuring stiffness modulus and has been standardized (Nunn 1996). To minimize human errors, a fully automated closed loop testing and data acquisition system was recommended for ITT (Banksdale *et al.* 1997). The Nottingham Asphalt Tester (NAT) and Material Testing Apparatus (MATTA) are two recently developed experimental systems to measure stiffness modulus of asphalt concrete (Leech & Sexton 1996). MATTA testing system was utilized in this research.

A review of the literature indicates that a number of researchers have studied the relationship between the resilient modulus and other characteristics of asphalt concrete. Relationships between the resilient modulus and other bearing characteristics of the pavement layer were developed. These include LBR (Limerock Bearing Ratio) and FWD (Falling Weight Deflectometer) backcalculated modulus (Ping *et al.* 2001). An equation was developed for the elastic modulus of asphalt concrete and the results were compared with the Hashin and Shtrikman theoretical bounds and Henkelom and Klomp equation (Li *et al.* 1999). Using two identical asphalt mixtures, a research programme for comparing the Marshall test with the splitting tension test was conducted in Germany (Adedimila 1986). The repeated-load indirect tensile test was utilized to develop relationships between various engineering properties and optimum asphalt contents (Gonzales *et al.* 1975). In a recent study in Saudi Arabia, temperature correction factors and resilient modulus estimation equations from basic material physical properties were developed using statistical procedures to a high degree of reliability (Al-Abdul Wahab *et al.* 2001). The effect of temperature on stiffness modulus and load carrying capacity was studied in Kuwait in 1972 (Bissada, 1972).

Problem statement

The Ministry of Public Works (MPW) in Kuwait uses a locally-developed manual for pavement structural (thickness) design (MPW 1987b). The manual covers a range of values for the stiffness modulus (E) of the local asphalt layers. Currently, designers use the manual with assumed (typical) E-Values that may not represent the actual stiffness of the used material.

Use of these assumed values may result in thickness over-design, which means an extra cost for constructing the pavement, or under-design that may cause premature failure of the pavement layers. Therefore, actual stiffness modulus values should be used to avoid such problems. This is important since E-values, according to the Kuwait Design Manual, significantly affect the design thickness of a given layer (MPW 1987b).

Therefore, E-values of the used asphalt mix should be measured by conducting a standard E-test. Alternatively, they may be estimated from other mix properties if a correlation exists between E and such properties of the mix.

Objective

A study was conducted to establish a relationship between the stiffness modulus (E) and several Marshall parameters (Al-Shehab 1999). The Marshall parameters considered are stability/flow ratio (STF) and slope of the load-deformation curve plotted during the loading process in the Marshal machine, which is called the Marshall Index (MI), i.e.;

$$E = f(STF) \tag{1}$$

or

$$E = f(MI) \tag{2}$$

From such a relationship, the predicted modulus is used in the structural design of a pavement to determine its required layer thickness. The advantage of this is that the mix design results are used to estimate the stiffness of the mix without conducting an E-test.

ASPHALT PAVEMENTS IN KUWAIT

Asphalt Concrete (AC) is the most common type of paving material used in Kuwait. A typical pavement section includes a prepared subgrade, base course, binder course, and wearing course. The four AC mix types used in Kuwait are Types I, II, III, and IV. The mix names are local, and their gradations are shown in Table 1. The AC mixes used for base and binder courses are Type I and Type II, respectively. type III is used for the wearing course. Type IV is of limited use as a wearing course (MPW 1987a).

Table 2. Marshall design criteria for AC mixes used in Kuwait (MPW 1987a)

	Type I (Base Course)		**Type II** (Binder Course)		**Type III** (Wearing Course)		**Type IV** (Wearing Course)	
Marshall Criteria	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
No. of blows	75	-	75	-	75	-	75	-
Stability, kg	1660	-	1700	-	1800	-	1800	-
Flow, 0.01 in.	8	16	8	16	8	16	8	16
V.M.A.	13	-	14	-	15	-	15	-
Air voids, %	3	8	3	8	3	6	3	6
Filler/bitumen ration	-	1.6	-	1.5	-	1.4	-	1.4

The mix design of the AC used in Kuwait is based on the standard Marshall method of mix design (Asphalt Institute 1991) using an approved aggregate blend and asphalt cement. The Marshall design criteria used in Kuwait are shown in Table 2 (MPW 1987a). The structural (thickness) design of asphalt pavements in Kuwait is performed using the "Kuwait Design Manual for Asphalt Pavements in Arid and Hot Climates" (MPW 1987b). The Design Manual requires the following input:

- Subgrade soil load-bearing capacity (CBR)
- Design axle loads (in ESALs)
- Material stiffness (E)

Each of the above input parameters is important in the structural design of

AC pavements as it affects the selected layer thicknesses. Because of the time, effort, and skilled-labour requirements, the stiffness of the AC mixes is not determined experimentally, but rather assumed values are used from experience. Such assumed values may no longer represent the mixes being used because of many factors including change of mix proportioning, change of aggregate source, and change of asphalt cement type.

This study was performed to develop a model relating the stiffness modulus to some parameters obtained by conducting the Marshall test on samples of AC mixes to be used for pavements.

METHODOLOGY

The study started with preparing representative AC mixes satisfying the following requirements:

- Aggregates are cement coated, typical of what is used locally.
- Aggregate blends satisfy the local requirements as shown in Table 1.
- 60/70 penetration grade asphalt cement was used, as per local requirements (MPW 1987a).

The aggregate size gradations of the tested mixes are shown in Table 1. The mixes were prepared according to the standard method of Marshall mix design ASTM D-1559 (Asphalt Institute 1991), and the optimum asphalt cement content (OAC) was determined for the four considered mix type as shown in Table 2.

At each optimum value of asphalt cement content, three new identical specimens were prepared for each mix type. These specimens were tested for resilient modulus as per ASTM D-4123 (ASTM 1982) using the MATTA testing system at three temperatures and three loading frequencies. The considered temperatures were chosen to cover the range from room temperature (23°C), 40°C, and 60°C.

The resilient moduli of the specimens were determined using the following loading frequencies of 1.0 Hz, 0.5 Hz, and 0.33 Hz. Therefore, 108 values of resilient modulus were obtained in the testing program.

The specimens were then tested in the Marshall testing machine. The same specimens were used so that related values of Marshall parameters and resilient modulus would correspond to identical material. The following results were obtained for each of the tested specimens:

- Marshall stability

Table 1. Aggregate gradation and OAC for the tested AC mixes

Sieve Size	Cumulative % Passing				Specification Limits			
	Type I	Type II	Type III	Type IV	Type I	Type II	Type III	Type IV
37.5 mm (1.5")	100	-	-	-	100	-	-	-
25.0 mm (1")	86	100	-	-	72 - 100	100	-	-
19.0 mm (3/4")	75	91	100	-	60 - 89	82 - 100	100	-
12.5 mm (1/2")	61	72	81	100	46 - 76	60 - 84	66 - 95	100
6.25 mm (3/8")	54	62	71	90	40 - 67	49 - 74	54 - 88	80 - 100
4.75 mm (No. 4)	42	45	54	65	30 - 54	32 - 58	37 - 70	55 - 75
2.36 mm (No. 8)	33	34	39	43	22 - 43	23 - 45	26 - 52	35 - 50
1.18 mm (No. 16)	26	25	29	-	15 - 36	16 - 34	18 - 40	-
600 μm (No. 30)	19	19	22	24	10 - 28	12 - 25	13 - 30	18 - 29
300 μm (No. 50)	14	14	16	19	6 - 22	8 - 20	8 - 23	12 - 25
150 μm (No. 100)	9	9	11	13	4 - 14	5 - 13	6 - 16	8 - 18
75 μm (No. 200)	5	6	7	7	2 - 8	4 - 7	4 - 10	4 - 10
Asphalt cement content (% by total weight of aggregate)	5.0	5.0	5.5	6.5	3.5 - 5.0	4.0 - 6.5	4.5 - 7.5	4.5 - 7.5

- Marshall flow
- A graph relating the applied load to deformation - representing the Marshall loading conditions - using a plotter connected to the Marshall testing machine. A typical graph is shown in Figure 1.

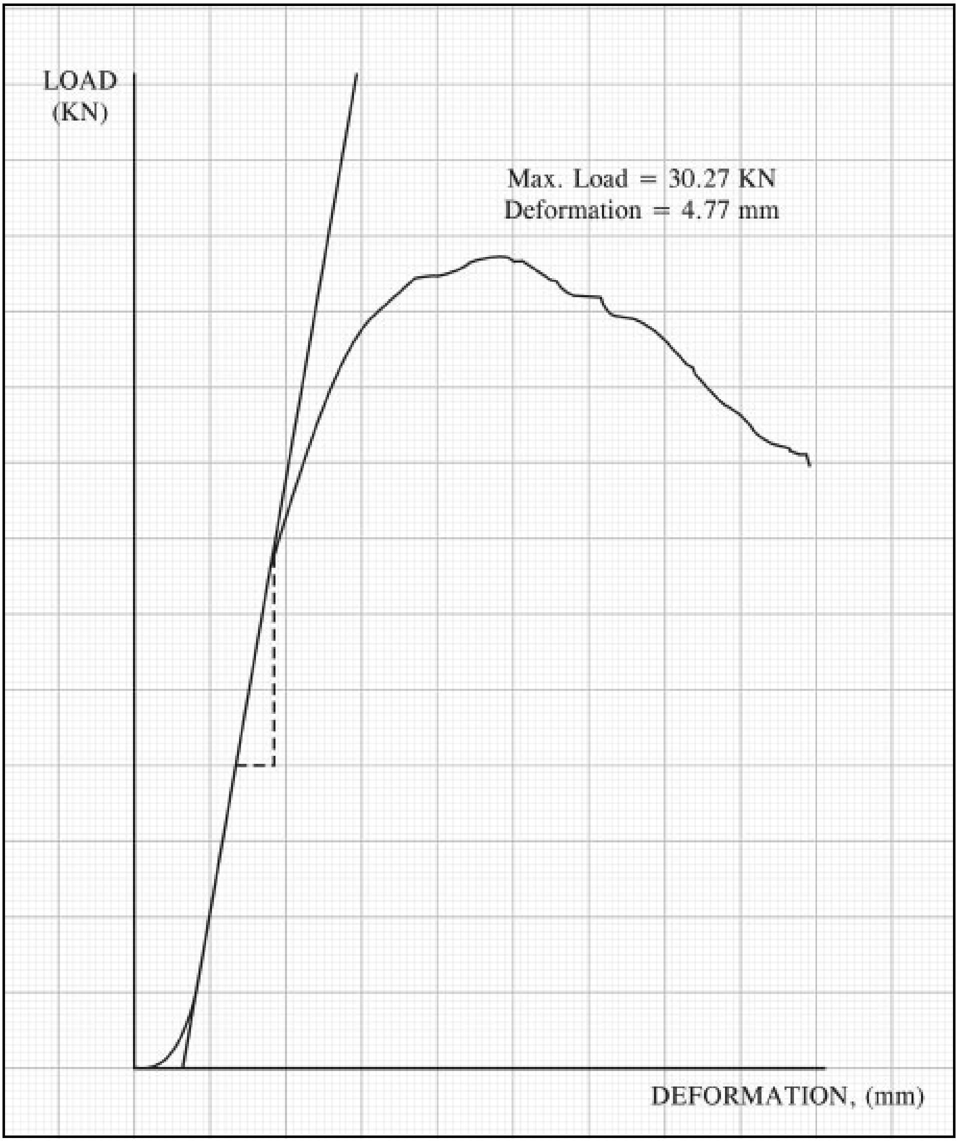

Fig.1. Marshall load-deformation curve for sample A1 of AC mix type I at 5.0% asphalt cement content

The ratio of Marshall stability to flow (STF) was calulated for each specimen. From the load-deformation graph, the slope of the straight portion (assumed to cover the range of actual traffic loading) was calculated. This slope was called the "Marshall Index" (MI).

Finally, results from resilient and Marshall tests were analyzed to establish a model correlating E to Marshall parameters.

RESULTS AND ANALYSIS

The results of resilient modulus testing are shown in Table 3. It can be seen that, in general, the resilient modulus decreases with decreases in loading frequency. Also, variation in testing temperatures show that the material stiffness decreases significantly with increases in temperature, as expected.

Table 3. Resilient modulus test results (resilient modulus average values, MPa)

Temperature (°C)	Mix Type	Loading Frequency (Hz)		
		1.0	0.5	0.33
23	I	795.7	829.2	836.1
	II	3814.6	3732.1	2839.0
	III	5141.4	4790.5	5059.0
	IV	3330.1	3247.7	3075.3
40	I	621.7	584.7	549.4
	II	582.2	540.3	523.5
	III	720.1	678.9	664.1
	IV	634.8	565.0	534.5
60	I	181.6	166.1	163.1
	II	243.8	231.8	221.2
	III	229.8	212.5	208.0
	IV	216.1	205.1	203.7

Testing the specimens in the Marshall machine resulted in stability and flow values, and load-deformation curves similar to the one shown in Figure 1. The stability/flow ratio (STF) was calculated for each specimen, and from the load-deformation curve, the Marshall Index (MI) was calculated.

Correlation analysis was performed to evaluate the relationship between the resilient modulus at different temperatures and loading frequencies, and the obtained STF and MI values. The best correlations were found to be between the resilient modulus at 60°C and STF. This may be due to the fact that STF is obtained from the Marshall test at the same temperature. It may also be due to the sensitivity of AC specimens to deformations at low temperatures (high E). Such correlations are shown in Figures 2 to 5, which resulted in the following relationships:

$$E_{1.0\ Hz} = 1.155\ STF \qquad R^2 = 0.76 \qquad (3)$$

$$E_{0.5\ Hz} = 1.075\ STF \qquad R^2 = 0.81 \qquad (4)$$

$$E_{0.33\ Hz} = 1.044\ STF \qquad R^2 = 0.82 \qquad (5)$$

where,

$E_{i\ Hz}$ = Resilient modulus at 60°C and i loading frequency, MPa;

STF = stability/flow ratio, kg/0.01 in.;

R^2 = correlation factor for the developed relationship.

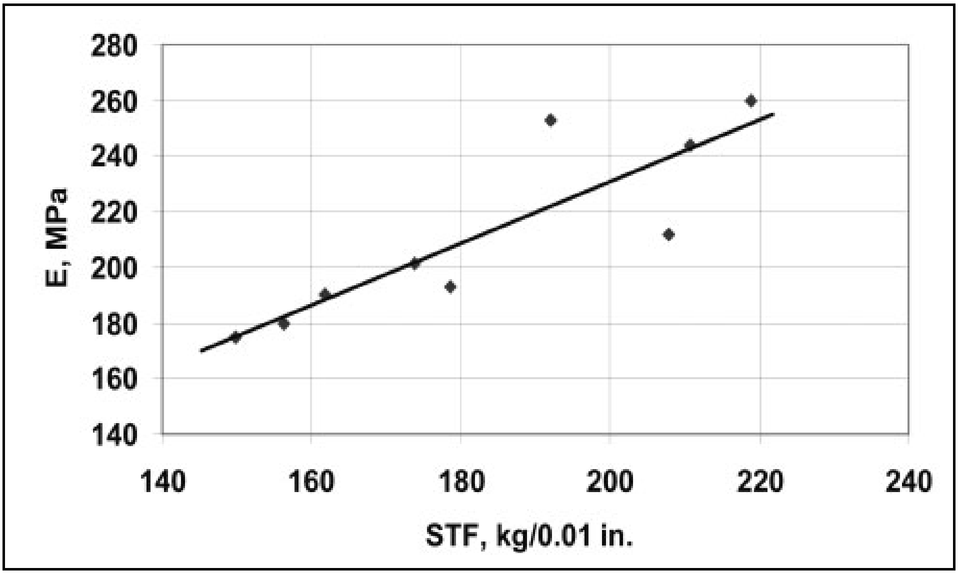

Fig.2. E versus STF at 60°C and 1.0 Hz

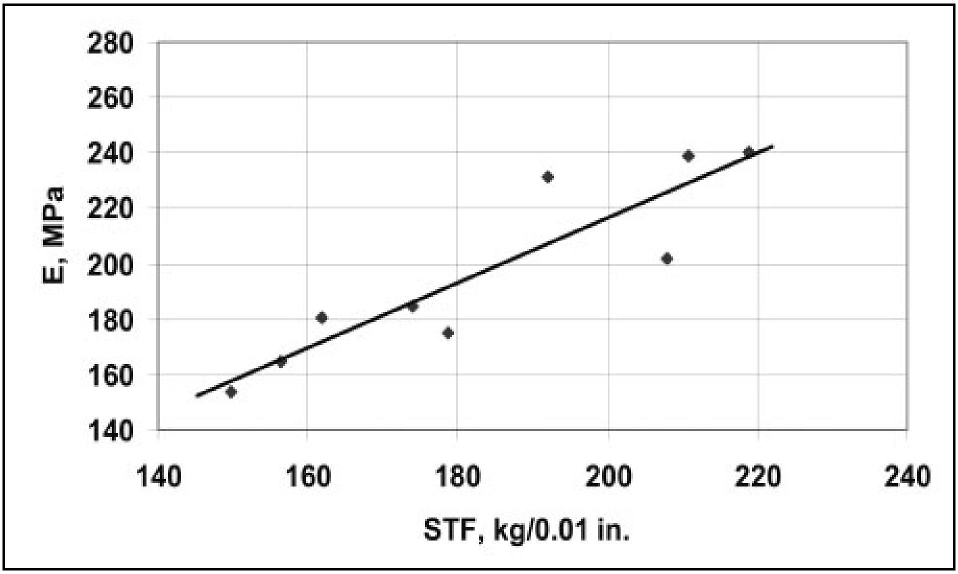

Fig.3. E versus STF at 60°C and 0.5 Hz

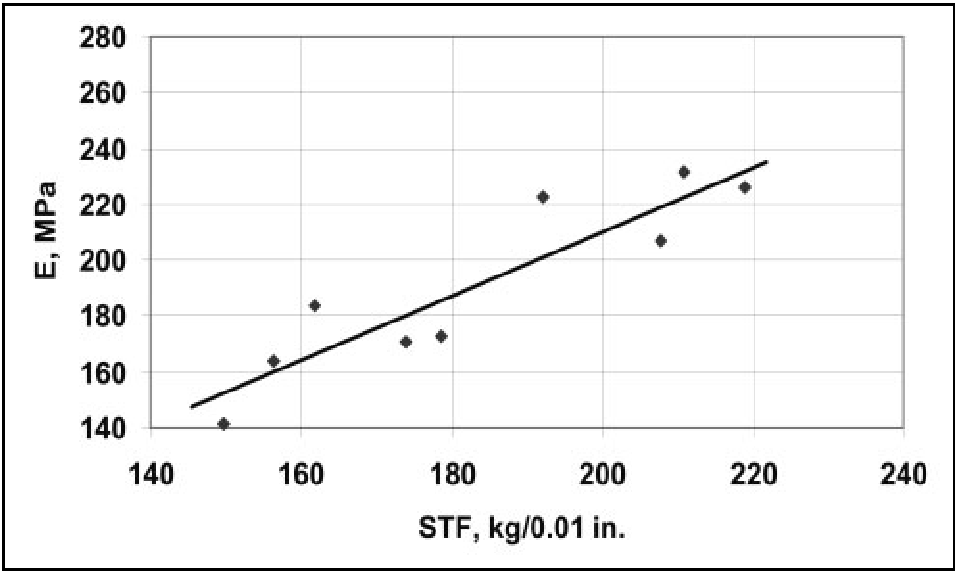

Fig.4. E versus STF @ 60°C and 0.33 Hz

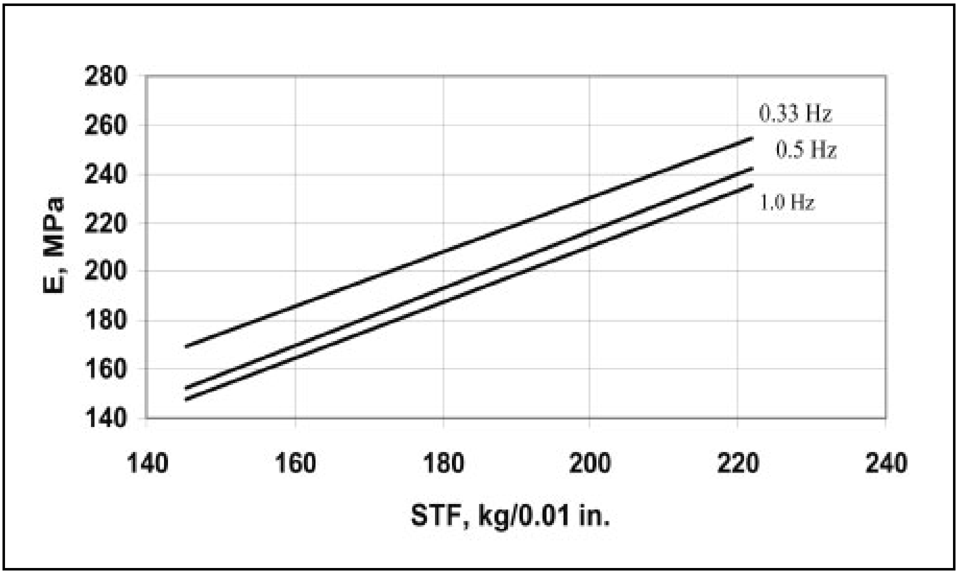

Fig.5. E versus STF @ 60°C and three loading conditions

CONCLUSIONS

The resilient modulus of asphalt concrete (AC) mixes is an important input in the structural desing process of AC pavements. In Kuwait, assumed (typical) values for this modulus are used to determine the required pavement layer thicknesses. This study shows that a relationship exists between certain parameters from the Marshall test and the resilient modulus. Three correlations were obtained relating the resilient modulus to the ratio of Marshall stability-to-flow at three different loading frequencies: 1.0, 0.5, and 0.33 Hz. During the course of testing and analysis, some conclusions were obtained, including:

- The stiffness of the AC mixes decreases with increases in temperature.
- The measured stiffness of an AC mix decreases with decreases in loading frequency, as shown in Figure 5. Therefore, slow traffic is expected to cause more deformation in pavements than faster traffic.
- The best relationships for predicting the AC resilient modulus are obtained by correlating it to the stability-to-flow ratio.
- The resilient modulus is linearly proportional to stability/flow ratio.
- The developed relationships shown in Figures 2 to 5 passed through the origin. This indicates that when stability equals zero, the material stiffness equals zero. This logical relationship strengthens the validity of the developed models.

- The developed models of the form E = f (STF) may be used to predict the resilient modulus of AC mixes using Marshall test results (stability and flow).
- The developed relationships may only be used within the range of moduli shown in Figures 2 to 5. Prediction of E-values outside this range needs further investigation. However, because the relationships pass through the origin of Figures 2 to 4, there is more confidence in using them in the lower.

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استخدام اختبار مارشال لتقييم معامل المتانة للخلطات الإسفلتية المستخدمة في الكويت

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خلاصة

يعتمد التصميم الإنشائي لطبقات رصف الطرق الإسفلتية على عدة عوامل من أهمها متانة خلطات الطبقات الإسفلتية. ويتم عمل التصميم الإنشائي لطبقات الرصف الإسفلتية في الكويت عادة باستخدام قيم إفتراضية لمعامل المتانة، وه قد لا تمثل القيم الحقيقية لمتانة طبقات الإسفلت المستخدمة. ويتطلب إجراء اختبار معامل المتانة وقتاً وجهداً وعمالة مدربة، بالإضافة إلى معدات مختبرية خاصة، ولك لا يتم عادة عمل ذلك الاختبار كإجراء روتيني للتحقق من متانة الخلطات الإسفلتية في الكويت.

وقد أجريت هذه الدراسة لإيجاد علاقة بين معامل المتانة للخلطات الإسفلتية من خلال ربطها بنتائج اختبار مارشال المستخدم أصلاً لتصميم تلك الخلطات. ويتم هذا التقدير من خلال إيجاد علاقة بين معامل المتانة وعناصر اختبار مارشال. والعناصر المستخدمة في هذه الدراسة هي نسبة الثبات/ التدفق، والعنصر الآخر هو دليل (مؤشر) مارشال، وهو عبارة عن ميل الجزء المستقيم من منحنى «الحمل – الانضغاط» الناتج من اختبار مارشال القياسي.

وقد تبين من التحليل التراجعي وجود علاقة بين قيم معامل المتانة ونسبة الثبات/ التدفق عند درجة حرارة 60 مئوية وذلك عند ترددات تحميل مختلفة. ويبدو من النموذج الناتج من التحليل وجود علاقة خطية بين معامل المتانة ونسبة الثبات/ التدفق بغض النظر عن نوعية الخلطة الإسفلتية المختبرة.