2 Material Characterization

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Contents

2.1 Introduction and Type of Characteristics-1

The properties of pavement materials characterized by
- Strength
- Deformation
- Fatigue resistance are of interest.

These material characteristics are defined by
- their use in the method of design
- evaluation of pavement structures.

2.1 Introduction and Type of Characteristics-2

They can be classified into three groups of characteristics,
- empirical or conventional strength and deformation
- classical Mechanics
- fatigue resistance characteristics.

The understanding of their characteristics and their determinations from
- correlation
- laboratory tests

Type of Characteristics

2.1.1 Conventional Strength and Deformation Characteristics

2.1.2 Characteristics Used in Classical Mechanics

2.1.3 Fatigue Resistance Characteristics

2.1.1 Conventional Strength and Deformation Characteristics

• routine tests in pavement design work

Test methods
- Plate load test
- Triaxial test
- CBR test
- Marshall test
- Stabilometer and Cohesiometer test
- Modulus of rupture test
- Indirect tensile test

2.1.2 Characteristics Used in Classical Mechanics-1

- The new methods of pavement design are based on rational approach.
- employs the classical Mechanics theory to predict stress and stain
- or called Mechanistic method
- requires input material properties from laboratory tests or from correlation

2.1.2 Characteristics Used in Classical Mechanics-2

- These are :
  - Resilient Modulus
  - Complex Modulus
  - Dynamic Stiffness
  - Asphalt mix stiffness
  - Modulus determined from wave propagation technique

2.1.3 Fatigue Resistance Characteristics

Mode of failures of pavement structures are
-fatigue crack
-and fatigue rutting.

- These two characteristics are needed in the design of pavements using mechanistic method.
- Several test methods for determination of the characteristics of
  - fatigue cracking
  - and rutting

2.2 Tests on Conventional Strength and Deformation Characteristics

2.2.1 Plate Load Test

-This is a routine test for the determination of an elastic property of soil foundation needed in the design of rigid pavements.

-The test is introduced to simulate the foundation response as a one dimensional spring stiffness or the Winkler elastic model. This soil stiffness is called the Modulus of Subgrade Reaction or the soil K value.

-The test is standardized by ASTM and AASHTO.
 - By Using 30 inches in diameter circular plate=> loading a prepared foundation.

-The plate is stiffened to ensure a uniform settlement. The resulted soil pressure and settlement are plotted as shown in Figure 2.1.

The Modulus of Subgrade reaction, k value which can be called a secant modulus is computed at the value of soil pressure of 10 psi. It is found that the k value depends on plate size, intensity of pressure and soil moisture.

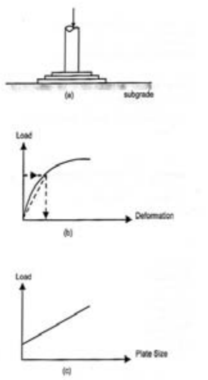


Figure 2.1 (a) Plate Load Test (b) Load V.S. Deformation (c) Effect of Plate Size

Since the k value depends on soil moisture condition, the test should be conducted to simulate that of the service conditions or the worst possible condition during the design life. The k value for other moisture conditions could also be estimated from the value at test condition using the relationship:

$$k_s = \frac{d_u}{d_s} k_u$$

where d is the deformation, s designates the service condition and u the field conditon.

d_s are to be determined in laboratory using a consolidation test under a pressure of 10 psi.

Plate loading test is time consuming and expensive, an other way of obtaining the k value is by correlation with simple tests such as C.B.R. and R value test. Figure 5.2 .shows the approximate relationship between k value and other soil properties.

2.2.2 Triaxial Test

A triaxial test for determining of the Modulus of deformation or Elastic modulus is a static test performed in a Triaxial apparatus. It is essentially a 3 can be determined from Elastic theory. For a triaxial test on elastic material the stress-strain relationship is written as:

$$\varepsilon_{zz} = \frac{1}{E}\left[\sigma_{zz} - \mu(\sigma_{rr} + \sigma_{\theta\theta})\right]$$

$$\varepsilon_{rr} = \frac{1}{E}\left[\sigma_{rr} - \mu(\sigma_{\theta\theta} + \sigma_{zz})\right]$$

$$\varepsilon_{\theta\theta} = \frac{1}{E}\left[\sigma_{\theta\theta} - \mu(\sigma_{rr} + \sigma_{zz})\right]$$

For triaxial test, σ_{rr} equal to $\sigma_{\theta\theta}$ so ε_{zz} can be written as

$$\varepsilon_{zz} = \frac{1}{E}\left[\sigma_{zz} - 2\mu\sigma_{rr}\right]$$

$$E = \frac{\sigma_{zz} - 2\mu\sigma_{rr}}{\varepsilon_{zz}}$$

Where E is called the Modulus of deformation
μ is the Poisson ratio

If the test is done on a saturated sample, ($\mu = 0.5$) the Modulus becomes:

$$E = \frac{\sigma_{zz} - \sigma_{rr}}{\varepsilon_{zz}}$$

where $(\sigma_{zz} - \sigma_{rr})$ is called the deviator stress.

Typical values of Elastic modulus for various types of materials are shown in Table 5.1

Table 2.1 Elastic Modulus for Different Materials.

Material	Range (psi)	Typical (psi)
Portland Cement Concrete	$3x10^6$ to $6x10^6$	$4x10^6$
Cement Treated Bases	$1x10^6$ to $3x10^6$	$2x10^6$
Soil Cement Materials	$5x10^4$ to $2x10^6$	$1x10^6$
Lime-fly-ash Materials	$5x10^5$ to $2.5x10^6$	$1x10^6$
Stiff Clay	7,600-17,000	12,000
Medium Clay	4,700-12,300	8,000
Soft Clay	1,800-7,700	5,000
Very Soft Clay	1,000-5,700	3,000

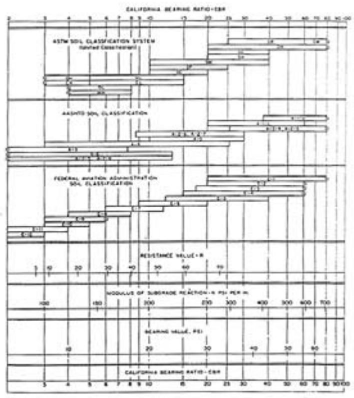


Figure 2.2 Approximate relationship between k values and other soil properties (1 psi = 6.9 kPa, 1 pci = 271.3 kN/m³. (After PCA (1966).)

2.2.3 CBR Test

This is an empirical strength evaluation of pavement materials developed by the Department of Highway, state of California. It is widely used as strength parameter for the design of pavement structures. It is now a standard test designated by AASHTO and ASTM.

CBR test, (Figure 2.3) is essentially a penetration test where a standard piston having an end area of 3 sq. inches is forced to penetrate the soil at a standard rate of 0.05 inches/min. The CBR. Value is generally computed as the ratio between the load at 0.1 inches penetration to the standard load obtained from a high quality crushed stone material. The standard loads obtained from crushed stone material are:

Penetration (inch)	Load (psi)
0.1	1000
0.2	1500
0.3	1900
0.4	2300
0.5	2600

2.2.4 Stabilometer and Cohesiometer Test

- The tests are introduced by California Division of Highway which can be used for unbounded and bounded materials (Aggregate and Asphalt Concrete).
- The Stabiometer test is a means of measuring internal friction whereas the Cohesionmeter is for measuring the cohesion. They are mainly used by the State of California in his method of flexible pavement design.

The Stabilometer test

is done on a cylindrical specimen of 4 inches in diameter and 2.5 inches in height. The specimen is loaded by a lateral pressure and a vertical load as shown in Figure 2.4

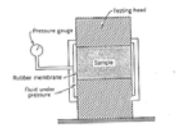


Figure 2.4 Stabilometer, schematic diagram.

The test result is evaluated in terms of the soil resistance value (R) for unbounded materials and of the Stability value for bounded materials.

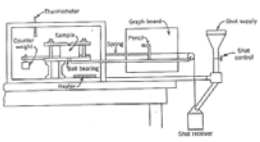


Figure 2.5 cohesiometer.

Cohesiometer test

- is employed for a measurement of cohesion, tensile strength or Modulus of rupture. It is performed using Cohesiometer, an apparatus capable of breaking small beams of specimen under constant rate of loading as shown in figure 2.5

2.2.5 Marshall Test

The test is performed basically for the design of asphalt concrete mixes. However two characteristics of mix are important to its performance as road making material.

They are the Stability and the Flow value.

- Marshall stability is the maximum load that the specimen can withstand.
- The Flow value which is measure of flexibility is the vertical distortion of the specimen at failure.

The test is done on a specimen of 4 inches in diameter and 2.5 inches height. It is loaded vertically along the axis of specimen with constant loading rate of 2 inches/min. The Stability and the Flow value are measured at the time of specimen failure

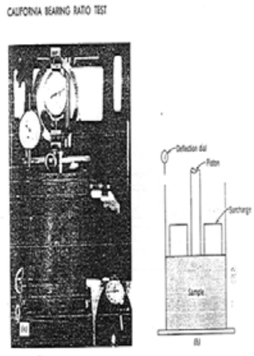


Figure 2.3 California Bearing Ratio test. (a) View of cylinder and dial; (b) schematic diagram.

2.2.6 Modulus of Rupture

- The Modulus of Rupture, MR is the extreme fiber stress under the breaking load of the standard specimen under the third-point loading. It is normally performed on concrete specimen with 6 inches x 6inches square cross section and 18 inches long.
- The Modulus value con also be estimated from correlation with the compressive strength of concrete.

$$MR = k\sqrt{f_c'}$$

where MR is the Modulus of Rupture
k is a constant between 8 and 10
f_c' is the compressive strength in psi

2.2.7 Indirect Tensile Test

- It is used for determining the tensile strength of stabilized material, concrete and cement mortar. The test specimen is of a cylindrical shape. It is load as line load along cylindrical axis. This results in a splitting failure generally occurring along the diametrical plane. The test is sometime called Splitting Test or Brasilian Test.
- The stress distributions result in a uniform tension along the vertical diametral plane which is the plane of failure and a compression on horizontal diametral plane as shown in figure 2.6

The value of tensile strength is given by

$$S_t = \frac{2P_{max}}{\pi t d}$$

where P_{max} is the maximum applied load
d is the specimen diameter (inch)
t is specimen thickness (height)

2.3 Classical Mechanics Characteristics

2.3.1 Resilient Modulus

It is defined for subgrade soil, untreated granular subbase and base materials. The Resilient modulus is similar to the modulus of deformation however it is evaluated under repeated loading. The modulus value could be estimated using repeated loading triaxial test after a curtained numbers of loading cycles from:

$$M_R = \frac{\sigma_{zz} - \sigma_{rr}}{\varepsilon_{zz}}$$

where M_R is the Resilient modulus
$\sigma_{zz} - \sigma_{rr}$ is the deviator stress
ε_{zz} is the axial recoverable strain

The modulus is found to depend on the state of stress, θ which is the summation of the three principal stress σ_{ii}. The Resilient modulus can also be estimated from correlation. For fine grain soil such as subgrade, the modulus could be estimated using the relationship:

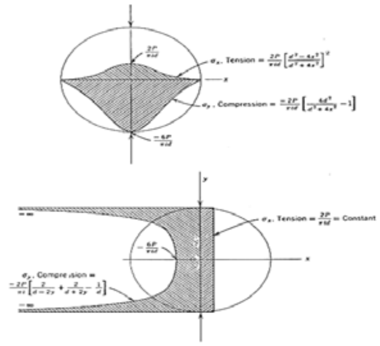


Figure 2.6 Theoretical stress distribution on horizontal and vertical diametral planes for indirect tensile test. (From Froch t.)

$$M_R = 1500 \text{ C.B.R.}$$

where M_R is in psi and C.B.R. in percent.
For granular subbase and base, the modulus can be estimated from:

$$M_R = k_1 \theta^{k_2}$$

where k_1 and k_2 are constants
θ is the summation of principal stress, $\Sigma\sigma_{ii}$

AASHTO suggests the modulus value for subbase and base under various conditions as shown in Table 5.2

2.3.2 Complex Modulus

- The complex modulus is used to represent the linear visco-elastic property of pavement materials. It is a complex number which relates stress to strain. A test is done by exciting a specimen using a dynamic sinusoidal force. The force can be represented by:

$$\sigma = \sigma_o \sin\omega t$$

For steady state condition, the deformation response is also in sinusoidal form but with a lag time ϕ due to inertia effect:

$$\varepsilon = \varepsilon_o \sin(\omega t - \phi)$$

In complex notation, σ and ε can be written as

$$\sigma = \sigma_o e^{i\omega t}$$
$$\varepsilon = \varepsilon_o e^{i(\omega t - \phi)}$$

The modulus which is defined as the ratio of σ / ε is :

$$E^* = \frac{\sigma_o e^{i\omega t}}{\varepsilon_o e^{i(\omega t - \phi)}} = \frac{\sigma_o}{\varepsilon_o} e^{i\phi} = |E_o| e^{i\phi}$$

Written in complex number as:

$$E^* = E' + iE''$$

Moisture State	Developed Relationship	Stress State (psi) $\theta = 5$	$\theta = 7.5$	$\theta = 10$
Damp	$M_R = 5400\,\theta^{0.6}$	14,183	18,090	21,497
Wet	$M_R = 4600\,\theta^{0.6}$	12,082	15,410	18,312

Asphalt Concrete Thickness (inches)	Stress State(psi)
less than 2	10.0
2 - 4	7.5
greater than 4	5.0

Table 2.2(a) AASHTO Recommended Values of K_1, K_2 and θ for Subbase Layer

Moisture State	Equation	Stress State (psi) θ = 5	θ = 10	θ = 20	θ = 30
Dry	$8000\theta^{0.6}$	21,012	31,848	48,273	61,569
Damp	$4000\theta^{0.6}$	10,506	15,924	24,136	30,784
Wet	$3200\theta^{0.6}$	8,404	12,739	19,309	24,627

Asphalt Concrete Thickness (inches)	Roadbed 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

Table 2.2(b) AASHTO Recommended Values of K_1, K_2 and θ for Base Layer

where E' is $\frac{\sigma_0}{\varepsilon_0}\cos\phi$, a real part representing the spring behaviour.

E'' is $\frac{\sigma_0}{\varepsilon_0}\sin e\,\phi$, an imaginary part representing the energy lost or the dissipation of energy.

The complex modulus can be represented physically by a model of Kelvin-Voigt as shown in Figure 2.7

For simultaneous response, a response with no delay, $\phi=0$, the model becomes an elastic model with the modulus equal to σ_0/ε_0.

2.3.3 Dynamic Stiffness

- This is an elastic modulus determined from bending test of a beam under repeated loading. The most well known is that of the University of California at Berkeley which used a 1.5x1.5 inch cross section and 15 inches long specimenas shown in figure 2.8. Repeated haversine loading with a load duration of 0.1 sec. and a rest period of 0.4 sec. are applied at the third points. By using beam theory, the stress, stiffness modulus and strain can be computed.

2.3.4 Asphalt Mix Stiffness

- Modulus From Correlation
- The dynamic stiffness can be estimated from correlation. Shell introduced two nomographs for the determination of asphalt mix stiffness. The value is terms "Stiffness modulus". The procedure consists of first determining the stiffness of bitumen and then apply it to determine the mix stiffness using the percent volume of bitumen and the percent volume of the mineral aggregate in the mix.
- The stiffness of bitumen depends on temperature, the time of loading and the characteristics of bitumen. The characteristics of bitumen are expressed as a penetration index, P.I., defined by:

$$PI = \frac{20-500A}{1+50A}$$

in which A is the temperature susceptibility, which is the slope of the straight line plot between the logarithm of penetration and temperature, or

$$A = \frac{\log(\text{Pen at } T_1) - \log(\text{Pen at } T_2)}{T_1 - T_2}$$

T_1 and T_2 are two temperatures at which penetrations are measured. Normally, T_2 is taken as the temperature at the ring and ball softening point where all bitumens have the same viscosity or penetration of about 800.

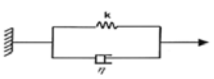


Figure 2.7 Kelvin-Voigt Visco-elastic Model

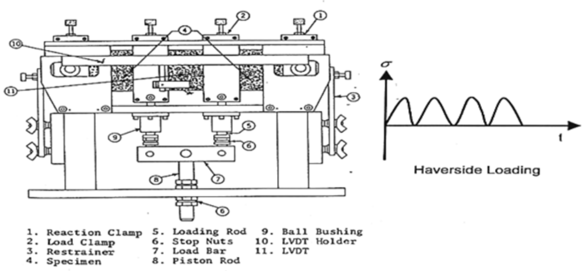


Figure 2.8 Fatigue testing equipment.

It has been suggested that a loading time of 0.02 sec. Which corresponds to a frequency of 8 HZ is representative of the range of loading times occurring in practice and equivalent to a vehicle speed of 30 to 40 mph. figure 2.9. shows the nomograph for the determination of stiffness modulus of bitumens.

The stiffness modulus of asphalt mixes depends on the bitumen stiffness, the percent volume of bitumen and the percent volume of mineral aggregate. The empirical relationship is of the form:

$$S_m = S_b\left[1+\left(\frac{2.5}{n}\right)\left(\frac{C_v}{1-C_v}\right)\right]^n$$

where S_m is the mix stiffness
S_b the stiffness of bitumen
n equal to 0.83 log $\left[(4\times10^5)/S_b\right]$

$$C_v = \frac{\text{Volume of Aggregate}}{\text{Volume of Aggregate} + \text{Volume of bitumen}}$$

The nomograph for determining the stiffness modulus of mixes is shown in Figure 5.10

2.3.5 Modulus from Wave Propagation Technique

- It is well known that the velocity of wave propagation which will be called wave velocity depends on the material type and property. In a half-space solid excited by a dynamic force, three types of waves are generated, the P-wave or compression wave, the S-wave or Shear wave and the Rayleigh or surface wave. The velocities of the three waves can be related to the Young modulus as follows:

- Typical Value of Asphalt Concrete Modulus

The modulus of asphalt concrete depends on temperature, loading time (loading frequency) and mix composition. The typical value are shown in Table 2.3

Table 2.3 Typical Asphalt Concrete Modulus Value

Temperature (°F)		Load Frequency (Hz) 1 cps	2 cps	3 cps
40	Mean	12.0*	16.0	18.0
	Range	6.0-18.0	9.0-27.0	10.0-30.0
70	Mean	3.0	5.0	7.0
	Range	2.0-6.0	4.0-9.0	5.0-11.0
100	Mean	0.7	1.0	1.6
	Range	0.5-1.5	0.7-2.2	1.0-3.2

* Value x10^5 psi

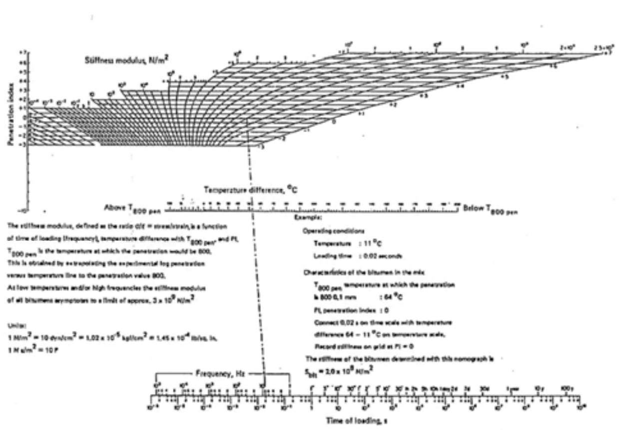


Figure 2.9 Nomograph for stiffness modulus of bitumens. (After Van der Poel (1954).)

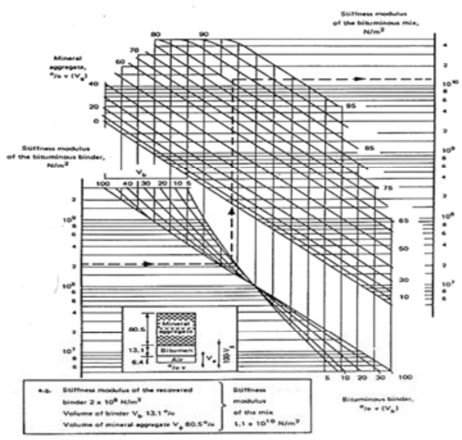


Figure 2.10 Nomograph for stiffness modulus of mixes. (After Shell ,1978.)

For S-wave : $E = 2(1+\nu)V_s^2\rho$

For P-wave : $E = \dfrac{(1+\nu)(1-2\nu)}{(1-\nu)}V_p^2\rho$

For R-wave (Approximation) : $E = \dfrac{2(1+\nu)}{\alpha^2}V_R^2\rho$

where E is the Young modulus
ν Poisson ratio
ρ mass density
V_s, V_p, V_R the wave velocity of shear, compression and Rayleigh wave
α is the ratio between V_R and V_s (V_R/V_s)

α is found to depends on Poisson ratio and ranges between 0.875 (ν=0) to 0.955 (ν=0.5)

- It can be seen, from theory that if the wave velocity is known, the modulus of material can be determined. This application has been used extensively in Geotechnical Engineering field for a determination of soil modulus using the so-called Cross-hole technique.

- An application to determine the modulus of pavement layers consists of loading the pavement surface with harmonic force using vibratory plate. At various distances from plate center, install devices such as oscilloscope or electrical pickup for measuring the numbers of wave within each distance. The wave velocity is then computed from two basic relationships:

$$V = \lambda f$$
$$\lambda = x / n$$

where v is the wave velocity (in this case is Rayleigh wave)
λ the wave length
f wave frequency
x distance from plate center to detector
n numbers of wave within distance x.

- **The Case of a Homogeneous Half-Space**
  The above mentioned technique can be employed directly. The numbers of wave for each distance Xi are measured and the average wave length can be determined, thus the surface wave velocity and the modulus. Figure 2.11 illustrates the wave propagation technique.

- **The Case of a Layered Half-Space**
  Pavement structures consist of rather thin layers of different materials. Since the energy carried by the surface (Rayleigh) wave is negligible at a depth greater than half the wave length, the modulus of each layer can be determined by selecting the frequency of exciting force producing the appropriate wave lengths.

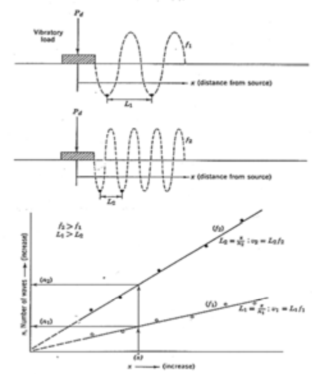


Figure 2.11 Schematic illustration of surface wave propagation through ideal elastic media.

- The procedure to determine the modulus of layered pavement in described in detail in the reference, The Principles of Pavement Design, 2rd Edition by Yoder and Witczak, 1975.

- It is however important to state that the modulus of materials are frequency dependent. This implies that the modulus should be determined for a loading frequency simulating what happening in reality. This poses a severe limitation on the wave propagation technique for layered pavement problems.

2.3.6 The Falling Weight Deflectometer (FWD)

- The Falling Weight Deflectometer (FWD) is developed from French "Deflectometer a' boulet". It is a test to measure the road surface deflection basin caused by impact load. The force pulse with duration of 25-30 sec. is produced from dropping a weight on a plate resting on the road surface. At present time there are two types of FWD in use, the light weight FWD which could produce the peak force of up to 120 Kn and the heavy weight FWD which produces of up to 250 Kn. It is claimed that the Light Weight FWD simulates closely to the moving wheel load of heavy truck whereas the heavy weight is suitable to be used for airfield structure. The deflection basin is measured by seven geophones placed along the radial line from the plate center. Figure 2.12 show the Dynatest 8000FWD.

The main use of FWD is for the determination of the modulus of pavement layer. If the deflections at various distance is known, the modulus of each layer could be determined by back-calculation using theory of mechanics. There are computer programs based on this theory which can be used, two of them are the program MODULUS and WESDEF
The concept used in the back-calculation is to very the modulus value of each layer until the calculated deflections match to the measured values. This can be accomplished by using an optimization technique.
Taking The objective function as the sum square error of the deflection :

$$\varepsilon^2 = \sum_{i=1}^{n}\left(\frac{w_i^m - w_i^c}{w_i^m}\right)^2$$

where w_i^m is the measured deflection at point i
w_i^c is the calculated value
n the number of measurement

when w_i^c can be determined using the theory of mechanics, then a search method can be used to find the value of modulus which give the sum square, ε^2 the minimum.

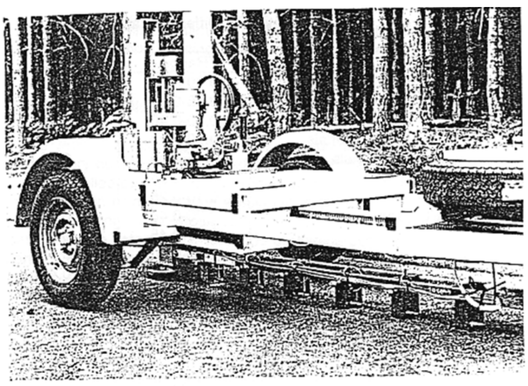


Figure 2.12 The Dynatest 8000 Falling Weight Deflectometer.

2.3.7 Poisson Ratio

In classical mechanic analysis, the stresses and deformations depend on the Poisson ratio. The Poisson ratio, v is defined as the ratio of the lateral strain to the axial strain under a uni-axial loading. Poisson ratio has the value between zero, no lateral deformation and 0.5, incompressible materials. Poisson ratio has a relatively small effect on results so typical values can be used in analysis. Table 2.4 gives typical Poisson ratio for paving materials.

Table 2.4 Poisson Ratios for Different Materials

Material	Range	Typical
Hot mix asphalt	0.30-0.40	0.35
Portland cement concrete	0.15-0.20	0.15
Untreated granular materials	0.30-0.40	0.35
Cement treated granular materials	0.10-0.20	0.15
Cement treated fine grain soils	0.15-0.35	0.25
Lime-stabilized materials	0.10-0.25	0.20
Lime-fly ash mixtures	0.10-0.25	0.15
Loose sand or silty sand	0.20-0.40	0.30
Dense sand	0.30-0.45	0.35
Fine-grain soils	0.30-0.50	0.40
Saturated soft clays	0.40-0.50	0.45

2.4 Fatigue Resistance Characteristics

A fatique failure is characterized by a failure under repeated loading where the load magnitude is well below a design static load.

The first reported investigations were carried out in 1829 by a German mining engineer who made repeated loading test on iron chains. Most following researches were emphasized on fatigue failures in service occurred in the axles of stage coaches and in those of rolling stock of railway systems. Much current fatigue research has been provided by the aircraft industry, both in relation to structural materials and assemblies. However It is in the aeronautical field that the major developments for predicting the fatigue lifes of structure under actual service conditions or load spectra have taken place, and these have been associated with the laboratory testing of both simple specimens and complete structures under lading sequences closely simulating those experienced in service. This approach is now being used more generally for both machine components and for other types of engineering structure such as railway, road and bridges.

Since the recognition that pavements fail by fatigue and the coming of mechanistic method of pavement design which require the knowledge of fatigue resistance characteristics of materials, the research on predicting fatigue life of pavements is spreadly carried out. The failure modes of pavements are cracking of asphalt concrete and concrete surface, the rutting of asphalt concrete and subgrade soil. Most tests on fatigue resistance characteristics have been done of these types of pavement materials.

2.4.1 Methods of Test

It is important to emphasize here that any test method which can generate repeated stresses or strains at a required frequency and loading can be used to investigate the fatigue characteristics. The main types of fatigue testing machines in used can be grouped according to the basic types of straining action or loading system applied to the specimen. These are rotating bending, plane bending, axial loading, torsion and combined stress as shown in Figure 2.13

Current research on fatigue life of pavement materials devices the methods of test, loading wave form, loading frequency as shown in Table 5.5

2.4.2 Modes of Loading

The modes of loading where the method by which stress and strain are permitted to vary during repetitive loading are controlled-stress and controlled-strain mode. In controlled-stress mode, the load or stress is maintained constant during test whereas strain or deformation amplitude is constant for controlled-strain mode. The choice of loading mode should reflect what actually happens in reality. Attempts have been made to determine what mode of loading best simulates actual pavement conditions. One approach is to make use of a parameter termed the mode factor, defined as:

$$MF=A-B / A+B$$

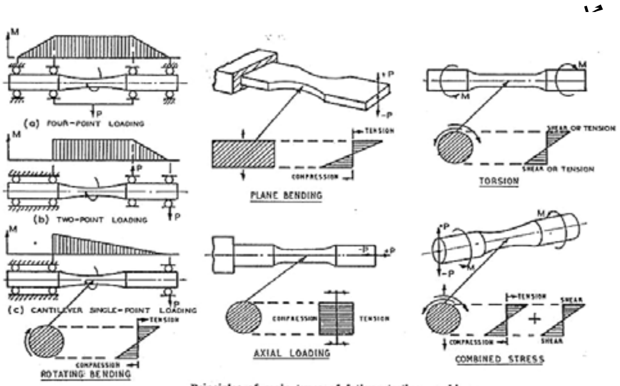
where MF is the the mode factor, A is the percentage change in stress due to a stiffness decrement of C percent, B is the percentage change in strain due to a stiffness decrement of C percent, and C is an arbitrary but fixed reduction in stiffness resulting from the accumulation of fatigue damage under repetitive loading. The mode factor assumes a value of -1 for controlled-stress conditions and +1 for controlled-strain conditions. Normally controlled-stress is used for the case of thick surface and controlled-strain for thin surface (<3 inches). Table 5.6 shows the comparative evaluation of controlled-stress and controlled-strain loading.

2.4.3 Description of Test Methods

Several test methods are used in determining the fatigue characteristics of pavement materials. Here only some common methods will be described.

- **The University of California Bending Test**

  A simply supported asphalt-concrete beam specimen is subjected to a controlled load or deflection under the third-point loading. The beam specimen is 1.5 in. x 1.5 in. x 15.0 in. and the loads are applied at two locations to ensure a uniform bending moment through the mid span of the beam. A haversine pulsation loading having a time of loading of 0.1 sec. And a frequency of loading of 100 repetitions per minute is applied. This method is also used by the Asphalt Institute but with the larger beam size of 3 in. x 3 in. x 15 in. Figure 2.14 shows the UCB bending test apparatus.



Principles of main types of fatigue testing machines

Figure 2.13

Table 2.5 Summary of Fatigue Test Characteristics (Modified from Porter and Kennedy, 1975)

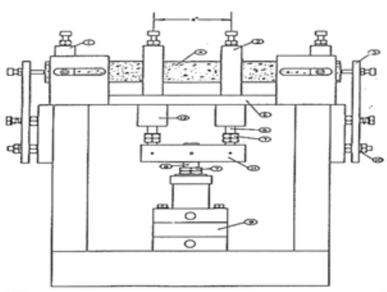
Test	Loading Configuration	Stress Distribution	Loading Waveform	Loading Frequency, cps	Performance Deformation Allowed?	State of Stress	Does failure occur in a Uniform Bending Moment or Tensile Stress Zone?
Third Point Flexure			Haversine Load Rest - 1.9	1-1.67	No	Uniaxial	Yes
Center Point Flexure		Same as above	Sine, Triangular Rectangular Load Rest - 1:100 max	1:100	No	Uniaxial	No
Cantilever			Sine (Bonnot), Sine, Triangular Load Rest - 1:100 (van Dijk) max	25 (Bonnot) - 1:100 (van Dijk)	No	Uniaxial	No
Rotating Cantilever				16.67	No	Uniaxial	Yes

Table 2.5 Summary of Fatigue Test Characteristic, (Modified from Porter and Kennedy, 1975), continued

Test	Loading Configuration	Stress Distribution	Loading Waveform	Loading Frequency, cps	Performance Deformation Allowed?	State of Stress	Does failure occur in a Uniform Bending Moment or Tensile Stress Zone?
Axial				8.33-25.0	No	Uniaxial	Yes
Diametral		Horiz Vert	Horizontal Vertical	1.0	Yes	Biaxial	No
Supported Flexure (Beam)			Haversine	0.75	Yes	Uniaxial	No

Table 2.6 Comparative Evaluation of Controlled-Stress and Controlled-Strain Loading

VARIABLES	CONTROLLED-STRESS (LOAD)	CONTROLLED-STRAIN (DEFLECTION)
Thickness of asphalt concrete layer	Comparatively thick asphalt bound layers	Thin asphalt-bound layer; < 3 inches
Definition of failure; number of cycles	Well-defined since specimen fractures	Arbitrary in the sense that the test is discontinued when the load level has been reduced to some proportion of its initial value; for example, to 50 percent of the initial level
Scatter in fatigue test data	Less scatter	More scatter
Required number of specimens	Smaller	Larger
Simulation of long-term influences	Long-term influences such as aging lead to increased stiffness and presumably increased fatigue life	Long-term influences leading to stiffness increase will lead to reduced fatigue life
Magnitude of fatigue life, N	Generally shorter life	Generally longer life
Effect of mixture variables	More sensitive	Less sensitive
Rate of energy dissipation	Faster	Slower
Rate of crack propagation	Faster than occurs in situ	More representative of in-situ conditions
Beneficial effects of rest periods	Greater beneficial effect	Lesser beneficial effect



Key:
1. Reaction clamp
2. Load clamp
3. Restrainer
4. Specimen
5. Base plate
6. Loading rod
7. Stop nut
8. Piston rod
9. Double-acting, Bellofram cylinder
10. Rubber washer
11. Load bar
12. Thomson ball bushing

Figure 5.14 Third-Point Flexure Apparatus (Monismith, et al., 1971)

This type of test is adopted at the University of Nottingham, U.K. A rotating cantilever machine, shown in Figure 2.15, is used. The specimen is mounted vertically on a rotating cantilever shaft, a constant load or displacement is applied at the top to crete a sinusoidal form of loading. The majority of the tests were conducted at a temperature of 10 C and a speed of 1000 rpm.

- Bending Test of Trapezoidal Beam

Test on trapezoidal specimens have been conducted by the Shell researcher, Belgium researcher and by the LCPC, France. The test Setup is shown in Figure 2.16

The larger dimension of the trapezoidal specimen is fixed and the smaller end is subjected to either a sinusoidal applied stress or strain. By properly selecting the dimensions of trapezoid, the specimen will fail at about mid height where the bending stress is largest. Specimen used by Shell has a base cross section of 55 mm x 20 mm, a top cross section or 20 mm x 20 mm and a height of 250 mm.

- Diametral Test

The diametral fatigue test is an indirect tensile test conducted by repetitive loading on a cylindrical specimen with a compressive load which acts parallel to and along the vertical diametral plane. Test specimens are usually 4 in. in diameter and 2.5in.high. Load is transmitted to the side of the right circular cylinder through a 0.5 inch wide loading strip, Figure 2.17

Stresses at the center of the specimen under a strip load are as follows:

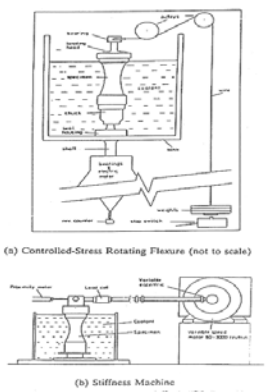
$$\sigma_t = \left[\frac{2P}{\pi at}\right]\left[\sin 2\alpha - \frac{\alpha}{2R}\right] \text{ along the vertical diametral plane}$$

$$\sigma_c = \left[\frac{(-6P)}{\pi at}\right]\left[\sin 2\alpha - \frac{\alpha}{2R}\right] \text{ along the horizontal diametral plane}$$

where P is the applied load, a the width of loading strip, t the height of specimen, 2α, is the angle at the origin subtended by the width of loading strip, R the radius of specimen, σ_t and σ_c are tensile and compressive stresses.

Wheel Tracking Test

- The wheel tracking test as shown in Figure 2.18, based on TRRL specification is employed at the University of Nottngham. Its main advantage is that it could better simulate the effect of rolling wheel on the pavement and thus give a better understanding of the cracking and rutting phenomena of asphalt slab.



(a) Controlled-Stress Rotating Flexure (not to scale)

(b) Stiffness Machine

Figure 2.15 Flexure Apparatus Used by Pell (1965)

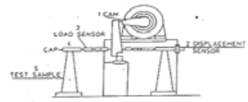


Figure 5.16 Bending Test of Trapezoidal Beam

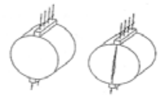


Figure 5.17 Diametral Test

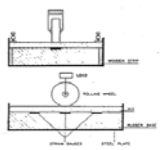


Figure 2.18 wheel Tracking Test

2.4.4 Fatique Resistance Correlation

- **Asphalt Concrete and Subgrade Soil**

The main objective of fatigue investigation is to determine fatigue life. Fatigue life is defined as the numbers of load repetition for a specific magnitude of loading (either stress or deformation), which cause failure to structures. Early fatigue research found that fatigue life was often better correlated with strains than with stresses, and that the basic failure relationship could be represented as follows:

$$N_f = a\left(\frac{1}{\varepsilon}\right)^b$$

where N_f is the fatigue life, ε is the applied strain, and a and b are constants determined from laboratory testing.

The fatigue life depends on mix properties which differ among agencies. Several correlation for the value of fatigue cracking life, (table. 5.7)and fatigue rutting life of subgrade soil, (table 5.8) have been proposed.

Table 2.7 Fatigue Cracking Criteria of Asphalt Concrete

Agency	Correlation form	f_1	f_2	f_3
Asphalt Institute	$N_f = f_1(\varepsilon_t)^{-f_2}(E_1)^{-f_3}$	0.0796	3,291	0.854
Shell	$N_f = f_1(\varepsilon_t)^{-f_2}(E_1)^{-f_3}$	0.0685	5.671	2.363
Illinois Department of Transport	$N_f = f_1(\varepsilon_t)^{-f_2}$	$5x10^{-6}$	3.0	-
TRRL, U.K.	$N_f = f_1(\varepsilon_t)^{-f_2}$	$1.66x10^{-10}$	4.32	-
Belgian Road Research Center	$N_f = f_1(\varepsilon_t)^{-f_2}$	$4.92x10^{-14}$	4.76	-

Table 2.8 Subgrade Strain Criteria Used by Various Agencies

Agency	Correlation form	f_4	f_5	Rut depth (in.)
Asphalt Institute	$f_4(\varepsilon_c)^{-f_5}$	$1.365x10^{-9}$	4.477	0.5
Shell (revised 1985)				
50% reliability	$f_4(\varepsilon_c)^{-f_5}$	$6.15x10^{-7}$	4.0	
85% reliability	$f_4(\varepsilon_c)^{-f_5}$	$1.94x10^{-7}$	4.0	
95% reliability	$f_4(\varepsilon_c)^{-f_5}$	$1.05x10^{-7}$	4.0	
TRRL, U.K. (85% reliability)	$f_4(\varepsilon_c)^{-f_5}$	$6.18x10^{-8}$	3.95	0.4
Belgian Road Research	$f_4(\varepsilon_c)^{-f_5}$	$3.05x10^{-9}$	4.35	

- Portland Cement Concrete

Fatigue characteristics of concrete is well established. It is widely accepted that concrete can endure unlimited load repetition provided that the ratio of applied tensile stress to the modulus of rupture is less than about 0.5. This point is called the fatigue endurance limit. When the ratio is greater than this value, the repetitions produce failure.
A fatigue test of Portland cement concrete usually applies a repeated flexural loading on beam specimen 15 in. long 3 in x 3in. cross section. Loading is generally applied at third points with a rate of 1 to 2 repetitions per second and duration of 0.1 sec.
Test results have been fitted to equation suggested by Vesic as:

(a) $$N_f = 225{,}000\left(\frac{MR}{\sigma}\right)^4$$

An average result for 50% probability of failure is shown by solid line in Figure 5.19. The most used result is that of the P.C.A. which shows as broken line. The equation form of average value : (solid line) is :

(b) $$\log N_f = 17.61 - 17.61\left(\frac{\sigma}{MR}\right)$$

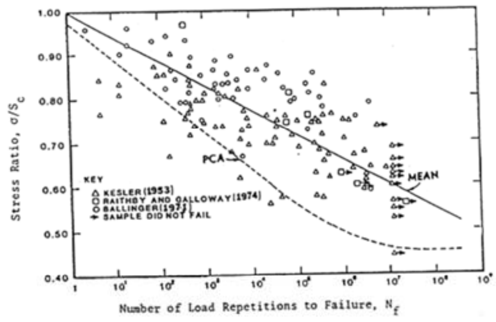


Figure 2.19 Results of fatigue tests on concrete from different sources.

Reference:

Boonsong SATAYOPAS, Pavement analysis and Design, Department of civil engineering Faculty of engineering, Chiangmai university, May,2000

Question?

Thank you for your kind attention