V-28 A PREDECTIVE EQUATION OF ASPHALTIC CONCRETE MIX MODULUS

Tohoku Univ.,Student member, A.H.Meiz.

1. INTRODUCTION

One major difficulty in response analysis of pavement structure is to determine the elastic moduli of pavement constituent layers.Two methods are currenly available for modulus determination.One method is by means of laboratory testing on specimens either compacted in the laboratory or extracted from the pavement structure,the other method is by nondestructive testing on the pavement surface.The first method was used in this investigation to determine the dynamic elastic modulus(DEM) of asphaltic concrete mixtures by transforming the response of these mixtures from time domain(creep test using triaxial apparatus) to the frequency domain (1).The influence of main mix components (aggregate gradation,asphalt content,and asphalt type) and test temperature on the DEM was investigated.Finally,a predective equation relating the DEM and the aforementioned variables was derived and examined statistically.

2. DEFINITION

The asphaltic concrete mix is a viscoelastic body,therefore,its mechanical properties depends on stress duration as well as the temperature at which this stress takes place.Many investigators indicated that,by applaying to a viscoelastic body a sinusoidal stress of the form

$$\sigma = \sigma_0 e^{i\omega t}$$

where:

σ_0 = stress amplitude,psi or kg/cm^2

$i = \sqrt{-1}$

ω = angular frequency,rad/sec

t = time,sec

The resulting strin has the same frequency as the stress but out of phase by an angle and is expressed by

$$\epsilon = \epsilon_0 e^{i(\omega t - \phi)}$$

where:

ϵ_0 = recoverable strain amplitude

ϕ = phase lag, degress

Figure(1-a)represents the relation between the sinusoidal stress and the resulting sinusoidal strain.Under these conditions, stress and stain are related by a complex number expressed by

$$E^* = \frac{\sigma_0}{\epsilon_0} e^{i\phi}$$

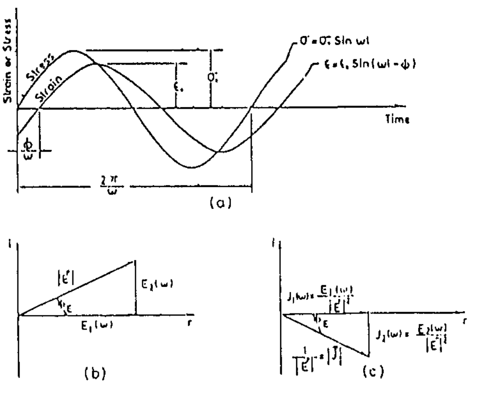

Fig.1.Dynomic Viscoelastic Response and Vectorial Resolutions : (a) Steady-State Response of Viscoelastic Material to Sinusoidal Strain or Stress,(b) Vectorial Resolution of Modulus Components in Sinusoidal Deformation, (c) Vectorial Resolution of Compliance Components in Sinusoidal Deformation.

Where E^* is defined as the complex modulus of the asphalt concrete mix.

The relation of the respective amplitudes of the stress and strain is called stiffness modulus S_m

$$S_m = \frac{\sigma_0}{\epsilon_0}$$

The phase-lag between these two values is called phase angle,its value gives an idea of the viscous or elastic predominance of the material under well defined conditions(for an elastic body is null)

The complex modulus E^* can also be written in the form

$$E^* = E_1 + iE_2$$

The relation between these three terms is shown in Figure(1-b).E_1 is the real component of the modulus,in phase with the stress,represents the part of the stored energy in the material,which could be restored. E_2 is the imaginary component of the modulus,in quadrature with the stress,gives an idea of the energy lost by internal friction inside the material.Figure(1-c) represents another way of expressing E^* using an alternative expression J^*(complex elastic compliance)which is the reciprocal of the complex modulus.

3. MATERIALS AND TESTING PROGRAM

To investigate the asphaltic concrete mix components and temperature changes effect on the DEM,cylindrical asphalt concrete specimens 7cm by 15cm were prepared for the creep test with an average density $2.4 gm/cm^3$.

One aggregate type(silicious sand,crushed limestone,and limestone filler)was used with two gradations,one with a maximum

Test	Designation Number	Test Results Suez	Test Results Alex.
Specific gravity at 22/25°C	AASHO T-63	1.02	1.10
	ASTM D-70		
Penetration,25°C,100 gm,5 sec	AASHO T-49	65	65
	ASTM D-5		
Kinematic viscosity,centis		352	207
tokes softening Point, °C	ASTM D-36	52	50

Table 1. Physical Properties of the Asphalt Cements.

size 9.53mm and the other with a maximum size of 12.7mm[5-A(dense)and 3-B(open),respectively according to the Asphalt Institute specifications].

Two asphalt cements obtained from Suez and Alexandria refineries in Egypt were used.The physical properties for the asphalts are given in Table(1).Also,the asphalt content varies between 4.5%and 6.5%.

Test temperatures in the range of 10°c to 40°c according to typical ambient temperature in Egypt.

Test specimens were cassified to three groups A,B,and C and a total of 54 specimens were molded for testing.Table (2) illustrates the various combinations in the experimental design of the laboratory testing program.

4. ANALYSIS AND DISCUSSION OF RESULTS

4.1 Creep Test Results

Creep tests were performed on uncofined test cylinders using the traixial compression test.The exprimental stress levels used were selected to be sufficiently law (approximately in the range of 0.2 to 1.2 kg/cm²).

Mix Type	Asphalt Type: Suez	Asphalt Type: Alex.	Asphalt content	Aggregate Gradation: 5 A	Aggregate Gradation: 3 B	Test Temperature: 20°C	30°C	40°C	Number of Replicates
			4.5			x	x	x	6
A	x		5.5	x		x	x	x	6
			6.5			x	x	x	6
			4.5			x	x	x	6
B	x		5.5		x	x	x	x	6
			6.5			x	x	x	6
			4.5			x	x	x	6
C		x	5.5	x		x	x	x	6
			6.5			x	x	x	6

Table 2 . Experimental program: Investigation of mix component and test temperature

4.2 Determination of DEM

The DEM was determined by transforming the response of the asphalt concrete mixtures from the time domain (creep test) to the frequency domain.This method depends on the equation of the 4-element model as well as the Laplace transformation As DEM is a complex number it must be resolved into magnitude and phase as shown in Figure (2), or real and imaginary parts as shown in Figure (3).Figure (2) has the advantage of yielding directly the amplitude and phase angle of the material response and Figure (3) depicts the change in the degree of elasticity of the material due to change in frequency.

4.3 Factors Affecting DEM

The following are pertinent to the results and findings of this research :

1. The DEM increases by a factor of 2.5 as the frequency (time of loading) increases from 10^{-3} to 10^{-1} rad/sec.For frequency over 10^{-1} rad/sec, the change in DEM value is not appreciable.
2. For a constant temperature,asphalt type, aggregate gradation,the DEM decreases by nearly 65% as the asphalt content increases from 4.5% to 6.5%.4.5% asphalt content could be considered as the limit at which the asphalt film reaches a critical thickness and consequently,any increase in the asphalt content tends to decrease the DEM
3. The DEM of dense asphalt mix is approximately 20% higher than the open mix

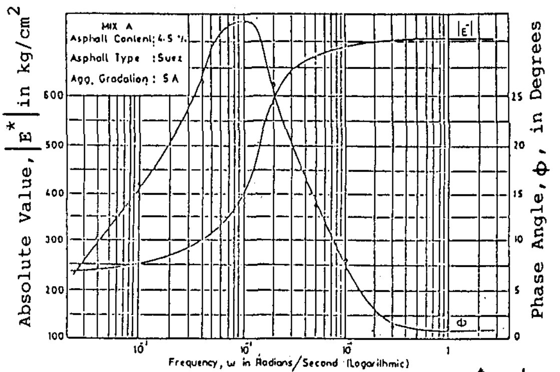

FIG. 2: Magnitude and Phase Angle of Complex Elastic Modulus, E*, at 20°C

4. The DEM decreases by nearly 40% as the temperature increases from 20°c to 40°c.

5. MATHEMATICAL RELATIONSHIP

The suggested equation is:

$$\log_{10}|E^*| = 2.13613 + 0.0722324\, X_1 - 0.0024956\, X_2 - 0.054983\, X_3 - 0.0204573\, X_4$$

$R^2 = 0.942$ S.E. = 0.0626791

where :

$|E^*|$ = DEM in kg/cm²

X_1 = percent passing sieve No. 200,

X_2 = asphalt viscosity, centistakes (at 135°C),

X_3 = percent asphalt by weight of mix,

X_4 = test temperature,°C,

R^2 = coefficient of multiple determination,

S.E.= standard error of estimate.

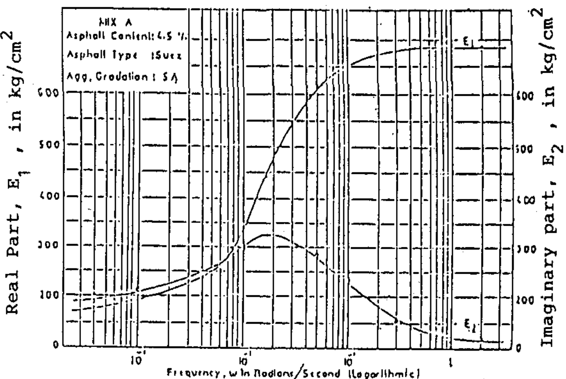

FIG. 3: Real and Imaginary Parts of Complex Elastic Modulus, E*, at 20 C

6. CONCLUSIONS

1. DEM is affected by the mix components (aggregate gradation,asphalt type and content) and test temperature.
2. The proposed equation relating DEM to the mix components and test temperatures may be used to estimate DEM using the results of routine tests.

REFERENCES

1. H.S. Papazian,"The response of linear viscoelastic materials in the frequency domain with emphasis on asphaltic concrete" Proc.,Internat.Conf.on Struct.Design of Asphalt pavements,Ann Arbor,Mich.,(1962), pp. 454-643.