Soils 101

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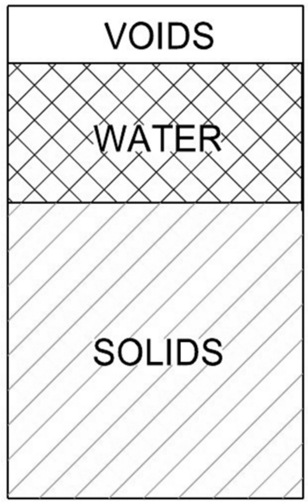
Definitions

Soil: The top layer of the earths surface, consisting of rock and mineral particles mixed with organic matter. (Webster)

Soil: Material that can be worked without drilling or blasting. (In Engineering Context)

The term "Soil" is applicable to all those particles smaller than 3 inches.

Composition of Soil



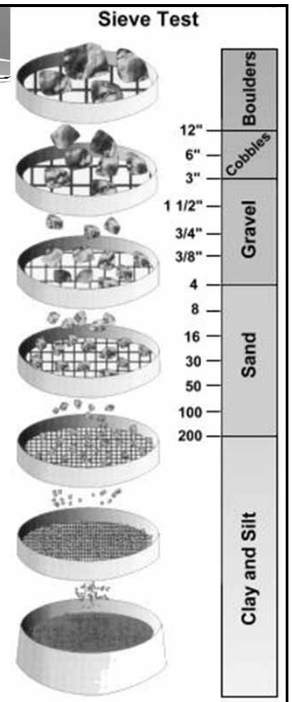
Particle Size Breakdown

- Boulders (>12”)
- Cobbles (12” to 3”)

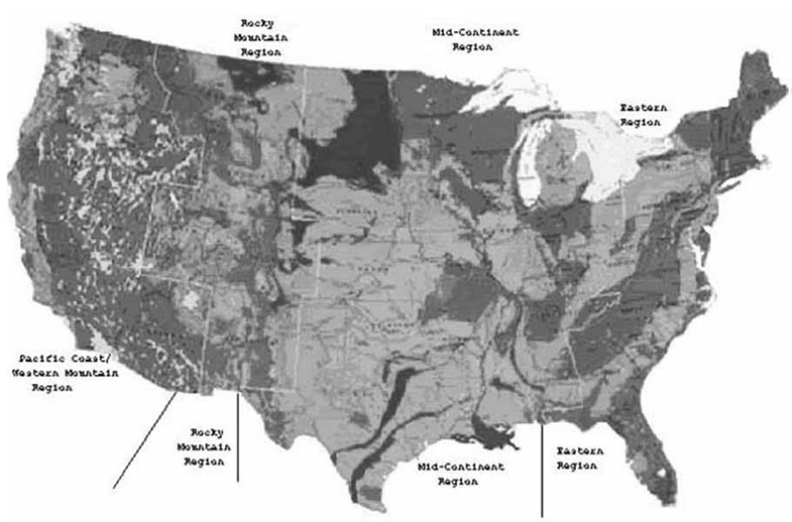
- Gravel (-3” to +No. 10)
- Coarse Sand (-No. 10 to +No. 40)
- Fine Sand (-No. 40 to +No. 200)
- Silt (.005 mm < d < .074 mm)
- Clay (< .005 mm)

Soil Groups

- There are three basic soil groups:
  - Cohesive
  - Granular
  - Organic



Expansive Soils Map



Red = Highly Expansive

Blue = Moderately Expansive

Classification of Soils for Engineering Purposes

NDDOT
- AASHTO Soil Classification System
- Bi-axial Textural Chart

Other
- Unified Classification System

AASHTO Classification System

- Developed in 1945 by the Highway Research Board
- Groups range from A-1 to A-8
- Classification is based on grain-size distribution, PI and LL
- Used mainly by DOT's for classification of highway subgrades.

AASHTO Classification System

General Classification	Granular Materials (35% or Less Passing the No. 200)							Silty-Clay Materials (More than 35% Passing the No. 200)			
Group Classification	A-1			A-2							
	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7	A-4	A-5	A-6	A-7-5, A-7-6
Sieve Analysis % passing:											
No. 10	50 Max	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------
No. 40	30 Max	50 Max	51 Min	---------	---------	---------	---------	---------	---------	---------	---------
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 Material Passing the No. 40											
Liquid Limit	-----------		------	40 Max	41 Min	40 Max	41 Min	40 Max	41 Min	40 Max	41 Min
Plasticity Index	6 Max		N.P.	10 Max	10 Max	11 Min	11 Min	10 Max	10 Max	11 Min	11 Min*
Usual Types	Stone, gravel, sand		Fine Sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General Ratings as Subgrade	Excellent to Good							Fair to Poor			

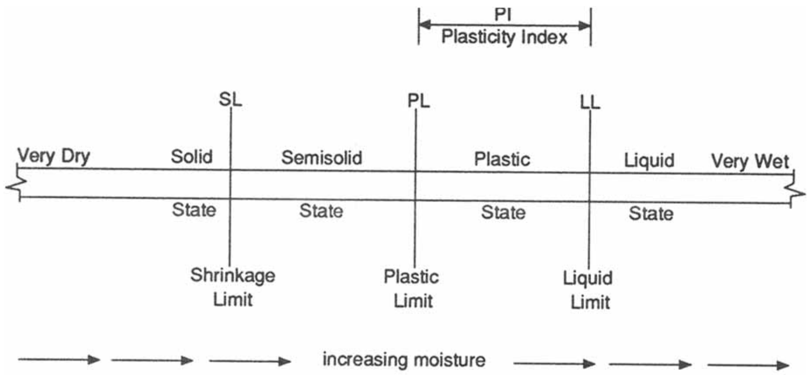
*Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30.

Atterberg Limits

- Liquid Limit (LL): the water content at which the soil passes from a plastic to a liquid state.
- Plastic Limit (PL): the lowest water content at which the soil remains plastic.
- Shrinkage Limit (SL): the water content at which the volume of the soil mass ceases to change.

Plasticity Index (PI) is the difference between in the LL and the PL. This is the range where the material is in a plastic state.

$$PI = LL - PL$$



- Plasticity– Ability of a material to be deformed without cracking or crumbling and then maintain that deformed shape after the deforming force has been released.
- From this information, we make an estimation of the state the soils are in (semi-plastic, plastic, or liquid) and if there will be any potential Construction related problems in the field.

Group Index

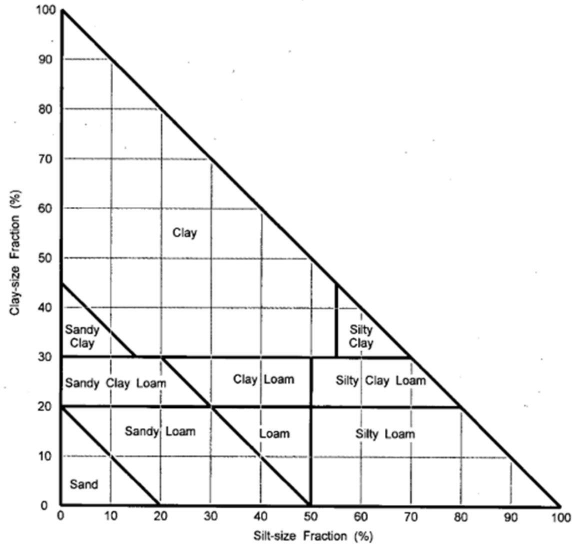
AASHTO M 145

$$GI=(F_{200}-35)[0.2+0.005(LL-40)]+0.01(F_{200}-15)(PI-10)$$

F_{200}= % passing no. 200 sieve
LL = Liquid Limit
PI = Plasticity Index

GI gives qualitative evaluation of the suitability of a given soil to be used as a subgrade material. The higher the value, the weaker will be the soil’s performance as a subgrade. A GI of 20 or Greater indicates a “Very Poor” subgrade material.

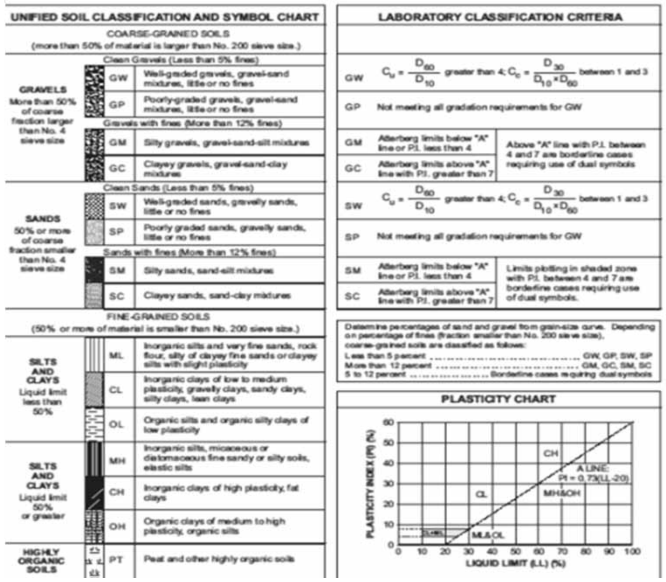
NDDOT Bi-Axial Textural Chart



Unified Classification System

- Originally proposed by Dr. Arthur Casagrande of Harvard University in 1942.
- Later adopted by US Bureau of Reclamation and Corps of Engineers.
- Widely used by Geotechnical Consultants

Unified Soil Classification System



Engineering Properties of Soils

- Consistency
- Swell Potential
- Frost Heave Potential
- Bearing Capacity
- Permeability
- Moisture Density Relationship
- Uniformity

Consistency

- In the lab we compare the Atterberg Limits to the In-Place Moisture Content to give us the Consistency of the soils at a given depth.

Swell Potential

- NDDOT uses the Plasticity Index (PI) to predict swell potential.
  - Low = PI < 25
  - Medium = 25 < PI < 35
  - High = PI > 35

  Soils in the "High" category have a high attraction for moisture and can undergo large volume changes. These soils can exert very high uplift pressures on pavements.

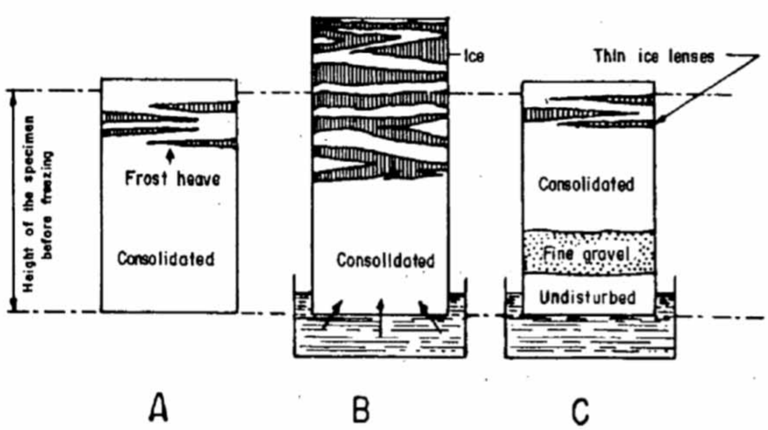
Frost Heave Potential

- To help predict if a soil is susceptible to frost heaving, the NDDOT Classifies Soils as F1, F2, F3 or F4 with F4 Soils being the most Frost Susceptible.

- For soils to frost heave they need:
  - The ideal soil structure that will allow rapid movement of capillary water upward. (ie. high silt content)
  - Available Water Source (slough, spring) to feed the growing ice lense.
  - Proper Freezing Conditions

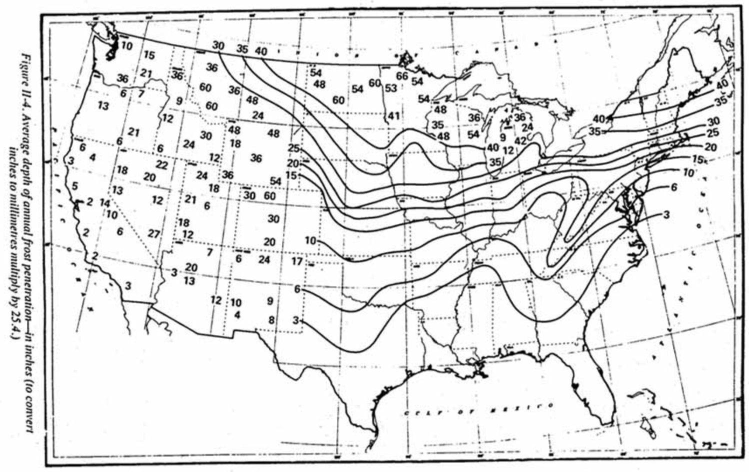
ALL SOILS CAN FROST HEAVE GIVEN THE RIGHT CONDITIONS

Frost Heave Potential



Frost Heave Potential

Frost Penetration in Inches



Recommendations for Repair of Frost Heave Areas

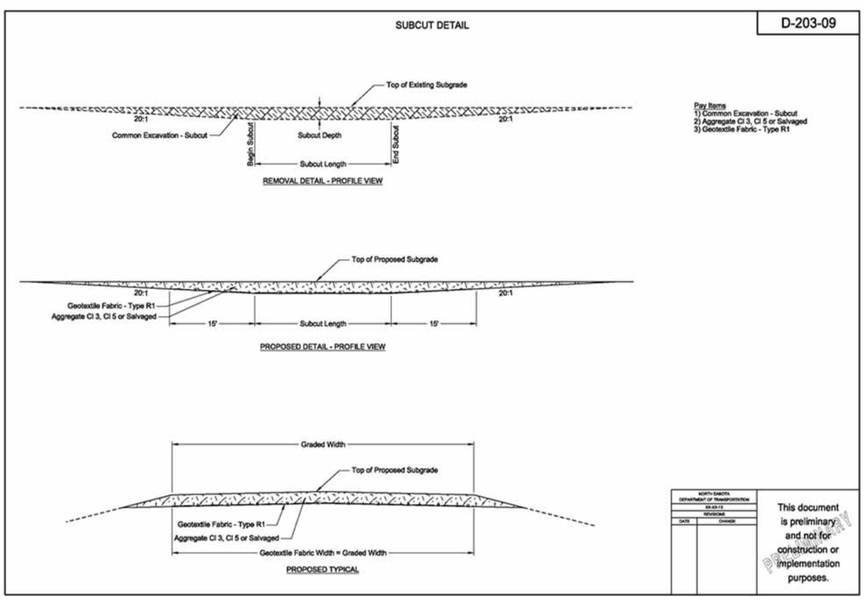
- We typically call for a subcut to a depth of 2/3 of the extreme frost depth below the top of the pavement.
  - i.e. Devils Lake Extreme Frost Depth = 6.5’ (78”) per USGS

Subcut

- Removal of poor subgrade material and replacing with good subgrade material (aggregate).

- Generally subcuts are required when:
  - Unsuitable material is present in embankment
  - Maintenance areas caused by poor subgrade material
    - Swelling or Heaving
    - Rutting
    - Uneven pavement surface
  - Time restraints when working with undesireable material

- Requirements
  - Subcut XX" below the top of the proposed grade for a given length
  - <u>Transition</u> the excavation at the beginning and end of the subcut back up to the top of the subgrade at a 20:1 slope
  - Place reinforcement fabric at the bottom of the subcut
  - Backfill with Class 3 or Class 5 aggregate
    - Place 12" of aggregate on top of fabric prior to compacting



Transitions

- Provide a gradual change from one subgrade support condition to another.
- Currently we call for a 20:1 on subcuts, shallow culverts and at bridge ends.

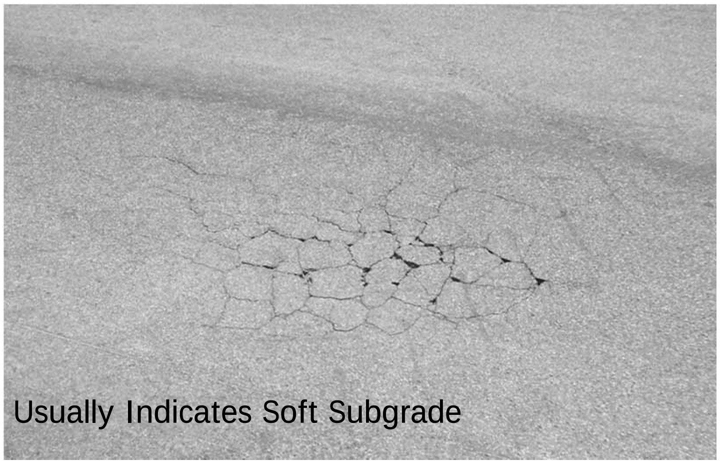
If not installed, these areas will be adversely reflected in the finished pavement.

Bearing Capacity

- Defined as the amount of load the soil can support without a shear failure.
  - Shear Strength in Granular soils is generated from friction between particles
  - Shear Strength in Fine grained soils is generated from interparticle attraction called Cohesion.
- Moisture content does not have a significant impact on the shear strength of a granular soil.
- Moisture content has a significant impact on the shear strength of a cohesive material.

Bearing Capacity

Alligator Cracking



Permeability

- Defined as the velocity at which a quantity of water passes through a soil when submitted to a unit hydraulic gradient.

  Ease with which water will flow or pass through the pores of a soil.

- Typically, the lower the permeability, the poorer the material is for subgrades.

Moisture Density Relationship

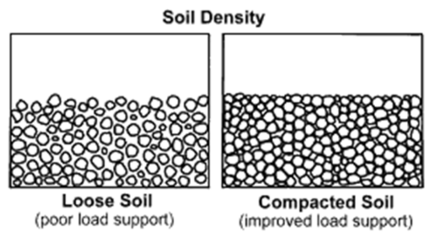
- Optimum Water Content
  - The water content that results in the greatest density for a specified compactive effort.
- Maximum Dry Density
  - Maximum density for a given soil for a specific compactive effort and method of compaction.
- Compactive Effort
  - T-99
  - T-180

Moisture Density Relationship

- Soil Too Wet
  - Compacting at water contents higher than the optimum water content results in a relatively dispersed soil that is weaker and more susceptible to shrinking.
- Soil Too Dry
  - Compacting at water contents lower than the optimum water content results in a relatively flocculated (granular or crumbly) soil that is more susceptible to swelling.

Soil Compaction,

- The method of mechanically increasing the density of soil.
- Compaction is achieved by reducing the void space between soil particles
- Inadequate Compaction may Result in general and differential settlement, which causes Depressions and Possibly Premature Failure of the Pavement Section.



Compaction and Uniformity

- Compaction of a soil layer is the most important aspect of proper embankment construction.
- A "uniform" densely compacted embankment will provide a satisfactory platform upon which to place the pavement section.
- Uniform conditions during construction will result in uniform behavior of the pavement.

The benefits of compaction are substantial and the consequences of poor compaction are severe.

Why is compaction so Important

- There are several reasons for compaction
  - Increases load-bearing capacity
  - Increases resistance to frost action
  - Provides stability on slopes
  - Decreases permeability, swelling, and contraction
  - Decreases settlement

Factors Affecting Compaction

- **Soil Type/Group**
- **Compaction Effort (Energy)**
- **Water Content**

Soil Type / Group

- **Cohesive Soils**
  - dense and tightly bound together by molecular attraction
  - Proper water content, evenly distributed, is critical for proper compaction
- **Granular (non-cohesive) Soils**
  - Water tends to move more freely through granular soils.
  - Water plays less of a role in the consistency of the material. Thus it may be harder to visually see what the optimum moisture should be.

Energy in Compaction Process

Some form of energy must be applied to the soil to perform adequate compaction.

General Compaction Methods

	Coarse-grained soils	Fine-grained soils
Laboratory	•Vibrating hammer (BS)	•Falling weight and hammers •Kneading compactors •Static loading and press
Field	•Hand-operated vibration plates •Motorized vibratory rollers •Rubber-tired equipment •Free-falling weight; dynamic compaction (low frequency vibration, 4~10 Hz)	•Hand-operated tampers •Sheepsfoot rollers •Rubber-tired rollers
	Vibration	Kneading

Equipment

Smooth-wheel roller (drum)

- 100% coverage under the wheel
- Contact pressure up to 60 PSI
- Can be used on all soil types except for rocky soils.
- Compactive effort: static weight
- The most common use of large smooth wheel rollers is for proof-rolling subgrades and compacting asphalt pavement.

Equipment

Pneumatic (or rubber-tired) roller

- 80% coverage under the wheel
- Contact pressure up to 100 PSI
- Can be used for both granular and fine-grained soils.
- Compactive effort: static weight and kneading.
- Can be used for highway fills or earth dam construction.

Equipment

Sheepsfoot rollers

- Has many round or rectangular shaped protrusions or “feet” attached to a steel drum
- 8% ~ 12 % coverage
- Contact pressure is from 200 to 1000 PSI
- It is best suited for clayed soils.
- Compactive effort: static weight and kneading. Could also be vibratory

Equipment

Tamping foot roller

- About 40% coverage
- Contact pressure is from 200 to 1200 PSI
- It is best for compacting fine-grained soils (silt and clay).
- Compactive effort: static weight and kneading.

Equipment

Mesh (or grid pattern) roller

- 50% coverage
- Contact pressure is from 200 to 900 PSI
- It is ideally suited for compacting rocky soils, gravels, and sands. With high towing speed, the material is vibrated, crushed, and impacted.
- Compactive effort: static weight and vibration.

Equipment

Smaller Equipment for confined spaces

Waters Role in Compaction Process

- Water lubricates the soil grains so that they slide more easily over each other and can thus achieve a more densely packed arrangement.
  - A little bit of water facilitates compaction
  - Too much water inhibits compaction.

Equipment

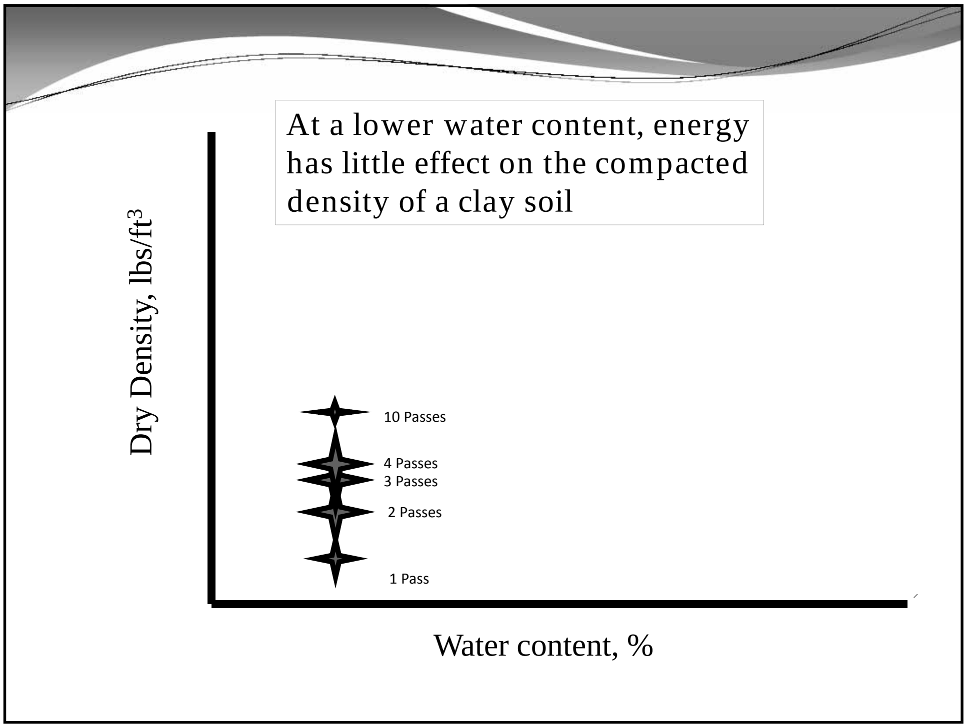
Water Sprayers

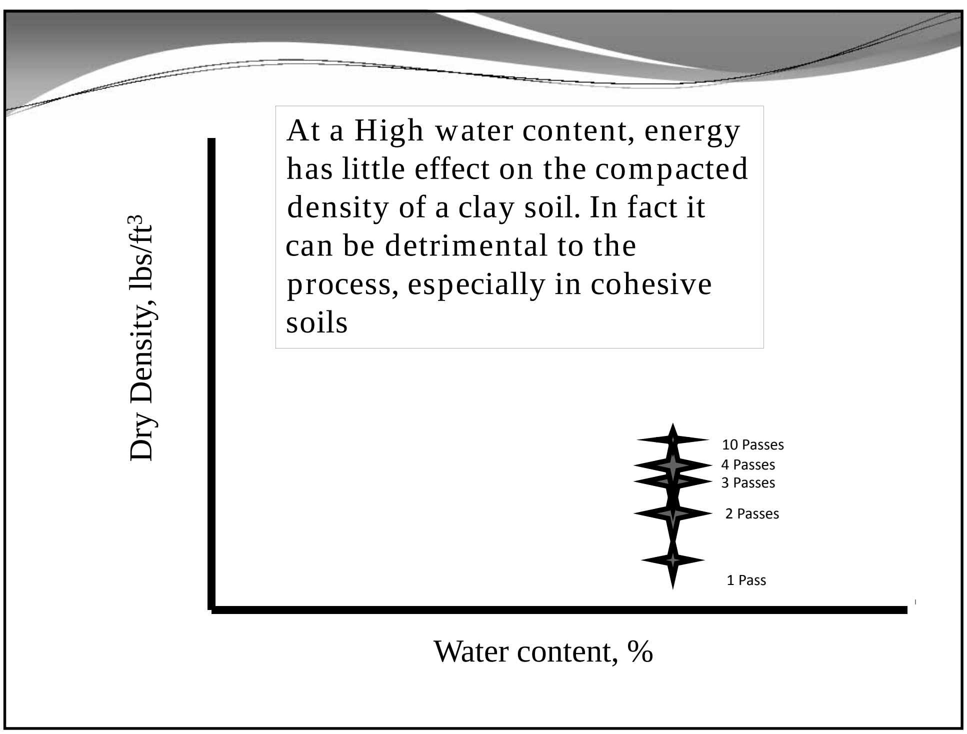
- Adds moisture to soil when soil is dry of optimum moisture content.
- Evenly distributes moisture to the soil to facilitate compaction.

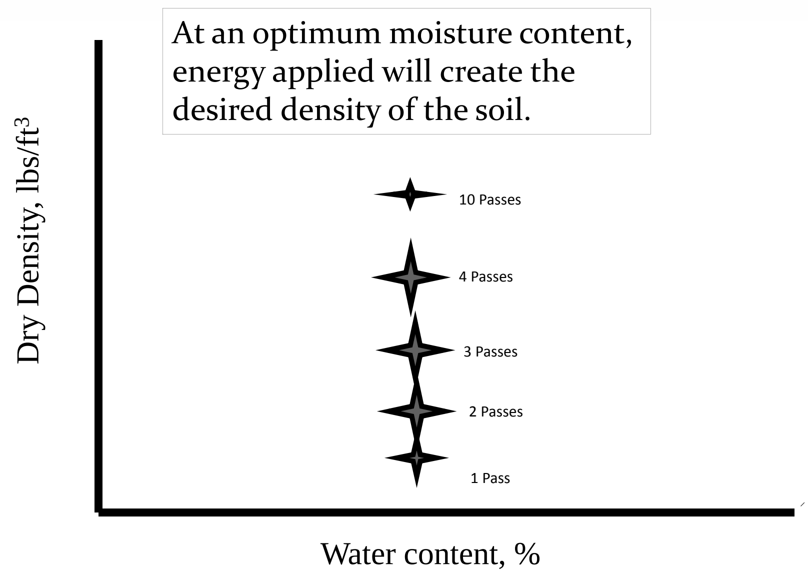
Equipment

Discs and Rippers

- Used to mix soil to create a uniform section.
- Used to allow greater exposure to allow for drying out of soils.


At a lower water content, energy has little effect on the compacted density of a clay soil
Dry Density, lbs/ft3
10 Passes
4 Passes
3 Passes
2 Passes
1 Pass
Water content, %


At a High water content, energy has little effect on the compacted density of a clay soil. In fact it can be detrimental to the process, especially in cohesive soils
Dry Density, lbs/ft3
10 Passes
4 Passes
3 Passes
2 Passes
1 Pass
Water content, %

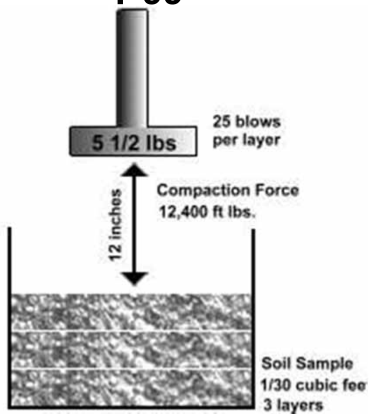


Moisture Density Relationship

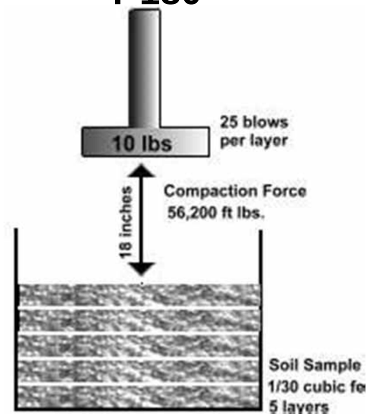
- This methodology is the basis behind the proctor tests which are used to determine the optimum moisture and maximum dry density for a given soil type.
- This is the Basis for the Standard and modified proctor tests.

Moisture Density Relationship

Standard Proctor Test
T-99

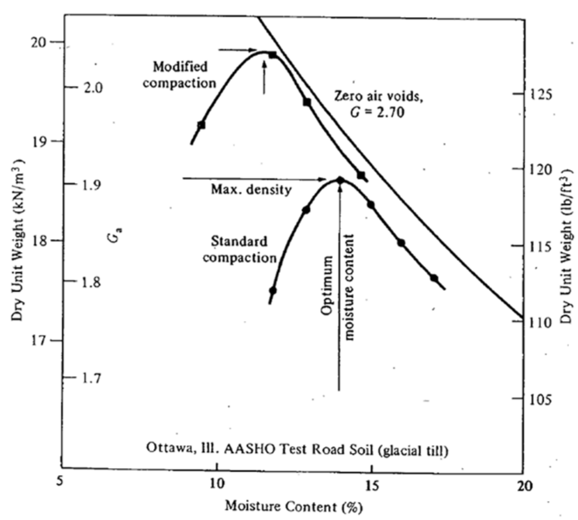


Modified Proctor Test
T-180



Moisture Density Relationship

T-99 vs. T-180



Moisture Density Relationship

T-99 Compaction Control

- Specified in areas with high natural moisture contents
- High Swell Potential
- High Groundwater Conditions

Typically T-99 Compaction Control is required in the Red River Valley Soils

Moisture Density Relationship

T-180 Compaction Control

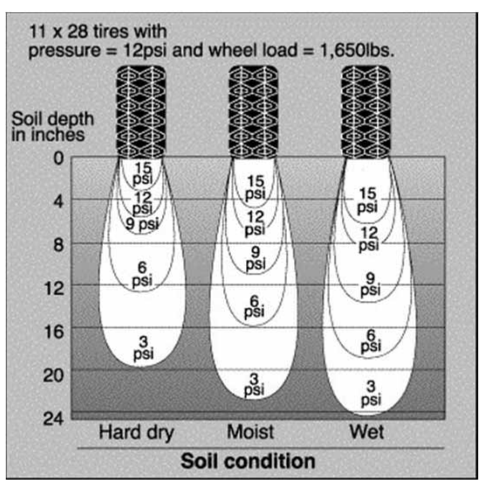
- Specified in areas with moderate to low natural moisture contents
- Low to moderate swell potential
- In areas where groundwater/pumping are not a concern

Majority of the state receives T-180 compaction control

Inspection

- Main purpose is to verify the embankment is uniform and compacted to density spec.
- It is extremely important that the lift thickness does not exceed the maximum allowable thickness
- More testing at the beginning of the project and whenever encounter new soils

Lift Thickness



Uniformity

- **Uniformity of earthwork throughout the project is necessary for adequate stability and satisfactory long term performance of both the embankment and pavement surface.**

Subgrade Preparation

- Increases Bearing Capacity
- Increases Uniformity
- Blends differing soil types together

Shown in Plans as 6", 12", 18" or 24", Type A, B or C.

Subgrade Preparation

Subgrade Preparation

Fill Materials					
	Permeability	**Foundation Support**	**Pavement Subgrade**	**Expansive**	**Compaction Difficulty**
Gravel	Very High	Excellent	Excellent	Low	Very Easy
Sand	Medium	Good	Good	Low	Easy
Silt	Medium Low	Poor	Poor	Low To Moderate	Difficult
Clay	Low to Very Low	Moderate	Poor	Moderate to High	Very Difficult
Organic	Low	Very Poor	Not Acceptable	Moderate	Very Difficult

Soil Investigations

- Linear Soil Survey
  - Major Rehabilitation (Reconstruction): boring every 500' – 1000'
  - Minor Rehabilitation (Overlay): boring(s) at each maintenance area
    - Bulk Sample from each boring
    - Moisture sample every foot
    - Pavement and Base Depth Check

Soil Investigations

- Deep Foundation
  - Bridge Foundations
  - Landslides
    - Split Spoon Sampling (Disturbed Sample)
      - Blow Counts
    - Shelby Tube Sampling (Undisturbed Sample)
      - Shear Strength

Soil Investigations

- Borrow Area Investigations
  - Similar to Linear Soil Surveys

Soil Investigations

- Lab Data

Linear Laboratory Analysis
Department of Transportation, Materials and Research Division
300 Airport Road, Bismarck ND 58504 (701) 328-6900

Page 1 of 6

Report Number SS-12-2014 **Date Reported** 7/28/2014 **District** Devils Lake
County EDDY **Submitted By** Naumann **Project Number** SS-3-020(077)061
AASHTO Test Method T-180 **PCN** 17765

Comments

Lab Number	266	267	268	269
Reference Pt + Feet	61+2300	61+2411	61+2505	61+2622
Distance From CenterLine (Ft.)	Rt 8 NB	Rt 8 NB	Rt 8 NB	Rt 8 NB
Depth, Ft.	0.4 - 4.5	1.0 - 5.0	1.0 - 4.0	1.2 - 5.0
Field Sample No.	266	267	268	269
% Pass. 3/8" Sieve	100	100	100	100
% Pass. No. 4 Sieve	98	99	99	100
% Pass. No. 10 Sieve	92	97	96	99
% Coarse Sand (-No. 10 + No. 40)	10	6	6	2
% Fine Sand (-No. 40 + No. 200)	26	28	23	15
% Silt (0.074 - 0.005 mm)	31	42	43	48
% Clay (-0.005 mm)	24	21	25	33
Liquid Limit (-No. 40)	32	28	33	40
Plasticity Index (-No. 40)	14	9	13	19
Plastic Limit	18	19	20	22
Soil Color	BRN	BRN/GRY/BLK	BRN/GRY/BLK	BRN/GRY/BLK
Textural Class	CLY LM	CLY LM	CLY LM	CLY
Soil Class (AASHTO M-145)	A-6(5)	A-4(4)	A-6(7)	A-6(15)
Frost Class	F3	F4	F3	F3
Optimum Moisture (%)	12.0	11.9	13.2	14.3
Maximum Dry Density (pcf)	120.6	121.1	117.7	115.2
% Organic Content				
Depth (Ft.) | Moisture (%)	2 | 21.6	2 | 23.4	2 | 24.6	2 | 14.7
	3 | 15.5	3 | 23.7	3 | 23.2	3 | 28.4
	4 | 23.7	4 | 19.2	4 | 24.8	4 | 31.1
	5 | 39.1	5 | 27.6	5 | 21.0	5 | 27.5
Avg. Moisture of Sample Depth	20.2	23.5	24.2	25.5

Scott W. Wutzke, Testing Lab Supervisor
Date Printed: 8/25/2014

Soil Investigations

- Linear Soil Survey

LINEAR SOILS SURVEY AND RECOMMENDATIONS

PROJECT NO. SS-3-020(122)061

PCN 17765

COUNTY Eddy

Highway 20 from RP 61.198 to RP 69.313

PREPARED BY: Jordan M. Nehls, P.E.

NORTH DAKOTA DEPARTMENT OF TRANSPORTATION
MATERIALS AND RESEARCH DIVISION

SEPTEMBER 2014

Construction Issues

- Unsuitable / Suitable Materials
- Weaving or Pumping
- Cold Weather Construction
- Drainage

Unsuitable Materials

- Coal
- Shale
- Organics
- Very High Plasticity Silts & Clays

Suitable Materials

- All other materials that are suitable for constructing a roadway embankment

Unsuitable VS Undesirable

- Unsuitable Material is material that will not perform well for embankment construction under any condition

- Undesirable Material is material that has properties under certain conditions (i.e. too wet) that make it tough to work with and meet specifications. However, the material will perform well for embankment construction.

  *This is a common discussion between our office and the field staff. It is important that these two different types of material are understood.

Weaving or Pumping

Weaving or Pumping

- Conditions that contribute to weaving or pumping
  - Soils with a high silt content that is non-plastic or of low plasticity
  - The presence of excess soil moisture content
  - An excessive compaction effort
  - Excessive construction traffic on the soil
- We generally see this in embankment construction from a combination of excess soil moisture content and excessive construction traffic (scrapers) on the embankment.

Weaving or Pumping

- Conditions that may prevent or reduce weaving or pumping
  - If excess soil moisture conditions occur simply stay off the area and allow the excess pore water pressures dissipate naturally
  - Lighter weight compaction
- If scrapers or very large compaction equipment are not allowed on a pavement surface why would we want to run them on a finished subgrade repeatedly.

Cold Weather Construction

Cold Weather Construction

- It is extremely difficult, uneconomical, and under some circumstances virtually impossible to compact moist or wet soil while freezing temperatures exist.
- This will result in:
  - Significant differential settlement
  - Sideslope instability
- The resulting poor performance of the embankment may require substantial maintenance to correct.

Cold Weather Construction

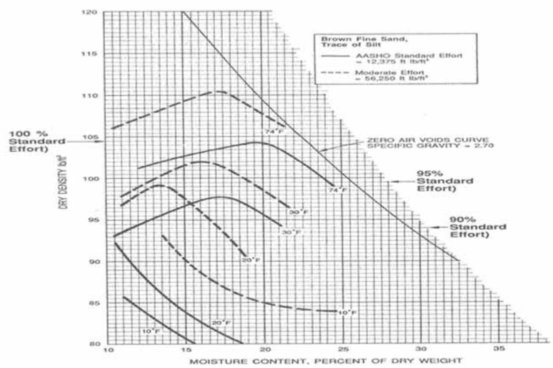


FIGURE 4-1 Compaction control curves (standard and modified AASHTO) for a brown fine sand with a trace of silt at different temperatures (*courtesy W. P. Hofmann*).

Drainage

- Water affects many aspects of earthwork construction. Controlling water on the construction site should be one of the contractor's major concerns, but tends to be neglected.
- Basic Principles of Drainage
  - Water runs downhill
  - Gravity is cheaper than plumbing
  - Erosion depends on water velocity
  - Erosion problems are easier to prevent than to fix

Drainage

- Surface Water
  - Surface water should be removed from the embankments as quick as possible and it should be controlled to prevent erosion.
  - If surface water is not controlled you may see erosion on:
    - Side Slopes
    - Ditches
    - Culvert and Pipe Outlets
    - Surrounding Areas
  - Ditch work should be performed first to ensure proper drainage.

Drainage

- Subsurface Water
  - Subsurface water is a concern because it affects the strength and load-carrying capacity of the soil
  - It is a factor in almost all failures of slopes (landslides) and excavations.
  - Common solutions to remove groundwater or stabilize soil:
    - Subsurface Drains
    - Flatten the slope


05/20/2010


10/11/2011


10/11/2011

Questions?