Basics of Pavement Design

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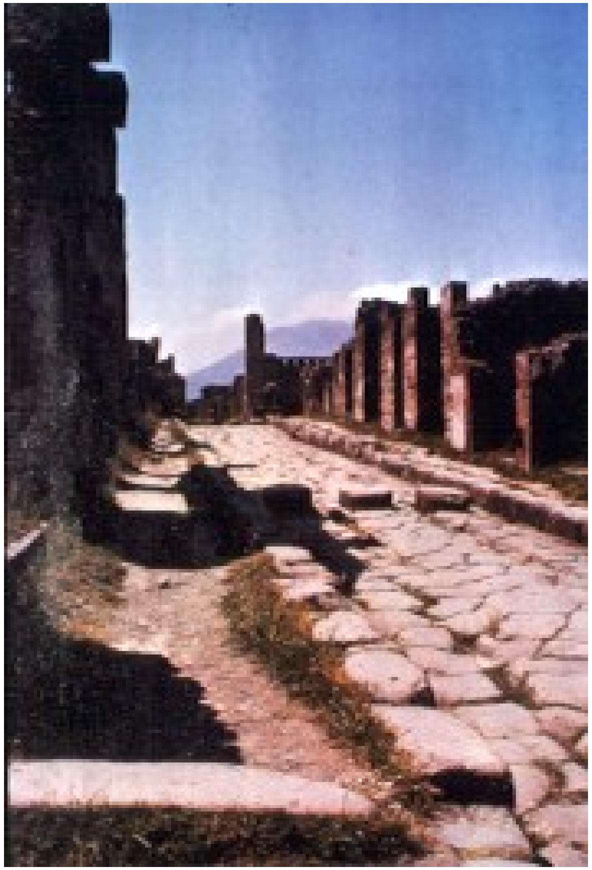
Outline of Presentation

- Introduction
- Roadway Distresses
- Flexible Pavements
- Road Tests
- Design Factors

Introduction

Evolution of Pavement Technology



Roadways

- Roadways
  - Unpaved roads
    - Gravel roads
    - Haul roads
    - Construction platform
  - Paved roads
    - Rigid pavements
      - Concrete pavements
    - Flexible pavements
      - Asphalt pavements

Unpaved vs. Paved

← Unpaved

Paved →

Flexible vs. Rigid Pavements

← **Flexible**

Rigid →

Rigid vs. Flexible Pavements

- **The essential difference between the two types of pavements is the manner in which they distribute the load over the subgrade**

- **The rigid pavement, because of its rigidity and high modulus of elasticity, tends to distribute the load over a relatively wide area of soil**

- **The major factor considered in the design of rigid pavements is the structural strength of the concrete not subgrade strength**

Advantages and Disadvantages of Flexible Pavements

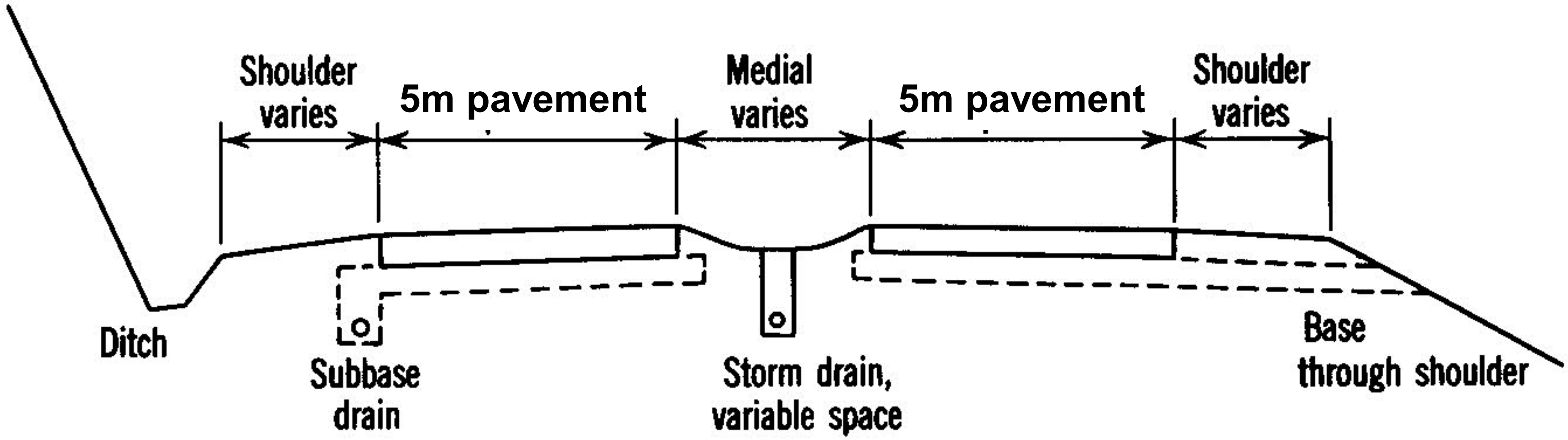
Advantages

- More tolerable to differential settlement
- Easily repaired
- Additional thickness added at any time
- Non-skid properties do not deteriorate
- Quieter and smoother
- More temperature tolerant

Disadvantages

- Loses some flexibility and cohesion with time
- Needs resurfaced sooner than rigid pavements
- Not normally chosen where water is expected

Typical Cross Section of Highway



Yoder and Witczak (1975)

Roadway Distresses

Typical Problems of Unpaved Roads

Failure of Flexible Pavements

- Fatigue cracking
- Rutting
- Thermal cracking
- Shear/slippage
- Reflection cracking
- Migration of fines

Fatigue Failure

Rutting

Thermal Cracking

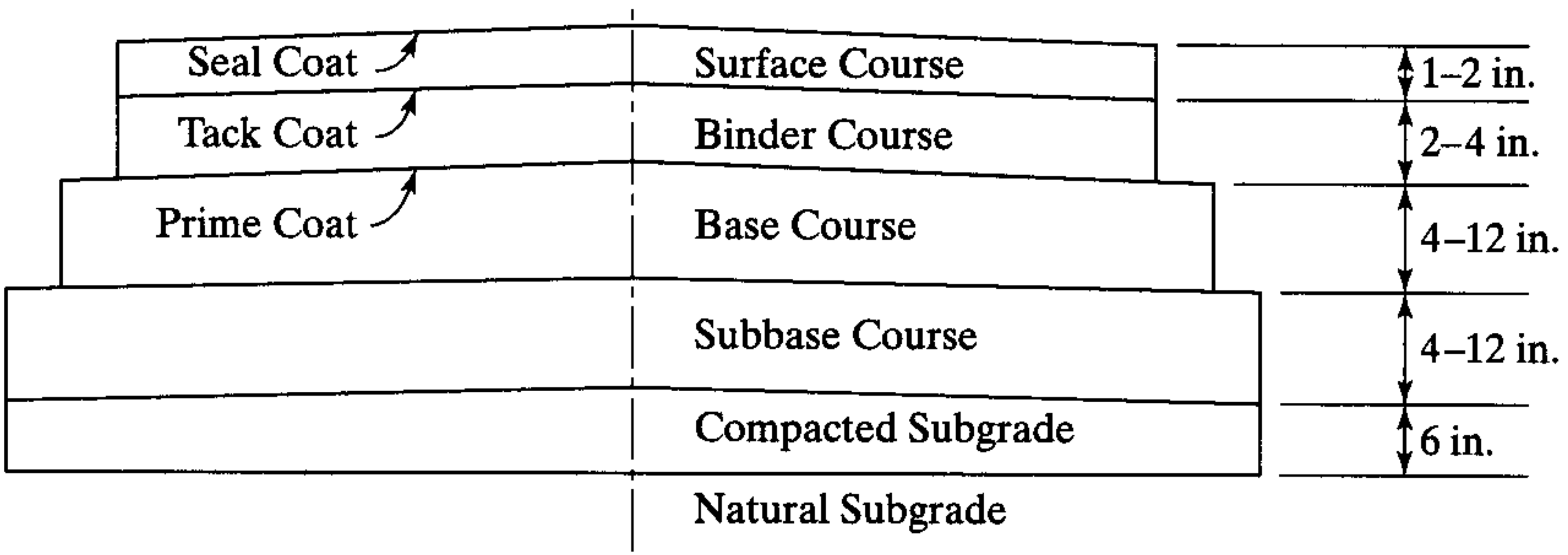
Shear/Slippage Failure

Reflection Cracking

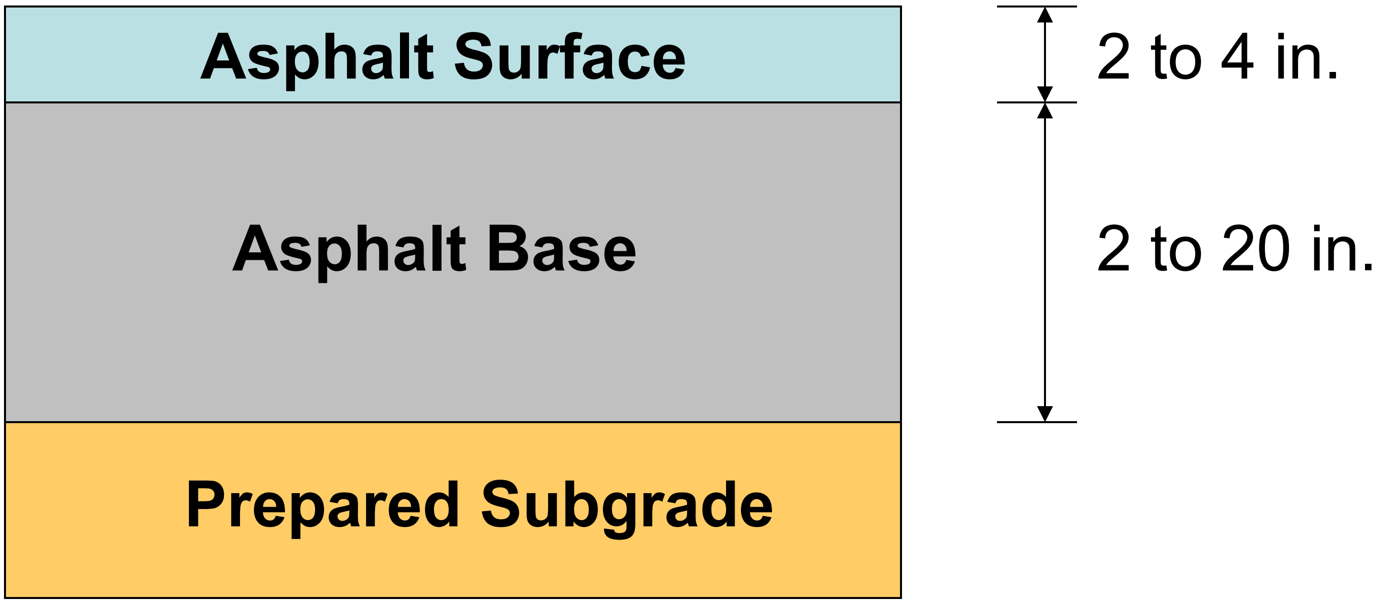
Migration of Fines to Surface

Flexible Pavements

Typical Cross-Section of Conventional Flexible Pavements



Typical Cross-Section of Full-Depth Flexible Pavements



Advantages of Full-Depth Asphalt Pavements

- No permeable granular layers to entrap water and impair performance
- Reduce time for construction
- Provide and retain uniformity in the pavement structure
- Less affected by moisture or frost

Design Methods

- Empirical method with or without a soil strength test
- Limiting shear failure method
- Limiting deflection method
- Regression method based on pavement performance or road test
- Mechanistic-empirical method

Empirical Methods

- Estimation of pavement thickness based on soil group from A-1 to A-7 without soil strength value
- Relate pavement thickness to CBR
- Disadvantages
  - applied only to a given set of environmental, material, and loading conditions

Limiting Shear Failure Methods

- Determine the thickness of pavements so that shear (bearing) failures will not occur
- The major properties of pavement components are their cohesion and friction angle
- Disadvantages
  - pavements should be designed for riding comfort rather than for barely preventing shear failures

Limiting Deflection Methods

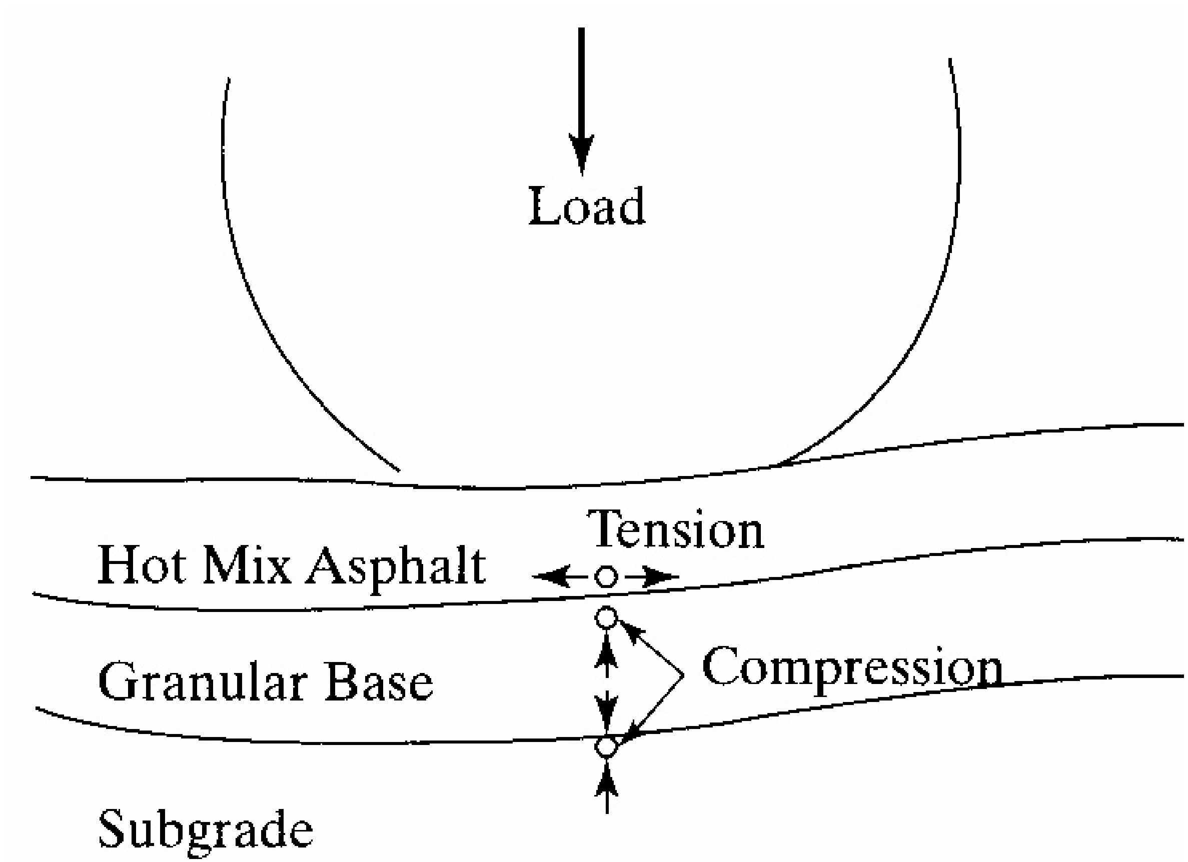
- Determine the thickness of pavements so that the vertical deflection will not exceed the allowable limit

- The Kansas State Highway Commission (1947) modified Boussinesq's equation and limited the deflection of subgrade to 0.1 in.

- The U.S. Navy (1953) applied Burmister's two-layer theory and limited the surface deflection to 0.25 in.

- Disadvantages
  - pavement failures are caused by excessive stresses and strains instead of deflections

Tensile and Compressive Strains in Flexible Pavements



Regression Methods

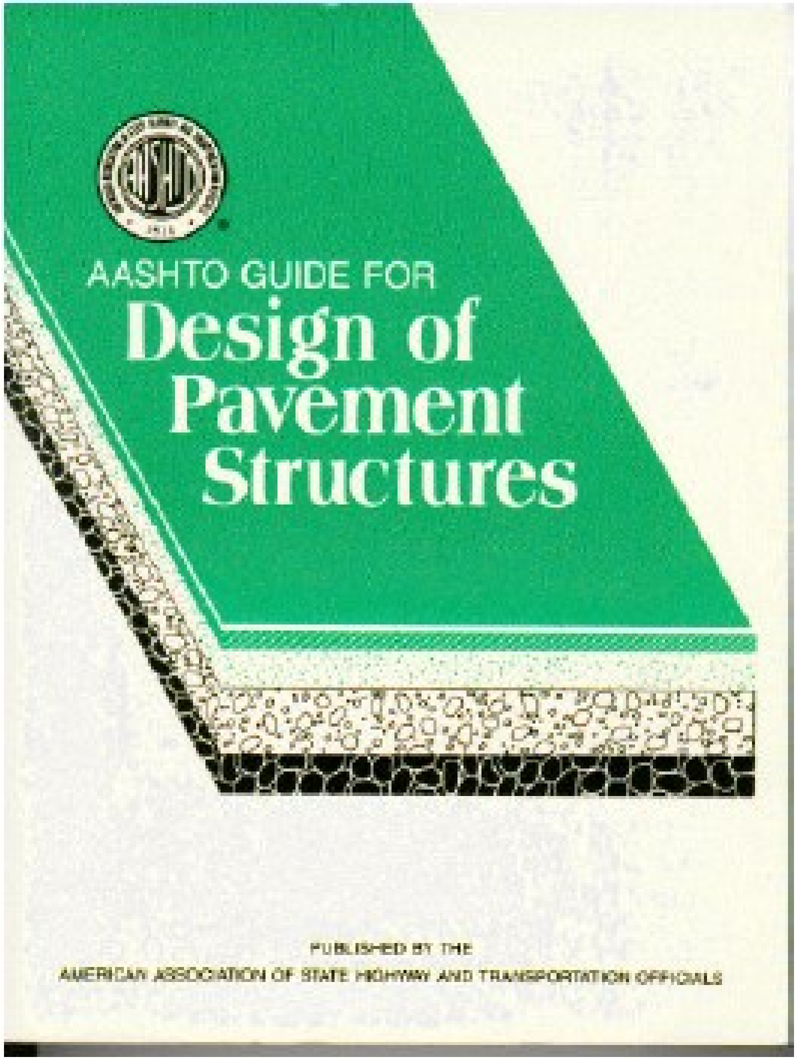
- Regression equations were developed based on pavement performance of road tests or existing roads

- AASHTO method is a good example of regression methods

- Disadvantages
  - the design equations can be applied only to the conditions at the road test site
  - for other conditions, extensive modifications based on theory or experience are needed

AASHTO Design Procedures

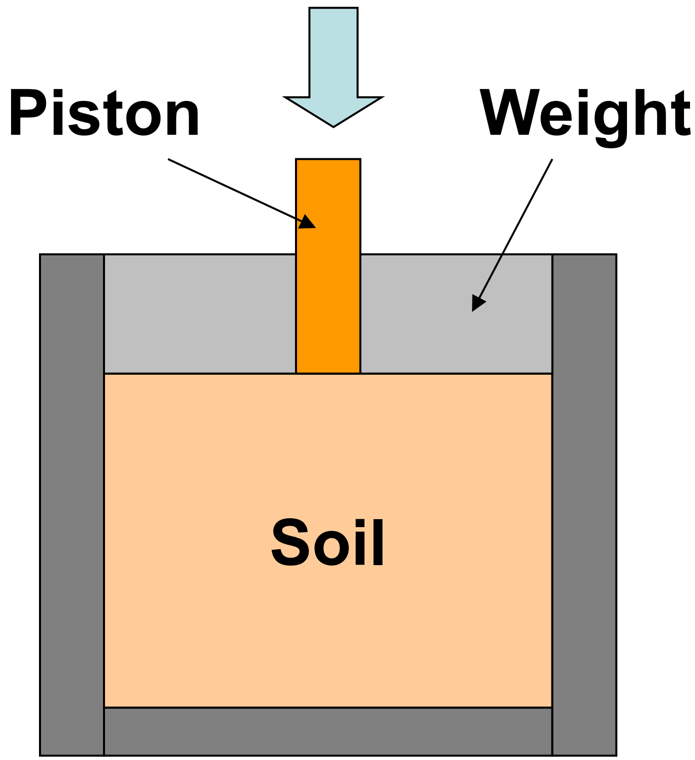
AASHTO Guide for Design of Pavement Structures



Current Practice in DOTs

Design Procedures	DOTs
1972 AASHTO Guide	3
1986 AASHTO Guide	2
1993 AASHTO Guide	26
Agency's own pavement design guide or combination of AASHTO/Agency design procedures	17

California Bearing Ratio (CBR) Test

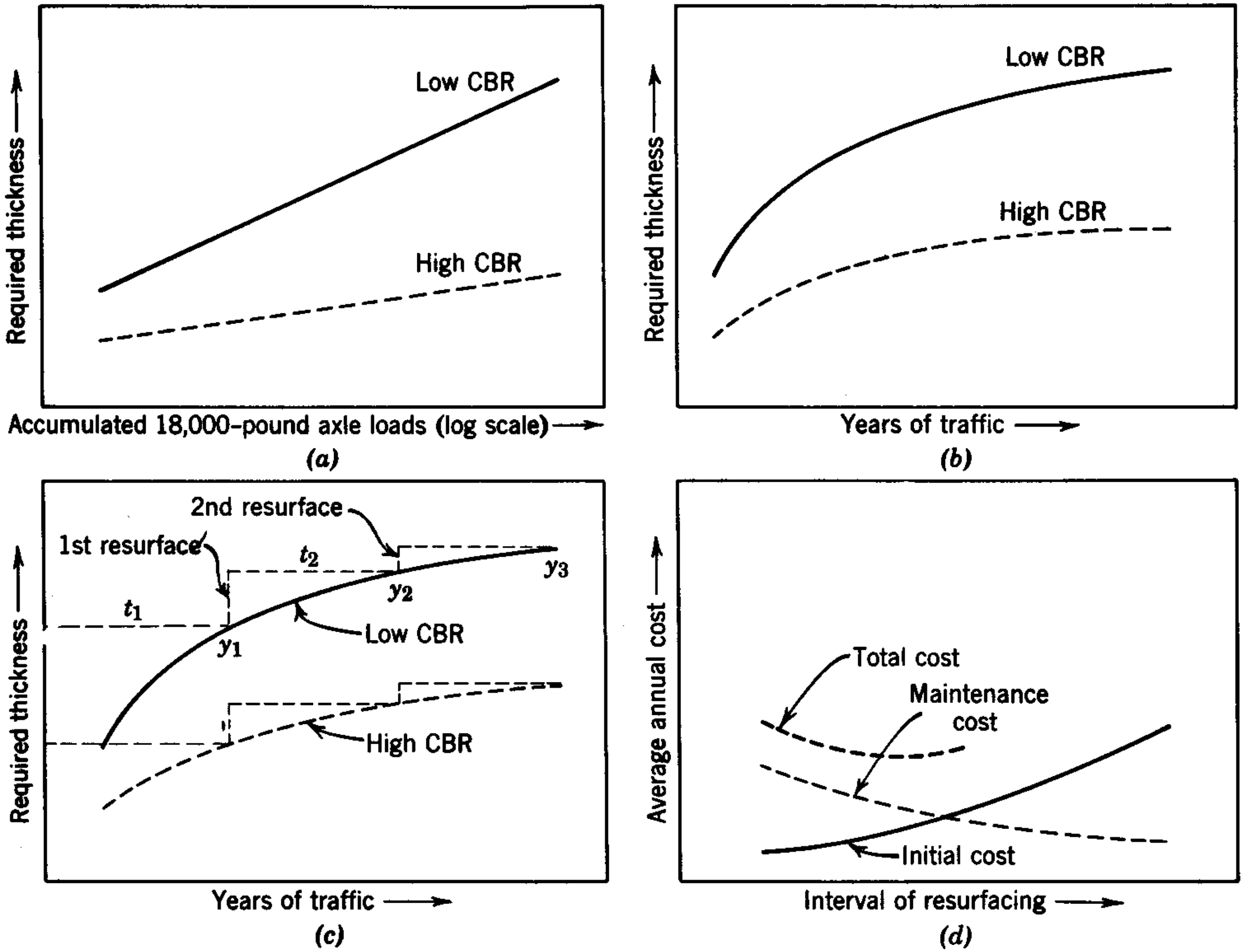


Standard values for a high-quality crushed stone

Penetration (in.)	Pressure (psi)
0.1	1000
0.2	1500

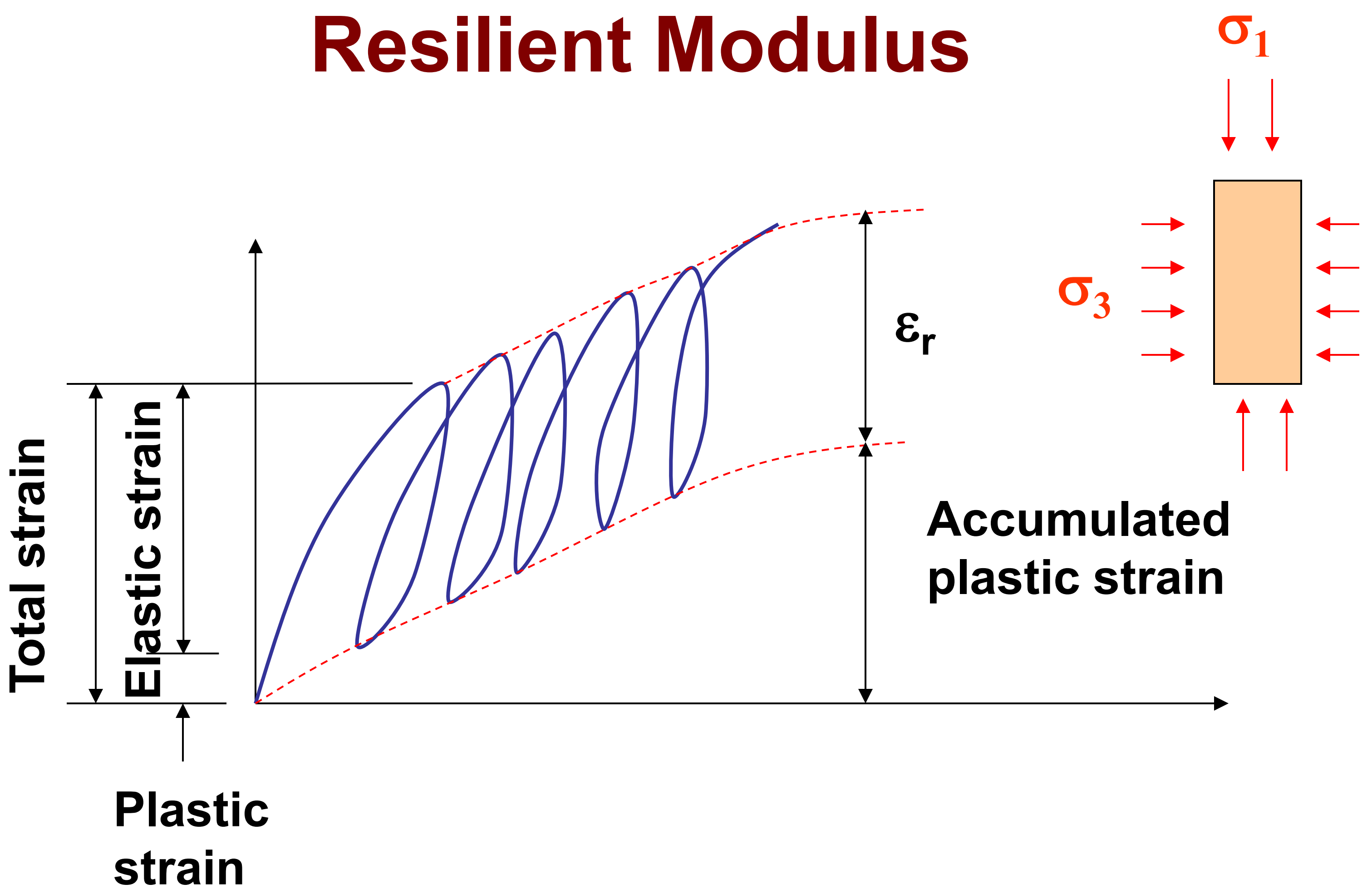
$$\text{CBR} = \max\left(\frac{\text{measured pressure@0.1in.}}{\text{standard pressure@0.1in.}}, \frac{\text{measured pressure@0.2in.}}{\text{standard pressure@0.2in.}}\right) \text{x}100\%$$

Effects on Pavement Thickness



Yoder and Witczak (1975)

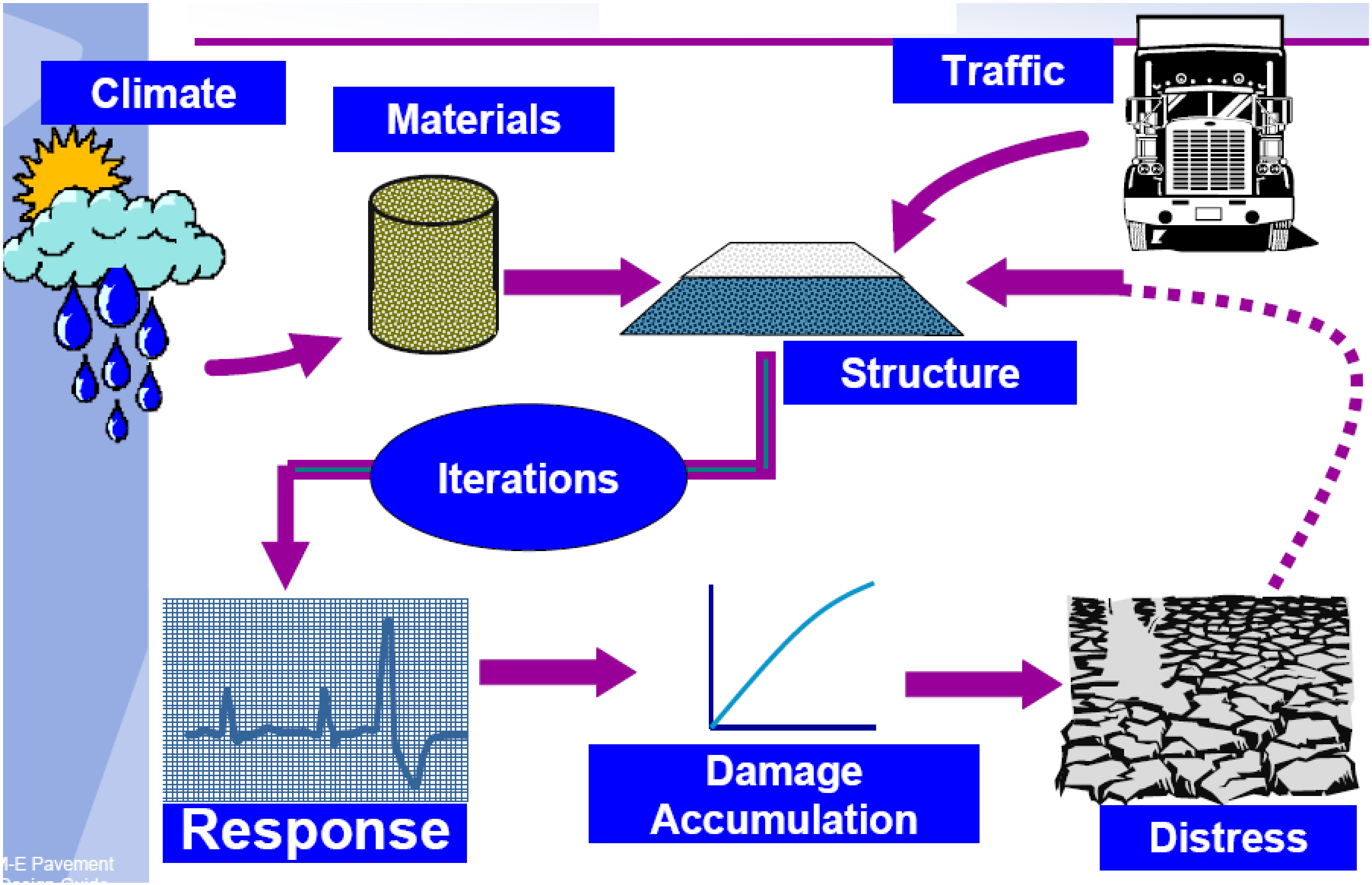
Resilient Modulus



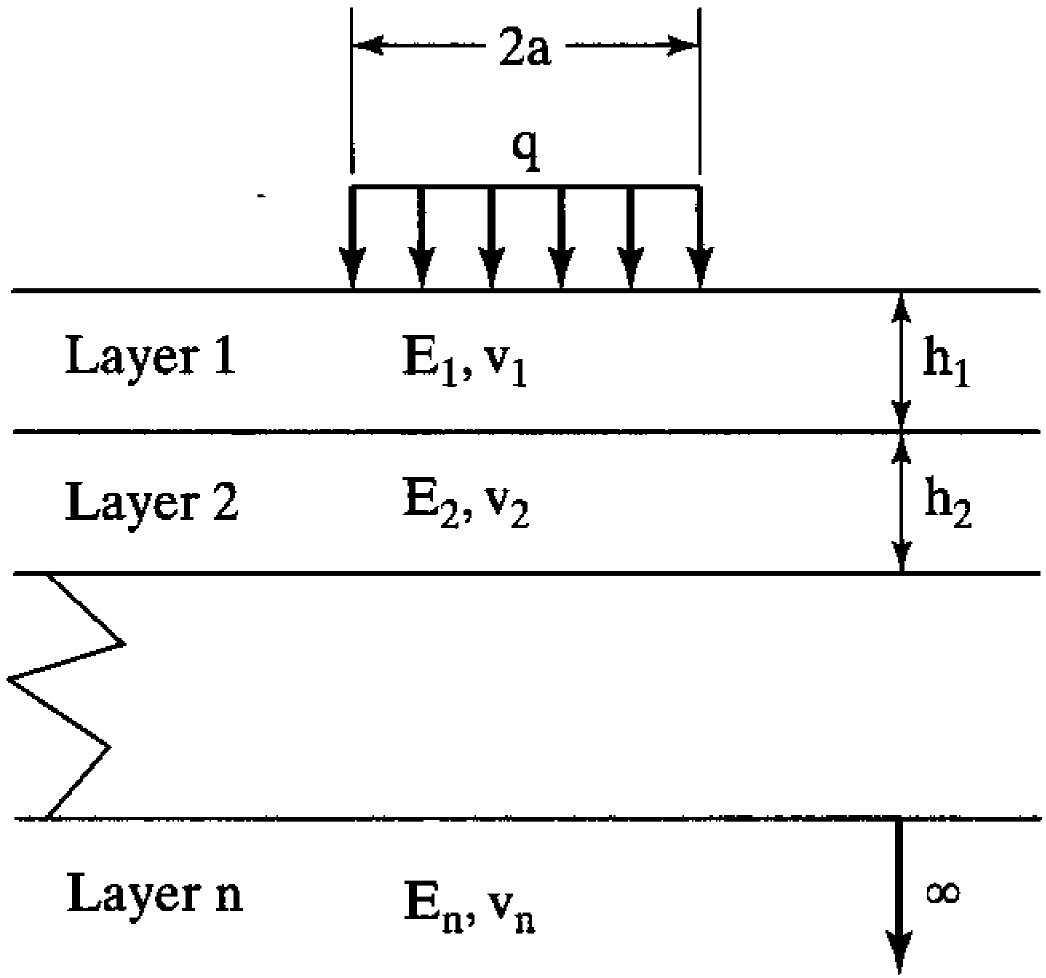
$$M_R = \frac{\sigma_d}{\varepsilon_r}$$

σ_d = deviator stress ($\sigma_1 - \sigma_3$)

Mechanistic-Empirical Design Process - 1-37A Guide



Layered Theory



Predicted Distresses

Herbold

Design Software

Road Tests

Major Road Tests

- Maryland Road Test
  - Concrete pavements
- WASHO Road Test
  - Asphalt pavements
- AASHTO Road Test
  - Concrete and asphalt pavements
- Mn/Road
  - Concrete and asphalt pavements
- NCAT Road Test
  - Asphalt pavements

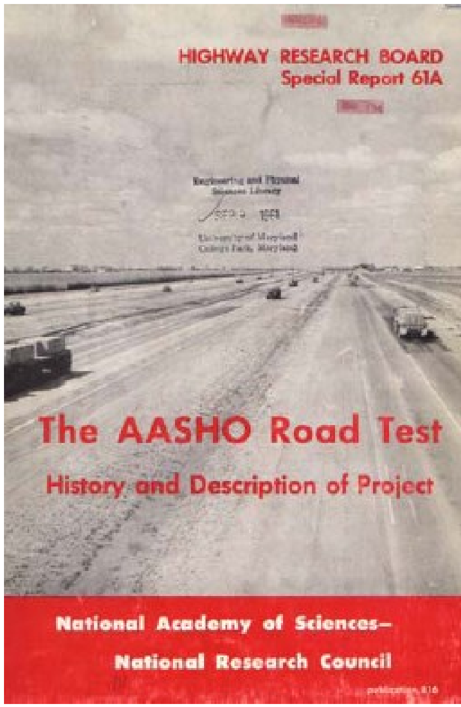
AASHTO Road Test
(1958 – 1960)

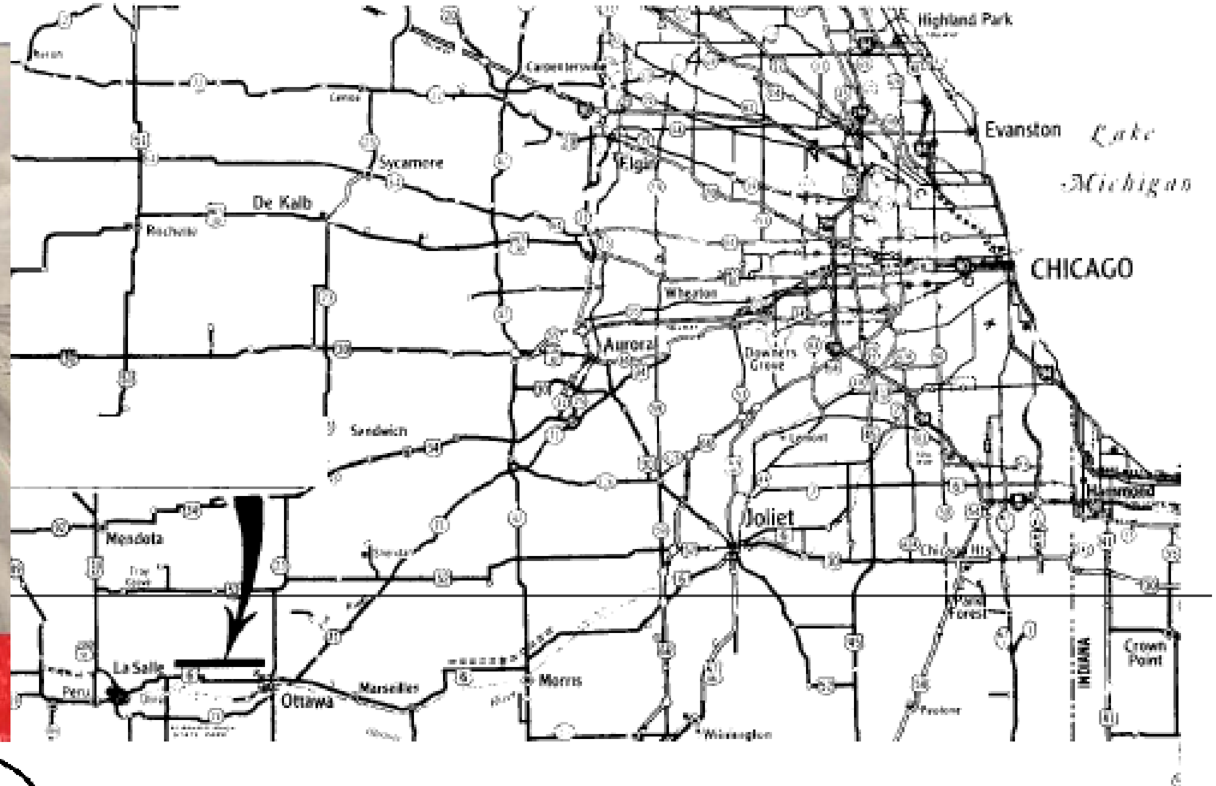
- Third large scale road test
  - Maryland road test (1950-51)
    Rigid pavements only
  - WASHO road test (1952-54)
    Flexible pavements only
- Include both rigid and flexible designs
- Include a wide range of axle loads and pavement cross sections

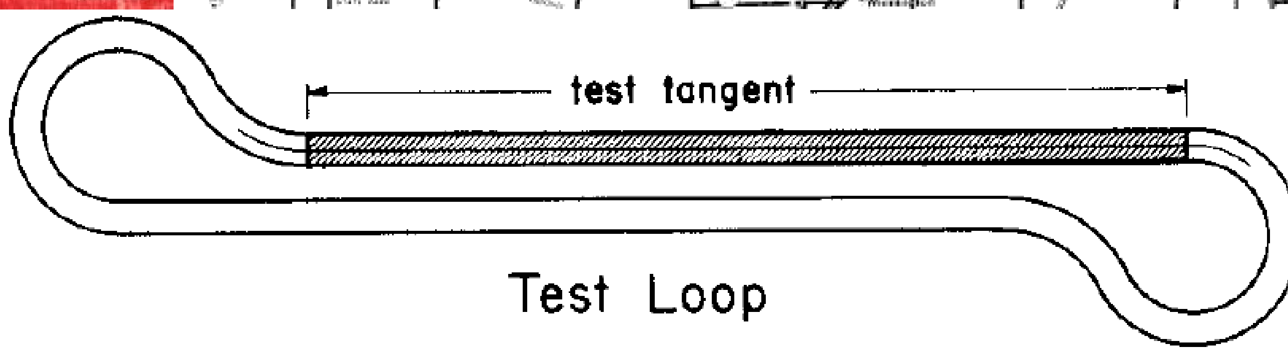
AASHO Road Test

- Designed to evaluate performance of different pavement types and as a basis for cost allocation.
- Introduced Pavement Service Index (PSI) concept.
- AASHO thickness design procedure resulted from the test road.
- Basis for most of the pavement designs since the 1960s.

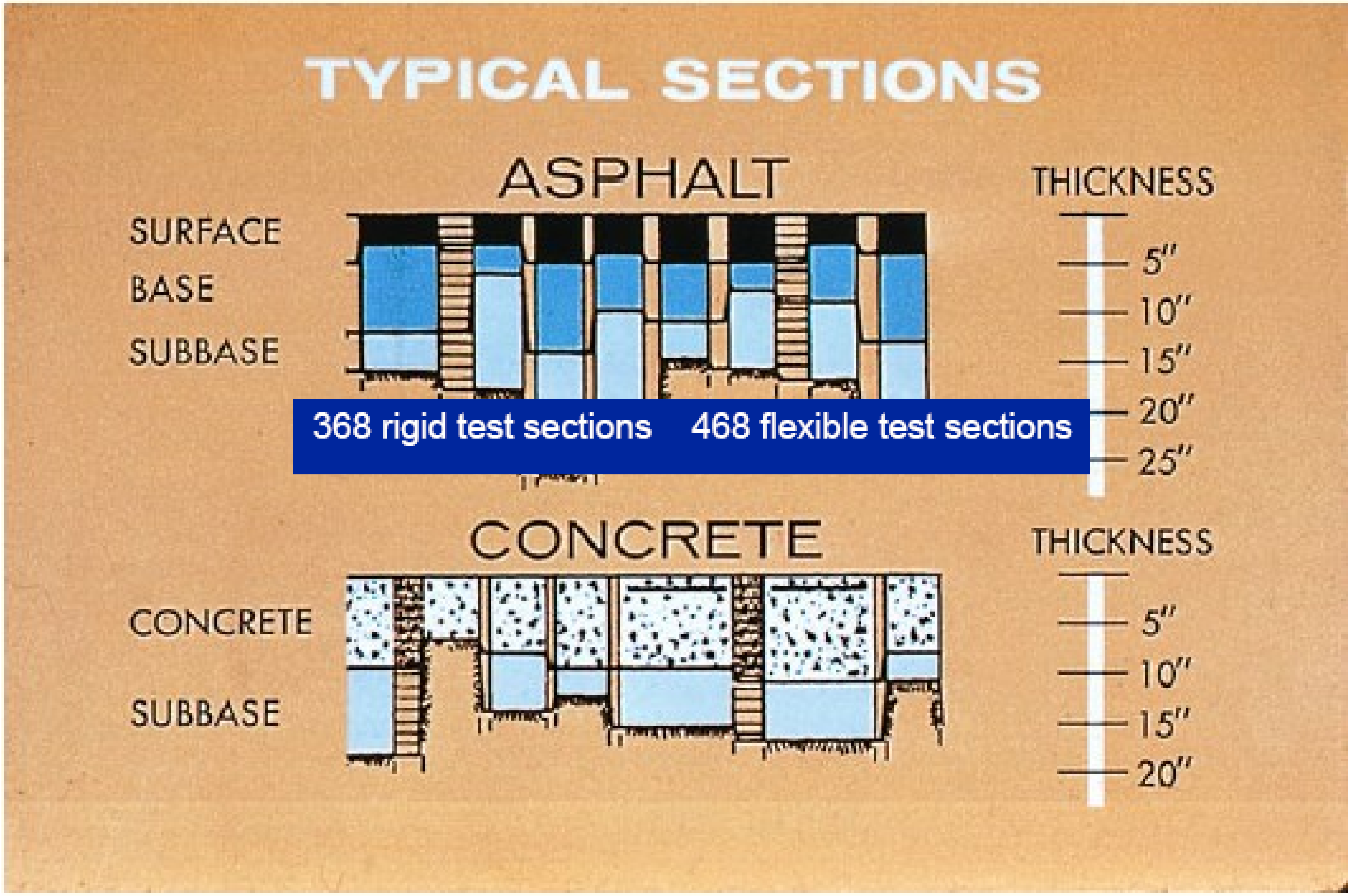
AASHTO Road Test







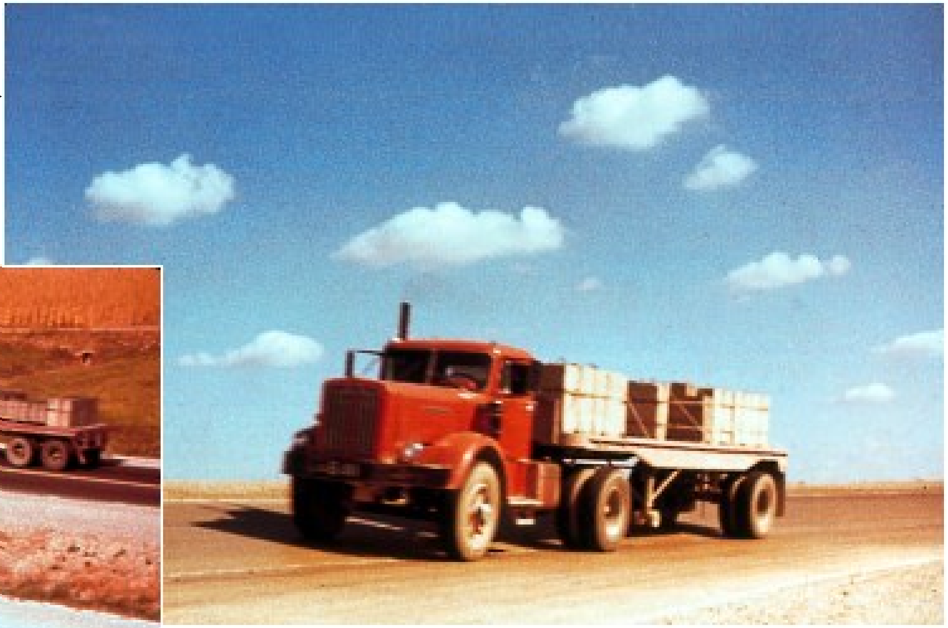
AASHTO Road Test Sections



368 rigid test sections & 468 flexible test sections

AASHTO Road Test Traffic

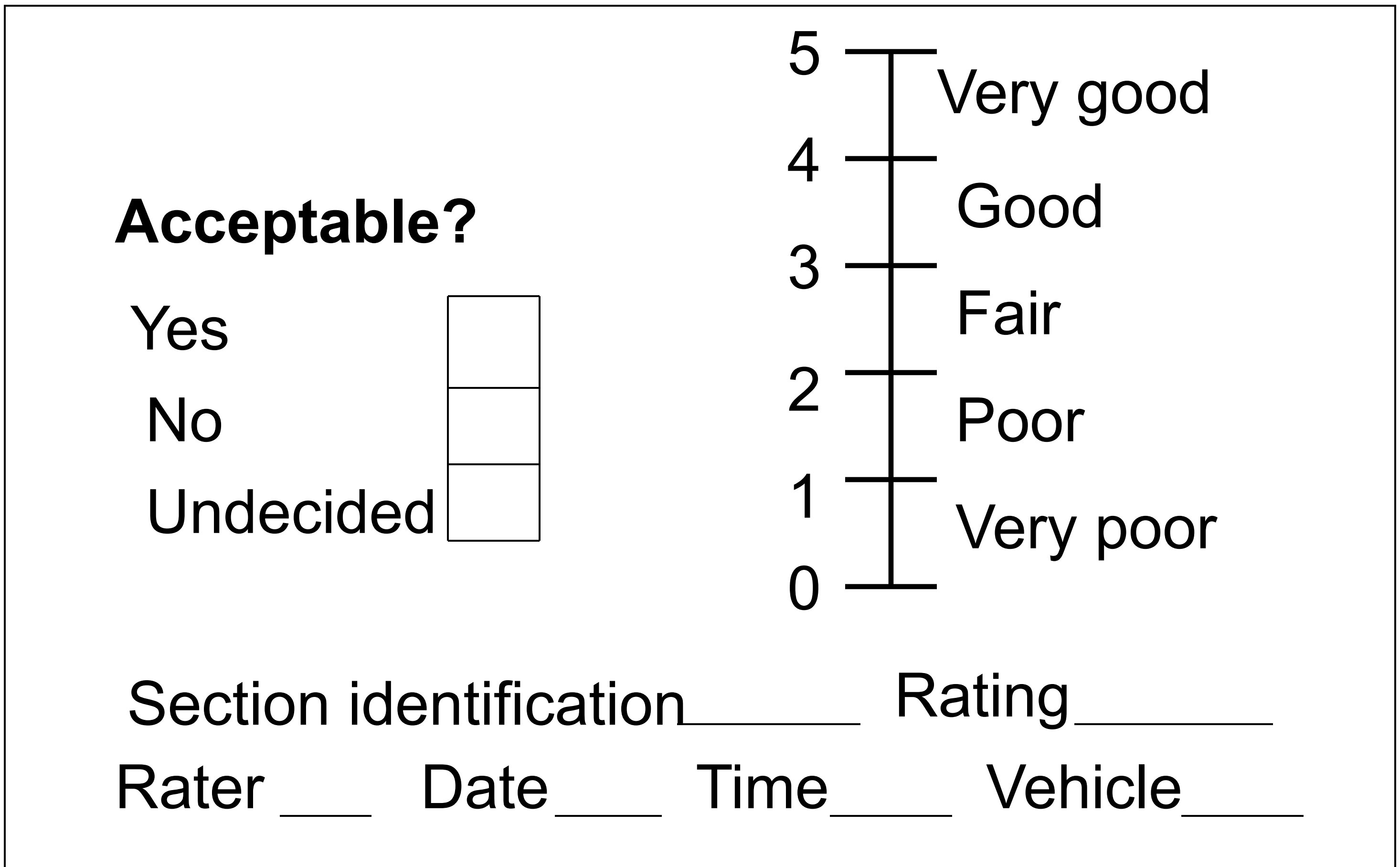
Max single Axle →



← Max Tandem Axle

Serviceability

- Developed during the AASHTO Road Test (1960)



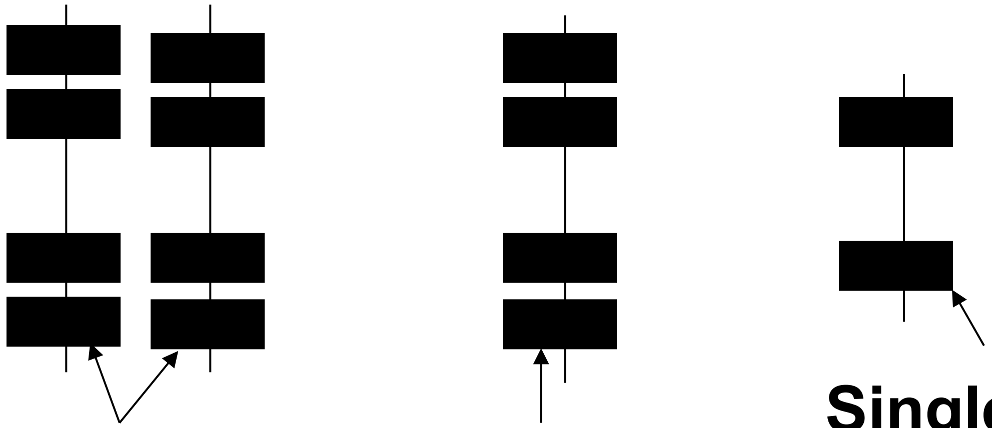
NCAT Test Track (2000 -)

Design Factors

Traffic and Loading

- Axle loads
- Number of repetitions
- Contact area
- Vehicle speed

Wheel Configurations

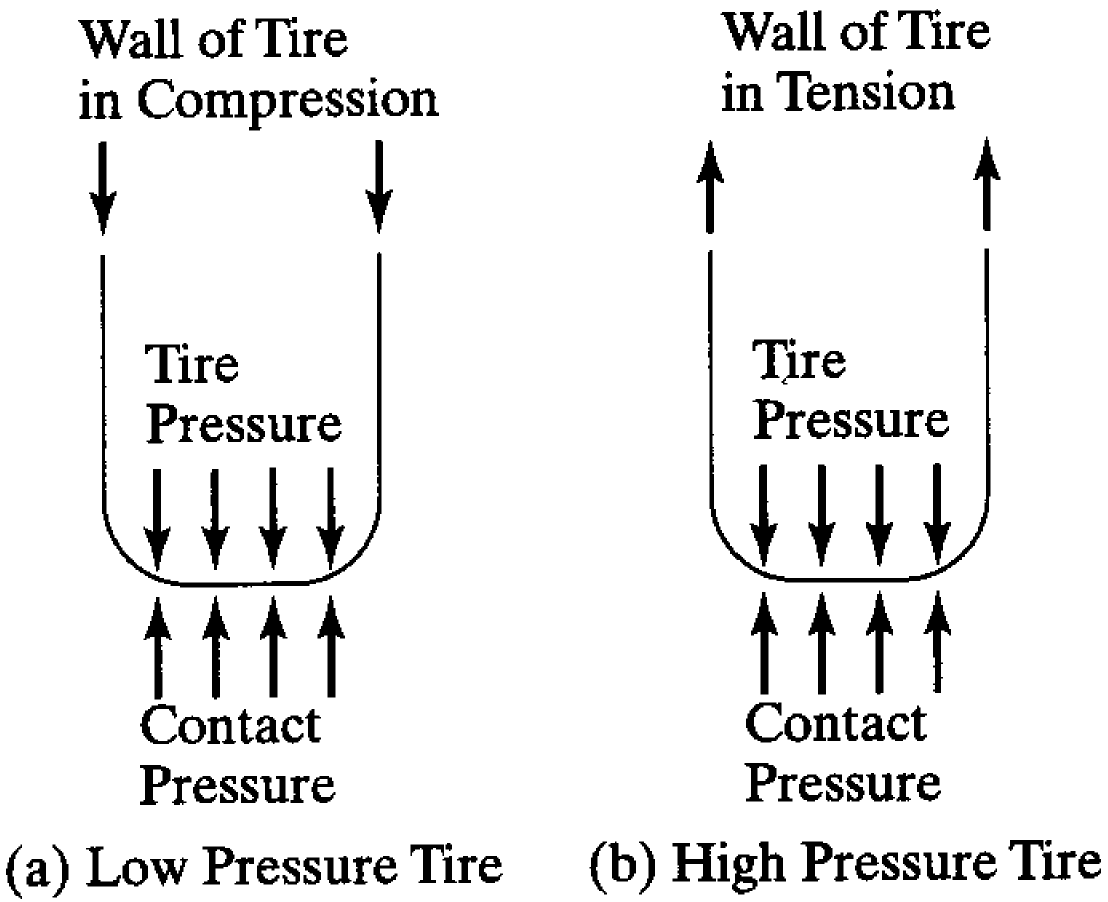


Tandem axle
with dual tires

Single axle
with dual tires

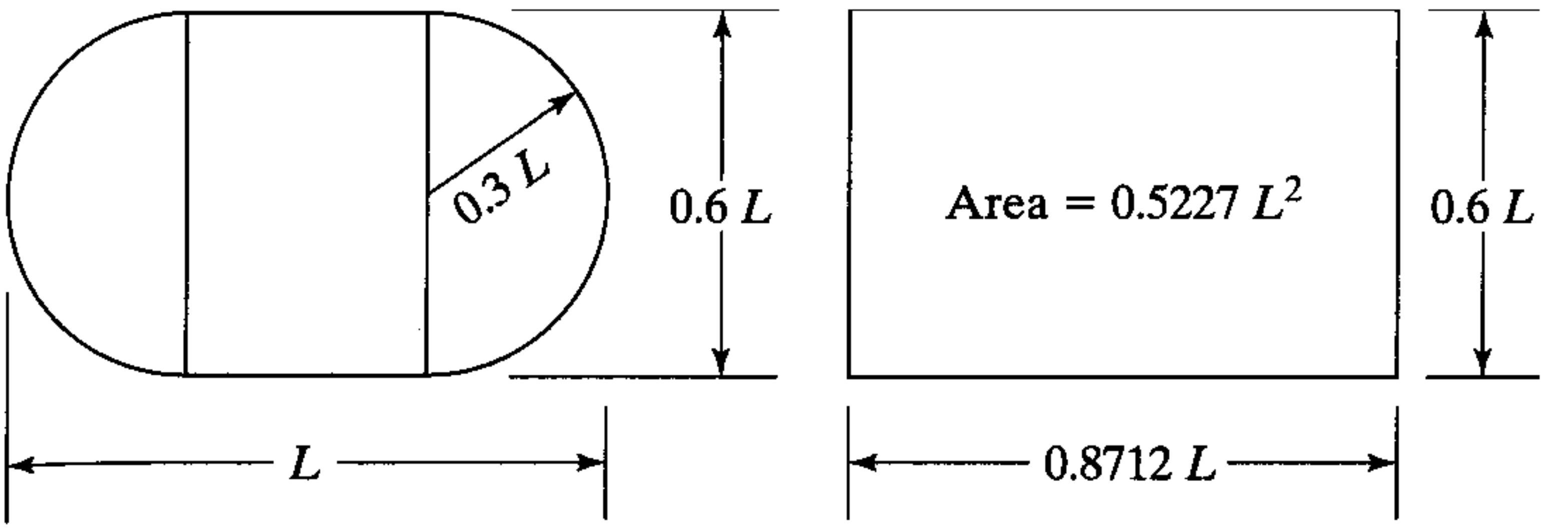
Single axle
with single tire

Contact Pressure vs. Tire Pressure



Huang (2004)

Dimension of Tire Contact Area



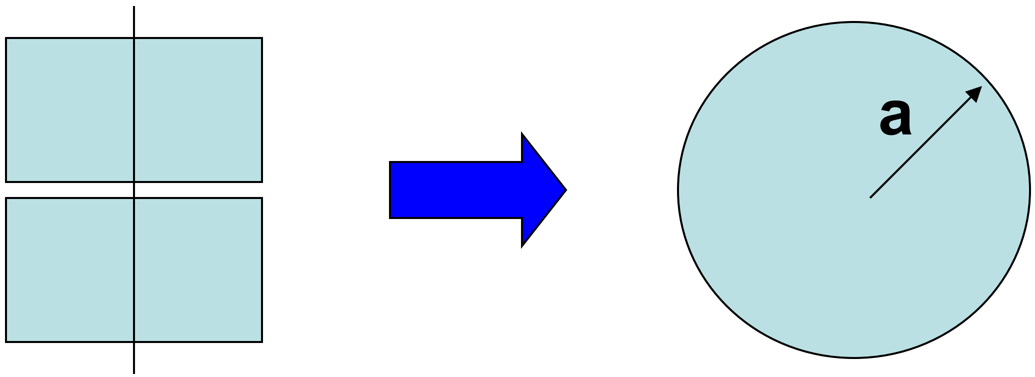
(a) ActuaL Area (b) Equivalent Area

$$L = \sqrt{\frac{A_c}{0.5227}}$$

Huang (2004)

Tire Contact Area for Analysis

Dual tires



$$A_c = \frac{P_w}{q} = \frac{P_a}{2q}$$

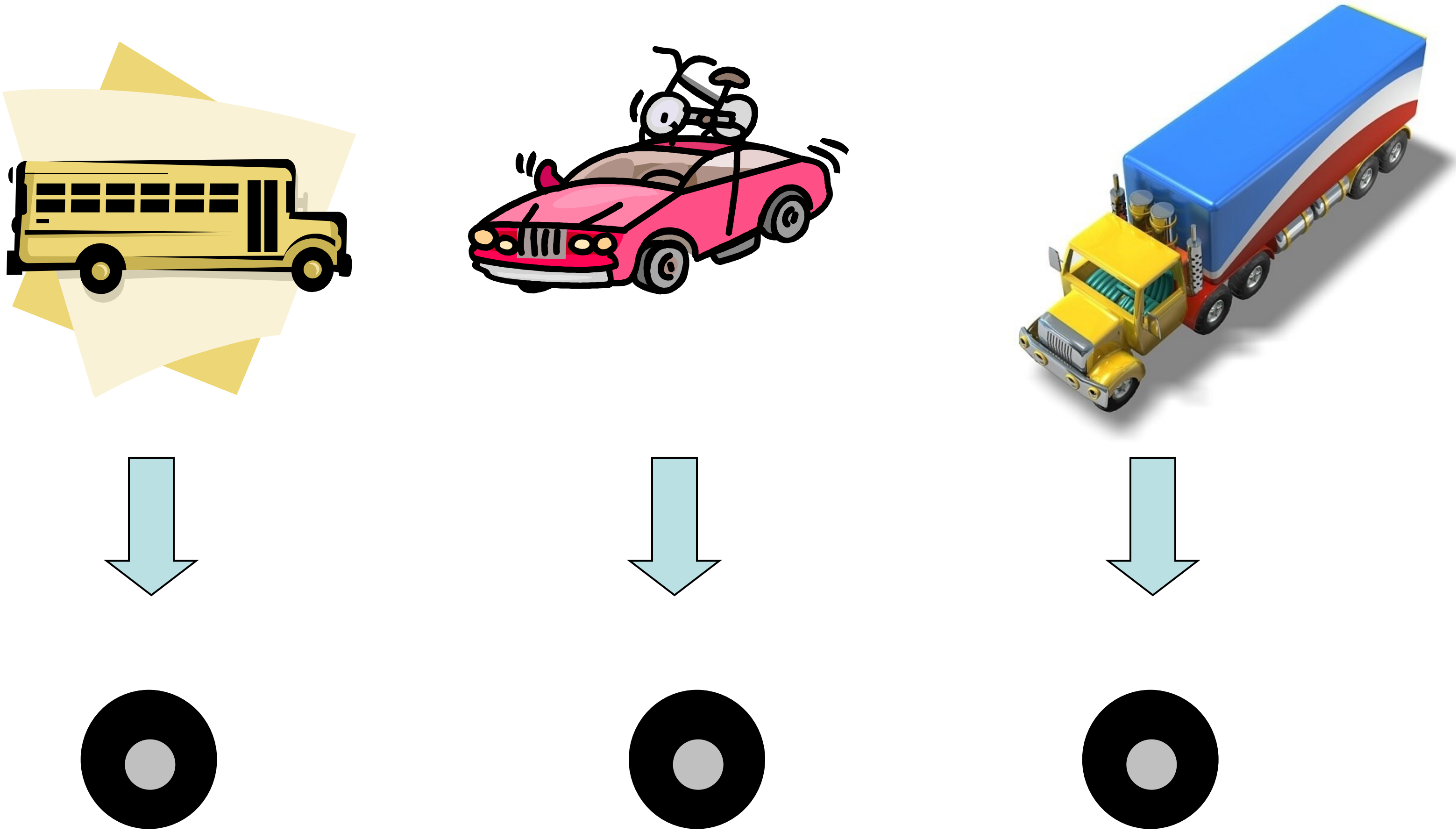
$$a = \sqrt{\frac{A_c}{\pi}}$$

P_w = wheel load, P_a = axle load

Equivalent Single Axle Load (ESAL)

The number and weight of all axle loads from the anticipated vehicles expected during the pavement design life – expressed in 18-kip (80 kN)

ESALS



Load Equivalence Factor (LEF)

The ratio of the effect (damage) of a specific axle load on pavement serviceability to the effect produced by an 18-kip axle load at the AASHTO road test

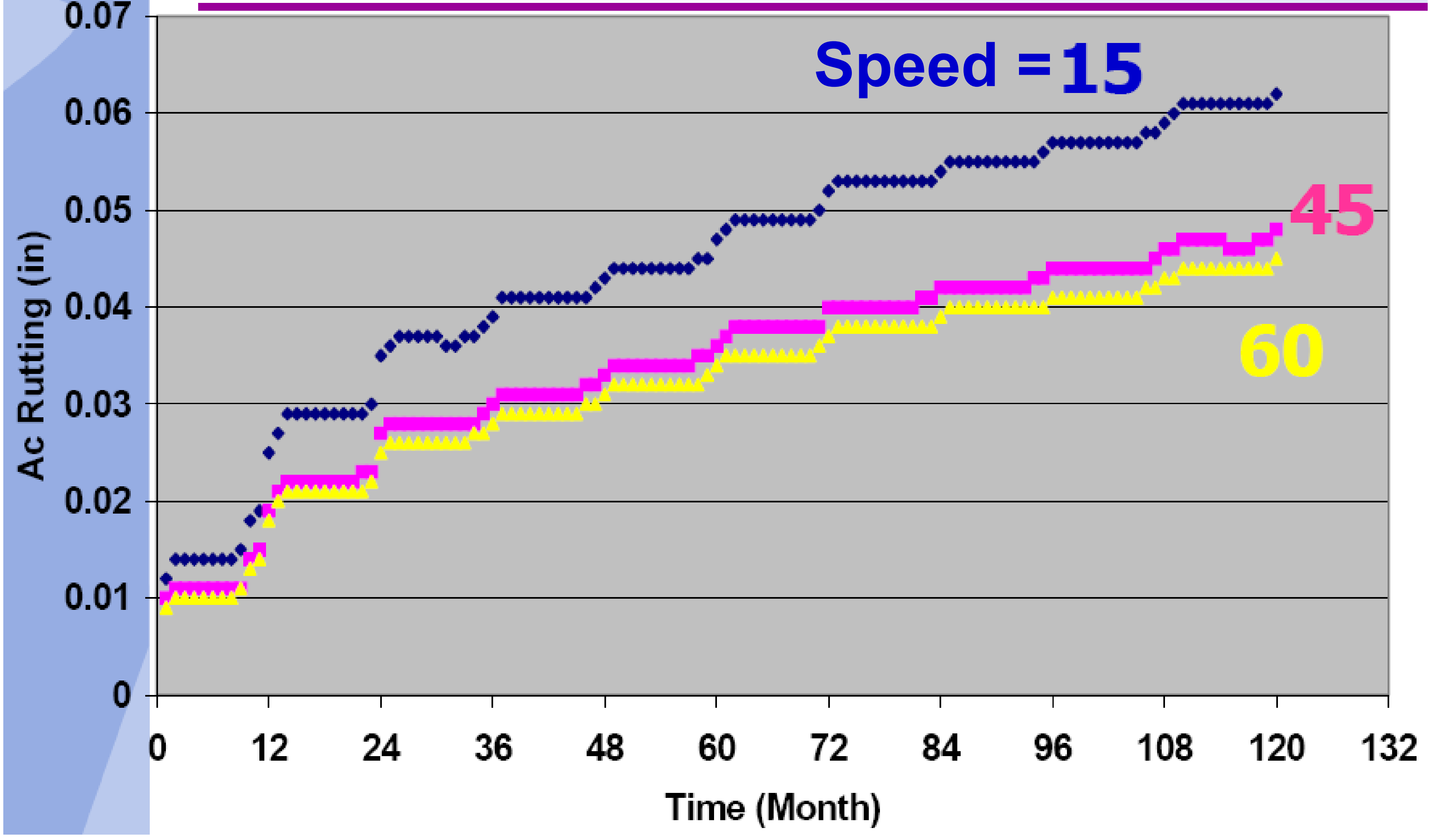
Depend on:

- **Pavement type (asphalt or concrete)**
- **Thickness**
- **Terminal serviceability**

ESALs Generated by Different Vehicles/Day

Vehicle	Number	Factor	ESALs
Single units 2 axles	20	0.3055	6.11
Busses	5	1.746	8.73
Panel trucks	10	1.111	11.11
Semi-tractor trailer 3 axles	10	1.341	13.41
Semi-tractor trailer 4 axles	15	1.992	29.88
Semi-tractor trailer 5 axles	15	2.458	36.87
Automobile, pickup, van	425	0.005294	2.25
Total	500		108.36

Effect of Vehicle Speed



Environment

- Temperature
  - Effect on asphalt layer
  - Effect on concrete slab
  - Frost penetration
  - Freezing index

- Precipitation - drainage

Performance Criteria

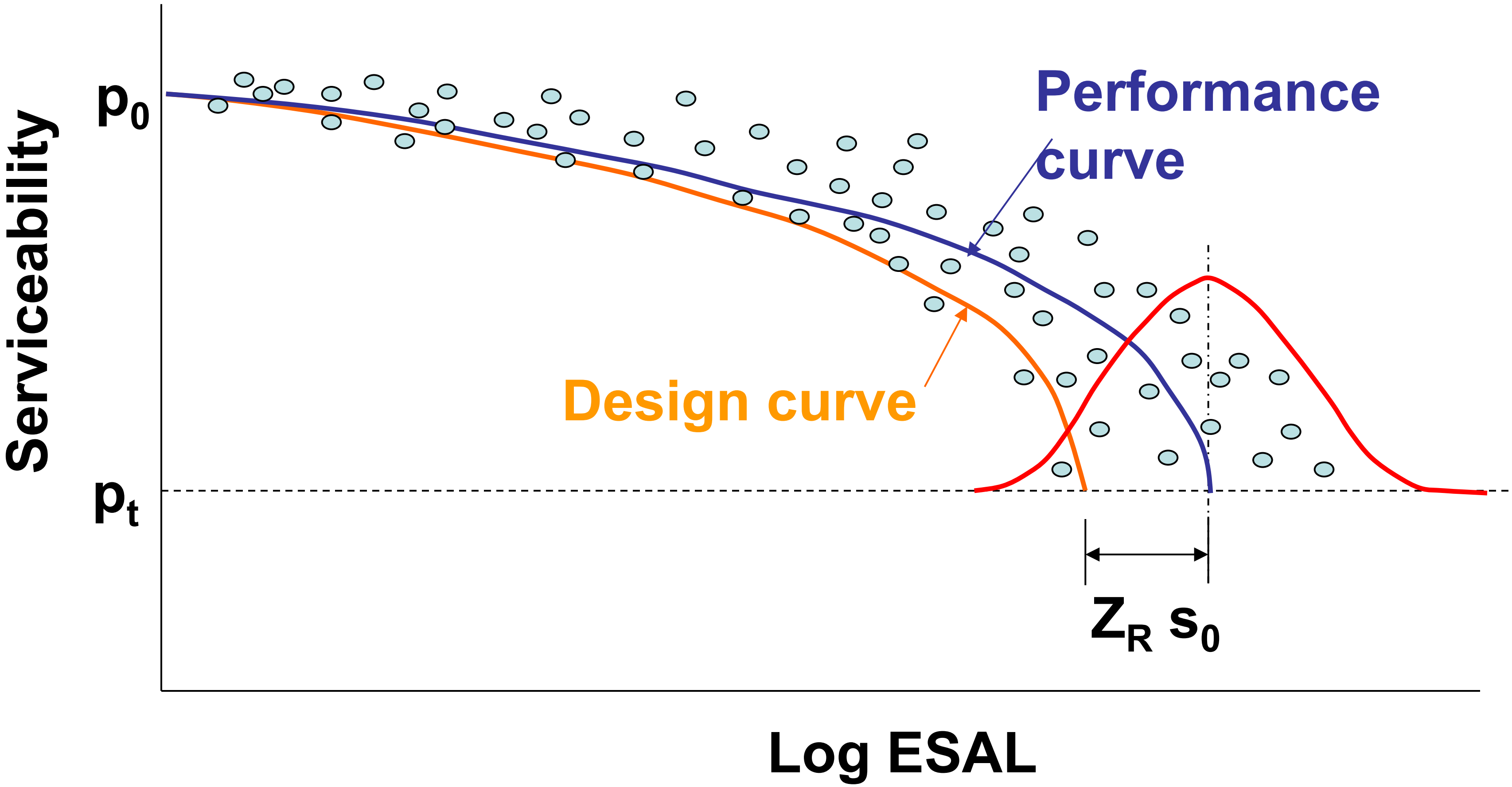
- Rut
  - typically 75 to 100 mm for unpaved roads
  - 25 mm for paved roads

- Cracking (fatigue, thermal, …)

- Present serviceability index (PSI)

- International Roughness Index (IRI)

Reliability



Pavement Management Systems