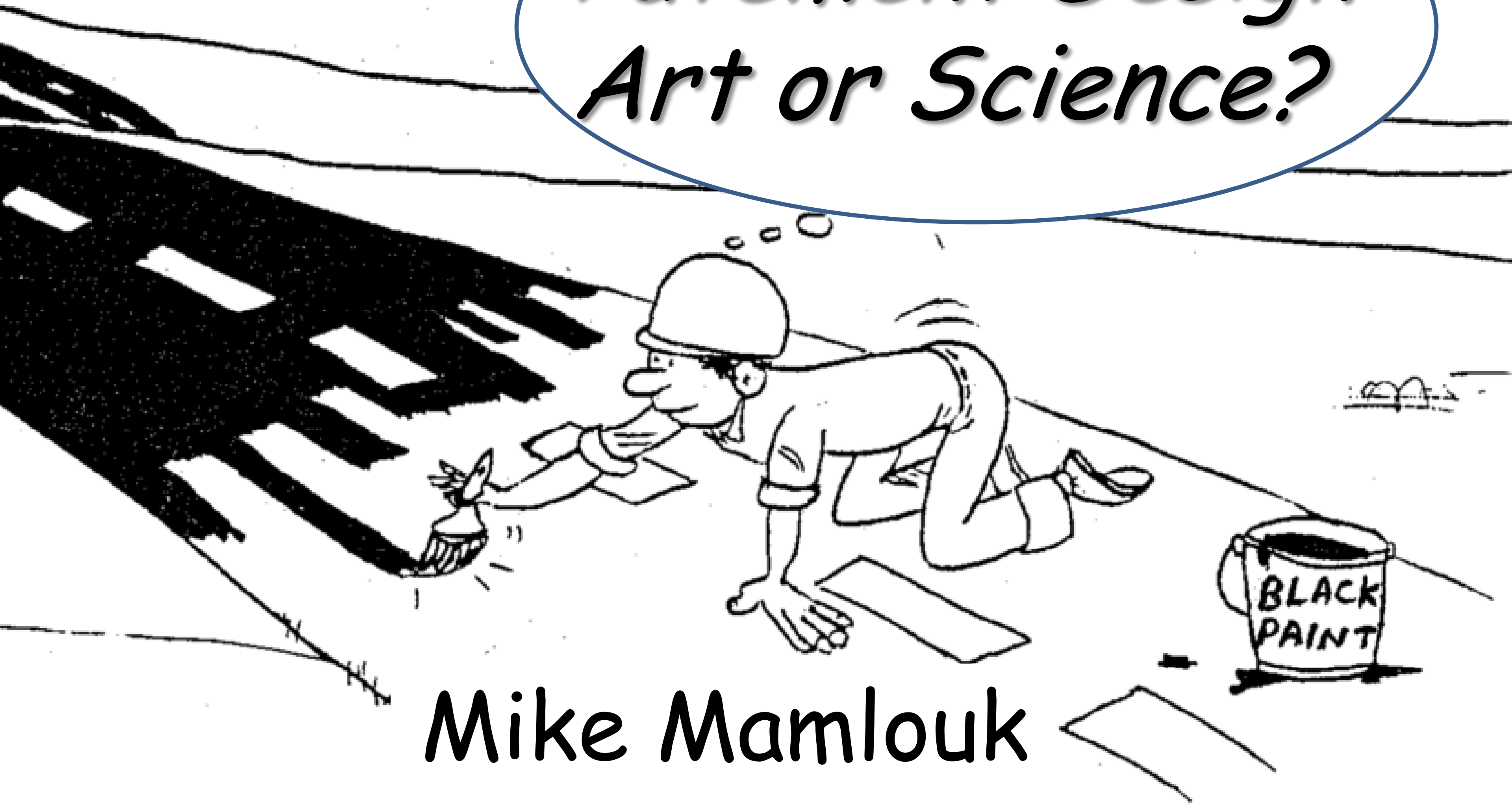
Pavement Design: Art or Science?



Mike Mamlouk
ASU

Roman Design (200 AD)

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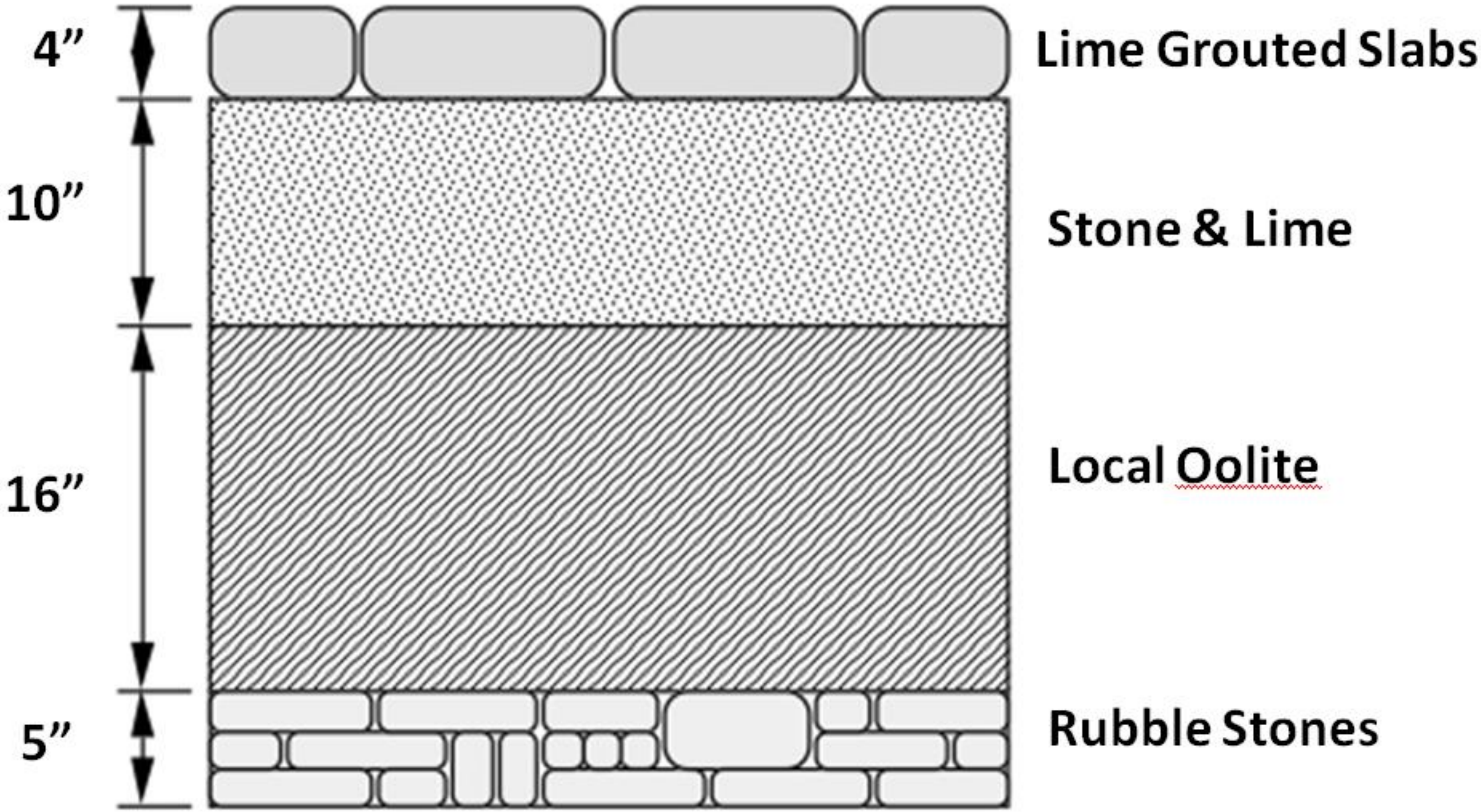
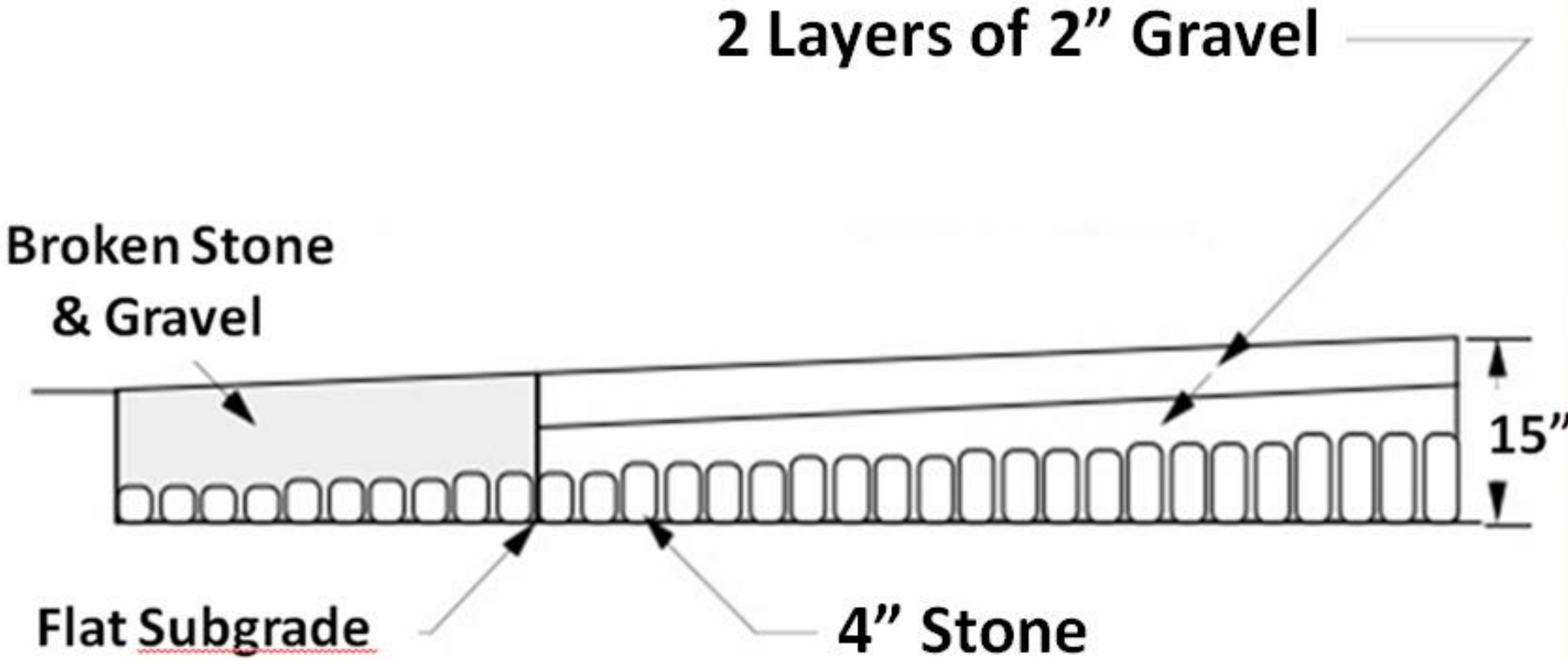
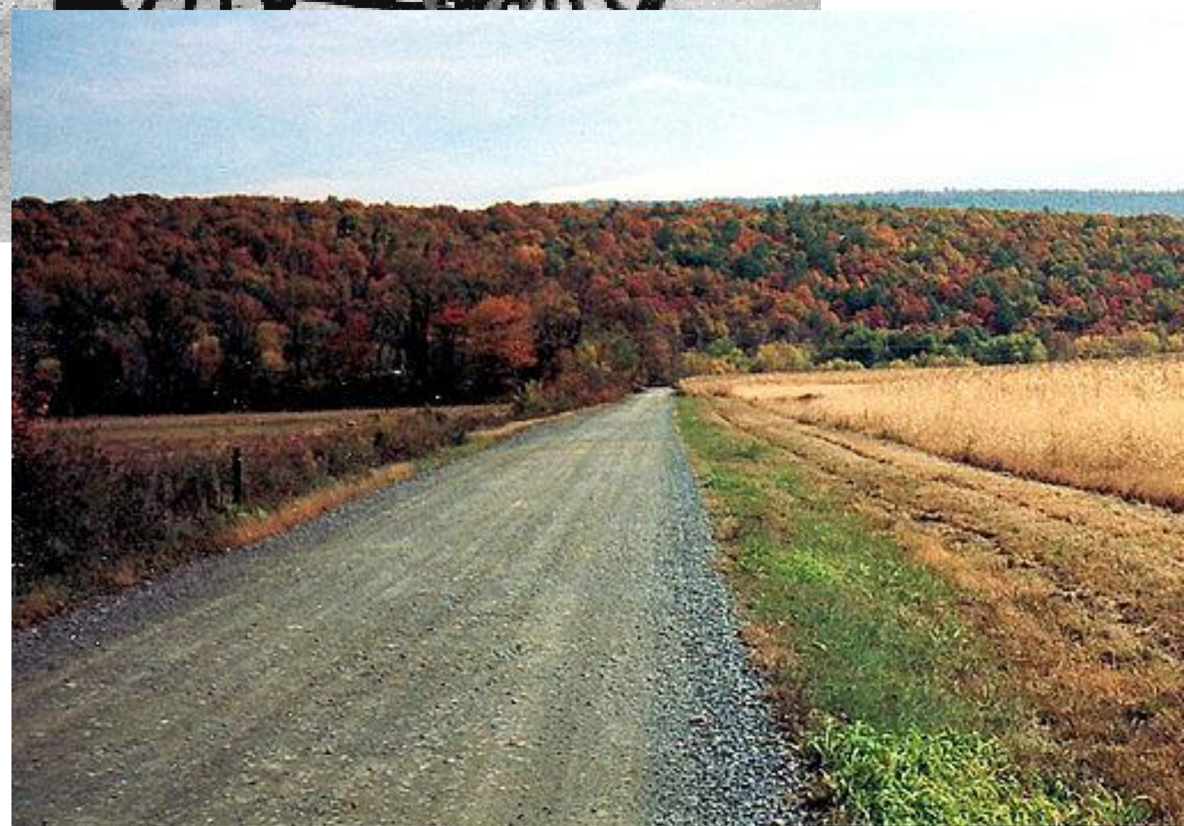
Roman Design (200 AD)



Telford Design (Early 1800s)





Early 1800s

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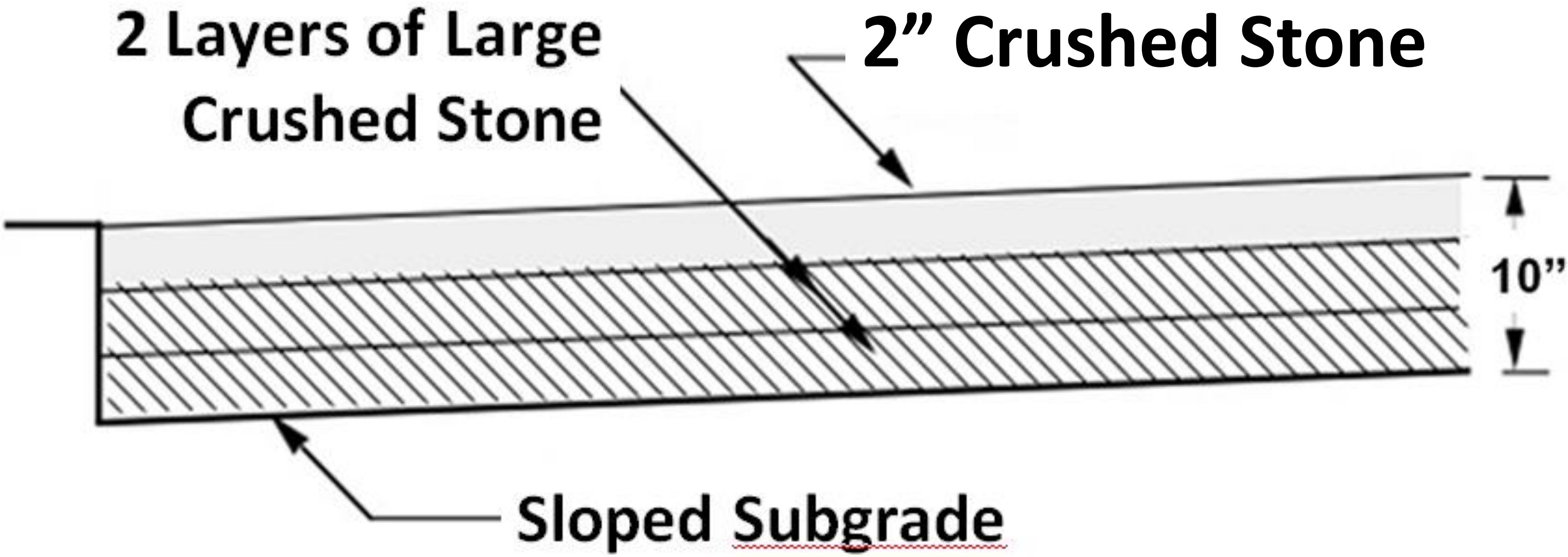
Macadam Design (Early 1800s)



Maximum aggregate size:

"No stone larger than will enter a man's mouth should go into a road" (Macadam)

Early Bituminous Pavement (Mid-1800s)

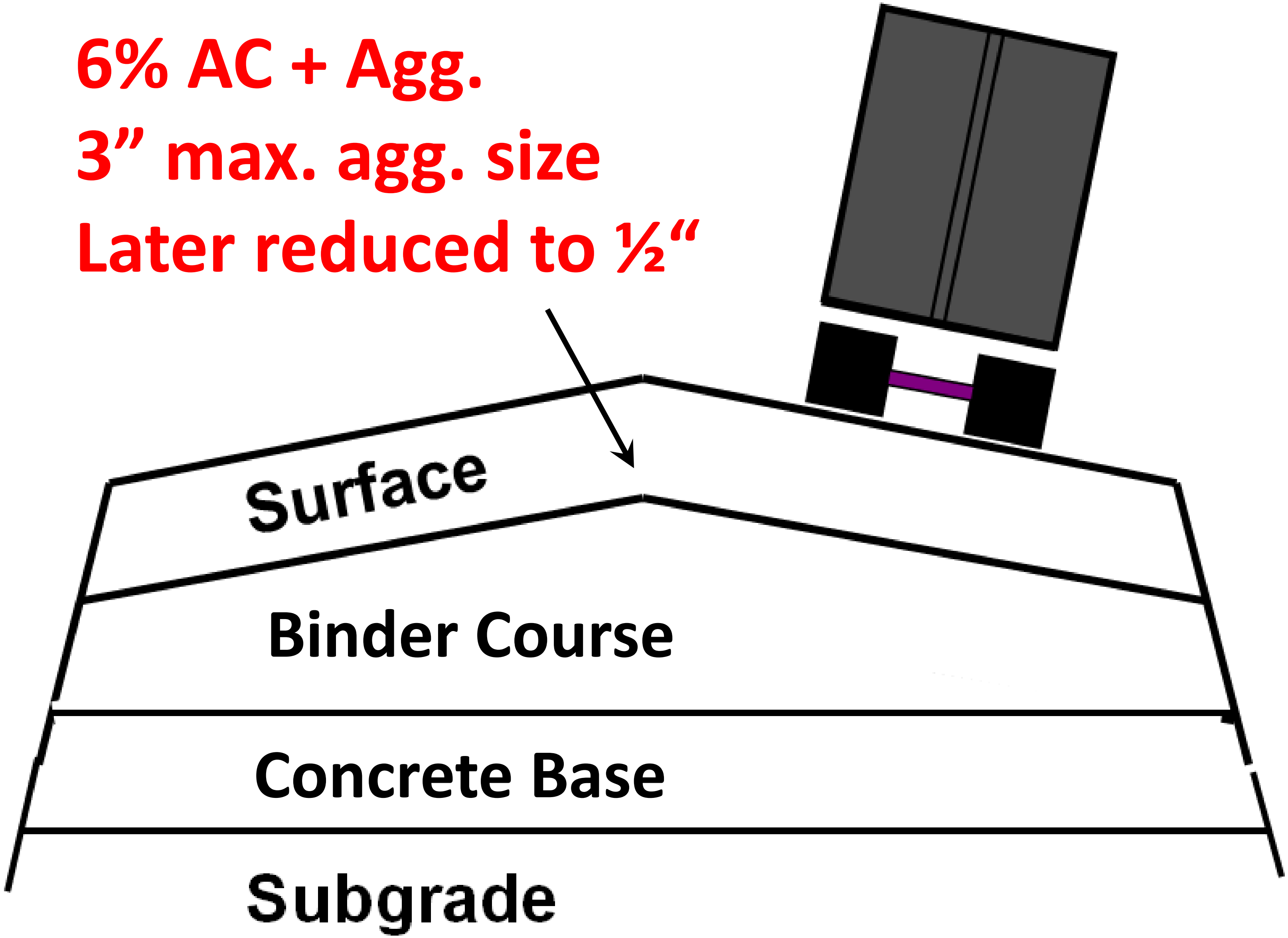
- Tar Macadam (Tarmac)
  - 2” wearing course (6% coal tar + aggregate)

- Sheet Asphalt
  - 1.5”-2” wearing course (AC + sand)
  - 1.5” Binder course (AC + crushed stone)
  - 4”-6” Base (PCC, granite block, bricks, etc.)

Trinidad Lake Asphalt

Bitulithic Pavements (Early 1900s)

6% AC + Agg.
3” max. agg. size
Later reduced to ½“

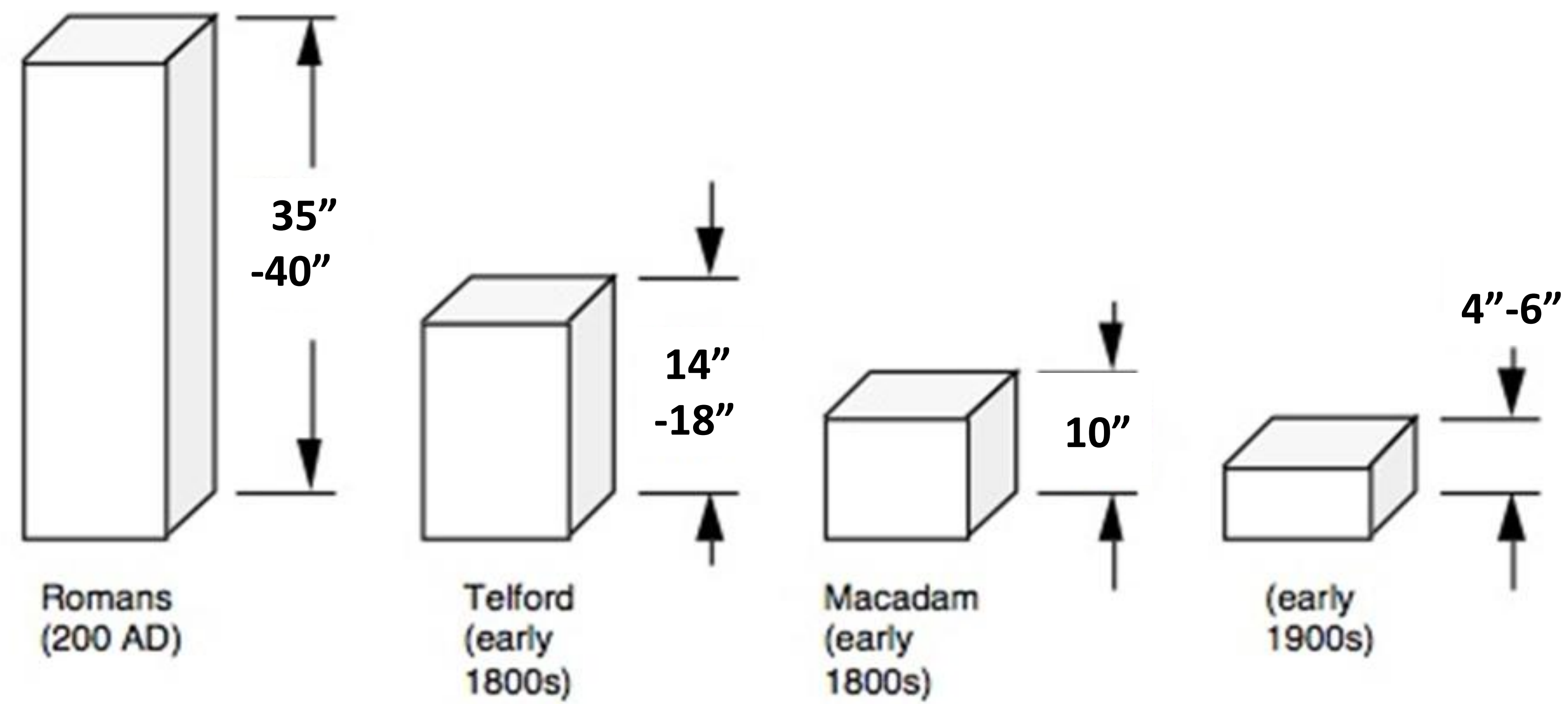


Early Traffic

- Light load
- Solid rubber tires

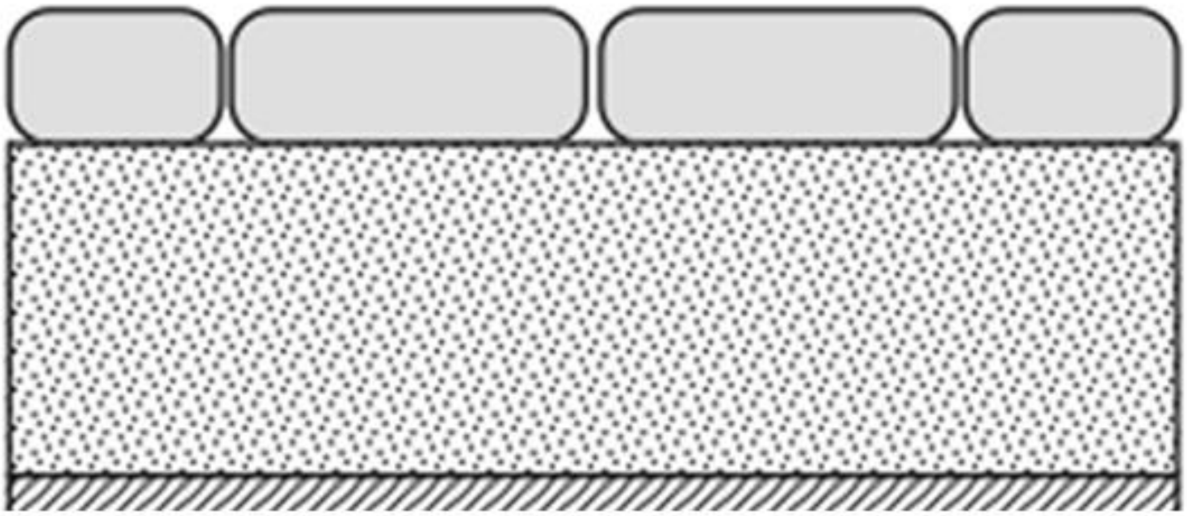
Early Thickness Trend

- Improved material quality
- Reduced thickness



Early Concrete Pavements (Early 1900s)

- Until 1910 PCC was used as a “stiff” base to support the wearing course



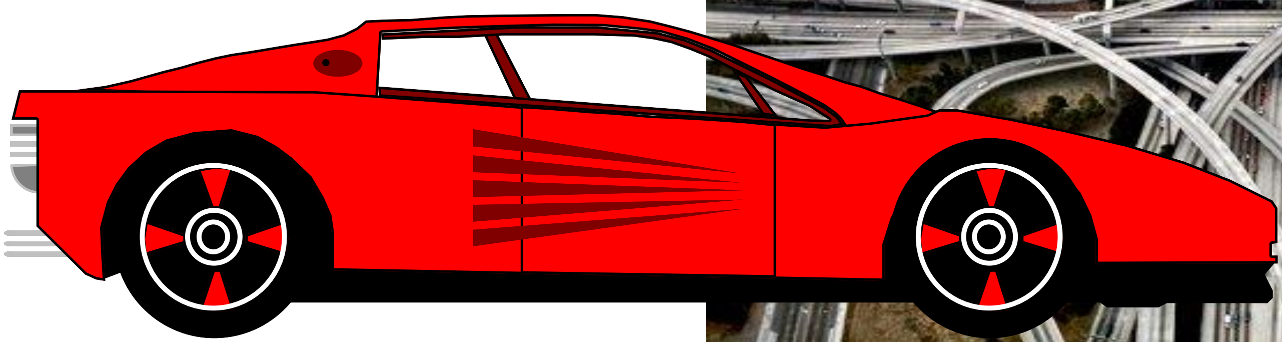
Early Concrete Pavements

- In 1910 PCC started to be used as a pavement wearing course

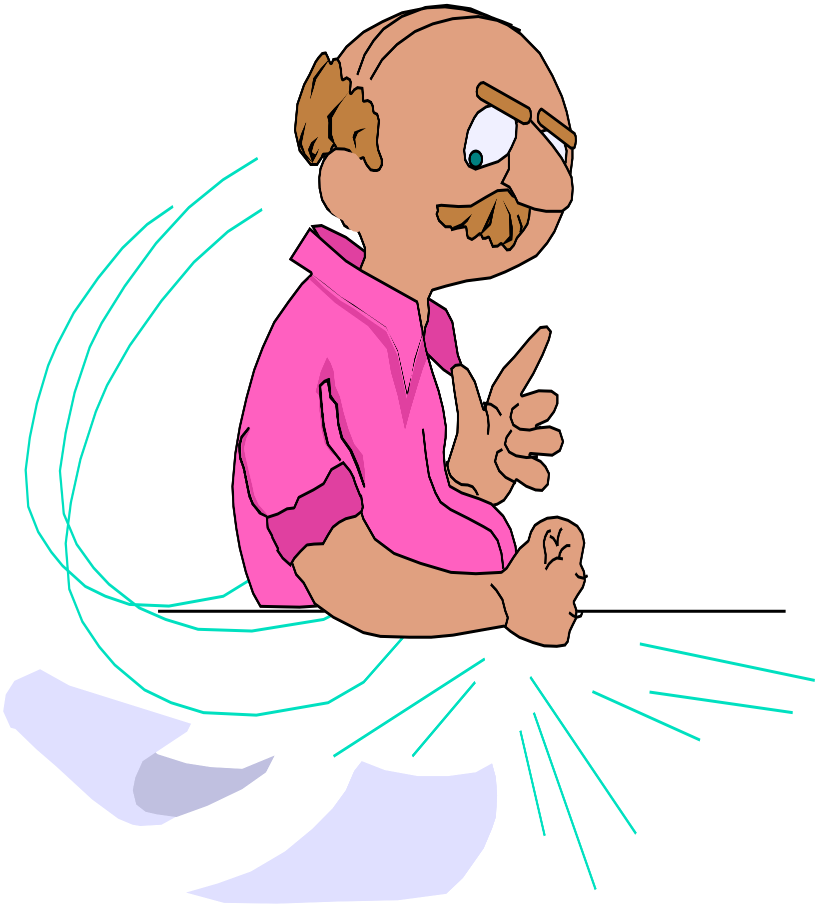
Today's Pavement

Current Pavement in U.S.

- 2.3 million miles of paved roads
- Boom of road construction in 1960s-70's
- Largest highway network in the world
- Smoother surface

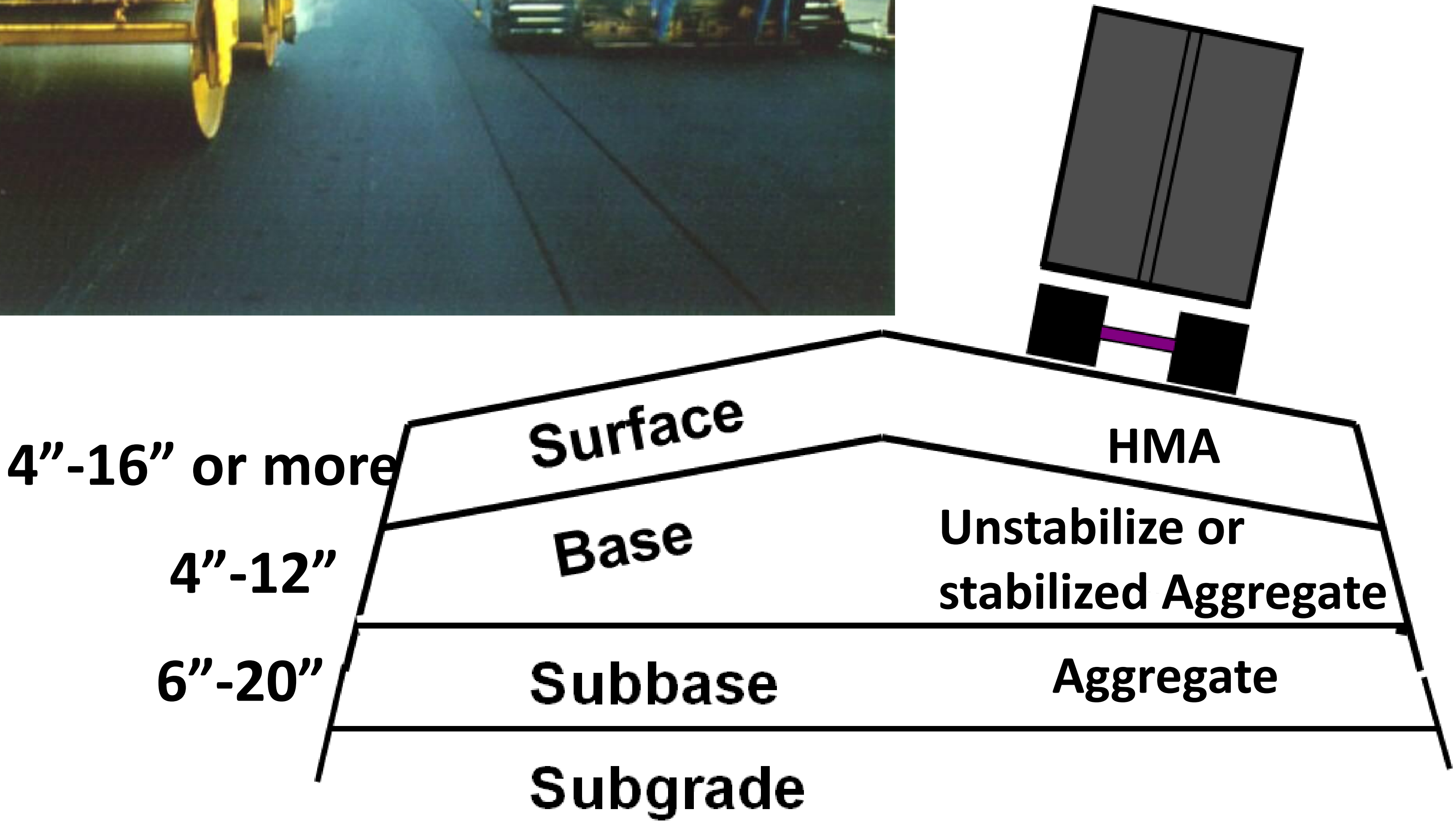


Pavement Types



- –Flexible (Asphalt)
- –Rigid (Concrete)
- –Composite

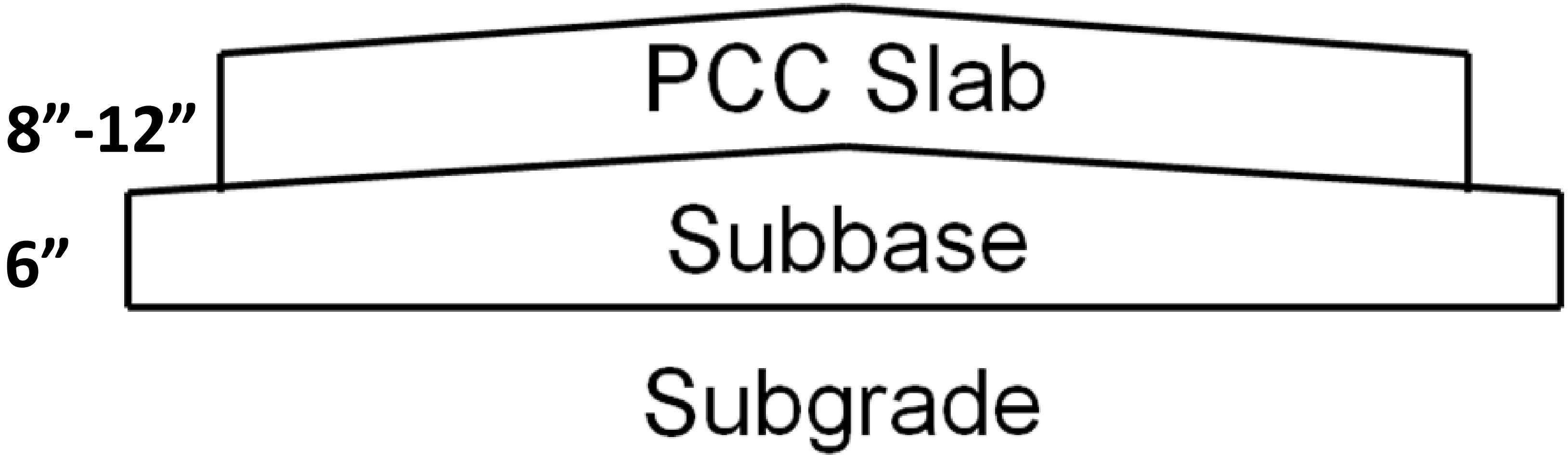
Asphalt Pavement



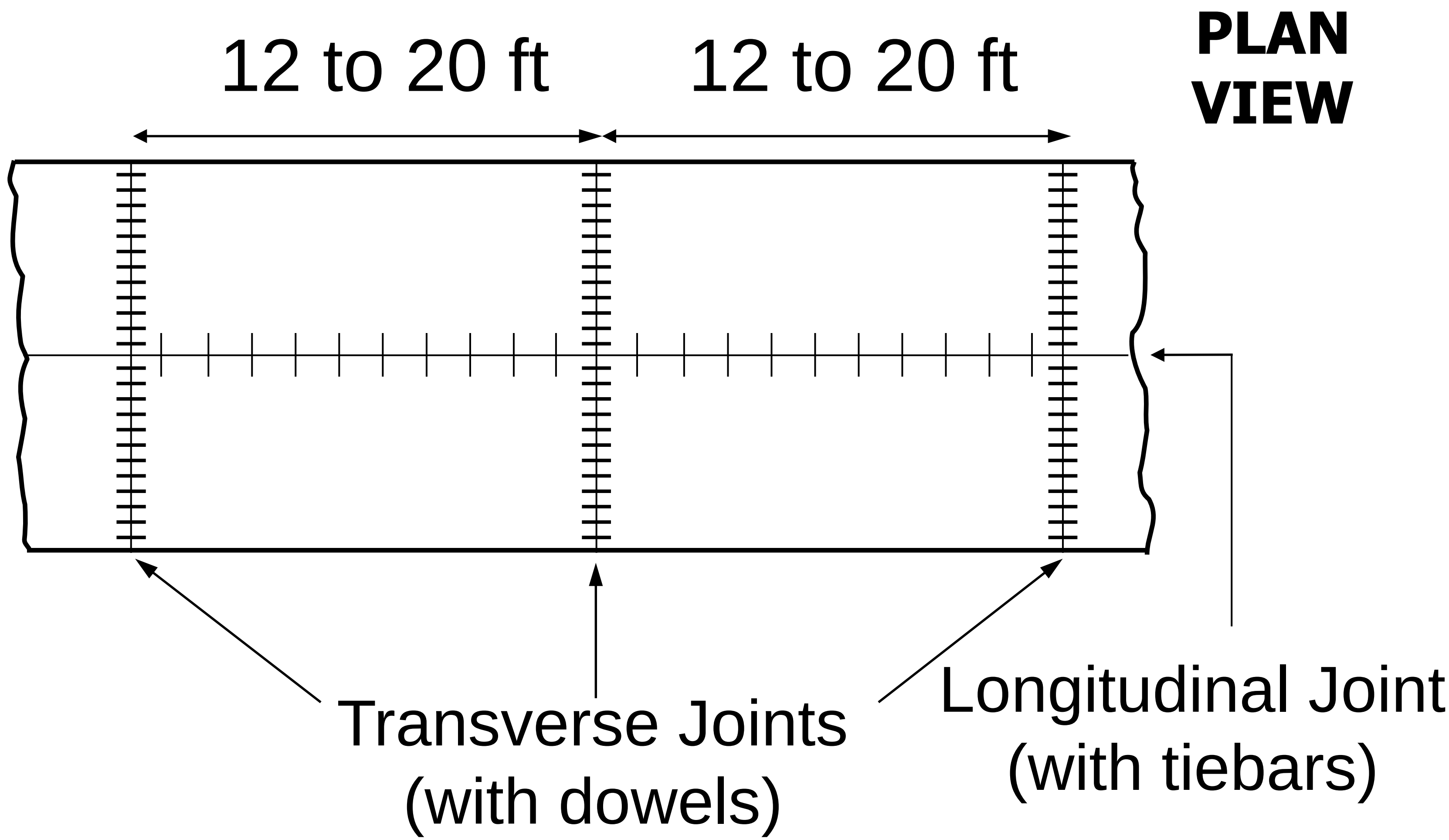
Evolution of Asphalt Concrete Mix Design

1. Hubbard-Field method (mid-1920s)
2. Hveem method (1940s)
3. Marshall method (1950s)
4. Superpave method (1990s)

Concrete Pavement



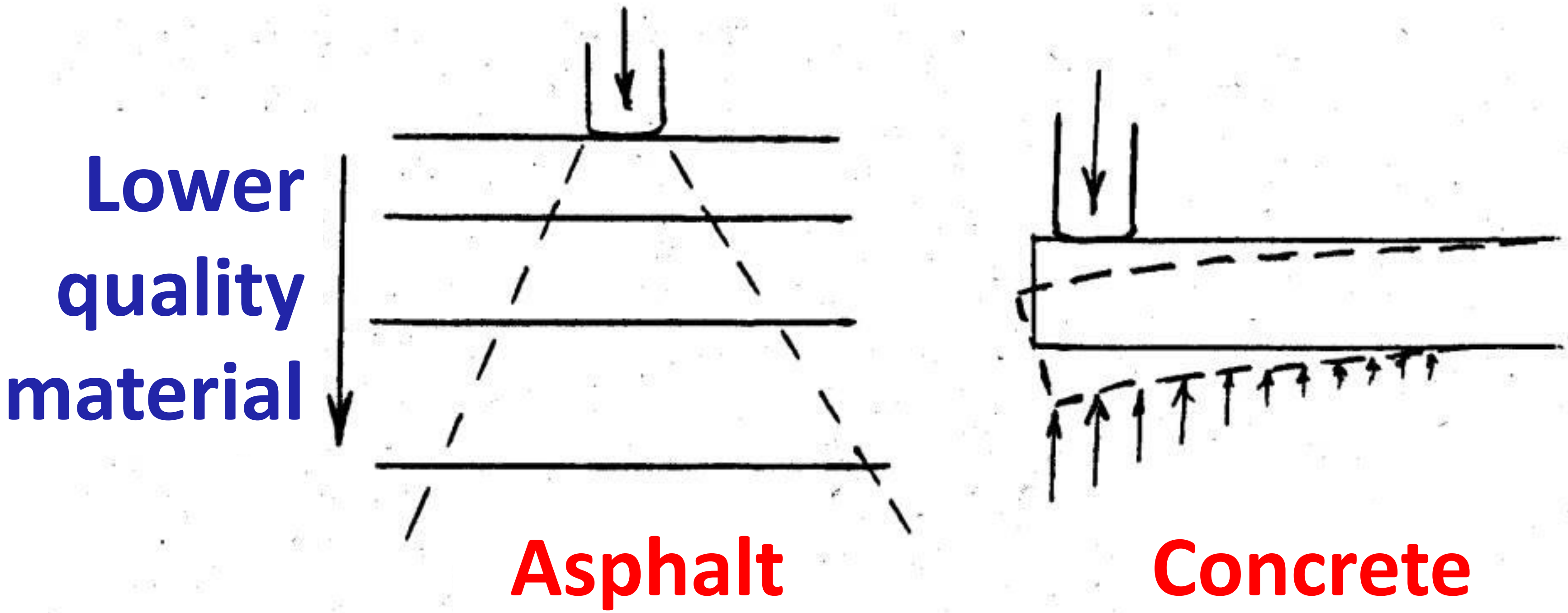
Jointed Plain Concrete Pavement (JPCP)



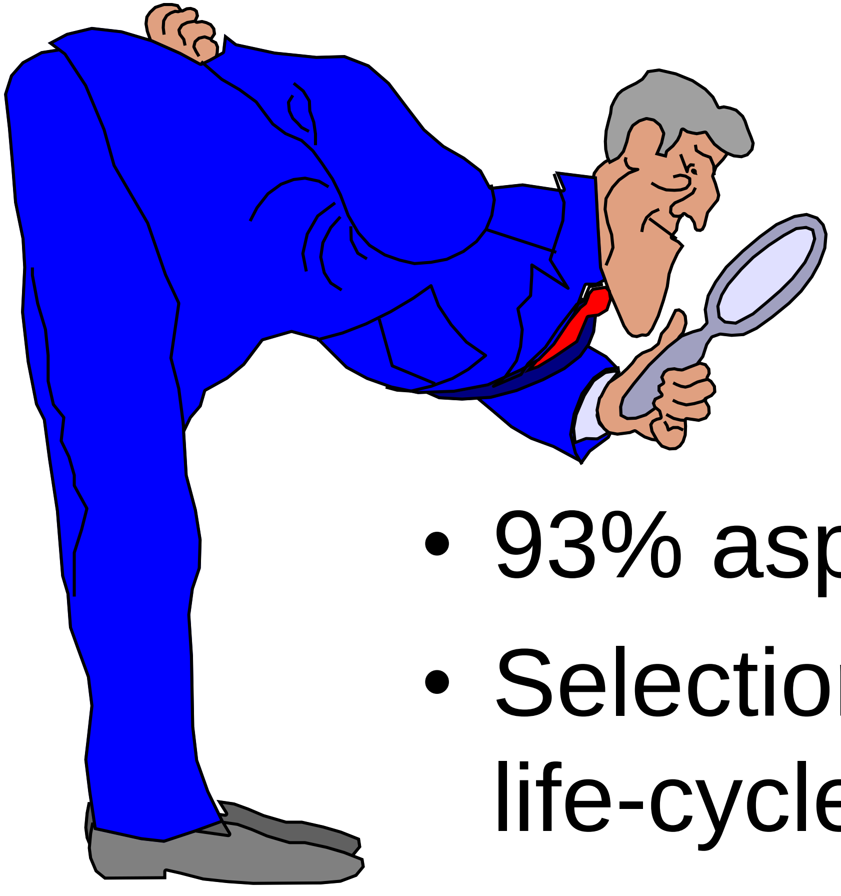
JPCP

Asphalt vs. Concrete Pavements

- Load distribution



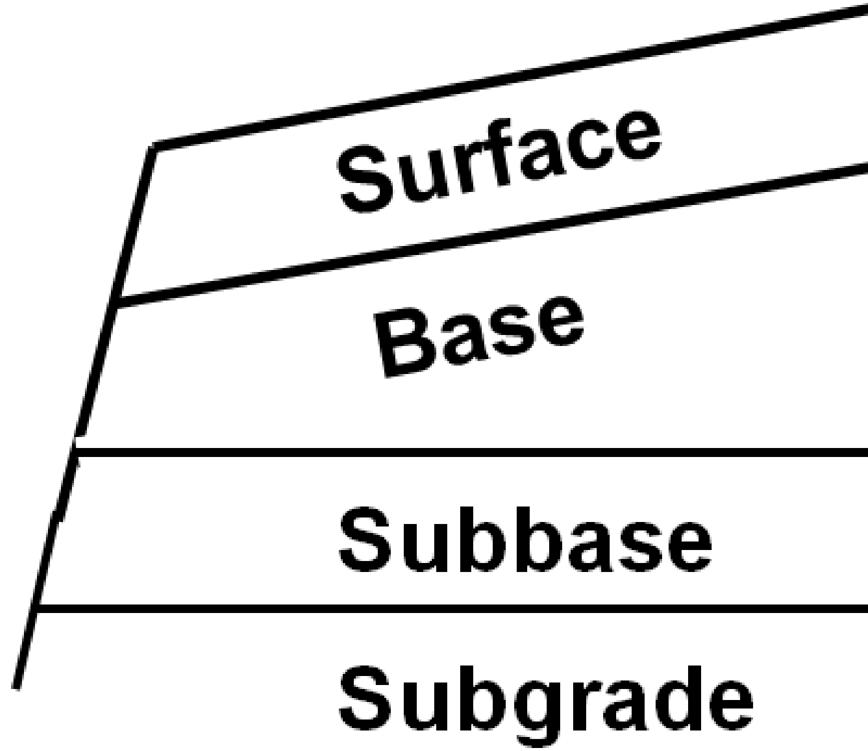
- Initial cost
- Durability



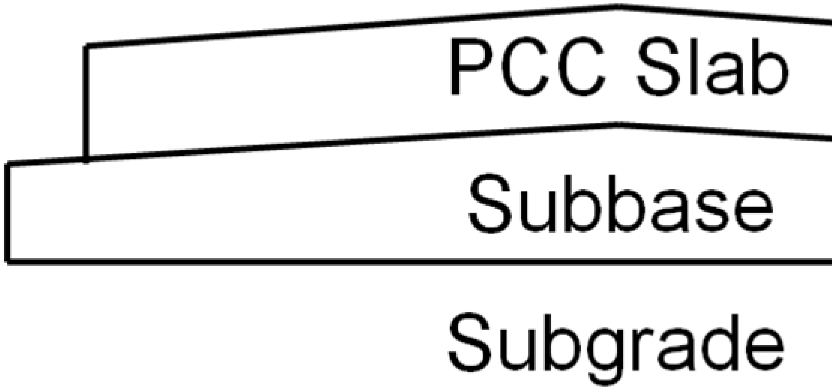
- 93% asphalt roads
- Selection should be based on life-cycle cost

Function of Base/Subbase

- Asphalt Pavement
  - –Structural support
  - –Drainage
  - –Control of frost effect
  - –Reduce effect of volume change of subgrade



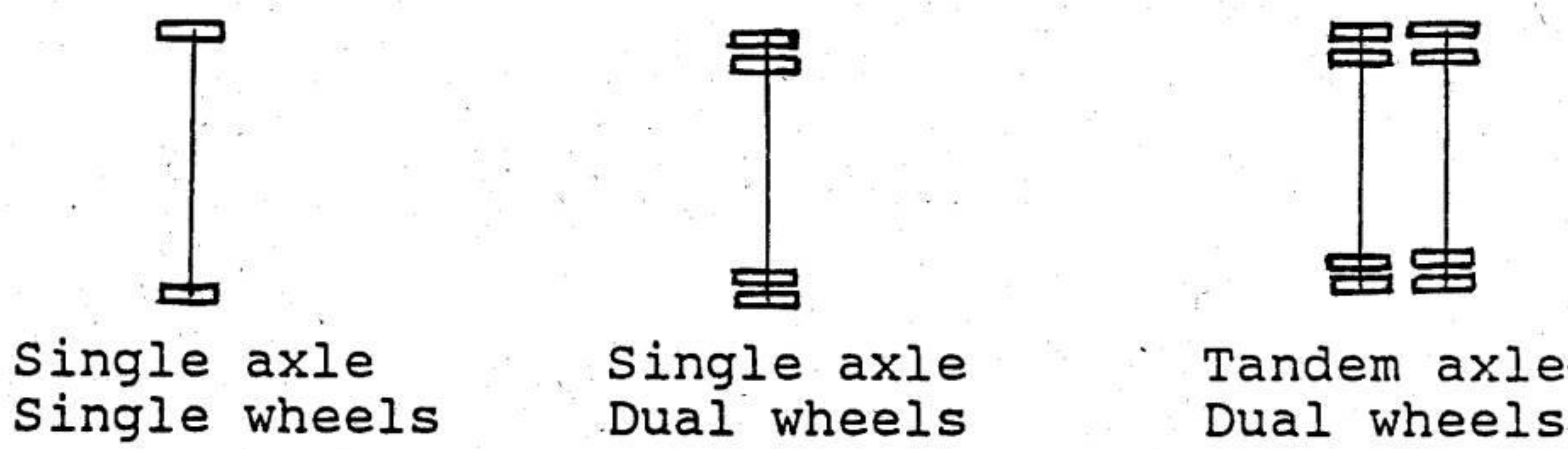
Function of Subbase



- Concrete Pavement
  - Drainage
  - Prevent pumping
  - Control frost effect
  - Reduce effect of volume change of subgrade
  - Construction platform

Unique Properties of Pavements

1. Continuous and fast deterioration with time (traffic)
2. Different load magnitudes and configurations

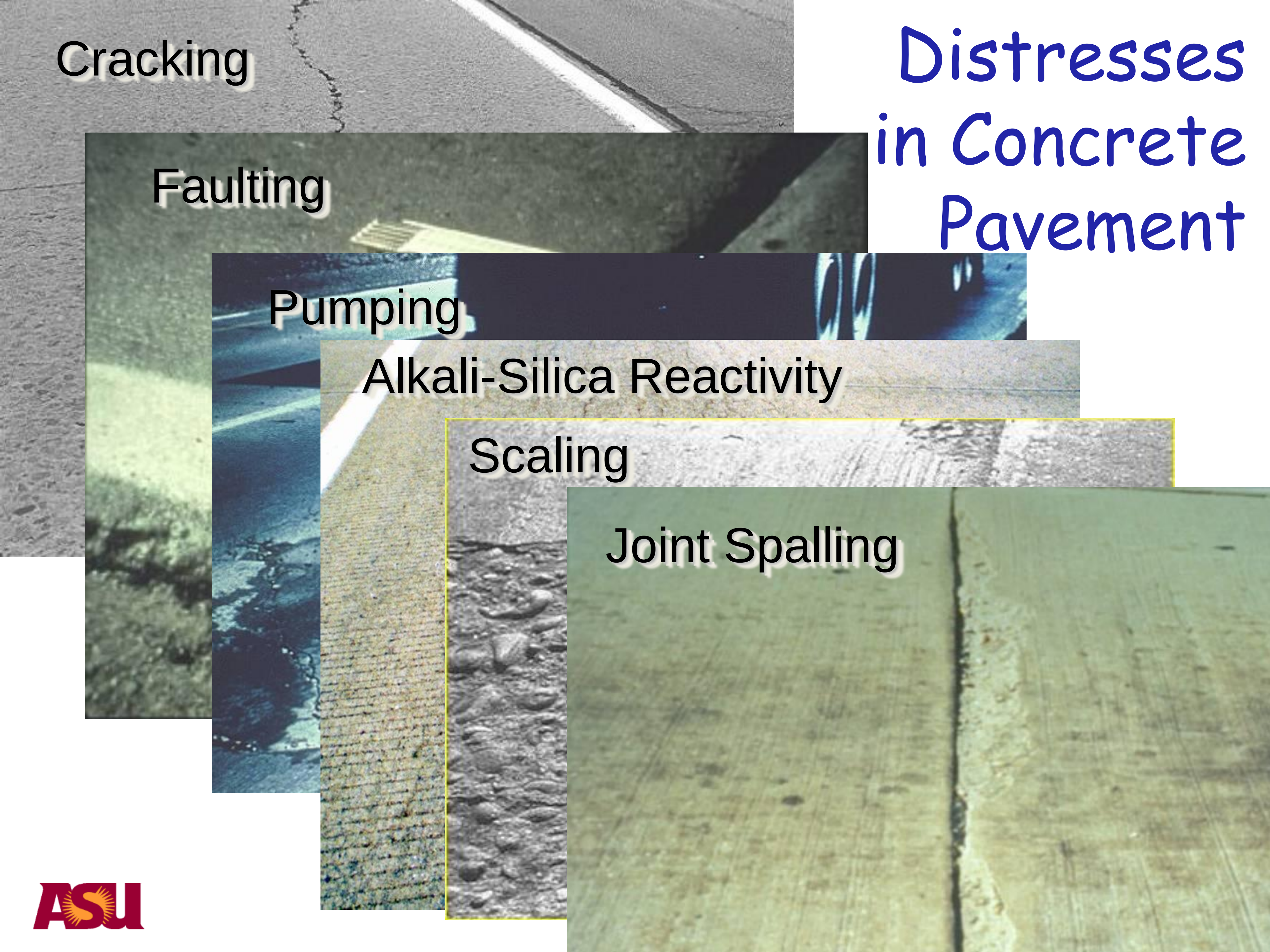


Unique Properties of Pavements

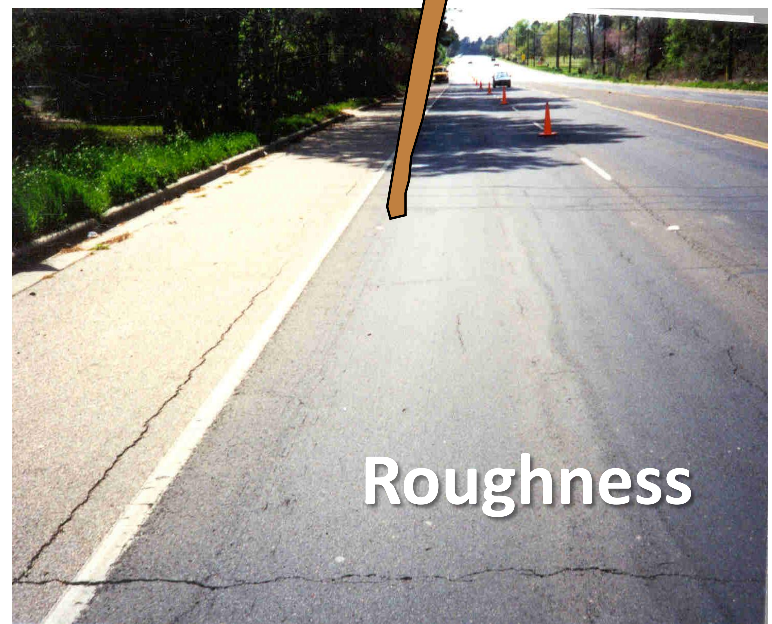
3. Unpredictable traffic growth
4. Environmental effects
   - Temperature
   - Rain
   - Freeze and thaw
   - Aging of asphalt
5. Multilayered system
6. Unconventional definition of failure

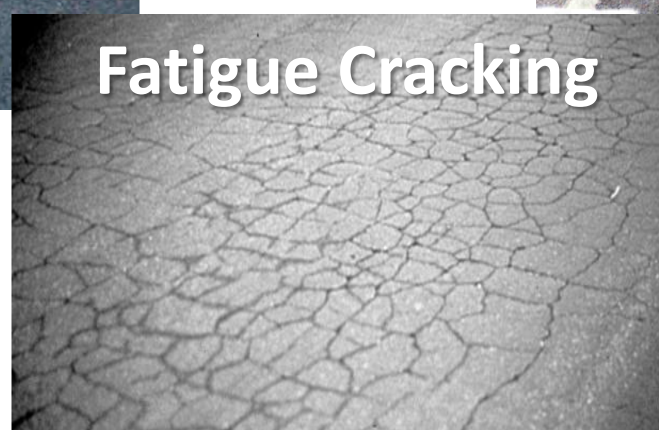
Distresses in Asphalt Pavement

Distresses in Concrete Pavement

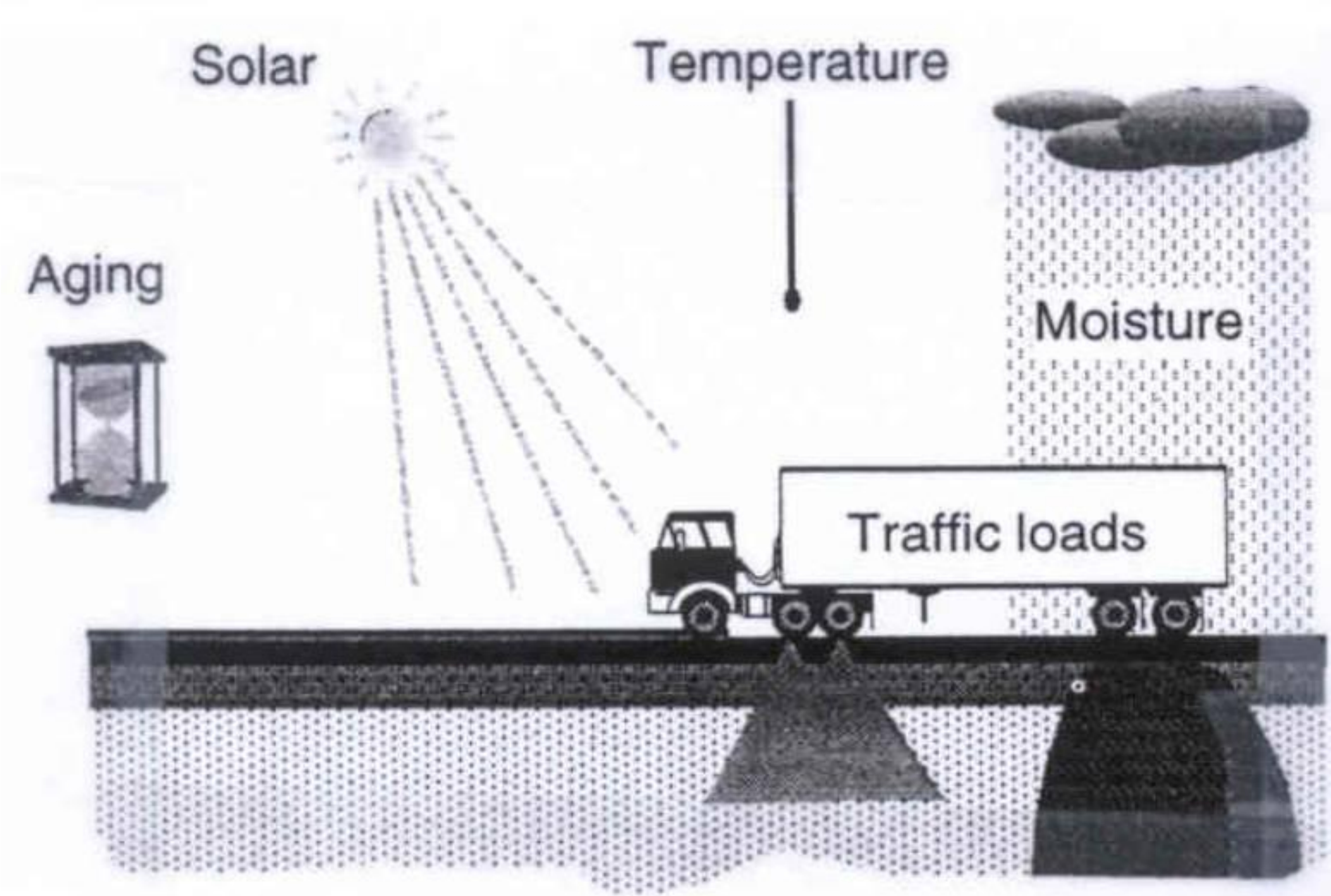


Challenge of Pavement Design





Factors Affecting Pavement Performance



Factors Affecting Pavement Performance

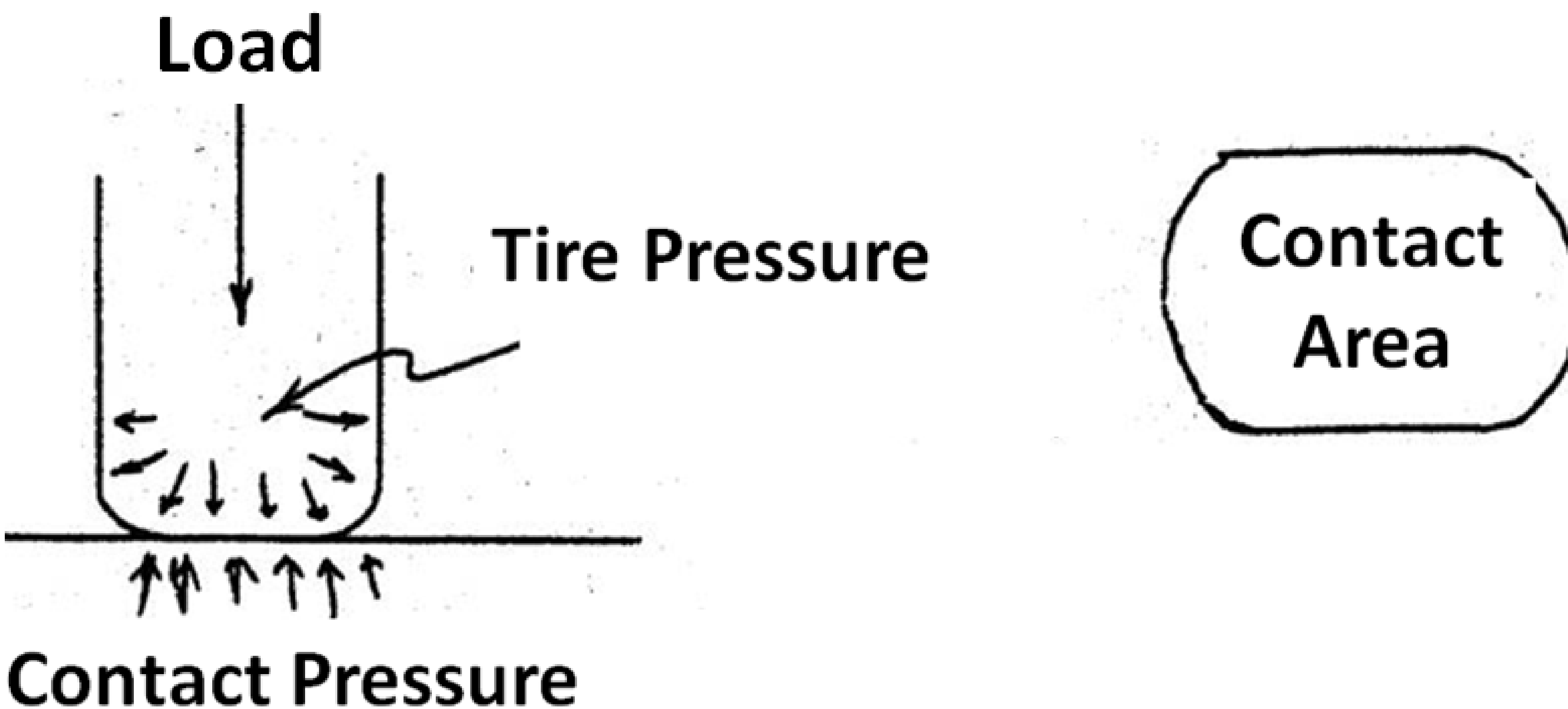
1. Traffic
2. Soil and pavement materials
3. Environment
4. Construction and maintenance

ASU

Improved Truck Technology (Mid-1900s - Present)

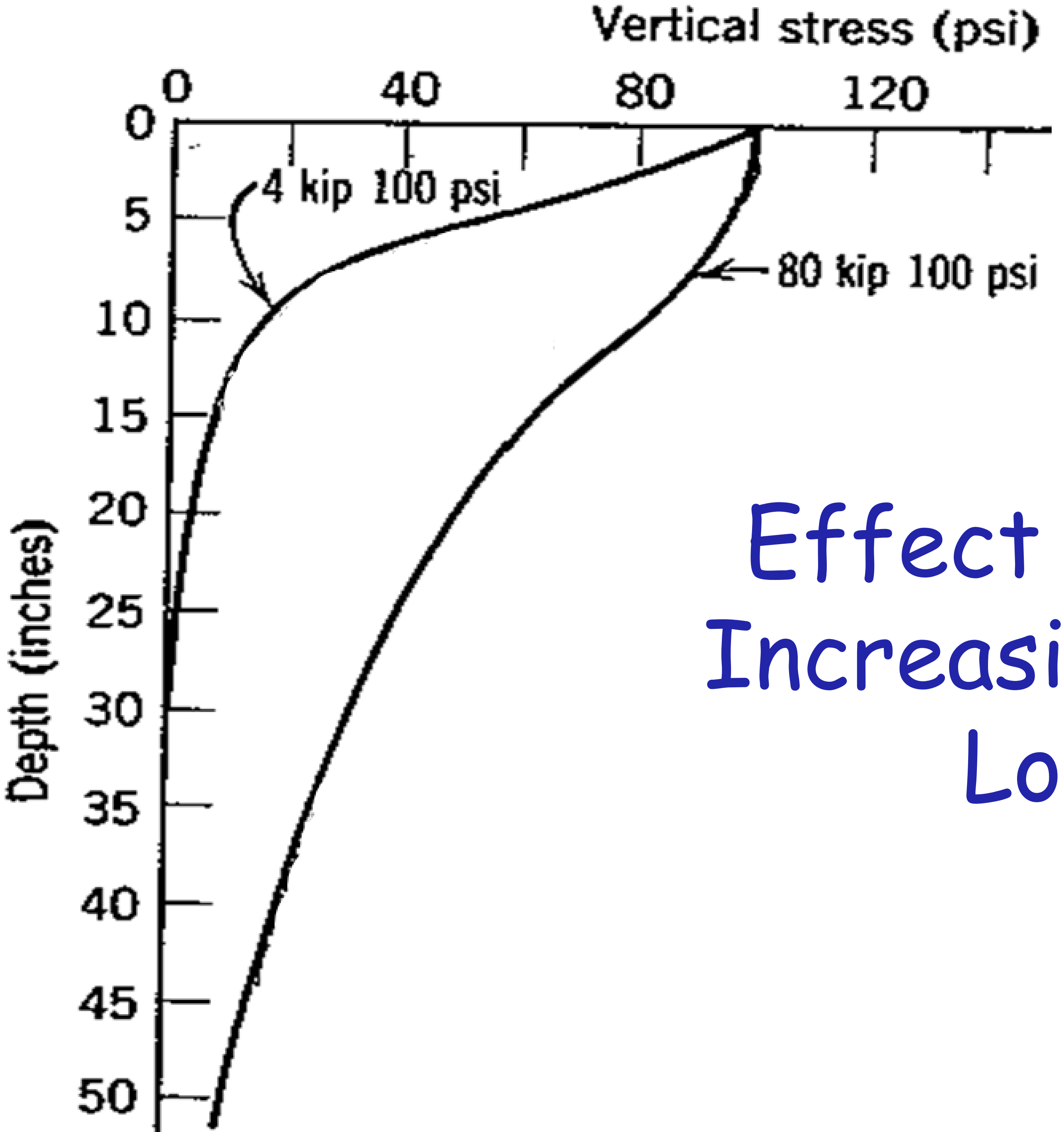
- Increased average truck load
- Increased tire pressure
- Increased traffic volume
  - Large effect on Pavement design

Load, Tire Pressure & Contact Area



Tire Pressure & Contact Pressure

- Contact pressure is not constant throughout the contact area
- Usually we assume:
  - Constant contact pressure
  - Tire pressure = contact pressure
  - $$Contact\,Area = \frac{\text{Load}}{\text{Contact Pressure}}$$

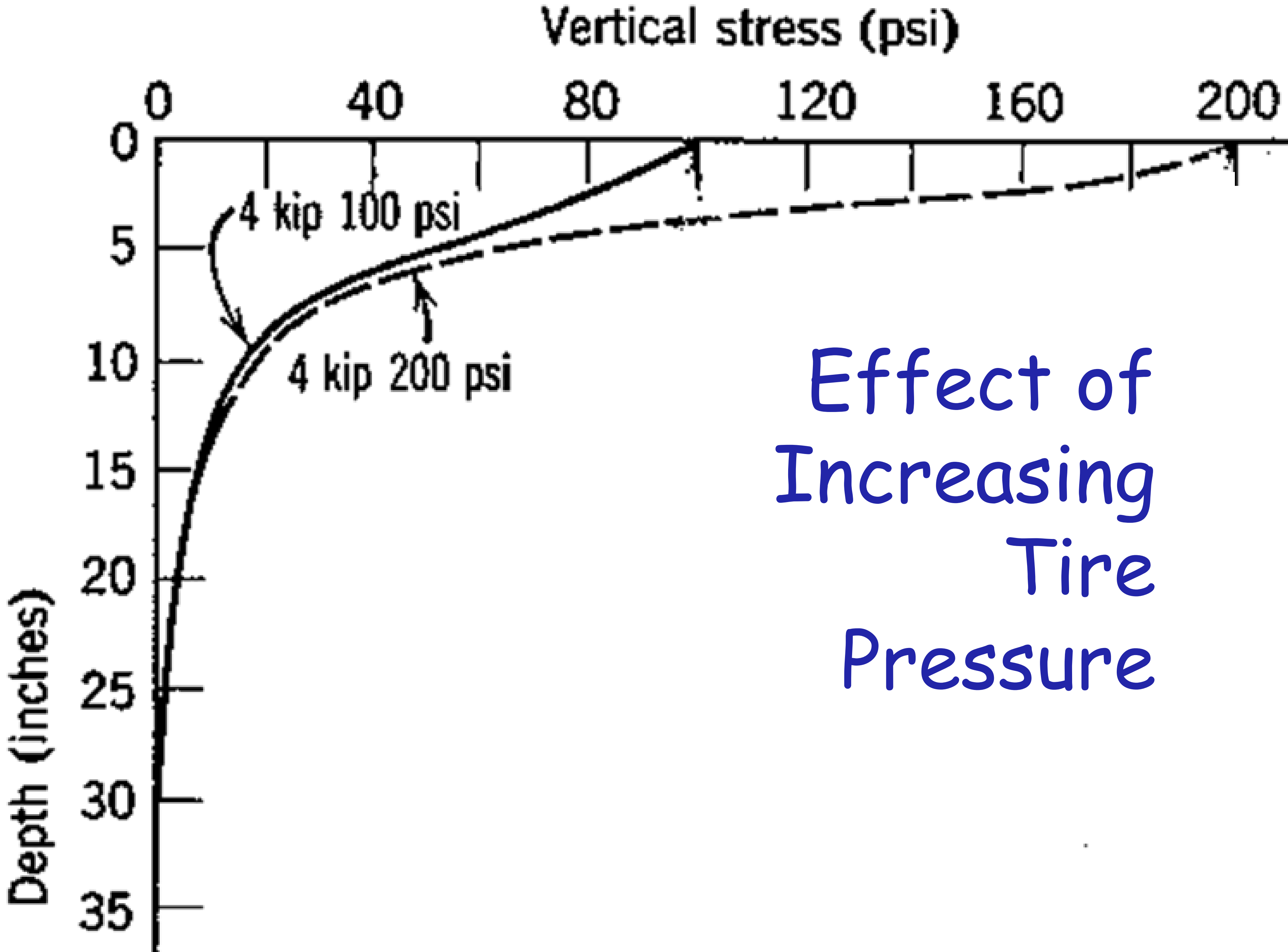


Effect of Increasing Load

Increasing Load Magnitude

- Increasing load affects deeper layers

- Required pavement thickness is mostly determined by load magnitude



Effect of Increasing Tire Pressure

Increasing Tire Pressure

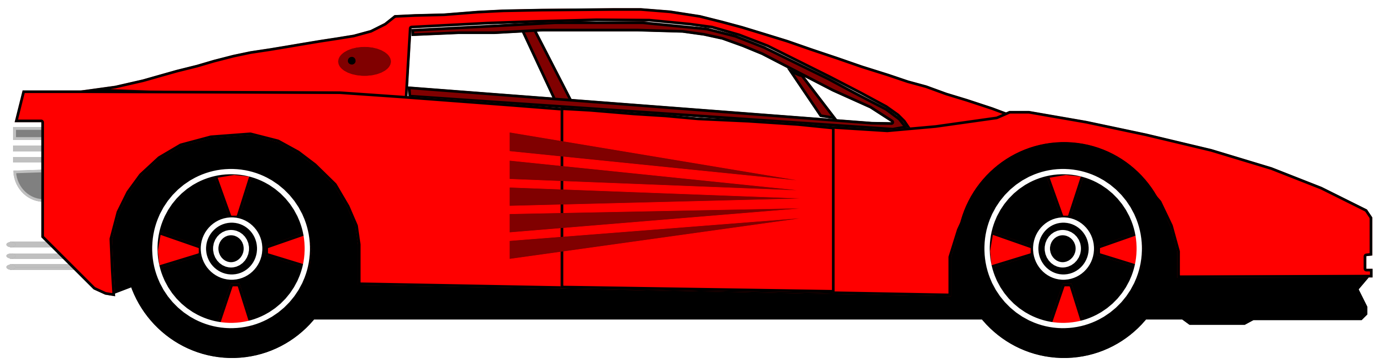
- Increasing tire pressure affects upper layers

- Required quality of surface is mostly determined by tire pressure

Increasing Traffic Volume

Traffic volume accumulates pavement damage

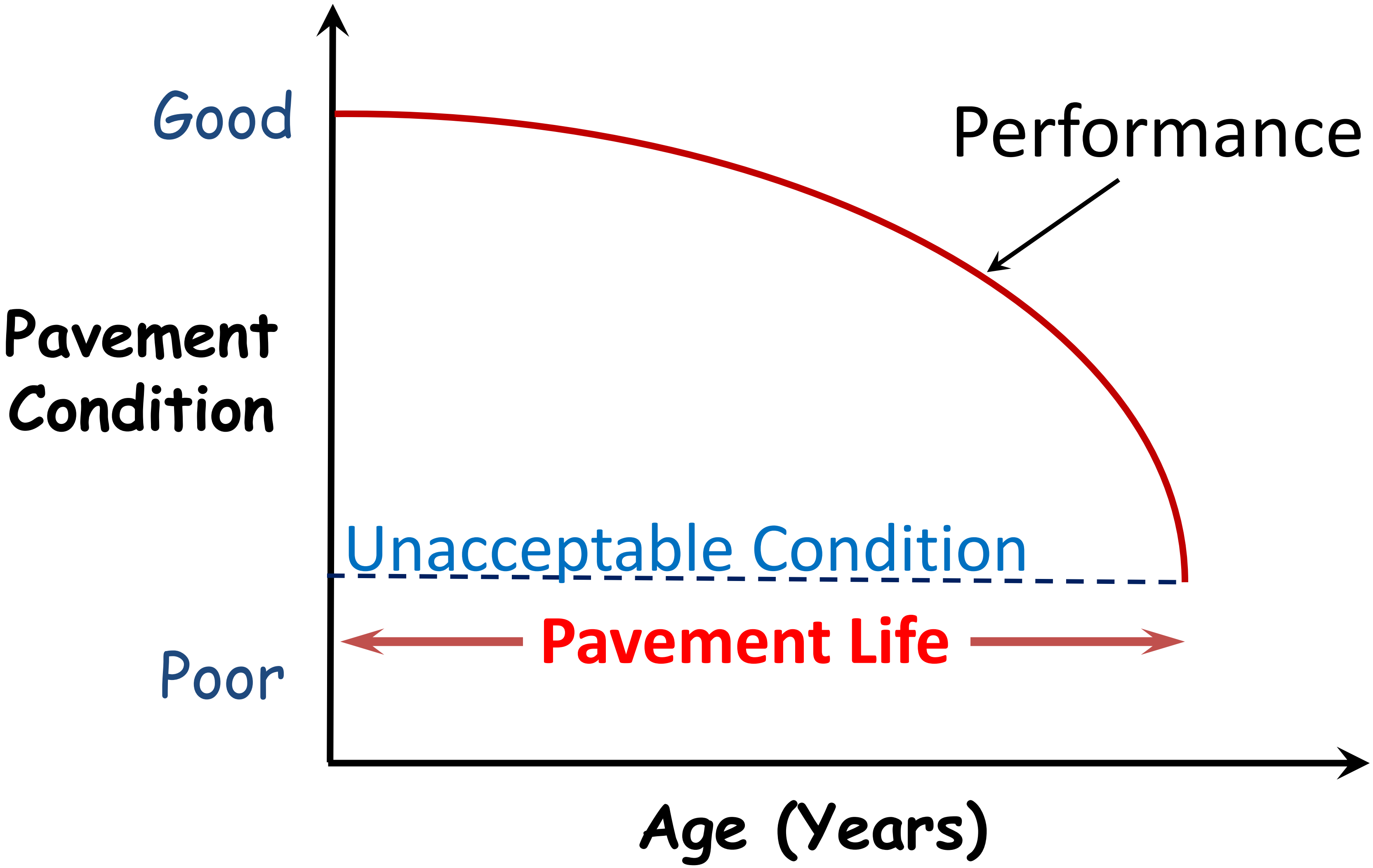
Load Duration



Parked cars have larger effect than moving car


Pavement does not
last forever

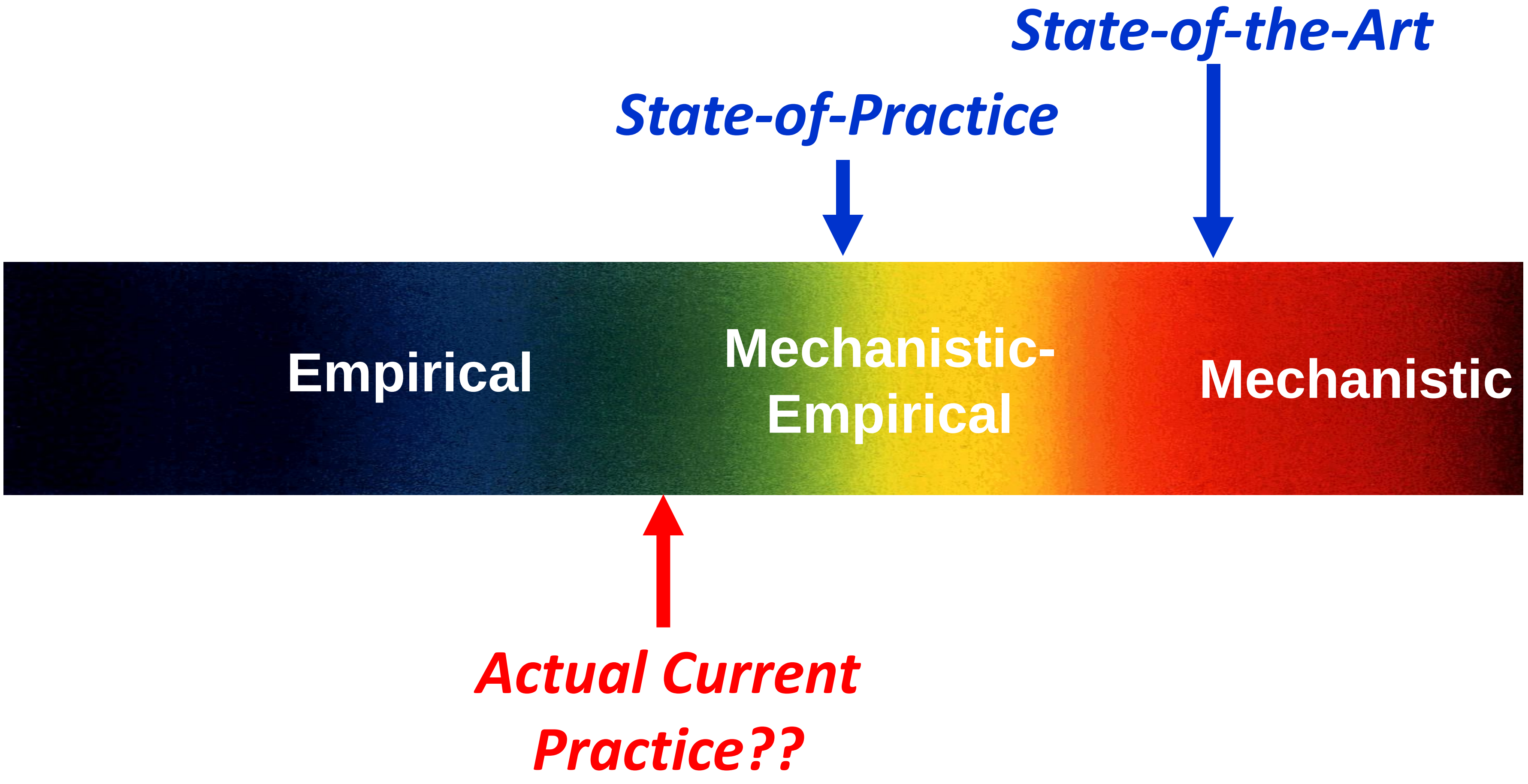
How Long Does Pavement Last?



Pavement Design Approaches

1. Engineering judgment
2. Standard thicknesses
3. Empirical
4. Mechanistic or mechanistic/empirical

The Continuum of Development



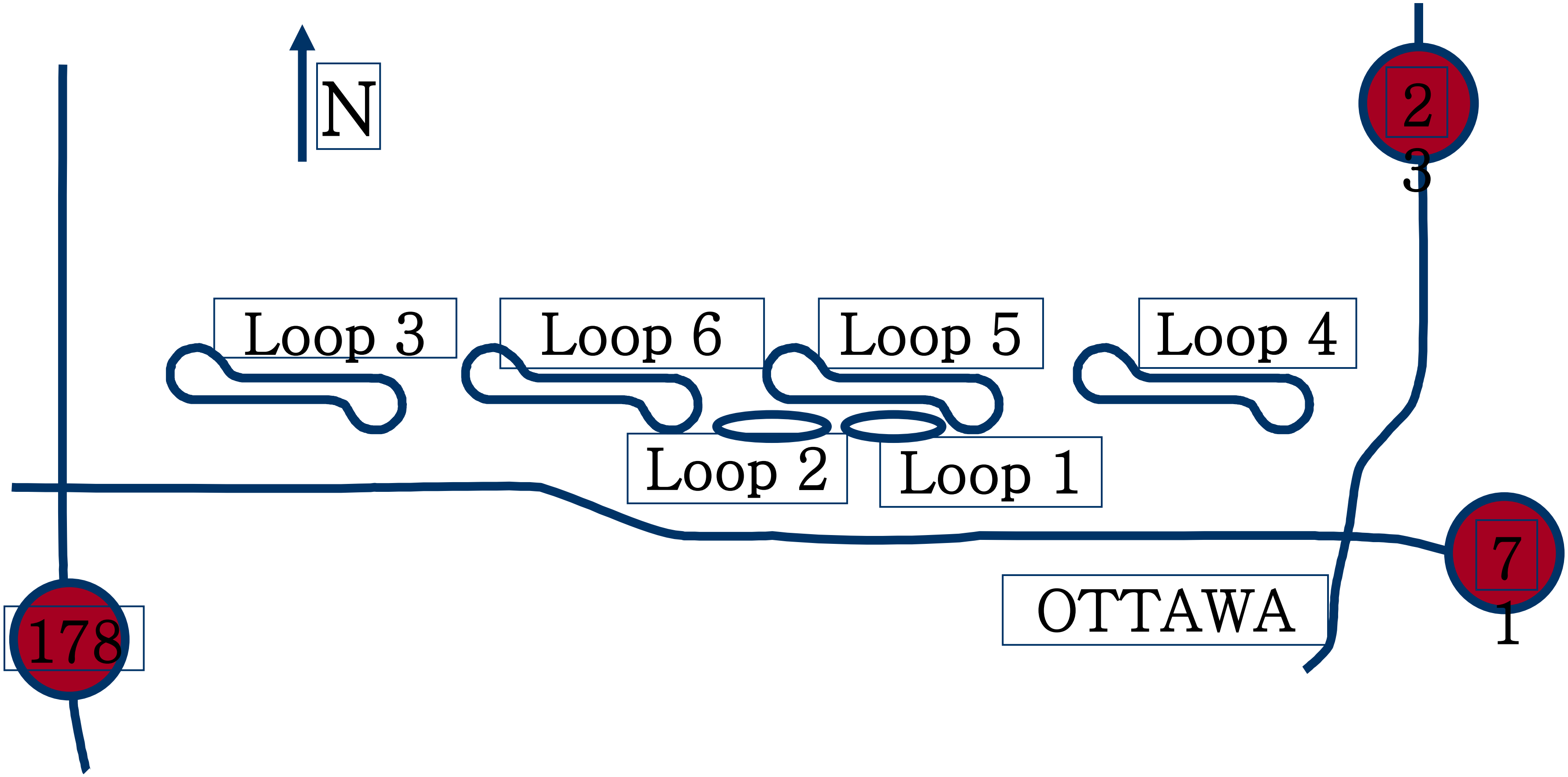
Moving from Art to Science

- AASHO Road Test
- Strategic Highway Research Program (SHRP)
- Mechanistic-Empirical Pavement Design Guide

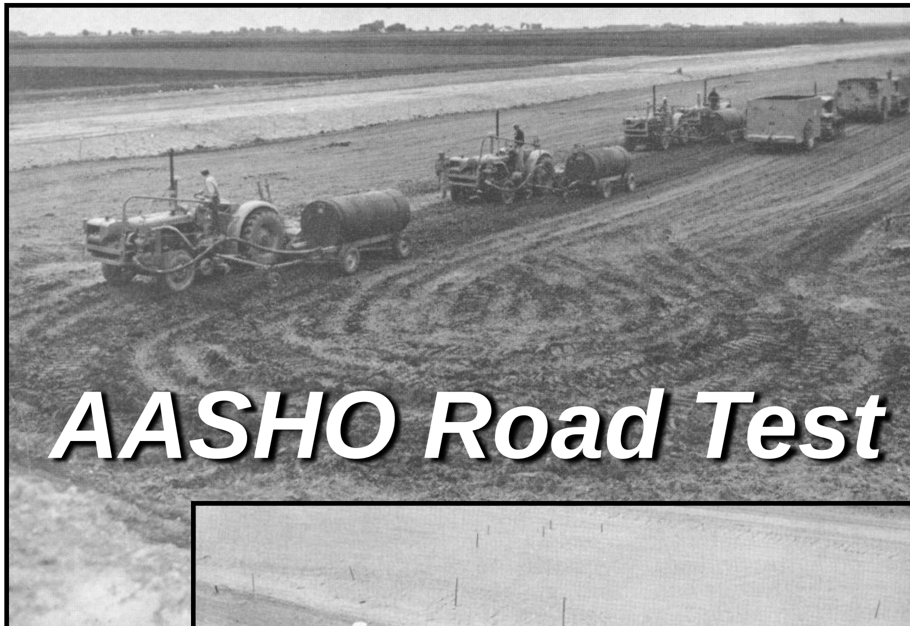
AASHO Road Test

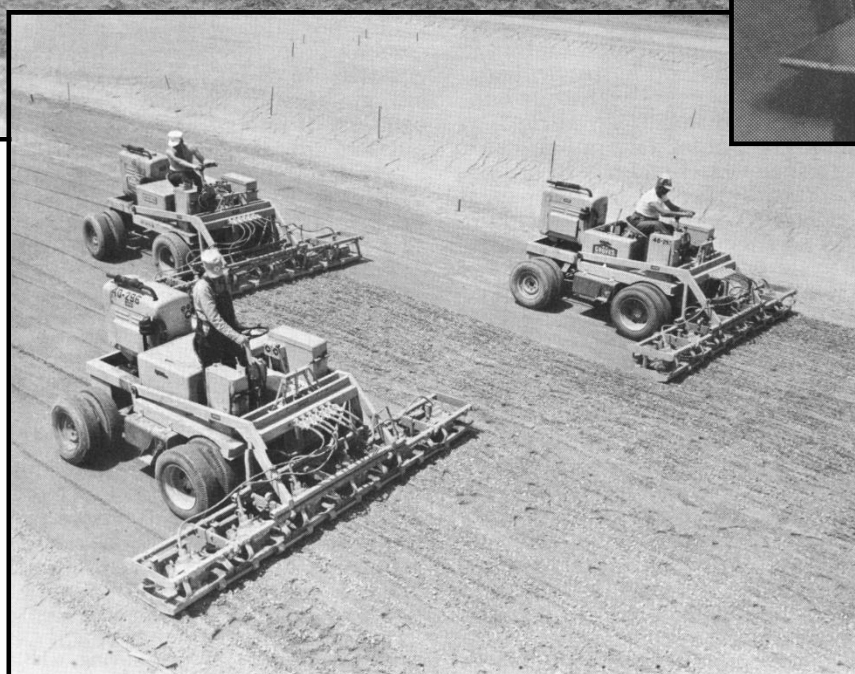
- Late 1950’s and early 1960’s
- Ottawa, Illinois
- Loops of pavements with different materials & different numbers of layers
- Traffic loads
- Continuous observations

Layout of AASHO Road Test



Historical Perspective





AASHO Road Test

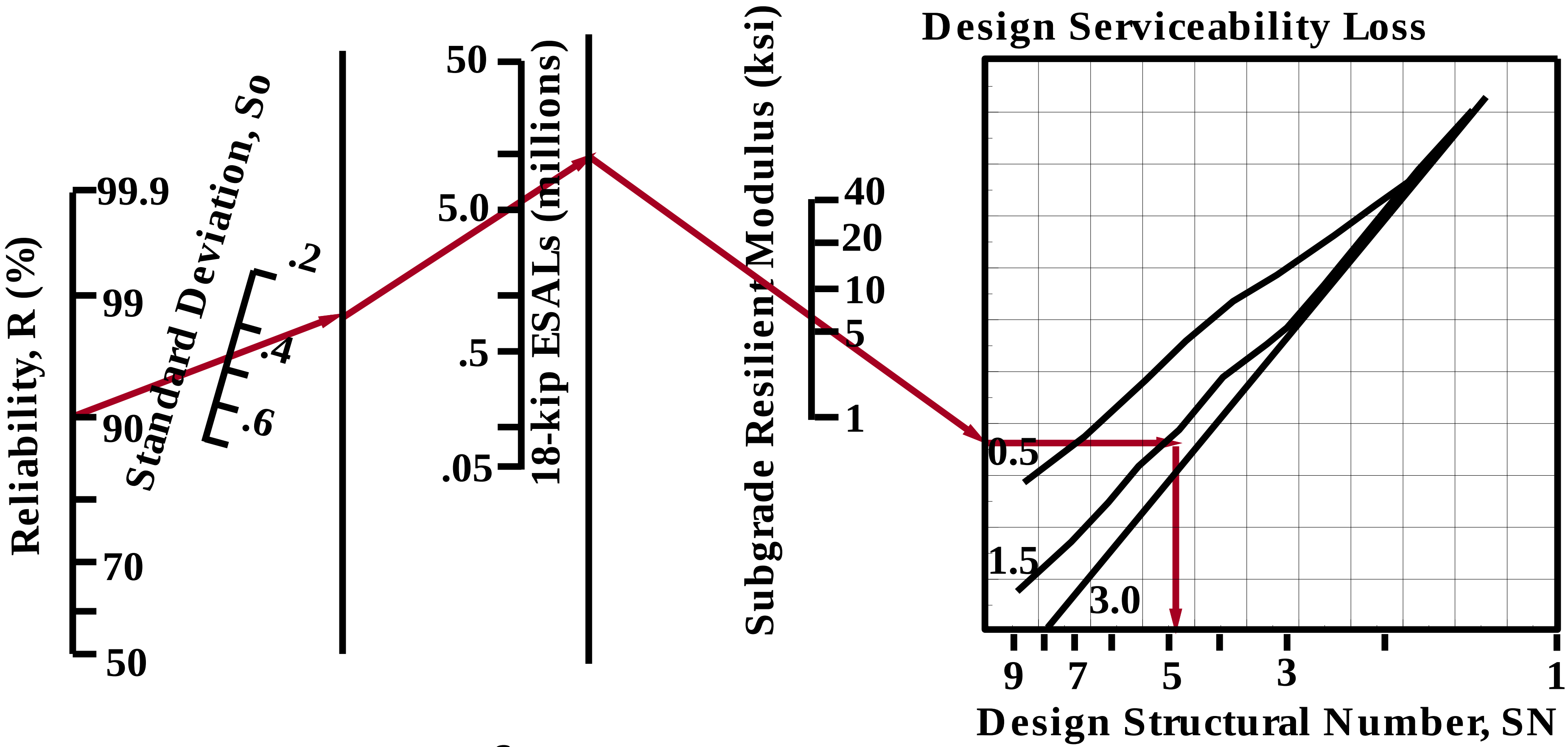
- Produced the equivalent single axle load (ESAL) concept
- Relationship between traffic and performance
- AASHTO pavement design method (1961, 1972, 1981, 1986, 1993)

1993 AASHTO Design

Required Data

1. Traffic (cumulative ESAL)
2. Soil properties
3. Layer material properties (surface, base & subbase)
4. Initial and terminal serviceability
7. Structural layer coefficients
8. Drainage coefficients

1993 AASHTO Design Nomograph



- DARWin software
- Both asphalt and concrete pavements

Limitations of 1993 AASHO Design

- Empirical performance models
- Specific climate, subgrade, and materials
- Short performance period of AASHO Road Test

Strategic Highway Research Program (SHRP)

- 5-year program (1987-1993)
  - Asphalt
  - Concrete and construction
  - Highway operation
  - Long-term pavement performance (LTPP)

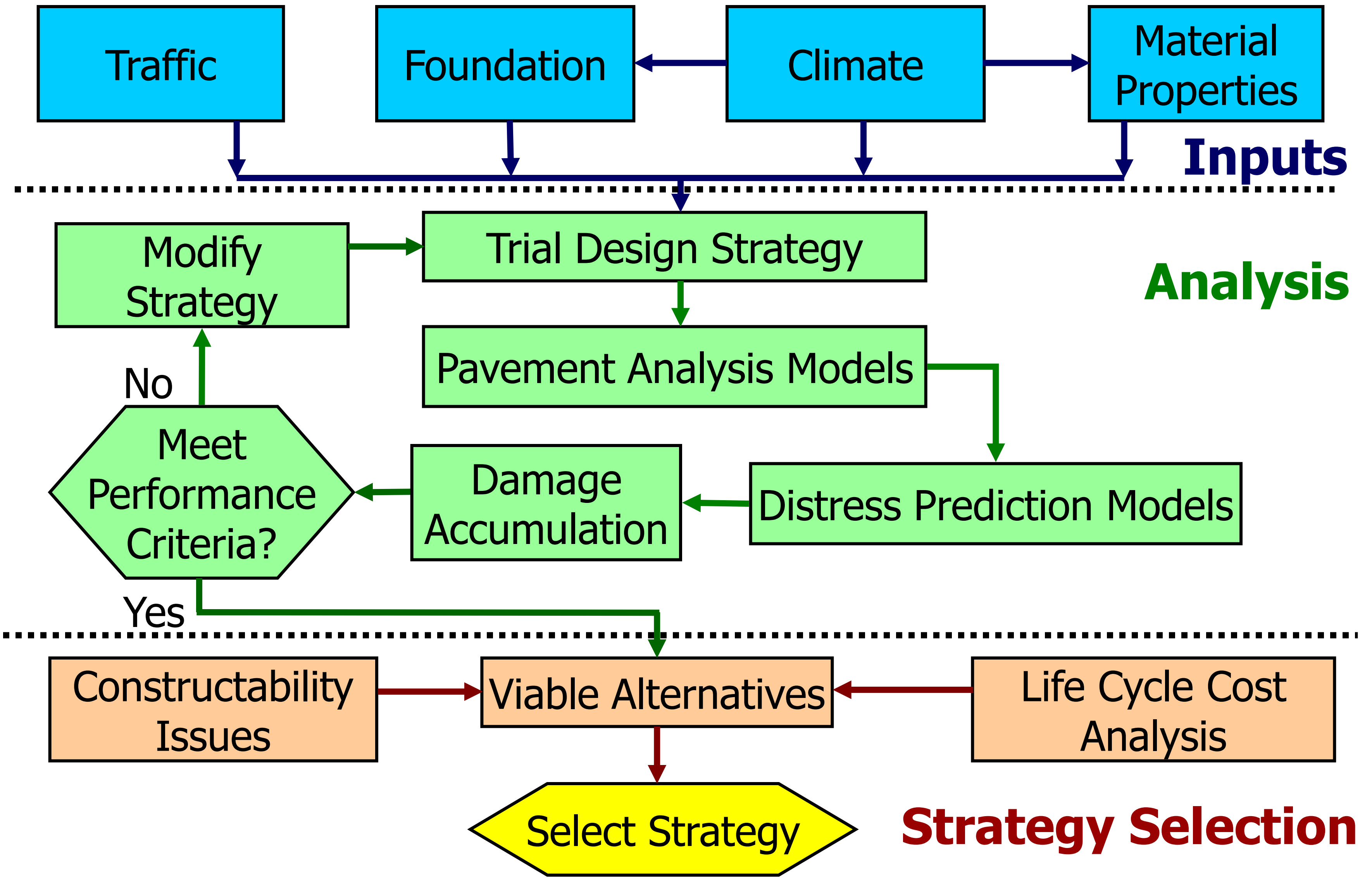
Mechanistic-Empirical Pavement Design Guide (MEPDG)

An Analysis Method

An Iterative Design Method

- DARWin-ME software

MEPDG Design Process Overview

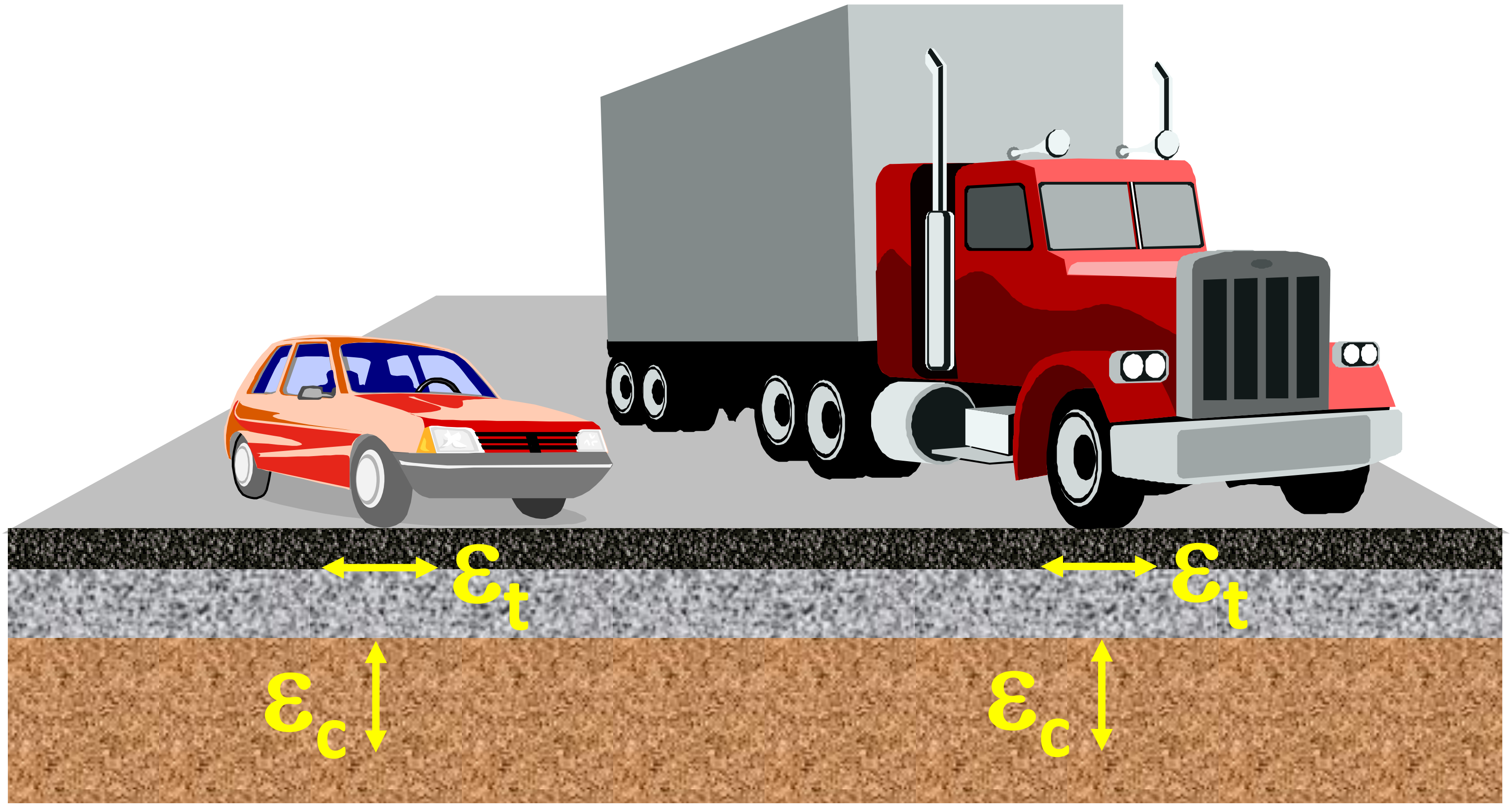


MEPDG Design Inputs

A hierarchical approach for determining the design inputs.

Input Level	*Determination of Input Values*	*Knowledge of Input Parameter*
1	**Specific Measurements, Extensive data input**	**Good**
2	**Correlations, Regional values**	**Fair**
3	**Defaults, Educated Guess**	**Poor**

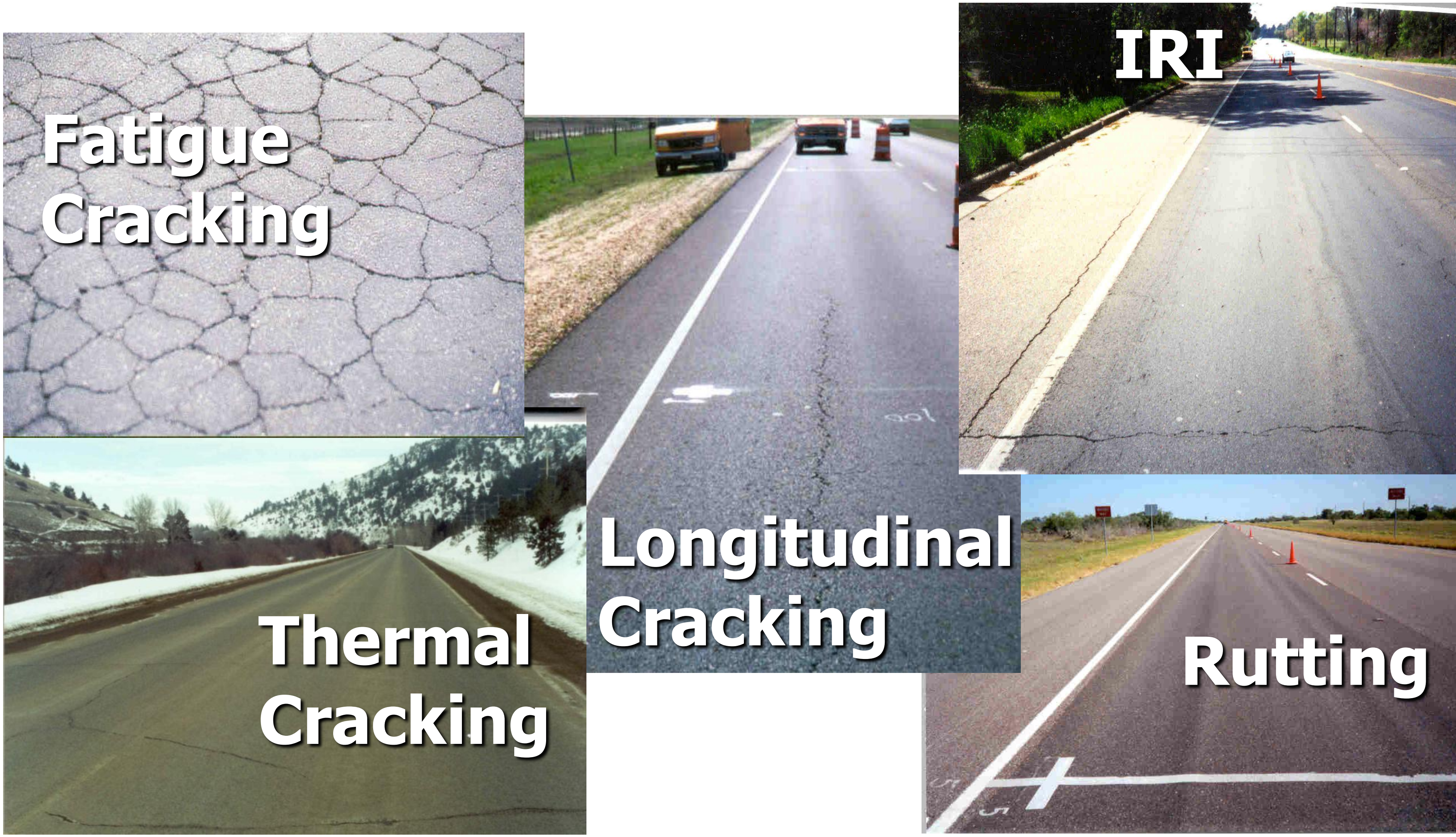
MEPDG Critical Response Values



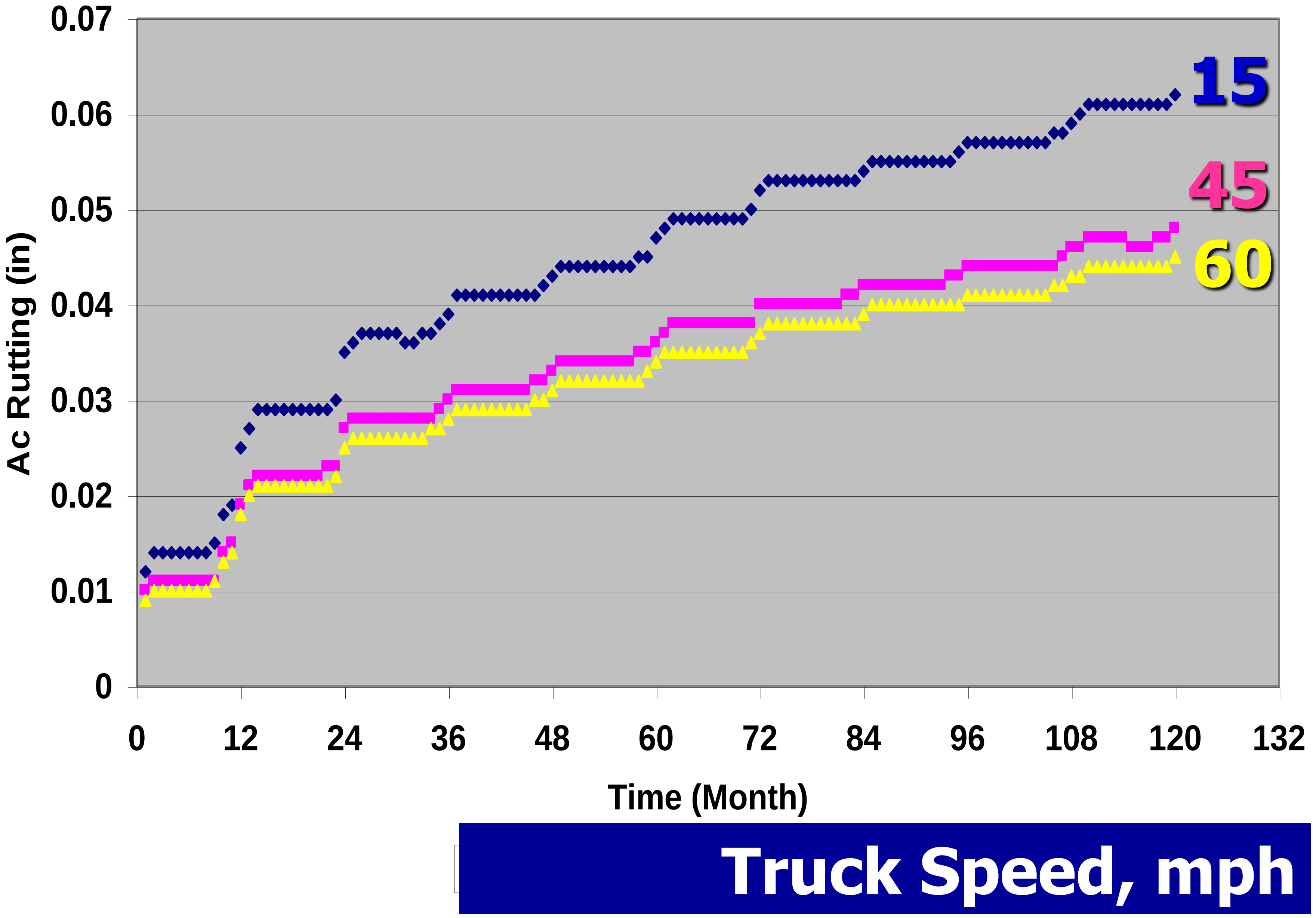
ε_t at surface + bottom of all bound layers (cracking)

ε_c at mid-thickness of all layers + top of subgrade (rutting)

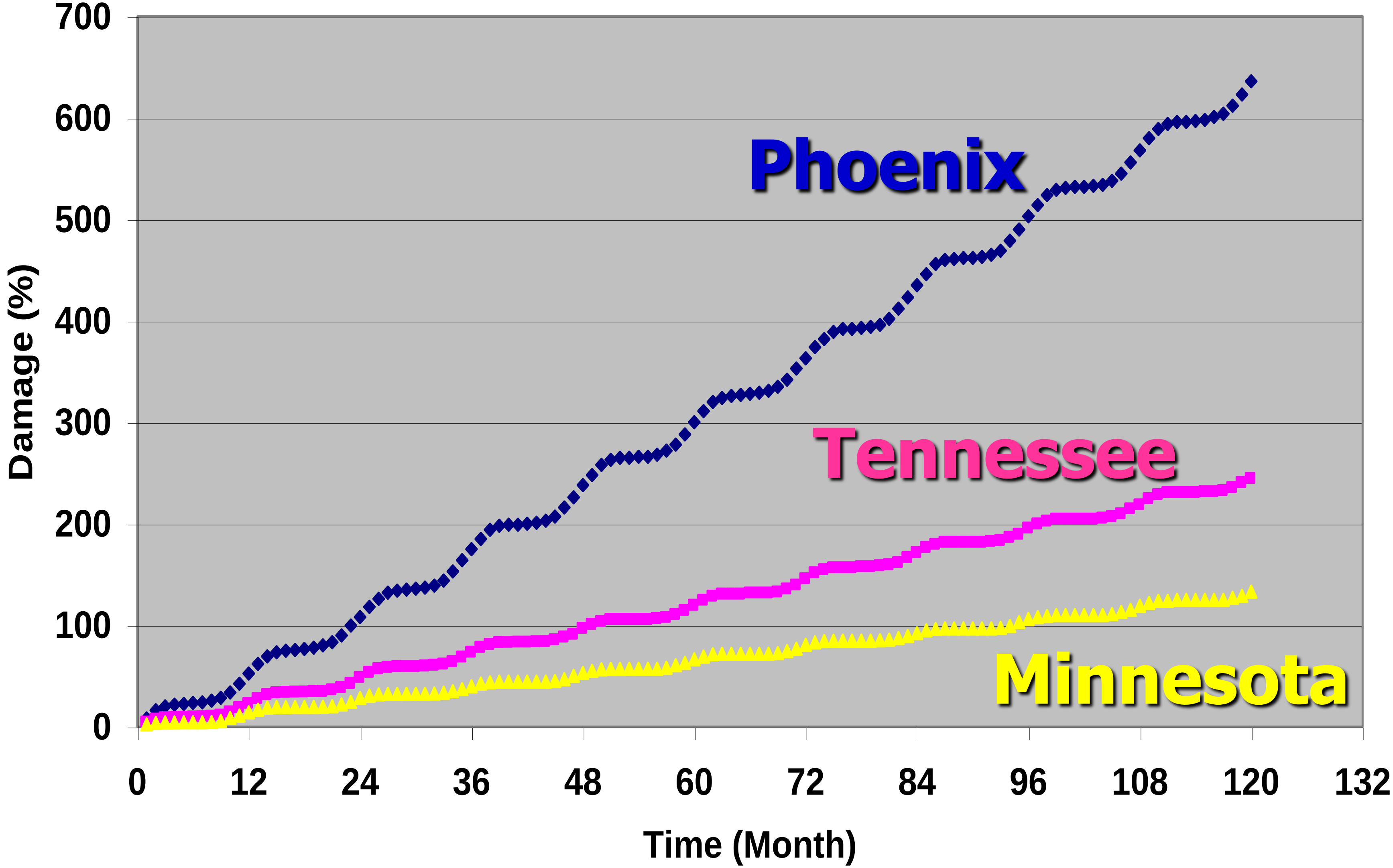
MEPDG Predicted Distresses



MEPDG Rutting in HMA



MEPDG Fatigue Cracking



Climate/Area

Asphalt Rubber

- About 1" overly on existing pavement is common in Arizona (AR-ACFC)
  - Binder
    - 80 % Asphalt
    - 20 % Ground tire rubber
  - Gap graded aggregate

Asphalt Rubber (Cont.)

- Reduces cracking
- Reduces noise
- Improves skid resistance
- Reduces standing water
- Improves driver visibility

Concept of Perpetual Pavement

- Extended-life HMA pavement
- Limit distresses in the surface layer
- Has been used in Europe

Example of Perpetual Pavement

SMA 1.5” – 3”

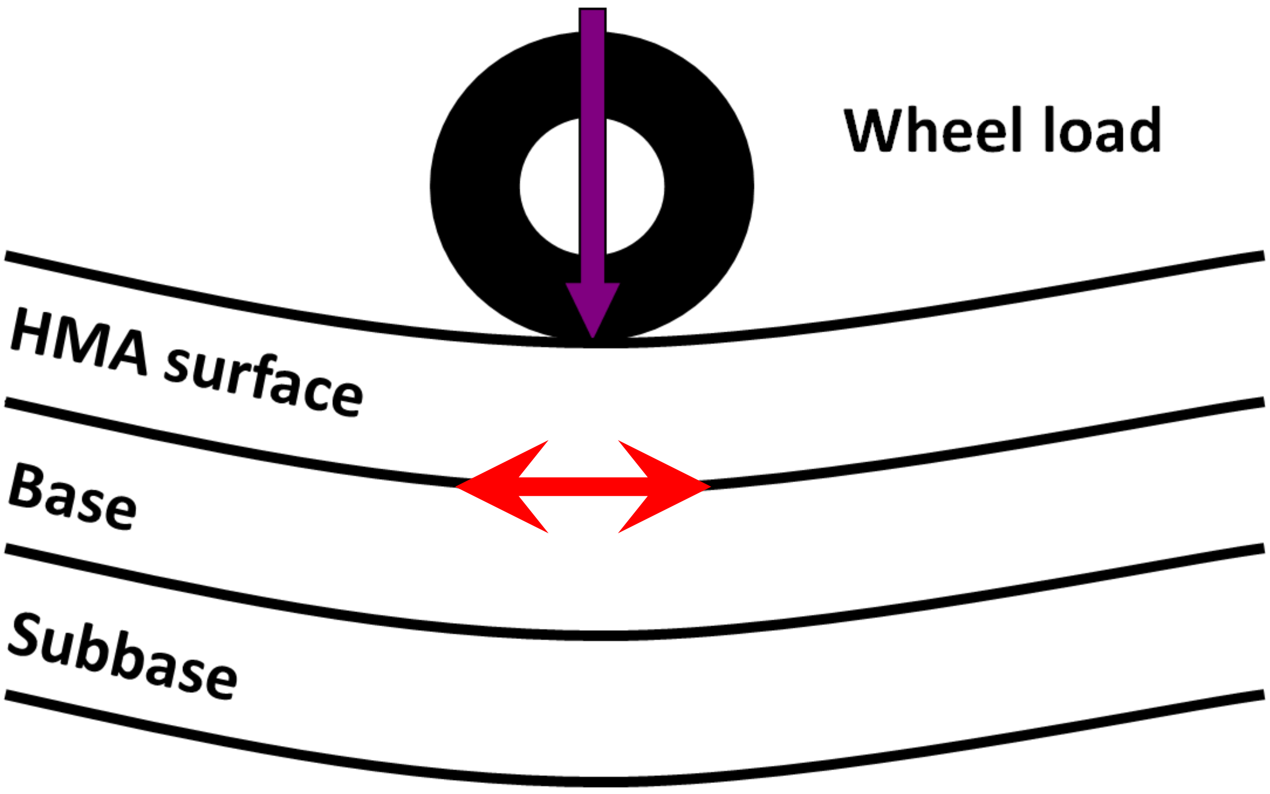
High Modulus
Rut Resistant Material
4” – 7”

Flexible Fatigue Resistant
Material 3” – 4”

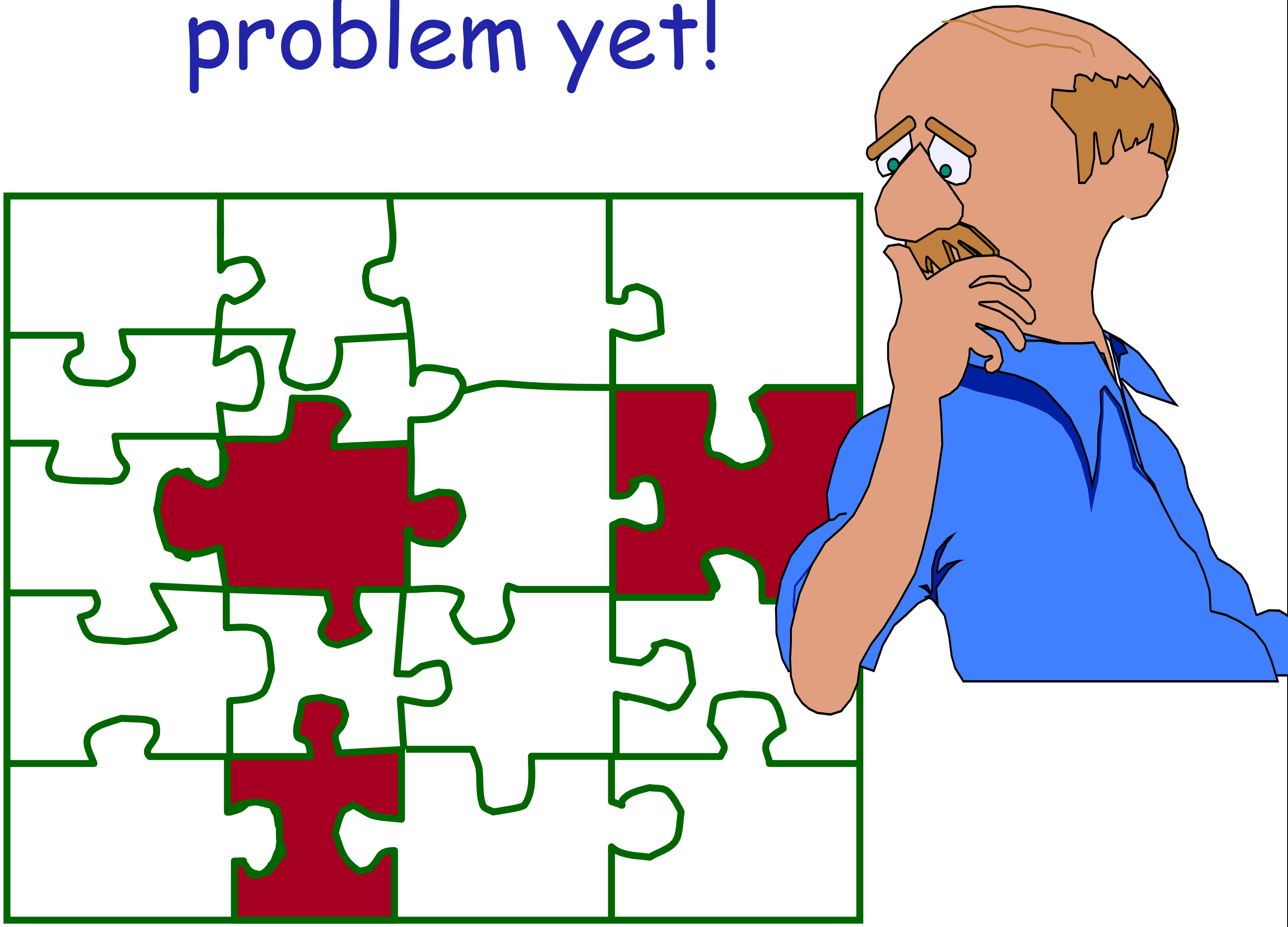
Pavement
Foundation

Endurance Limit

- Strain level below which HMA would endure indefinite load repetitions without developing fatigue cracks



We have not solved the whole problem yet!



Conclusions

- Pavement design evolved throughout the years
- Combination of art and science
  - ❖ Started with empirical
  - ❖ Gradually becoming mechanistic (scientific)
  - ❖ A completely mechanistic design is yet to come


THE END