Importance of Resilient Modulus (MR) and it’s Interpretation Subgrade Design Inputs

Kumar Dave, P.E.
Manager, Pavement Engineering, INDOT

2015 Purdue Road School

JPCP cross section

9” – 13” JPCP

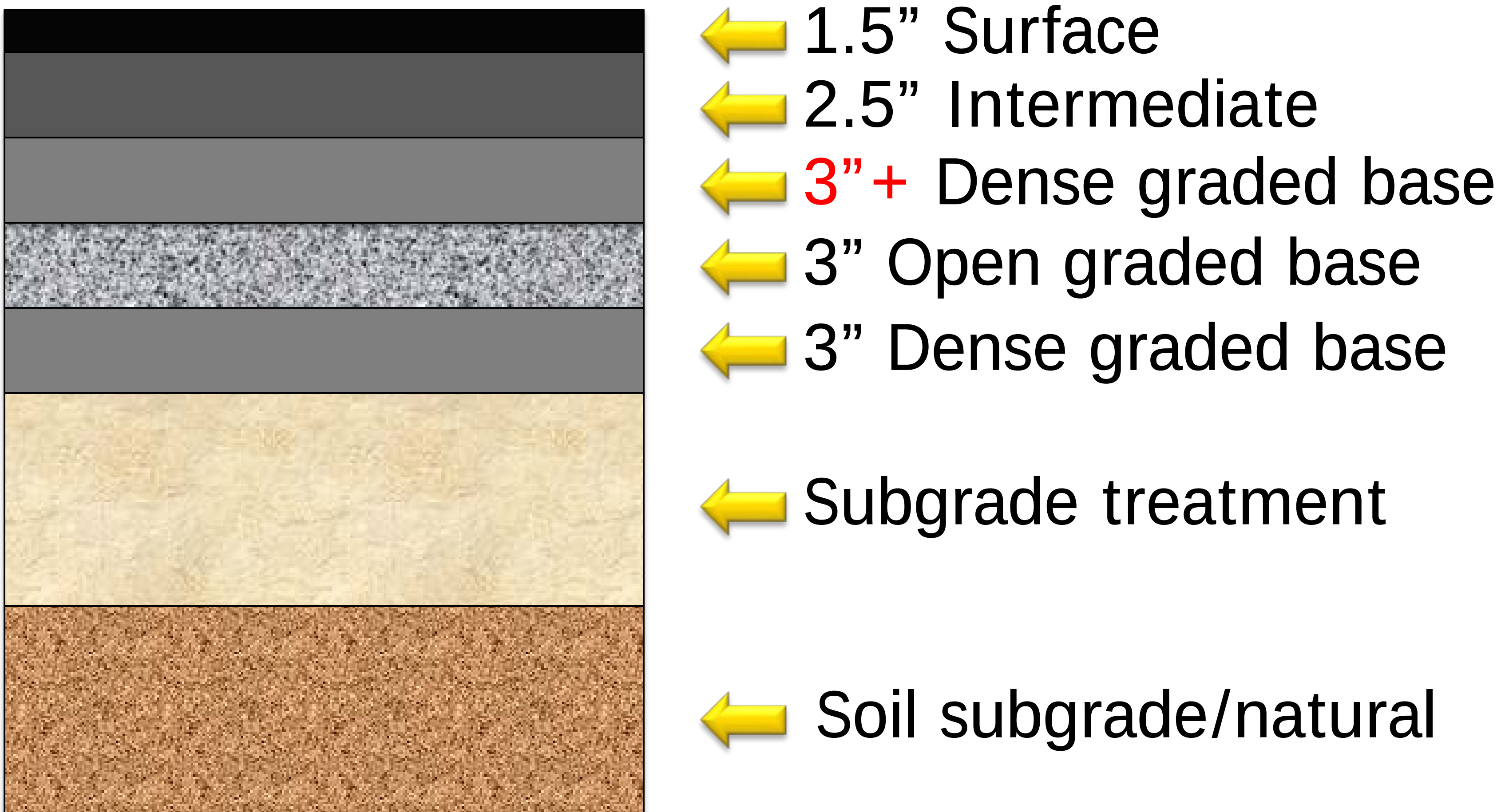
3” Open graded stone

6” Dense graded stone

Subgrade treatment

Soil Subgrade/natural

HMA pavement cross section



AASHTO 1993 Guide

- **Pavement Design Considerations:**
  - Pavement performance
  - Traffic
  - Roadbed soil
  - Material for construction
  - Environment
  - Drainage
  - Reliability
  - Life Cycle cost
  - Shoulder design

Subgrade Design Inputs(1993)

- Mr=Resilient Modulus(Psi) used for flexible pavement
- Elastic property of soil(non linear)
- Represents compacted layer of subgrade
- K value=Modulus of subgrade reaction used for Rigid pavement
- Mr=1500 X CBR
- Mr from FWD used for Rehab

MEPDG(2009)

- **Mechanisti Empirical Pavement Design Guide**
  - State-of-art tool for design and analysis of new and rehabilitated pavement structure
  - Based on M-E principles
  - Calculates pavement responses(stresses, strains & deflection)
  - Uses responses to calculate damage over time
  - MEPDG predicts multiple performance indicators

MEPDG(2009)

- MEPDG is a iterative process
- Outputs are pavement distresses and not tk
- Trial design based on performance criteria
- Level 1, 2, 3
- Performance criteria for flexible pavement
  - Roughness(IRI)
  - Rutting
  - Transverse cracking
  - Fatigue cracking

MEPDG(2009)

- Performance criteria for Rigid Pavement
  - Roughness(IRI)
  - Faulting
  - Cracking

  - Ref: Chapter 304 IDM

MEPDG(2009)

- **MEPDG design Considerations**
  - Foundation/Subgarde
  - Existing pavement condition
  - Paving material
  - Construction factors
  - Environmental factors
  - Traffic loading
  - Subdarinage
  - Shoulder design
  - Rehabilitation treatment & strategies

Cont.

- New pavement & rehab options
- Pavement performance
- Design relaibility
- LCC

Subgrade/Foundation Inputs

- Characterization of the pavement foundation
- Subsurface characterization
- Laboratory testing of subgrade soils
- Condition of Mr lab test specimens
- Identification and treatment of special subsurface condition
- Foundation improvement & strengthening

AASHTOWare Pavement ME….

- **Subgrade**
  - General

Layer thickness (in): The thickness of the selected layer

- Poisson's ratio: ME Design provides a default value of 0.35.

- Coefficient of lateral earth pressure (k0): ME Design provides a default value of 0.5.

Modulus

- Resilient Modulus (psi): ME Design displays the default value (Level 3) for the selected material class
- Input Level: 2 & 3

- Level 2: directly or using its correlations with soil index and strength properties.

- Level 3: override the default resilient modulus value (Level 3) of the subgrade material.

- ME Design does not provide Level 1 input option for resilient modulus of subgrade materials.

Analysis Types

- Seasonal variations (freezing, thawing and moisture)
- Values by temperature/moisture:.

- Monthly representative values:

- Annual representative values:

Method

- Resilient modulus (psi)
- California Bearing Ratio (CBR) (percent)
- R-value
- Layer Coefficient-ai
- Dynamic Cone Penetrometer (DCP) Penetration (in./blow)
- Plasticity Index (PI) and Gradation (i.e., Percent Passing No. 200 sieve)

Gradation & other Eng prop..

Gradation

- Liquid Limit
- Plasticity Index
- Is Layer Compacted?
- Maximum dry unit weight
- Saturated hydraulic conductivity (ft/hr)
- Specific gravity of solids
- Optimum gravimetric water content (%)
- User-defined Soil Water Characteristic Curve (SWCC)

Importance of Resilient Modulus (MR) and it's Interpretation

Nayyar Siddiki, P.E.
Geotech Construction & Tech Support Engineer, INDOT

2015 Purdue Road School

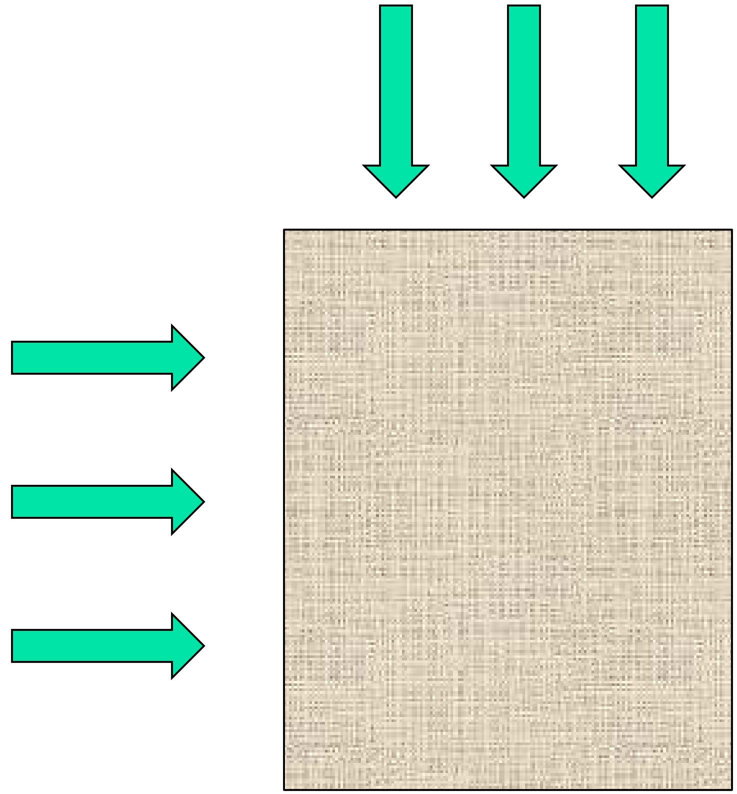
March 2015

MR Research Under JTRP

- **FHWA/IN/JHRP 92-23, SPR-2032, Development Subgrade Resilient Modulus for Pavement Design and Evaluation, Woojin Lee, A.G. Altshaeffl**
- **FHWA/JTRP 98-SPR-2134, Implementation of Subgrade Resilient Modulus for Pavement.**
- **FHWA/JTRP 2010 SPR-3008, Evaluation of In-situ Stiffness of Subgrade by Resilient Modulus and FWD.**

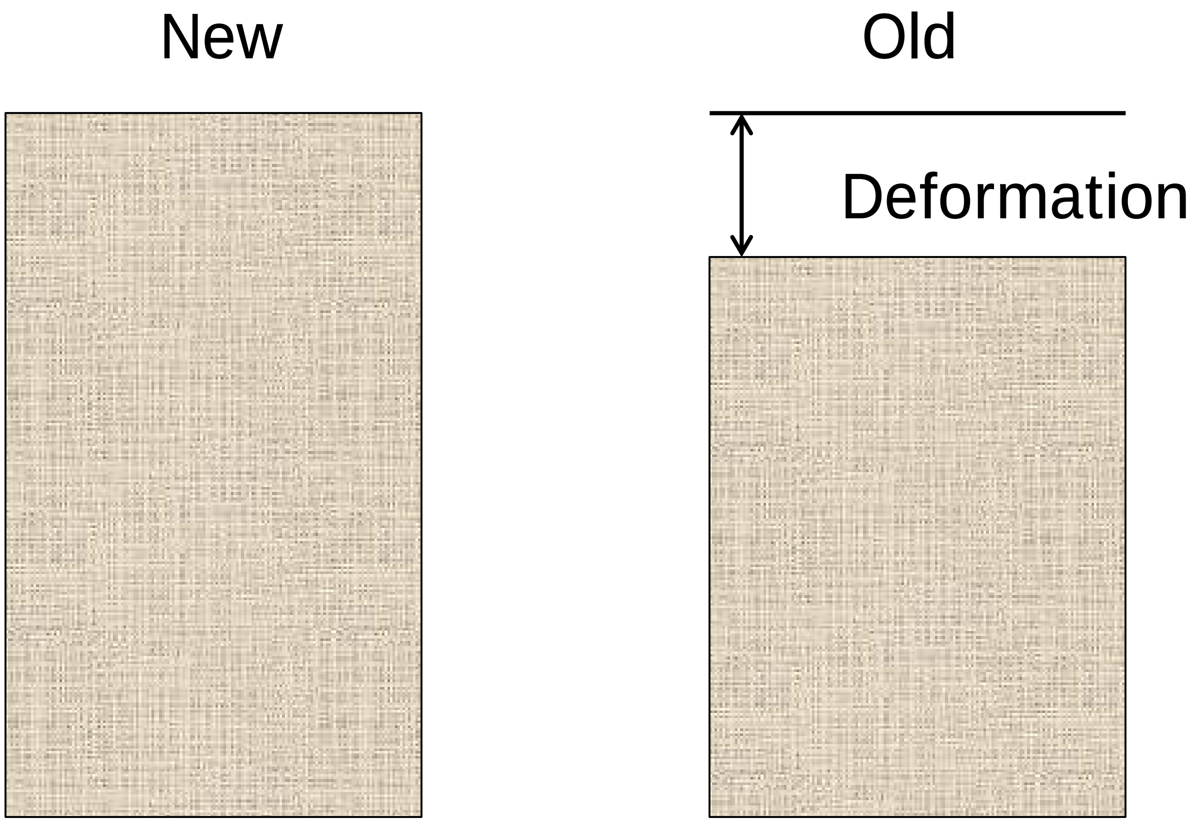
Base Stresses

σ_v Vertical Stress

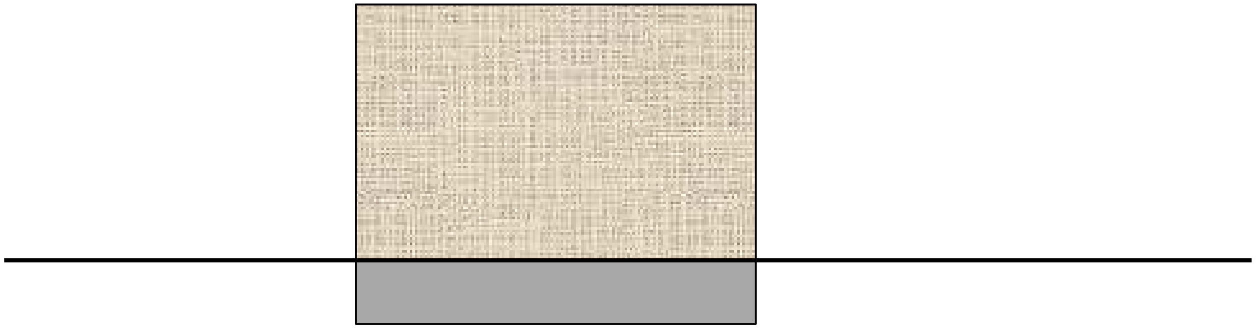


σ_h Horizontal Stress

Deformation Under Load



Deformation



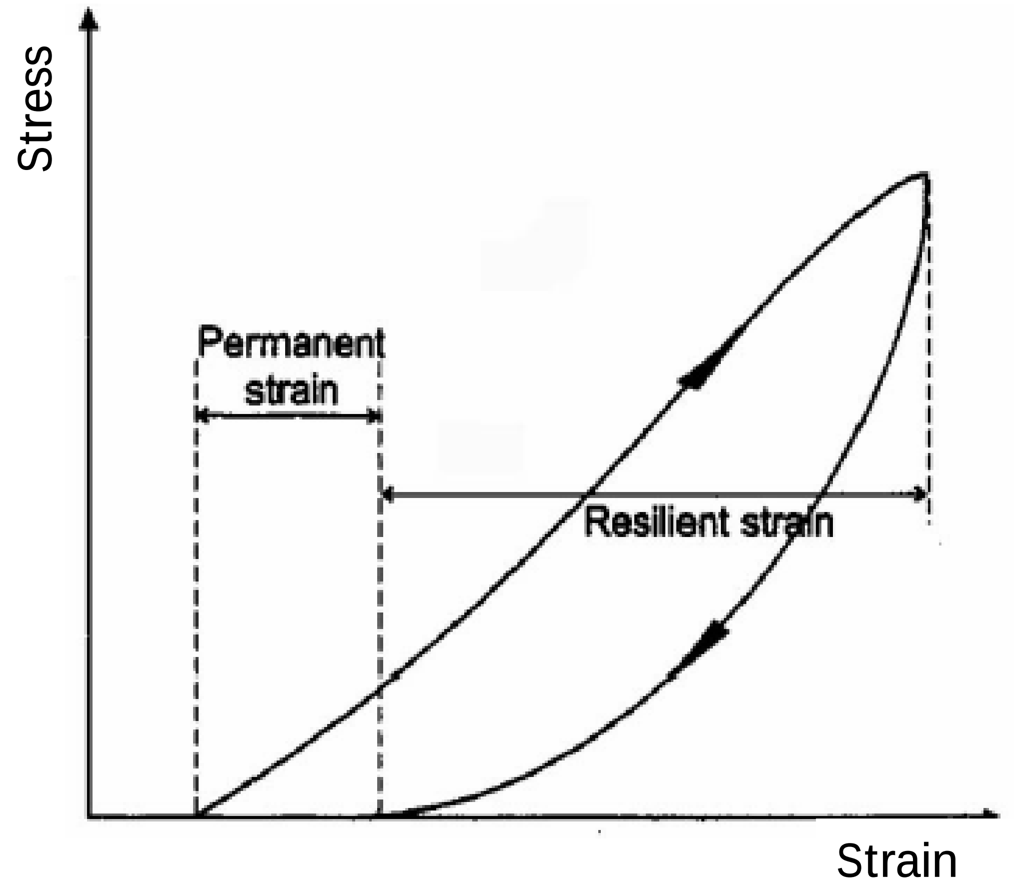
Total Deformation consists of Two Components:

Elastic → **Recoverable**

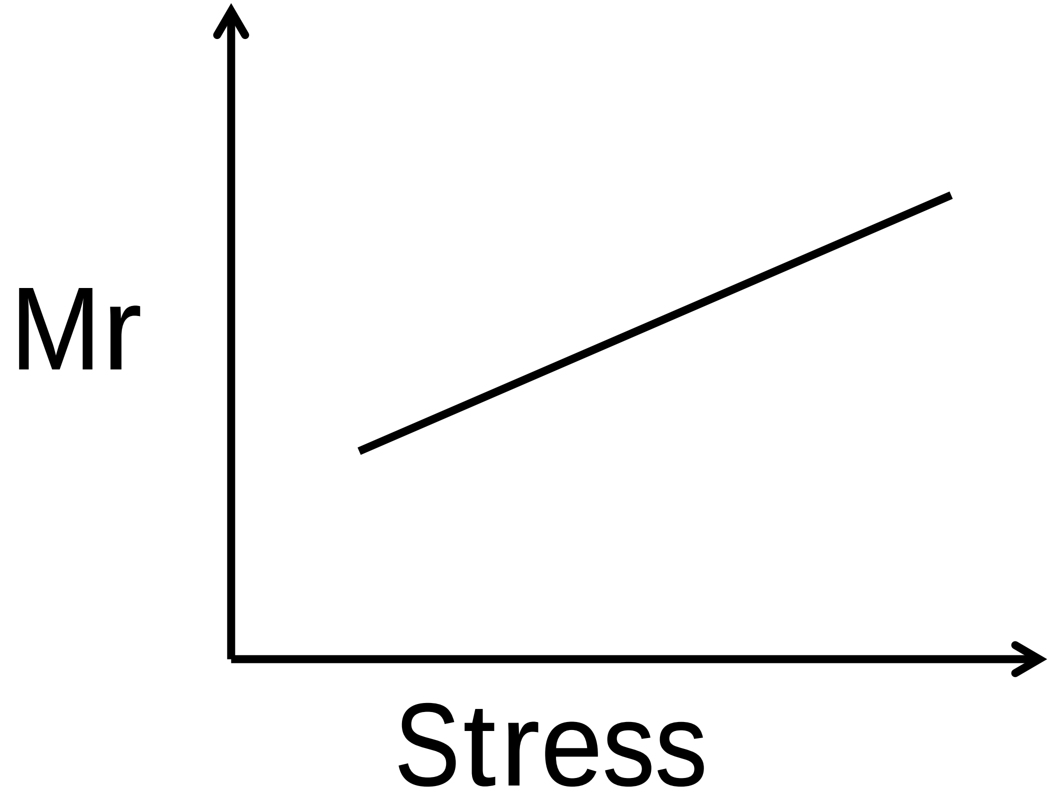
Plastic → **Permanent**

Resilient Modulus:

Dynamic Deviator Stress/Resilient Strain



As the confining stress on the base material increases the stiffness on the Mr increases.



Resilient Modulus, M_R

$$M_R = \frac{\text{Stress}}{\text{Recoverable Strain}}$$

Units of Stress – psi, ksi, kPa, etc.

AASHTO Classifications

Classification of Soil and Soil-Aggregate Mixtures from AASHTO M-145

General Class.	Granular Materials (35% Or Less Passing No. 200)							Silt-Clay Materials (More than 35% Passing No. 200)			
Group/ Classifications	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis, % Passing											
No. 10	50 max.	—	—	—	—	—	—	—	—	—	—
No. 40	30 max.	50 max.	51 min.	—	—	—	—	—	—	—	—
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Charac.'s of Fraction passing No. 40											
Liquid Limit	—		—	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity Index	6 max.		N.P.	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.
Usual types of Significant Constituent Materials	Stone Fragments, Gravel and Sand		Fine Sand	Silty or Clayey Gravel and Sand				Silty Soils		Clayey Soils	
General Rating as Subgrade	Excellent to Good				Fair to Poor						

How is the Resilient Modulus performed?

The Laboratory Model

- The pavement stresses are modelled in the laboratory in a triaxial cell.

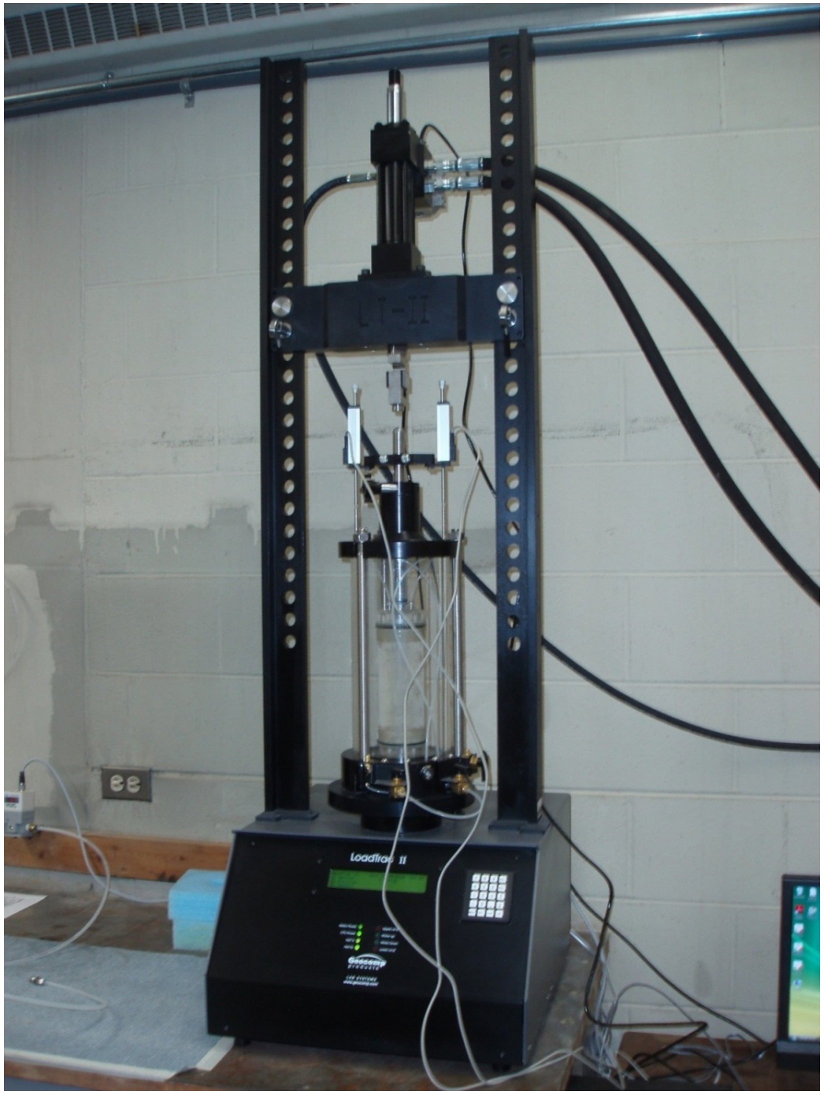
  - Cylindrical soil specimen separated from cell pressure by rubber membrane.
  - Cell is pressurized to provide confining stress (normal stress).
  - Hydraulic actuator ram provides cyclic shear and normal stresses.
  - Digitally controlled.

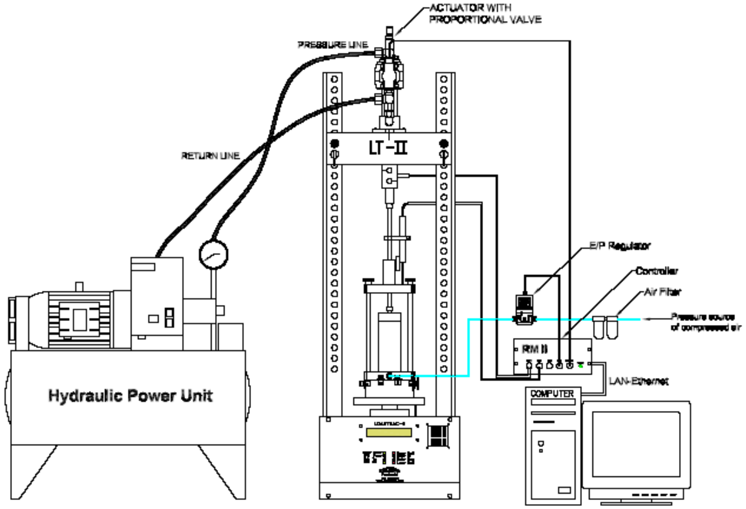
AASHTO T-307

Resilient Modulus Test Sequence

- Conditioning sequence – 1000 cycles
  (6 psi conf. , 4 psi deviator stress)
- 15 test sequences – 100 cycles each
  - 3 different confining stress levels (6,4,2 psi)
  - 5 different (increasing) deviator stress (2,4,6,8,10 psi) per confining stress
  - Modulus is calculated from last 5 cycles of each sequence

Resilient Modulus Machine





Resilient Modulus Machine

Preparing the Sample

- **A specimen shall be molded at 95% compaction at OMC.**
- **A Shelby sample for MR**
- **Data sheet of a resilient modulus test showing the stress sequence shall be provided.**

Data sheet shall include: confining stress, deviator stress, resilient strain, permanent strain, resilient modulus etc.

Typical Confining and Deviatoric Stress Values

Confining Stress (psi) (δ_c or δ_3)	Deviatoric Stress (psi) (δ_d or δ_{cyclic})	References
2	5.4	Rahim (2005)
2	7.5	George (2004)
2	5	Ping et al. (2001)
2	6	Asphalt Institute (as cited by Ping et al. 2001)
2	2	Daleiden et al. (as cited by Ping et al. 2001)
2	6	Lee et al. (1997)
2	6	Jones and Witczak (1977)

RESILIENT MODULUS TEST DATA

Confining Stress (psi)	Nom. Max. Deviator Stress	Mean Deviator Stress (psi)	Std. Dev. Deviator Stress (psi)	Mean Bulk Stress (psi)	Mean Resilient Strain (%)	Std. Dev. Resilient Strain (%)	Mean Resilient Modulus (psi)	Std. Dev. Resilient Modulus (psi)
2.072	2	1.914	0.0698	8.128	0.02	0.00	10480	1122.6

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2.072	2	1.914	0.0698	8.128	0.02	0.00	10480	1122.6
2.068	4	3.847	0.048	10.05	0.05	0.00	7175.6	91.964

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2.063	6	5.771	0.0811	11.96	0.09	0.00	5559.2	52.737

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2.063	6	5.771	0.0811	11.96	0.09	0.00	5559.2	52.737
2.059	8	7.68	0.1201	13.86	0.14	0.00	5104.4	131.6

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2.063	6	5.771	0.0811	11.96	0.09	0.00	5559.2	52.737
2.059	8	7.68	0.1201	13.86	0.14	0.00	5104.4	131.6
2.109	10	9.691	0.1257	16.02	0.19	0.00	4506	51.894

JTRP MR Report Conclusion

- Deviator Stress = 6 psi
- Confining Stress = 2 psi
- Based on limited Testing for A-6, A-7, A-4 (Indiana Soils)
- M_R = 695.4 (Su 1%) – 5.93 (Su 1%)^2
- Su at 1% Strain rate
- R^2 = .97

MR and CBR Relations

- M_r (ksi) = 1.42 x CBR (Heukelom and Klomp)
- M_r (ksi) = 5.409 x $CBR^{0.711}$ (Green and Hall)
- M_r (ksi) = 2.554 x $CBR^{0.64}$ (Powell et. al.)
- M_r (ksi) = 1.2 x CBR (Ohio DOT)
- M_r (psi) = 1500 x CBR (INDOT)

Full Depth Reclamation

Mr Test for FDR Samples						
Sample No.	Sample Description	Compaction AASHTO T-99 (Method A)		Dry Density & Moisture Content (Before & After Test)		
		Max. Dry Density (pcf)	OMC %	% Compaction	Molded Dry Density (pcf)	MC %
1	Sample passing (# 4 Sieve) and mix with (5 % Cement)	125.5	6	93	116.5	6.4
3	Sample passing (# 4 Sieve) and mix with (5 % Cement)	125.5	6	93	116.6	7
4	Sample passing (# 4 Sieve) and mix with (5 % Cement)	125.5	6	92	116.1	6.8
5	Sample passing (# 4 Sieve) and mix with (5 % Cement)	124.5	6.4	95	117.8	8
6	Sample passing (# 4 Sieve) and mix with (5 % Cement)	124.5	6.4	95	118.7	8

Note: Sample 2 was crumbled during the test.

Cont.

Resilient Modulus (M_R) of FDR Samples

Passing No. 4 sieve material

Sample No.	Confining Stress (psi)	Deviator Stress (psi)	Avg. M_R (psi)	R^2
1	6	*2 thru 10	15660	0.8628
	4	2 thru 10	16246	
	2	2 thru 10	13086	
3	6	2 thru 10	18613	0.8147
	4	2 thru 10	14085	
	2	2 thru 10	9864	
4	6	2 thru 10	15262	0.8959
	4	2 thru 10	12962	
	2	2 thru 10	9390	
5	6	2 thru 10	33491	0.8852
	4	2 thru 10	27954	
	2	2 thru 10	26301	
6	6	2 thru 10	20626	0.8131
	4	2 thru 10	17618	
	2	2 thru 10	13909	

Note: 59 % Material passing # 4 sieve.

* Deviator Stress: 2,4,6,8,10

Sample No. 5 tested 3% above the OMC

Sample # 2 was crumbled during test.

Typical Pavement Subgrade Recommendations

- **Subgrade Type in accordance with 207.04**
- **Resilient Modulus of prepared subgrade xxxx psi**
- **Resilient Modulus of undisturbed subgrade xxxx psi**
- **Predominant Soil encountered in Subgrade INDOT Textural Classification AASHTO**
- **Presence of Groundwater Table…(based on boring information)**
- **Subsurface drains if Geotechnical problems exist**
- **Filter fabric if soils are silty (> 50% or soils are erodible)**

INDOT Policy For MR test

INDOT has been performing the MR test for Geotechnical consultants on state projects.

On Local agency projects the Mr test is required to go to an Approved Geotechnical Laboratory.

Resilient Modulus Procedure

Geotechnical consultants will provide the following:

- Shelby Tube Sample ($\geq$ 50 % recovery)
- A 10 lb. sample bag (Passing #4 sieve)
- Specific Gravity test
- Atterberg Limits Testing
- Moisture Density Curve (Standard Proctor)

Cont.

- **Optimum Moisture, Maximum Wet & Dry Densities**

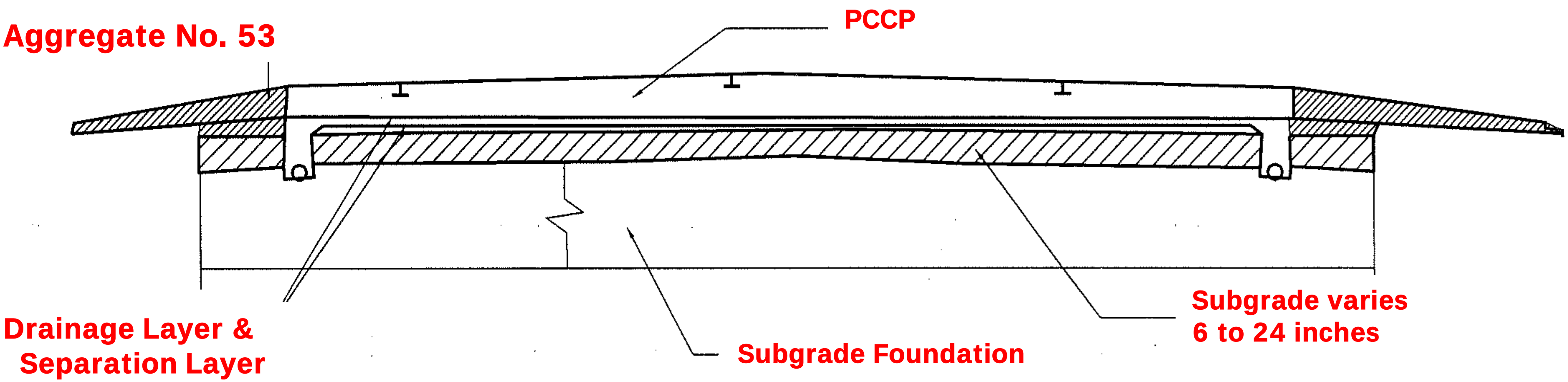
- **Natural Moisture Test (as received)**

- **Sample bag must contain following information:**
  - Date, Geotechnical Consultant, Des # and/or Contract #, Road, County, Boring #, Sample Depth, Station, and Location.

Summary of all Tests

Resilient Modulus Sample Info	
Sample ID	
Soils Classification	
AASHTO Class. & Group Index	
Passing #10	
Passing #40	
Passing #200	
% Gravel	
% Sand	
% Silt	
% Clay	
LL	
PL	
PI	
Sulfate Content ppm	
Specific Gravity	
LOI	
Ca/mg	
Max Wet Density	
Max Dry Density	
Optimum Moisture	

Pavement, Subgrade & It's Foundation Section



MR Sample Collection

Following procedure should be used for Resilient Modulus sampling for cohesive soils:

Re-Construction / New Construction

- A continuous flight auger shall be used to penetrate the existing pavement and pavement sub-base material to a depth approximately 4-6 inches blow the top of the subgrade.
- A 24 inch long and 3 inches in diameter Shelby Tube sample shall be collected from the borehole. The sample shall have minimum of 50% recovery.

Cont.

- Upon completion of the Shelby tube sampling the flight auger shall be reintroduced to the borehole and advanced to a depth of approximately 4-5 feet.
- Approximately 25 lbs. of auger cuttings shall be collected for the bag sample.
- Soils from bag sample and Shelby Tube sample should be the same.
- Rubblization / Full depths Reclamation etc.
- Shelby Tube Sample / Soil samples to be remolded for MR.

Resilient Modulus Test Requirements

- New Construction / Re-Construction / Lane Widening etc.
  - One Resilient Modulus test on remolded / mile of roadway or 10 roadway or subgrade borings.
  - One Resilient Modulus test on Shelby Tube / mile of roadway or 10 roadway or subgrade borings.
  - When soils are consistent, MR test may be reduced.

Cont.

- For FDR projects :A resilient modulus on Shelby Tube or remolded to natural density / mile of roadway or 10 roadway borings.
- Roadway <800 Lft. MR can be estimated from unconfined test of 1% strain rate. (Woojin & Lee eq.)

Questions?