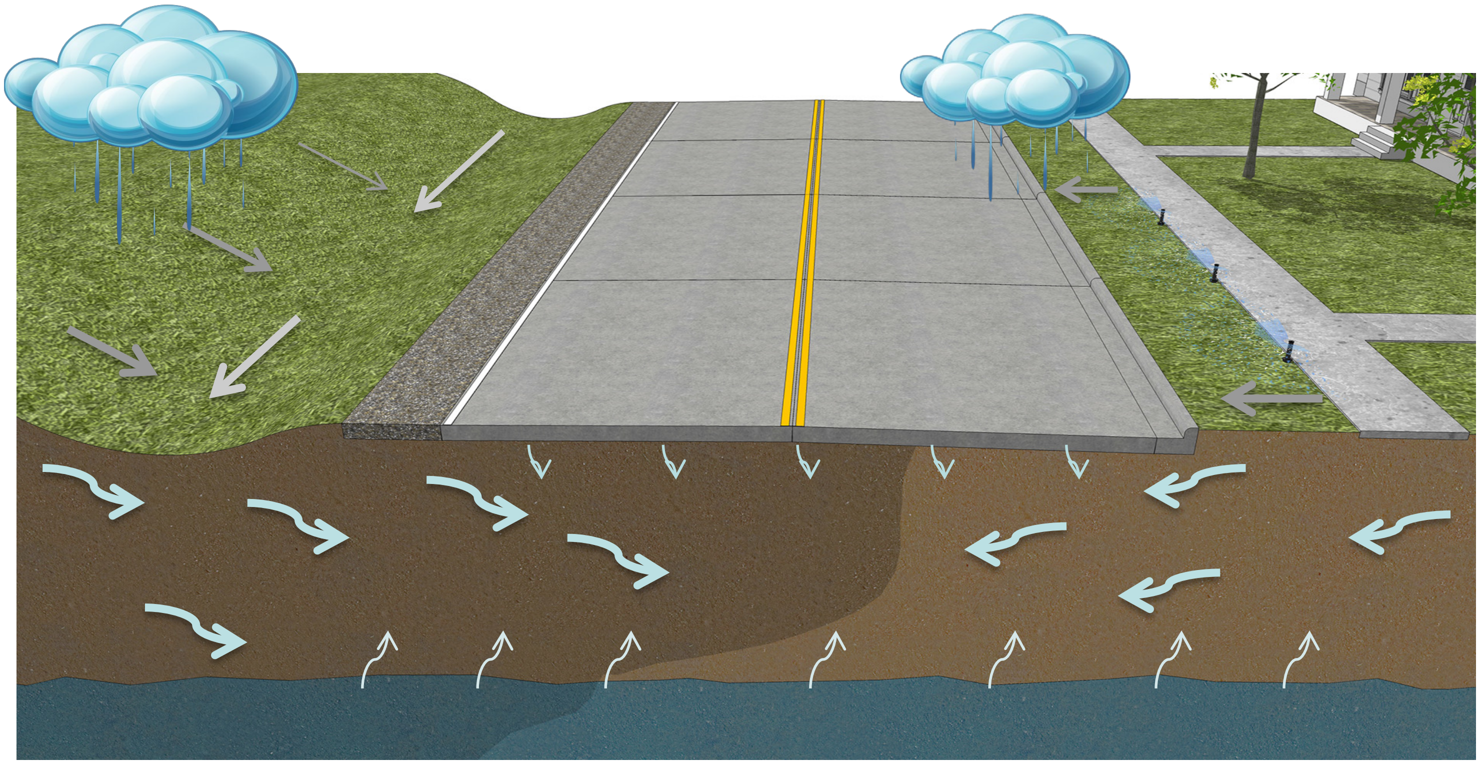
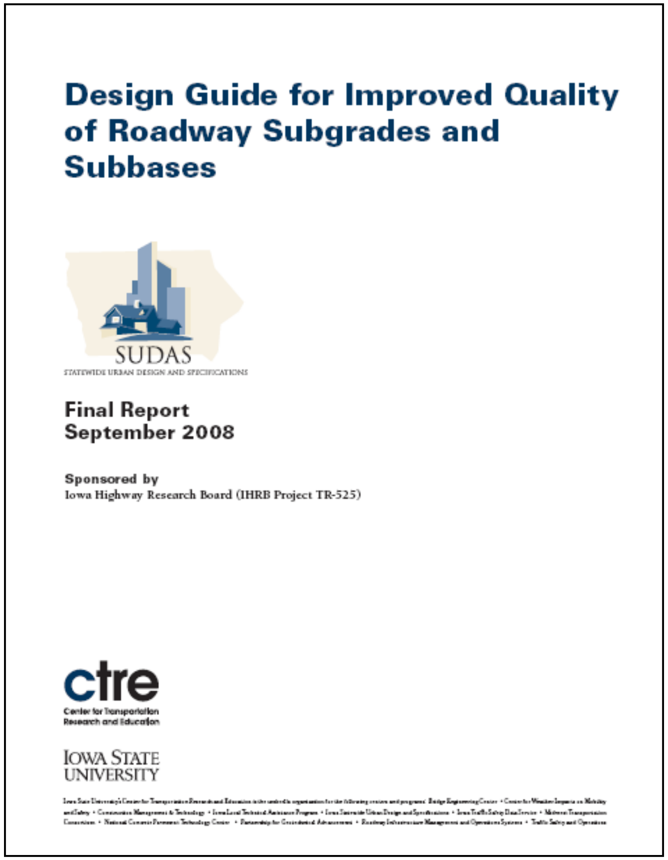
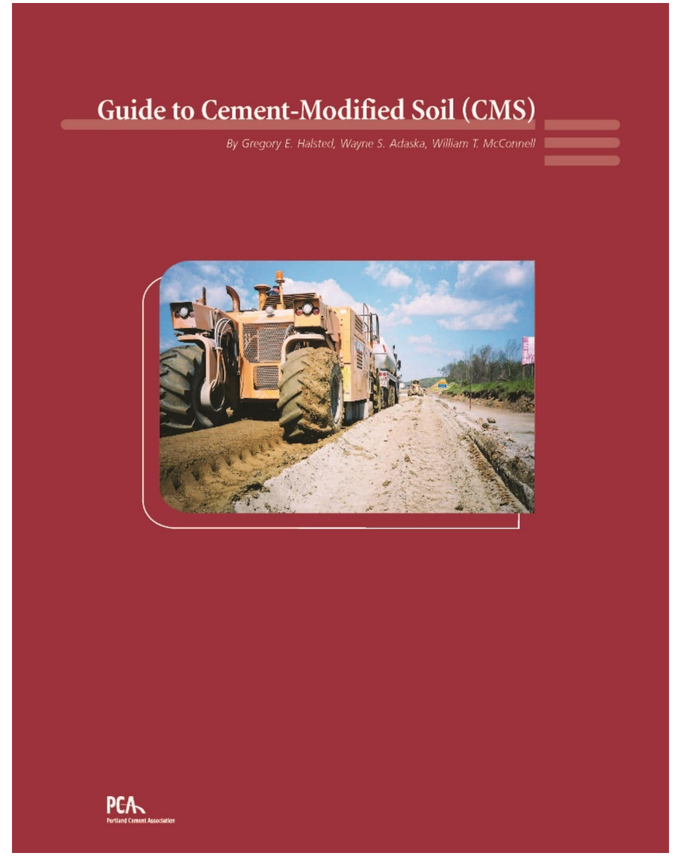
Optimizing Subgrades & Subbases for Concrete Pavements



National Concrete Pavement Technology Center
Iowa's Lunch–Hour Workshop
In cooperation with the Iowa DOT
and the Iowa Concrete Paving Association

Design Guide for Improved Quality of Roadway Subgrades & Subbases





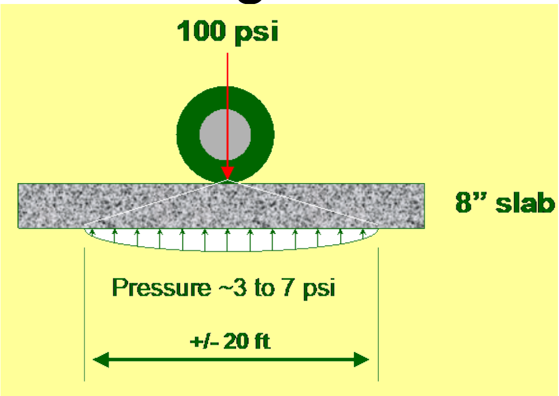
The performance of a pavement depends on the quality of its subgrade and subbase layers and the drainage of these foundation layers; They can play a key role in mitigating the effects of climate and the stresses generated by traffic.

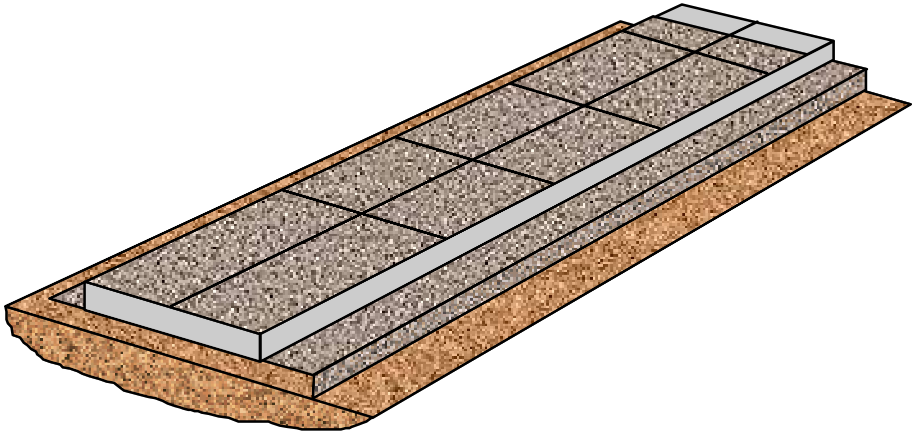
Presentation Items

1. Uniformity
2. Soils
3. Soil Stabilization
4. Subbases (unstabilized)
5. Geosynthetics

Pavement Support Basics

- Firm, uniform, and non-erodible support is essential for concrete pavements
  - Reduces pavement defections from vehicle loadings
  - Avoids stress concentrations
- Must provide a stable working platform to expedite all construction operations
- Subgrade uniformity is more important than strength





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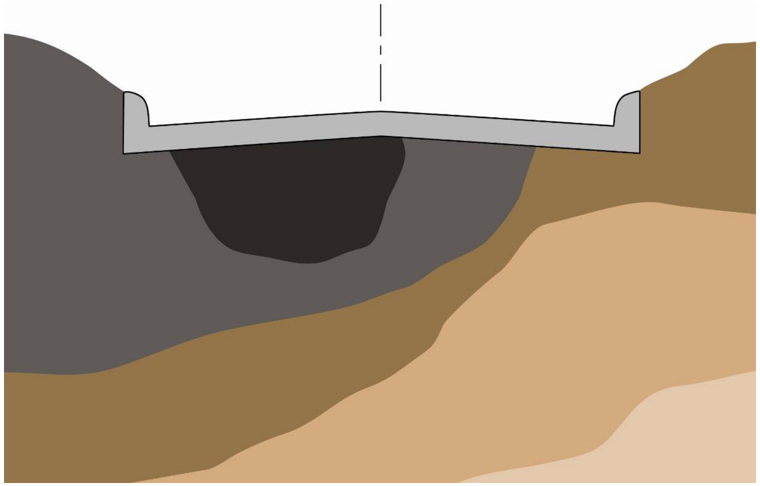
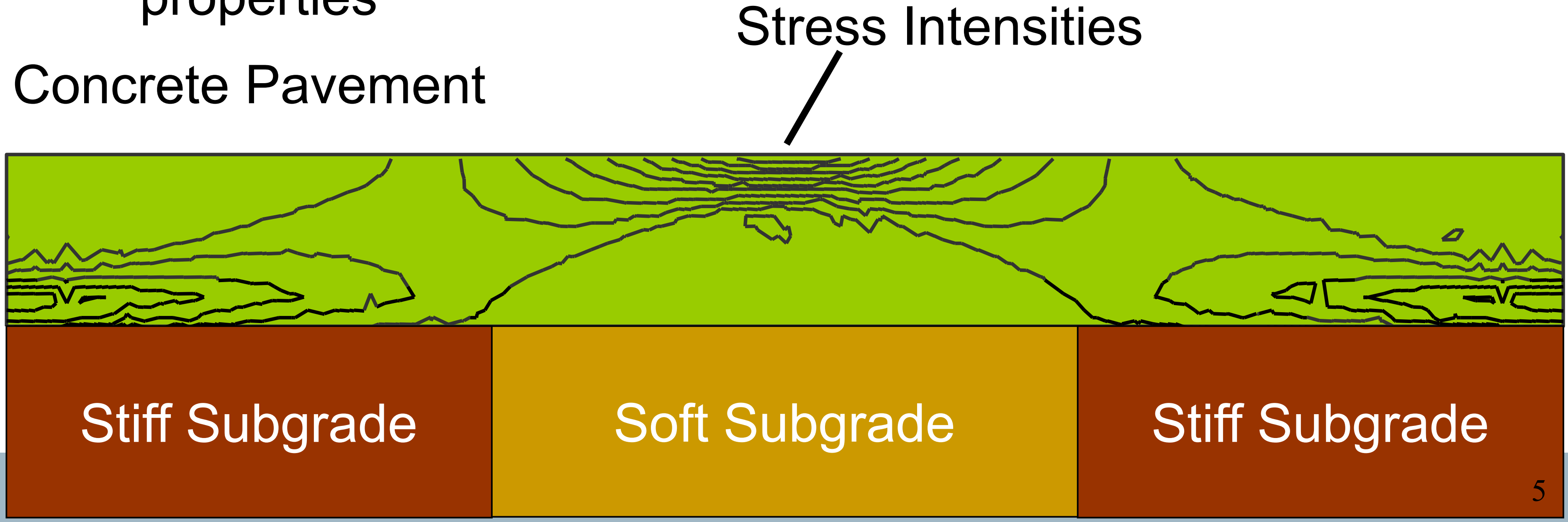
Non-Uniform Subgrade Support

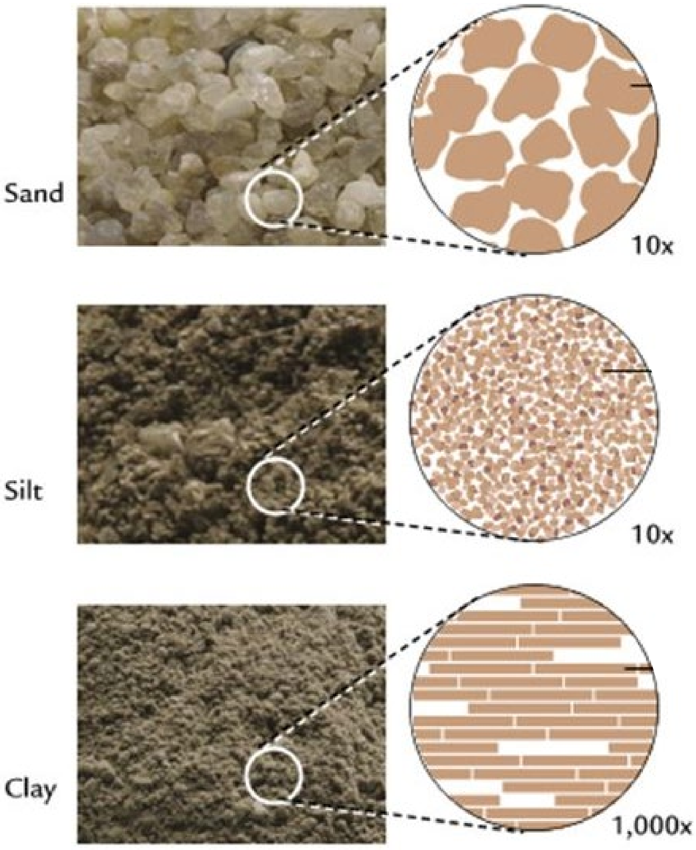
- Non-uniform support results in differential deflections, causing stress concentrations in the pavement
- Have different soil properties

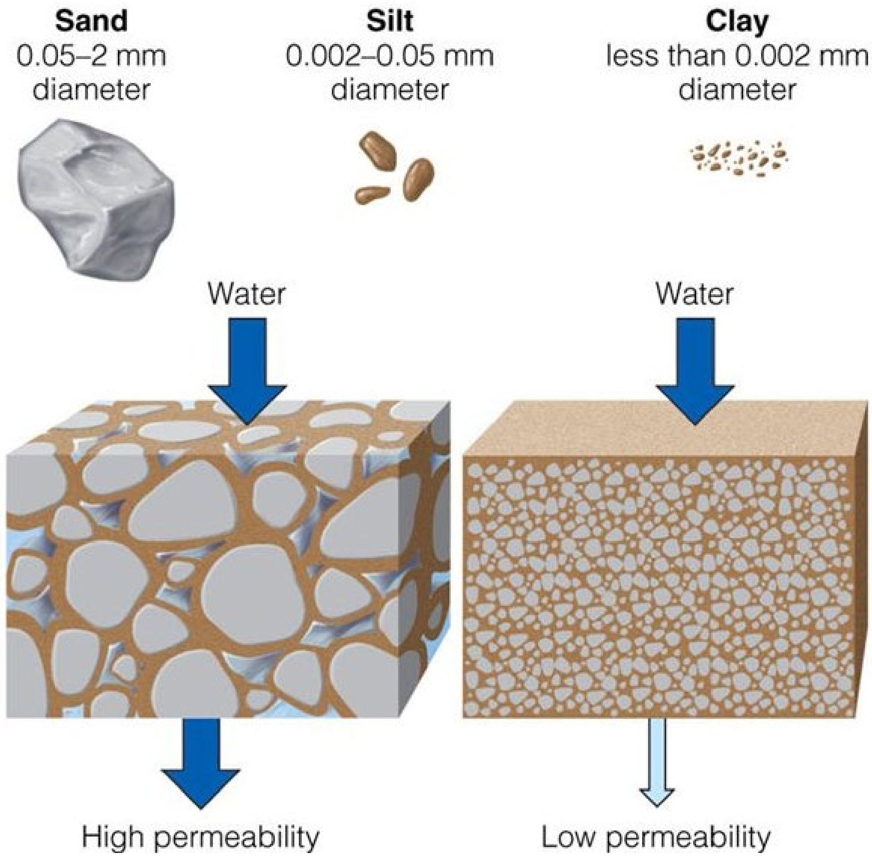




SOILS

Soil Particle Size (by themselves)





Soil Classification

AASHTO CLASSIFICATON	GENERAL DESCRIPTION
A-1	Well graded coarse to fine; non-plastic or feebly plastic; includes coarse without binder
A-1-a	Mostly stone fragments or gravel
A-1-b	Mostly coarse sand; may need added fines for a firm base; suitable or can be made suitable for granular base coarse
A-2-4 A-2-5	Granular with binder characteristics of A-4 and A-5 soils
A-2-6 A-2-7	Granular with binder characteristics of A-6 and A-7 soils
A-2	Soils are inferior to A-1 soils due to poor grading, inferior binder, or both generally are suitable as a blanket for very plastic subgrades slated to receive concrete pavement
A-3	Sands deficient in soil binder and coarse material; equigranular; examples are fine beach or desert blown sands. Water has little affect on A-3 soils
A-4	Composed mostly of silt with only moderate to small amounts of coarse material and only small amounts of clay; can vary texturally from sandy loams to silt to clay loams
A-5	Similar to A-4 except that they include very poorly graded soils containing such things as mica; is a poor stability soil.
A-6	Composed predominately of clay with moderate to negligible amounts of coarse material; have low stability at high moisture contents but are pretty stable otherwise; show shrinkage cracks during dry weather; is a good soil other than the fact that it has great affinity for water
A-7	Composed predominately of clay like A-6 but due to the presence of one-size silt particles, organic matter, mica flakes, or lime carbonate, is elastic
A-7-5	Moderate plasticity indexes; may be highly elastic. P.I. less than or equal to L.L. –30
A-7-6	High plasticity indexes P.I. greater than L.L. –30

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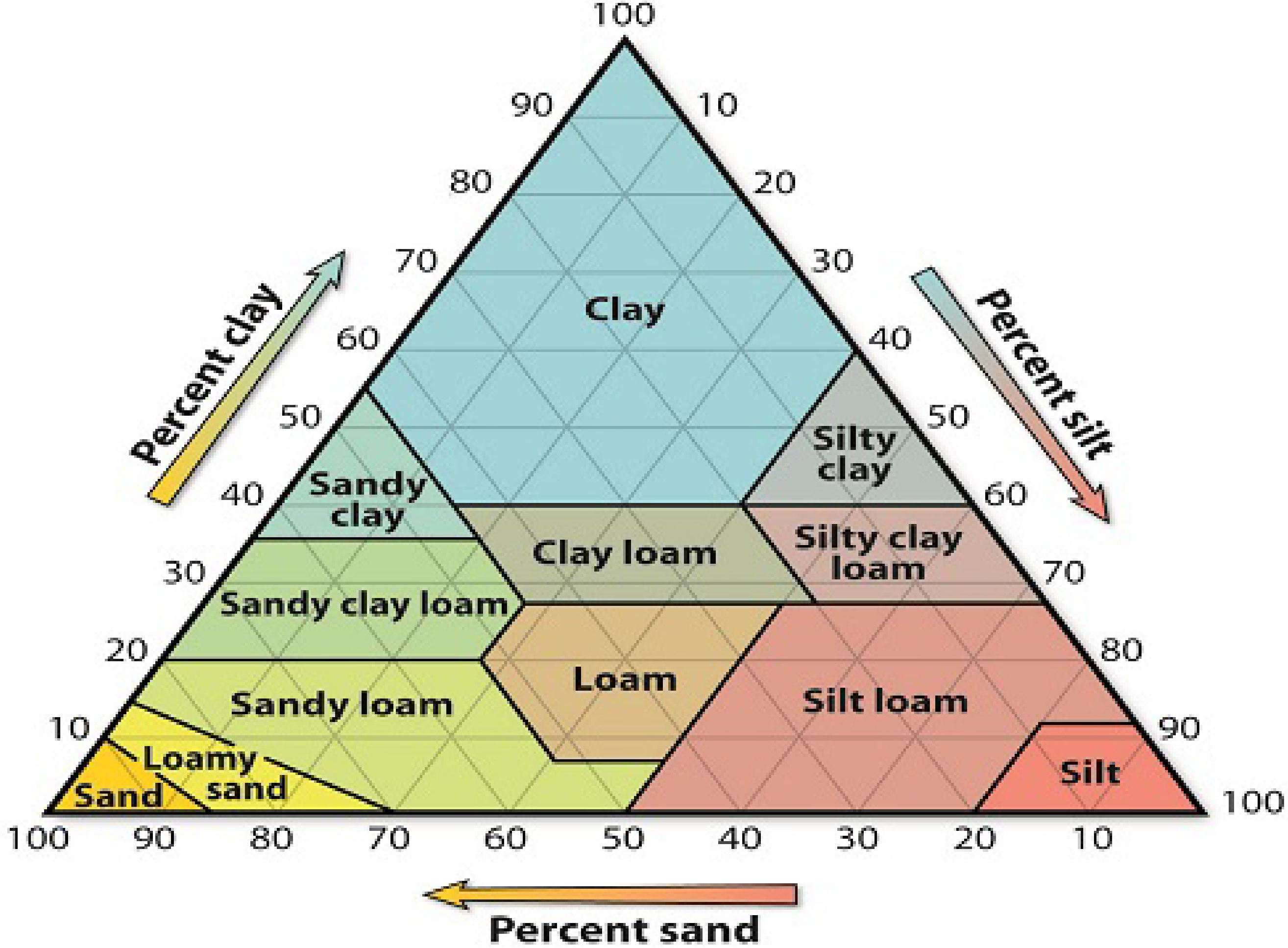
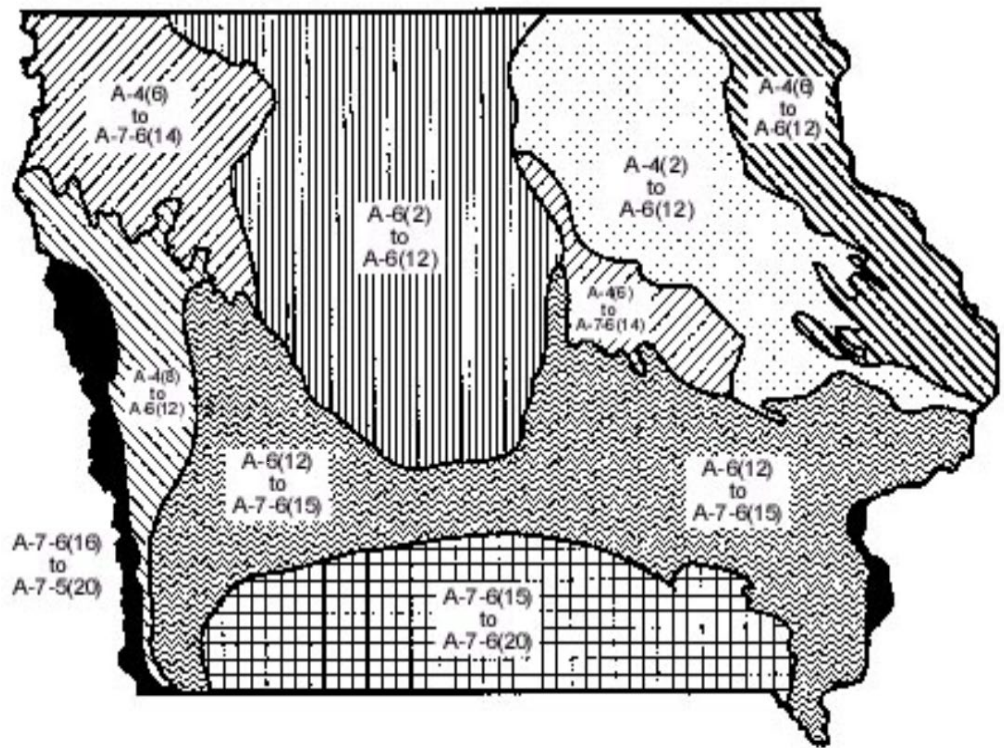
Soil Texture Triangle



This is the textural triangle. If you know the percent clay (flat line) and percent sand or silt, you can draw lines into the triangle to figure out what textural catergory the soil belongs too.

AASHTO Distribution of Iowa Soil



A-4 through A-7 = Subgrade rating of Fair to Poor

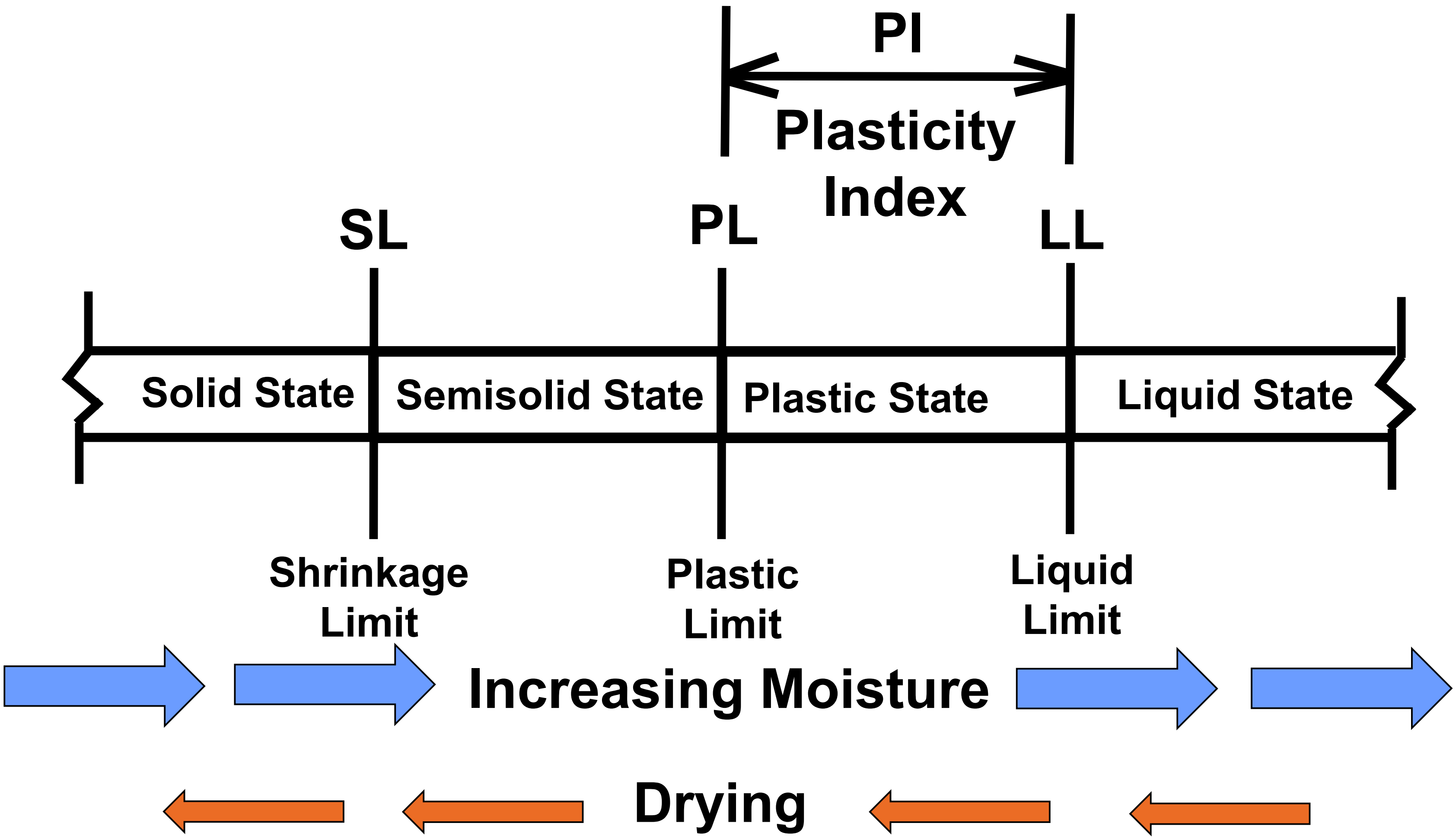
A-4 soils are predominantly silts with variable amounts of granular material or clay and some plasticity. Their strength varies with moisture content. These soils are very susceptible to frost heaving when located over sand pockets holding water in glacial till. They are very susceptible to erosion.

A-5 soils are silty soils with moderate liquid limit (40 max)

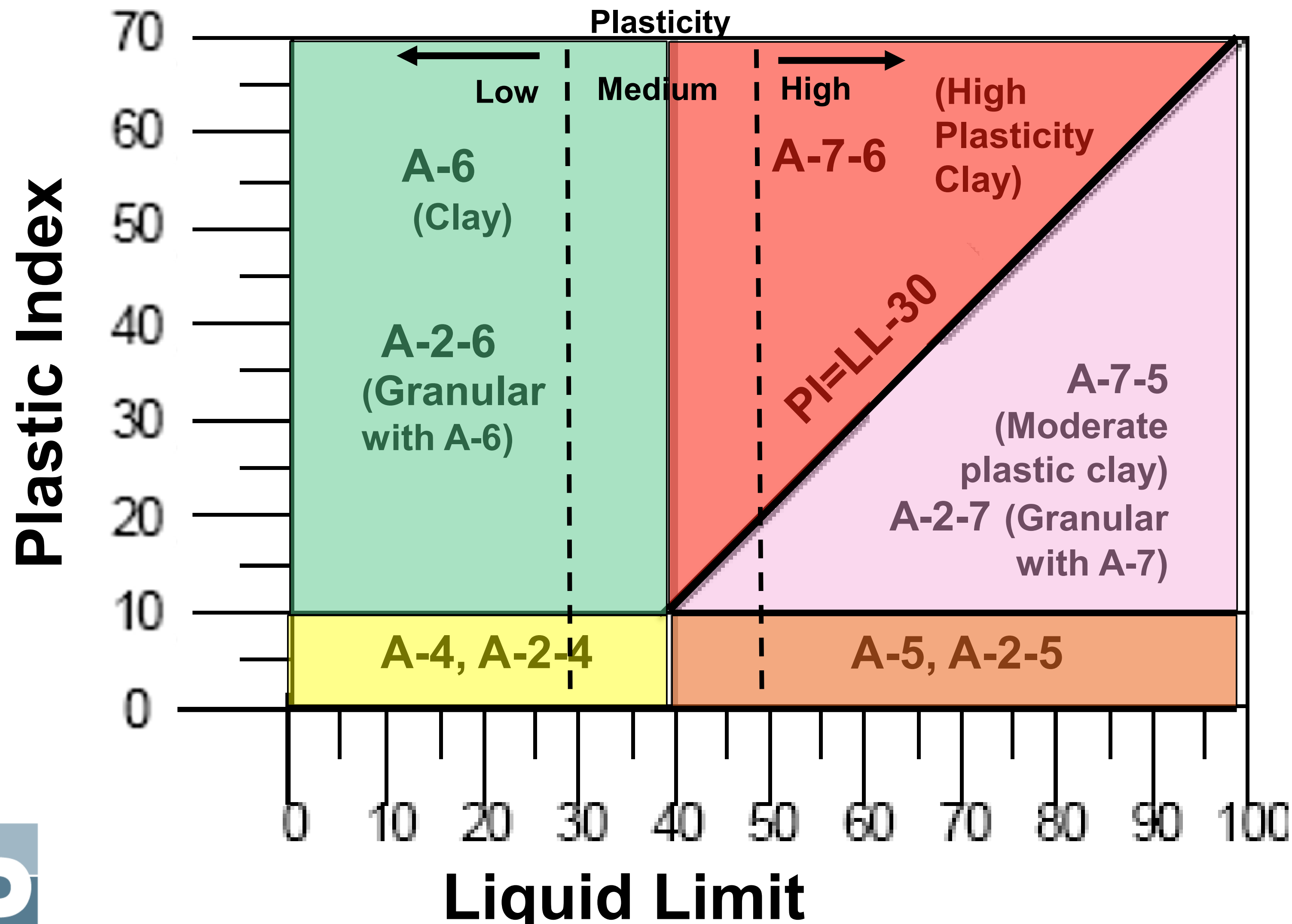
A-6 soils are clay soils with higher liquid limit (41 min)

A-7 soils are predominantly clay with variable amounts of granular material or silt. They are highly plastic and their strength varies appreciably with moisture content. They are also expansive.

SL=Shrinkage Limit (While drying, no more shrinkage)
PL=Plastic Limit (Beginning of Plastic State. The higher, the more swelling)
LL=Liquid Limit (Beginning of Liquid State. The higher, the greater compressibility)
PI=Plasticity Index (LL-PL) (The higher, the more plastic the soil and higher swell)



AASHTO Criteria



Cohesive Soils (Plastic)

- The consistency of these soils can range from a dry, solid state to a wet, liquid state with the addition of water.
- Eventually, all of the empty pores will be occupied by water and the addition of any more water will cause the system to expand.
- If the addition of water occurs in small enough steps, the consistency of silts and clays can be seen passing from solid to semisolid to plastic and to liquid.

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Organic Soils

Any soil that contains a sufficient amount of organic matter to influence the engineering properties is called organic soil.

As a result, organic soils have the following characteristics:

- Have a lower density than other mineral soils
- May have a low shear strength
- May be highly compressible
- Can be very difficult to compact
- May continue to degrade over time

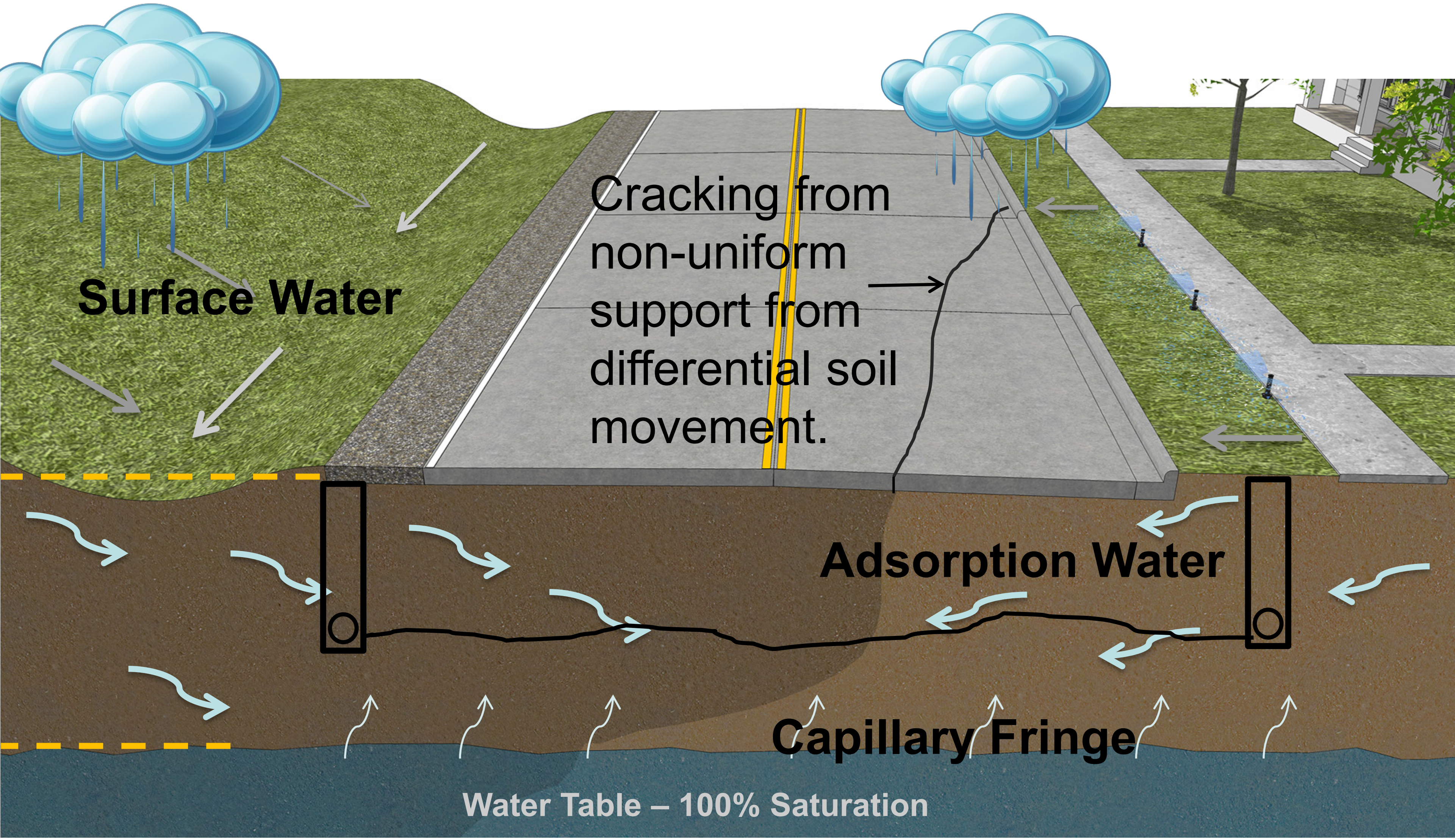
Unsuitable Soils

Definition	Use
1. Peat or Muck. 2. Soils with a plasticity index of 35 or greater. 3. A-7-5 or A-5 having a density less than 85 pcf (1350 kg/m^3) (AASHTO T 99 Proctor Density or Materials I.M. 309).	Slope Dressing Only.
1. All soils other than A-7-5 or A-5 having a density of 95 pcf (1500 kg/m^3) or less (AASHTO T 99 Proctor Density or Materials I.M. 309). 2. All soils other than A-7-5 or A-5 containing 3.0% or more carbon.	Type C placement placed 3 feet (1 m) below top of subgrade in fills.
1. A-7-6 (30 or greater). 2. Residual clays (overlaying bedrock), Paleosols, gumbo, and gumbotils regardless of classification.	Type B placement placed 5 feet (1.5 m) below top of subgrade in fills.
1. Shale 2. A-7-5 or A-5 soils having a density greater than 86 pcf (1351 kg/m^3) but less than 95 pcf (1500 kg/m^3) (AASHTO T 99 Proctor Density or Office or Materials I.M. 309).	Type A placement placed in layers 5 feet (1.5 m) below top of subgrade in fills (Alternate layers to consist of suitable soils or Type C placement soils).

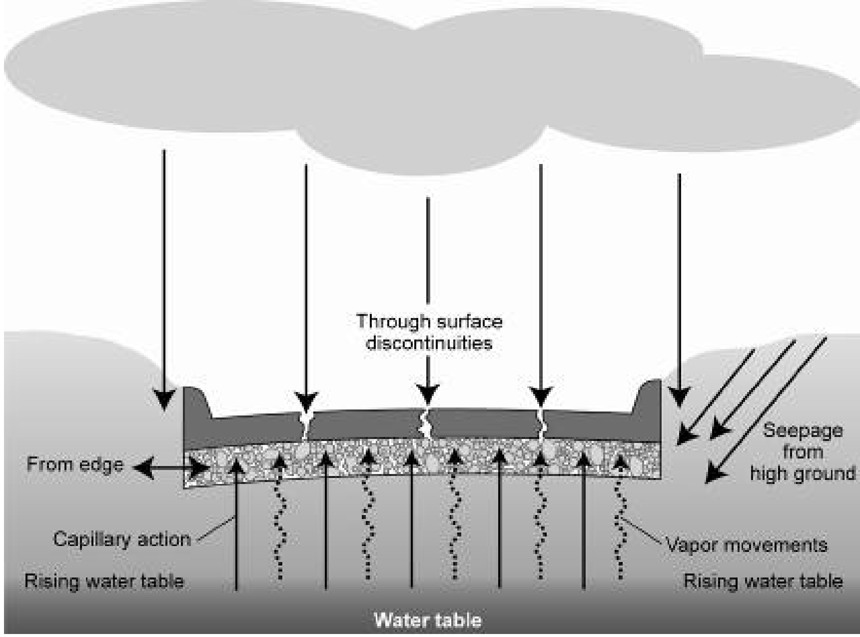
Iowa DOT Table 2102.02-1: Uses for Unsuitable Soils

(SUDAS – Not allowed in ROW)

Water Sources



Water Movement

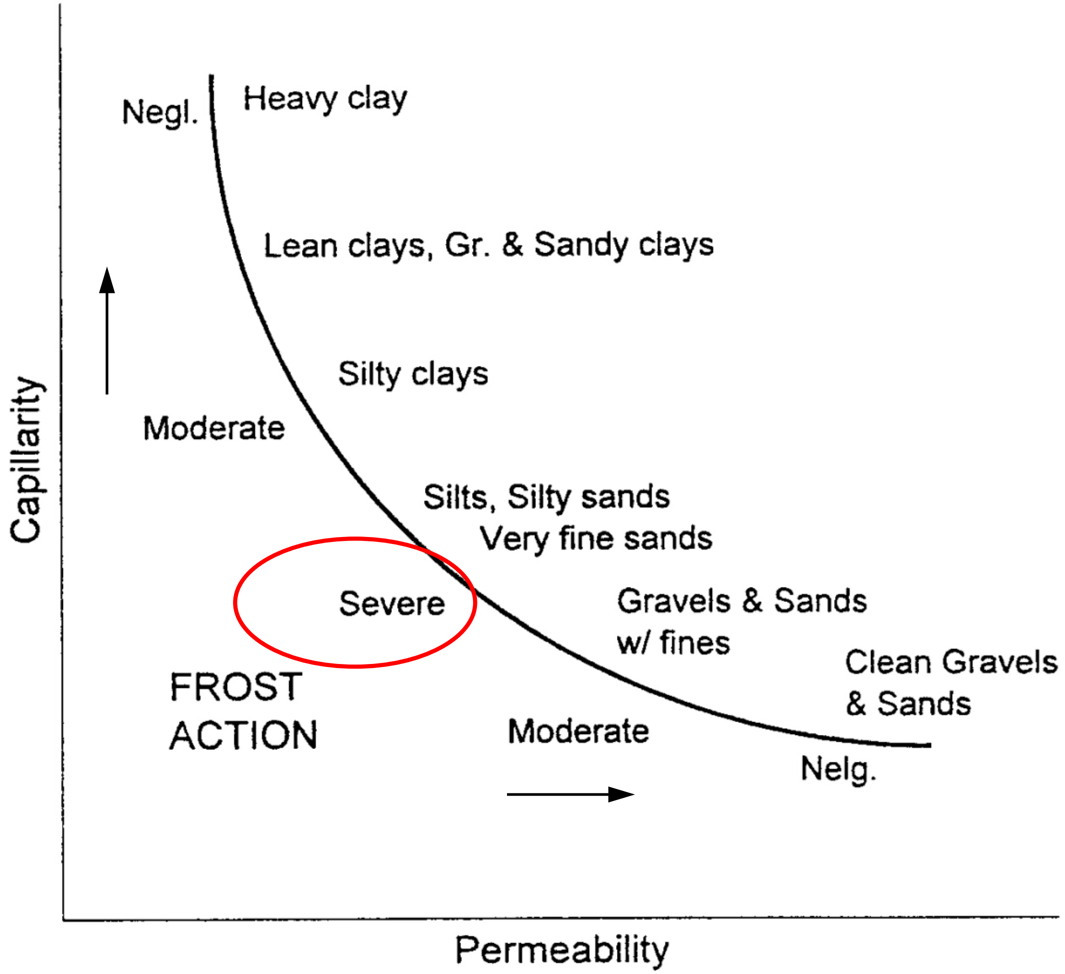


- Capillary Action;
  Movement of water in narrow soil pores through intermolecular attractive forces between the soil and water.

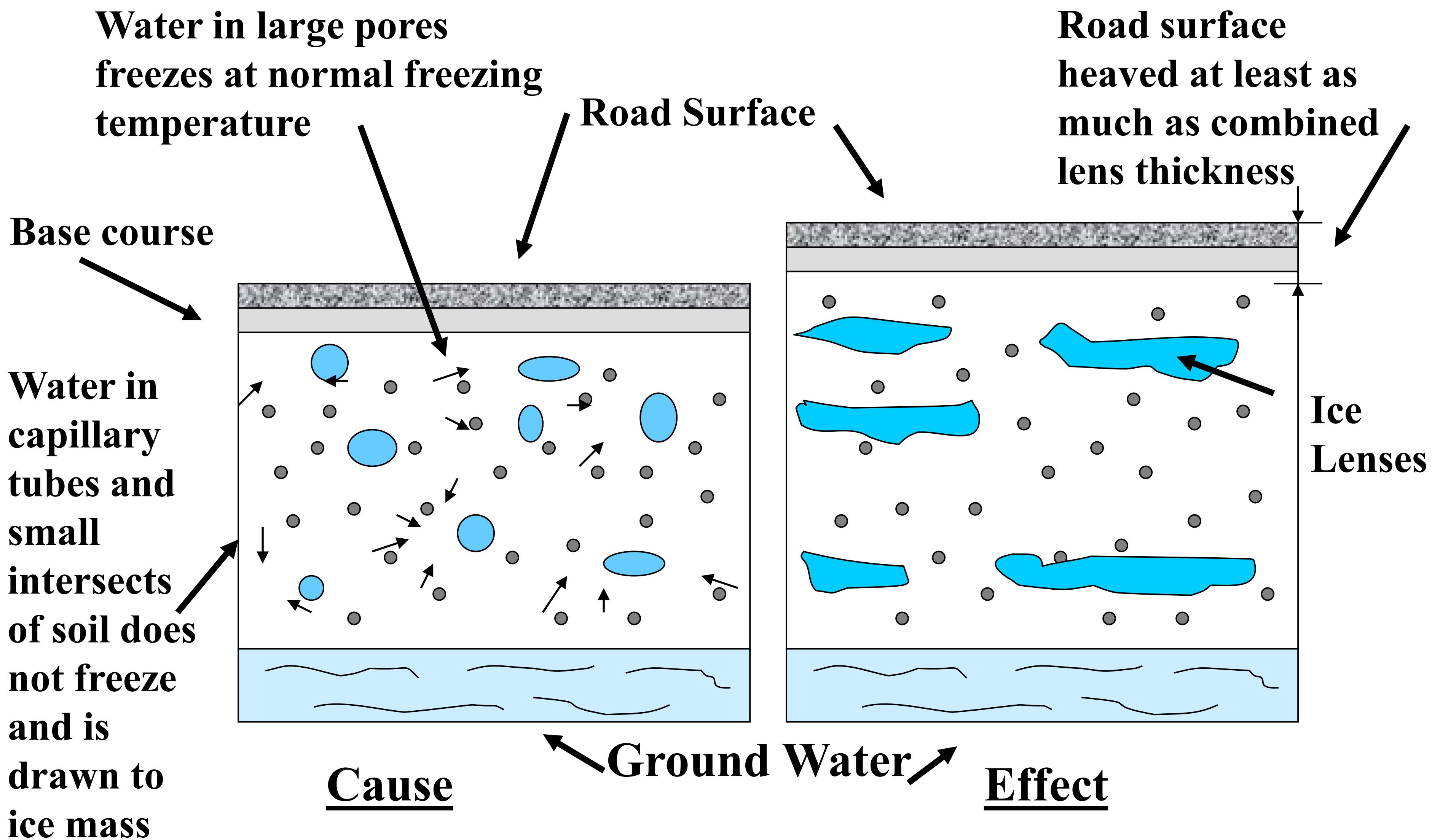
- Pore Pressure- During compaction of the soil the pores become smaller and the water bonded to the soil loosens and becomes unbounded free water causing the pressure to rise, resulting in the rising of the free water.

Capillarity, Permeability, and Frost Action

- The finer the grain, the higher the capillarity
  - Very little air content between grains
  - Pore network affect permeability.
  - The simpler the network the higher the permeability



Frost Heave



Water in large pores freezes at normal freezing temperature
Road Surface
Road surface heaved at least as much as combined lens thickness
Base course
Water in capillary tubes and small intersects of soil does not freeze and is drawn to ice mass
Ice Lenses
Ground Water
Cause
Effect

Compaction of Soils

Why compact the soil?

- Removes air and moisture
- Well compacted soils minimize the amount of moisture moving through
- Reduces settlement
- Increases bearing capacity
- Reduces frost heave if soil freezes
- Reduces expansion and contraction

California Bearing Ratio (CBR)

Modulus of Subgrade Reaction (k)

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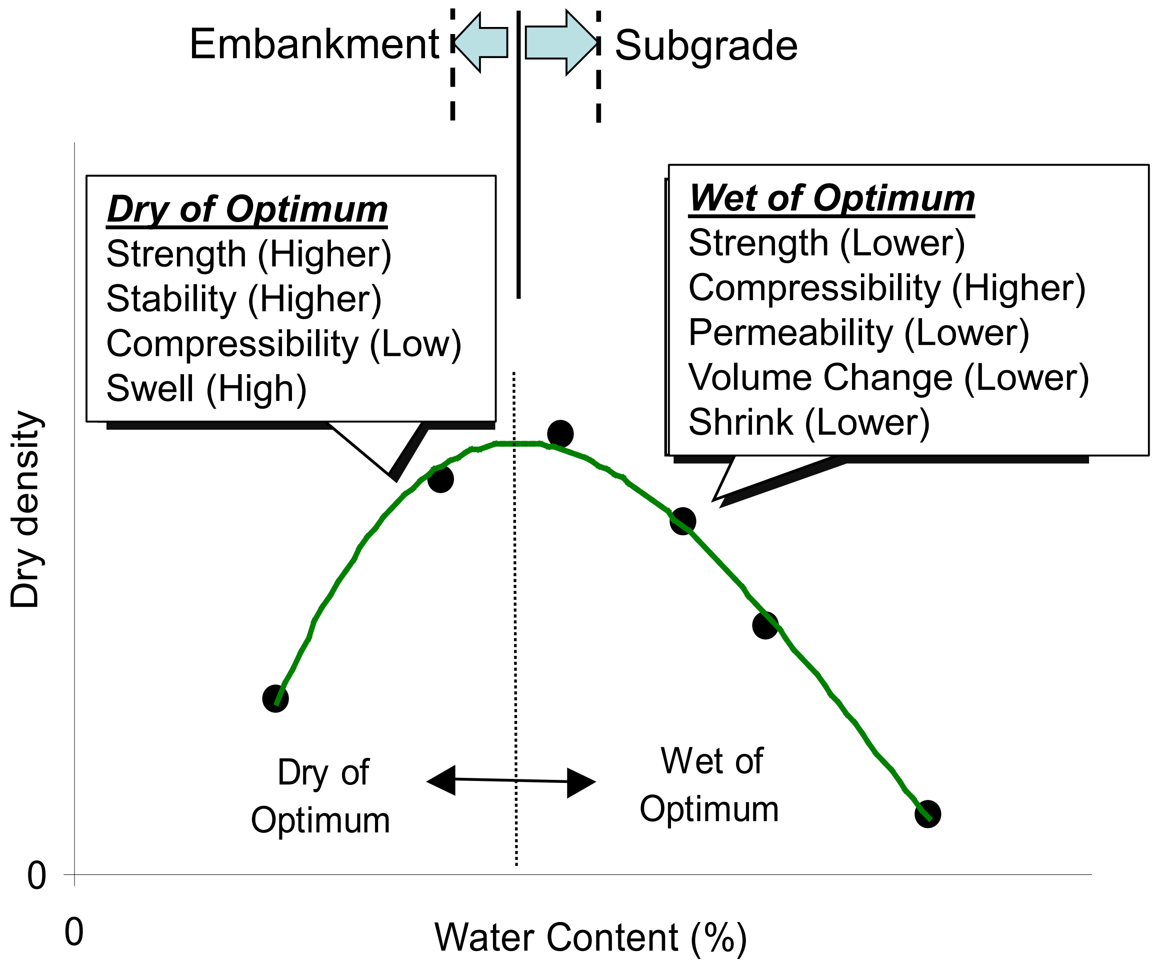
Influence of Moisture on Engineering Properties



- Want to achieve
  - High strength
  - Low compressibility
  - Low Shrink/Swell potential

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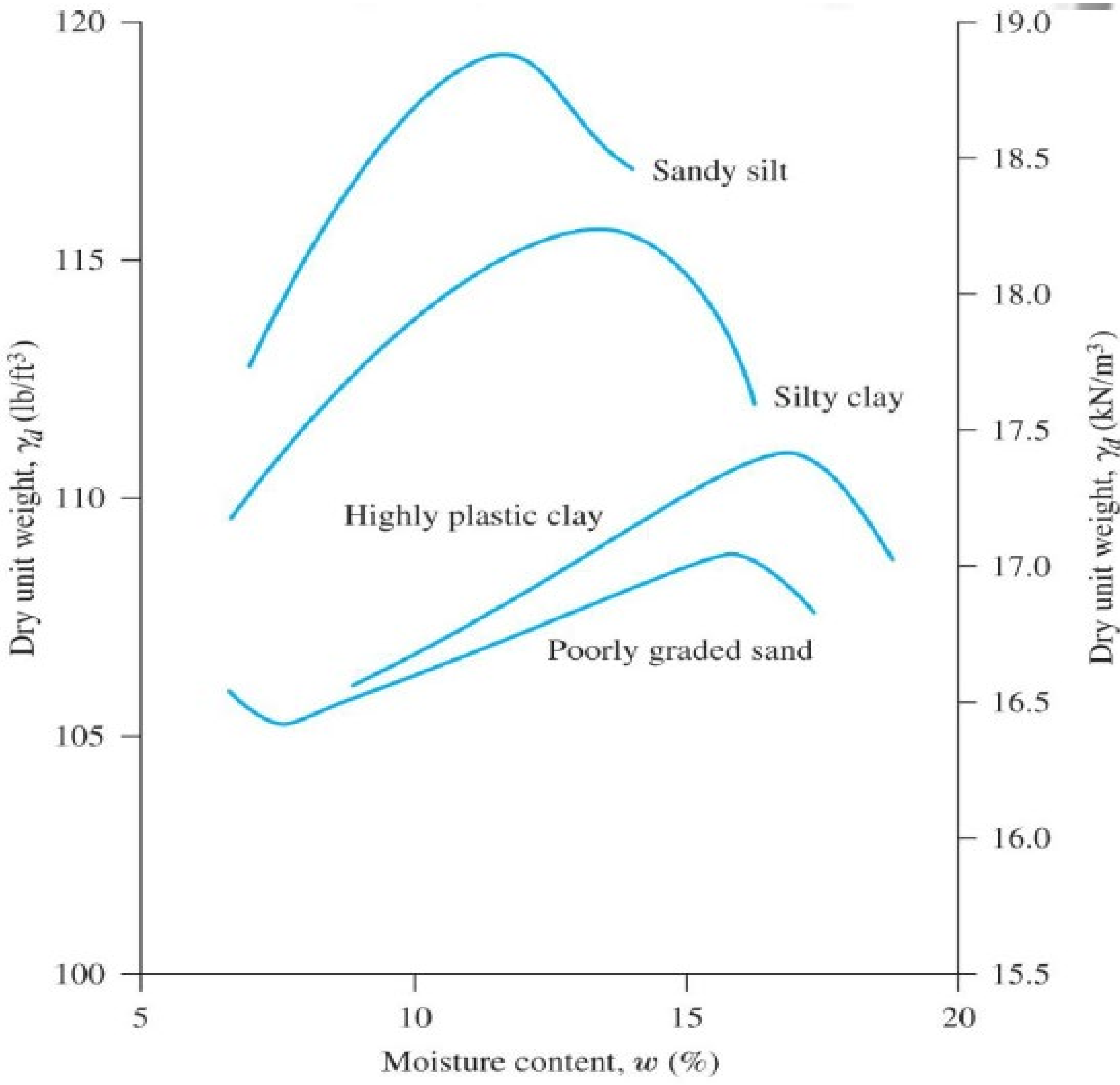
M & D for Different Soils



Subgrade Testing – Compaction with M & D

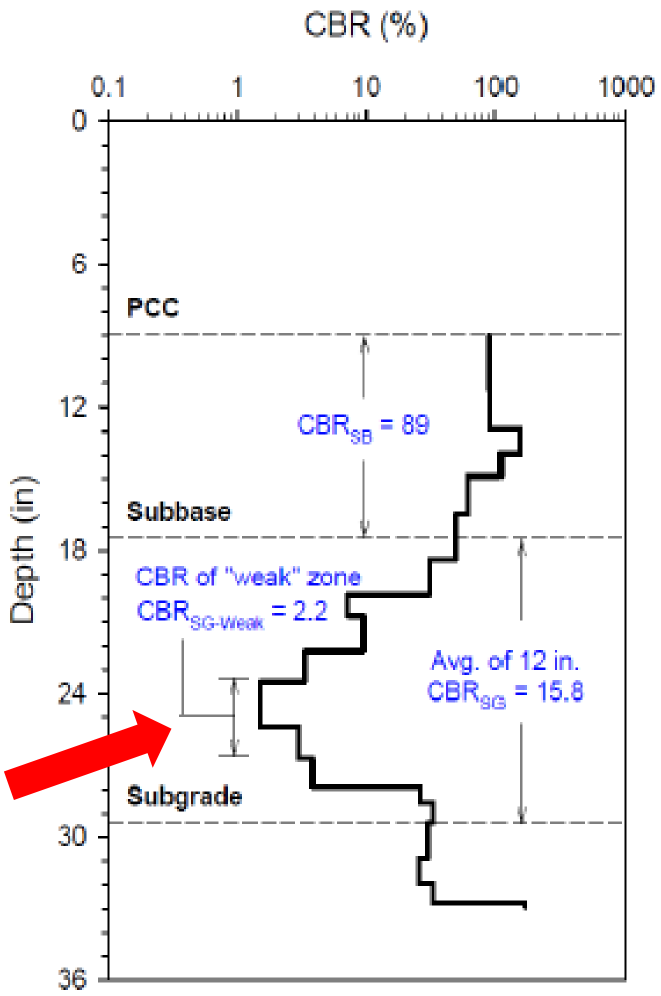
- Compact to 95% of maximum Standard Proctor Density
- Ensure moisture content is within range of optimum moisture to 4% above optimum (SUDAS)

Test soil strength with CBR Test

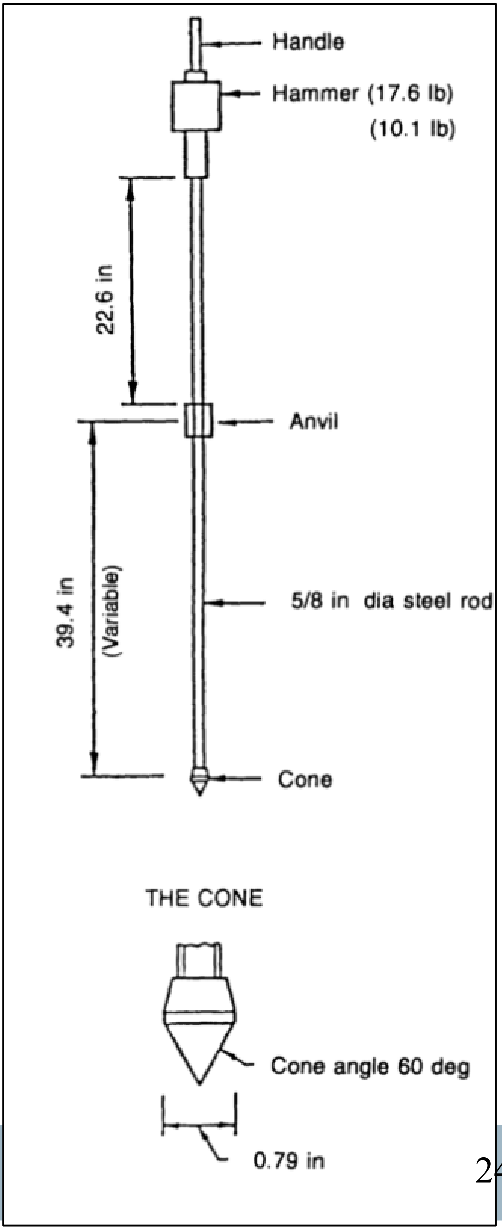
- Compares soil bearing capacity vs. well graded crushed stone
- High quality crushed stone CBR = 100%
- Typically 3-4 in Iowa

Source: ELE International

Dynamic Cone Penetrometer (DCP)



Weak Zone



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Subgrade Testing – Proof Roll

Proof Roll

- loaded single axel (20,000 pounds)
- loaded tandem axle (34,000 pounds)
- 10 mph

Unstable if:

- soil wave in front of load
- rutting >2 inches


Source; Geomax Soil Stabilization

Working Platform Problems

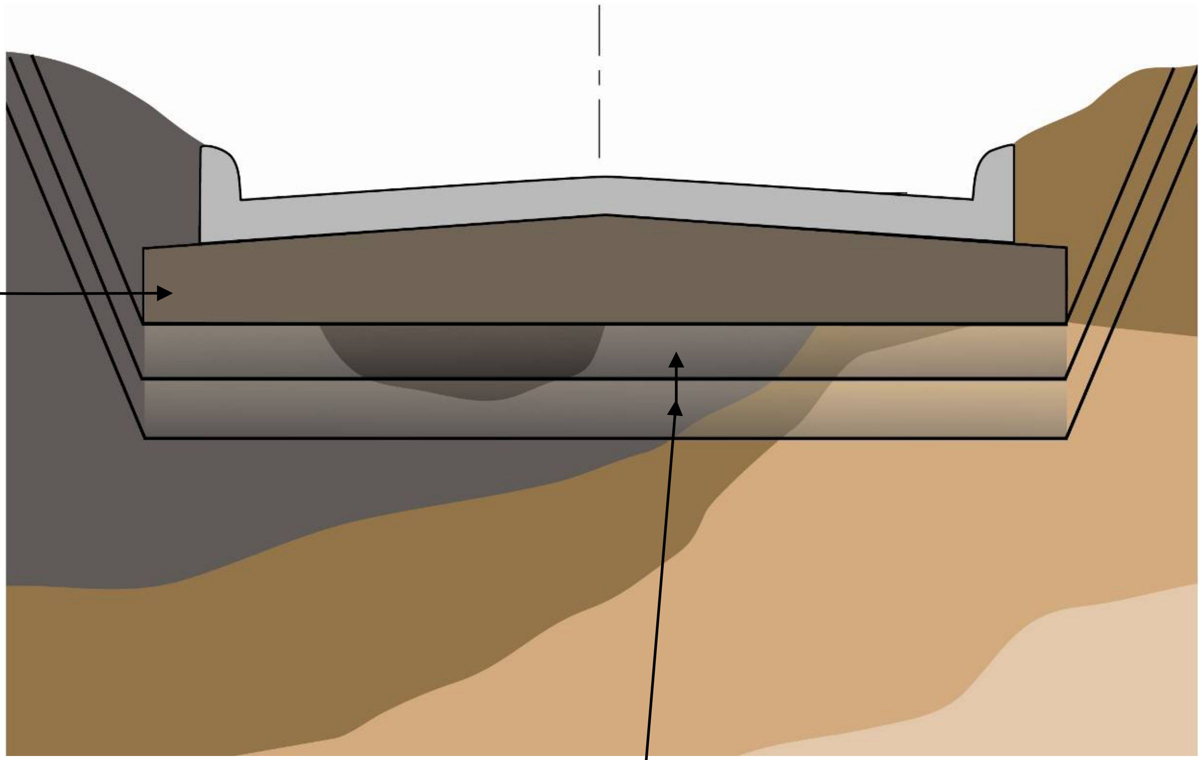
- High Plasticity = High Plasticity Index = Instability
- Expansive clays = Volume change
- Weak soils = Poor bearing capacity
- Wet/soft subgrade = Poor support

Soil Improvement Options

1. Scarify and drying
2. Blending soil
3. Add geogrid and subbase
4. Add chemical stabilization
5. Remove unsuitable and replace with select material in at least upper 2’

Subgrades – Proper Compaction and Consolidation to Prevent Settlement

12” Subgrade Preparation



Blend non-uniform soil in 8” lifts and provide M&D at 95% standard proctor density

Geogrids

Geogrid + aggregate subbase:

- Creates stronger composite structure
- Minimizes subbase fill
- Serves as construction platform
- Extends service life

Source: Geofabrics

<u>SUDAS Specification 2010 or Iowa DOT 4196.01B</u>

- Rectangular or Triangular
- Max. Aperture size 2”
- Min. Aperture size 0.5”
- Min. Tensile strength @2% strain 250 lbs/ft
- Min. Ultimate junction strength 800 lbs/ft

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Chemical Soil Stabilization Options

<u>Soil Stabilization:</u>
To amend the undesirable properties of poor native soils to make suitable for construction

Fly Ash
- Class C 15-18%

Quick lime
- High quality 3-4%
- Dolomite quicklime 6-8%

Cement Modified Soils (CMS)
- Cement 2-3%

Fly Ash & Lime

Fly Ash

- Some concern for weakening in spring thaw
- May tend to group clay particles together and make more frost susceptible
- Recommend compaction within 2 hours

Quicklime

- Has slower reaction than Fly Ash
- If applied to dry soil, it can expand later

Both create a working platform

Source: Boone County Expo Research Study

Cement Modified Soils (CMS)

Use 2 - 3% Cement

1. Provides Uniformity
2. Provides Working Platform
3. Provides bonding of particles
4. Reduces Shrink-Swell Potential of Clay Soils
5. Wet cohesive soils may require disking to cut in cement
6. All operations in one day
7. May be applied in dry or slurry form

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Source: PCA

Chemical Soil Stabilization Construction

- Recommend placement in temperatures above 40ºF otherwise it sits dormant
- Blend in soil with rotary mixer
- Use sheepsfoot roller for initial roll, then smooth drum roller
- Shape with motor grader to final crown and grade

Effect of 3%Cement on Cohesive Soils

SL=Shrinkage Limit (While drying, no more shrinkage)
PL=Plastic Limit (Beginning of Plastic State. The higher, the more swelling)
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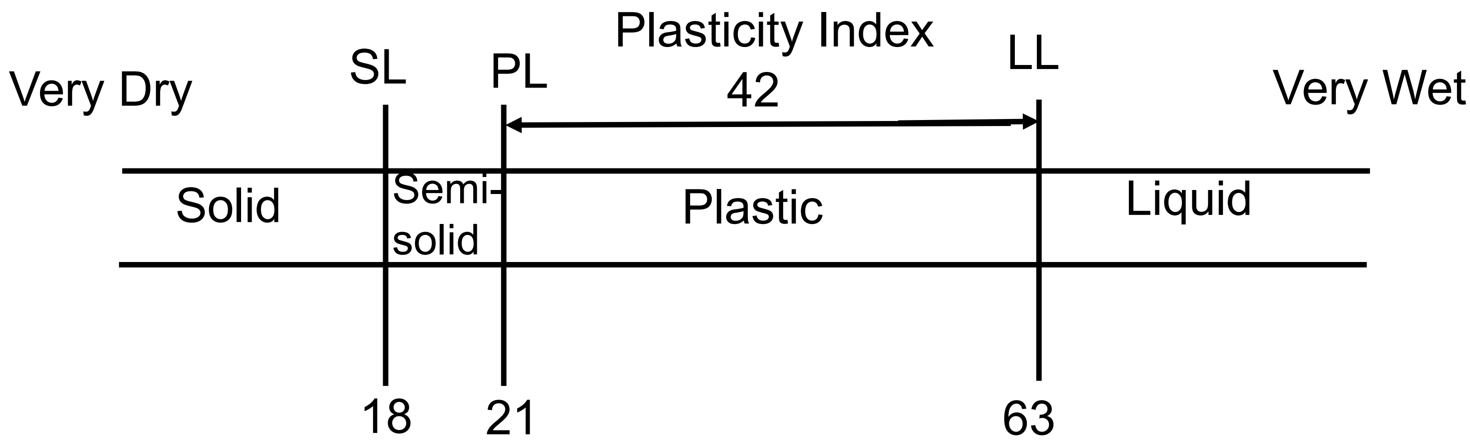
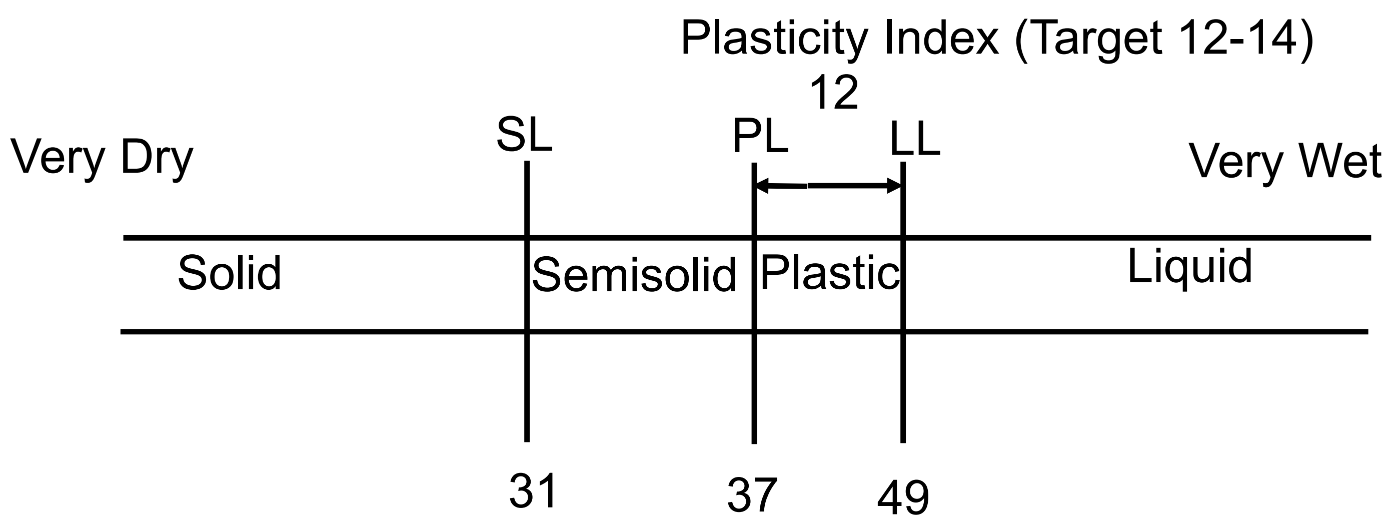
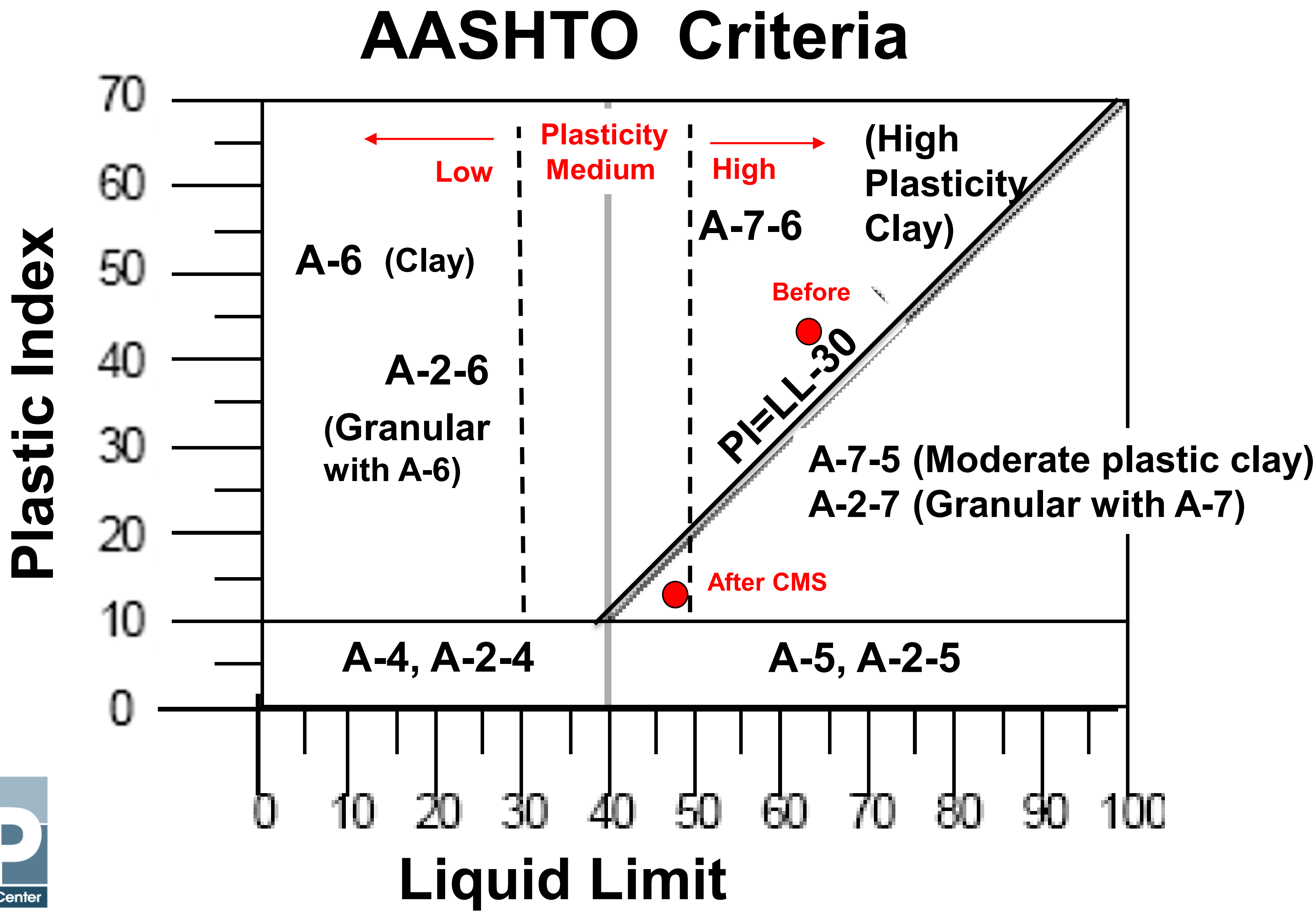
Before CMS



7 days after adding 3% cement



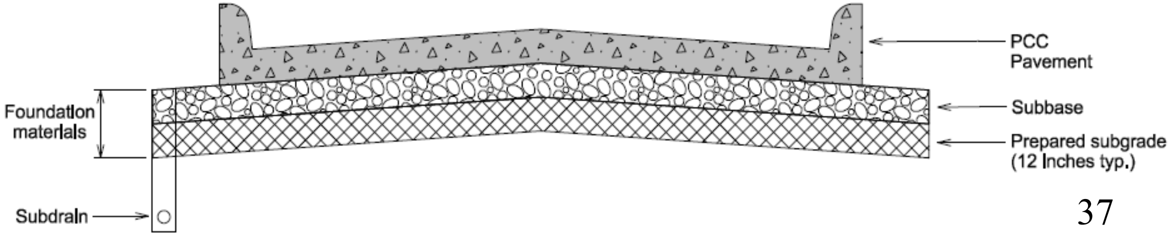
Effect of Cement on Cohesive Soils



SUBBASES (UNSTABILIZED)

Subbases

- Used when soil is reasonably stable & not excessively wet.
- Provides a working platform during construction
- Provides uniformity as a support layer
- Serves as a drainage system to help drain surface water away from the pavement
- Provides a cutoff layer from subsurface moisture (and risk for pumping)
- Reduces shrink and swell of high volume change soils
- A subdrain and outlet system needs to be provided



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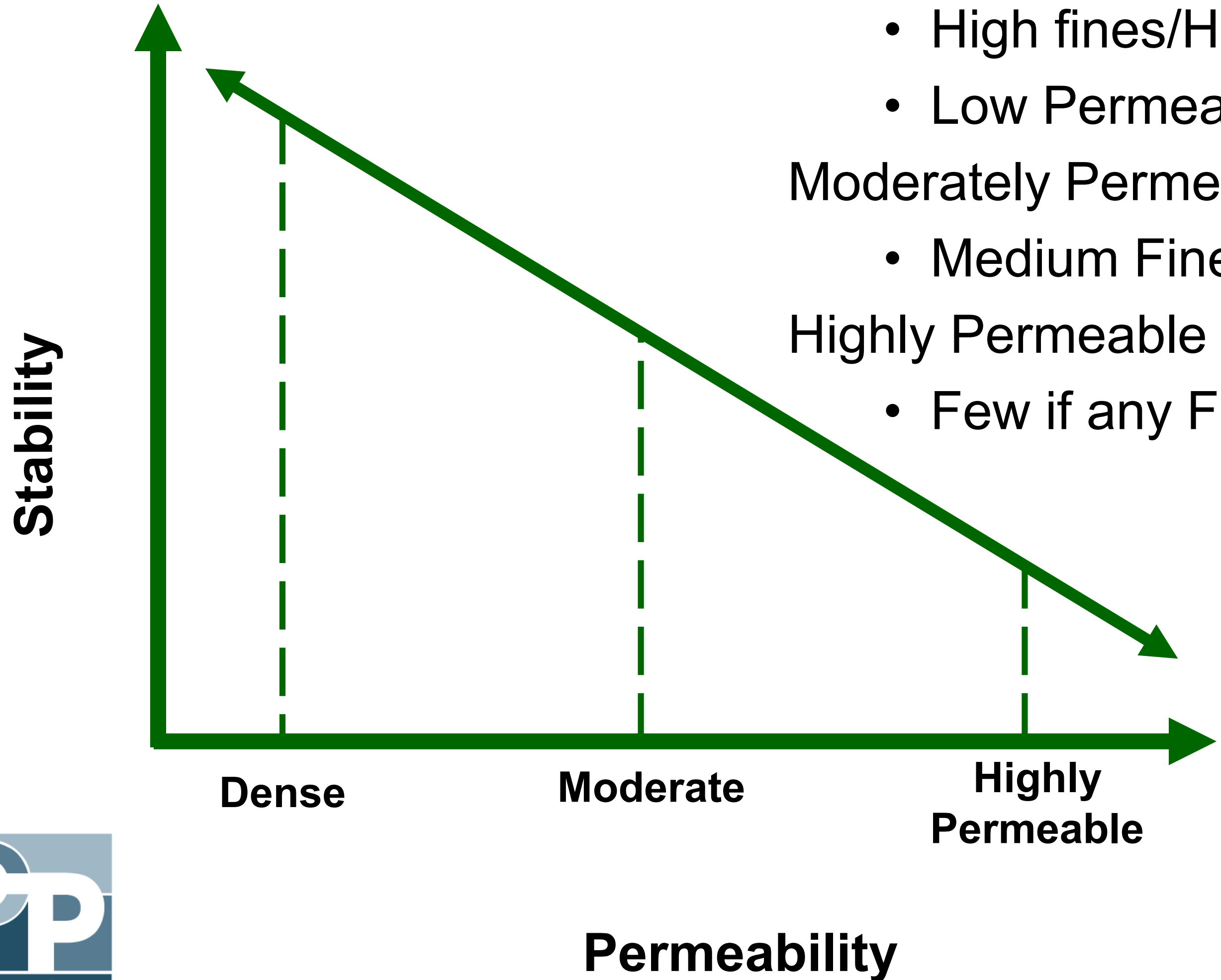
Granular Subbases Stability versus Permeability



Dense stable (Class "A")

- High fines/High Stability
- Low Permeability

Moderately Permeable (Modified Subbase)

- Medium Fines/Medium Stability

Highly Permeable (Granular Subbase)

- Few if any Fines/Low stability

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NEW RESEARCH FINDINGS ON PAVEMENT SUPPORT LAYERS

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IHRB TR–640 Optimizing Pavement Base, Subbase and Subgrade Layers for Cost and Performance on Local Roads


DRAFT

Optimizing Pavement Base, Subbase and Subgrade Layers for Cost and Performance on Local Roads

JULY 2013

Final Report

CENTER FOR CEER EARTHWORKS ENGINEERING RESEARCH

National Concrete Pavement Technology Center

IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Iowa Highway Research Board
(IHRB Project TR-640)
Iowa Department of Transportation
(InTrans Project 11-422)

Field Investigation

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Associate Professor
Director, CEER

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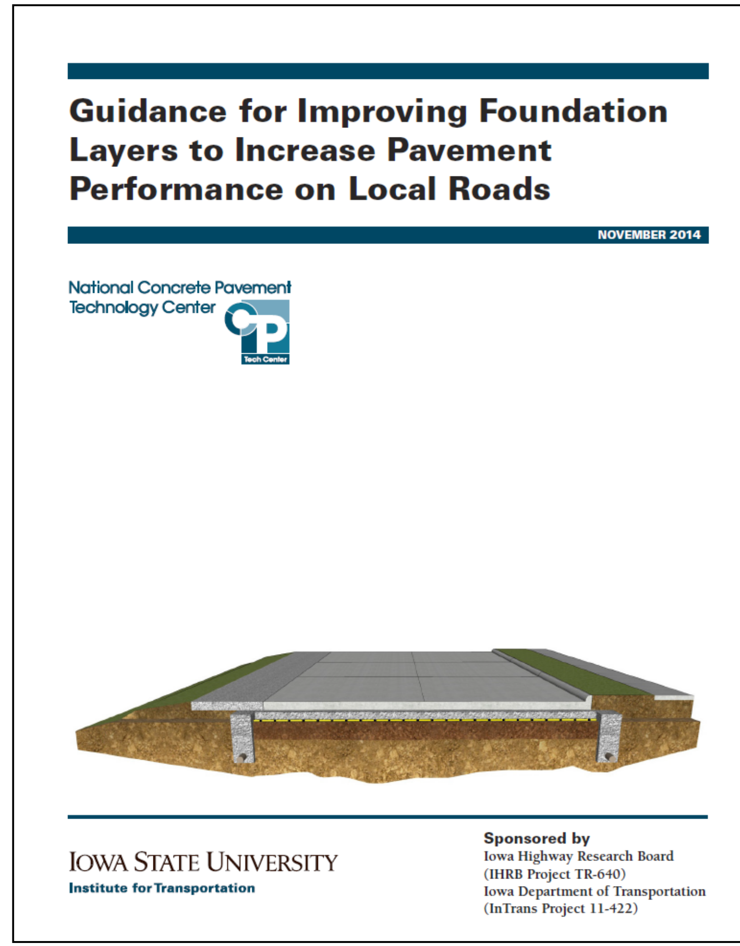
Asst. Director, CEER


Guidance for Improving Foundation Layers to Increase Pavement Performance on Local Roads

NOVEMBER 2014

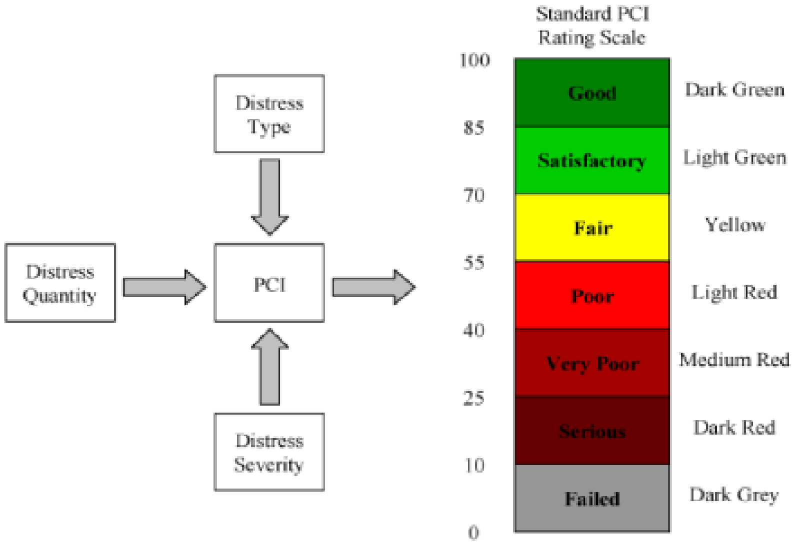
National Concrete Pavement Technology Center

IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Iowa Highway Research Board
(IHRB Project TR-640)
Iowa Department of Transportation
(InTrans Project 11-422)

Project Objectives

- Determine the level of increased performance when Portland Cement Concrete (PCC) is placed on granular subbase
- Quantify the performance and cost effectiveness
- Develop a user guide for various traffic, soils and pavement factors
- Performance measured by PCI



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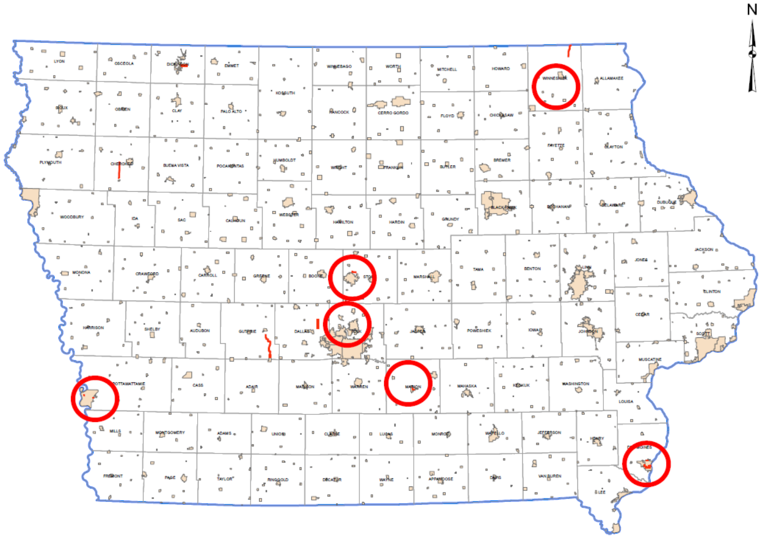
IHRB TR-640

- PCC Pavement (16 Sites) were tested to capture range of conditions statewide
  - Pavement Age: 30 days to 42 years
  - Surface Distress Conditions: Poor to Excellent (PCI = 35 to 92)
  - Support Conditions:
    - Natural Subgrade
    - Fly Ash Stabilized Subgrade
    - 6 in. to 12 in. Granular Subbase
  - Pavement Thickness: 6 to 11 in.
  - Traffic (AADT): 110 to 8900



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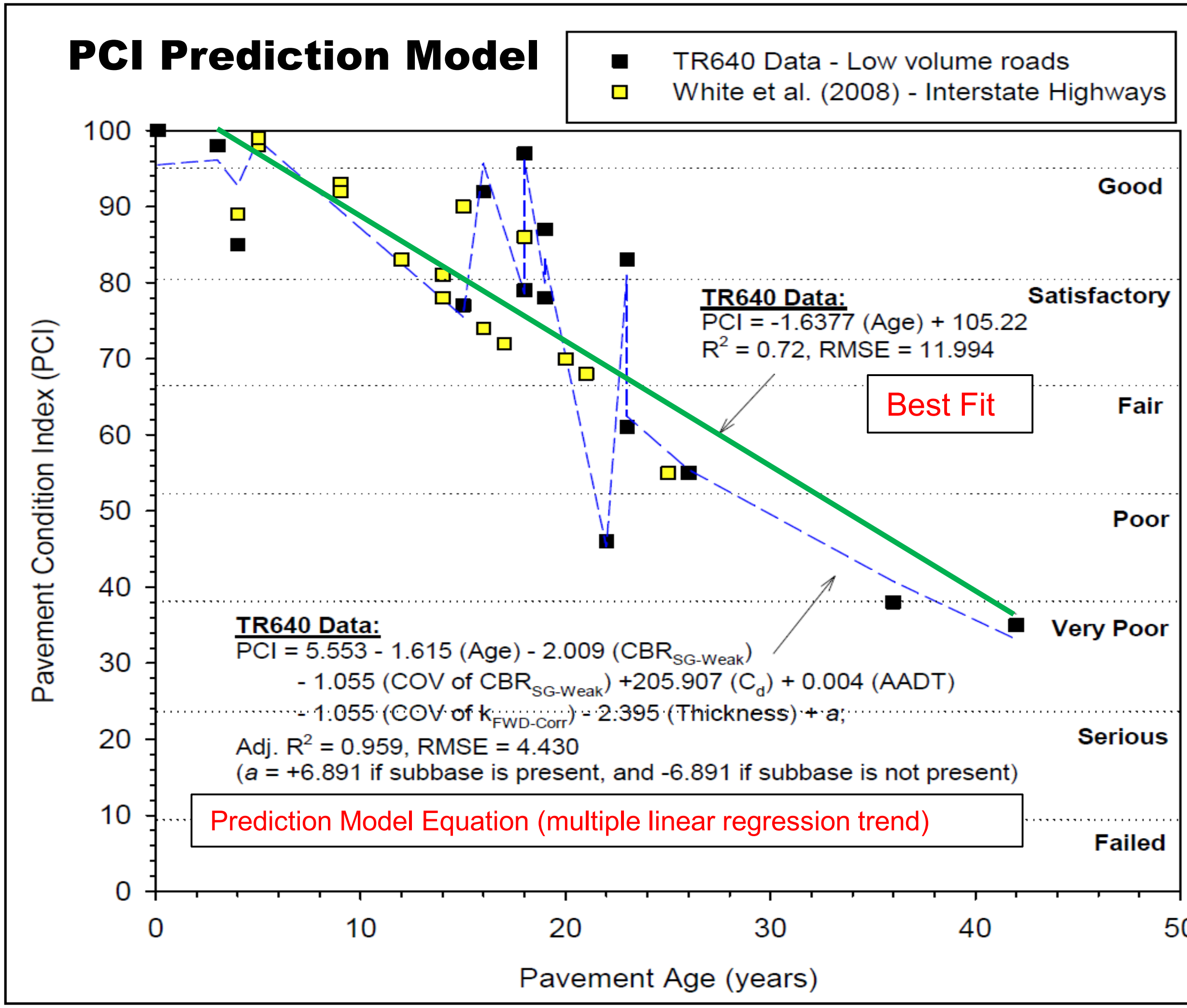
TR-640 Findings

- Low & variable support values (due to low CBR)
- Poor drainage (Cd)
- Loss of support
- The more uniform subgrade and higher coefficient of drainage (Cd), the higher the PCI
- Increase in drainage has the largest effect on the PCI

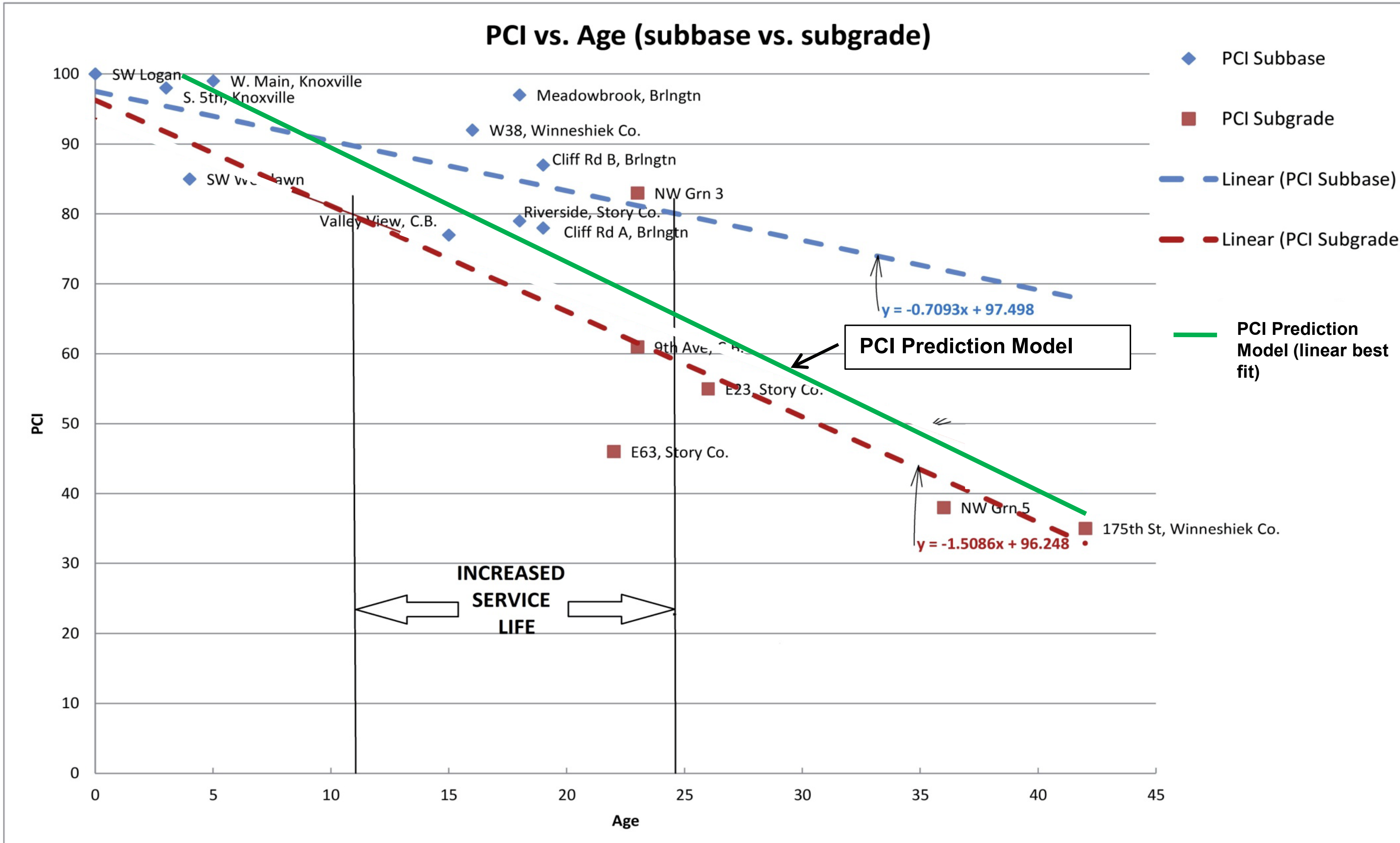
TR-640 Performance Prediction Model

Factors:

- Age
- Drainage Coefficient (C_d)
- Coefficient of variation for k & CBR
- Weak subgrade layer (CBR)
- Traffic
- Pavement thickness
- Subbase (if or if not)

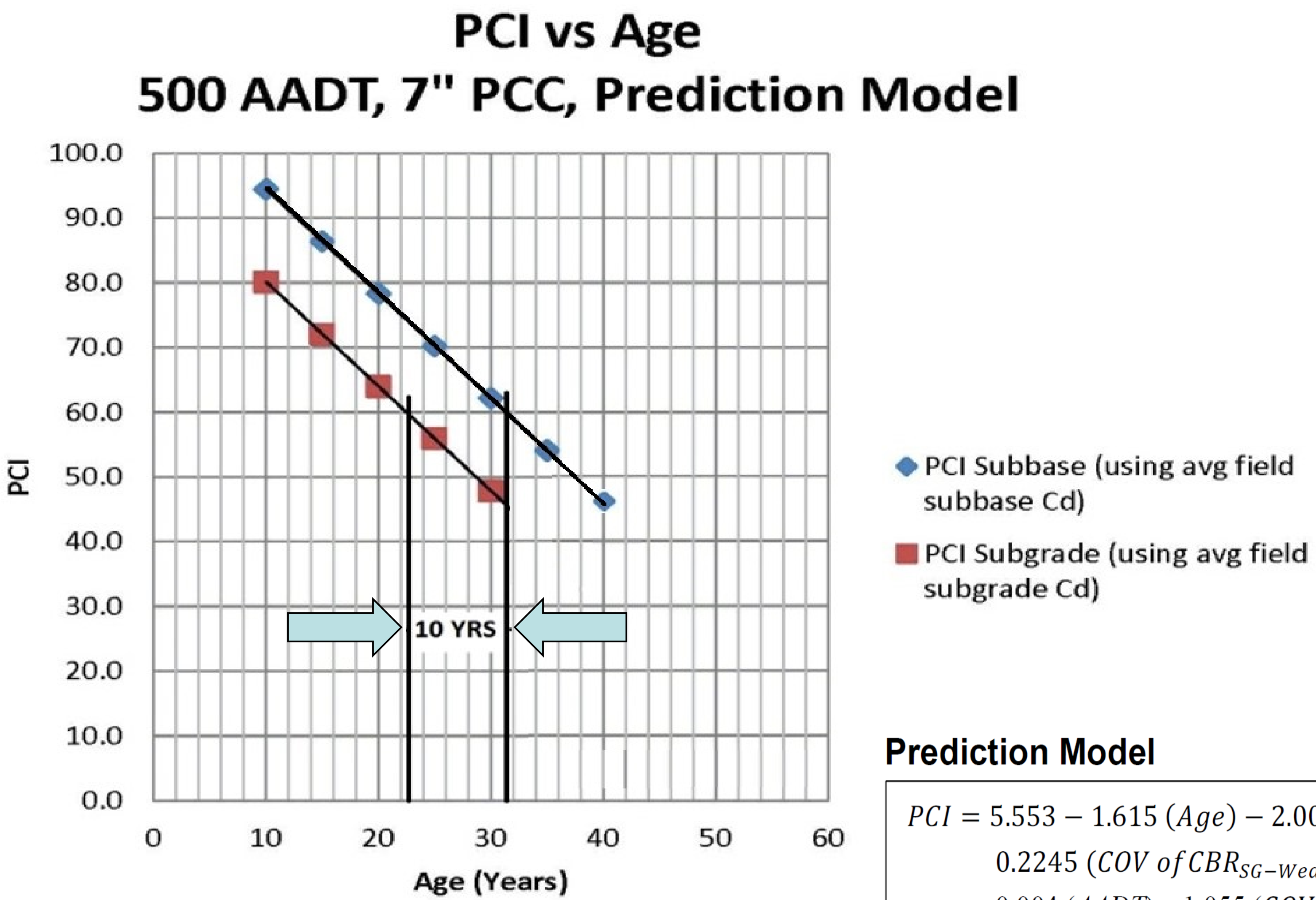


Guidance for Improving PCC Pavement Performance



Pavements with aggregate subbase are performing better than those without

PCI Prediction Calculation

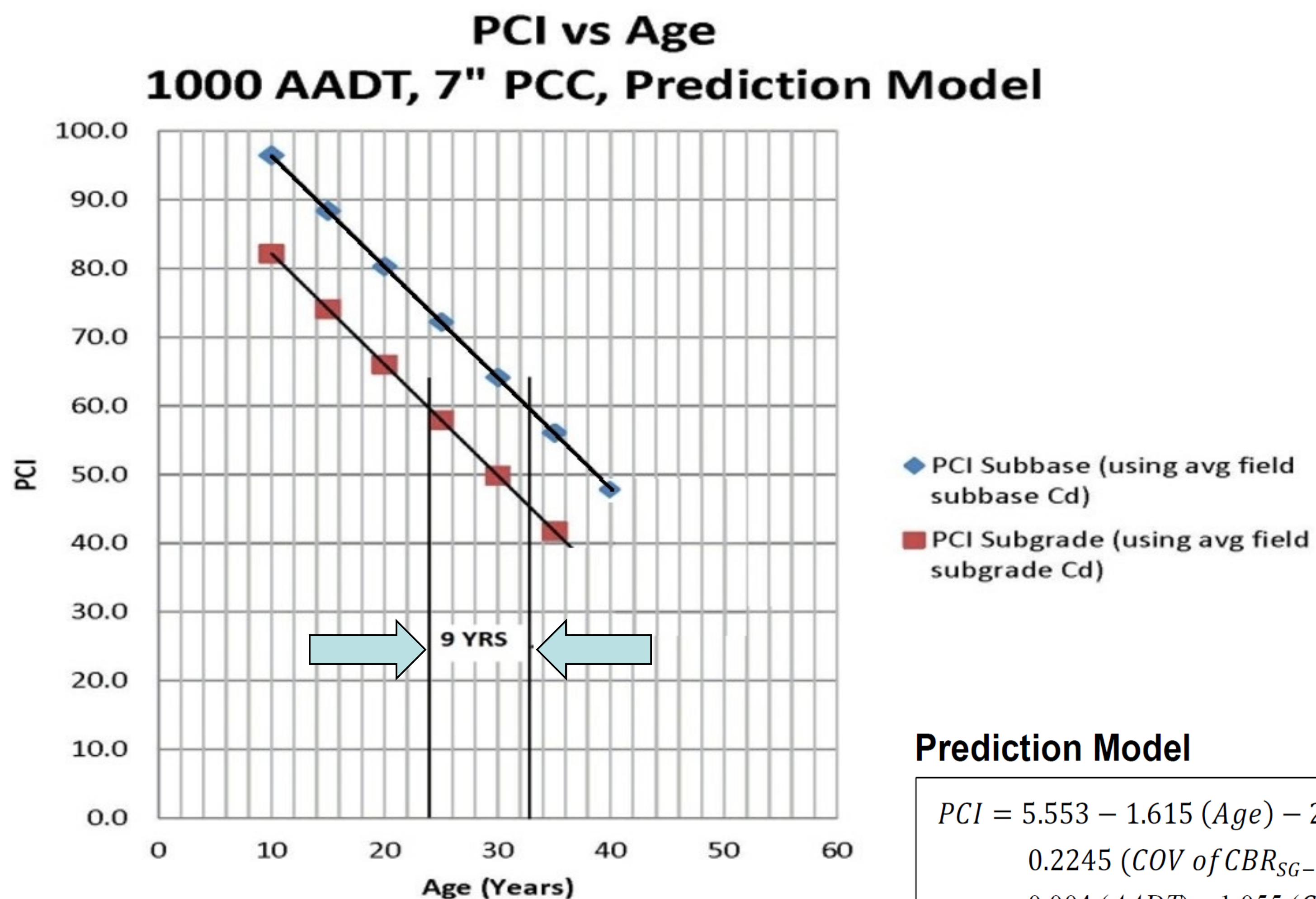


Prediction Model

$$PCI = 5.553 - 1.615\,(Age) - 2.009\,(CBR_{SG-Weak}) - 0.2245\,(COV\ of\ CBR_{SG-Weak}) + 205.907\,(C_d) + 0.004\,(AADT) - 1.055\,(COV\ of\ k_{FWD-Corr}) - 2.395\,(PCC\ Thickness) + a$$

[a = +6.891 if subbase is present and -6.891 if subbase is not present]

PCI Prediction Calculation



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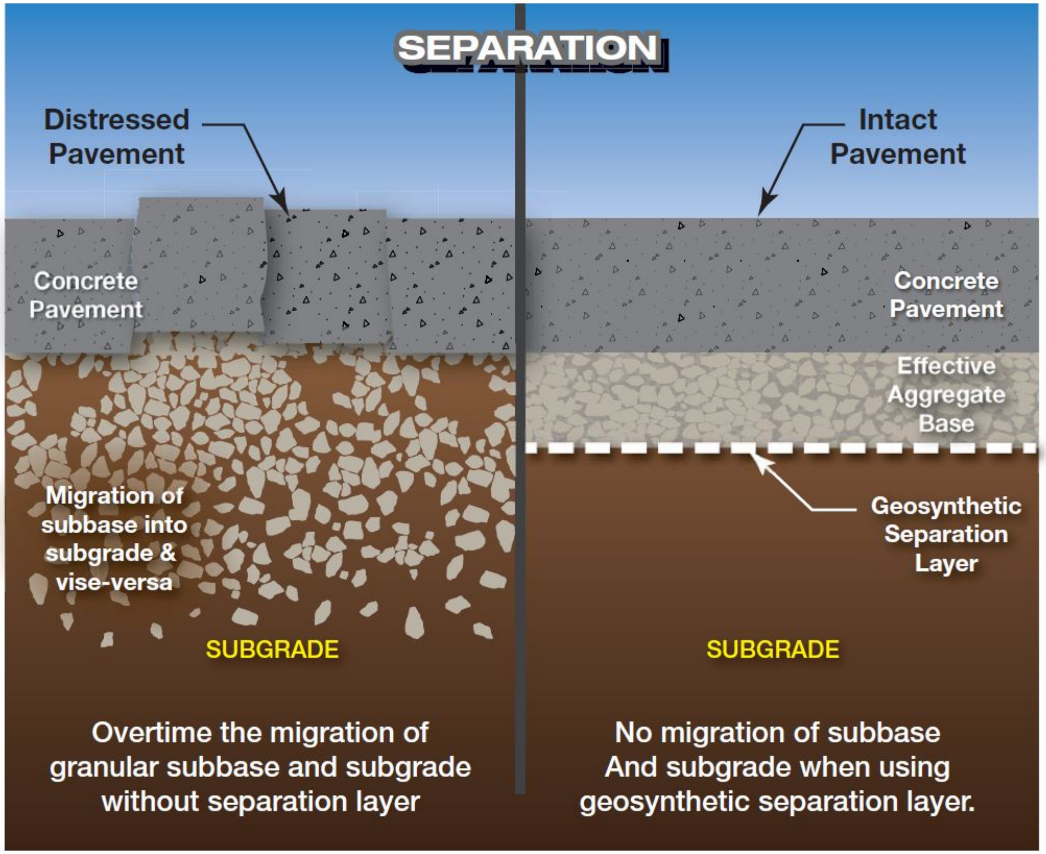
[a = +6.891 if subbase is present and -6.891 if subbase is not present]

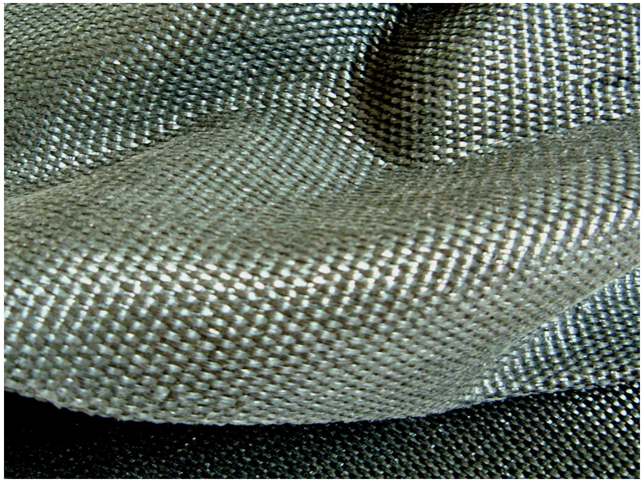
What was Learned from the IHRB-TR640 Study

Aggregate Subbase Loss

Pavement thickness design software programs do not reflect actual pavement foundation conditions except immediately after construction



Geotextiles



<u>Woven</u>

- High strength support
- Less permeable
- Used to increase support & stabilization (and filtration and separation)

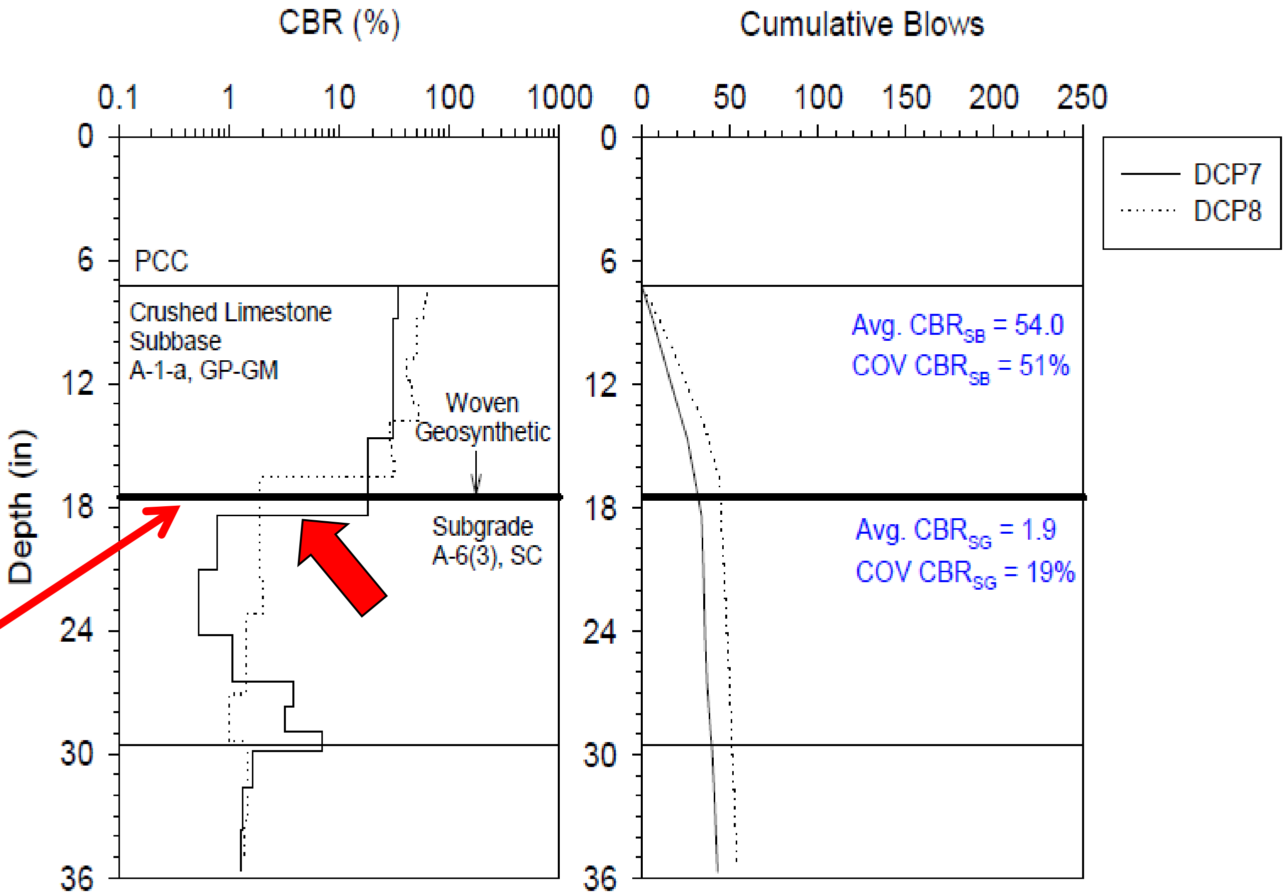
<u>Nonwoven</u>

- Felt-like
- More permeable
- Used for filtration and separation

Made of Polypropylene fibers

Benefits of Geotextiles

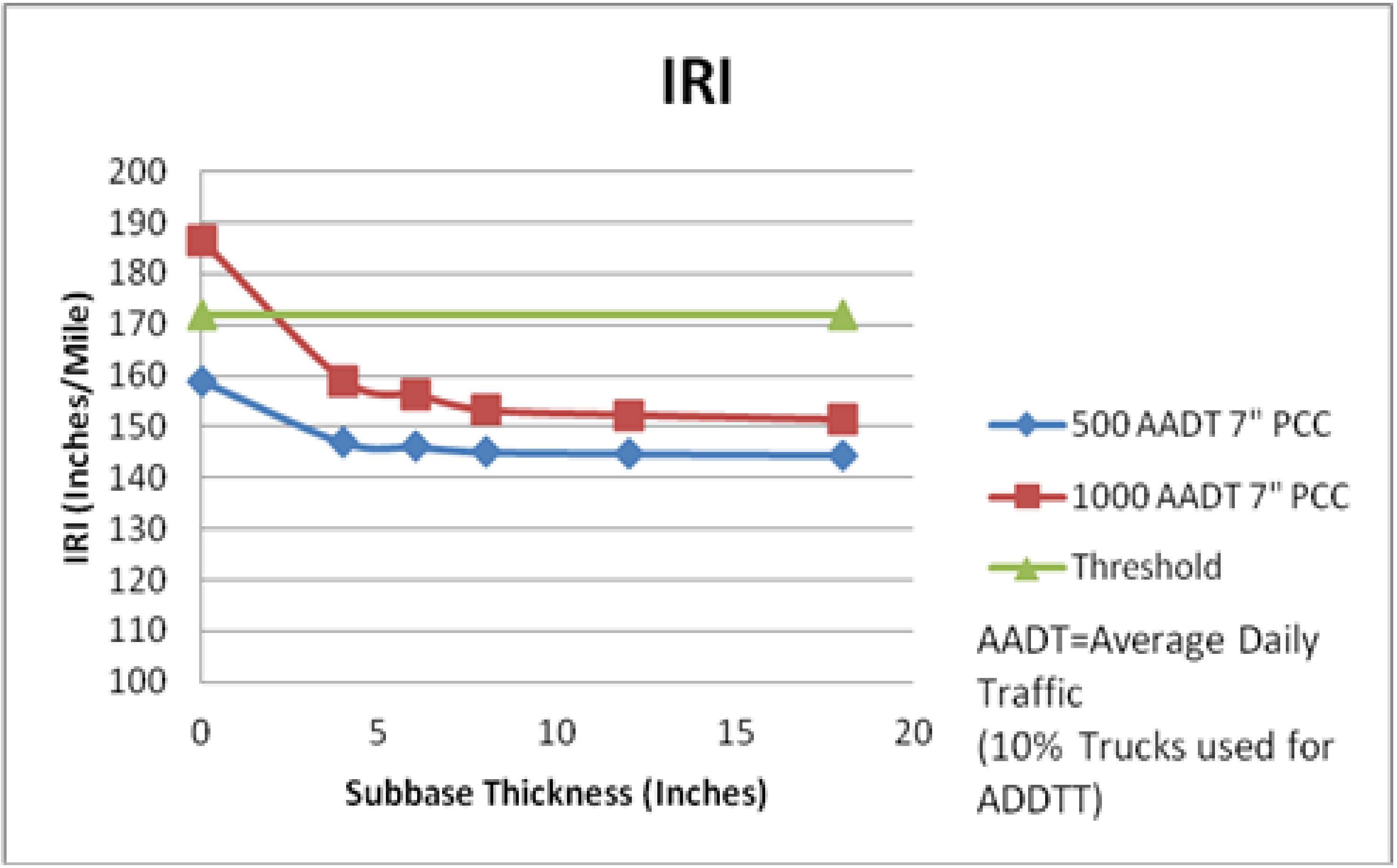
Woven Geosynthetic Fabric



Southwest Westlawn Drive (Poor Subgrade)

Aggregate Subbase Thickness Limitations (IRI)

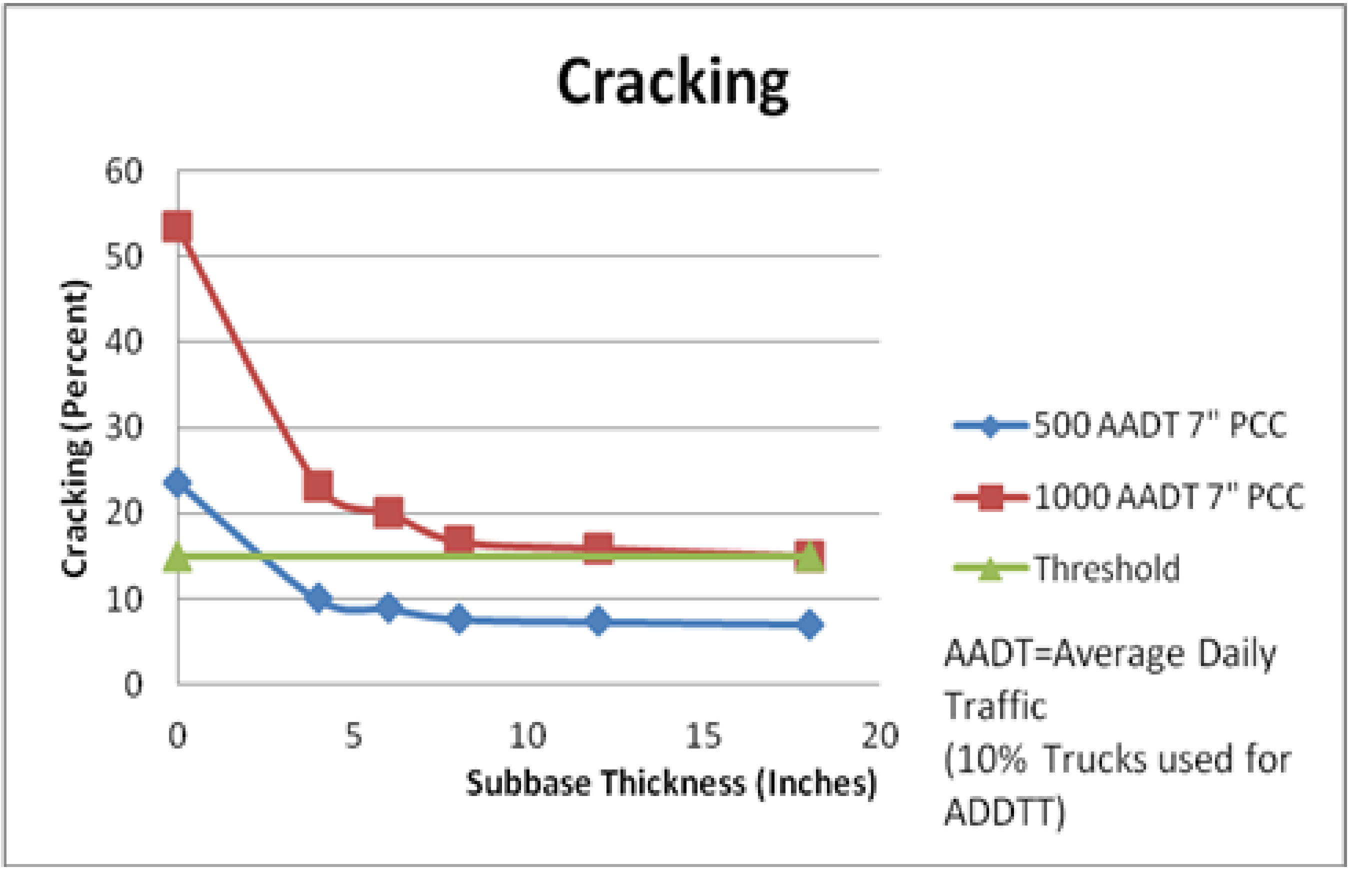
MEPDG Failure mode: IRI (in./mi)



Subbase thickness over 5” does not benefit PCC

Aggregate Subbase Thickness Limitations

MEPDG Failure mode: % Cracked Slabs



Subbase thickness over 5” does not benefit PCC

Cost Example for Improved PCC Pavement Performance

Subgrade Conditions	Approach & Costs
Wet & Unstable	Chemically treated soils 6" Cement Modified Soils = $4.50/ Sq.Yd. 5" aggregate subbase = $6.00/ Sq.Yd. **$10.50/ Sq.Yd**.
After compaction, slightly wet & somewhat stable but will not pass proof rolling	Dry out soil, place woven geotextile with 5" aggregate subbase. Geotextile (woven) = $2.50/Sq.Yd. 5" aggregate subbase = $6.00/Sq.Yd. **$8.50/Sq.Yd**.
Meets moisture & density control and passes proof rolling	Non woven geotextile = $1.75/Sq.Yd. 5" aggregate subbase = $6.00/Sq.Yd. **$7.75/Sq.Yd.**

CMS or Fly Ash $0.75/Sq.Yd/in; Aggregate $1.20 /Sq. Yd/in.

Thank you!

National CP Tech Center
www.cptechcenter.org/