Basics of Pavement Design/Down to the Subgrade

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January 31, 2023

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Little bit about myself(Kumar Dave) & role

- Working with INDOT since 1990
- Working mainly in Pavement Design in CO
- Worked in Roadway Asset Management(2010-12)
- Have 30+ yrs of experience in Pavement Design
- Working closely with District, Geotech, OMM, Research and Asset
- Working with Asphalt and Concrete industries
- Had worked with IMAA (Recently visited)
- Main Responsibility: Pavement designs for all INDOT projects

Outline(Pavement Design 101)

- Indot Facts
- History of Roads
- Types of Pavements
- Pavement Typical Section
- Pavement Design Considerations
- Pavement Design Methods
- Indot Pavement Design History

INDIANA DEPARTMENT OF TRANSPORTATION

INDOT

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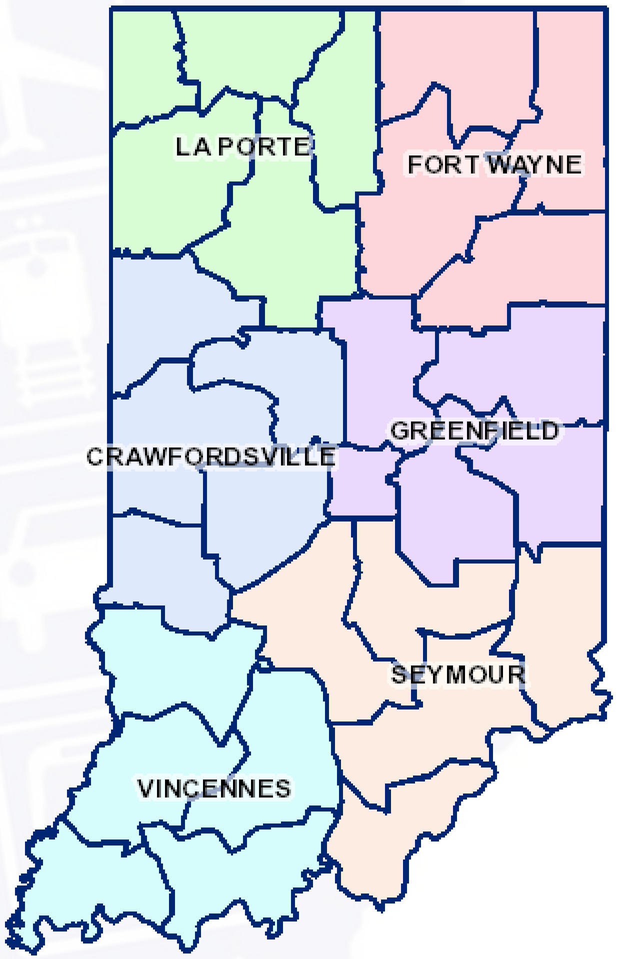
INDOT History

- 100 Years in July 2019



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INDOT Facts

- INDOT maintains more than 29,800 lane miles (over 11,200 centerline miles) of highways in Indiana.
- INDOT is responsible for maintaining more than 5,700 bridges across the state.
- INDOT supports approximately 4,500 rail miles, regulates more than 110 public access airports, and 560 private access airports across the State.

Continue….

- INDOT has approximately 3,500 employees, making it one of the state's largest agencies.
- INDOT's FY 2022 capital expenditures budget was more than $2.55 billion annually.
- INDOT's FY 2022 operating budget is approximately $570.6 million annually.

History of Roads

- Early Roads
  - Harappan roads
  - Wheeled transport
  - Roman Roads
  - Early tar-paved roads
  - Macadam roads

  - Modern Road

Harappan road(4000 BC)

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Wheeled transport(3000 BC)

Roman roads…

Tar road(from coal,wood,petrol)

The Pitch Lake(Trinidad)

Pitch Lake, Trinidad

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Macadamized road(1820s,30s,

Modern road(since 1870’s & 1920’s)

Types of pavements

Types of Roads(Indiana)

- Aggregate roads
- Brick roads
- Asphalt Roads
- Concrete Roads
- Composite roads

Aggregate road

Aggregate Road

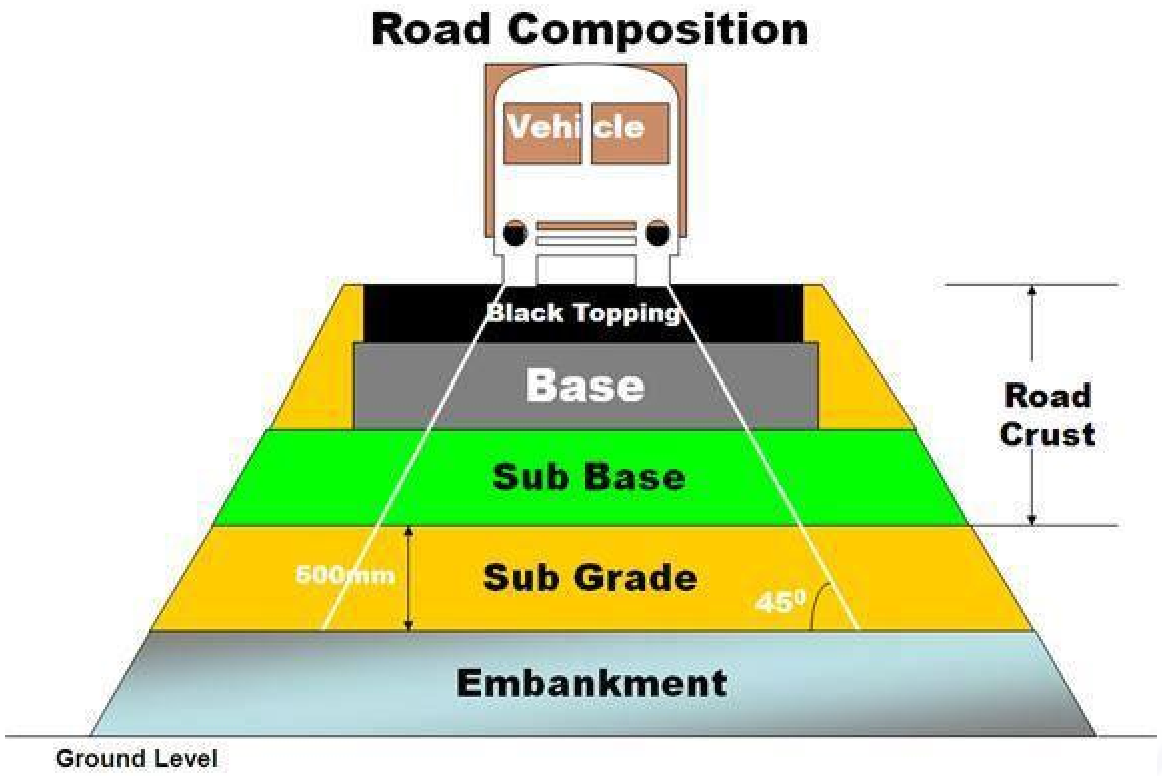
Brick Road


STOP


RELIANCE

Asphalt Road

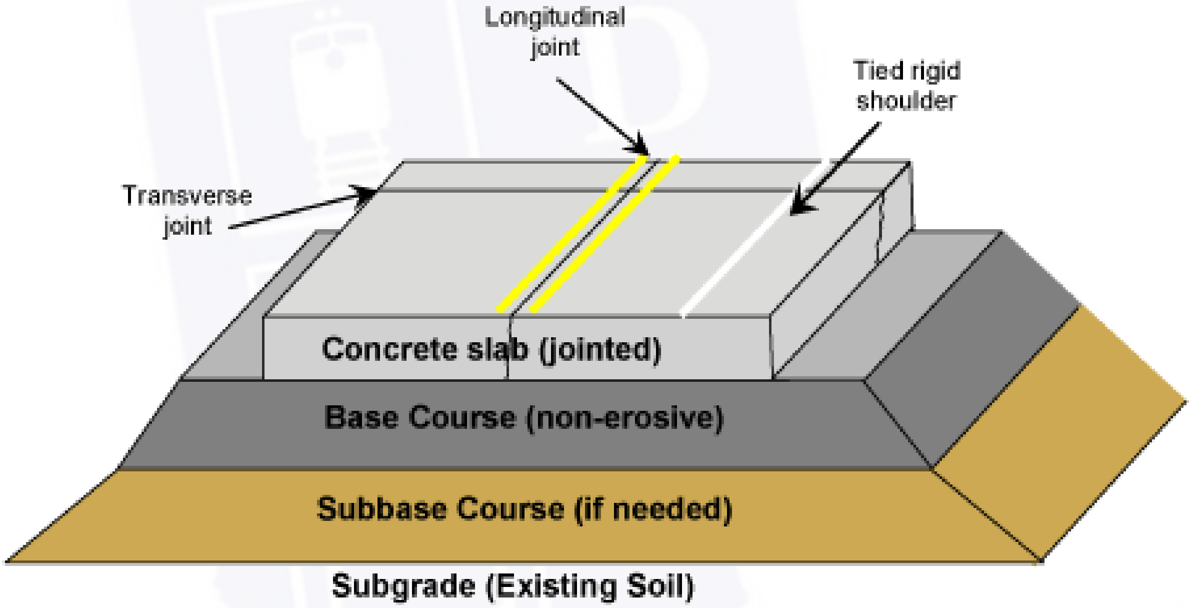
Asphalt Road composition



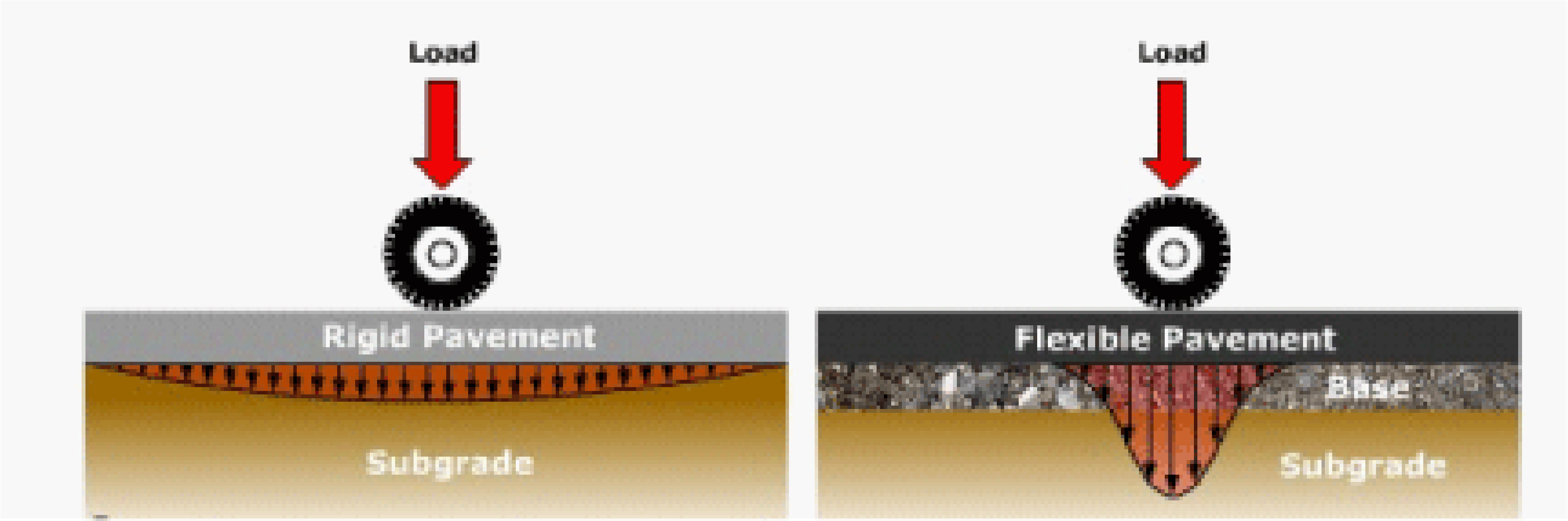
Concrete Road

Concrete Road

Concrete Road composition



Load distribution



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Asphalt & Concrete core

HMA pavement cross section

1.5" HMA Surface
2.5" HMA Intermediate
8"+ HMA Base
3" HMA OG Base
6" CA#53 on Geotextile

14" Soil treatment(Cement/Lime
Or 12" CA

Foundation Improvement Or
Natural Soil subgrade

JPCP cross section

10″ – 14″ JPCP

3″ HMA OG Base

6″ CA#53 on Geotextile

14″ Soil treatment(Cement/Lime
Or 12″ CA#53

Foundation Improvement Or
Natural Soil subgrade

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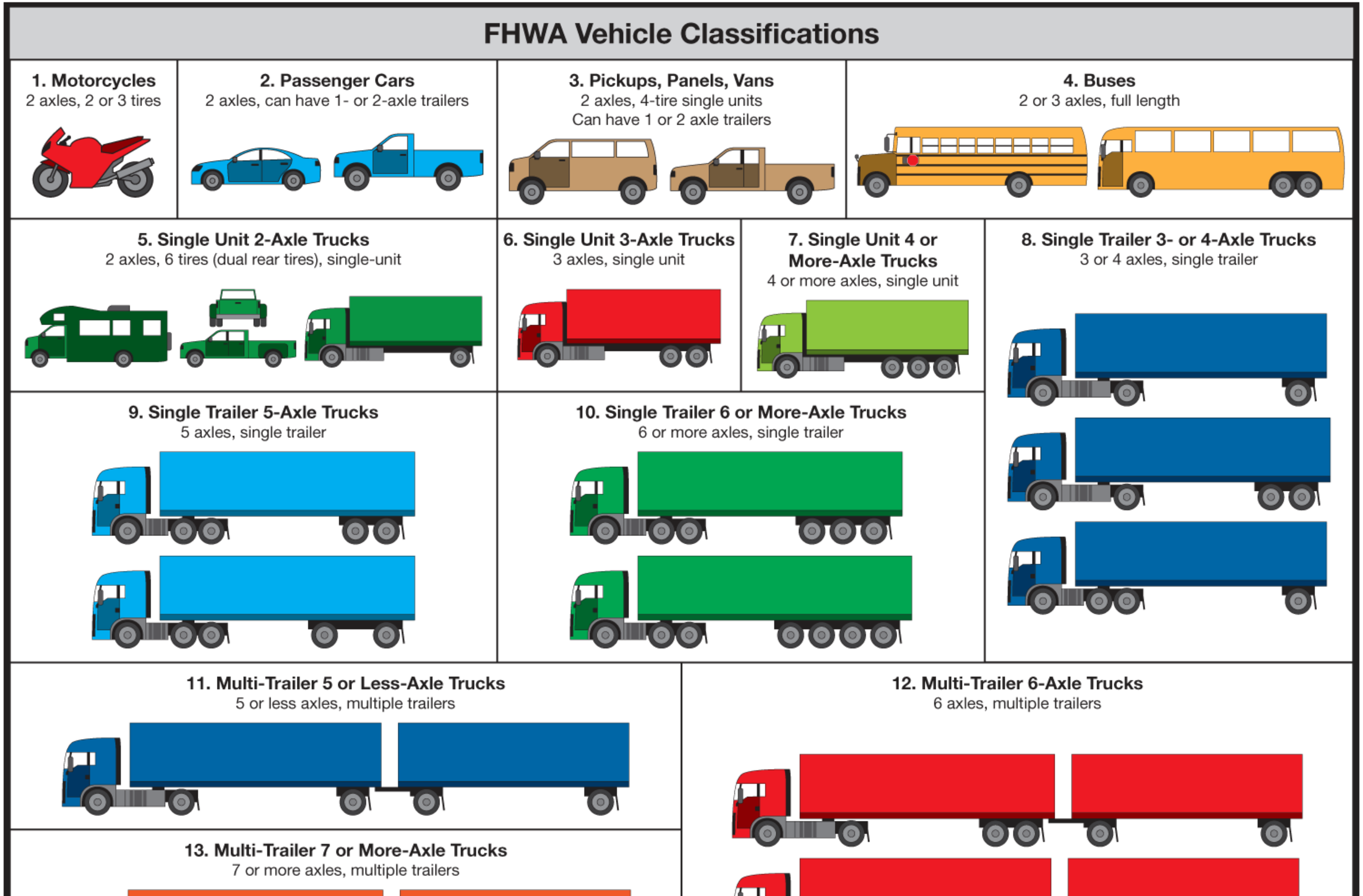
Pavement Design Considerations

- pavement performance
- traffic
- roadbed soil
- materials of construction
- environment
- drainage
- reliability
- life-cycle costs and
- Shoulder design

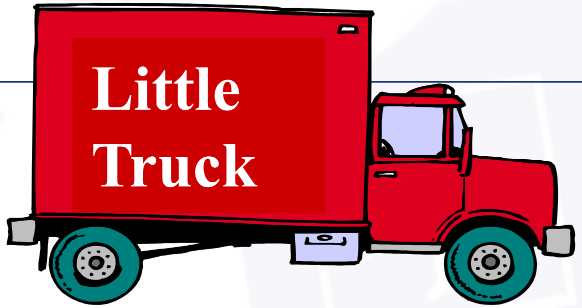
pavement performance(functional & structural)

- Pavement design life=20, 30, 50 years
- Asphalt road=20 years
- Concrete road=30 years
- Heavy duty road=50 years

traffic


FHWA Vehicle Classifications
1. Motorcycles
2 axles, 2 or 3 tires
2. Passenger Cars
2 axles, can have 1- or 2-axle trailers
3. Pickups, Panels, Vans
2 axles, 4-tire single units
Can have 1 or 2 axle trailers
4. Buses
2 or 3 axles, full length
5. Single Unit 2-Axle Trucks
2 axles, 6 tires (dual rear tires), single-unit
6. Single Unit 3-Axle Trucks
3 axles, single unit
7. Single Unit 4 or More-Axle Trucks
4 or more axles, single unit
8. Single Trailer 3- or 4-Axle Trucks
3 or 4 axles, single trailer
9. Single Trailer 5-Axle Trucks
5 axles, single trailer
10. Single Trailer 6 or More-Axle Trucks
6 or more axles, single trailer
11. Multi-Trailer 5 or Less-Axle Trucks
5 or less axles, multiple trailers
12. Multi-Trailer 6-Axle Trucks
6 axles, multiple trailers
13. Multi-Trailer 7 or More-Axle Trucks
7 or more axles, multiple trailers

ESAL's



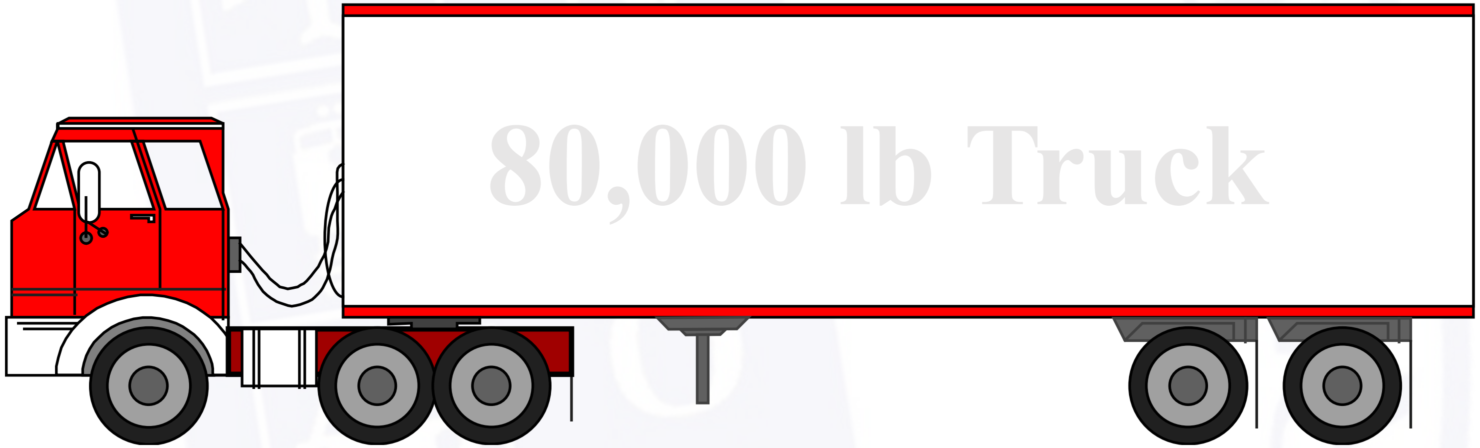
67 kN		27 kN
15,000 lb	+	6,000 lb
0.48 ESAL		0.01 ESAL

= 0.49 ESAL's

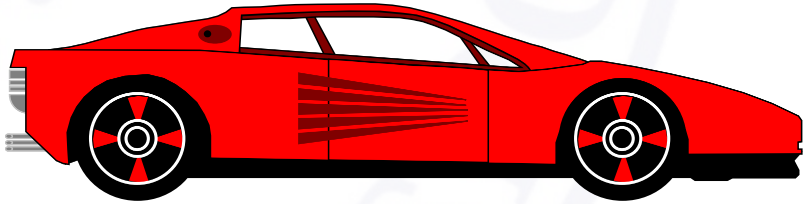
151 kN		151 kN		54 kN
34,000 lb	+	34,000 lb	+	12,000 lb
1.10		1.10		0.19

= 2.39 ESAL's

ESAL's



= 6,000



Subgrade Treatment Types

- Section 207, Standard Specification
- Type I 24 in. soil compaction
- Type IBC 14 in. chemical soil modification using cement
- Type IBL 14 in. chemical soil modification using lime
- Type IC 12 in. CA No.53
- Type II 6 in. CA No.53
- Type III 6 in. soil compaction
- Type IV 12 in. CA 53, geogrid
- Type IV A 12 in. CA 53 with geocell
- Type V 3 in. excavate & 3 in. CA 53
- In pavement design we use the resilient modulus(Mr)(Mr=1500XCBR)

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Roadbed soil(subgrade)


SAGAMORE
READY MIX


CAT
640

Materials of construction

- Soil
- Coarse Aggregate
- Fine Aggregate
- Asphalt
- Cement
- Plastic pipe
- Metal(dowel bars, tie bars etc.)
- Geosynthetic

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Environment

- Temperature
- Moisture
- Drainage
- Lat-Long
- Depth of water table

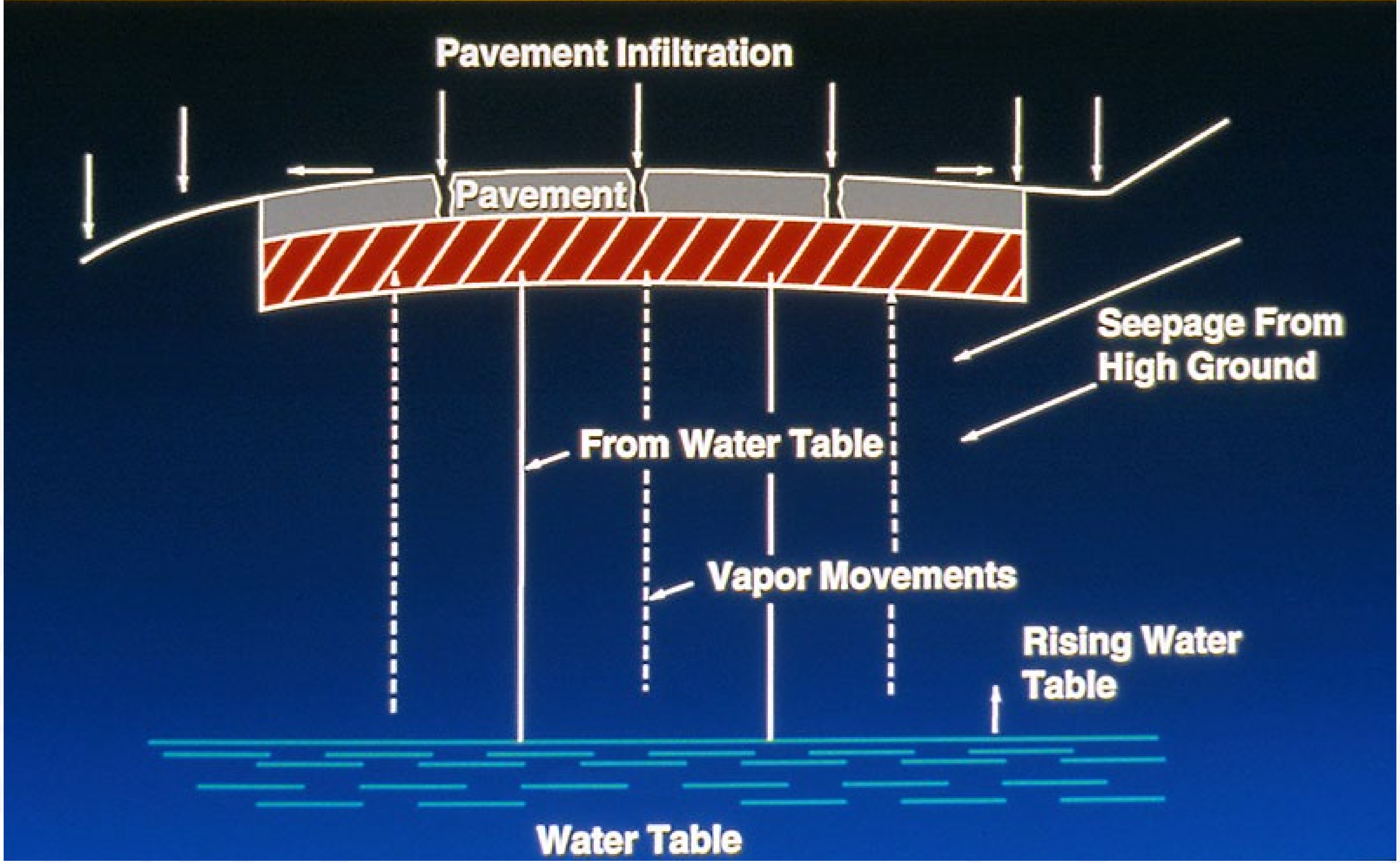
- Superpave History 1990's

Drainage

Three things are imp for pavement

- drainage
- drainage
- drainage

SOURCE OF WATER



Underdrain

SR 37

Underdrain Trench at I-74

SR 37

SR 37

I-69 Finish Line

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Outlet Pad

Underdrains

- Are we maintaining underdrain??????
- YES
- NO
- MAY BE

Reliability

- Probability
- Varies for functional class
- 70-98%
- AASHTO
- MEPDG

Life Cycle Cost Analysis

- Economic evaluation
- Analysis Period=50 years
- Initial cost
- Future cost
- Maintenance cost
- Discount rate
- Present Worth(PW)
- Salvage Value

- Cost/Lane Mile/Year used for comparing various treatments

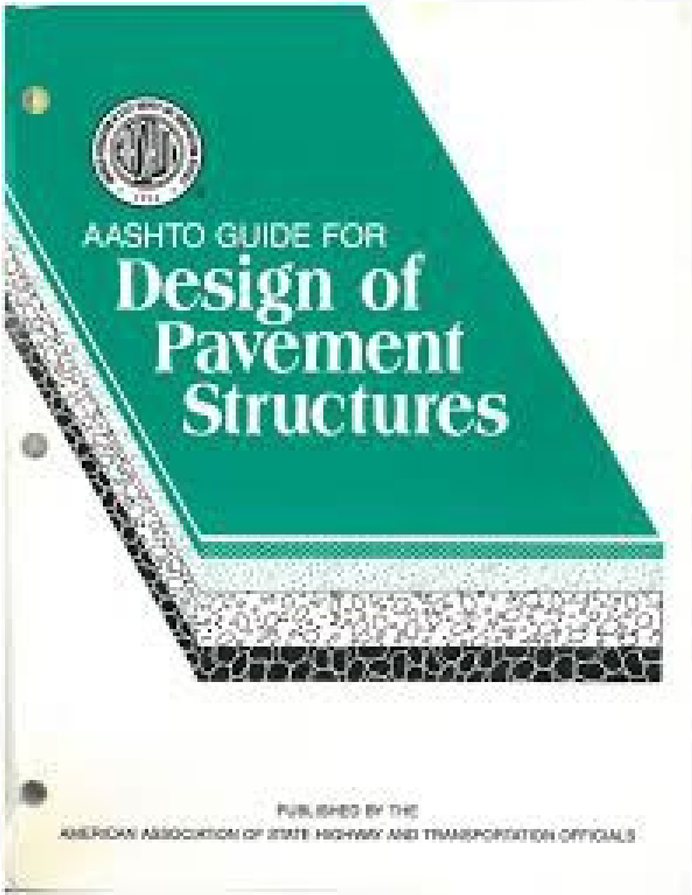
- Pavement Type Selection:

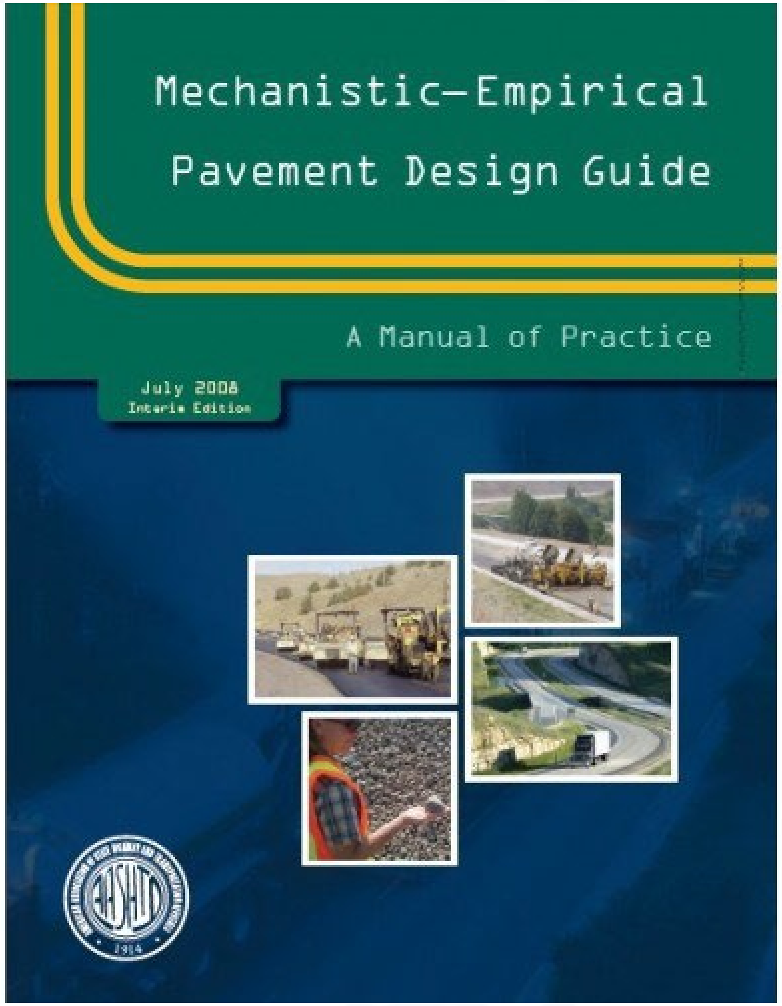
Shoulder design/ Temporary Pavement

- Purpose
- Varies with functional class
- MOT

Pavement design methods

- AASHTO(Old)
- MEPDG(New)





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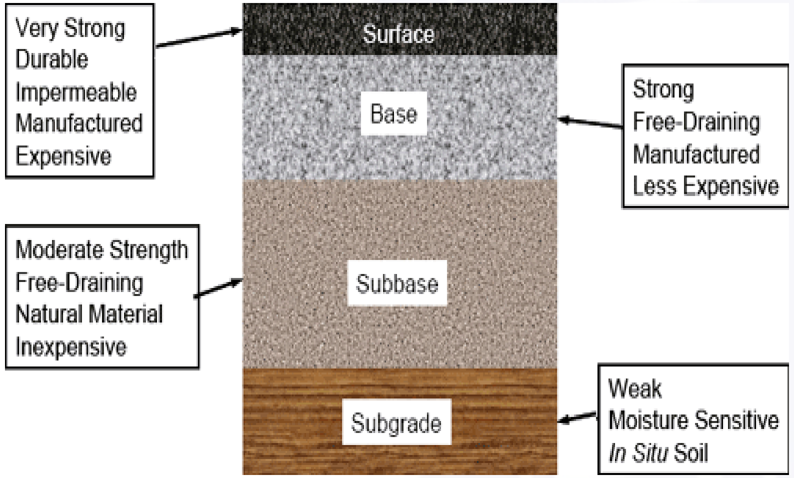
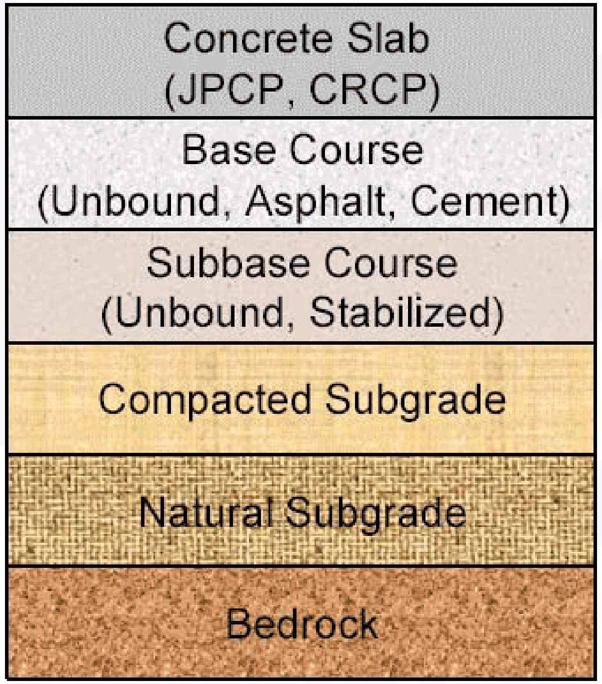
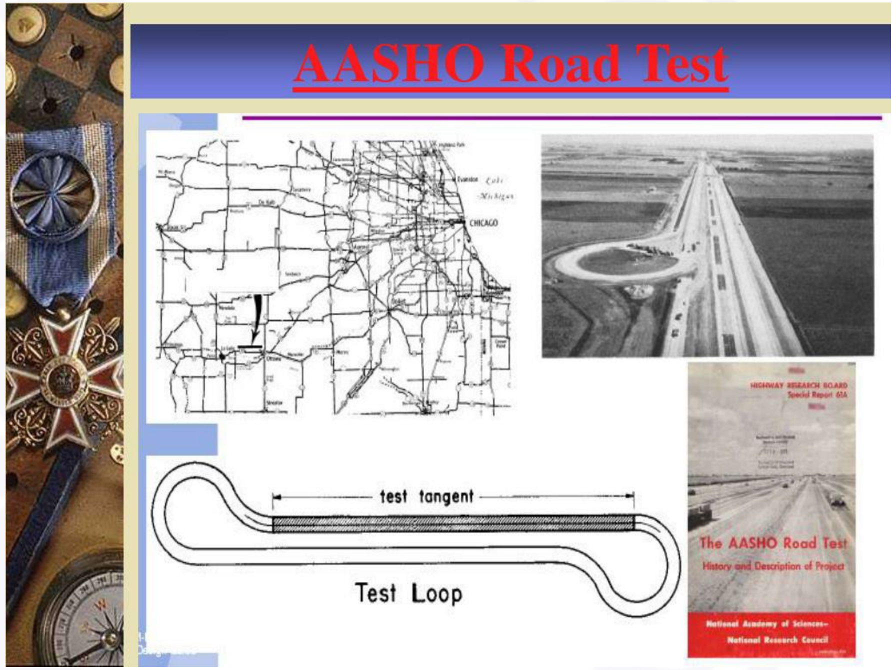
Pavement Design Methods





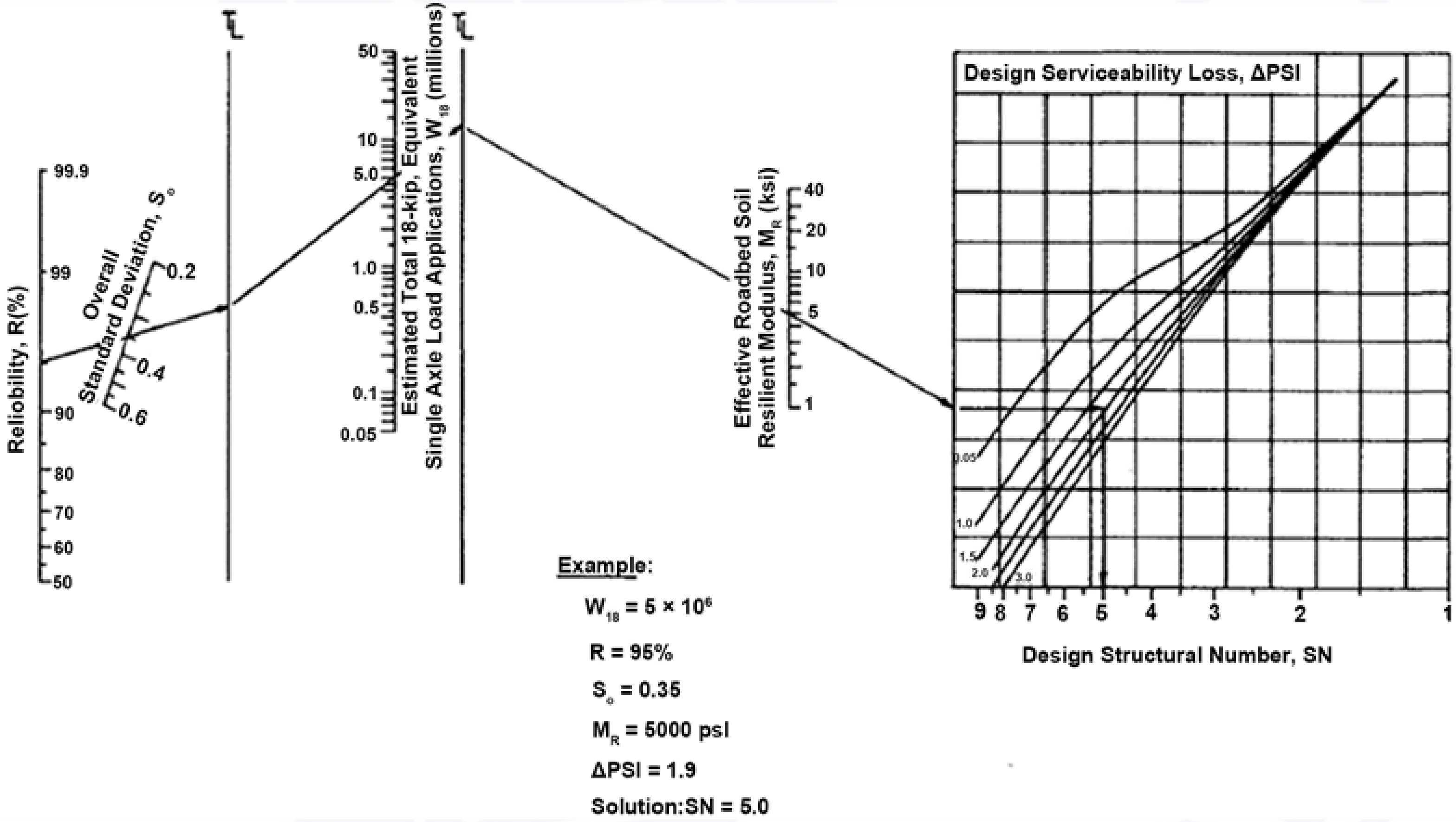
AASHTO 1993

- AASHO Road test(1958)
- Flexible pavement design(Sn)
- Rigid pavement design(thickness)
- Nomograph(design chart)



Pavement Design Formula

$$\log N = Z_R \cdot S_0 + 9{,}36 \cdot \log\,(SN+1) - 0{,}2 + \frac{\log\left(\frac{\Delta PSI}{p_0 - 1{,}5}\right)}{0{,}40 + \frac{1094}{(SN+1)^{5{,}19}}} + 2{,}32 \cdot \log M_R - 8{,}07$$


Reliobility, R(%)
99.9
99
90
80
70
60
50
Overall Standard Deviation, S_o
0.2
0.4
0.6
TL
Estimated Total 18-kip, Equivalent Single Axle Load Applications, W_{18} (millions)
50
10
5.0
1.0
0.5
0.1
0.05
TL
Effective Roadbed Soil Resilient Modulus, M_R (ksi)
40
20
10
5
1
Design Serviceability Loss, ΔPSI
0.05
1.0
1.5
2.0
3.0
9 8 7 6 5 4 3 2 1
Design Structural Number, SN
Example:
$W_{18} = 5 \times 10^6$
R = 95%
S_o = 0.35
M_R = 5000 psi
ΔPSI = 1.9
Solution: SN = 5.0

1993 AASHTO Pavement Design

DARWin Pavement Design and Analysis System

A Proprietary AASHTOWare
Computer Software Product

Flexible Structural Design Module

I-65 (0600304) Northbound

Flexible Structural Design

18-kip ESALs Over Initial Performance Period	66,466,820
Initial Serviceability	4.5
Terminal Serviceability	2.5
Reliability Level	98 %
Overall Standard Deviation	0.35
Roadbed Soil Resilient Modulus	5,000 psi
Stage Construction	1
Calculated Design Structural Number	7.17 in

Simple ESAL Calculation

Performance Period (years)	20
Two-Way Traffic (ADT)	67,130
Number of Lanes in Design Direction	3
Percent of All Trucks in Design Lane	60 %
Percent Trucks in Design Direction	50 %
Percent Heavy Trucks (of ADT) FHWA Class 5 or Greater	30 %
Average Initial Truck Factor (ESALs/truck)	1.3
Annual Truck Factor Growth Rate	0 %
Annual Truck Volume Growth Rate	1.52 %
Growth	Compound
Total Calculated Cumulative ESALs	66,466,820

Specified Layer Design

Layer	Material Description	Struct Coef. (Ai)	Drain Coef. (Mi)	Thickness (Di)(in)	Width (ft)	Calculated SN (in)
1	HMA Surface 9.5 mm	0.34	1	1.5	12	0.51
2	HMA Intermediate 19.0 mm	0.36	1	2.5	12	0.90
3	HMA Base	0.34	1	17	12	5.78
Total	-	-	-	21.00	-	7.19

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1993 AASHTO Pavement Design

DARWin Pavement Design and Analysis System

A Proprietary AASHTOWare
Computer Software Product

Rigid Structural Design Module

I-65 (0200007) ~~South Section~~ North Section

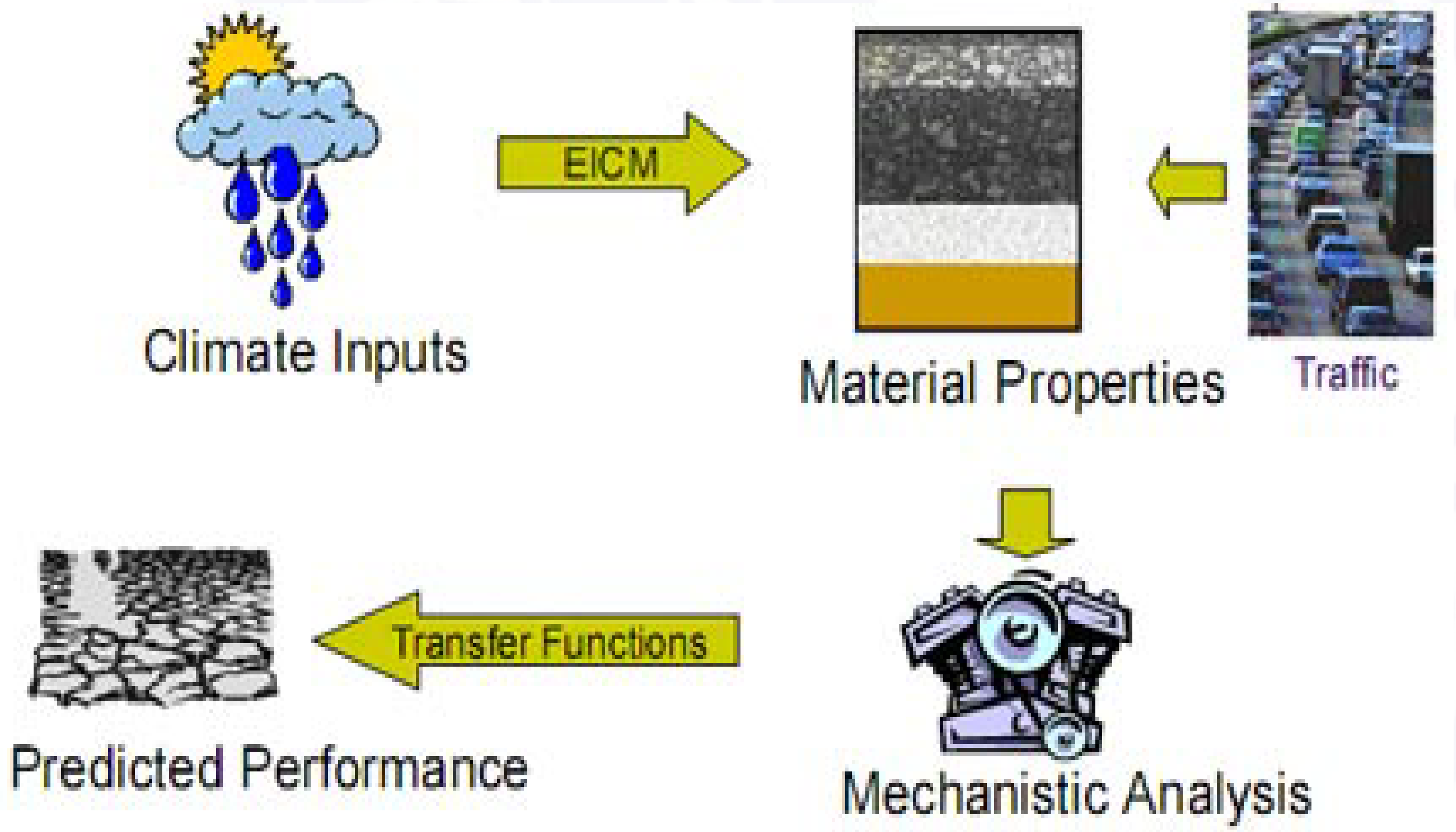
Rigid Structural Design

Pavement Type	JPCP
18-kip ESALs Over Initial Performance Period	467,253,451
Initial Serviceability	4.5
Terminal Serviceability	2.5
28-day Mean PCC Modulus of Rupture	650 psi
28-day Mean Elastic Modulus of Slab	3,500,000 psi
Mean Effective k-value	100 psi/in
Reliability Level	90 %
Overall Standard Deviation	0.35
Load Transfer Coefficient, J	2.8
Overall Drainage Coefficient, Cd	1
Calculated Design Thickness	16.85 in

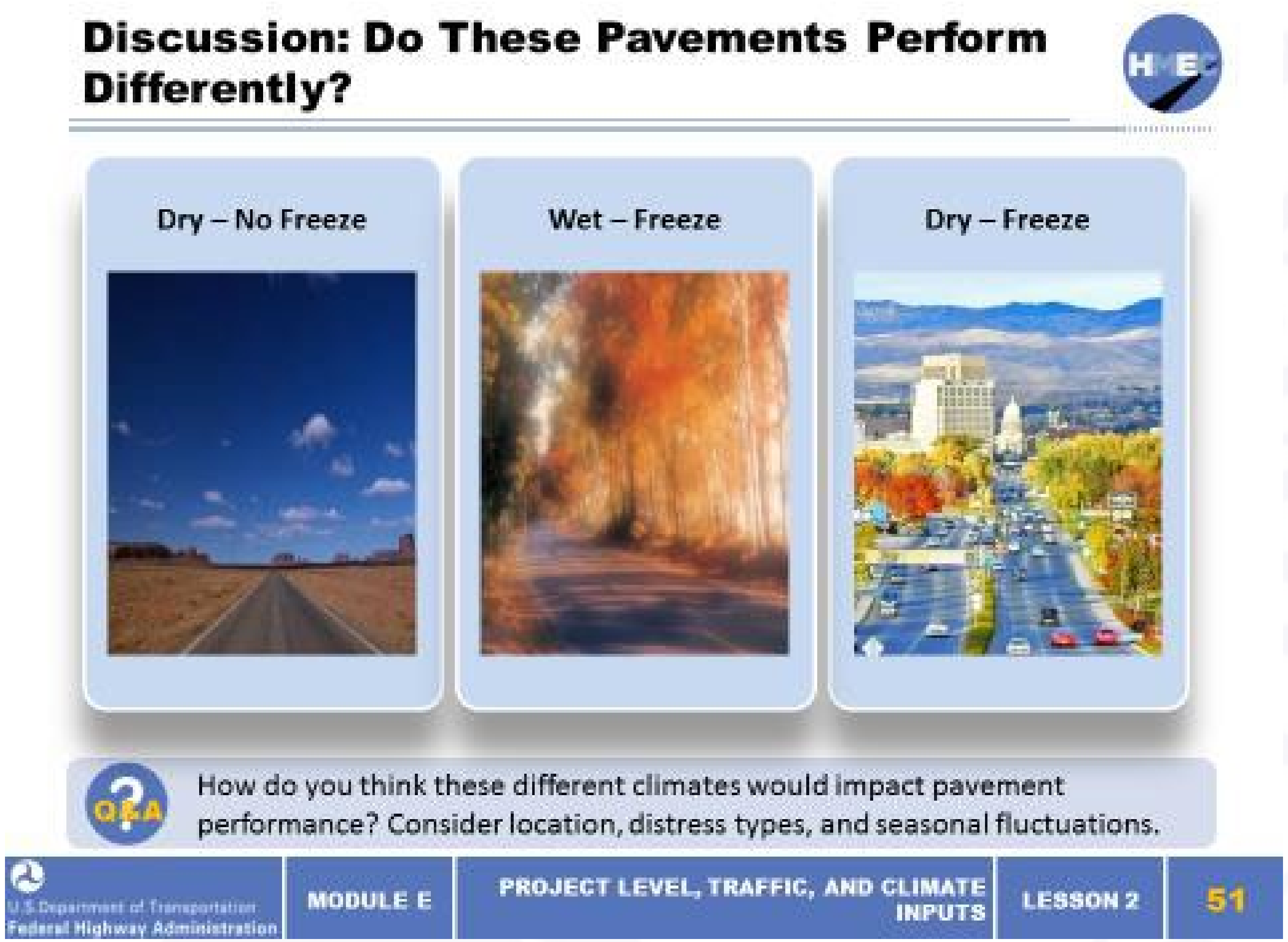
Simple ESAL Calculation

Performance Period (years)	30
Two-Way Traffic (ADT)	53,927
Number of Lanes in Design Direction	2
Percent of All Trucks in Design Lane	90 %
Percent Trucks in Design Direction	100 %
Percent Heavy Trucks (of ADT) FHWA Class 5 or Greater	35 %
Average Initial Truck Factor (ESALs/truck)	2
Annual Truck Factor Growth Rate	0 %
Annual Truck Volume Growth Rate	1.52 %
Growth	Compound
Total Calculated Cumulative ESALs	467,253,451

MEPDG(Mechanistic Empirical Pavement Design Guide)



Climate



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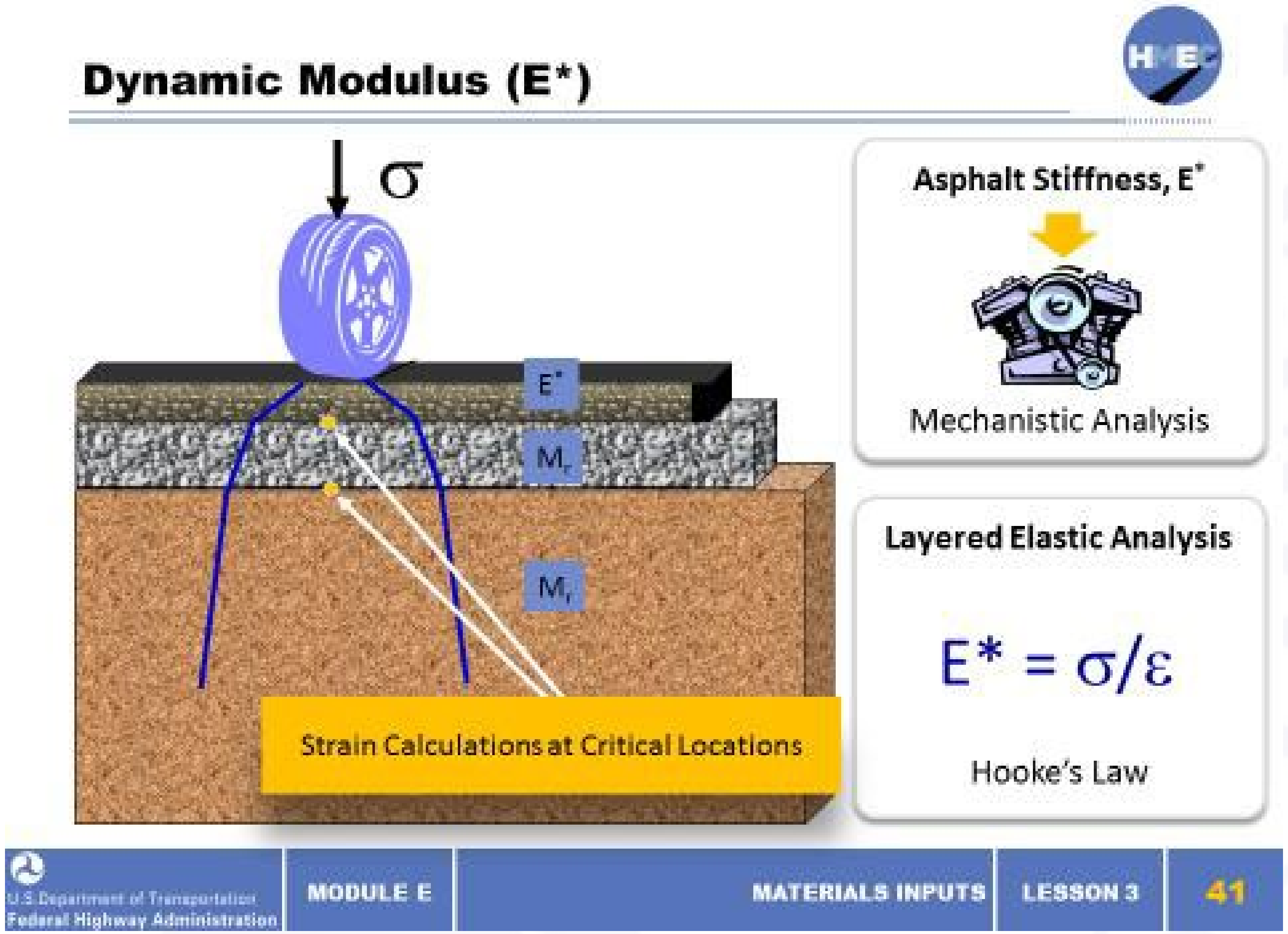
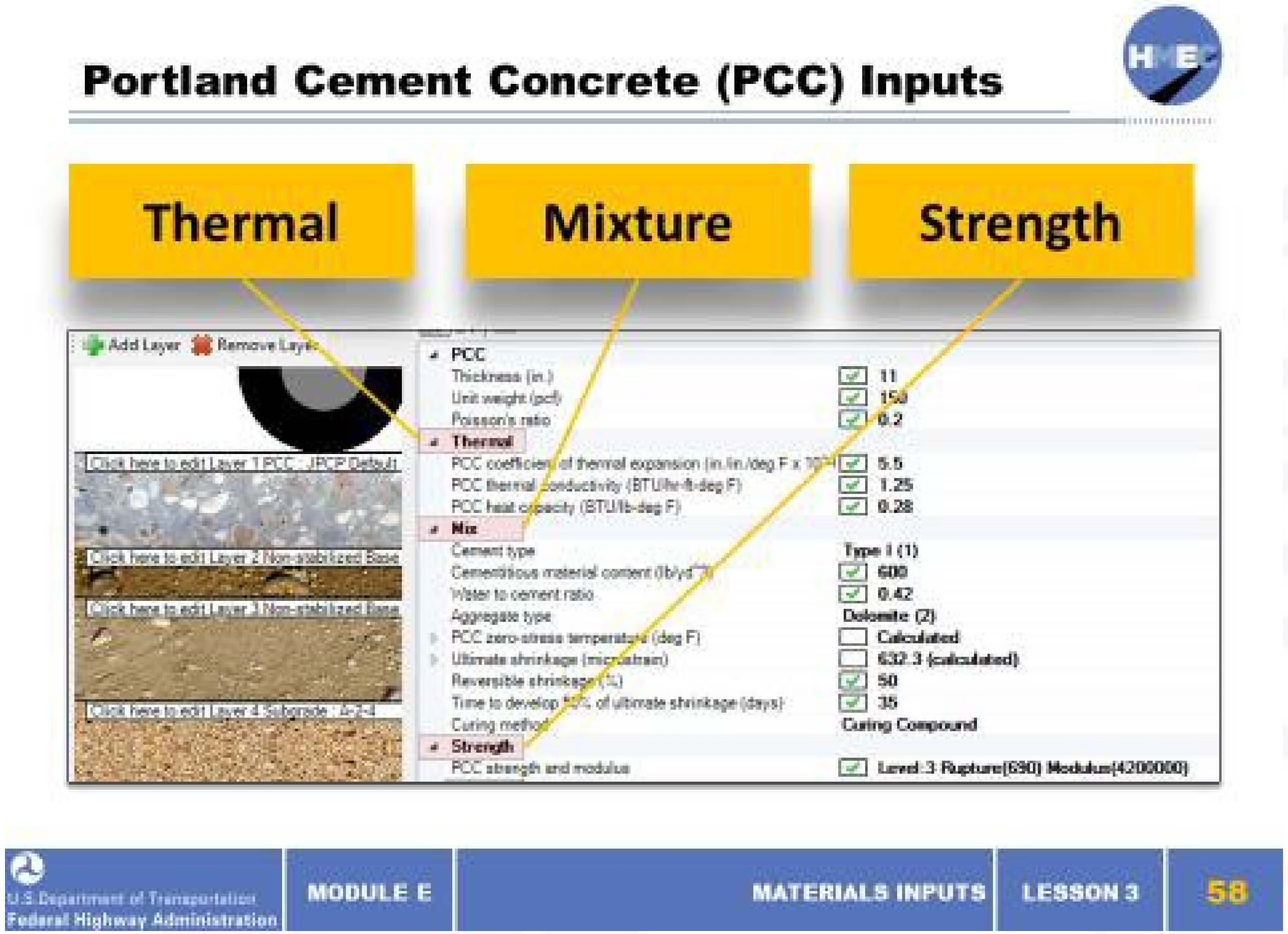
Materials testing


Dynamic Modulus (E*)
σ
E*
Mr
Mr
Strain Calculations at Critical Locations
Asphalt Stiffness, E*
Mechanistic Analysis
Layered Elastic Analysis
E* = σ/ε
Hooke's Law
U.S. Department of Transportation
Federal Highway Administration
MODULE E
MATERIALS INPUTS
LESSON 3
41

Material properties



Reliability

Design Reliability

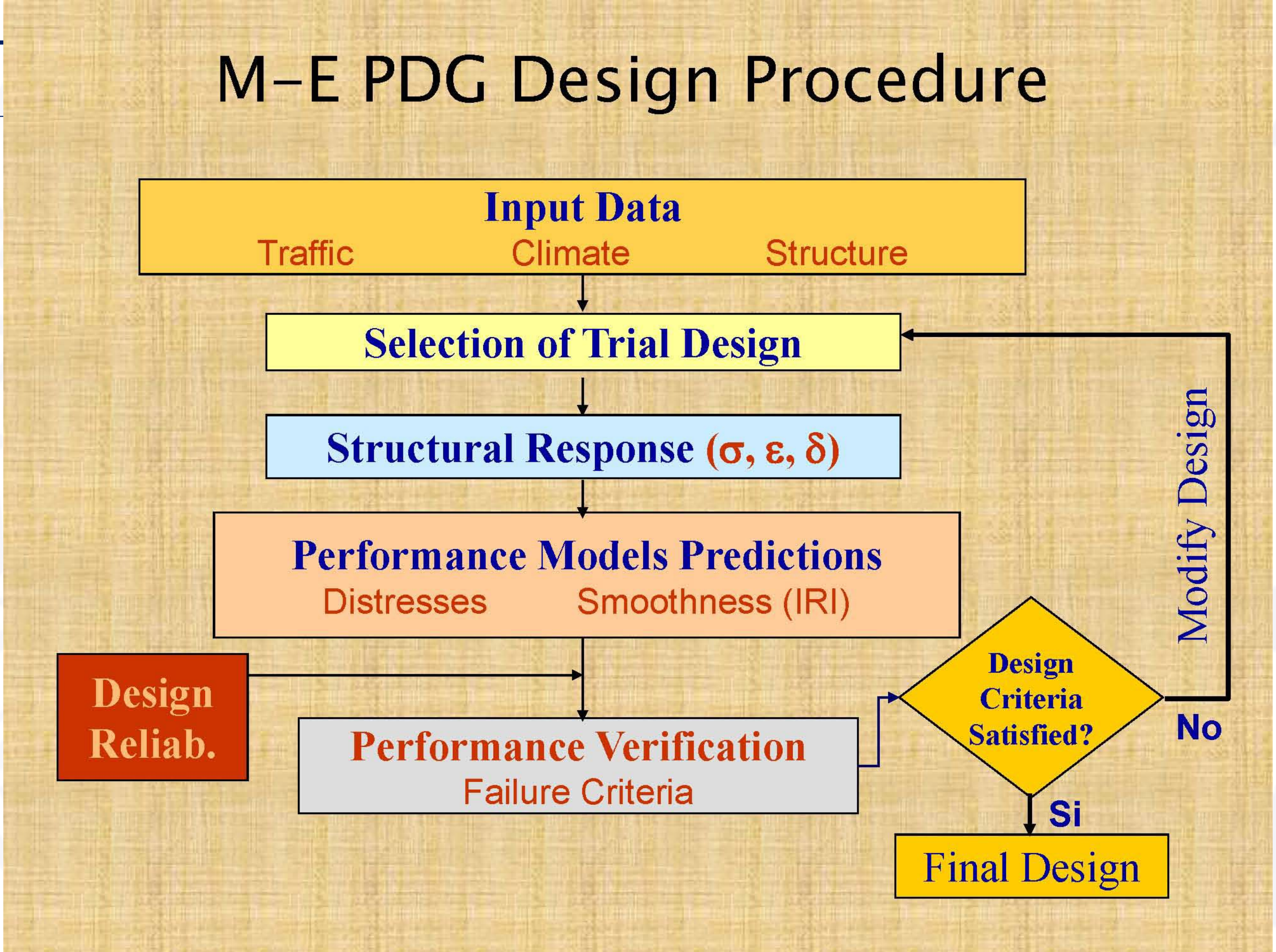
Functional Classification	Level of Reliability (%)	
	Urban	Rural
Interstate/Freeways	95	95
Principal Arterials	90	85
Collectors	80	75
Local	75	70

The greater the consequences of premature failure, the higher the design reliability.

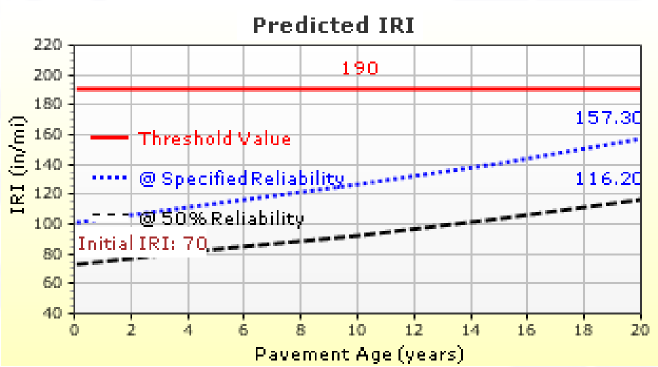
High Reliability + **Low Distress Limits**

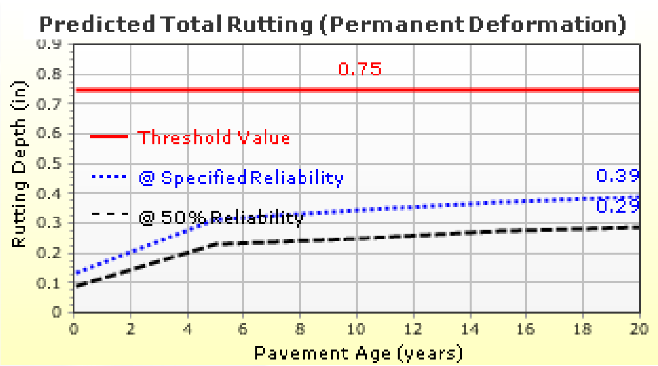
Conservative Design

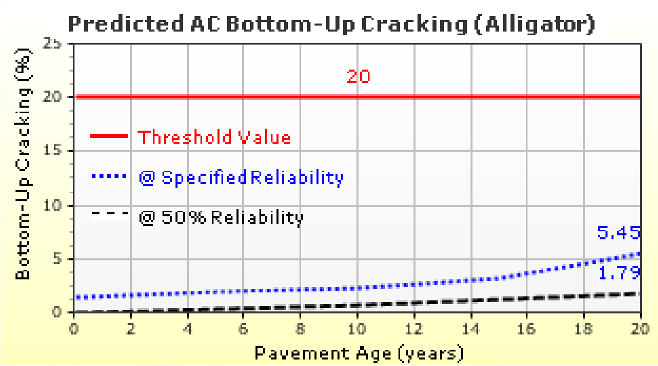
AASHT

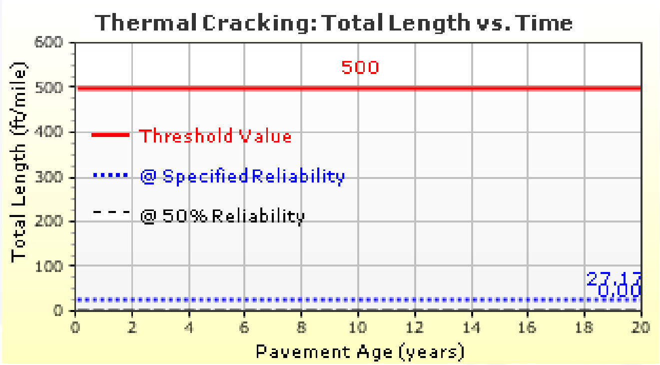

M–E PDG Design Procedure
Input Data
Traffic
Climate
Structure
Selection of Trial Design
Structural Response (σ, ε, δ)
Performance Models Predictions
Distresses
Smoothness (IRI)
Design Reliab.
Performance Verification
Failure Criteria
Design Criteria Satisfied?
No
Modify Design
Si
Final Design

10 in. HMA, for Low ESAL(<3 million)

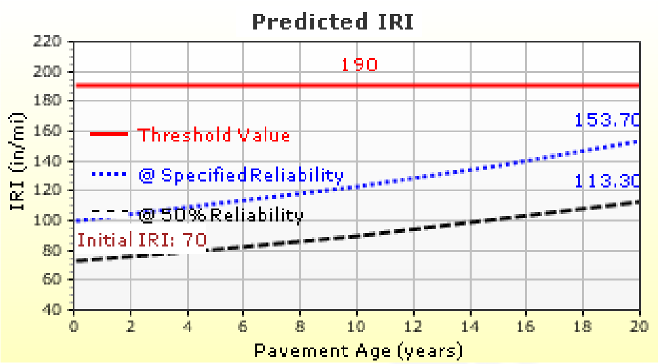


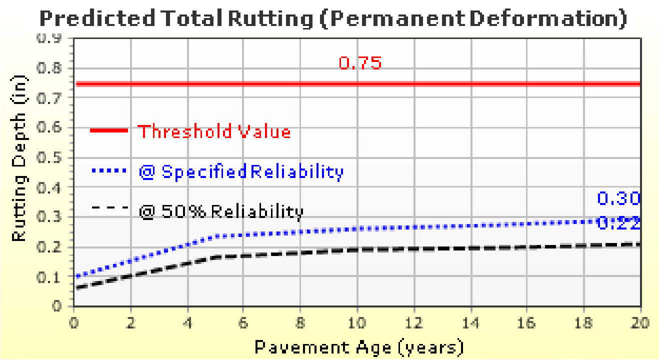


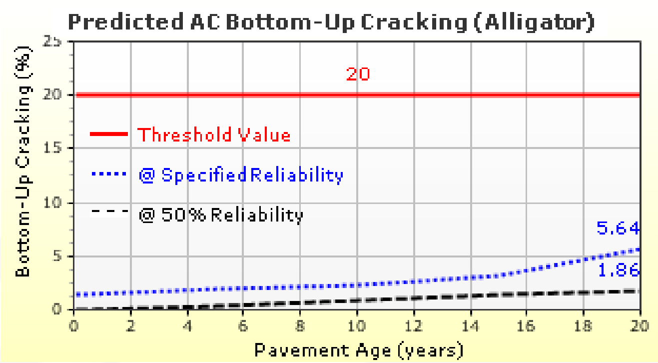


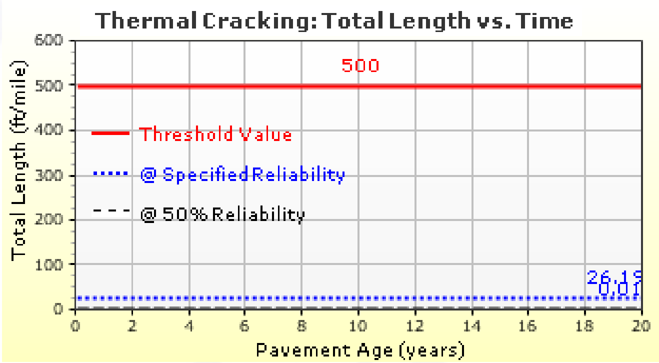


12 in. HMA for Medium ESAL(3 to 10 million)

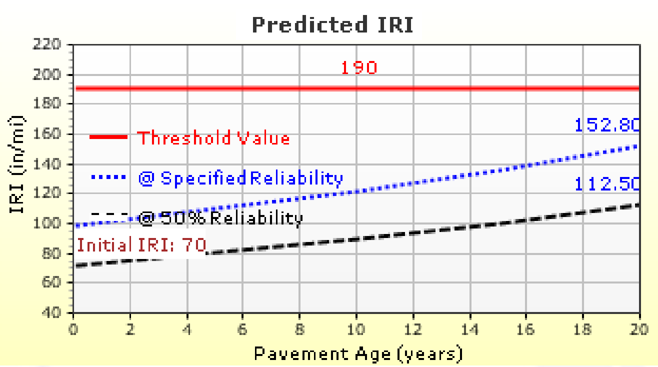


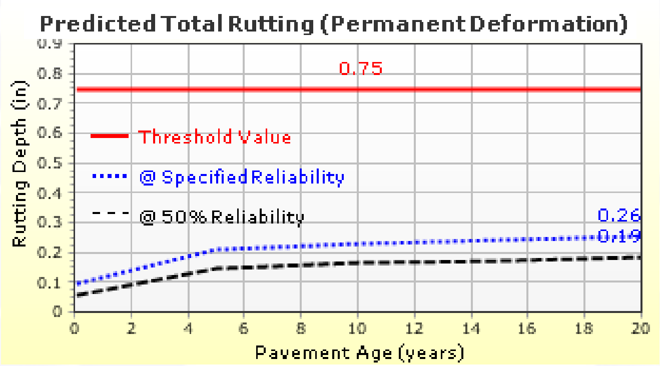


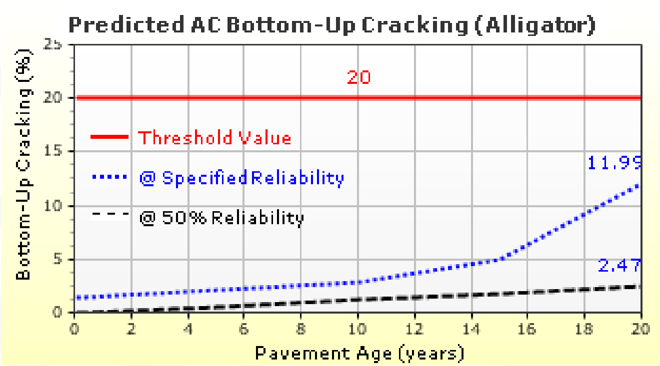


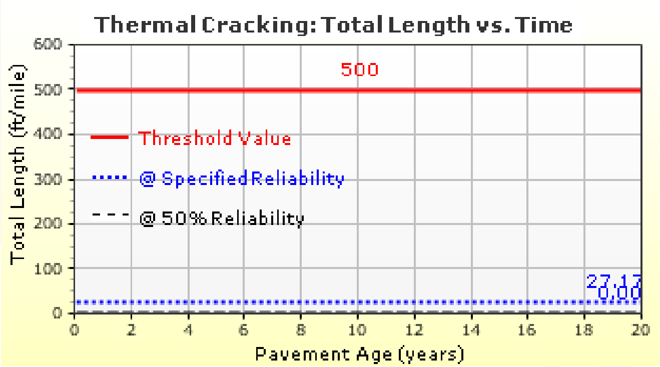


14 in. HMA for ESAL(10 to 30 million)









Indot Pavement Design.

- Total pavement designs
  - FY 14=426
  - FY 15=560
  - FY 16=542
  - FY 17 =649
  - FY 18 =498
  - FY 19= 510
  - CY 20=669
  - CY 21=593
  - CY 22=550

Ave=500+

40 to 50 PD/Month

Pavement Design Team(Central Office)

- Kumar Dave
  1. Nick Cosenza
  2. Pankaj Patel
  3. Matt Thomas
  4. Allen Davidson
  5. Tony Jones

Indot Pavement Design History

- AASHTO 93(1990-2009)
- Pavement ME(since 2010)
- Pavement ME Implementation(2002-2010)
- AASHTO 93 has limited inputs
- AASHTO Pavement ME has 1000's inputs(traffic, material, climate)
- Currently Indot uses AASHTO Pavement ME Ver 2.3
- In process of calibration/verification to use Ver 2.6
- Goal is to use Ver 3.0 in 2023

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Work Types

- New Road/Road Reconstruction
- Added Travel Lanes
- Road Rehabilitation
  - Single lift
  - Two lift
  - Three lift
  - Recycling(CIR/CCPR/FDR)
  - CPR
  - TCO/Unbonded Concrete Overlay
  - Intersection Improvement/Land slides

  - **Small Structure Replacement**
  - Bridge projects

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Chapter 304 Revisions/ IDM Part 6

- Chapter 304 Published in 2014
- IDM Part 6 Published in …2020
    - Recycling existing pavement(FDR & Cold R..)
    - Design lives table
    - Patching
    - MEPDG Inputs
    - LPA
    - Thin Concrete Overlays
    - Drainage and separation layers

    - Design Memo 22-02, LCPCA Update
    - Design Memo 22-03: Pavement Design for Small Structure and Bridge Projects

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Milling video

IMG_3136.MOV

SMA Surface paving video

IMG_3185.MOV

I-69 Finish Line(2022)

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HMA Section:

1) HMA on Compacted Aggregate Pavement (AADTT < 50)
   - 165 lb/yd^2 QC/QA, HMA, 2, 64, Surface 9.5 mm on
   - 275 lb/yd^2 QC/QA, HMA, 2, 64, Intermediate 19.0 mm on
   - 6 in. Compacted Aggregate, No. 53 on
   - Subgrade Treatment Type ____

2) HMA on Compacted Aggregate Pavement (AADTT < 250)
   - 165 lb/yd^2 QC/QA, HMA, 2, 64, Surface 9.5 mm on
   - 385 lb/yd^2 QC/QA, HMA, 2, 64, Intermediate 19.0 mm on
   - 5 in. Compacted Aggregate, No. 53 on
   - Subgrade Treatment Type ____

3) HMA on Compacted Aggregate Pavement (AADTT < 500)
   - 165 lb/yd^2 QC/QA, HMA, 2, 64, Surface 9.5 mm on
   - 495 lb/yd^2 QC/QA, HMA, 2, 64, Base 25.0 mm on
   - 4 in. Compacted Aggregate, No. 53 on
   - Subgrade Treatment Type ____

PCCP Section:

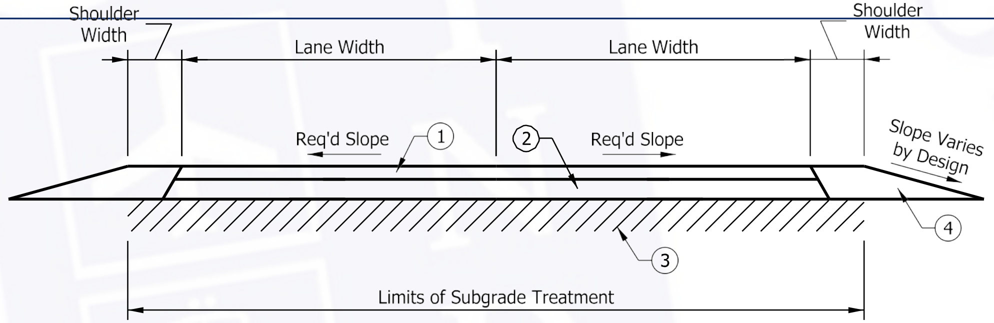
1) AADTT < 50
   - 7 in. of PCCP at 14-ft joint spacing with 1-in. dowel bar on
   - 6 in. of Dense Graded Subbase on
   - Subgrade Treatment Type ____

2) AADTT < 500
   - 7.5 in. of PCCP at 15-ft joint spacing with 1-in. dowel bar on
   - 6 in. of Dense Graded Subbase on
   - Subgrade Treatment Type ____

NOTE: These pavement sections (HMA or PCCP) should not be used for Rest Area Parking.

PARKING LOT PAVEMENT SECTIONS

Figure 602-3EE

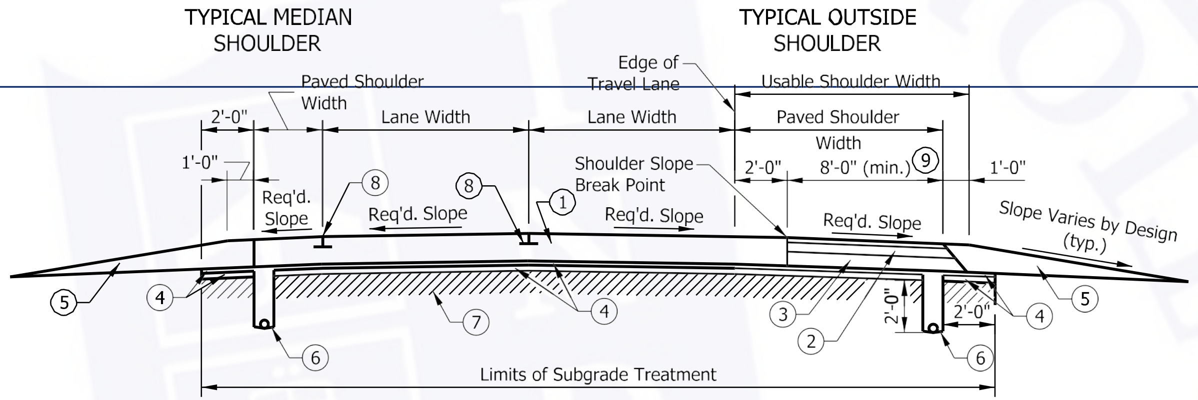


NOTES:

1. 4 in. Compacted Aggregate, No. 73
2. 6 in. Compacted Aggregate, No. 53
3. Subgrade Treatment, Type __
4. Variable-Depth Suitable Material

AGGREGATE PAVEMENT

Figure 602-3DD



NOTES:

(1) PCCP

(2) 165 lb/yd² HMA Surface 9.5 mm
275 lb/yd² HMA Intermediate 19.0 mm

(3) HMA Base 25.0 mm

* (4) Subbase for PCCP (3 in. Agg. Drainage Layer on 6 in. Agg. Separation Layer)

(5) Variable-Depth Compacted Aggregate

(6) Underdrain. See Figure 602-3X for detail.

(7) Subgrade Treatment, Type ____

(8) Longitudinal Joint or Longitudinal Construction Joint. See figure 602-3Z for detail.

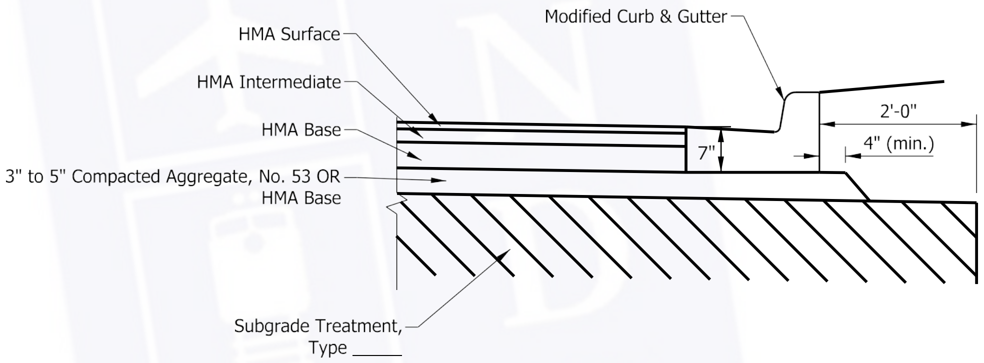
(9) For width < 8'-0", pavement type is per pavement design.

10. Safety edge as required. See Figure 602-3AA for detail.

* Where underdrains are not required, Dense Graded Subbase should be used.

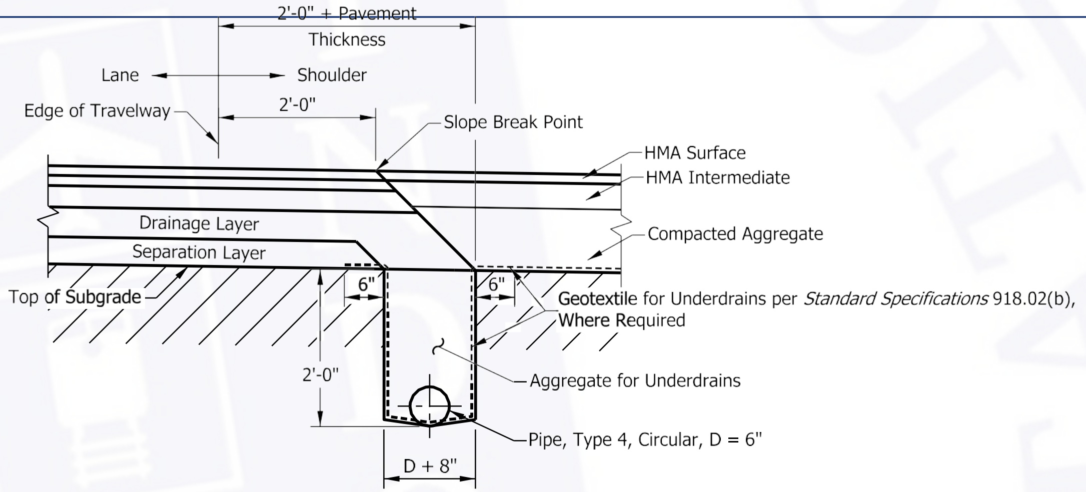
PCCP SECTION WITH HMA OUTSIDE SHOULDER

Figure 602-3T



MODIFIED CONCRETE CURB AND GUTTER SECTION FOR HMA PAVEMENT
ON COMPACTED AGGREGATE WITHOUT UNDERDRAIN

Figure 602-3Q



NOTE:

- Configuration for median shoulder is the same as for an outside shoulder.
- Layer thicknesses are not to scale. Apparent thicknesses shown may not be representative of the selected drainage or seperation layer

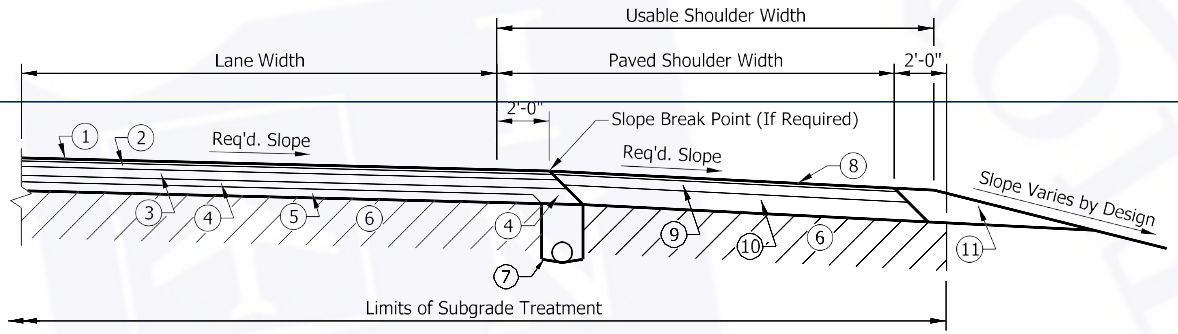
UNDERDRAIN FOR FULL-DEPTH HMA PAVEMENT
WITH HMA ON COMPACTED AGGREGATE SHOULDER

Figure 602-3L

HMA Pavement Thickness	Layer No.	Course	Lay Rate lb/yd²	Aggregate Size, mm	Layer Thickness in.
4.0 inches	1	Surface	165	9.5	
	2	Intermediate	275	19.0	
	3	CA, No. 53	-	-	6"
4.5 inches	1	Surface	165	9.5	
	2	Intermediate	330	19.0	
	3	CA, No. 53	-	-	5.5"
4.5 inches	1	Surface	220	12.5	
	2	Intermediate	275	19.0	
	3	CA, No. 53	-	-	5.5"
5.0 inches	1	Surface	220	12.5	
	2	Intermediate	330	19.0	
	3	CA, No. 53	-	-	5"
5.5 inches	1	Surface	220	12.5	
	2	Intermediate	385	19.0	
	3	CA, No. 53	-	-	4.5"
6.0 inches	1	Surface	220	12.5	
	2	Intermediate	440	25.0	
	3	CA, No. 53	-	-	4"

TYPICAL HMA PAVEMENT ON COMPACTED AGGREGATE

Figure 602-3 I



NOTES:

Mainline

- (1) ___ lb/yd² HMA Surface *
- (2) ___ lb/yd² HMA Intermediate *
- (3) ___ lb/yd² HMA Base *
- (4) ___ Drainage Layer
- (5) ___ Separation Layer
- (6) Subgrade Treatment, Type _____
- (7) Underdrain. See Figure 602-3L for detail.

* See Figure 602-3E for lay rate.

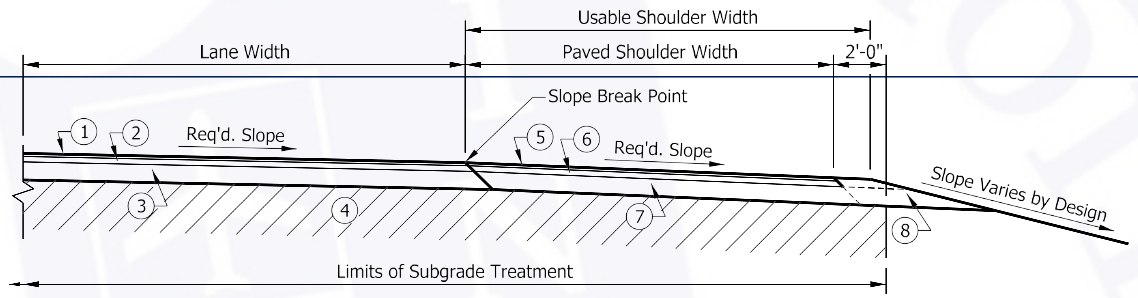
Shoulders

- (8) 165 lb/yd² HMA Surface 9.5 mm
- (9) 495 lb/yd² Min. HMA Base 25.0 mm
- (10) Compacted Aggregate (Depth equals Mainline HMA thickness minus 6 in.)
- (11) Variable-Depth Compacted Aggregate

12. Safety edge as required for top two HMA layers. See Figure 602-3AA for detail.
13. Longitudinal joint adhesive required for Surface and Intermediate layers.
14. Liquid Asphalt Sealant required on Surface layer over longitudinal joint, 24" width

FULL-DEPTH HMA PAVEMENT WITH HMA ON COMPACTED AGGREGATE SHOULDER WITH UNDERDRAIN

Figure 602-3D



NOTES:

Mainline, Section with Shoulders

* (1) ___ lb/yd² HMA Surface
(2) ___ lb/yd² HMA Intermediate
(3) ___ in. Compacted Aggregate, No 53
(4) Subgrade Treatment, Type _____

Shoulders

* (5) ___ lb/yd² HMA Surface
(6) ___ lb/yd² HMA Intermediate
(5), (6), and (7) may be replaced by 10 in. equivalent thickness consisting of 4 in. Compacted Aggregate, No. 73 on 6 in. Compacted Aggregate, No. 53.
(7) ___ in. Compacted Aggregate, No. 53. Depth equal to (3).
(8) Variable-Depth Compacted Aggregate

9. Safety edge as required for Surface and Intermediate layers. See Figure 602-3AA for detail.
10. Longitudinal joint adhesive required for Surface and Intermediate layers.
11. Liquid Asphalt Sealant required on Surface layer over longitudinal joint, 24" width

* See Figure 602-3 I for lay rate.

HMA ON COMPACTED AGGREGATE PAVEMENT

Figure 602-3H

Asphalt Road

Concrete Road

GUNTERT & ZIMMERMAN
RIETH-RILEY
6777

I-65

Questions?

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