CONCRETE PAVEMENT DESIGN
WHAT HAVE WE LEARNED

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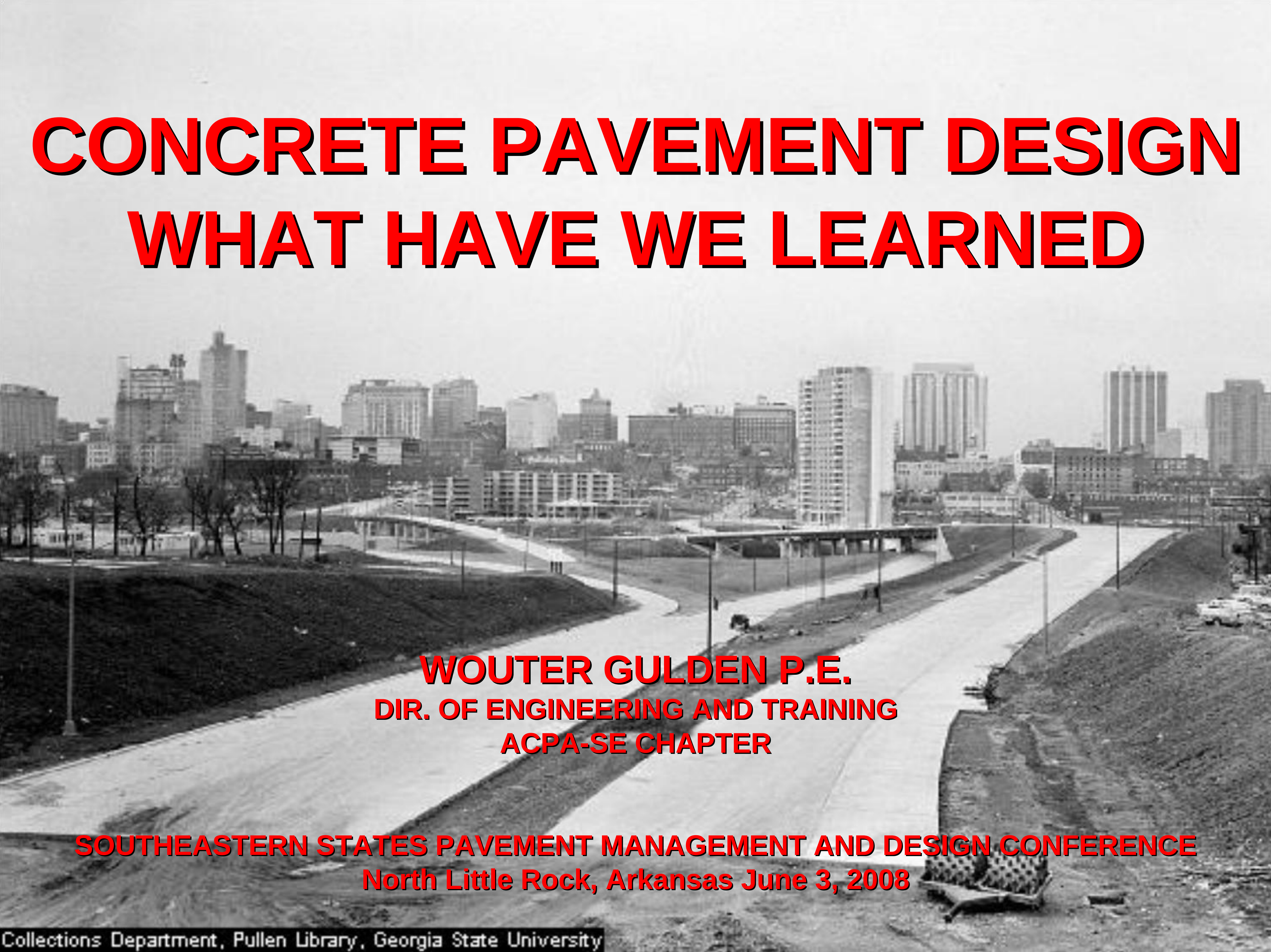
DIR. OF ENGINEERING AND TRAINING
ACPA-SE CHAPTER

SOUTHEASTERN STATES PAVEMENT MANAGEMENT AND DESIGN CONFERENCE
North Little Rock, Arkansas June 3, 2008



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PAVEMENT DESIGN

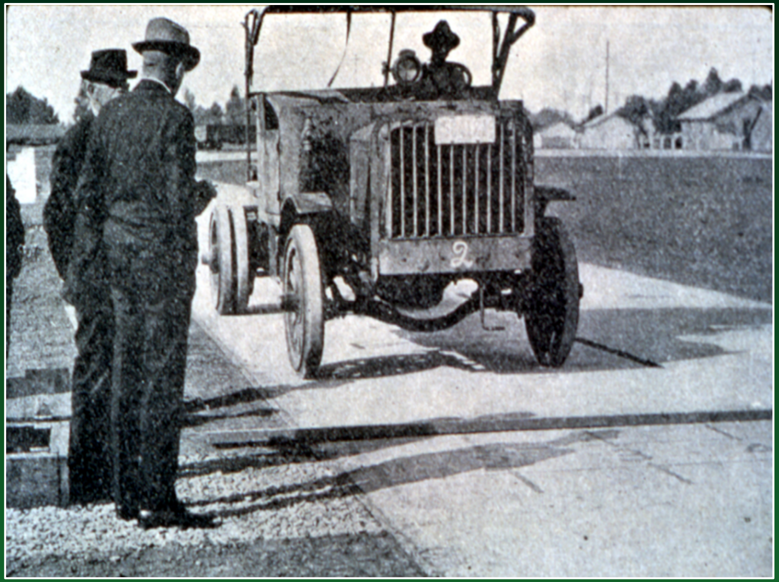
- Pavement design is an “a priori” process.

    The new pavement will be built in the future, on subgrades often not yet exposed or accessible; using materials not yet manufactured from sources not yet identified; by a contractor who submitted the successful "low dollar" bid, employing unidentified personnel and procedures under climatic conditions that are frequently less than ideal.

Historical Overview of Pavement Design

Bates Road Test

- In 1920, Illinois passed a $200 million bond issue to build 9000 miles of paved roads
- To determine the best paving material, they built sections of brick, asphalt, and concrete
- Developed thickness design procedures and chose concrete for the Illinois pavements



Old WWI Army trucks with 9000# wheel loads

1921-23 Pittsburgh Road Test

- Pittsburgh Steel conducted tests in Pittsburgh, CA on plain and reinforced pavements.
- Hoped to prove that reinforced concrete was better

Additional Road Tests

- Maryland Road Test
  - Set up on existing concrete pavement
  - Set up between truckers and railroad operators to see who was paying their fair share of taxes.
- WASHO Road Test
  - All new asphalt pavements

AASHO 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

Purpose of the AASHO Road Test

- Determine relationships between axle loading (type and magnitude) and pavement performance.
  - To explain performance measurements in terms of design factors.
  - To explain capability measurements in terms of design factors.
  - To determine a correlation between the various measurements of performance and capability.
  - Determine equitable cost allocation tables.

AASHO Test Traffic

- Started Nov. 1958
- Ended Dec. 1960
- Loops 3-6:
  - 6 veh/lane
  - 10 veh/lane (Jan ‘60)
- Operation
  - 18 hr. 40 min.
  - 6 days/wk
- Total Loads
  - 1,114,000 Applications
  - Avg. ESAL - 6.2 million
  - Max ESAL - 10 million (Flex)

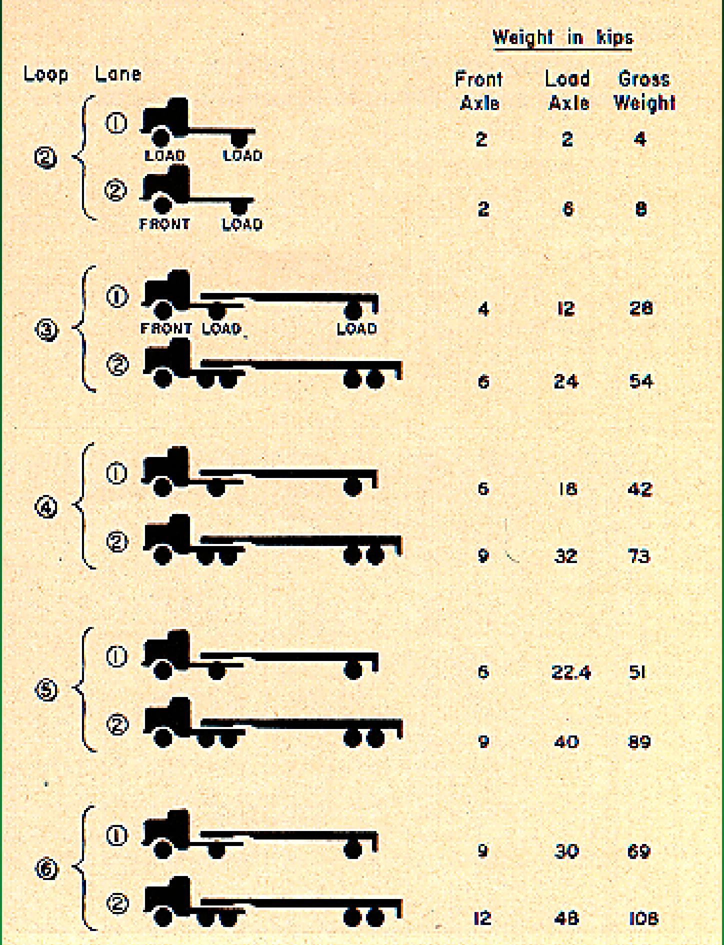


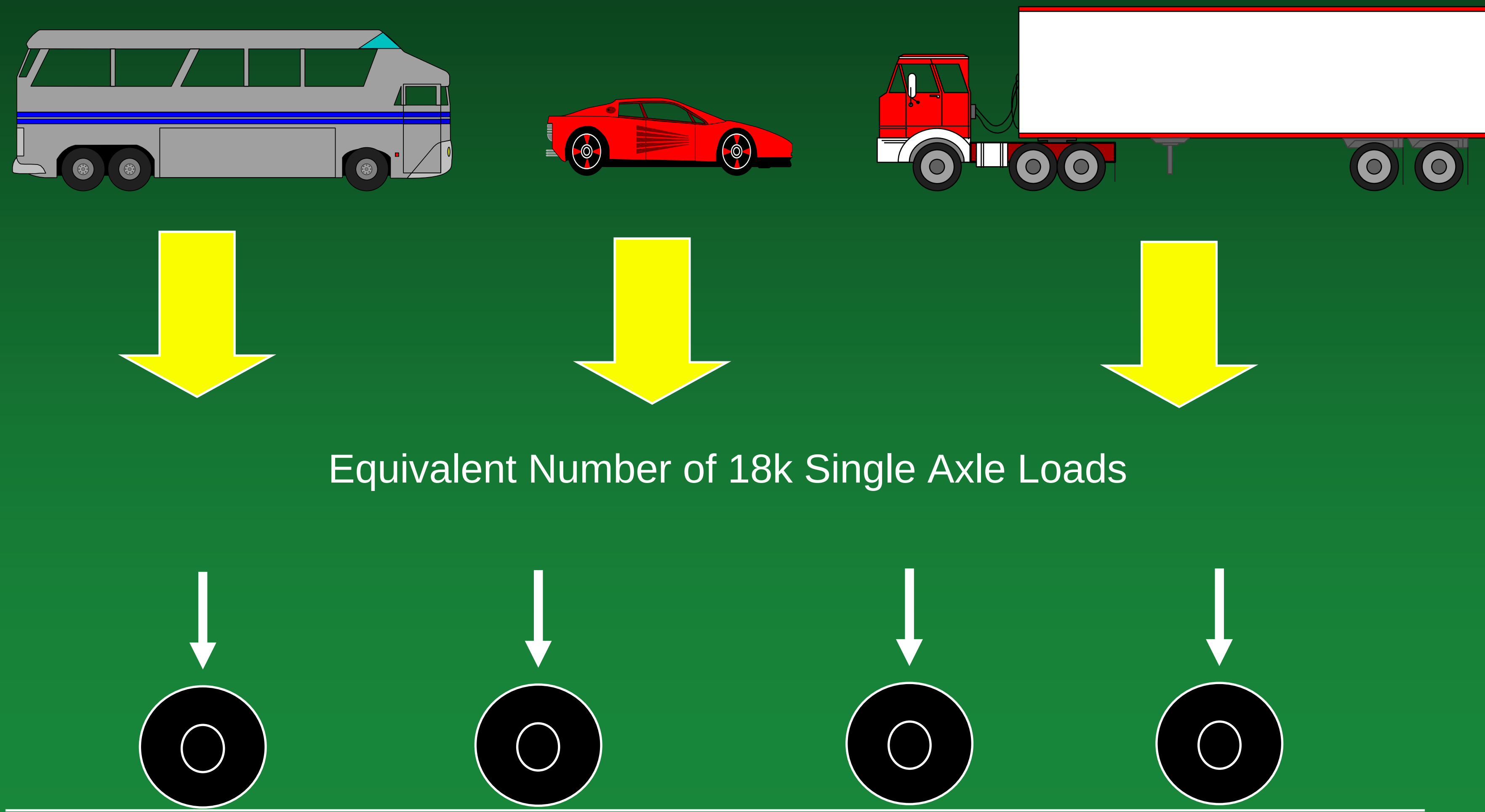
Figure 22. Typical test vehicle axle loadings.

AASHTO DESIGN
Serviceability

- **Serviceability** -
- the pavement's ability to serve the type of traffic (automobiles and trucks) that use the facility

Present Serviceability Index (PSI)

REGULAR MIXED TRAFFIC



Perspective

- 1960 – Completion of Road Test Experiment
- 1961-62 Interim Guide for the Design of Rigid and Flexible Pavements
- 1972 Interim Guide for the Design of Pavements
- 1981 Revised Chapter III on Portland Cement Concrete Pavement Design
- 1986 Guide for the Design of Pavement Structures
- 1993 Revised Overlay Design Procedures
- 1998 Supplement to Concrete Design Procedures

1972 AASHTO Design Inputs

- Loadings in ESAL,s
- Initial and Terminal Serviceability
  (Preset in GA)
- Concrete Flexural Strength
  (working stress of 450 psi in GA)
- Concrete Modulus of Elasticity
- Support Value, k factor
- Load Transfer Coefficient
  (Preset in GA)

1962 Rigid Pavement Design Equation (Georgia)

$$\text{Log(ESAL)} = 7.35 * \text{Log}(D+1) - 0.06 - \frac{0.1761}{1 + \frac{1.624 * 10^{7}}{(D+1)^{8.46}}}$$

$$+ (4.22 - 0.32p_t) * \text{Log}\left[\frac{f'_c}{(215.63 * J)} \frac{\left[D^{0.75} - 1.132\right]}{\left[D^{0.75} - \frac{18.42}{(E_c / k)^{0.25}}\right]} \right]$$

Preset at 3.42

(690)preset

1993 AASHTO Additional Design Inputs

- Drainage Factor
- Reliability Factor
- Overall Deviation
- Edge Support

1993 Rigid Pavement Design Equation

$$\text{Log(ESALs)} = Z_R * s_o + 7.35 * \text{Log}(D+1) - 0.06 + \frac{\text{Log}\left[\frac{\Delta PSI}{4.5 - 1.5}\right]}{1 + \frac{1.624 * 10^7}{(D+1)^{8.46}}}$$

$$+ (4.22 - 0.32 p_t) * \text{Log}\left[\frac{S'_c * C_d * \left[D^{0.75} - 1.132\right]}{215.63 * J * \left[D^{0.75} - \frac{18.42}{(E_c / k)^{0.25}}\right]}\right]$$

Standard Normal Deviate (Z_R)

Overall Standard Deviation (s_o)

Depth (D)

Change in Serviceability (ΔPSI)

Terminal Serviceability (p_t)

Modulus of Rupture (S'_c)

Drainage Coefficient (C_d)

Load Transfer (J)

Modulus of Elasticity (E_c)

Modulus of Subgrade Reaction (k)

DESIGN FEATURES OF CONCRETE PAVEMENTS (Until mid 70's)

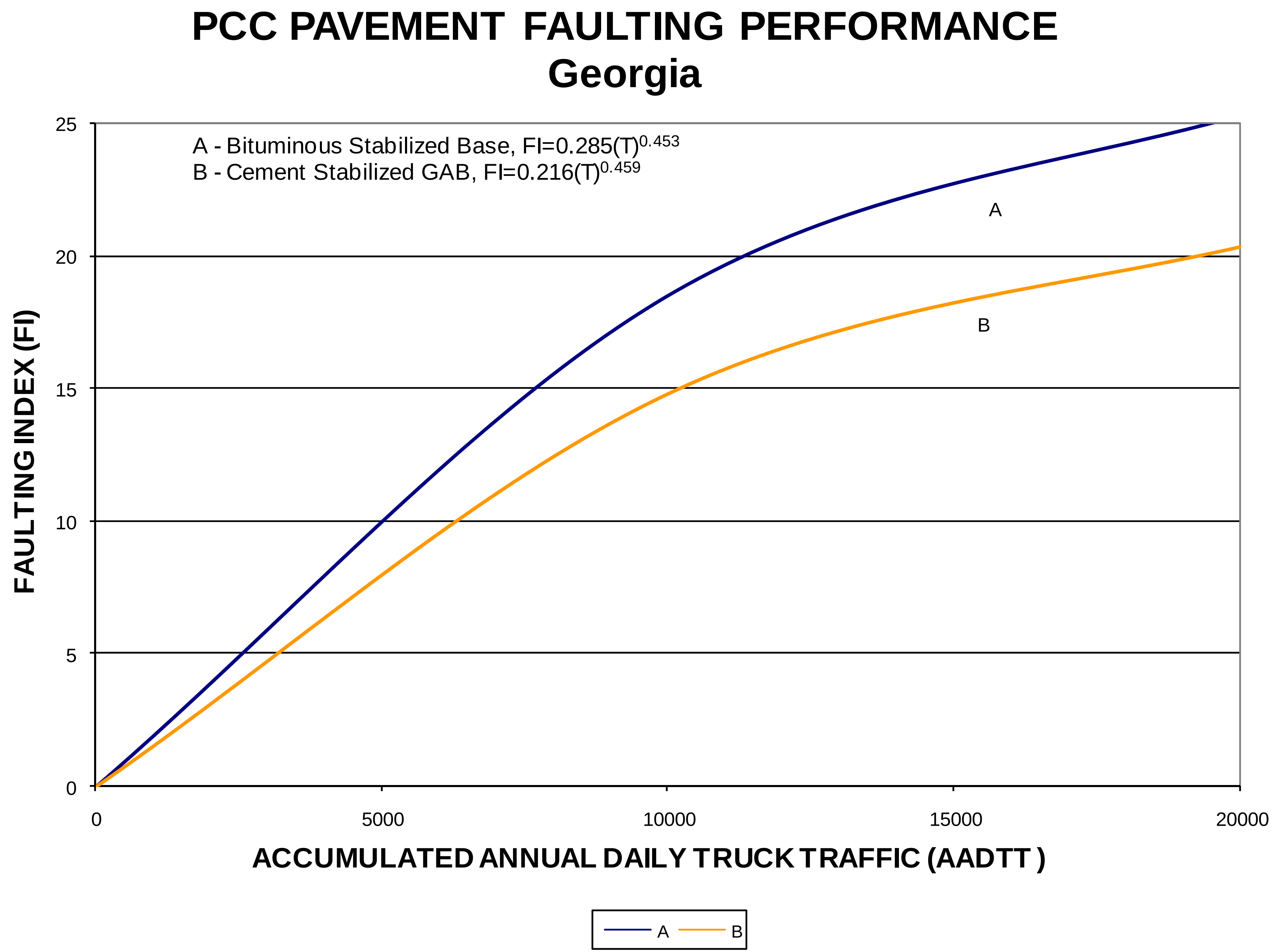
- 9 INCH or 10 INCH THICKNESS
- ERODIBLE BASES
- UNDOWELLED JOINTS
- LONG SLAB LENGHTS (30ft)
- HOT POUR JOINT SEALS
- ASPHALT SHOULDERS

I-475

- OPENED TO TRAFFIC 1966/1967
- 9 INCH THICK PCC
- NO DOWELS, 30 FT JOINT SPACING
- SOIL/ BIT STAB. BASE
- DESIGNED FOR 3.25 MILLION ESAL'S
- CARRIED ±15 MILLION at 1st CPR IN 1980. (± 50 MILLION TOTAL)

I-285
From I-20 to Chamblee-Tucker Road

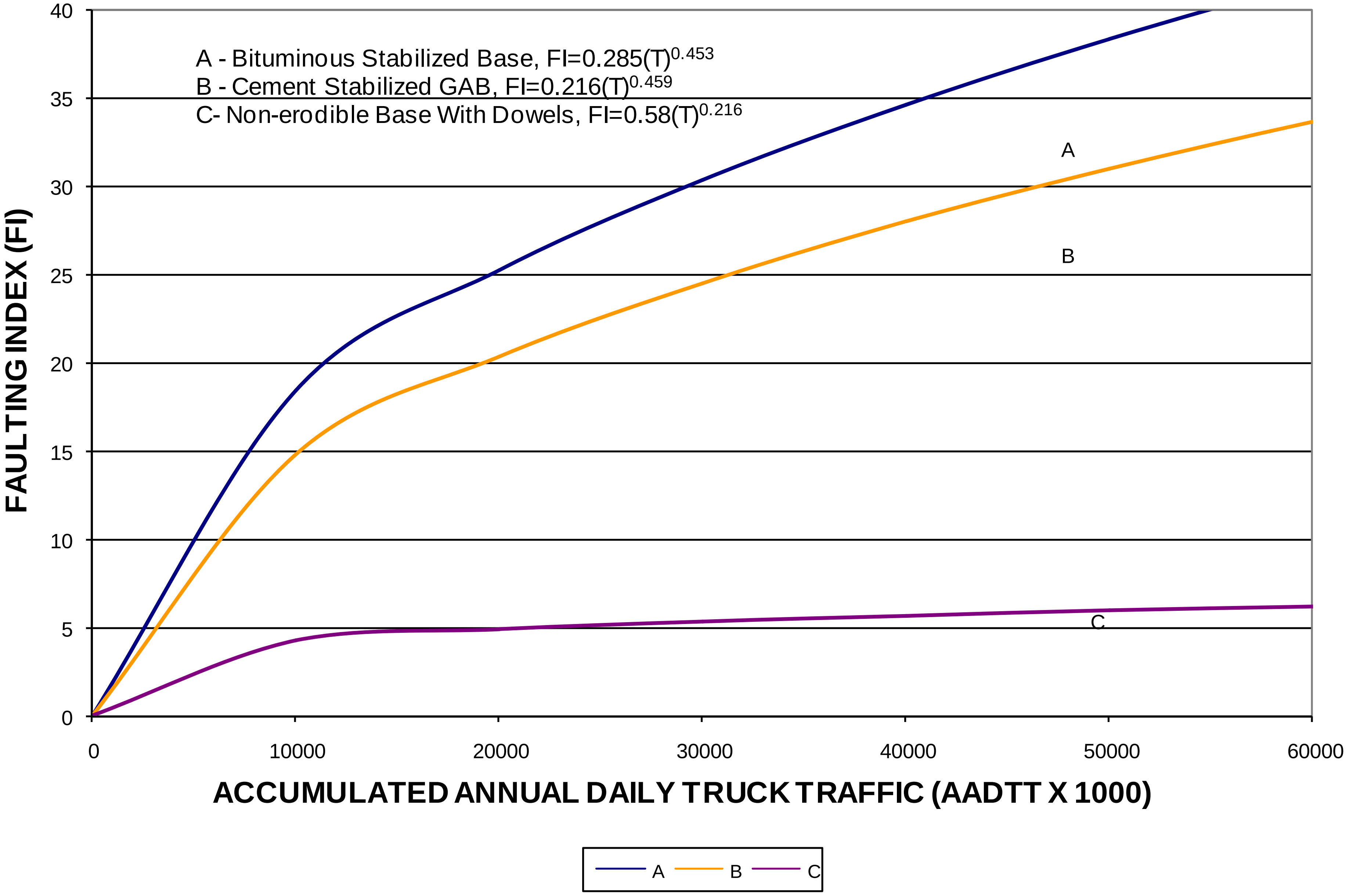
- Opened to Traffic 1967/1968
- 10 inches Thickness
- No dowels. 30 ft joint spacing
- Inside lane added 1981
- Design Loads 6 million ESAL’s
- CPR in 1981 at 23 million ESAL,s
- Current est. ESAL’s 140 million


PCC PAVEMENT FAULTING PERFORMANCE
Georgia
A - Bituminous Stabilized Base, FI=0.285(T)^0.453
B - Cement Stabilized GAB, FI=0.216(T)^0.459
A
B
FAULTING INDEX (FI)
25
20
15
10
5
0
0
5000
10000
15000
20000
ACCUMULATED ANNUAL DAILY TRUCK TRAFFIC (AADTT)
A
B

CONCRETE PAVEMENT DESIGNS
(SINCE MID 70'S)

- NON-ERODIBLE BASE
- DOWELLED JOINTS
- SHORTER JOINT SPACING
- TIED CONCRETE SHOULDERS or WIDENED LANE
- EFFECTIVE JOINT SEALS

PCC PAVEMENT FAULTING PERFORMANCE
Georgia



1955

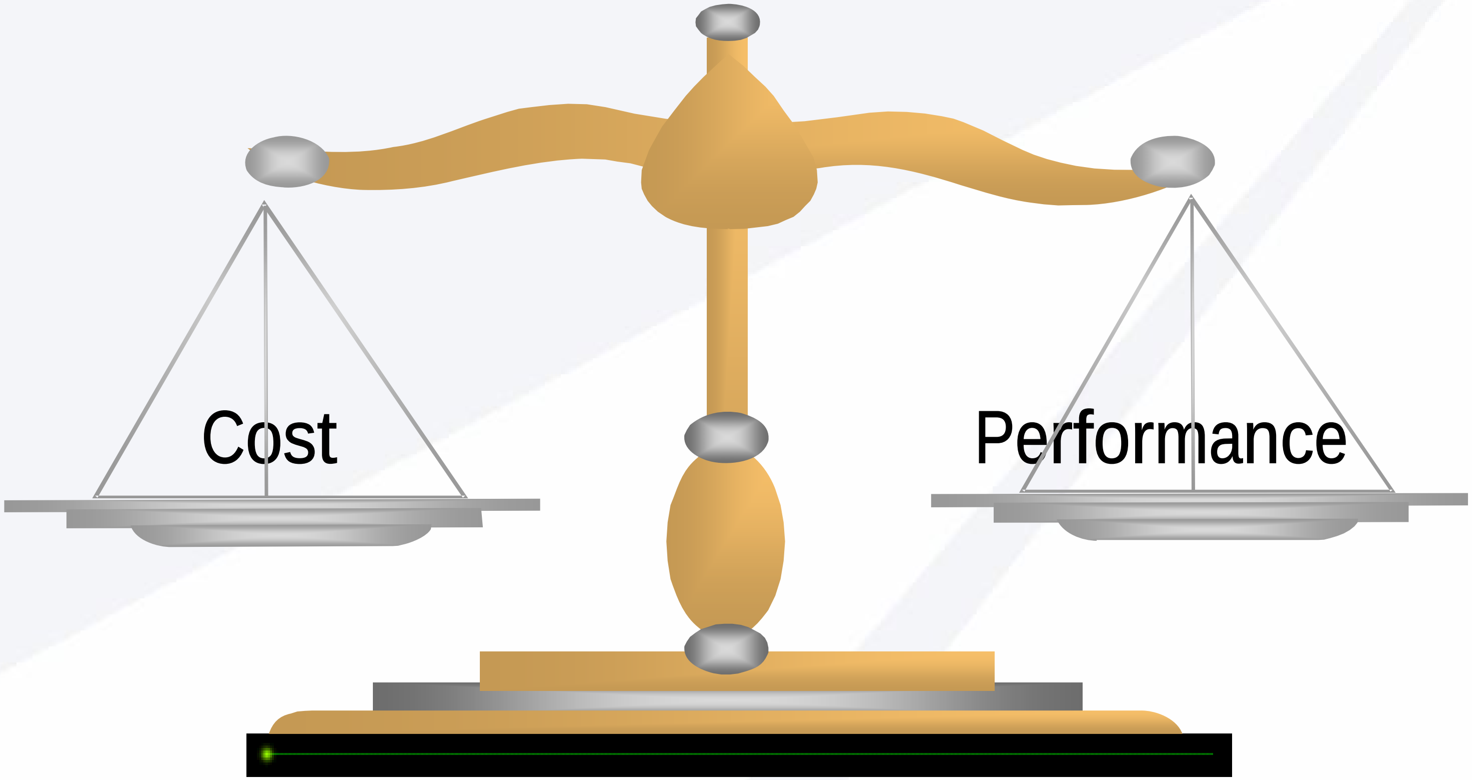
2004

South from 14th Street in 1953

South from 14th Street in 2004

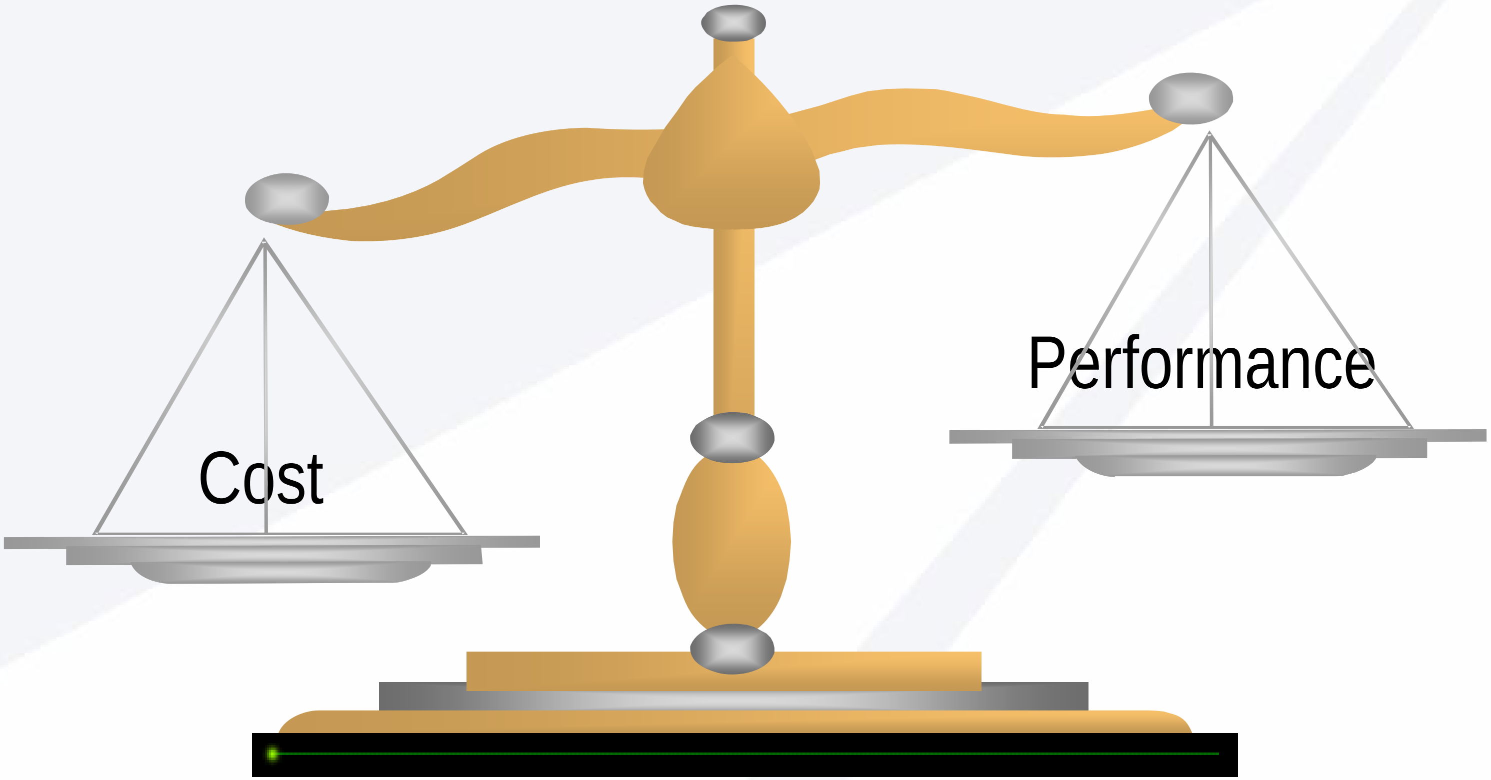

ESCO INC.
ck Leasing & Rental
Chattanooga, TN

Is it about “Cheap”?



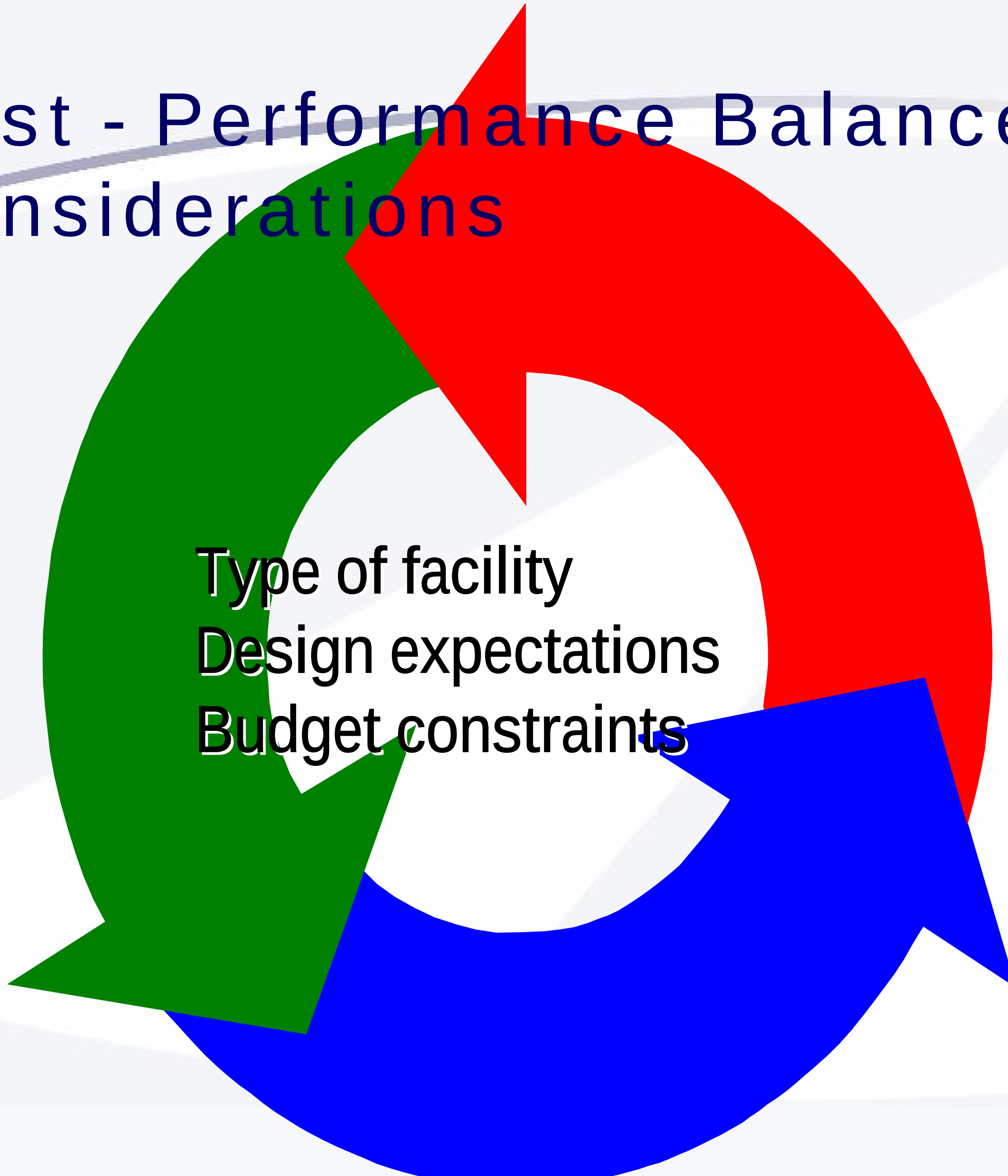
Count on Concrete
PAVEMENT

The question becomes...



What is the optimum design for the expected performance?

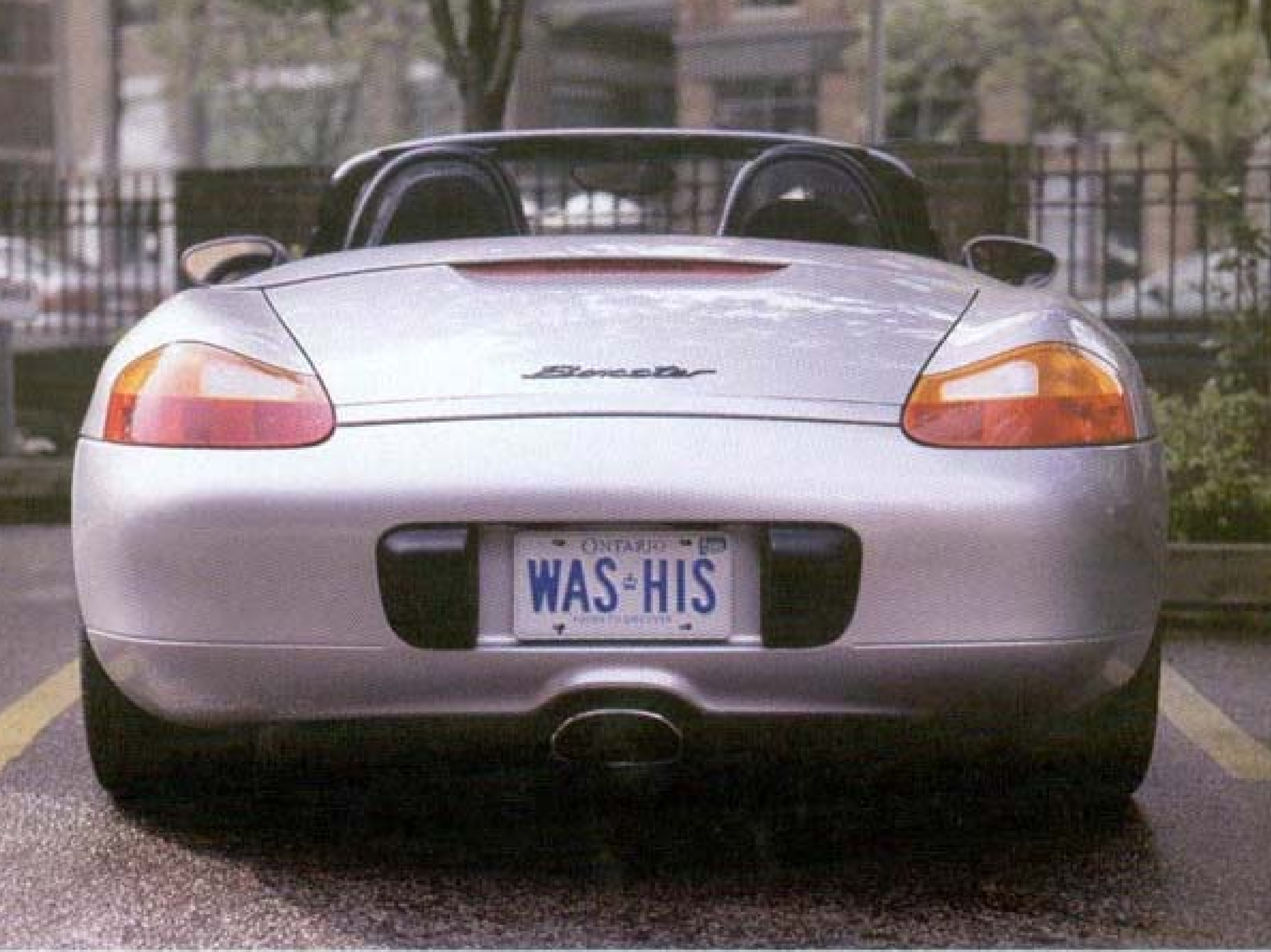
Cost - Performance Balance Considerations



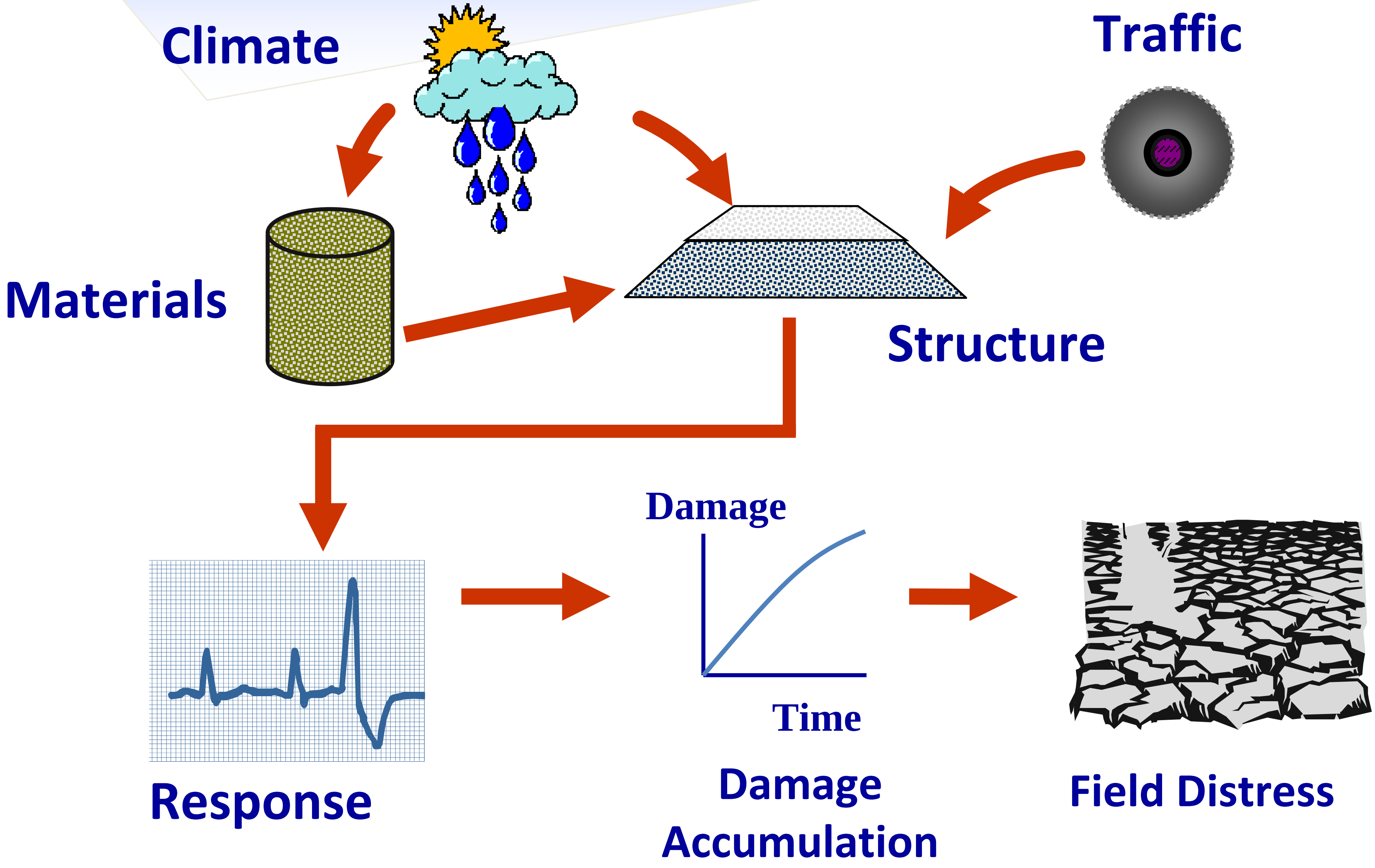
Need for Major Improvement in Pavement Design

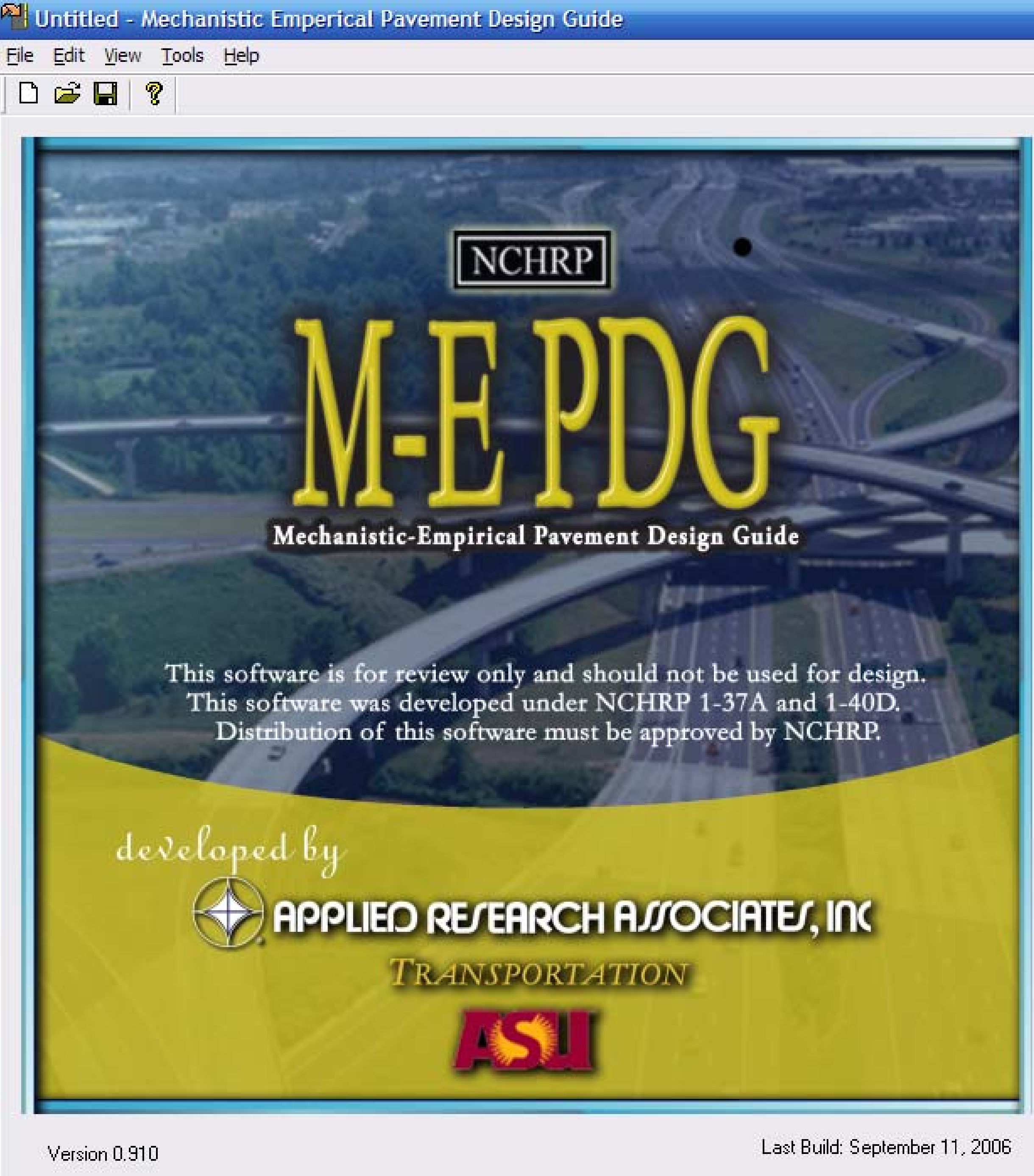
- 1990's — AASHTO Joint Task Force on Pavements realized technology and theory exist to move to mechanistic design
- 1996 NCHRP "Workshop on Improved Pavement Design" that included 70 top pavement engineers concluded this could, and should, be accomplished by 2002

Count on Concrete
PAVEMENT


ONTARIO
WAS HIS

Pavement Design Factors





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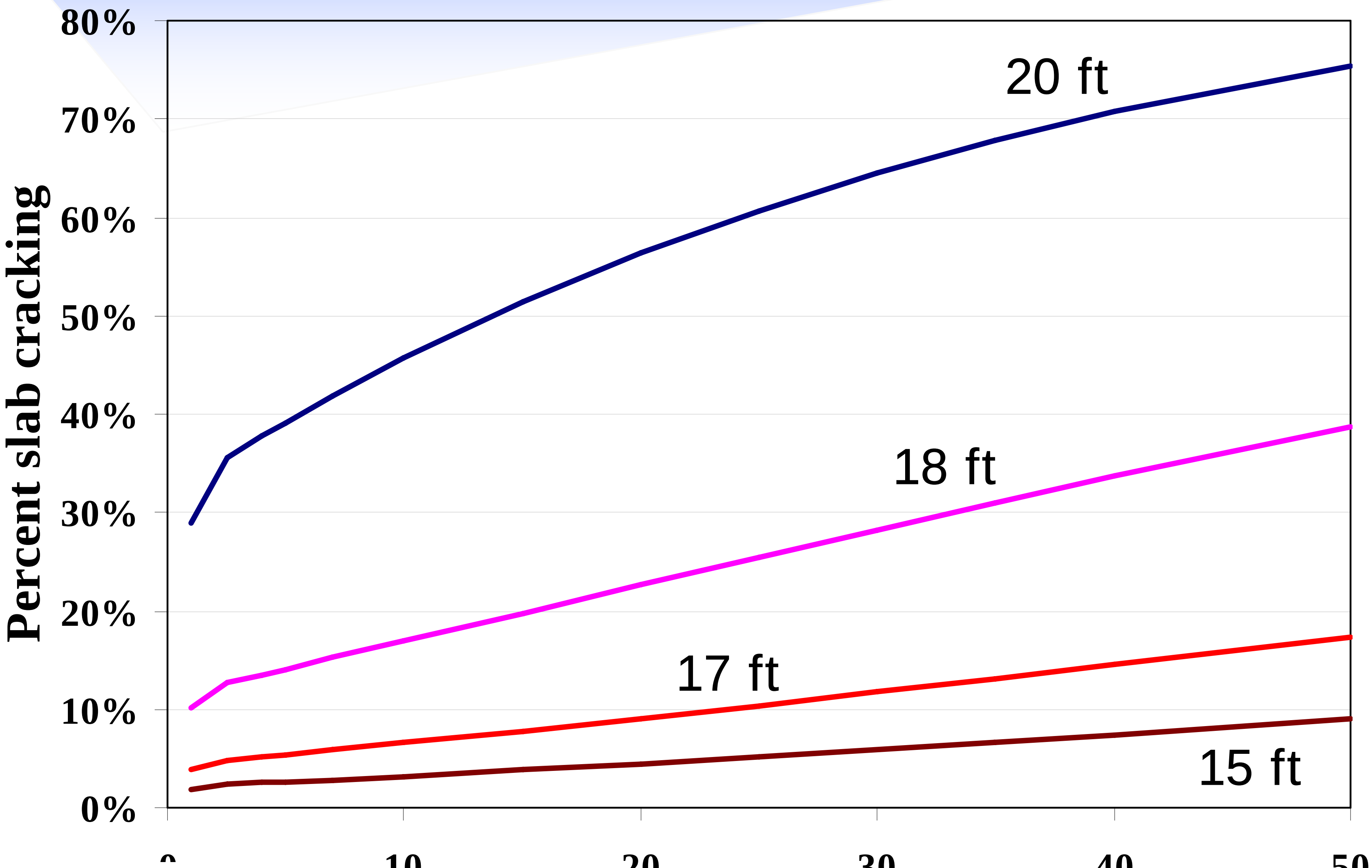
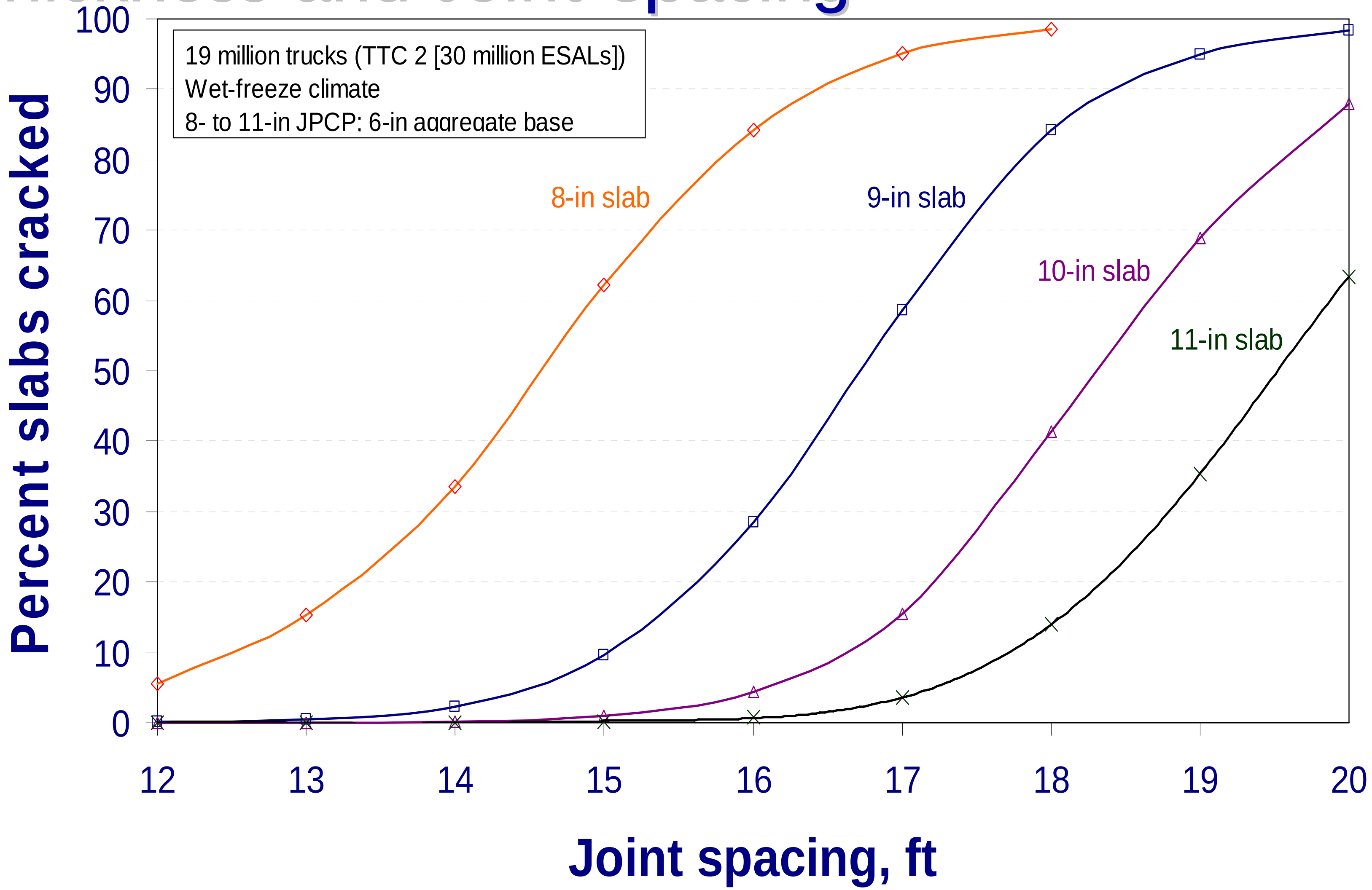
CAUTION
THIS SIGN HAS
SHARP EDGES
DO NOT TOUCH THE EDGES OF THIS SIGN
ALSO, THE BRIDGE IS OUT AHEAD

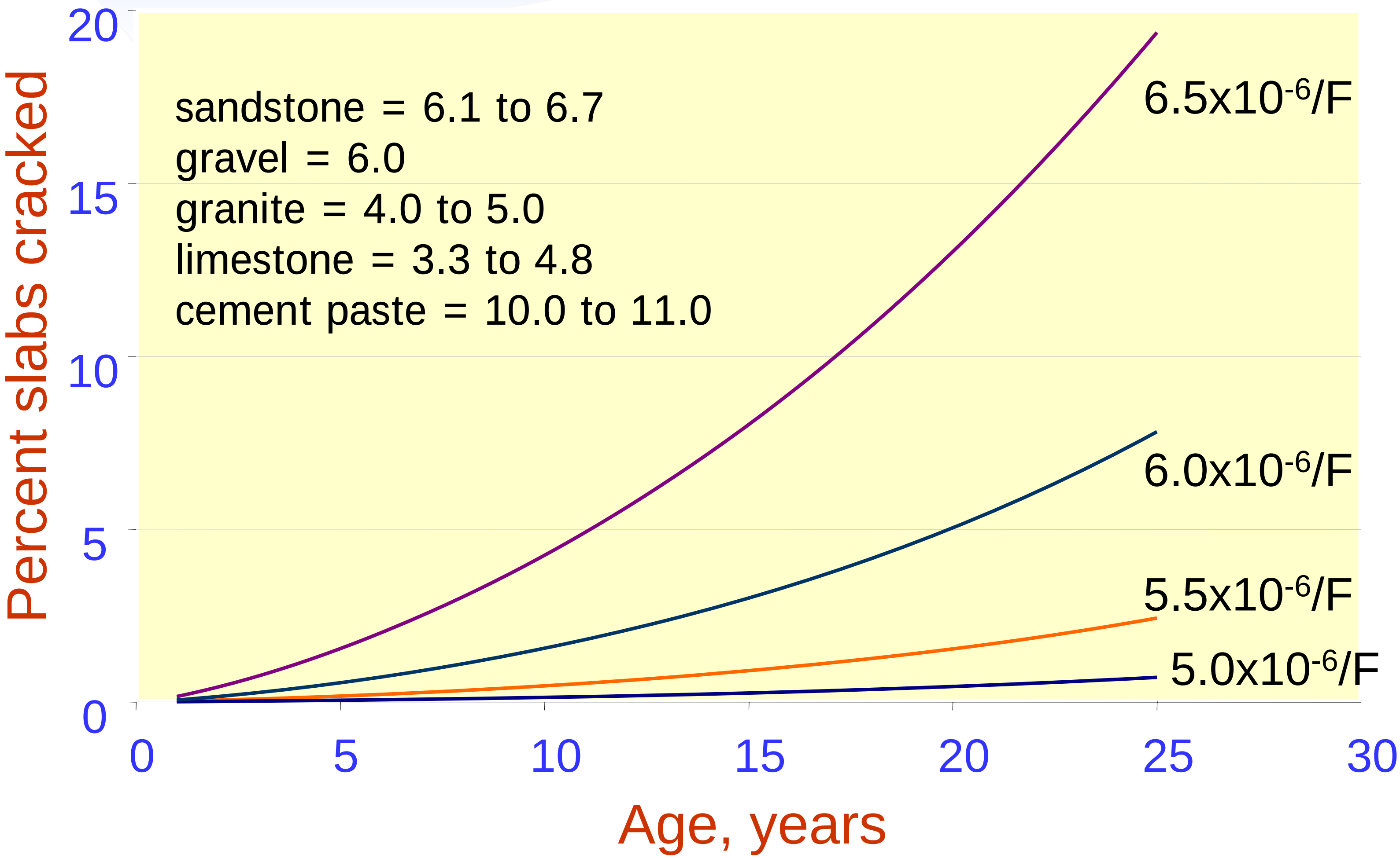
Effect of Joint Spacing



Sensitivity of JPCP Cracking to Slab Thickness and Joint Spacing

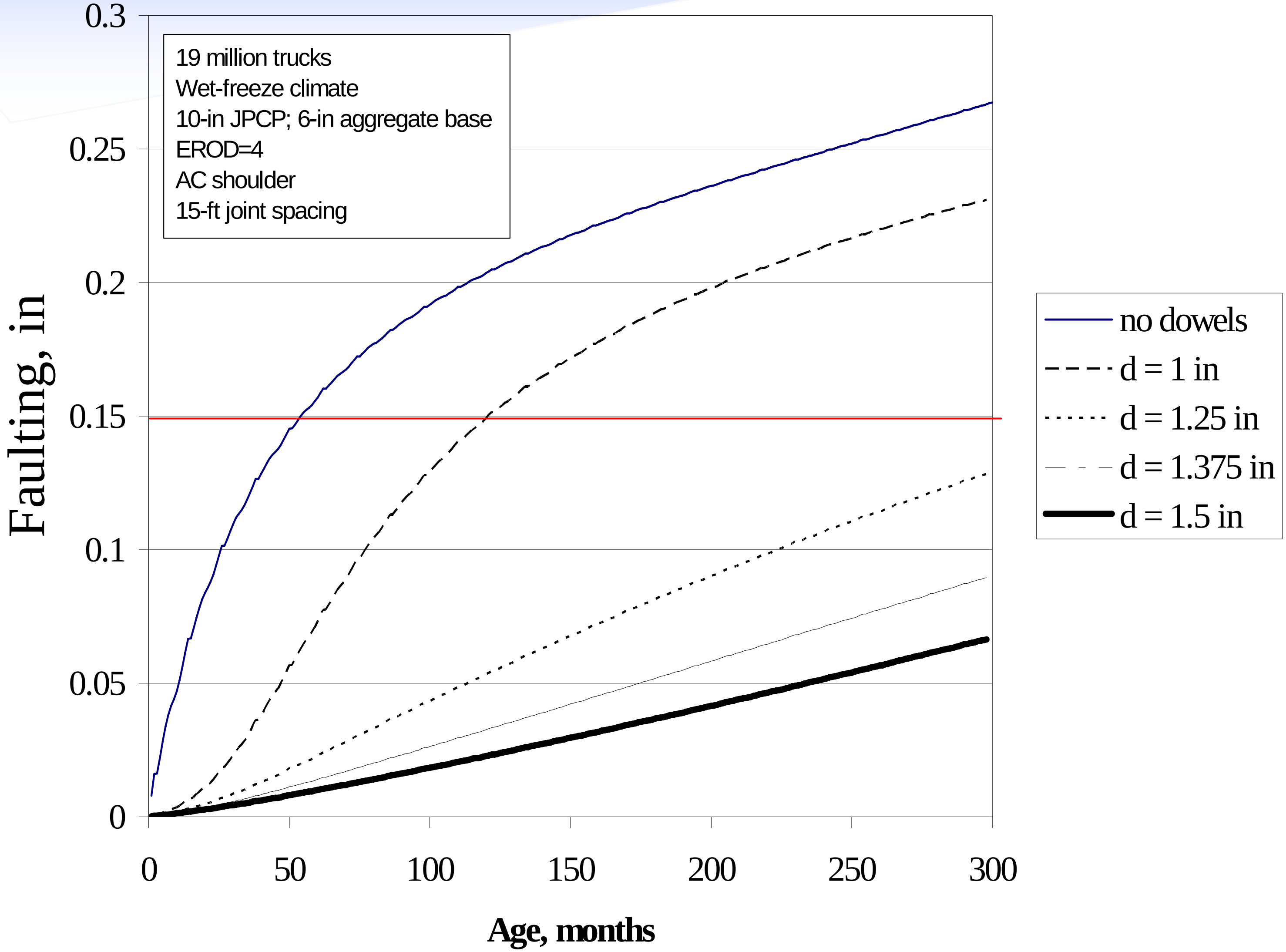


Concrete Coefficient of Thermal Expansion



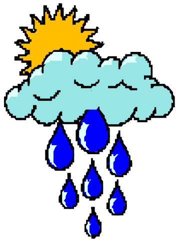
Benefits

Effect of Dowel Diameter on Faulting

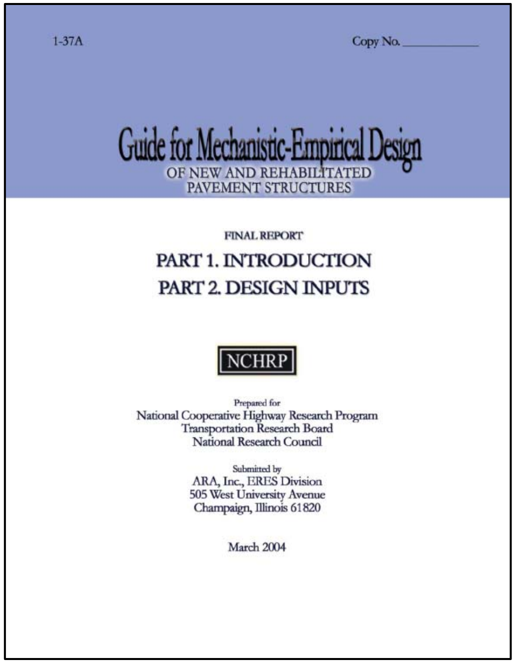


Climate and PCC Design

- MEPDG



Climate Inputs



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Guide for Mechanistic-Empirical Design
OF NEW AND REHABILITATED
PAVEMENT STRUCTURES

FINAL REPORT
PART 1. INTRODUCTION
PART 2. DESIGN INPUTS

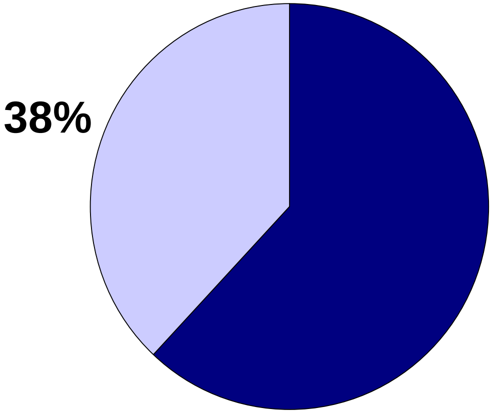
NCHRP

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
National Research Council

Submitted by
ARA, Inc., ERES Division
505 West University Avenue
Champaign, Illinois 61820

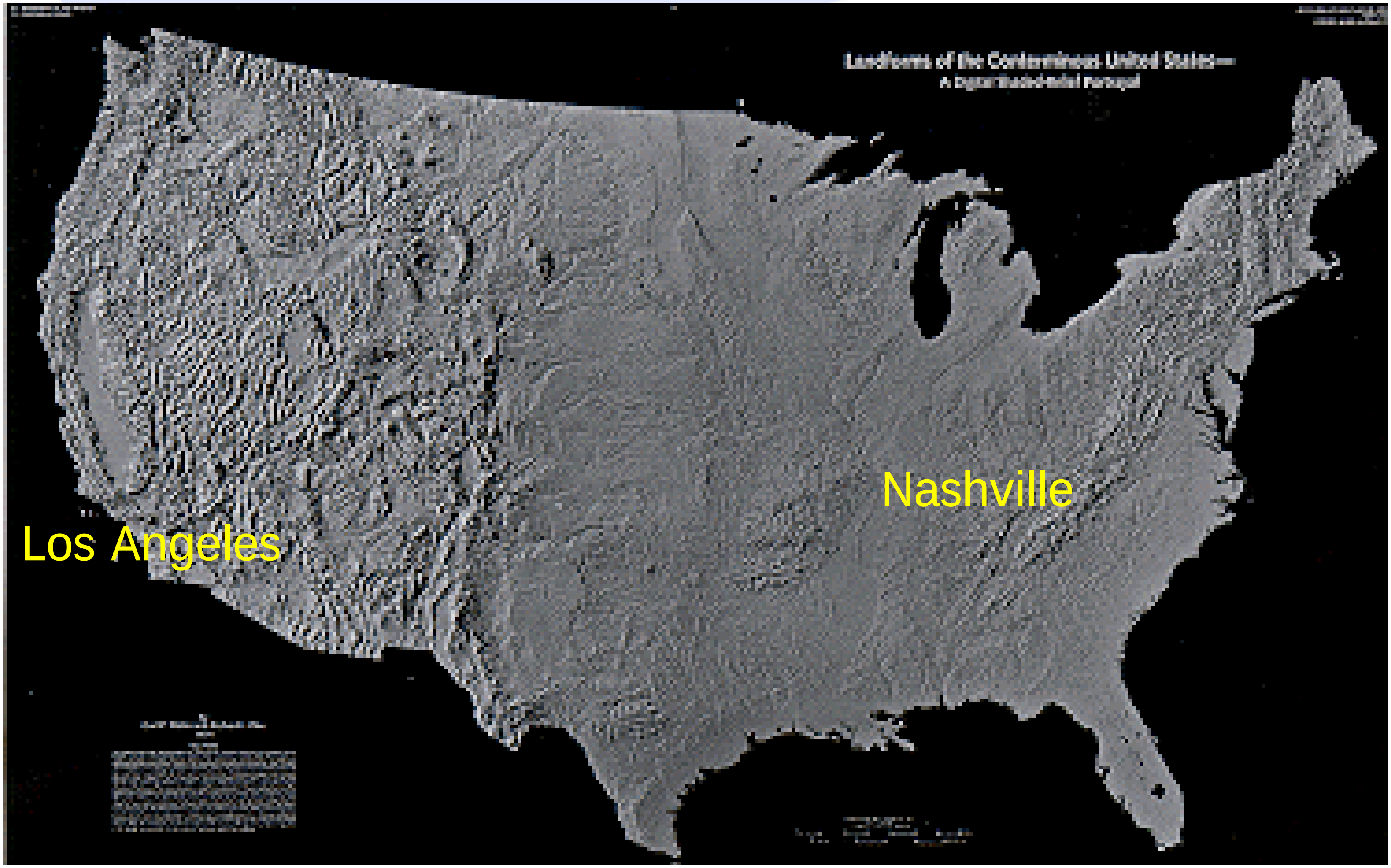
March 2004

1735 Total Pages*

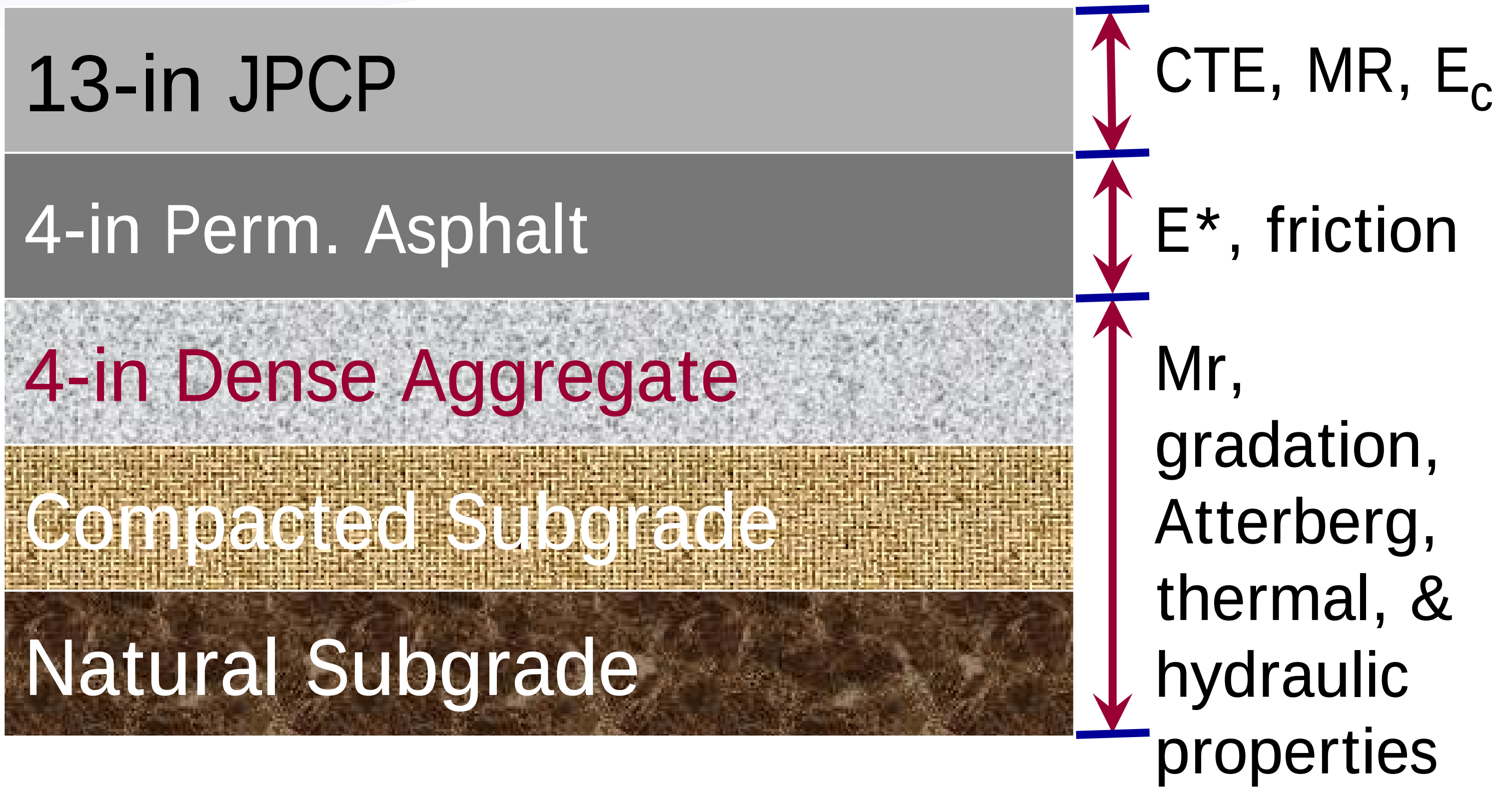


659 pages
Dedicated to Drainage
And Climate Effects

Dry Non-Freeze & Wet Freeze Climates



Project I-65 Nashville, TN



Effect of Climates

Climate Parameter	Nashville, TN	Los Angeles, CA
Mean Annual Rainfall (in)	49.96 in	14.65 in
Mean Annual Freezing Index	141 ^{o}F-days Below 32 F	0 ^{o}F-days below 32 F

Pavement Life for Thickness

Slab Thickness (in)	Location	Age when Joint Faulting >Terminal	Age when Slab Cracking > Terminal	Age when IRI > Terminal
10	Nashville	**26 years**	22 years	**30 years**
	Los Angeles	**> 60 years**	28 years	**60 years**
13	Nashville	42 years	**> 60 years**	**46 years**
	Los Angeles	**> 60 years**	**> 60 years**	**> 60 years**

EXAMPLE PCC PROJECT DESIGN
1981 AASHTO GUIDE (MOD 72 GUIDE)

- 4 lane divided highway
- 20 yr design loadings: 25 million ESAL,s
- Pi = 4.5 Pt=2.5
- Base: 12 inch GAB + 3 inch AC
- K value: 290 psi
- Design Concrete Strength: 600 psi flex
  - (use 450 psi in design equation)
- Design PCC Thickness: 11.7 (use 12 inches)

EXAMPLE PCC PROJECT DESIGN
1993 AASHTO GUIDE

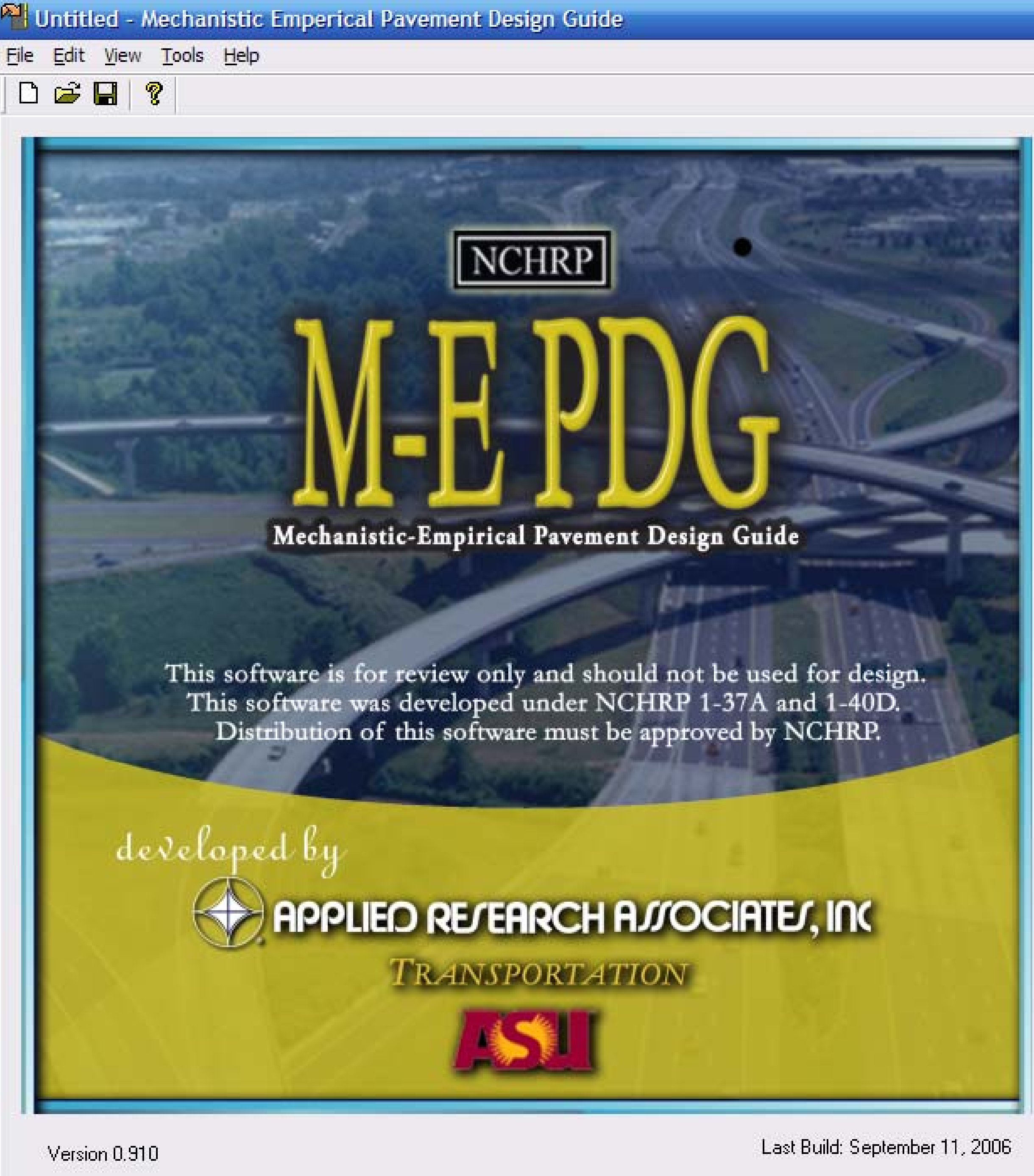
- 4 lane divided highway; non-interstate
- 20 yr design loadings: 25 million ESAL,s
- Pi = 4.5 Pt=2.5
- Base: 8 inch GAB ; K value 190 psi
- Drainage factor: 1.2
- Load Transfer factor: 3.2 (dowels, no edge support)
- Reliability: 90%
- Design Concrete Strength: 600 psi flex
- Design PCC Thickness: 10.8 inches

EXAMPLE PCC PROJECT DESIGN
1993 AASHTO GUIDE

- 4 lane divided highway; non-interstate
- 20 yr design loadings: 25 million ESAL,s
- Pi = 4.5 Pt=2.5
- Base: 8 inch GAB ; K value 190 psi
- Drainage factor: 1.2
- Load Transfer factor: 3.2(dowels, no edge support)
- Reliability: 90%
- Design Concrete Strength: 690 psi flex (field strength)

- Design PCC Thickness: 10.1 inches

WHY NOT USE 9 INCHES



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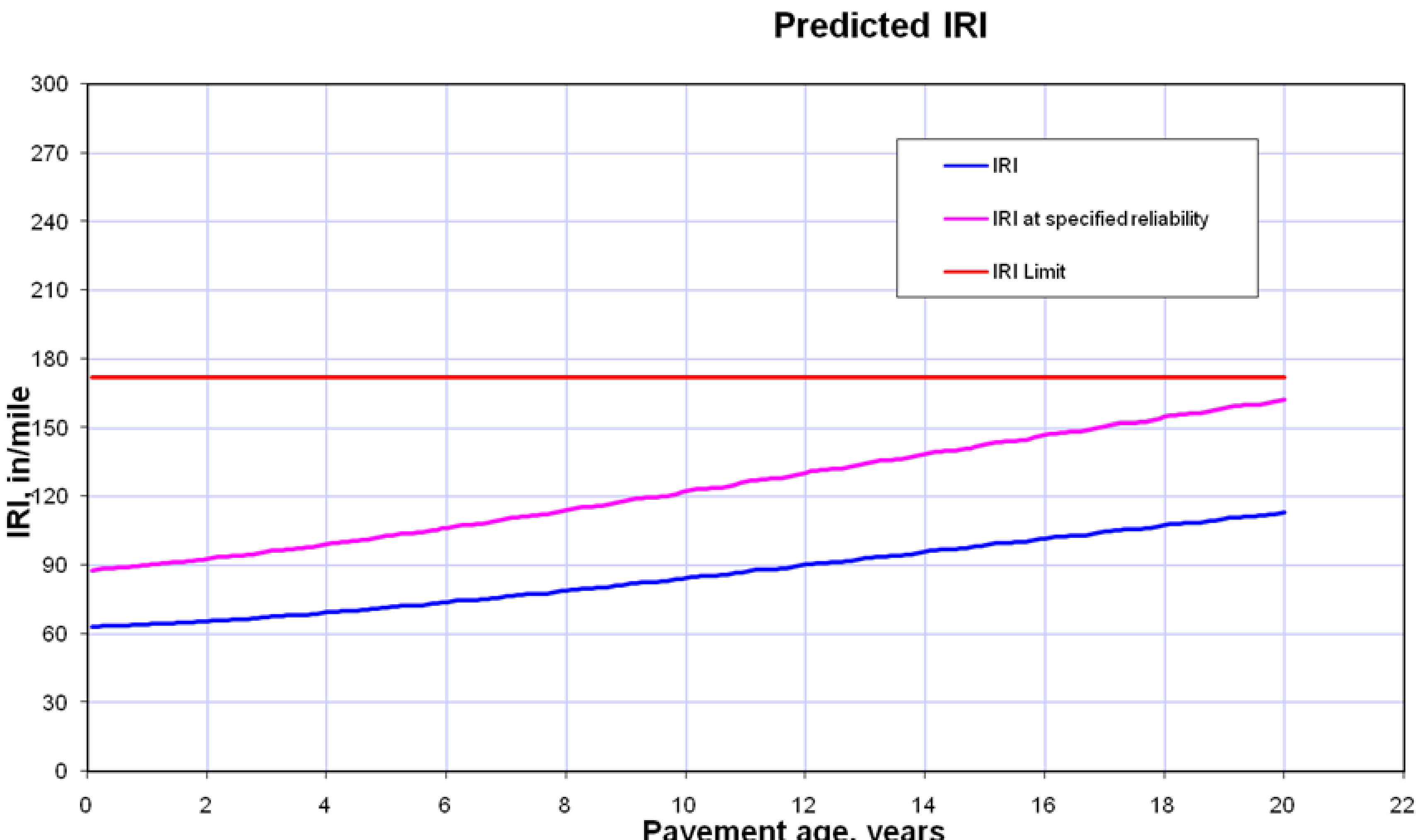
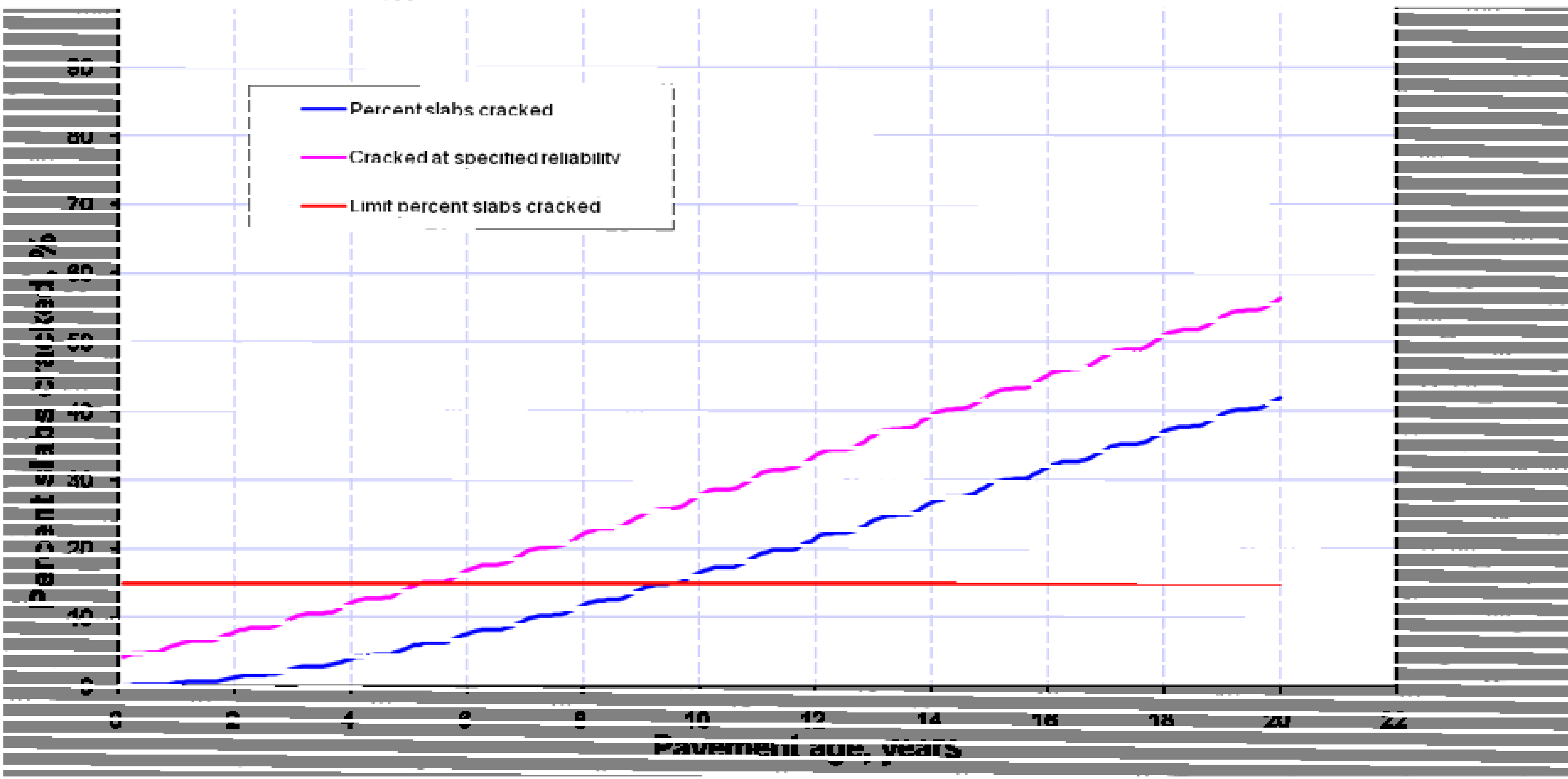
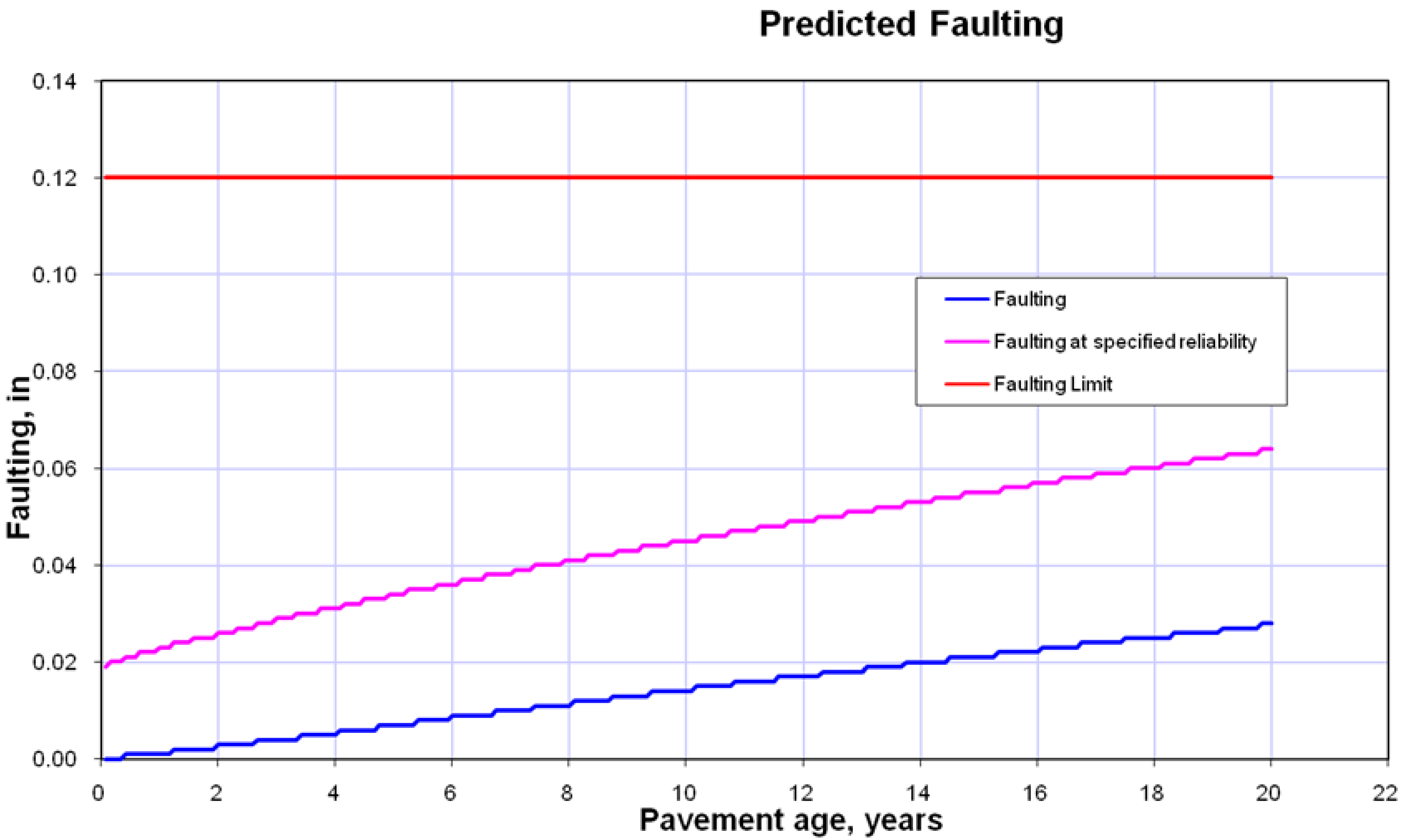
EXAMPLE PROJECT
9 INCH PCC, 8 INCH GAB, 12FT OSL



EXAMPLE PROJECT
9 INCH PCC, 8 INCH GAB, 12FT OSL



EXAMPLE PROJECT
9 INCH PCC, 8 INCH GAB, 12FT OSL

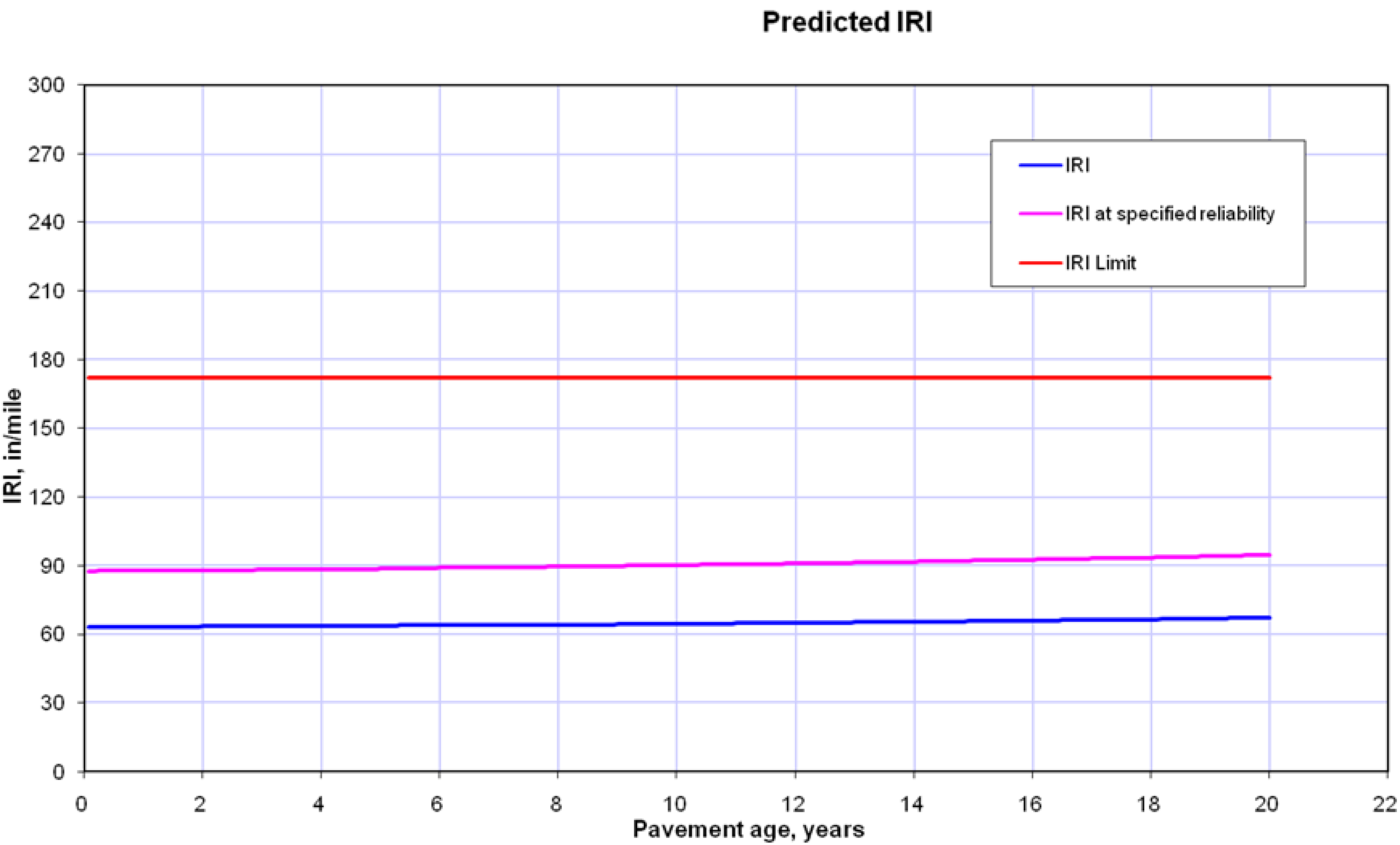


EXAMPLE PCC PROJECT DESIGN
1993 AASHTO GUIDE

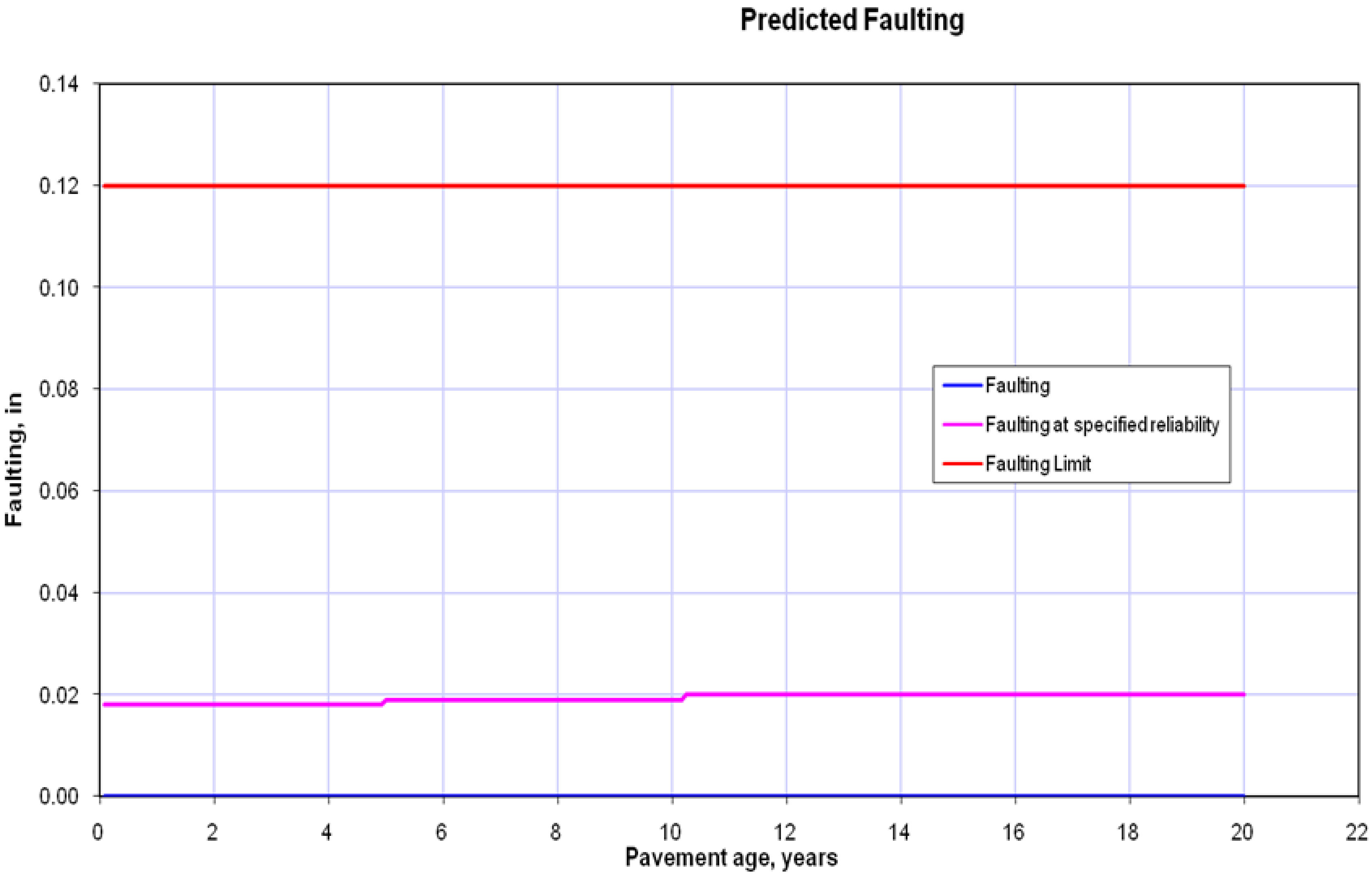
- 4 lane divided highway; non-interstate
- 20 yr design loadings: 25 million ESAL,s
- Pi = 4.5 Pt=2.5
- Base: 8 inch GAB ; K value 190 psi
- Drainage factor: 1.2 ;
- Load Transfer factor: 2.7 (dowels, edge support)
- Reliability: 90%
- Design Concrete Strength: 690 psi flex (field strength)

- Design PCC Thickness: 9.2 inches (use 9 inches)

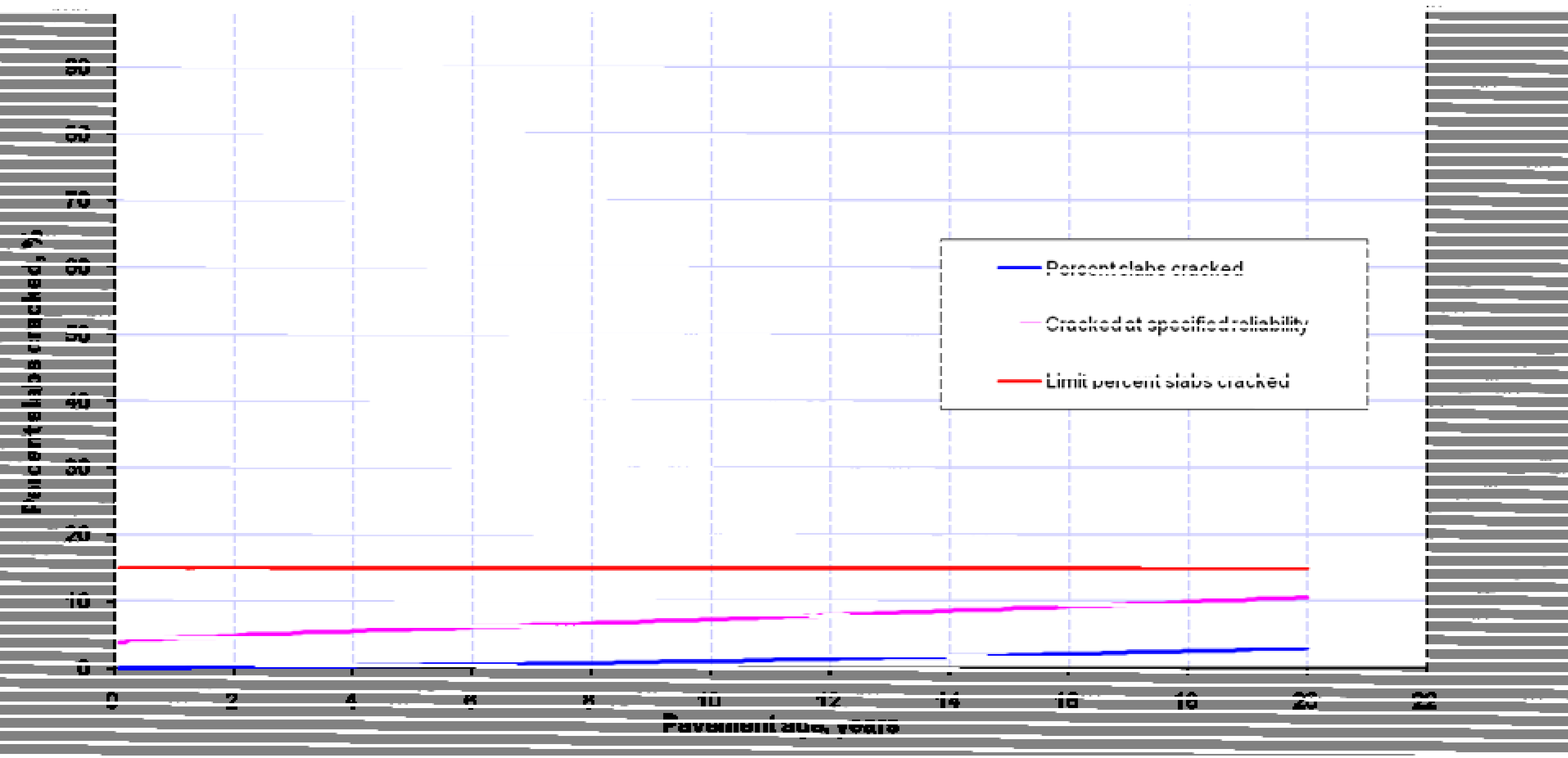
EXAMPLE PROJECT
9 INCH PCC, 8 INCH GAB, 13FT OSL



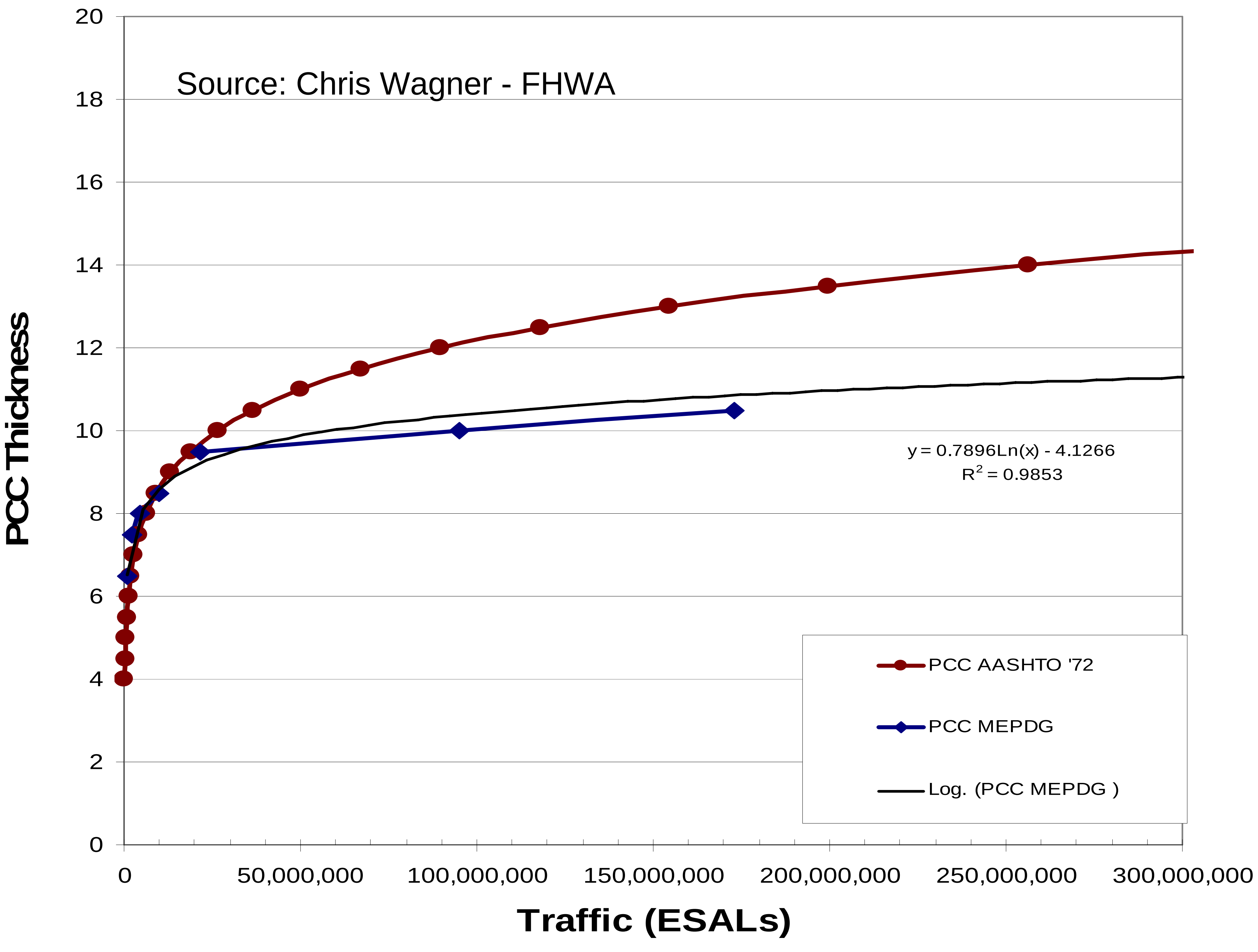
EXAMPLE PROJECT
9 INCH PCC, 8 INCH GAB, 13FT OSL



EXAMPLE PROJECT
9 INCH PCC, 8 INCH GAB, 13FT OSL

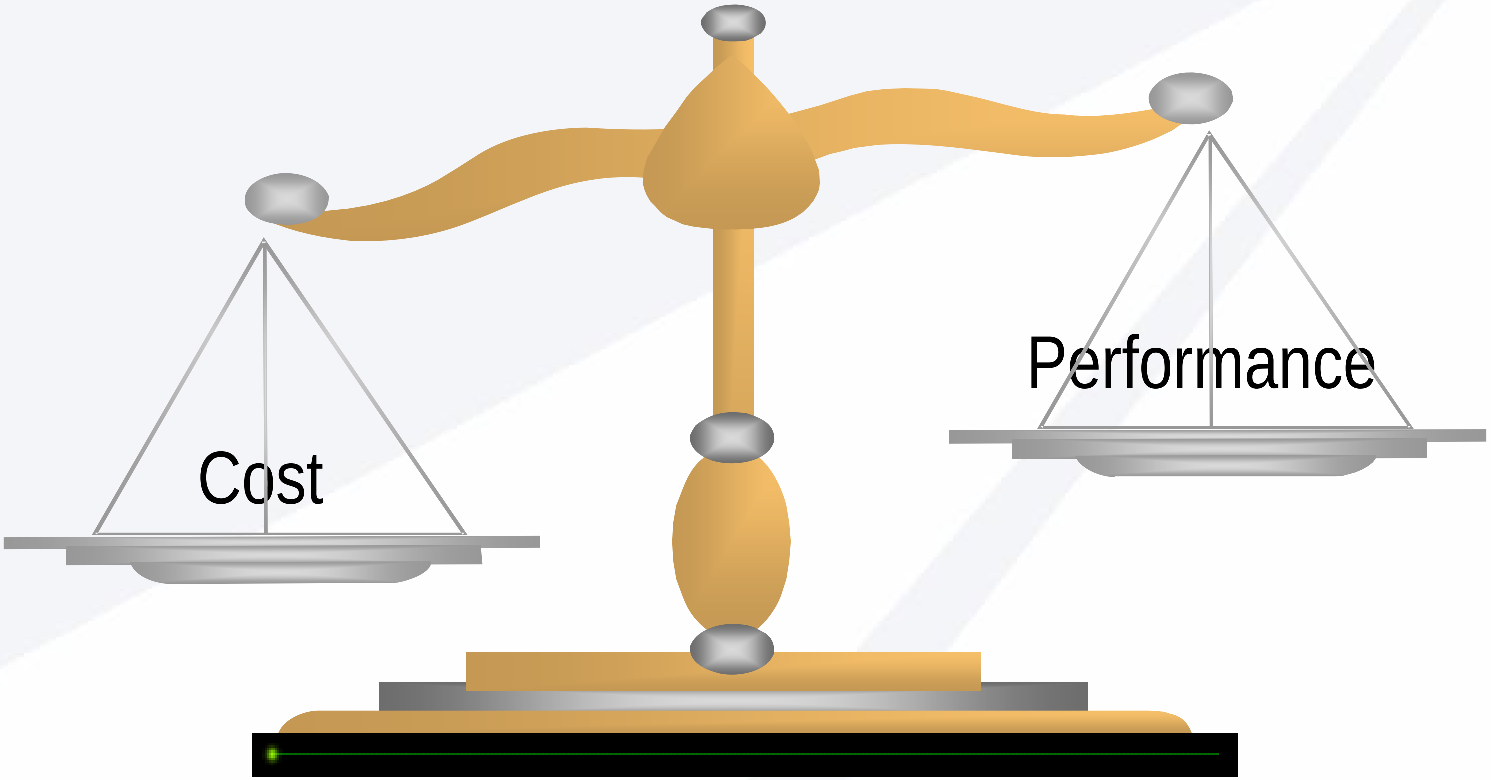


PCC AASHTo '72
PCC MEPDG
Log. (PCC MEPDG)
Source: Chris Wagner - FHWA
y = 0.8166Ln(x) - 4.5483
R2 = 0.9721
AASHTO = MEPDG
Difference in
AASHTO vs. MEPDG
PCC Thickness
Traffic (ESALs)
0
2
4
6
8
10
12
14
16
18
20
100,000
1,000,000
10,000,000
100,000,000
1,000,000,000



Source: Chris Wagner - FHWA
PCC Thickness
Traffic (ESALs)
20
18
16
14
12
10
8
6
4
2
0
50,000,000
100,000,000
150,000,000
200,000,000
250,000,000
300,000,000
y = 0.7896Ln(x) - 4.1266
R2 = 0.9853
PCC AASHTO '72
PCC MEPDG
Log. (PCC MEPDG)

QUESTIONS or COMMENTS



Cost-Effective Concrete Pavement Design
for the Desired Performance

Count on Concrete
PAVEMENT