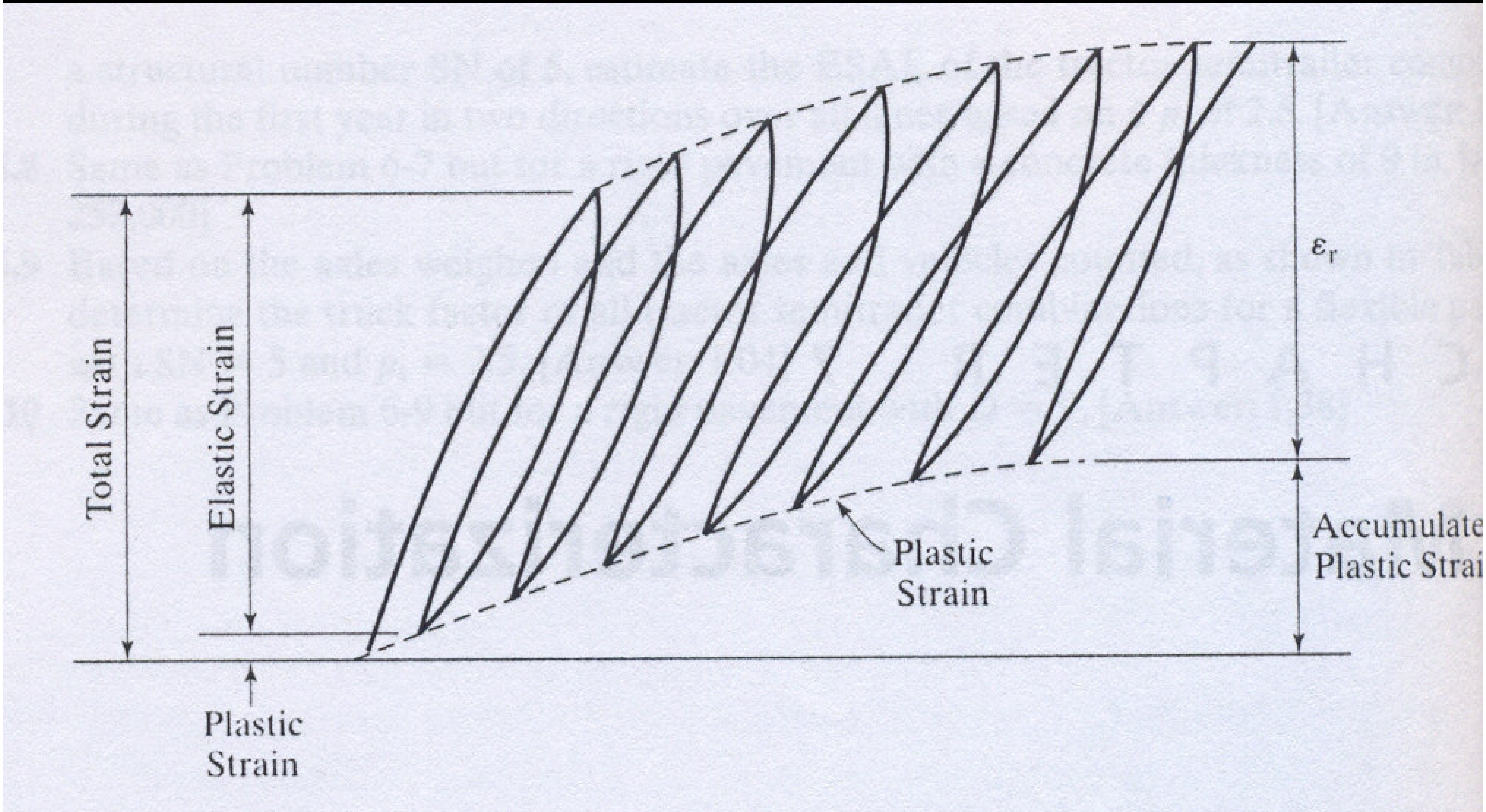
Resilient Modulus

Strains under Repeated Loads



Resilient Modulus

The resilient modulus M_R is the elastic modulus based on the recoverable strain under repeated loads, and is defined as

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

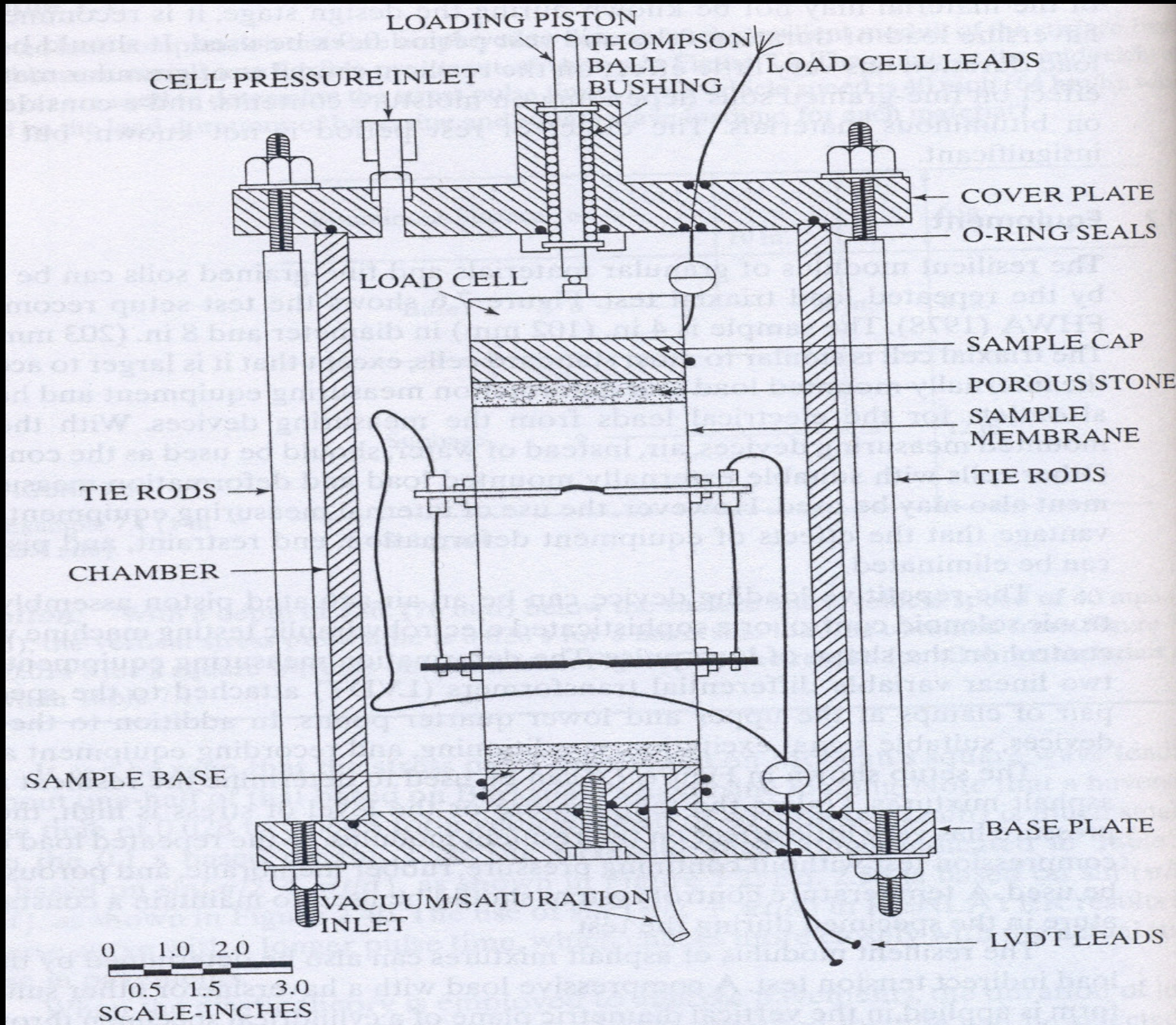
σ_d = deviator stress
ε_r = recoverable elastic strain

Test Apparatus

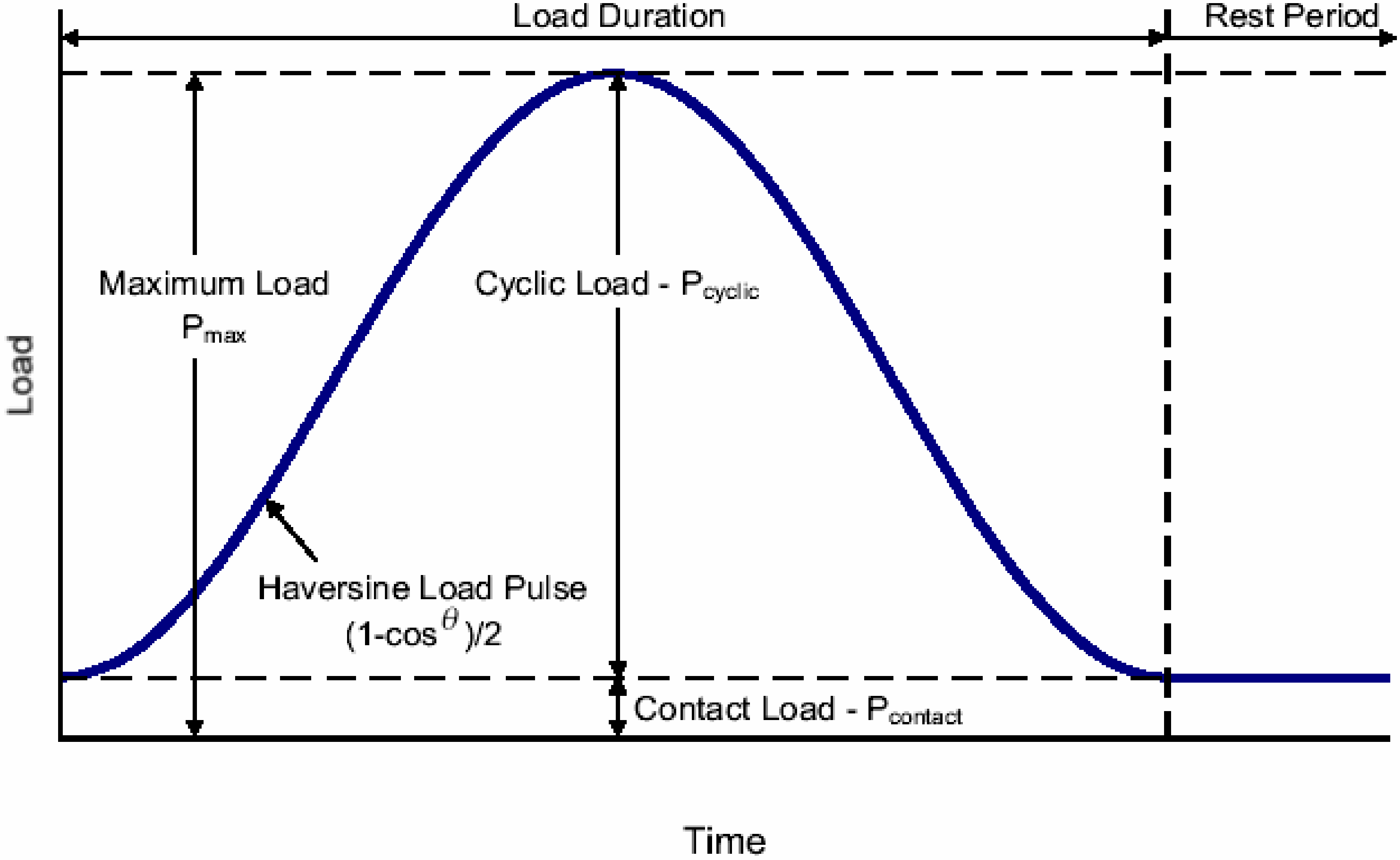
Triaxial Pressure Chamber - The pressure chamber is used to contain the test specimen and the confining fluid during the test. Air shall be used in the triaxial chamber as the confining fluid for all testing.

Periodic System Calibration: The entire system (transducers, signal conditioning and recording devices) shall be calibrated every two weeks or after every fifty resilient modulus tests.

Triaxial Cell for Testing Cylindrical Specimens



Loading Pattern



Load Duration and Rest Period

Load duration is the time interval the specimen is subjected to a cyclic stress pulse. (0.1 second)

Cycle duration is the time interval between the successive applications of a cyclic stress (usually 0.9 sec). This is also called as rest period

Loading Device and other Equipment

Loading Device - The loading device shall be a top-loading, closed-loop electro-hydraulic testing machine with a function generator which is capable of applying repeated cycles of a haversine-shaped load pulse.

Load and Specimen Response Measuring Equipment

This includes optical extensometer, non-contact sensors, or clamps attached to the specimen axial deformation. Also includes an analog-digital device for data acquisition.

Loading Device and other Equipment

Specimen Preparation Equipment: A variety of equipment is required to prepare undisturbed samples for testing and to prepare compacted specimens that are representative of field conditions.

Equipment for trimming test specimens from undisturbed thin-wall tube samples of subgrade soils.

Miscellaneous Apparatus: This includes calipers, micrometer gauge, steel rule , rubber membranes thickness, vacuum source with bubble chamber and regulator, membrane expander and porous stones.

Test Procedure

- Specimen Dimensions:
  - Diameter: 102 mm
  - Height: 203 mm
- Sample conditioning
  - First the sample is conditioned by applying various combinations of confining pressures and deviator stresses.
- After sample conditioning “constant confining pressure – increasing deviator stress” sequence is applied, and the results are recorded at the 200th repetition of each deviator stress

Application of Resilient Modulus

- The resilient modulus test provides a means of characterizing pavement construction materials including surface, base, and sub-base materials under a variety of temperatures and stress states that simulate the conditions in a pavement subjected to moving wheel loads.
- The test provides an excellent means for comparing the behavior of pavement construction materials under a variety of conditions (i.e., moisture, density, gradation, etc.) and stress states.

Design M_R

- A minimum of 6 to 8 values are usually used to determine the design subgrade resilient modulus.
- Design resilient modulus is defined as the modulus value that is smaller than 60, 75, or 87.5 % of all the test values.

ESAL	Design M_R
$\leq 10^4$	60
$10^4 - 10^6$	75
$>10^6$	87.5

Example Problem

- The results of eight tests produced the following subgrade resilient modulus values: 42.8, 53.8, 60.7, 65.6, 69.0, 78.0, 82.1 and 93.2 Mpa. Determine the design subgrade resilient modulus for ESAL of 10^4, 10^5 and 10^6.

Dynamic Modulus

Dynamic Modulus

- *Dynamic modulus*
  - The absolute value of the complex modulus that defines the elastic properties of a linear viscoelastic material subjected to a sinusoidal loading, $|E^*|$
- *complex modulus*
  - a complex number that defines the relationship between stress and strain for a linear viscoelastic material, E^*.
- *Linear material*
  - a material whose stress to strain ratio is independent of the loading stress applied.

Test Method

- A sinusoidal (haversine) axial compression stress is applied to a specimen of asphalt concrete at a given temperature and loading frequency.
- The resulting recoverable axial strain response of the specimen is measured and used to calculate dynamic modulus.
- The minimum recommended test series consists of testing at 5, 25, and 40℃ at loading frequencies of 1, 4, and 16 Hz for each temperature.

Dynamic Modulus

- Dynamic modulus is Calculated as follows:

  Dynamic modulus = σ_o/ε_o

  where:

  σ_o = axial loading stress, kPa, and

  ε_o = recoverable axial strain

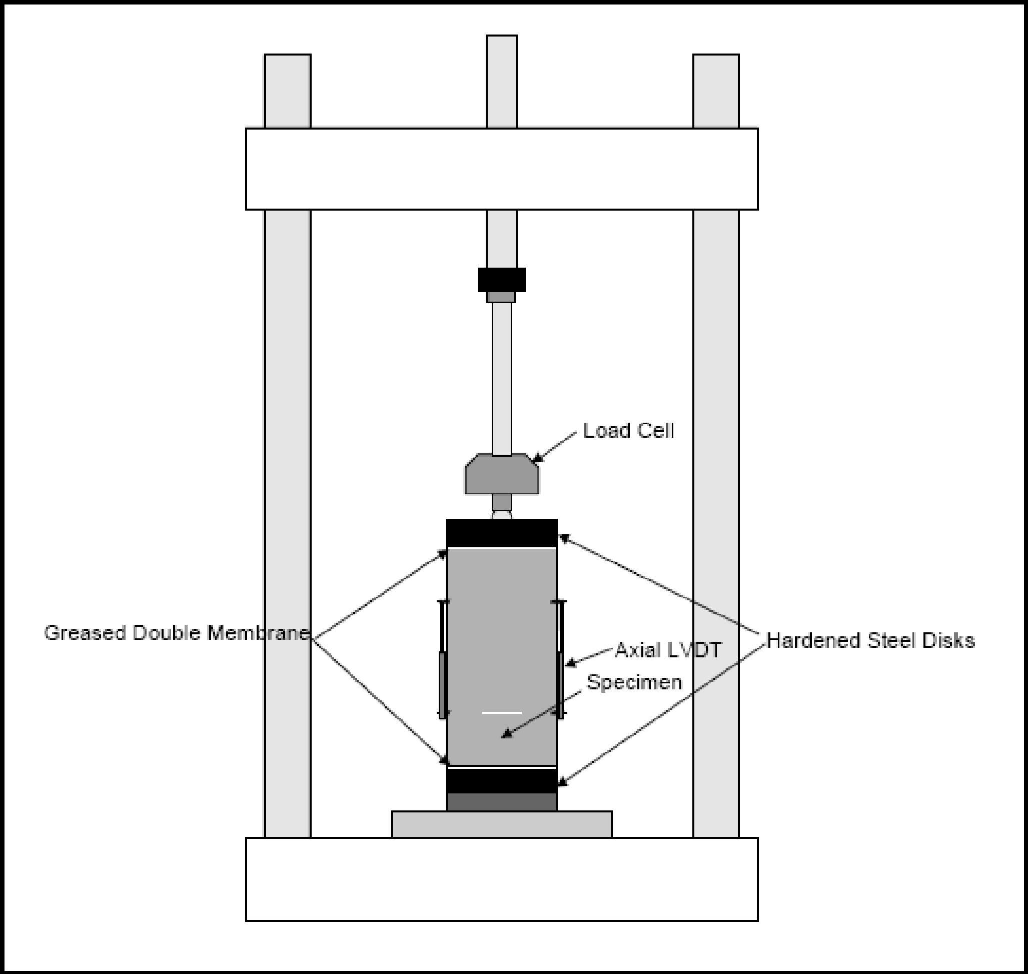
Resilient modulus $\Rightarrow$ Any wave form with a given rest period

Dynamic modulus $\Rightarrow$ Sinusoidal wave form without rest period

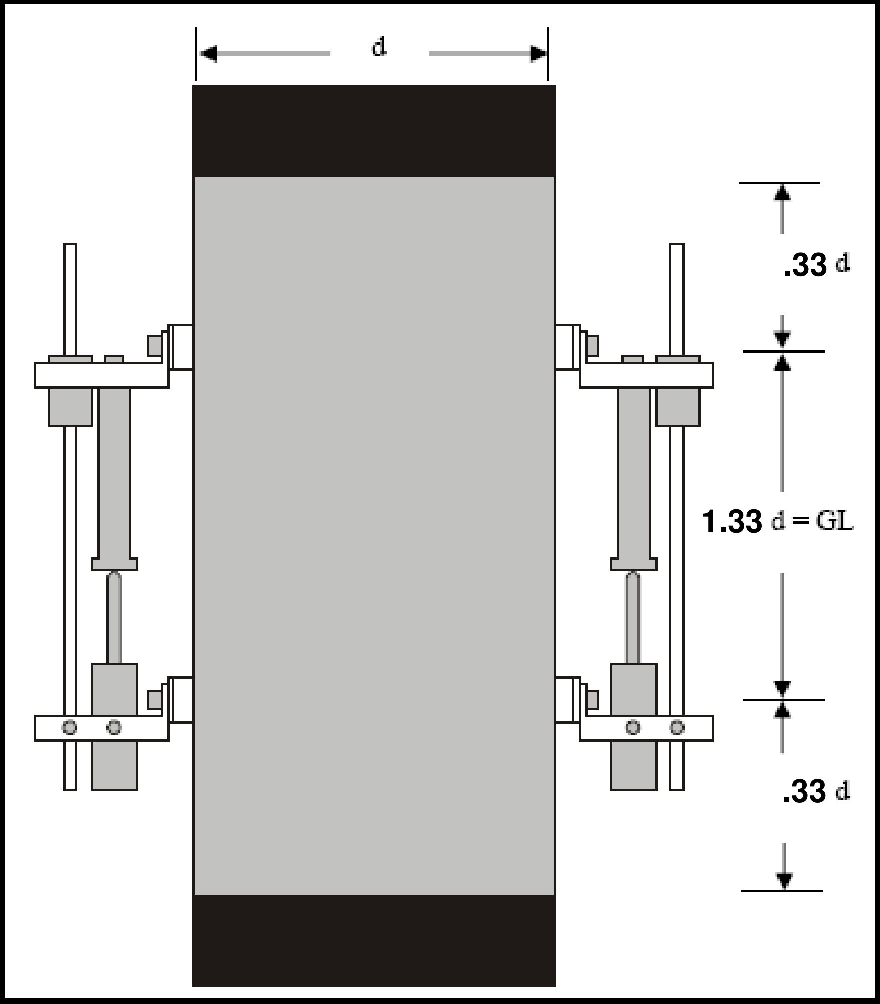
Dimensions of Test Specimens

- *Laboratory Molded Specimens*
  - The specimens should have a height-to-diameter ratio of 2 to 1, a minimum diameter of 101.6 mm and a diameter four or more times the maximum nominal size of aggregate particles.
  - A minimum of three specimens is required for testing.
- *Pavement Cores*
  - A minimum of six cores from an in-service pavement is required for testing.
  - Obtain cores having a minimum height-to- diameter ratio of 2 to 1 and with diameters not less than two times the maximum nominal size of an aggregate particle.
  - Select cores to provide a representative sample of the pavement section being studied.

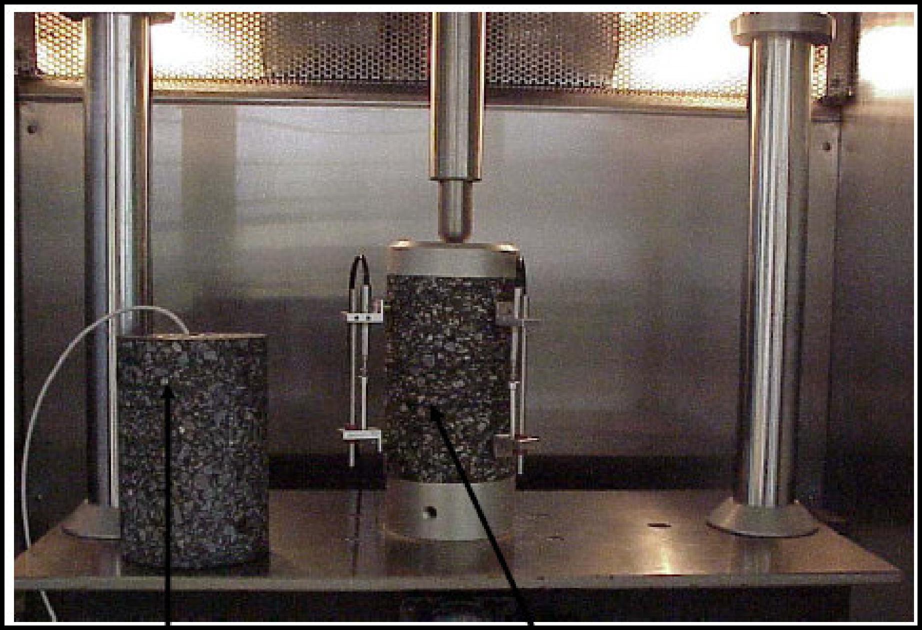
General Schematic of a Dynamic Modulus Test



Arrangement for Measuring Strain



Instrumented Specimen



Relation Between CBR and E

Subgrade

E (MPa) = 10 * CBR if CBR<5% and

= $176 * (CBR)^{0.64}$ for CBR > 5%

Granular subbase and base

$E_2 = E_3 * 0.2 * h^{0.45}$

E_2 = Composite modulus of sub-base and base (MPa)

E_3 = Modulus of subgrade (MPa)

h = Thickness of granular layers (mm)

Modulus Values for Bituminous Materials

Mix Type	Temperature °C				
	20	25	30	35	40
AC/DBM 80/100 bitumen	2300	1966	1455	975	797
AC/DBM 60/70 bitumen	3600	3126	2579	1695	1270
AC/DBM 30/40 bitumen	6000	4928	3809	2944	2276
BM 80/100 bitumen	-	-	-	500	-
BM 60/70 bitumen	-	-	-	700	-

Default Values of Poisson's Ratio (μ)

- Subgrade and unbound granular layers
  - Default value of $\mu = 0.4$
- Bituminous Layers
  - Default value of μ at 35/45 ^oC = 0.5
  - Default value of μ at 20 - 30 ^oC = 0.35

Correlation between Marshall stability and modulus values