Chasing the Automobile - History of Pavement Design and Construction

David K. Hein, P.Eng., M.ASCE

ASCE | KNOWLEDGE & LEARNING

ASCE | KNOWLEDGE & LEARNING

David K. Hein, P.E.

- Principal Engineer, Applied Research Associates, Inc.
- Over 35 years of experience in the design, evaluation and management of pavements
- Responsible for transportation asset management practice
- Extensively involved with ASCE
  - T&DI Board of Governors, President, 2018
  - Chair of the:
    - Interlocking Concrete Pavement Committee
    - Permeable Pavement Committee
    - Large Element Paving Slab Standards Committee (new)
    - Engineering Standards for the Smart City Committee (new)
  - Teaching and training through pavement related webinars

Webinar Outcomes

- Understand the history and evolution of pavement design
- Recognize key pavement design inputs and their impact on performance
- Understand the importance of pavement layer materials/properties
- Learn what to look for during construction to ensure high quality
- Understand the elements that may impact the long-term performance

History of Pavements

- Oldest stone paved streets in the City of Ur dating back to 4000 BC
- Oldest paved road was built in Egypt between 2600 and 2200 BC (discovered in 1996)
- The Ridgeway ran 140 km across central, southern England and was build around 2500 BC
- Flagstone roads found in Crete from 2000 BC

Historic national roads
This is to promote the maintenance, preservation, use and celebration of roads and streets with historical and cultural value, and to support unique and appealing regional development.

In the Nakadomari district are the Nakadomari remains which include the remains of houses from about 3,500 years ago. At the summit of the Hiyagonzaka stone paved road used as a post road, the view of the west coast is superb. In 1995, the Construction Ministry selected the Nakadomari district as the Kunigami-Toward West Sea Road historic national road, and the footpath near the Onna Museum is maintained by the Okinawa General Bureau with stone paving and rows of pine trees.

ASCE | KNOWLEDGE & LEARNING

“Modern” Road Development

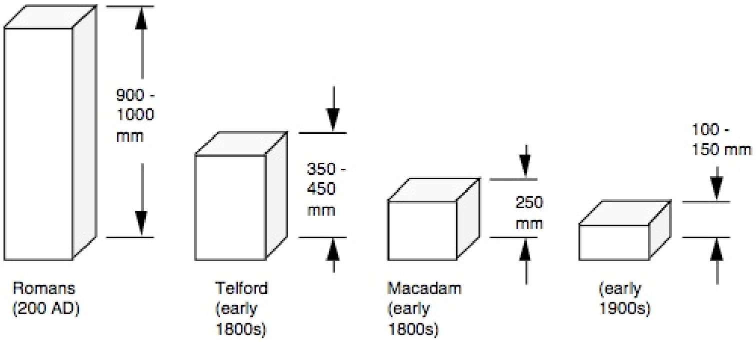
- Romans constructed over 50,000 miles of roads throughout southern Europe and north Africa
- Via Appia was 126 miles in length and constructed in 300 BC

ASCE | KNOWLEDGE & LEARNING

Roman Road Construction

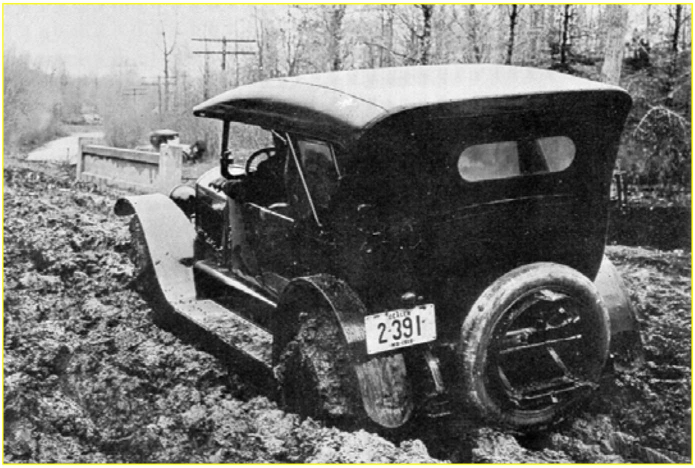
- Typically 3 components to the road
  - Surface (polygon or hexagon slabs 6 inch thickness)
  - Structure (12 to 20 inches of crushed aggregate cemented or bound with chalk)
  - Foundation (typically flints, broken tiles or larger aggregate about 2 to 3 feet in thickness)
- Knife blade used by soldiers used to check if the gap between the stones was too large
- Use of free draining gravel and ditches for drainage

Evolution of Road Structures



Early Roads

- Most roads normally earth or gravel surfaced



Structural Design

- Primary goal is to protect the subgrade from rutting

$$\delta = 6c_u/F$$

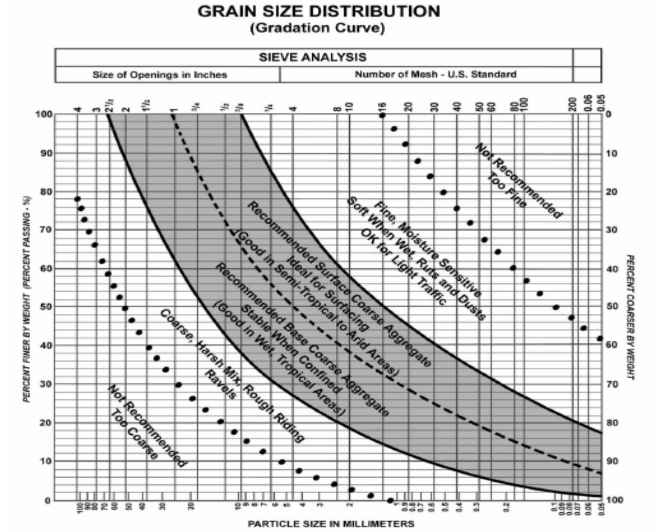
δ = allowable stress (psi)
c_u = undrained shear strength (psi)
F = Factor of safety (1.5)

- Shear strength for clayey type material is in the order of 625 psi for soft soils and 12,500 psi for stiff soils

Key Design Features

- Horizontal and vertical curvature
- Aggregate quality
    - Aggregate size, typically < 3/4 in for surface
- Gradation, keep fines < 10 percent
- Drainage, drainage, drainage

Recommended Aggregate Gradations



Final Gravel Surfaced Pavement

Early Road Surfaces

- Natural Stone

Early Road Surfaces

- Natural Stone

Early Road Surfaces

- Natural Stone

ASCE | KNOWLEDGE & LEARNING

Early Road Surfaces

- Clay brick

Early Road Surfaces

- Many are still around….just covered with asphalt

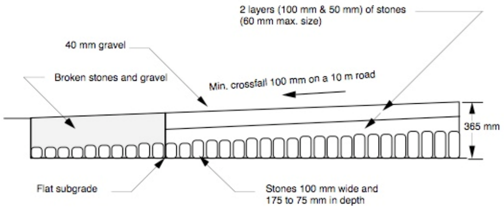
Early Road Surfaces

- Wood blocks

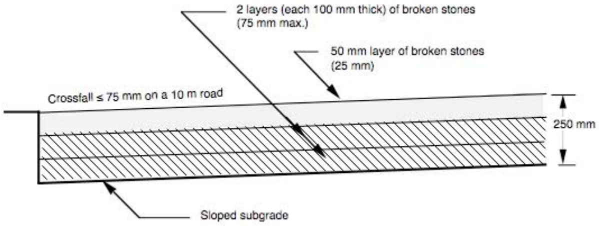
23

24

Evolution of Road Structures



Telford



Macadam

Evolution of Road Structures

Telford

Macadam

Early Pavements

- John Metcalf built 180 miles of roads in Yorkshire, England
  - Good drainage
  - Raised road bed
- Thomas Telford build 900 miles of roads in Scotland between 1803 and 1821
  - Designed for the weight and volume of traffic
- John McAdam
  - Focus on dry subgrade and angular aggregate
  - Used “hot tar” to bind “broken” stones
- Edmond DeSmedt’s laid a sand mix asphalt in Newark, New Jersey in 1852
- Many followed with patents for asphalt pavements/systems

Canadian Roads

- First graded road in Canada
  - Constructed in 1606
  - Samuel de Champlain
  - 16 km (10 mile) military road
  - Port Royal to Digby Cape, Nova Scotia
- Montréal and Québec City – 1734
  - 267 km (265 miles)
  - 4 ½ day trip by carriage

U.S. Roads

- Albany Post Road, New York to Albany – 1642
- Boston Post road, New York to Boston – 1673
- Farm Highway, Connecticut – 1696
- Forbes Road, Pennsylvania – 1769
- National (Cumberland Road), Maryland to Ohio River – 1811-1834
- Numerous trails and traces through the mid to late 1800s, many followed native trails and trade routes

---

Early Canadian Roads

- 1793 Act of Upper Canada Parliament
  - All roads under authority of “Pathmasters”
  - Statutory labour for construction
  - Settlers to maintain road adjacent to their property
  - Or work 3 to 12 days per year on road maintenance
  - Statutory labour commuted to “fine” in lieu
  - Toll roads introduced
- 1804 Appropriation of £1,000 for new road construction
- 1805 – Turnpike Trusts

Early Canadian Roads

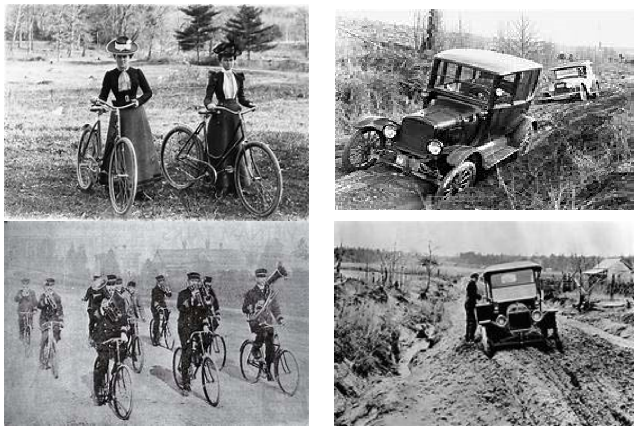
- Mid 1800s
  - Colonization Roads - Ontario, Hastings, Monck, Peterson Roads
  - Built to open wilderness areas to settlement, free grant lots
  - Esquimalt to Victoria, constructed by Royal Navy
  - Cariboo Road (650 km) – British Columbia, result of gold discovery
  - Built in 3 years for $2M, blasted out of mountainsides, gorge crossings on suspension bridges, timber trestles
  - Many built for military uses (Alaska Highway)
  - Resource development

Downfall of the Roads…

- Mid to Late 1800s
  - Completion of trans-continental routes
  - Railroads resulted in a reduction in new road construction
  - Neglect lead to road system deterioration

Resurgence in the early 1900s

- Public interest in bicycle transportation
- Mass production of the automobile



Early Pavements for Airports

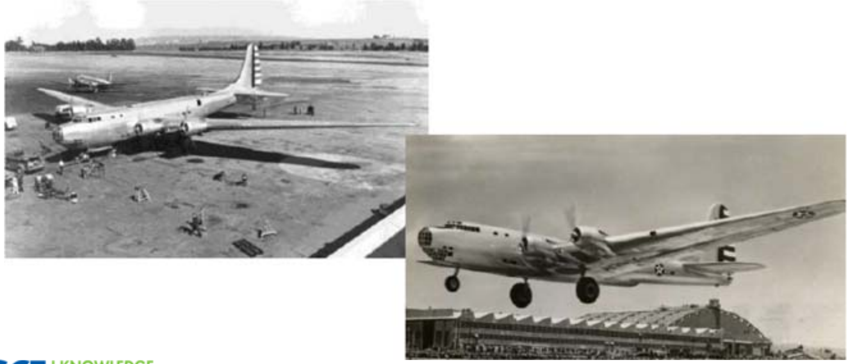
- Need to increase pavement strength is not new
  - Up to the 1930s, aircraft were relatively light and could land on dirt and natural grass runways
  - Aircraft loads in 1930 rarely exceeded 12,500 lbs
  - World War II introduced heavier aircraft
  - New bomber aircraft rapidly increased loads to > 70,000 lbs

Increasing Weight for Military Aircraft

- Larger and heavier aircraft required bound surfaces

Early Airfield Pavement Failures

- Douglas B-19 bomber built in 1941 had a gross weight of 171,000 lbs on only 3 wheels
  - Wheels sunk into the pavement when it was rolled out of the hanger
  - It could land and take off only on thicker concrete runways



Need for More Stable Surfaces

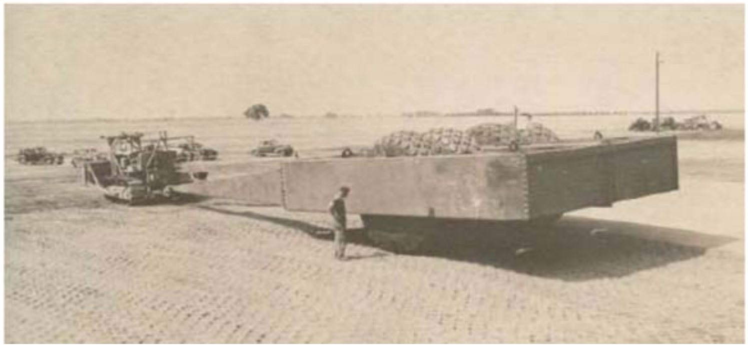
- Significant damage to pavements and aircraft
  - Existing airport pavement design life is 20 years

Emergency Airfield Pavement Advisory Group

- Army Corps of Engineers Airfield Pavement Advisory Group
  - Stockton California Test Track (1944)

Heavy Load Tests to Improved Subgrade/Pavement Compaction

- Evaluated the impact of heavy loads
- Developed a new design procedure based on the California Bearing Ratio

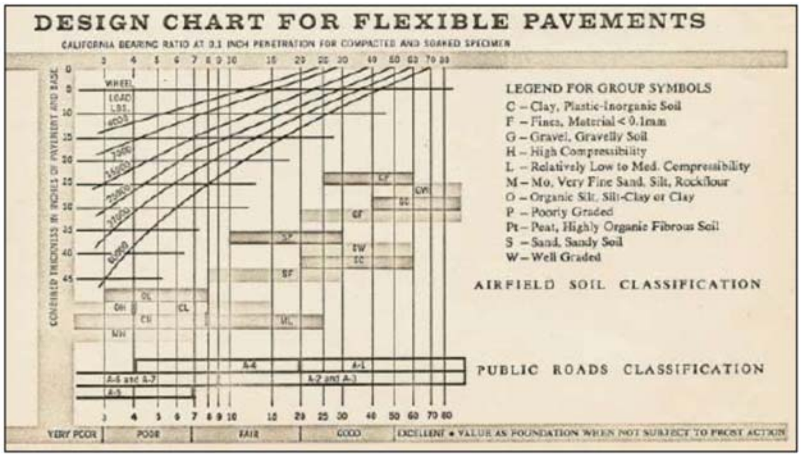


Pioneers of Pavement Design

- Westergaard (stresses due to rolling loads)
- Casagrande (soil mechanics and foundations)
- Terzaghi (“father” of soil mechanics)
- O. James Porter (CBR test procedure)
- Frederick Field (asphalt mix design)
- Ralph Proctor (moisture/density)
- Joseph Boussinesq (mathematician)
- Ludwig Bermester (geometric formulation)
- John Redus (foundations)
- Per Ullidtz (layered elastic theory)

Design Charts for Pavement Design

- New Designs, Reduced Pavement Damage



Pavement Design

- Experience based designs
- Learned from Macadam and Telfford from the U.K.
- Angular aggregate over a well compacted subgrade
- 3 inch sized “subbase” generally 8 to 12 inches
- 1 inch sized “surface” to provide a “smooth” ride
- Move to “sheet” asphalt and “bitulithic” pavements in early 1900

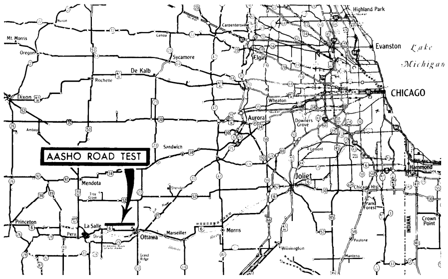
Pavement Design

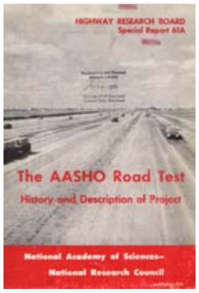
- Portland cement concrete originally used as a “base” and was surfaced with wooden blocks, bricks and cobble stones
- Issues for PCC pavements included:
  - Low compressive strength
  - Poorly prepared subgrade and inspection
  - Inadequate mix design, mixing, consolidation and curing
  - Jointing issues (orientation and spacing)
- Used in 1893 on South Fitzhugh Street in Rochester New York
- Longest lasting is in Bellefontaine in Ohio, 1891
- First used as a wearing surface for the Toronto-Hamilton Highway in Canada completed in 1917

Pavement Road Tests

- Pittsburg, California – 1921
- Bates Road Test, Illinois – 1922
- Road Test One, Maryland – 1950
- AASHTO Road Test, Illinois – 1958
- Brampton Road Test, Ontario – 1960
- Long Term Pavement Program – 1986
- National Center for Asphalt Technology Track – 1986
- Lamont Test Road, Alberta – 1991
- MnRoad Test Track – 1991

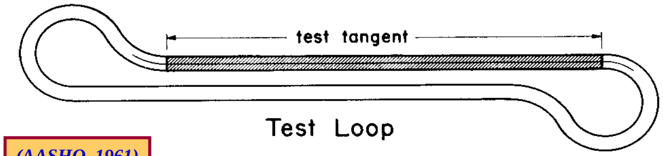
AASHO Road Test – Ottawa Illinois 1961




HIGHWAY RESEARCH BOARD
Special Report 61A

The AASHO Road Test
History and Description of Project

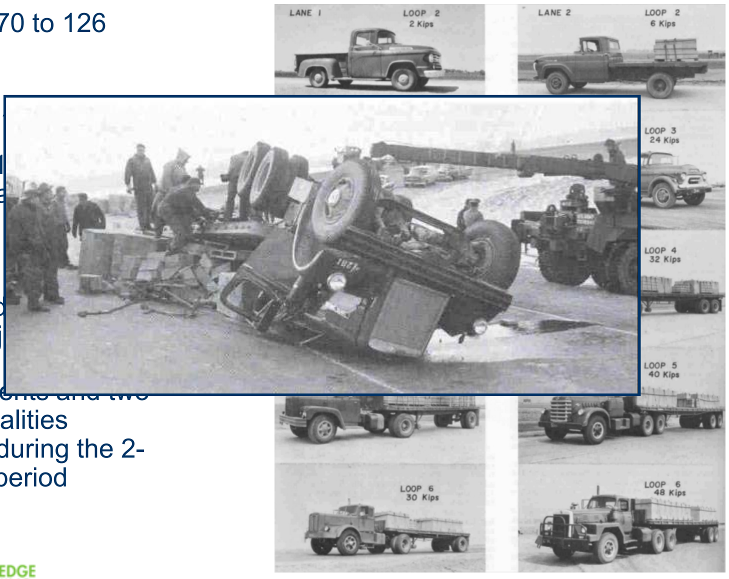
National Academy of Sciences—
National Research Council



(AASHO, 1961)

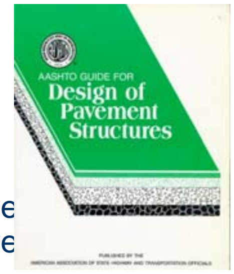
Loading of the AASHO Road Test

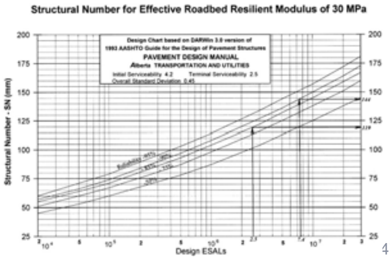
- A fleet of 70 to 126 vehicles
- Driven by
personnel
between 1
hours a da
a week
- 320 Army
were used
of the proj
- 141 accid
driving fatalities occurred during the 2-year test period



History of AASHTO Design Guide

- AASHO Road Test (1958-60)
- 1961 - AASHO Interim Guide
- 1972 - Revised Interim Guide
- 1981 - Revised Interim Guide for PCC
- 1986 - AASHTO Guide for the Design of Pave
- 1993 - AASHTO Guide for the Design of Pave
- 1998 - Supplement to the AASHTO Guide
- 2002 - Mechanistic-Empirical Pavement Design
- 1990s/2000s – Several State and Provincial Adaptations of AASHTO Guide





Evaluation of Road Condition

- Road was evaluated in terms of Pavement Serviceability Rating (PSR)
- Judgement of an observer as to the current ability of a pavement to serve the traffic it is meant to serve

Acceptable?

Yes ☐
No ☐
Undecided ☐

4-5	**Very Good**
3-4	**Good**
2-3	**Fair**
1-2	**Poor**
0-1	**Very Poor**

Section Identification________ Rating_________
Rater_________ Date_________Time_________Vehicle______

Results of the AASHO Road Test

- A better understanding of the difference in damage caused by different types and weights of trucks (ESALs)
- A better understanding of what users consider t be a good performing roadway (PSI)
- Design equations to relate the traffic with the damage seen on the roads

$$\log_{10}(W_{18}) = Z_R * S_0 + 7.35 * \log_{10}(D+1) - 0.06 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.511.5}\right]}{1.0 + \frac{1.624*10^7}{(D+1)^{8.46}}} + (4.22 - 0.32p_t) * \log_{10}\left[\frac{S'_c * C_d\left[D^{0.75} - 1.132\right]}{215.63 * J\left[D^{0.75} - \frac{18.42}{(E_c / k)^{0.25}}\right]}\right]$$

Key Factors – Pavement Foundation

- Soil type and moisture condition
- Measure the strength of support for the pavement

Good Support –

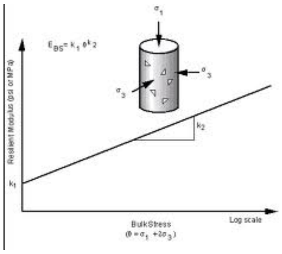
Dry Sandy Soil

Poor Support –

Wet Silty Clay

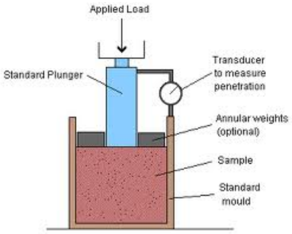
Resilient Modulus

- Used for flexible pavement design
- Soil samples placed in test frame
- Sample loaded and unloaded numerous times
- Measure the amount of deformation of the sample

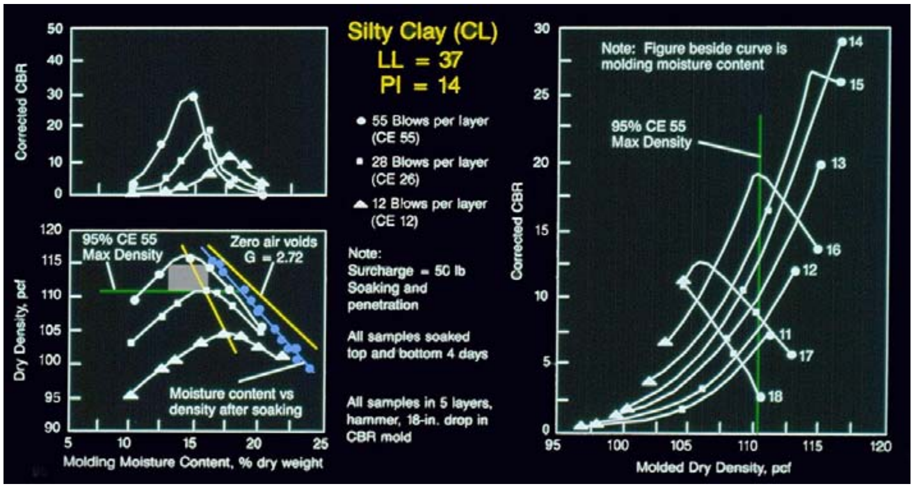


California Bearing Ratio Test

- Soil samples compacted and placed in mould
- Plunger pushed into the soil at a standard rate of time
- Measure of force at 0.1 and 0.2 in deformation
- Ratio to standard penetration for crushed stone
- Typical CBR values = 3 for clay and 15-20 for sand



Selection of Design Strength for Subgrade



Silty Clay (CL)
LL = 37
PI = 14

- ● 55 Blows per layer (CE 55)
- ■ 28 Blows per layer (CE 26)
- ▲ 12 Blows per layer (CE 12)

Note:
Surcharge = 50 lb
Soaking and penetration

All samples soaked top and bottom 4 days

All samples in 5 layers, hammer, 18-in. drop in CBR mold

Note: Figure beside curve is molding moisture content

Pavement Structural Capacity Issue?

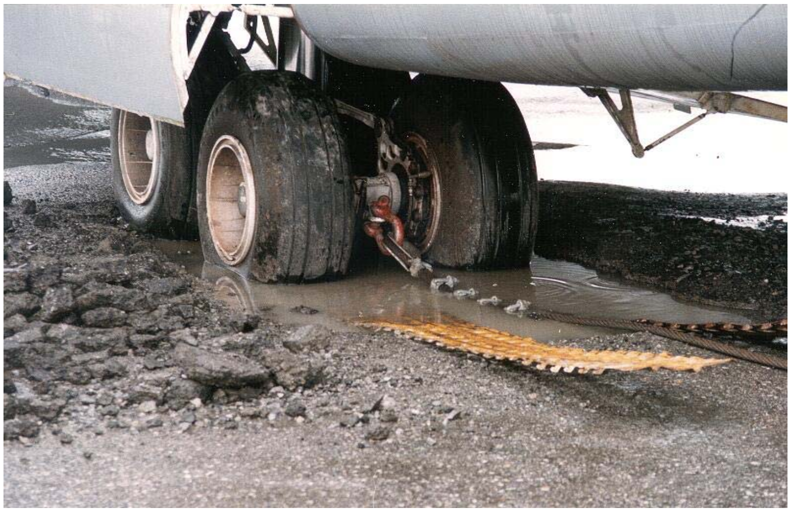
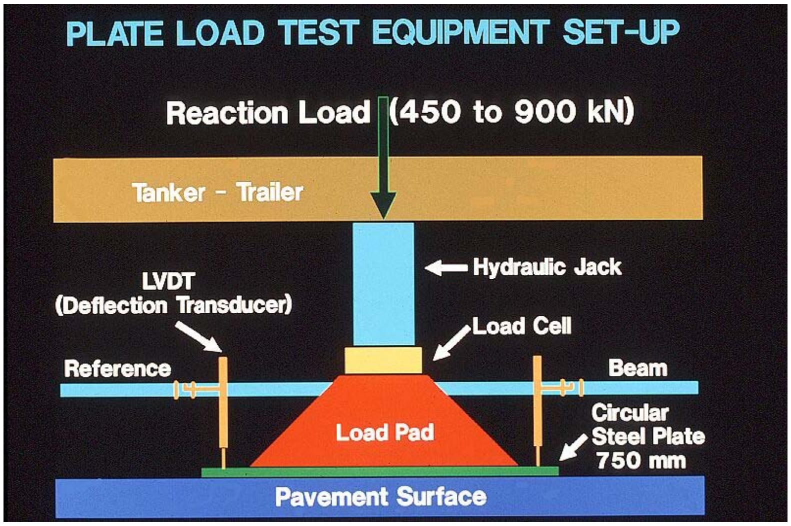


Plate Load Test



Reaction Load

Plate Load Test on Subgrade

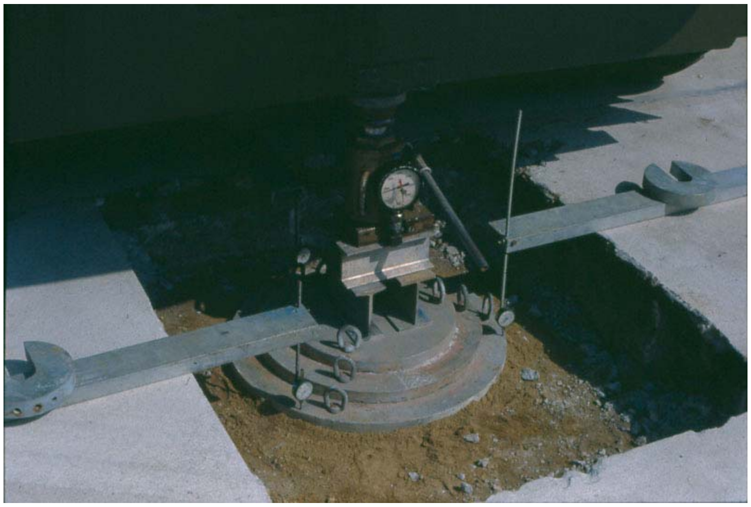
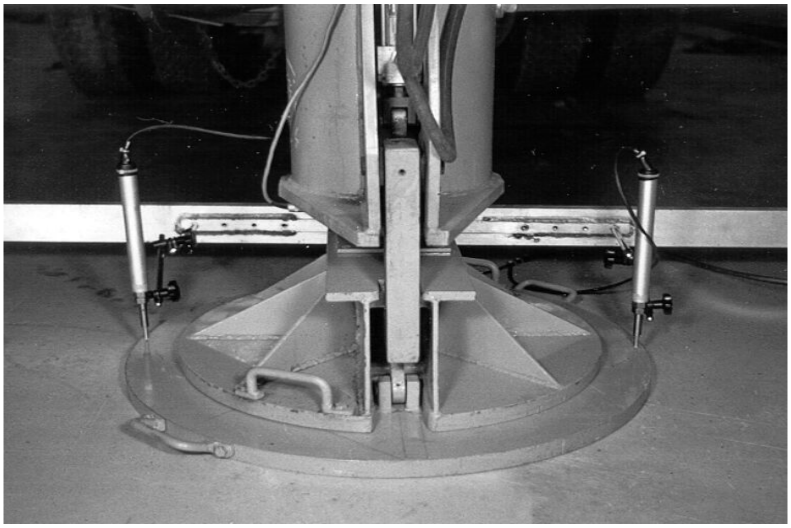
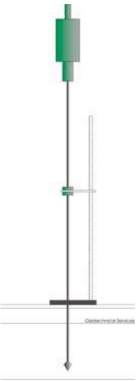


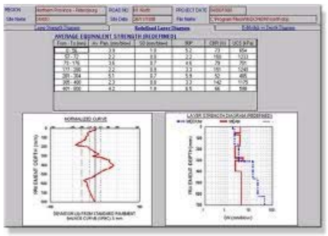
Plate Load Test on Pavement Surface



Dynamic Cone Penetrometer

- Standard rod and cone on end driven into the soil using a standard weight dropped from a set height
- Number of blows per set distance is a measure of soil strength capabilities





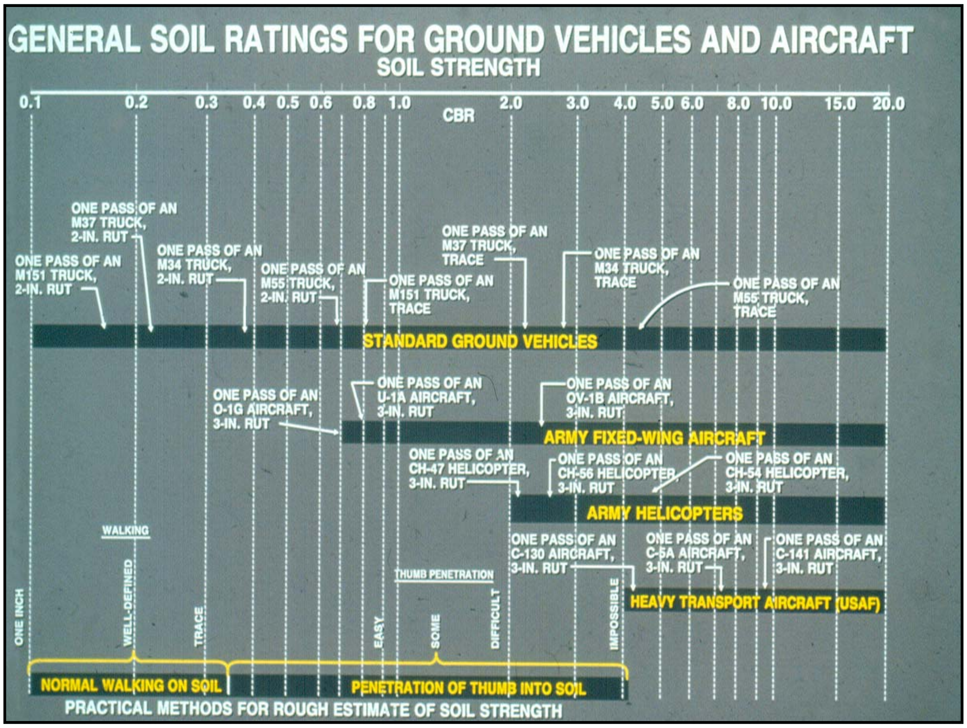
Light Weight Deflectometer

- Weight dropped on loading plate from standard height
- Load cell measures applied load
- Geophones measure the deflection of the pavement surface
- Data used to calculate soil resilient modulus or level of compaction

Falling Weight Deflectometer

- Can be used on individual pavement layers but generally used to back-calculate resilient modulus values and pavement strength for rehabilitation design


2004/ 8/17



Pavement Design Methods

63

Many Pavement Design Methods

64

Design Parameters

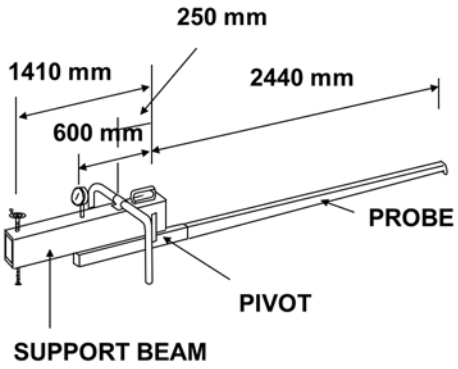
- Traffic
- Subgrade support
- Layer support
- Surface support
- Definition of “failure”
  - Rutting
  - Cracking
  - Smoothness

Catalog Based on Experience

- Protect the subgrade from excessive deformation (rutting)
- Protect the surface from cracking (asphalt or concrete)

			Average Annual Daily Truck Traffic (AADTT) - 25 Year Pavement Design			
			Collector		**Minor Arterial**	
			250	**500**	**1,000**	**1,500**
Subgrade Strength	**30 MPa (CBR=3)**	**PCC**	180 mm PCC 200 mm Granular A	190 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A
		HMA	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 400 mm Granular B	40 mm SP 12.5 FC1 90 mm SP 19 150 mm Granular A 450 mm Granular B	40 mm SP 12.5 FC1 100 mm SP 19 150 mm Granular A 450 mm Granular B
	40 MPa (CBR=4)	**PCC**	180 mm PCC 200 mm Granular A	190 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A
		HMA	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 300 mm Granular B	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 FC1 80 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 FC1 100 mm SP 19 150 mm Granular A 350 mm Granular B

Deflection Based Methods

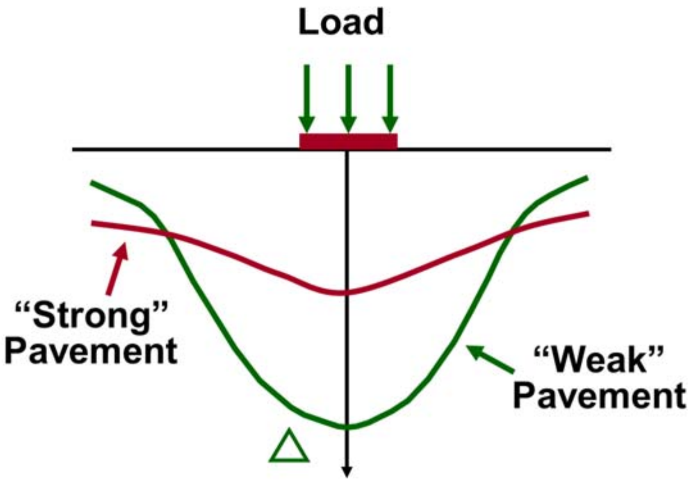


Benkleman Beam

Falling Weight Deflectometer

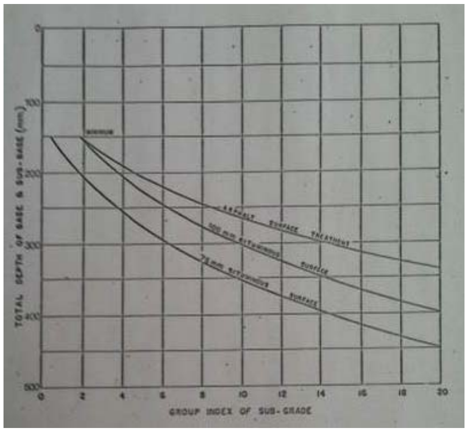
ASCE | KNOWLEDGE & LEARNING

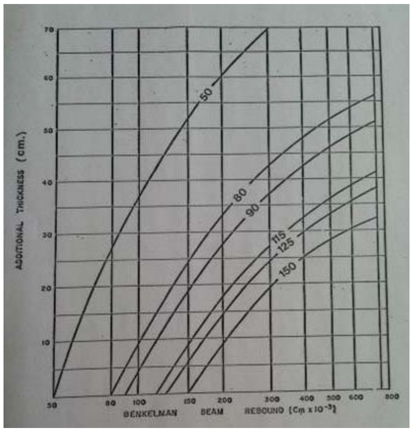
Strong Versus Weak Pavements



ASCE | KNOWLEDGE & LEARNING

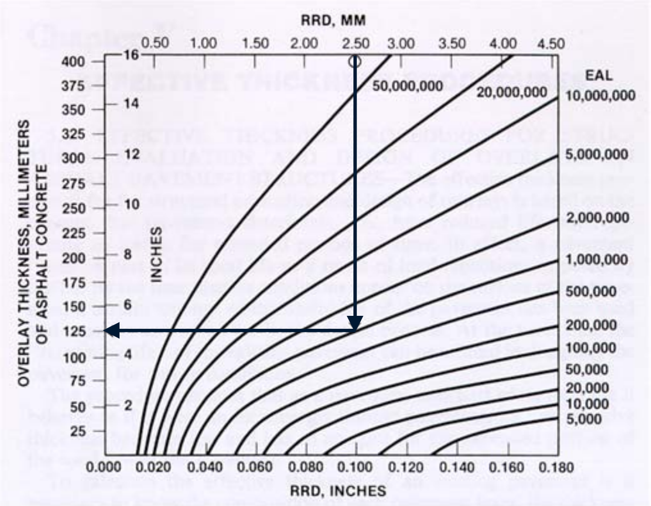
Early Deflection Versus Thickness Design Curves





ASCE | KNOWLEDGE & LEARNING

Rehabilitation Design Example – Asphalt Institute MS-17

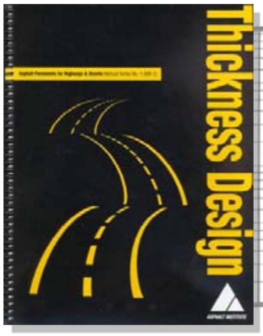


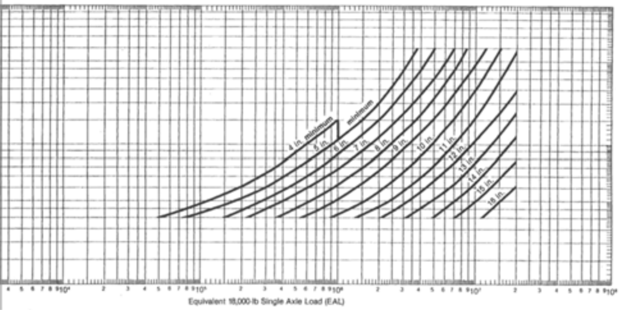
5 inches (125 mm)

ASCE | KNOWLEDGE & LEARNING

Many Other Design Methods

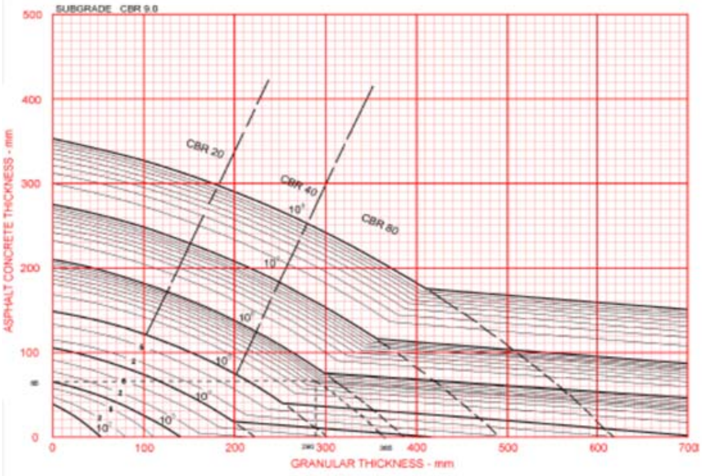
- Mechanistic-empirical design
- Limit tensile strain on bottom of HMA layer
- Limit vertical strain on top of subgrade





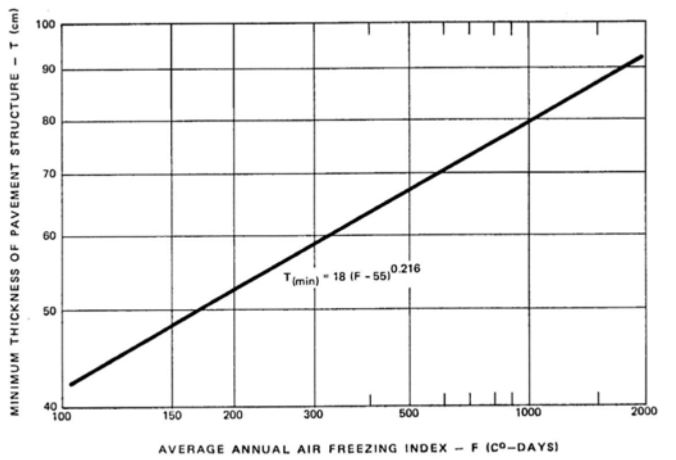
Many Other Design Methods

- Saskatchewan Method



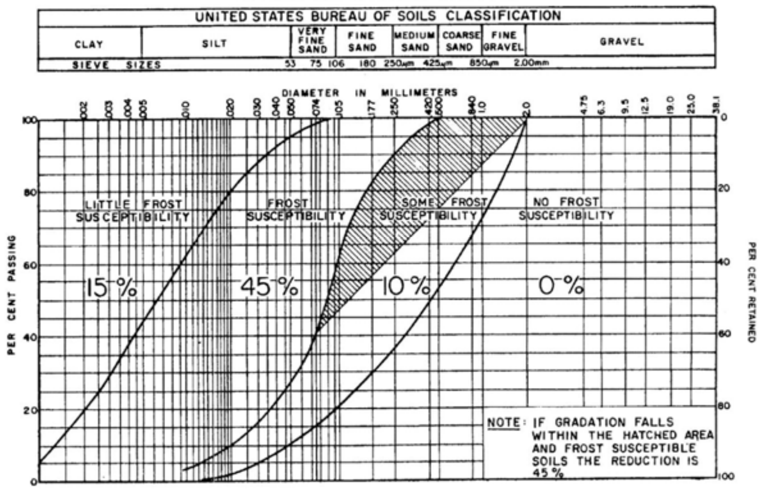
Also Need to Consider Frost

- Minimum pavement design thickness



Also Need to Consider Frost

SPRING REDUCTION FACTOR



NOTE: IF GRADATION FALLS WITHIN THE HATCHED AREA AND FROST SUSCEPTIBLE SOILS THE REDUCTION IS 45 %

AASHTO Structural Design Equation

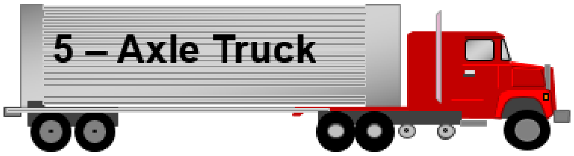
$$LogW = Z_R \times S_0 + 9.36 \times \log(SN+1) - 0.20 + \frac{\log\left[\frac{p_i - p_t}{p_i - 1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log(M_R) - 8.07$$

where:

W = design traffic load in equivalent single axle loads (ESALs)
Z_R = standard normal deviate for reliability “R”
S_0 = standard deviation

SN = structural number of the pavement
= Σ d_i x a_i x m_i, where, i, represents each pavement layer
  d_i = layer thickness
  a_i = structural layer coefficient
  m_i = drainage coefficient (typically 1.0)
p_i = initial serviceability
p_t = terminal serviceability
M_R = subgrade resilient modulus (units must be U.S. Customary)

Structural Loading – Not Linear with Damage – Concept of Equivalent Single Axle Loads



GROSS WEIGHT = 79,000 lbs

2 x 18,000 lbs **2 x 16,000 lbs** **11,000 lbs single**

LEF $= \left(\frac{18,000}{18,000}\right)^4 = 1$ **(x2)** **LEF** $= \left(\frac{16,000}{18,000}\right)^4 = 0.62$ **(x2)** **LEF** $= \left(\frac{11,000}{18,000}\right)^4 = 0.14$

TF = 2.00 + 1.24 + 0.14 = 3.38 ESALs

Structural Layer Coefficients (SLC)

- Surrogate for resilient modulus

Material	SLC
New and Recycled Hot Mix	0.42
Existing Hot Mix	0.14 to 0.28
Cold In-Place Recycled Mix	0.28 to 0.38
RAP/Granular Blend Expanded Asphalt Stabilized	0.20 to 0.25
Cold Mix Asphalt	0.11 to 0.24
Granular Base	0.14
Pulverized Asphalt and Granular Base	0.10 to 0.14
Granular Subbase	0.06 to 0.09
Open Graded Base	0.06 to 0.14
Rubblized Concrete	0.14 to 0.3

Structural Number Equation

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$$

AC Surface | Base | Subbase

a_i = Layer coefficient of layer i
D_i = Thickness of layer i
m_i = Drainage coefficient of layer i

Structural Design Example

From AASHTO Equation/Parameters $Sn_{req} = 5.7$

$$SN = \overbrace{5.5 \times 0.42}^{\text{Asphalt Surface}} + \overbrace{6 \times 0.14}^{\text{Base}} + \overbrace{26 \times .10}^{\text{Subbase}}$$

$$SN = 2.31 + 0.84 + 2.6$$

$$SN = 5.75 > 5.7 \text{ in}$$ **(Design OK)**

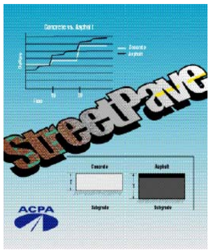
Heavy Vehicle Axle Load Spectrum and Counts

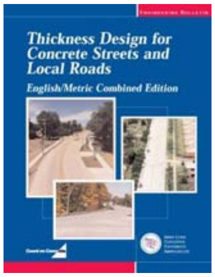
Single Axles		Tandem Axles	
Axle Load (kip)	Axles/1,000 Trucks	Axle Load (kip)	Axles/1,000 Trucks
34	0.19	60	0.57
32	0.54	56	1.07
30	0.63	52	1.79
28	1.78	48	3.03
26	3.52	44	3.52
24	4.16	40	20.31
22	9.69	36	78.19
20	41.82	32	109.54
18	68.27	28	95.79
16	57.07	24	71.16

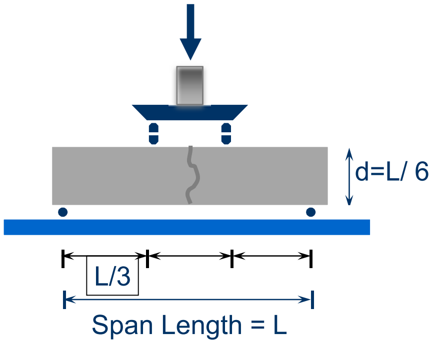
- Total trucks in design lane over the design life… calculated from trucks/day (2-way), traffic growth rate (%/yr), design life (yrs), directional distribution (%) and design lane distribution (%)

Concrete Thickness Design - ACPA

- Similar input procedures as those used for flexible pavement design
- Other specifics to assess the impact of slab length and width, dowel bar use, etc.
- Slab support and flexural strength very important

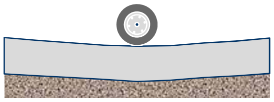






Traffic Loads Generate Stress

- Need equivalent stresses at slab edge

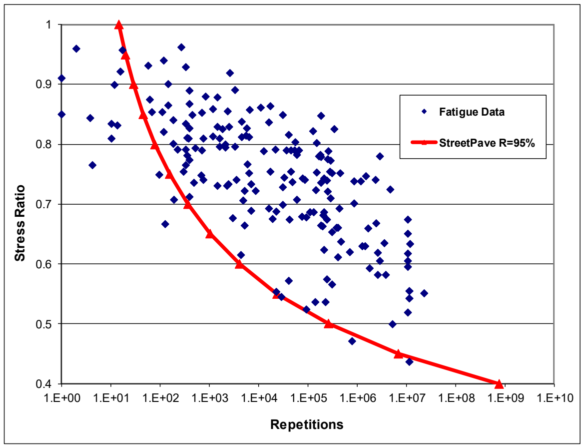


M_e =equivalent moment, psi; different for single, tandem, and tridem axles, with and without edge support - func on radius of relative stiffness, which depends on concrete modulus, Poisson's ratio, and thickness and the k-value
h_c = pavement thickness, in.
f_1 = adjustment for the effect of axle loads and contact area
f_2 = adjustment for a slab with no concrete shoulder
f_3 = adjustment to account for the effect of truck (wheel) placement at the slab edge
f_4 = adjustment to account for approximately 23.5% increase in concrete strength with age after the 28th day and reduction of one coefficient of variation (COV) to account for materials variability

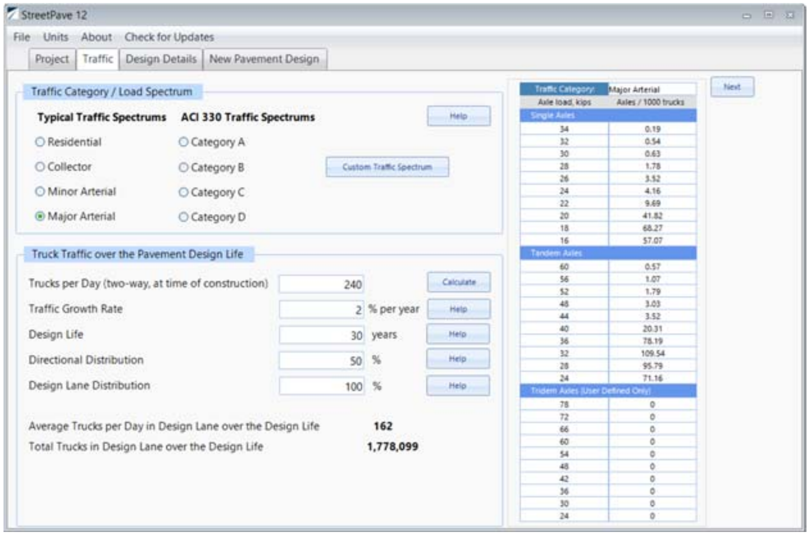
Limit Stress Ratios to Accommodate Design Repetitions

Stress Ratio (SR) = Stress / Concrete Strength

- Design adjusts slab thickness to limit stress ratio low enough to achieve the design traffic repetitions



Design Traffic Details



Traffic Category / Load Spectrum

Typical Traffic Spectrums	**ACI 330 Traffic Spectrums**
○ Residential	○ Category A
○ Collector	○ Category B
○ Minor Arterial	○ Category C
● Major Arterial	○ Category D

Truck Traffic over the Pavement Design Life

Trucks per Day (two-way, at time of construction) 240

Traffic Growth Rate 2 % per year

Design Life 30 years

Directional Distribution 50 %

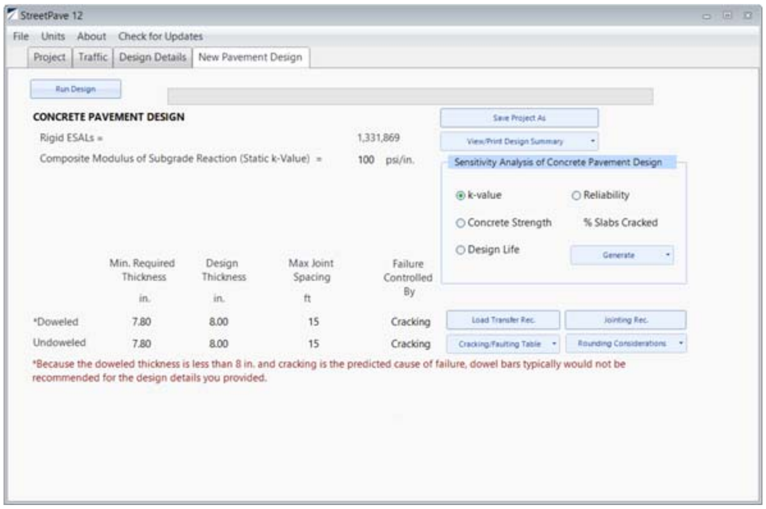
Design Lane Distribution 100 %

Average Trucks per Day in Design Lane over the Design Life **162**

Total Trucks in Design Lane over the Design Life **1,778,099**

Traffic Category:	Major Arterial
Axle load, kips	Axles / 1000 trucks
Single Axles	
34	0.19
32	0.54
30	0.63
28	1.78
26	3.52
24	4.16
22	9.69
20	41.82
18	68.27
16	57.07
Tandem Axles	
60	0.57
56	1.07
52	1.79
48	3.03
44	3.52
40	20.31
36	78.19
32	109.54
28	95.79
24	71.16
Tridem Axles (User Defined Only)	
78	0
72	0
66	0
60	0
54	0
48	0
42	0
36	0
30	0
24	0

Design Results



CONCRETE PAVEMENT DESIGN

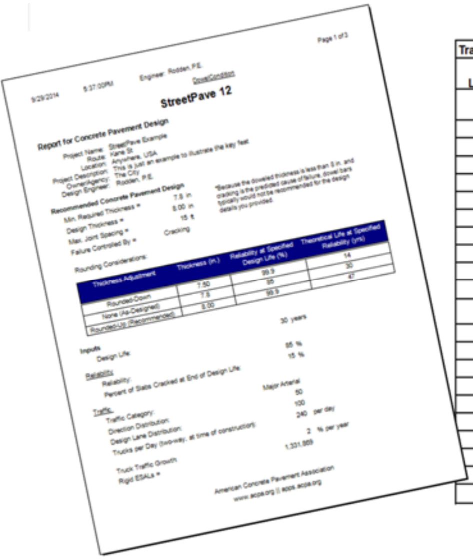
Rigid ESALs = 1,331,869

Composite Modulus of Subgrade Reaction (Static k-Value) = 100 psi/in.

	Min. Required Thickness in.	Design Thickness in.	Max Joint Spacing ft	Failure Controlled By
*Doweled	7.80	8.00	15	Cracking
Undoweled	7.80	8.00	15	Cracking

*Because the doweled thickness is less than 8 in. and cracking is the predicted cause of failure, dowel bars typically would not be recommended for the design details you provided.

Design Report



9/29/2014 5:37:00PM Engineer: Rodden, P.E. Page 1 of 3

DowelCondition

StreetPave 12

Report for Concrete Pavement Design

Project Name: StreetPave Example
Route: Kane St
Location: Anywhere, USA
Project Description: This is just an example to illustrate the key feat
Owner/Agency: The City
Design Engineer: Rodden, P.E.

Recommended Concrete Pavement Design

Min. Required Thickness = 7.8 in
Design Thickness = 8.00 in
Max. Joint Spacing = 15 ft
Failure Controlled By = Cracking

*Because the doweled thickness is less than 8 in. and cracking is the predicted cause of failure, dowel bars typically would not be recommended for the design details you provided.

Rounding Considerations:

Thickness Adjustment	Thickness (in.)	Reliability at Specified Design Life (%)	Theoretical Life at Specified Reliability (yrs)
Rounded-Down	7.50	99.9	14
None (As-Designed)	7.8	85	30
Rounded-Up (Recommended)	8.00	99.9	47

Inputs

Design Life: 30 years

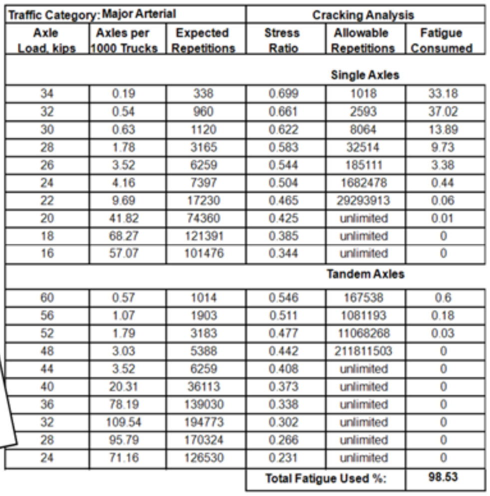
Reliability

Reliability: 85 %
Percent of Slabs Cracked at End of Design Life: 15 %

Traffic

Traffic Category: Major Arterial
Direction Distribution: 50
Design Lane Distribution: 100
Trucks per Day (two-way, at time of construction): 240 per day
Truck Traffic Growth: 2 % per year
Rigid ESALs = 1,331,869

American Concrete Pavement Association
www.acpa.org || apps.acpa.org



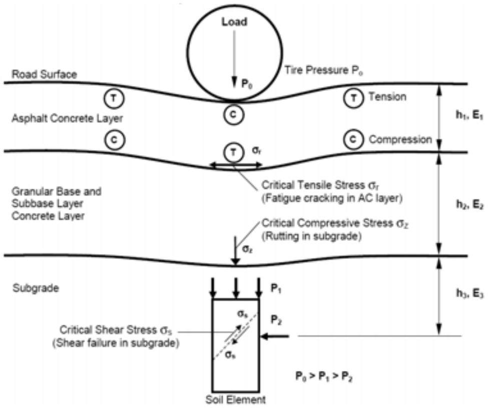
Traffic Category: Major Arterial			Cracking Analysis		
Axle Load, kips	Axles per 1000 Trucks	Expected Repetitions	Stress Ratio	Allowable Repetitions	Fatigue Consumed
				Single Axles	
34	0.19	338	0.699	1018	33.18
32	0.54	960	0.661	2593	37.02
30	0.63	1120	0.622	8064	13.89
28	1.78	3165	0.583	32514	9.73
26	3.52	6259	0.544	185111	3.38
24	4.16	7397	0.504	1682478	0.44
22	9.69	17230	0.465	29293913	0.06
20	41.82	74360	0.425	unlimited	0.01
18	68.27	121391	0.385	unlimited	0
16	57.07	101476	0.344	unlimited	0
				Tandem Axles	
60	0.57	1014	0.546	167538	0.6
56	1.07	1903	0.511	1081193	0.18
52	1.79	3183	0.477	11068268	0.03
48	3.03	5388	0.442	211811503	0
44	3.52	6259	0.408	unlimited	0
40	20.31	36113	0.373	unlimited	0
36	78.19	139030	0.338	unlimited	0
32	109.54	194773	0.302	unlimited	0
28	95.79	170324	0.266	unlimited	0
24	71.16	126530	0.231	unlimited	0
			Total Fatigue Used %:		98.53

Using AASHTO Data Today

- What has changed since the AASHO Road Test?
  - Significant changes to the types of materials used in pavement construction
  - Increase in traffic volume and vehicle weight
  - Large advancements in the construction practices
  - Other design factors (i.e. Drainage, friction, etc.)
- Our understanding of the materials and the mechanisms of the deterioration is greatly advanced

Mechanistic Design

- Relates stress/strain states to failures
- If modelled correctly, can be very accurate
- Long history of existing mechanistic models
  - Boussinesq
  - Burmister
  - Linear Elastic Analysis
  - Finite Element Analysis



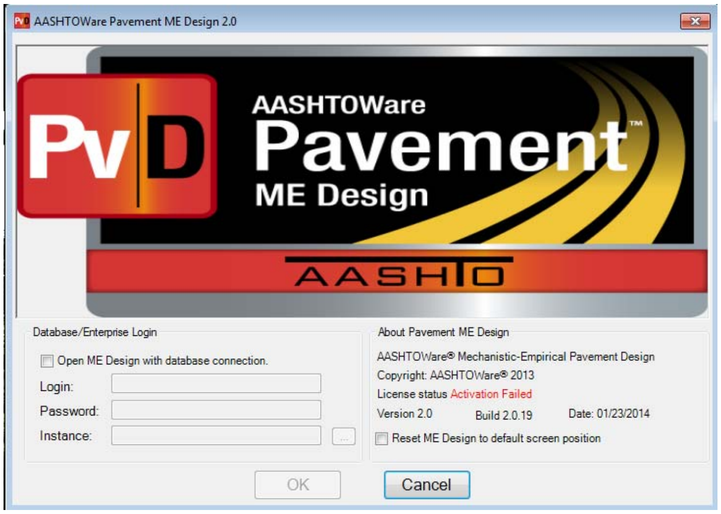
Why Not Use Mechanistic Design?

- Pavement systems are very complicated to model
  - Asphalt concrete is a non-homogenous, thermal-viscoelastic material and has properties that change with age
  - Variability in materials along a project
  - Materials are only as good as supplied and installed
  - Pavement designed for predicted traffic
- Early attempts to predict service life were very poor
- Relationships between stress/strain and failure modes are still being developed (ride quality, structural failure, rutting, etc.)

Mechanistic-Empirical Design

- Mechanistic design uses models to predict the effect of materials, traffic and environment on the expected performance
- Empirical calibration ensures that it matches what is seen in the field
- A large data set is used to calibrate pavement models used to predict various pavement distresses and their progression
- The large amount of data and mechanistic components allow for a more accurate reliability assessment of performance

AASHTOWare Pavement ME Design



Database/Enterprise Login

☐ Open ME Design with database connection.

Login:

Password:

Instance:

About Pavement ME Design

AASHTOWare® Mechanistic-Empirical Pavement Design

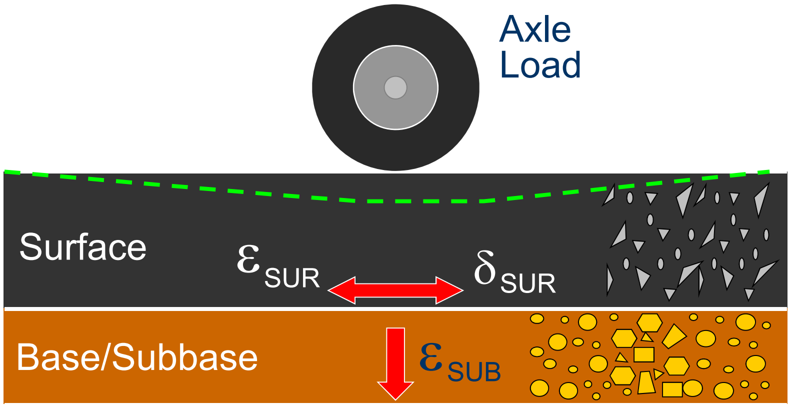
Copyright: AASHTOWare® 2013

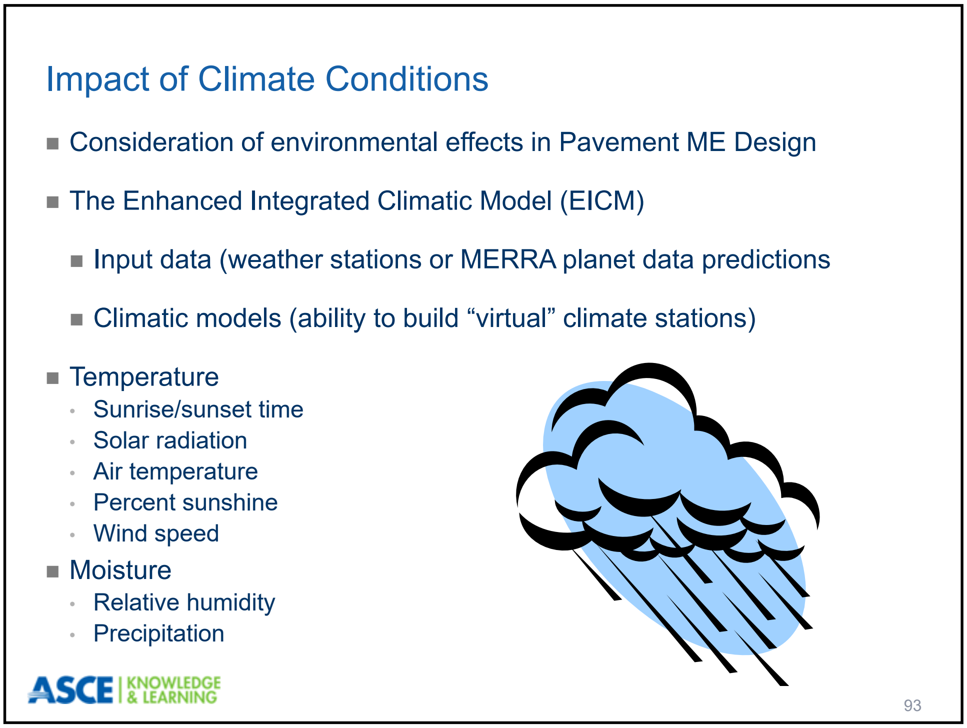
License status Activation Failed

Version 2.0 Build 2.0.19 Date: 01/23/2014

☐ Reset ME Design to default screen position

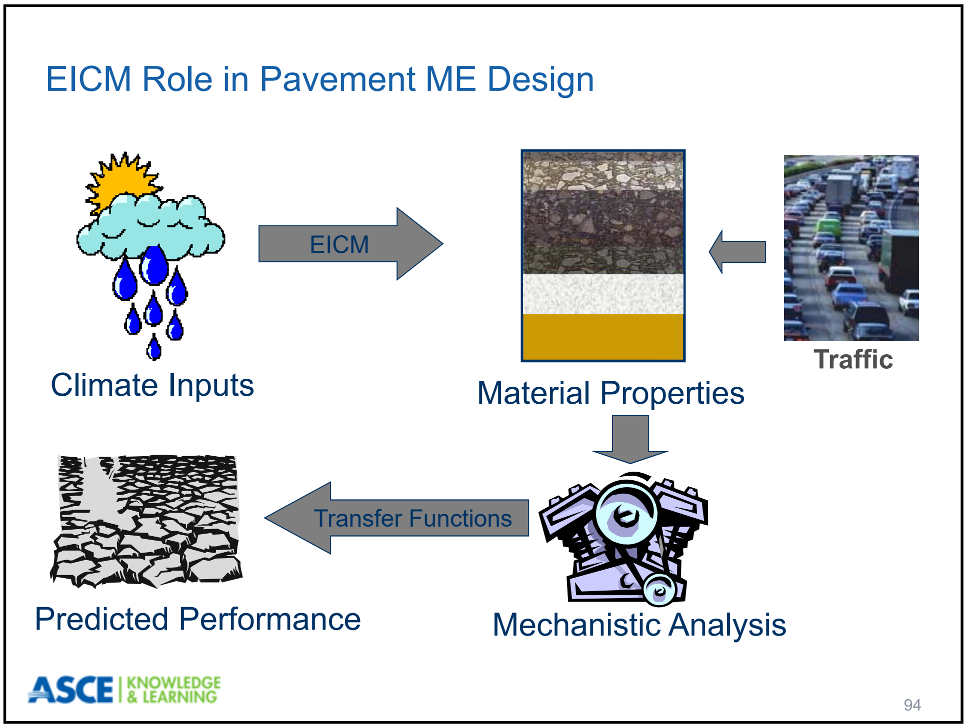
Pavement Response under Load





Impact of Climate Conditions

- Consideration of environmental effects in Pavement ME Design
- The Enhanced Integrated Climatic Model (EICM)
  - Input data (weather stations or MERRA planet data predictions
  - Climatic models (ability to build “virtual” climate stations)
- Temperature
  - Sunrise/sunset time
  - Solar radiation
  - Air temperature
  - Percent sunshine
  - Wind speed
- Moisture
  - Relative humidity
  - Precipitation



EICM Role in Pavement ME Design

Climate Inputs

EICM

Material Properties

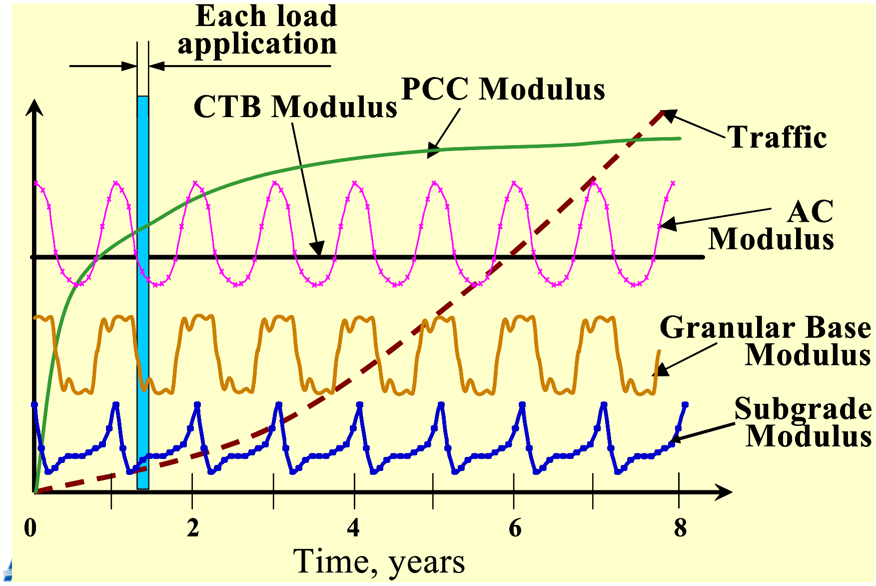
Traffic

Mechanistic Analysis

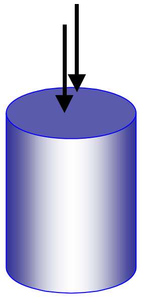
Transfer Functions

Predicted Performance

Incremental Damage Accumulation

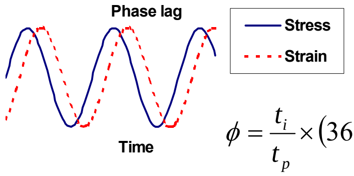


Accurate Modeling of Materials under Load



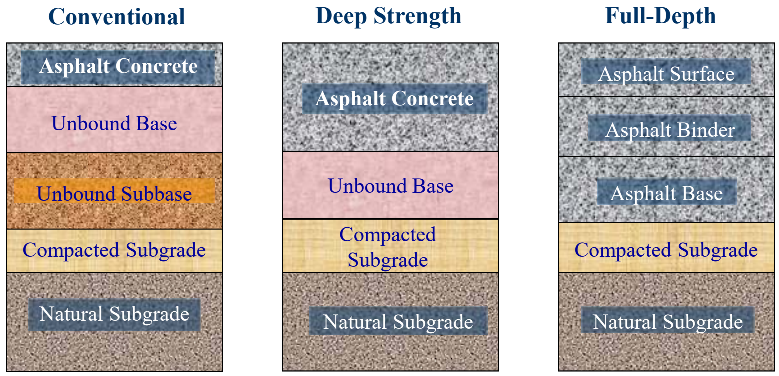
$$\left|E^*\right| = \frac{\sigma_0}{\varepsilon_0}$$

Adjusted for temperature & time of loading.



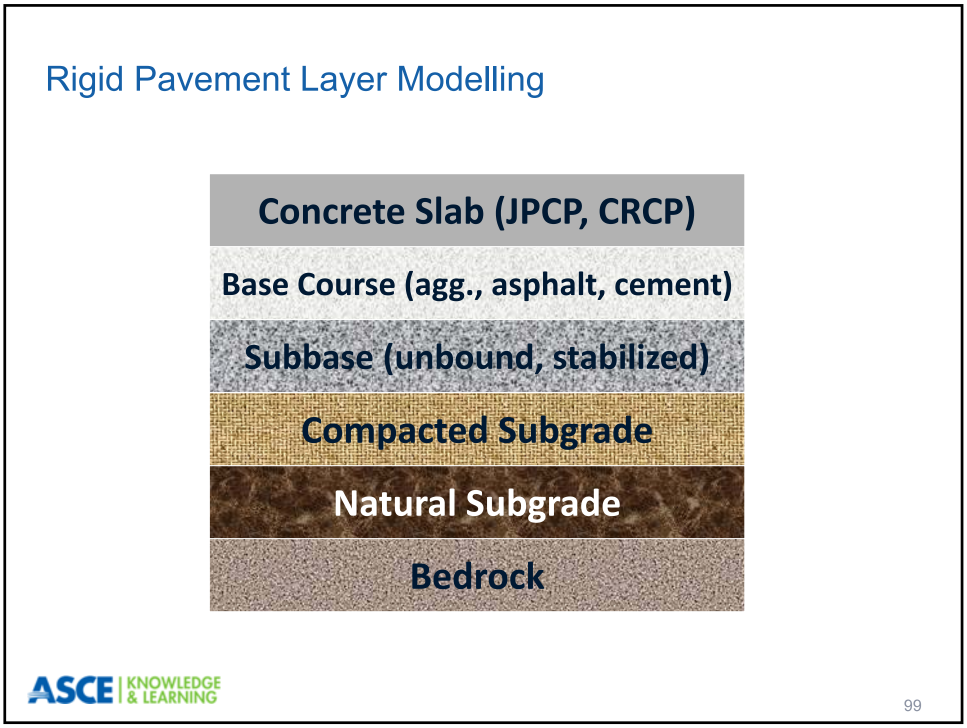
$$\phi = \frac{t_i}{t_p} \times (360)$$

Flexible Pavement Layer Modelling



Conventional	Deep Strength	Full-Depth
Asphalt Concrete	Asphalt Concrete	Asphalt Surface
Unbound Base	Unbound Base	Asphalt Binder
Unbound Subbase	Compacted Subgrade	Asphalt Base
Compacted Subgrade	Natural Subgrade	Compacted Subgrade
Natural Subgrade		Natural Subgrade

Flexible Pavement Distresses



Rigid Pavement Layer Modelling

Concrete Slab (JPCP, CRCP)

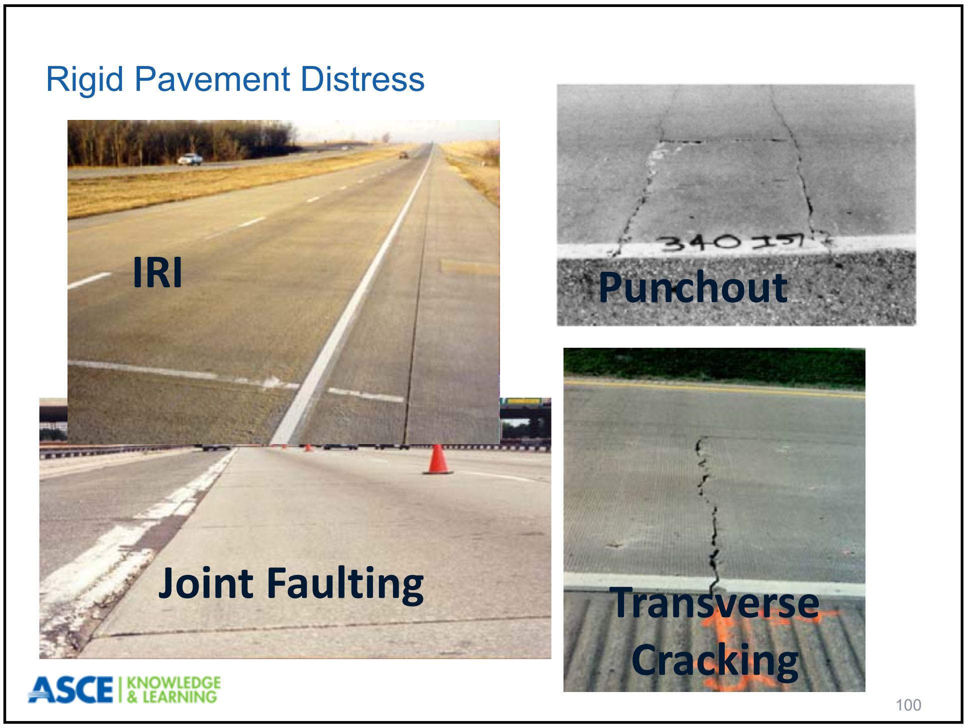
Base Course (agg., asphalt, cement)

Subbase (unbound, stabilized)

Compacted Subgrade

Natural Subgrade

Bedrock



Rigid Pavement Distress

IRI

Punchout

Joint Faulting

Transverse Cracking

Asphalt Concrete Pavement Construction

- Delivery and placement

Asphalt Concrete Pavement Construction

- Well, maybe a little

Asphalt Concrete Pavement Construction

- Compaction equipment

Asphalt Concrete Pavement Construction

- Equipment has not changed much

Concrete Pavement Construction

Concrete Pavement Construction

Concrete Pavement Construction

Concrete Pavement Construction

Concrete Pavement Construction

Early Roads/Bridges

Guiderails and Bridges

ASCE | KNOWLEDGE & LEARNING

Vehicles Changed Much Faster than Roads

ASCE | KNOWLEDGE & LEARNING

So…. What is the Future for Pavement Design

- Further development of mechanistic design
- Real time monitoring and reporting of pavement conditions and damage accumulation
- Nano technology to “heal” pavements before significant damage occurs
- Crowd sourcing of performance data, i.e. smoothness, texture, deflection, etc.
- RFID or similar technology to “embed” construction history data in pavement sections
- Improved material technologies to resist the impact of the environment on pavement performance