Pavement Design Webinar

JUNE 23, 2016

COLORADO ASPHALT PAVEMENT ASSOCIATION

Who is CAPA?

Producers /Suppliers
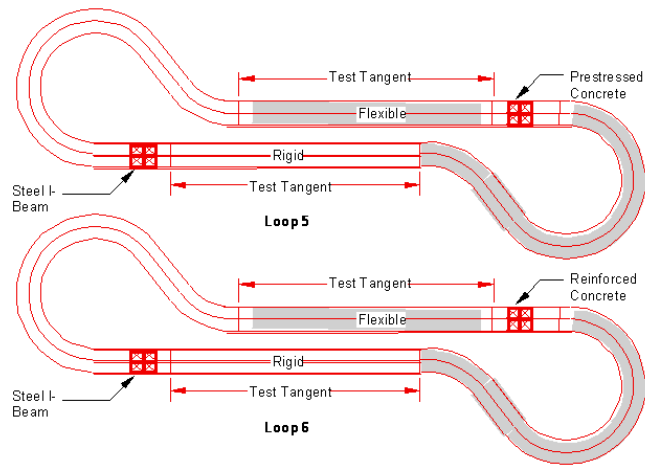
Local Agencies

Contractors

Designers

We are a resource for YOU

Mike Skinner, PE
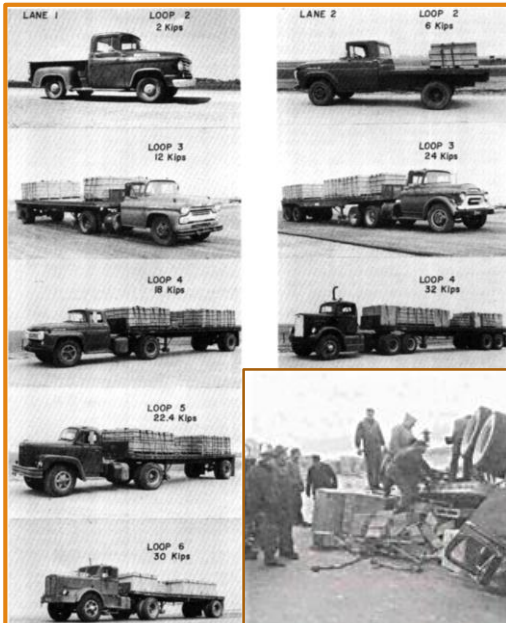Director of Pavement Engineering
Colorado Asphalt Pavement Association

AASHO Road Test

Constructed 1956-1958 for $27M

2

AASHO Road Test

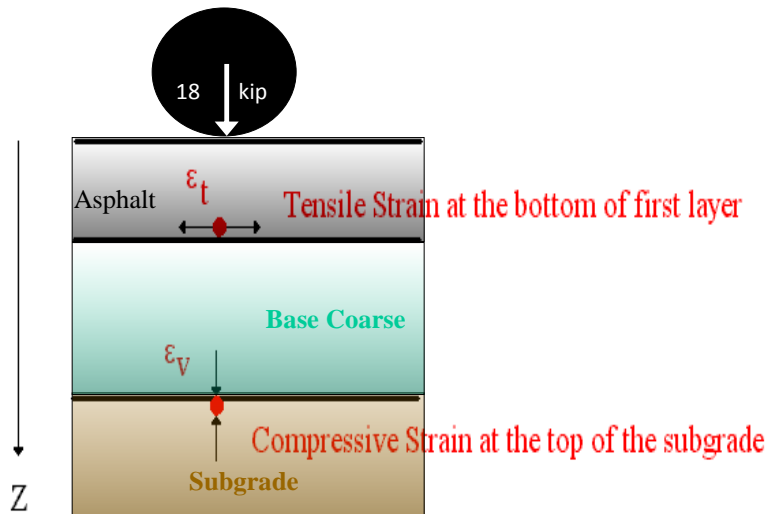Loop 1: No traffic, used to study environmental effects

I-80

Ottawa, Illinois

FIGURE 3 AASHO Road Test truck traffic.

AASHO Road Test

Test Traffic: 1958 - 1960

Structural Section Basics

18 ↓ kip

Asphalt ε_t Tensile Strain at the bottom of first layer

Base Coarse

ε_V

Compressive Strain at the top of the subgrade

Subgrade

Z

AASHO Road Test

Empirical Pavement Design

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\dfrac{\Delta PSI}{4.5-1.5}\right)}{0.40 + \dfrac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

Axle Load   Structural   Pavement   Subgrade
                   Number   Performance   Strength

Guidelines and Standards

Multiple procedures in the design world
◦ **AASHTO**
◦ **FHWA**
◦ **CDOT**
◦ **MGPEC**

Individual agencies will use one or more of these for project design

Used to determine pavement thickness

Options for different pavement types

MGPEC Design Standards for Metro Denver Area

Defined Truck Factors or Load Equivalency Factors [LEFs] for vehicle types.

Default ESAL calculation for basic residential, commercial, industrials roads. More refined methods are allowed.

Less costly soil support strength correlation to resilient modulus [Mr] is provided. Direct measurement allowed.

Swelling soils effect is mitigated with moisture treatment above normal optimum moisture contents to various depths. Proper pavement support is then achieved by stabilizing the upper layer with chemical (lime, cement, flyash) treatment techniques. Current efforts in developing methods to use geo-synthetics (grids or high strength fabrics).

Asphalt thickness design uses modified AASHTO equation that adds fatigue component adjustment.

Concrete thickness design is not modified from AASHTO.

Some inputs to AASHTO equation are set in the standard: reliability [R,Zr] serviceability limits [Po, Pt], asphalt 'strength' [a1] or concrete properties.

MGPEC software gives a MGPEC compliant design. Also has LCCA output.

Soil Basics 101

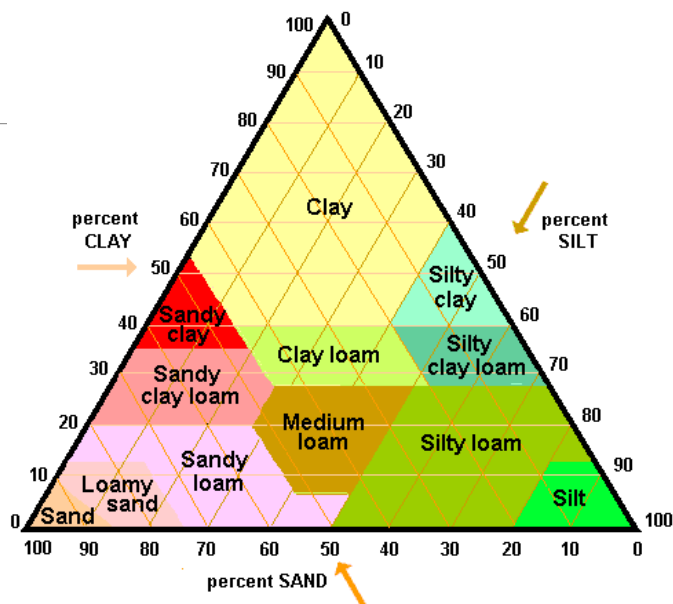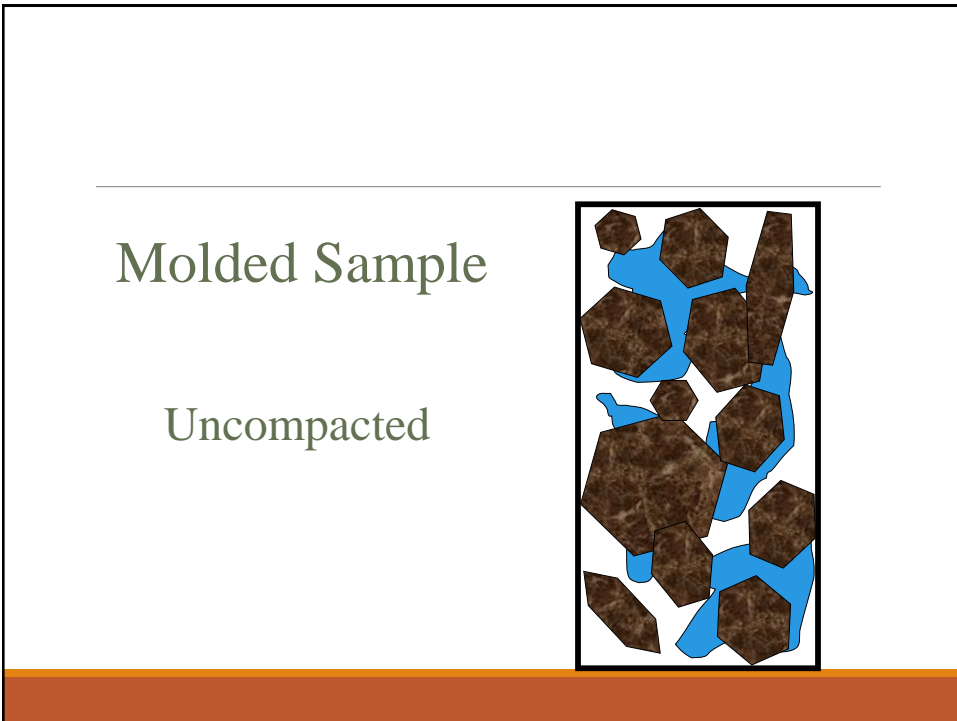Sands (granular)
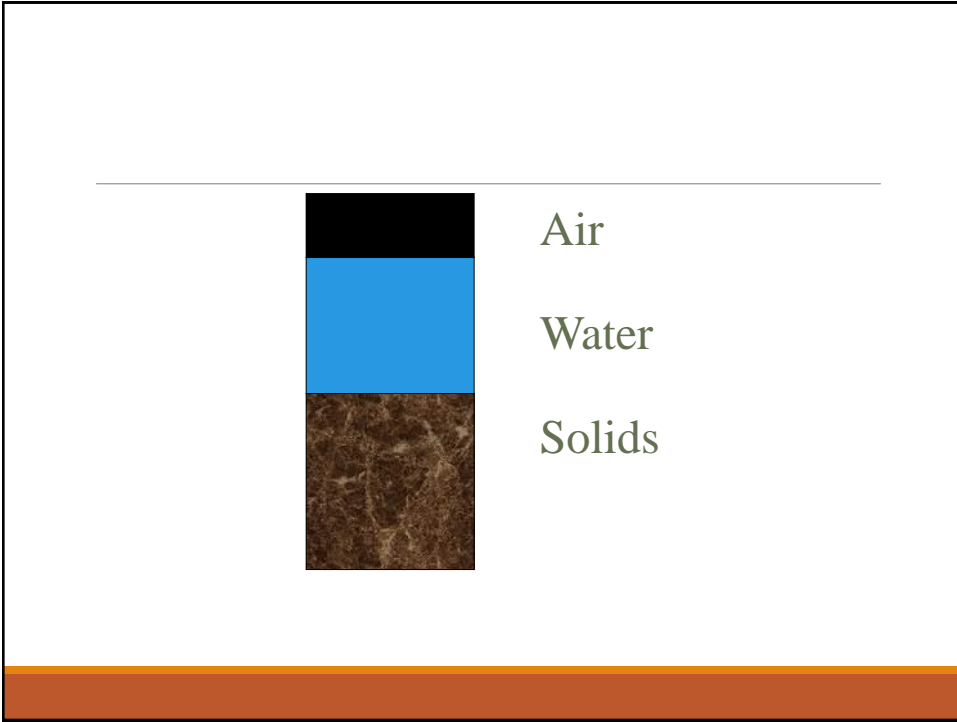
Silts

Clays (cohesive)

better

↓

worse

Atterberg Limits (PI, LL)

% passing -200 screen

Air

Water

Solids

Molded Sample

Uncompacted

Molded Sample

Compacted

Molded Sample

Compacted and Saturated

Proctor Curve

Dry Density (pcf)

Sands

Clays

Moisture Content (%)
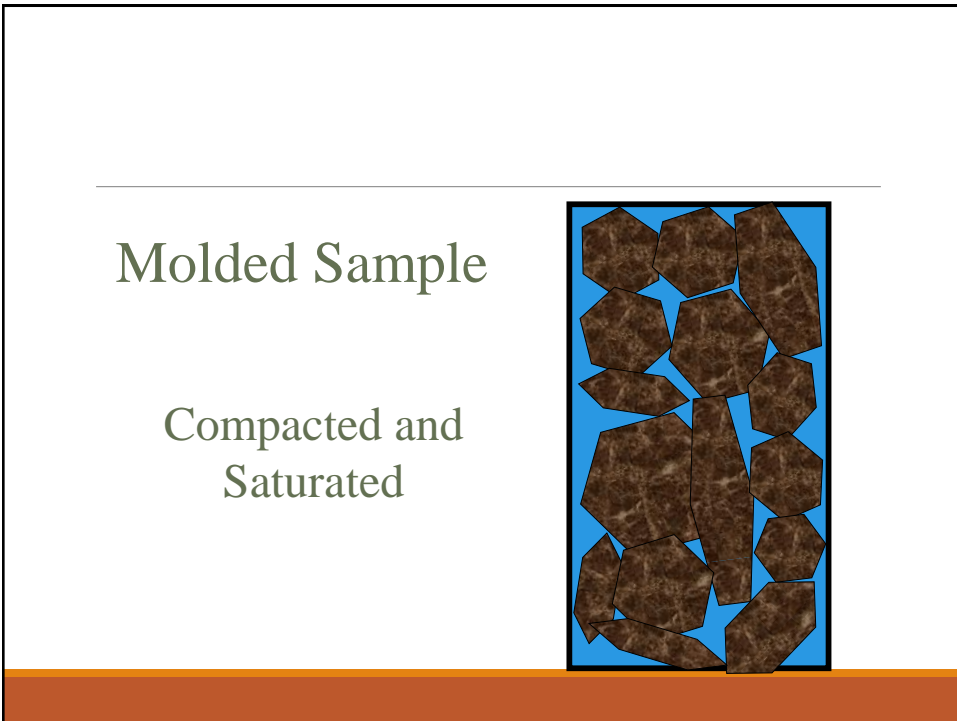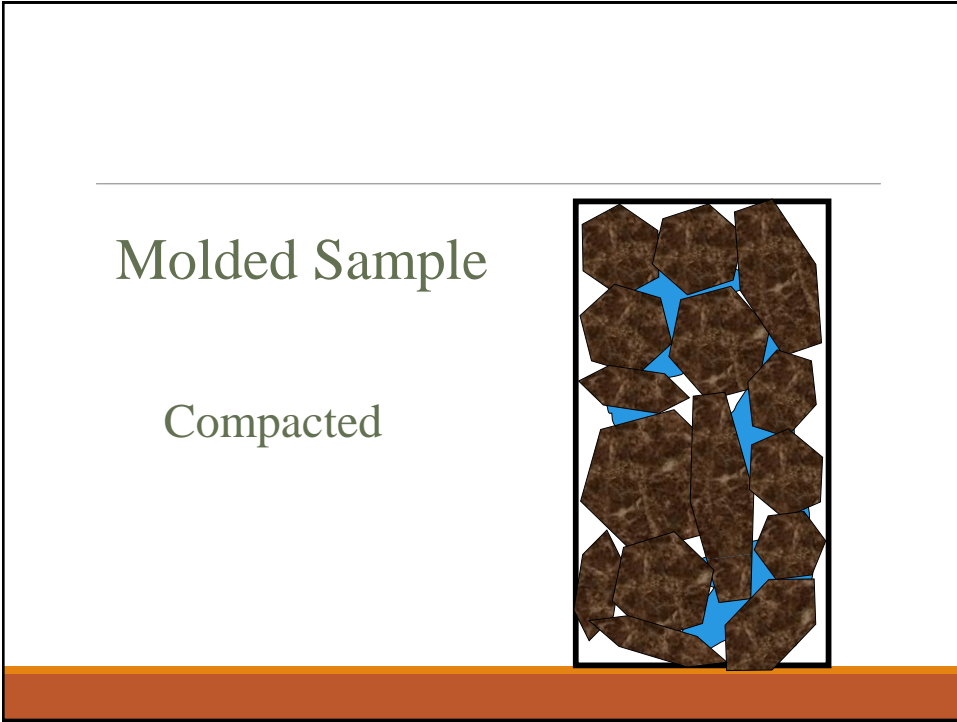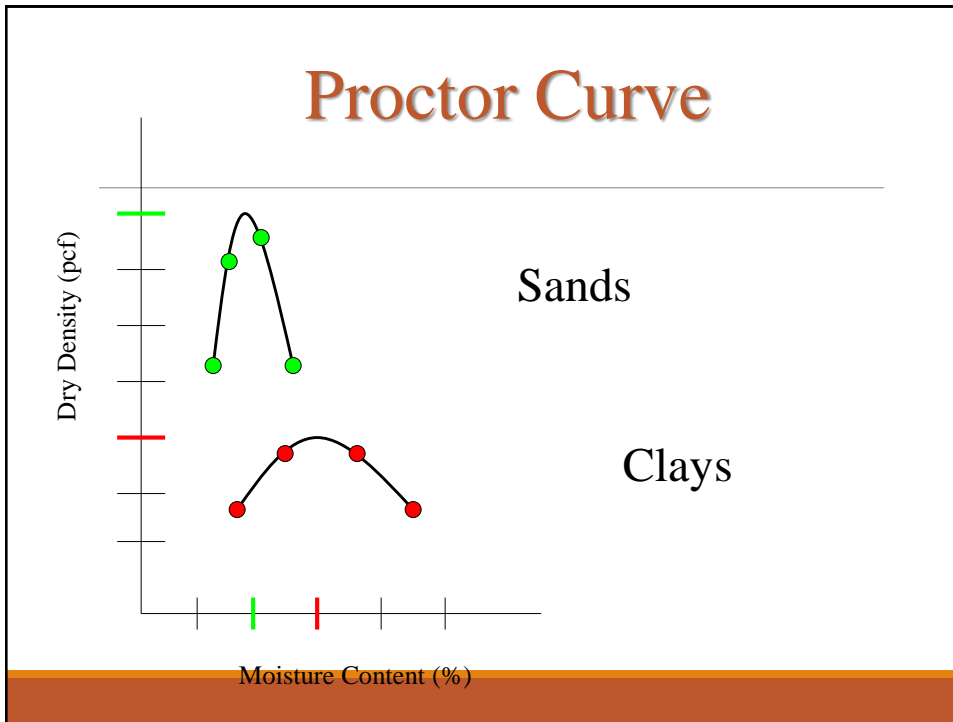
Strength of Subgrade

California Bearing Ratio (CBR)

Hveem Stabilometer (R-Value)

Unconfined Compression (Q_u)

Resilient Modulus (M_R)

Data

Subgrade Investigation
   Timing
   Spacing of Borings
   Depth of Borings
   Sampling

Data

Field Investigation

   –Preliminary & Final Design Reports

      •Boring Spacing: 250 ft

      •Depth: 4 to 9 ft

   –Design Confirmation Report

      •Boring Spacing: 500 ft

Data

Laboratory Testing
  Subgrade Support Testing
    (R-Value, CRB, Unconfined)
  Swell Testing
    (Drive vs Remolded Samples)
  Number of Tests Required

Data

Laboratory Testing
  –Soil Classification (each boring)
    •Gradation, atterberg limits, sulfates
  –Swell Testing
    •200psf
  –Strength Testing
    •Sands: R-Value, Modified Proctor
    •Clays: Unconfined, Standard Proctor
        Remolded to 95%, +2% OMC

Data

Design Traffic
  Street Classification
  What types of vehicles?
  Equivalent Daily Load Application (EDLA)
  Equivalent Single Axle Load (ESAL)
 Private?

Life Cycle Cost Analysis

Purpose

  LCCA is a process for evaluating the **total economic worth** of a project by analyzing initial construction costs, discounted future costs, maintenance, user costs and salvage value of the life of the pavement.

Life Cycle Cost Analysis

- When evaluating competing project designs, engineers are often confronted with the option of using alternative materials with wide ranges of design or useful life!

Concrete Overlay   Asphalt Overlay
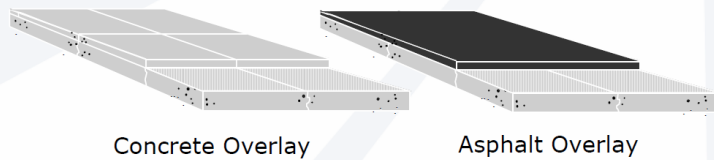
Life Cycle Cost Analysis

Agency costs
Preliminary engineering
Contract administration
Initial construction
Construction supervision
Maintenance
Rehabilitation
Administrative
Salvage value

Life Cycle Cost Analysis

General Procedure

User costs
- Normal operation
- Work zone
- Types of user costs
  - Vehicle operating
  - User delay
  - crash

General Procedure

Alternative comparison
- Net present value (NPV)
- Equivalent uniform annual costs (EUAC)

$$NPV = \text{initial cost} + \sum_{K=1}^{N} \text{Rehab cost}_k \left[\frac{1}{(1+i)^n} \right]$$

$$EUAC = NPV \left[\frac{(1+i)^n}{(1+i)^n - 1} \right]$$

i = discount rate

n = year of expenditure

$\left[\dfrac{1}{(1+i)^n} \right]$ = Present value (PV) factor

i = discount rate

n = Analysis period (the number of years into the future over which you wish to compare projects)

LCCA General Assumptions

Both pavements built at same time

Same traffic on each pavement

Same user costs between construction activities
◦ Implies road roughness is the same
◦ Maintenance/rehabilitation activities are scheduled such that user costs are the same
◦ Implies some unlikely activities must be scheduled

Differences will be in…
◦ Construction costs
◦ User delay costs during construction
◦ Salvage value

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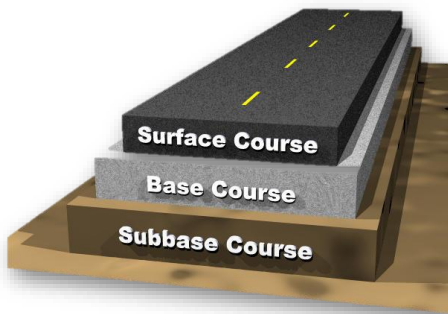# Without Pavement, We Would Be Stuck in the Mud!

Washington-Richmond road, 1919

6/23/2016

Brief Overview

Why PaveXpress?

What Is PaveXpress?

An Introduction

Overview of the System

Design Scenarios Using PaveXpress

Resources

AASHTO has been developing MEPDG for high volume roads, but a gap has developed for local roads and lower volume roads.

# What Is PaveXpress?

A free, online tool to help you create simplified pavement designs using key engineering inputs, based on the AASHTO 1993 and 1998 supplement pavement design process.

- Accessible via the web and mobile devices
- Free — no cost to use
- Based on AASHTO pavement design equations
- User-friendly
- Share, save, and print project designs
- Interactive help and resource links

1993 AASHTO Design Guide Equation — Basic Overview
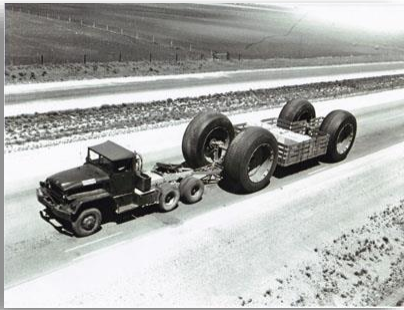
The equation was derived from empirical information obtained at the AASHO Road Test.

The solution represents the average amount of traffic that can be sustained by a roadway before deteriorating to some terminal level of serviceability, according to the supplied inputs.

1993 AASHTO Design Guide Equation — Basic Overview

$$\log_{10}(W_{18}) = Z_R \times S_0 + 9.36 \times \log_{10}(SN + 1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2 - 1.5}\right]}{0.4 + \frac{1094}{(SN + 1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

Where:

W_{18} = the predicted number of 18-kip equivalent single axle load (ESAL) applications

Z_R = standard normal deviate

S_0 = combined standard error of the traffic prediction and performance prediction

ΔPSI = difference between the initial design serviceability index (p_i) and the design terminal serviceability index (p_t)

M_R = resilient modulus of the subgrade (psi)

1993 AASHTO Design Guide Equation — Basic Overview

The designer inputs data for all of the variables except for the structural number (*SN*), which is indicative of the total pavement thickness required.

Once the total pavement *SN* is calculated, the thickness of each layer within the pavement structure is calculated

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 \ldots + a_i D_i m_i$$

Where: a_i = i^{th} layer coefficient
D_i = i^{th} layer thickness (inches)
m_i = i^{th} layer drainage coefficient

Design Thickness

Layer Coefficients

◦ Hot Mix Asphalt	0.40 to 0.44
◦ Granular Base Course	0.12 to 0.14
◦ Chemically Treated Subgrade	
◦ Lime, Cement, Fly Ash	0.11 to 0.14
◦ Cement Treated Base Course	0.20 to 0.22
◦ Bitum. Treated Base Course	0.20 to 0.22

Design Thickness

Drainage Coefficients

◦ Range from 0.7 - 0.8 for very poor subgrade to 1.1 - 1.15 for excellent subgrades

◦ Generally Accepted by Geotechnical/Pavement Engineers in Colorado to use a drainage coefficient of 1.0 for unbound base and subbase layers

General Guidance

- The solution represents the pavement thickness for which the *mean value* of traffic which can be carried given the specific inputs. That means there is a 50% chance that the terminal serviceability level could be reached in less time than the period for which the pavement was designed.

- As engineers, we tend to want to be conservative in our work. Understand that as we use values that are more and more conservative, the pavement thickness increases and the overall cost also increases.

General Guidance

- A reliability factor is included to decrease the risk of premature deterioration below acceptable levels of serviceability.
- In order to properly apply the reliability factor, the inputs to the design equation *should be the mean value, without any adjustment designed to make the input "conservative."*
- The pavement structure most likely to live to its design life will be the one with the most accurate design inputs. Whenever possible, perform materials testing and use actual traffic counts rather than relying on default values or guessing (*too much!*) regarding anticipated traffic levels.
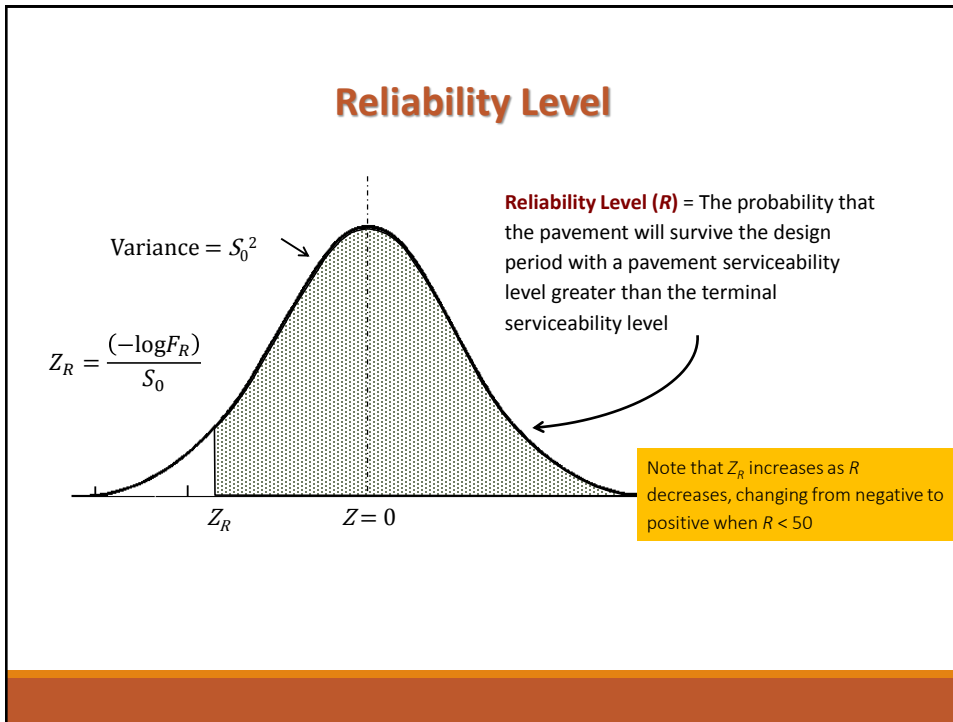
Roadway Classifications

Interstate: *All routes that comprise the Dwight D. Eisenhower National System of Interstate and Defense Highways belong to the "Interstate" functional classification category and are considered Principal Arterials.*

Arterials/Highways: *The roads in this classification have directional travel lanes are usually separated by some type of physical barrier, and their access and egress points are limited to on- and off-ramp locations or a very limited number of at-grade intersections. These roadways serve major centers of metropolitan areas, provide a high degree of mobility. They can also provide mobility through rural areas. Unlike their access-controlled counterparts, abutting land uses can be served directly.*

Local: *Local roads are not intended for use in long distance travel, due to their provision of direct access to abutting land. Bus routes generally do not run on Local Roads. They are often designed to discourage through traffic. Collectors serve a critical role in the roadway network by gathering traffic from Local Roads and funneling them to the Arterial network.*

Residential/Collector: *The roads in this classification have the lowest traffic loadings and are basically comprised of automobiles and periodic truck service traffic, such as garbage trucks, etc. The "Collector" name appended to this classification fits more with the "Local" classification above, i.e., "Collector/Local."*

Reliability Level

Variance $= S_0{}^2$

$$Z_R = \frac{(-\log F_R)}{S_0}$$

Z_R $\qquad Z = 0$

Reliability Level (R) = The probability that the pavement will survive the design period with a pavement serviceability level greater than the terminal serviceability level

Note that Z_R increases as R decreases, changing from negative to positive when $R < 50$

AASHTO Suggested Reliability Levels
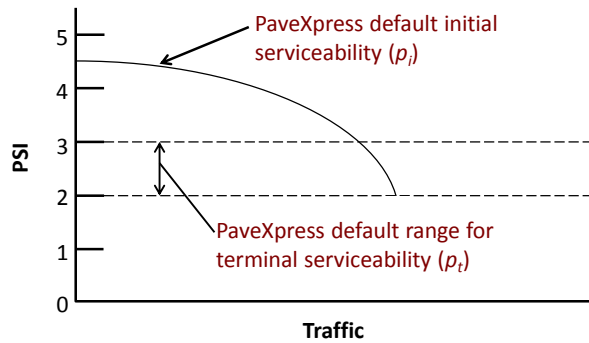# For Various Functional Classifications

Reliability Level (R): 50% to 95%, depending on Roadway Classification

The probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental conditions for the design period. This is then used to look up Z_R, the standard normal deviate which is the standard normal table value corresponding to a desired probability of exceedance level. Suggested levels of reliability for various Functional Classifications (1993 AASHTO Guide, Table 2.2, page II-9):

AASHTO GUIDE FOR
Design of
Pavement
Structures
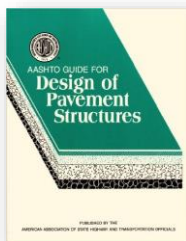
Functional Classification	Recommended Level of Reliability	
	Urban	Rural
Interstate and Other Freeways	85–99.9	80–99.9
Principal Arterials	80–99	75–95
Collectors	80–95	75–95
Local	50–80	50–80

Present Serviceability Index Concept

PaveXpress default initial serviceability (p_i)

PSI

PaveXpress default range for terminal serviceability (p_t)

Traffic

Roadway Classification Effect
On PaveXpress Default Values

	Interstate	Arterials/ Highway	Local	Residential/ Collector
Design Period	40 years	30 years	20 years	20 years
Reliability Level	95	85	75	50
Combined Standard Error (S_0)	0.5	0.5	0.5	0.5
Initial Serviceability Index (p_i)	4.5	4.5	4.5	4.5
Terminal Serviceability Index (p_t)	3.0	3.0	2.0	2.0
Change in Serviceability (ΔPSI)	1.5	1.5	2.5	2.5

Subgrade Considerations

The most common methods of classifying the subgrade for pavement design are:

- California Bearing Ratio (CBR)
- Resistance Value (R)
- Resilient Modulus (M_R)

| Surface Course (AC, PCC) |
| Base Course |
| Subbase |
| Compacted/Natural Subgrade |
| Embankment/Natural Soil |
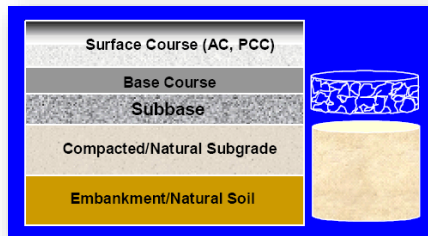
California Bearing Ratio (CBR)

The CBR Test can be performed either in the lab(AASHTO T 193, ASTM D 1883) or in the field in situ (ASTM D4429).

The CBR is a simple test that compares the bearing capacity of a material with a standard well-graded crushed stone, which has a reference CBR value of 100%.

Fine-grained soils typically have values less than 20.

Using the Dynamic Cone Penetrometer to Estimate CBR

The Dynamic Cone Penetrometer (DCP) Test can be performed in the field in situ (ASTM D6951) and used to estimate CBR values.

The U.S. Army Engineers Waterways Experiment Station has developed the following relationship between Dynamic Penetration Index (DPI) and CBR:

$$\log_{10}(\text{CBR}) = 2.46 - 1.12\log_{10}(\text{DPI})$$

DCP Testing at the NCAT Test Track

Resistance Value (*R*)

The Resistance Test is performed in the lab (AASHTO T 190, ASTM D 2844).

It tests both treated and untreated laboratory compacted soils or aggregates with a stabilometer and expansion pressure devices. It tests the ability of the material to resist lateral spreading due to an applied vertical load.

A range of values are established from 0 to 100, where 0 is the resistance of water and 100 is the resistance of steel.
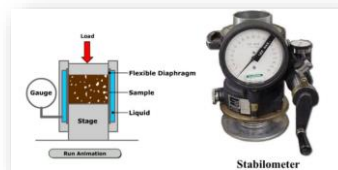
Resilient Modulus (M_R)

The Resilient Modulus Test is performed in the lab (AASHTO T 307, ASTM D 2844).

It is a measure of the soil stiffness and tri-axially tests both treated and untreated laboratory compacted soils or aggregates under conditions that simulate the physical conditions and stress states of materials beneath flexible pavements subjected to moving wheel loads.

As a mechanistic test measuring fundamental material properties, it is often thought preferable to the empirical CBR and *R*-value tests.

Resilient Modulus (M_R)

PaveXpress uses some common empirical expressions used to estimate M_R from CBR and *R*-values:

$$M_R = 2555 \times \mathrm{CBR}^{0.64}$$

$$M_R = 1000 + (555 \times R)$$

Although these equations may help the designer evaluate materials, it is usually best to determine M_R directly through testing, if possible, rather than from the use of correlation equations.

Subgrade Considerations

The Asphalt Institute publication IS-91 gives the following test values for various subgrade qualities:

| Relative Quality	R-Value	California Bearing Ratio	Resilient Modulus (psi)
Good to Excellent	43	17	25,000
Medium	20	8	12,000
Poor	6	3	4,500

Note that different design guides will show different ranges for the various subgrade qualities — use engineering judgment when evaluating subgrade design inputs.

Where Can I Find Traffic Data?

- Many DOTs post their traffic count data online
- Contact the Traffic Division of the DOT
- Contact the Traffic Division of the city, if available
- If no official traffic count is available, conduct a short-term count
- Interview local people and businesses

The bottom line is, try to document in some way why you selected the number for input into the design software.

Vehicle Load Factors

1 18,000 lb axle (truck) = **1929 cars**
1 bus = **2642 cars**
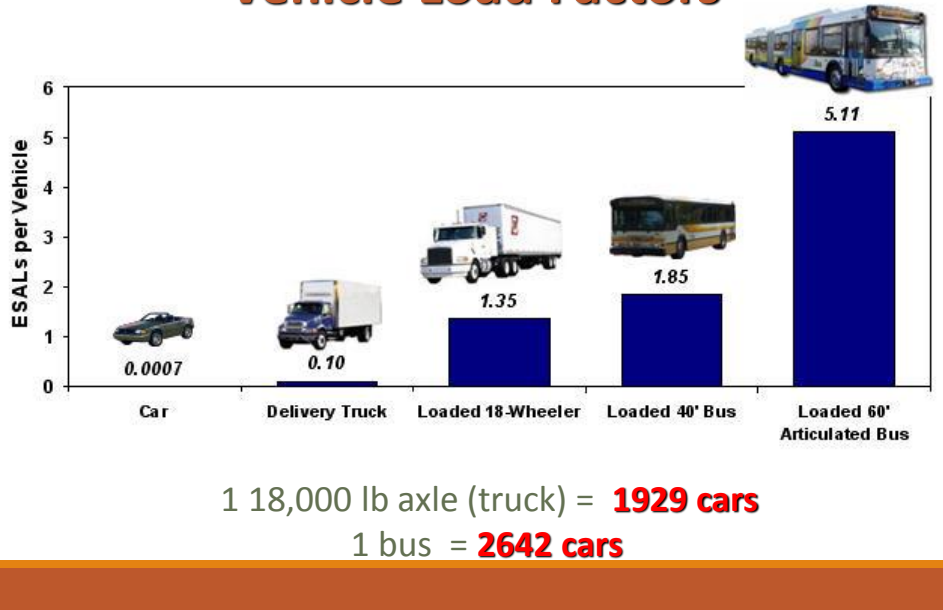
Design Traffic

Ranges in ESALs based on street classification

◦ Arterial - 1,460,000 to 1,825,000

◦ Major Collector – 730,000 to 1,095,000

◦ Minor Collector – 219,000 to 365,000

◦ Local – 58,400 to 73,000

◦ Cul-de-sac – 36,500 to 58,400

Design Traffic

Ranges in ESALs for parking lots

◦ Automobile stalls – 21,900 to 36,500

◦ Secondary drives – 36,500 to 58,400

◦ Primary drives – 58,400 to 73,000

◦ Loading docks – 73,000 to 182,500*

*Anticipated site specific traffic should be evaluated

Pavement Section Alternatives

Full-Depth

◦ Placed directly on prepared subgrade

◦ Thickness generally ranges from 5 to 10 inches

◦ Addition of base layer to be considered if over 10 inches is needed

Pavement Section Alternatives

Flexible Composite

◦ Asphalt over aggregate base course on prepared subgrade

◦ Separation geotextile should be considered on cohesive soils

◦ Edge drains should be considered on cohesive soils

Pavement Section Alternatives

Flexible Composite

◦ Base thickness generally ranges from 6 to 12 inches

◦ General guidance for ratio of aggregate base thickness to hot mix asphalt thickness

   ◦ 2:1 to 2.5:1

Pavement Section Alternatives

Chemically Treated

◦ Asphalt over chemically treated with lime, cement or fly ash

◦ Treated layer part of structural section

   ◦ Requires adequate improved strength (typical min. 160 psi)

◦ Range in thickness – 8 to 12 inches

Pavement Section Alternatives

Mechanically Treated

◦ Asphalt over reinforced granular base

◦ Reinforcement – multi-axial geogrid placed on stable prepared subgrade

◦ Provides for reduction in aggregate base thickness

◦ Starting to be recognized, yet to be officially accepted by most agencies