NRMCA's CONCRETEWORKS CONFERENCE & EXPO


Source: PavementInteractive.org

Soils 101: The Importance of Soil In Pavement Design and Construction

MCA Conference
February 21, 2017

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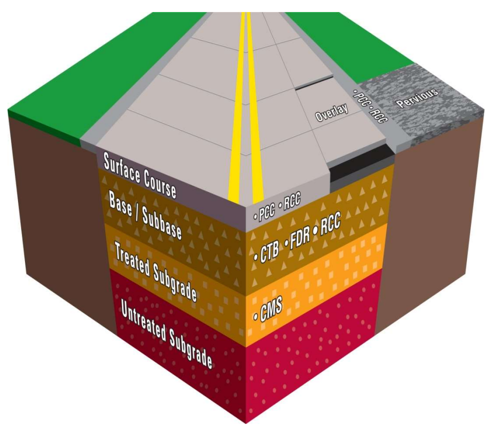
Soils 101 - Agenda

- Pavement Design Basics
- Soil Sampling/Data Collection
- Classifying Soils
  - ASTM
  - AASHTO
- Soil Density and Moisture
- Characterizing Soil Strength
  - Laboratory Methods
  - In-Situ Methods
- Soil Improvement
  - Chemical Stabilization
  - Mechanical Stabilization
- Field Compaction of Soils
- Bases and Subbases



Source: www.cement.org

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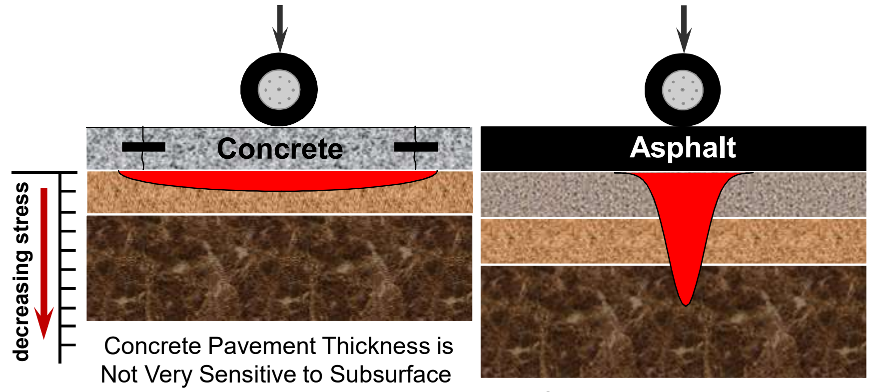
Pavements & Loads – Concrete vs. Asphalt

Subgrade stresses differ considerably.



Concrete Pavement Thickness is Not Very Sensitive to Subsurface Strength.

Source: www.pavementinteractive.com

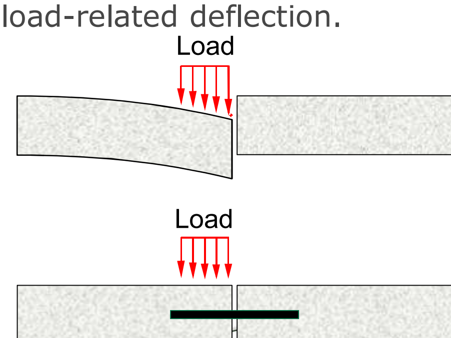
Definition – Load Transfer

Shear strength provided at joints (or cracks) by dowels or other features, aggregate interlock, or contact friction.

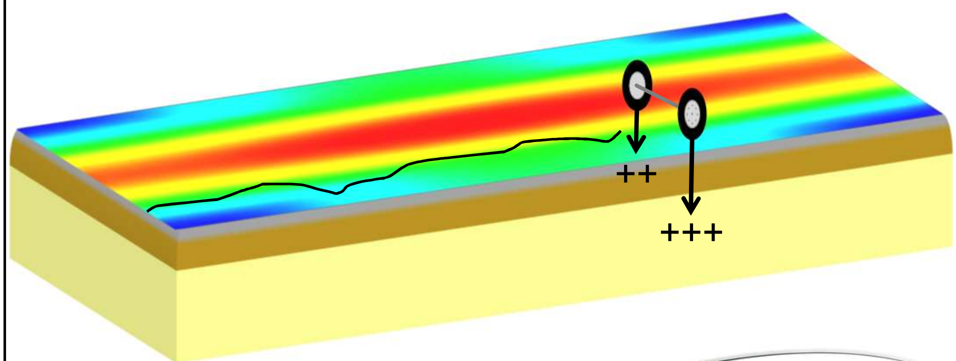
Significantly reduces load-related deflection.

Without load transfer:
Excessive deflections and flexure - same as free edge loading.

With load transfer:
Deflections and flexural stresses are reduced.



Support Uniformity vs. Strength Under Concrete Pavements



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Suitability of Subgrade Soils

Classification (Gradation, Atterberg Limits, etc.)
Depth to Bedrock
Depth to Water Table
Potential for Compaction
Presence of Weak or Soft Layers or Organics
Susceptibility to Frost Action or Excessive Swell
Soil Strength Characteristics

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Soil/Subbase Strength Characterization

- Soil Support Value (SSV)
- Resistance Value (R-Value)
- California Bearing Ratio (CBR)
- Resilient Modulus (M_r)
- Modulus of Subgrade Reaction (k-value)

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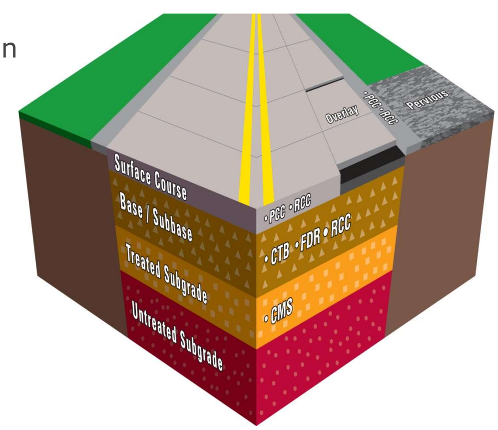

Source: www.cement.org

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Data Collection Activities - Drilling

Geotechnical Drilling (New Pavements)

- Minimum 5 feet below final top of subgrade elevation**
- Spacing a function of roadway type and soil conditions
- High plasticity soils increase drilling depth to 10 to 15 feet
- Materials for strength testing must be representative of subgrade soil supporting pavement materials
- May require larger augers at some boring locations

Geotechnical Drilling (Existing Pavements)

- Obtain existing pavement thicknesses
- Spacing as stated above
- Drilling depths as stated above
- Materials for soil strength as stated above
- Consider test pits if full depth reclamation is possible

**Airport, Industrial, and Port Facilities may be different!

Data Collection Activities - Other

Dynamic Cone Penetrometer (DCP)

Falling Weight Deflectometer (FWD)

Ground Penetrating Radar (GPR)

Geophysical

Soils 101 - Agenda

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Classifying Soils

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- AASHTO

Soil Density and Moisture

Characterizing Soil Strength

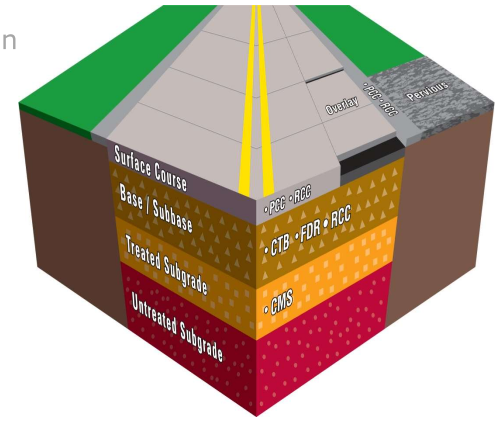
- Laboratory Methods
- In-Situ Methods

Soil Improvement

- Chemical Stabilization
- Mechanical Stabilization

Field Compaction of Soils

Bases and Subbases



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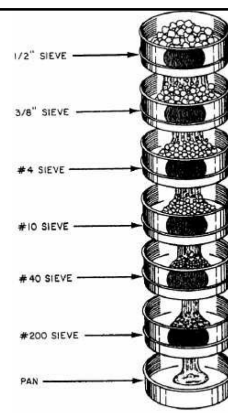
Soil Classification



Course or Fine Grained

Typically Classified as:

- Gravel
- Sand
- Silt
- Clay (Lean or Fat: Based on Plasticity*)
- Or a combination of any of the above
  - e.g. Sandy Gravel With Clay

*Soil plasticity refers to the manner in which water interacts with the soil particles.

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Atterberg Limits

Liquid Limit (LL)

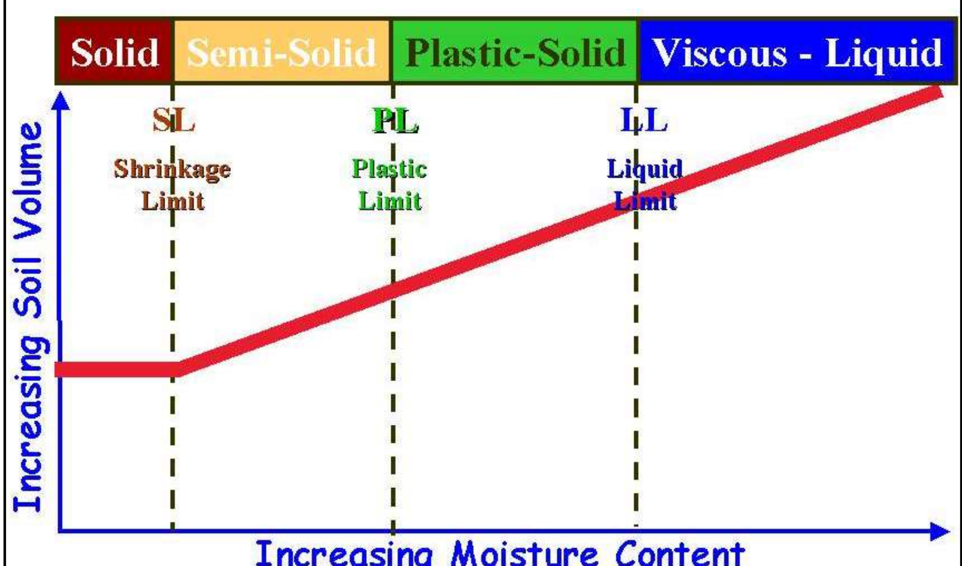
Plastic Limit (PL)

Plasticity Index (PI)

PI = LL - PL

Albert Atterberg
1846-1916

States of Consistency for Cohesive Soils (Soil Passing #40 Sieve)



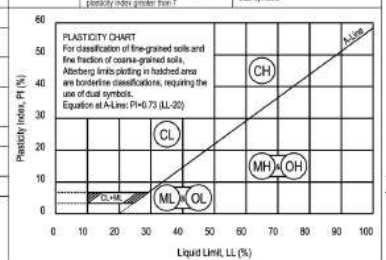
Unified Soil Classification System (USCS)

Source: ASTM D 3282

CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES
ASTM D 2487 and D 2488
(Unified Soil Classification System)

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES	FIELD IDENTIFICATION PROCEDURES	CLASSIFICATION CRITERIA		
COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve*	GRAVELS 50% or more of coarse fraction retained on No. 4 sieve	CLEAN GRAVELS	GW	Well-graded gravels and gravel-sand mixtures, little or no fines	Wide range in grain size and substantial amounts of all intermediate particle sizes	CLASSIFICATION ON BASIS OF PERCENTAGE OF FINES Less than 5% pass No. 200 sieve=GW, GP, SW, SP 5% to 12% pass No. 200 sieve=borderline classification, requiring the use of dual symbols More than 12% pass No. 200 sieve=GM, GC, SM, SC	$C_u = D_{60}/D_{10}$ Greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} x D_{60}}$ Between 1 and 3	
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing		Not meeting both criteria for GW	
		GRAVELS WITH FINES	GM	Silty gravels, gravel-sand-clay mixtures	Nonplastic fines or fines with low plasticity (for identification procedures, see ML below)		Atterberg limits plot below "A" line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
			GC	Clayey gravels, gravel-sand-clay mixtures	Plastic fines (for identification procedures, see CL below)		Atterberg limits plot above "A" line and plasticity index greater than 7	
	SANDS More than 50% of coarse fraction passes No. 4 sieve	CLEAN SANDS	SW	Well-graded sands and gravelly sands, little or no fines	Wide range in grain size and substantial amounts of all intermediate particle sizes		$C_u = D_{60}/D_{10}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} x D_{60}}$ Between 1 and 3	
			SP	Poorly graded sands and gravelly sands, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing		Not meeting both criteria for SW	
		SANDS WITH FINES	SM	Silty sands, sand-silt mixtures	Nonplastic fines or fines with low plasticity (for identification procedures, see ML below)		Atterberg limits plot below "A" line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
			SC	Clayey sands, sand-clay mixtures	Plastic fines (for identification procedures, see CL below)		Atterberg limits plot above "A" line and plasticity index greater than 7	

MAJOR DIVISIONS		GROUP SYMBOLS	TYPICAL NAMES	Identification Procedure On Fraction Smaller Than No. 40 Sieve Size: Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)
FINE-GRAINED SOILS 50% or more passes No. 200 sieve*	SILTS AND CLAYS Liquid limit 50% or less	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands	None to slight	Quick to slow	None
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium to high	None to very slow	Medium
		OL	Organic silts and organic silty clays of low plasticity	Slight to medium	Slow	Slight
	SILTS AND CLAYS Liquid limit greater than 50%	MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts	Slight to medium	Slow to none	Slight to medium
		CH	Inorganic clays of high plasticity, fat clays	High to very high	None	High
		OH	Organic clays of medium to high plasticity	Medium to high	None to very slow	Slight to medium
Highly Organic Soils		PT	Peat, muck, and other highly organic soils	Readily identified by color, odor, spongy feel, and frequently by fibrous texture		



*Based on the material passing the 3 inch sieve

AASHTO Soil Classification System

Source: AASHTO M 145

General Classification	Granular Materials (35% or Less Passing No. 200)							Silt-Clay Materials (More Than 35% Passing No. 200)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
Sieve analysis, percent passing:											
No. 10	50 max	—	—	—	—	—	—	—	—	—	—
No. 40	30 max	50 max	51 max	—	—	—	—	—	—	—	—
No. 200	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing No. 40											
Liquid limit	—		—	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity limit	6 max		NP	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

Source: AASHTO M 145-2

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How Do ASTM/AASHTO Compare?

Soil groups in AASHTO system	Comparable soil groups in USCS		
	Most probable	*Possible*	*Possible but improbable*
A-1-a	GW, GP	SW, SP	GM, SM
A-1-b	SW, SP, GM, SM	GP	---------------
A-3	SP	---------------	SW, GP
A-2-4	GM, SM	GC, SC	GW, GP, SW, SP
A-2-5	GM, SM	---------------	GW, GP, SW, SP
A-2-6	GC, SM	GM, SM	GW, GP, SW, SP
A-2-7	GM, GC, SM, SC	---------------	GW, GP, SW, SP
A-4	ML, OL	CL, SM, SC	GM, GC
A-5	OH, MH, ML, OL	---------------	SM, GM
A-6	CL	ML, OL, SC	GC, CM, CM
A-7-5	OH, MH	ML, OL, CH	GM, CM, GC, SC
A-7-6	CH, CL	ML, OL, SC	OH, MH, GC, GC, SM

Source: Liu, 1967

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Unified Soil Classification System

Soil Group Symbol	Group Name
GW	Well-graded gravel
GP	Poorly graded gravel
GM	Silty gravel
GC	Clayey gravel
SW	Well-graded sand
SP	Poorly graded sand
SM	Silty sand
SC	Clayey sand
CL	Lean clay
ML	Silt
OL	Organic silt or clay
CH	Fat clay
MH	Elastic silt
OH	Organic silt or clay
Pt	Peat

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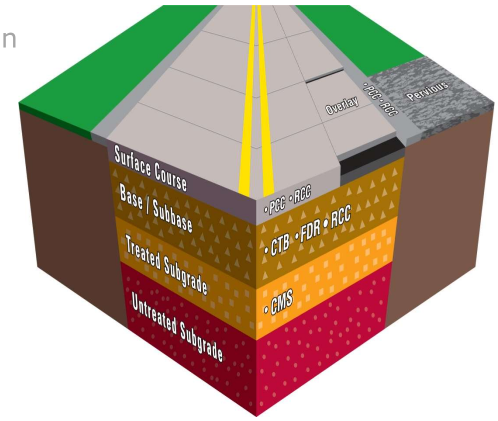
Field Compaction of Soils

Bases and Subbases



Source: www.cement.org

Soil Characteristics

Three Components:

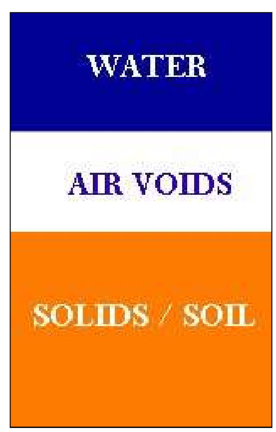
- Solids, Water, and Air

Water Effect

- Capillary Forces

Soil Density Test

- The Proctor Curve



Soil Compaction

Soil compaction is the process of “artificially” increasing the density (unit weight) of a soil by compaction (by application of rolling, tamping, or vibration).

Moisture-density testing as practiced today was started by R.R. Proctor in 1933. His method became known as the “standard Proctor” test.

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Moisture and Density Relationships of Soils & Base – Laboratory Methods

ASTM D 698 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbs/ft^3)

ASTM D 1557 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbs/ft^3)

AASHTO T 99 - Moisture-Density Relations of Soils Using a 5.5-lb Rammer and a 12-in. Drop

AASHTO T 180 - Moisture-Density Relations of Soils Using a 10-lb Rammer and a 18-in. Drop

American Association of State Highway and Transportation Officials AASHTO The Voice of Transportation

ASTM International Standards Worldwide

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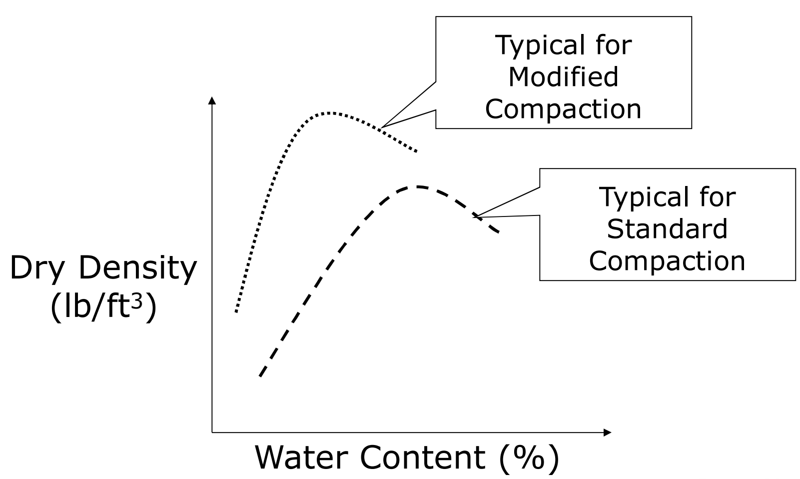
Why Compact Soils & Bases?

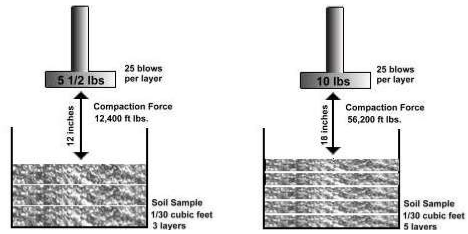
↑ Density = ↑ Strength

Typical Compaction Curves



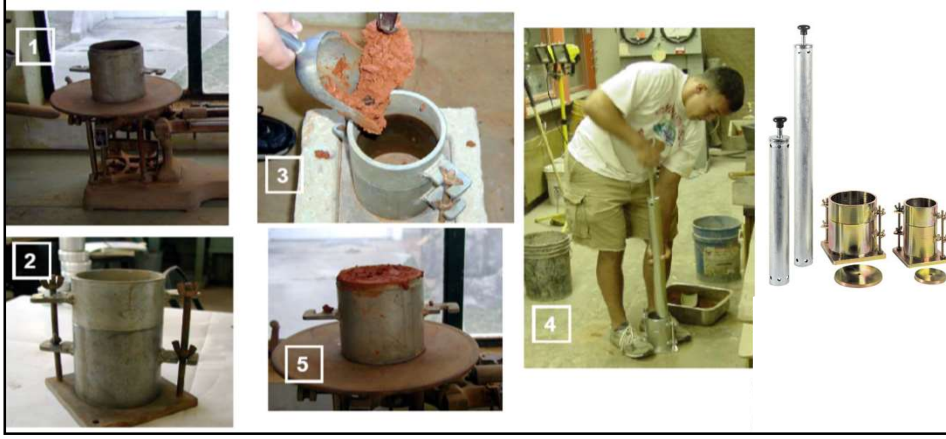
Total Compaction Energy Affects Maximum Dry Density and Optimum Moisture

Soil Compaction in the Lab:
1- Standard Proctor Test
2- Modified Proctor Test



Standard Proctor Test

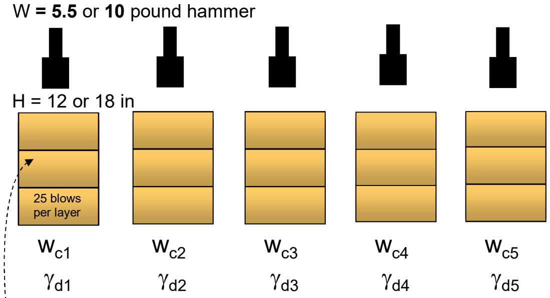
Modified Proctor Test



Soil Compaction in the Lab:
1- Standard Proctor Test
2- Modified Proctor Test

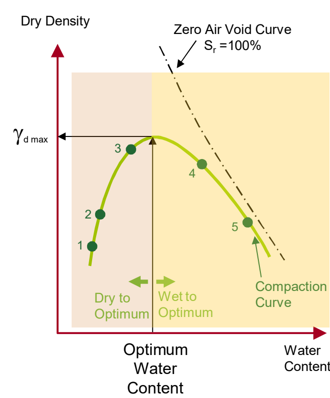
W = **5.5** or **10** pound hammer

H = 12 or 18 in



Increasing Water Content

4 inch diameter compaction mold.
(V = 1/30 of a cubic foot)



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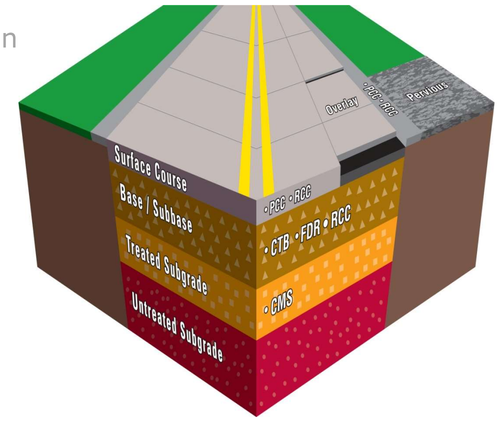


Source: www.cement.org

In-Situ Moisture and Density of Soils & Base – Nuclear Methods

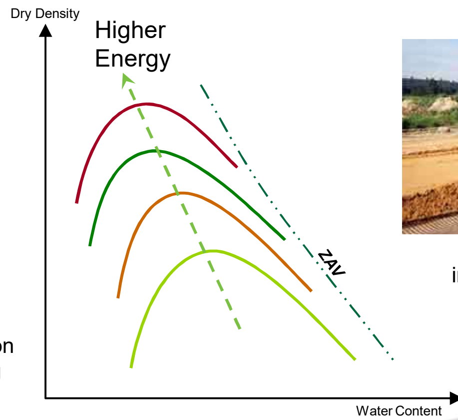
ASTM D6938 - Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

AASHTO T 310 - In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

Effect of Energy on Soil Compaction

Increasing compaction energy → Lower OWC and Higher Dry Density

In the lab
increasing compaction
energy = increasing
number of blows



In the field
increasing compaction
energy = increasing
number of passes or
reducing lift depth

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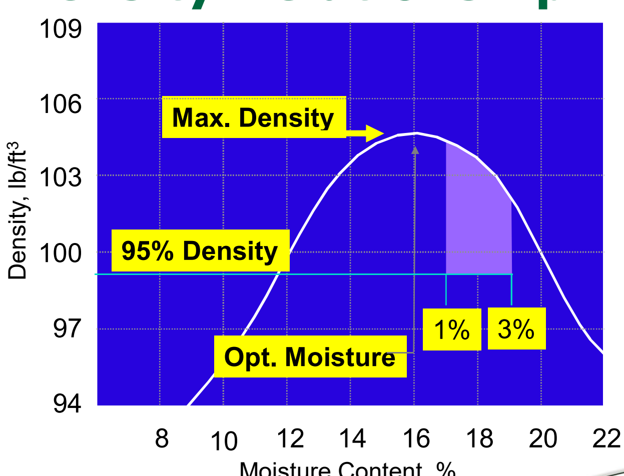
Compaction and Moisture-Density Relationship



Compact granular materials near optimum moisture, plastic soils slightly above optimum.

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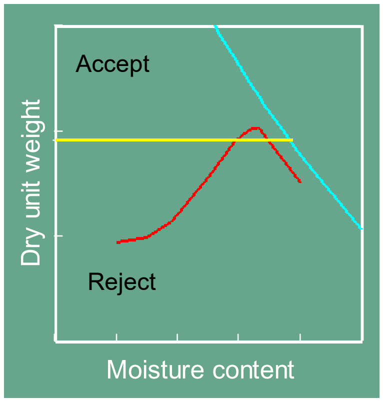
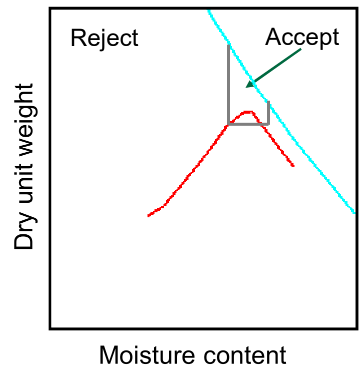
Field Specifications



(a) > 95% of maximum dry unit weight



(b) >95% of maximum dry unit weight and moisture within 2% of m_{opt}

During construction of soil structures there is usually a requirement to achieve a specified dry unit weight.

Subgrade Preparation

- Compact with proper moisture content.
- Check density with testing or proof rolling.
- Fine grading.
- Remove and replace soft or unsuitable soils.
- Consider subgrade stabilization when extremely poor soils are encountered.
- Insure adequate surface drainage.
- Water table depth – understand influence.
- Uniformity is the key!

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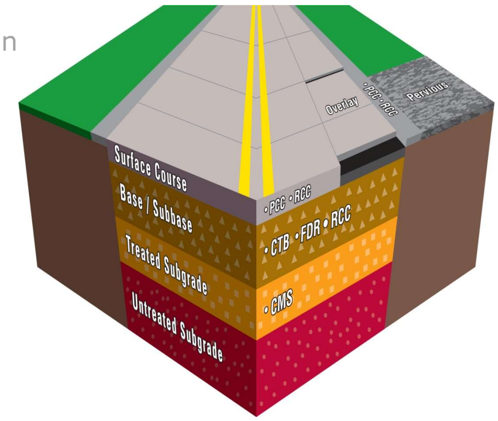
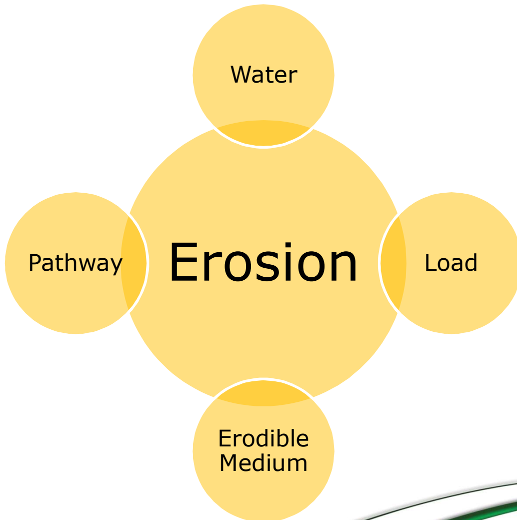


Source: www.cement.org

Drainage and Subgrade Issues: #1 Cause of Failures

Erosion Mechanisms: What's Needed?



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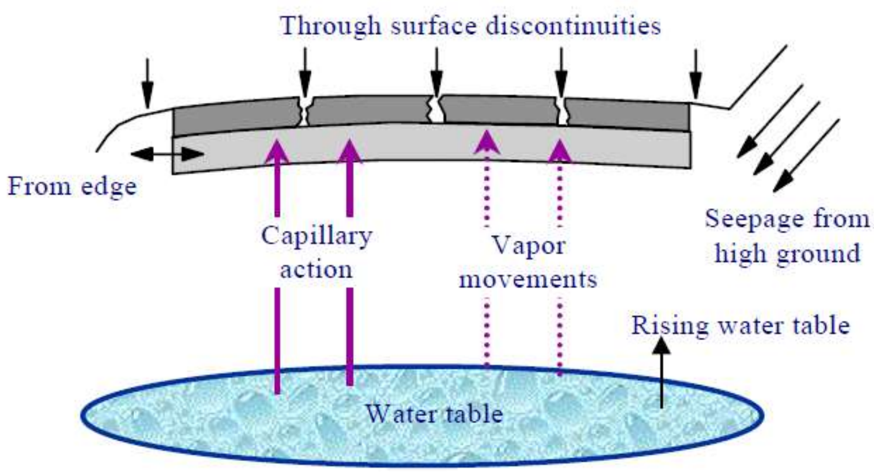
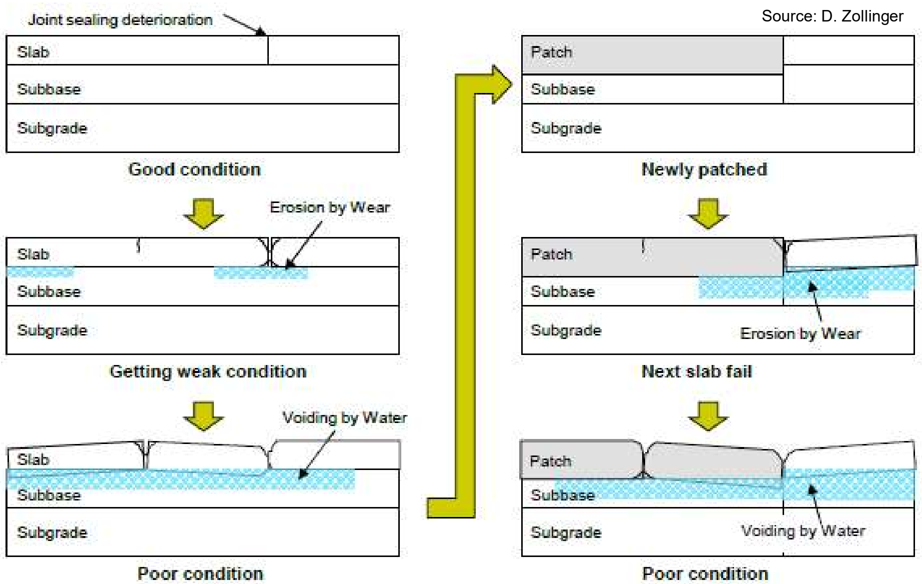


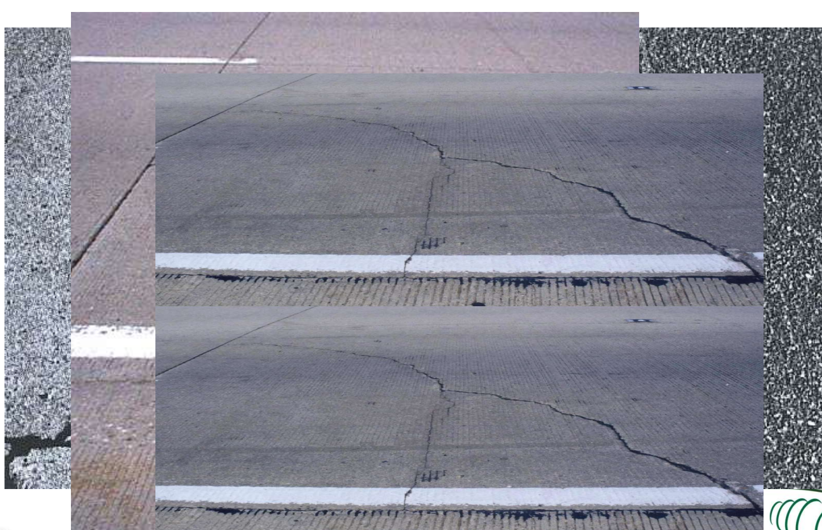
Erosion & Pavement Deterioration



Pumping: Symptom of Erosion

Faulting: Result of Erosion

Corner Cracking: Result of Erosion



Pumping and Joint Faulting

For control of pumping/faulting:

- Short slabs.
- Proper jointing design.
- Good load transfer.
- Good surface drainage.
- Use a non-erodible subbase.

Do edge drains neutralize erosion?

PAVEMENT EDGE DRAINS

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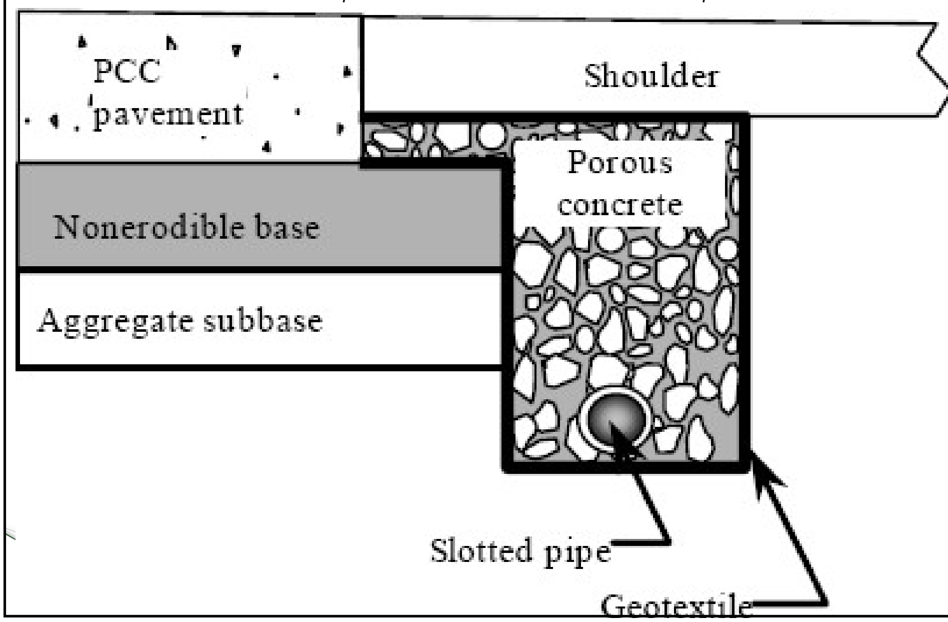
Example Edge Drain System

FHWA Geotechnical Aspects of Pavements Reference Manual Chapter 7.0



Summary

- Uniform Support Beneath Concrete is Key
- Various Methods to Characterize
  - Classification
  - Strength
- In-Situ Soils and Subbases Can Be Improved
  - Compaction
  - Stabilization
- Minimizing Erosion is Key

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