CHAPTER 1

CHARACTERISTICS OF SOILS AND THEIR RELATIONSHIP TO COMPACTION OF SOILS

GENERAL CHARACTERISTICS OF SOILS

Soil is defined, in soil mechanics, as "a natural aggregate of mineral grains that can be separated by such gentle mechanical means as agitation in water". Rock is defined as "a natural aggregate of mineral connected by strong and permanent forces". Some of the material used in construction by the Department is "soil". This could come from on-site sources (Regular Excavation), off-site sources (Borrow Excavation), crushed aggregate (Crusher Run, Dense Graded Aggregates for roadway base and subbase), or blended natural and crushed aggregates (Select Material).

Soils and aggregates can be classified into four broad groups based on the grain particle size. They are as follows:

Soil	Grain Size
Gravel	3" sieve to #10 sieve
Sand	#10 sieve to #200 sieve
Silt & Clay	smaller than #200 sieve

Note: In general laboratory work, the silt and clay sized particles are labeled as "minus #200 material". The percentage of silt and clay present in a soil sample can be determined by hydrometer analysis.

In nature, we generally find a mixture of these soils, such as sandy gravels, silty clays, clayey sands or any other combination of these materials.

Aggregates are classified into many mixtures based on particle size. In addition to using pit supplied aggregates (no manufacturing or crushing performed), VDOT uses processed blends of crushed stone and stone fines produced in a pugmill, to make a graded aggregate mixture for pavement foundations or bases. Besides producing the correct percentage retained on the chosen sieves in the pugmill, cement and other additives can be added to the mixture to change the aggregate blend's characteristics.

As defined above, soil is an earthen material overlaying the rock crust of the earth. The materials making up the loosely bound aggregate material we define as soil are mineral grains, organic material, water or moisture and gases or air. The mineral grains that make up most of the soil mixture are described by the following properties:

Size: described by particle or grain diameter or average dimension. Major division of classification systems using size as the criteria are gravel, sand , silt and clay. The very fine fraction of the soil, that is the silt and clay, have a wide variety of properties and determine a lot about the characteristics of the entire soil mixture.

Shape: the shape of the grains larger than 0.06 inches is distinguishable with the naked eye. These grains constitute the very coarse to coarse fractions of the soil. The shapes can be round, angular, sub-angular or sub-round. Finer fractions of soils are indistinguishable to the eye and generally have a plate-like shape. Elongated grains and fibers are sometimes found in the fine fractions of soil.

Surface Texture: refers to the degree of fineness and uniformity of a soil. Texture is judged by the coarser grains and the sensation produced by rubbing the soil between the fingers. Smooth, gritty, or sharp are several terms used to describe texture of soils.

Surface Forces: for soils with very fine particles with plate-like grains, electrical forces on the surfaces of the grains are the major influence as to the way these soils react with water.

Consistency: the degree of adhesion between soil particles, and is described by terms such as hard, stiff, brittle, friable, sticky, plastic and soft. The lab test that describes consistency is the Atterberg Limits, which will be discussed later.

Cohesion: The mutual attraction of particles due to molecular forces and the presence of moisture films. The cohesion of a soil varies with its moisture content. Cohesion is very high in clay, but of little importance in silt or sand.

Sensitivity: a characteristic exhibited by clays, and describes the loss in strength of a clay after it has been disturbed. That means that a clay material in a cut, that seems very strong, may lose a great deal of its strength after being cut and filled in another place. Other types of soils can be equally sensitive to other types of disturbance such as extreme changes in moisture or exposure to vibration.

Moisture Content: this is a measurement of how much moisture a soil is holding in its void spaces. It has a great impact on the consistency of the soil, its density, and its compactability. The importance of understanding and controlling soil moisture cannot be overstated.

To simplify the identification process, properties of these soil blends, such as gradation and soil moisture indices, are used to classify these materials so that we may easily identify which soils will provide the best service as a construction material and which materials will not. VDOT uses the Unified and AASHTO classification system for classifying soils but there are a lot of other methods available. Those include:

Pedological Soil Classification System (used by geologists)

Federal Aviation Agency Classification System

Unified Soil Classification System

US Department of Agriculture

Each of the above mentioned classification systems uses a slight variation of the same premise to best define a soil for a particular purpose.

Table 1-1 Soil Components and Significant Properties (Unified System)

	Soil Component	Symbol	Grain Size Range And Description	Significant Properties
Coarse-grained components	Boulder	None	Rounded to angular, bulky, hard, rock particle, average dia. Equal to or larger than 300 mm (12 in.)	Boulders and cobbles are very stable components, use for fills, ballast, and to stabilize slopes (riprap). Because of size and weight, their occurrence in natural deposits tens to improve the stability of foundation. Angularity of particles increase stability.
	Cobble	None	Rounded to angular, bulky, hard, rock particle, average dia. Smaller than 300 mm (12 in.) but larger than 76 mm (3 in.)	
	Gravel	G	Round to angular, bulky, hard, rock particle, passing 76 mm (3 in.) sieve retained on 4.75 mm (#4) sieve	Gravel and sand have essentially the same engineering properties differing mainly in degree. The 4.75mm (#4) sieve is arbitrary division, and does not correspond to significant change in properties. They are easy to compact, little affected by moisture, not subject to frost action. Gravels are generally more pervious and stable, resistant to erosion and piping than are sands. The well-graded sands and gravels are generally less pervious and more stable than those which are poorly graded and uniform in gradation. Irregularity of particles increases the stability slightly. Finer, uniform sands approaches the characteristics of silts, i.e. decreases in permeability and reduction in stability with increase in moisture.
	Coarse		76 mm to 19 mm (3 in. to 0.75 in.)	
	Fine		19 mm to 4.75 mm (0.75 in. to #4 sieve)	
	Sands	S	Rounded to angular, bulky, hard, rock particle, passing 4.75 mm (#4) sieve, retained on 0.075 mm (#200) sieve	
	Coarse		4.75 mm to 2.0 mm (#4 to #10) sieves	
	Medium		2.0 mm to 0.425 mm (#10 to #40) sieves	
	Fine		0.425 mm to 0.075 mm (#40 to #200) sieves	

Table 1-1 Soil Components and Significant Properties - continued				
	Soil Component	**Symbol**	**Grain Size Range And Description**	**Significant Properties**
Fine-grained components	Silt	M	Particles smaller than 0.075 mm (#200) sieve identified by behavior: that is, slightly or non-plastic regardless of moisture and exhibits little or no strength when air dried.	Silt is inherently unstable, particularly when moisture is increased, with a tendency to become quick when saturated. It is relatively impervious, difficult to compact, highly susceptible to frost heave, easily erodible and subject to piping and boiling. Bulky grains reduce compressibility; flaky grains, i.e., mica and diatoms, increase compressibility, produce an 'elastic' silt.
	Clay	C	Particles smaller than 0.075 mm (#200) sieve identified by behavior: that is, it can be made to exhibit plastic properties within a certain range of moisture and exhibits considerable strength when air dried.	The distinguishing characteristic of clay is cohesion or cohesive strength, which increases with decreases in moisture. The permeability of clay is very low, it is difficult to compact when wet and impossible to drain by ordinary means, when compacted is resistant to erosion and piping, is not susceptible to frost heave, is subject to expansion and shrinkage with changes in moisture. The properties are influenced not only by size and shape, flat, plate-like particles, but also by their mineral composition; i.e., the type of clay mineral, and chemical environment or base exchange capacity. In general, the montmorillonite clay mineral has greatest, illite and kaolinite the least adverse effect on the properties.
	Soil Component	**Symbol**	**Grain Size Range And Description**	**Significant Properties**
Organic Matter	Organic Matter	O	Organic matter in various sizes and stages of decomposition	Organic matter present even in moderate amounts increases the compressibility and reduces the stability of the fine-grained components. It may decay causing voids or by chemical alteration change the properties of the soil, hence organic soils are not desirable for engineering uses.

THE RELATIONSHIP OF LABORATORY TEST RESULTS TO COMPACTION OF SOILS

As part of preliminary engineering, the soil at a construction location is sampled and tested.

The final Soil Survey is done after the line for a project has been approved by the Location and Design Division. Soil Survey sampling is done by the District Materials Section's Geology crews. It consists of sampling the soil at specified points along a project.

For cut sections, 50 lb. samples of each material in the cut are taken. Since soil may be in many layers, it is likely that there will be more than one type of soil in any cut. To determine field moisture, samples weighing approximately 50 grams are taken each 5 feet down, especially when the soil is wet, or above optimum moisture content. Finding out the field moisture, or how wet the soil is in place, is very important in determining whether or not that soil can be used in one of the fill sections of the project.

When samples go to the lab, several tests are run. Each test gives information about the soil, and how it will behave under construction or loaded conditions. These tests are gradation, moisture content, optimum moisture/maximum density (also referred to as the laboratory proctor), Atterberg limits, CBR and soil classification. We will not be going over most of the testing procedures in any detail here, only what the results mean to you in the field, when you may be deciding how to handle a particular soil, or possibly having problems with it.

GRADATION

Names and definite size limits have been developed for different particle sizes of soil. This naming and defining places all soil tests on a common ground for comparison. The amount of each size group contained in a soil is one of the major tools used in judging, analyzing and classifying a soil.

The amounts of each particle size group are determined in the laboratory by tests referred to as "mechanical analysis". The amounts of gravel and sand are determined by passing the material through a set of sieves with different size openings with the sieve having the largest opening placed at the top and progressively smaller openings of the sieves as you go down the nest (see Figure 1.1). The weight retained on each sieve is determined and expressed as a percentage of the total sample weight. These sieves and their openings are in a table on the next page. The term "gradation" refers to the distribution and the size of the grains--how the soil breaks down into relative amounts of each size particle. An analysis of a soil is generally broken down into two parts: 1) the "coarse" gradation, and 2) the "fine" gradation. The coarse gradation is determined by using sieves or screens with progressively smaller openings to separate grains, while the fine gradation is determined by a hydrometer analysis, which uses particles settling in water as its principle. In this section only the coarse gradation will be discussed.

Table 1-2 Sieve Nominal Openings Table

Sieve	Nominal Opening in.	Type Material	
		Unified	AASHTO
3 in. (75 mm)	3		
2 in. (50 mm)	2		
1 in. (25 mm)	1		
3/4 in. (19mm)	0.750		
1/2 in. (12.5 mm)	0.500		
3/8 in. (9.5 mm)	0.375		
¼ in. (6.3 mm)	0.250		
No. 4 (4.75 mm)	0.187		GRAVEL
No. 8 (2.36 mm)	0.0937		
No. 10 (2.0 mm)	0.0787		
No. 20 (850 µm)	0.0331		
No. 40 (425 µm)	0.0165		
No. 60 (250 µm)	0.0098		
No. 80 (180 µm)	0.0070		SAND
No. 100 (150µm)	0.0059		
No. 200 (75 µm)	0.0029		
Less than No. 200 (75µm)			SILT/CLAY

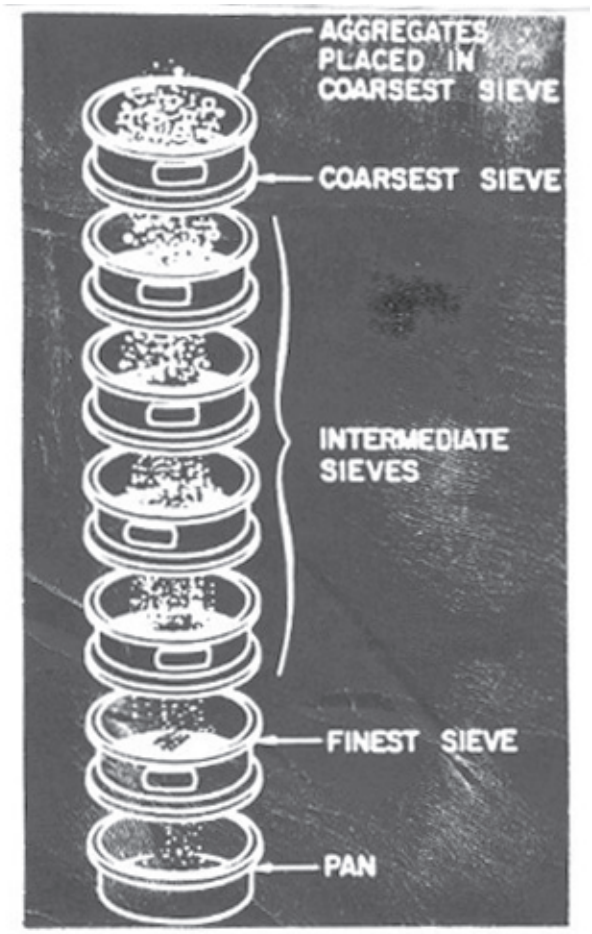
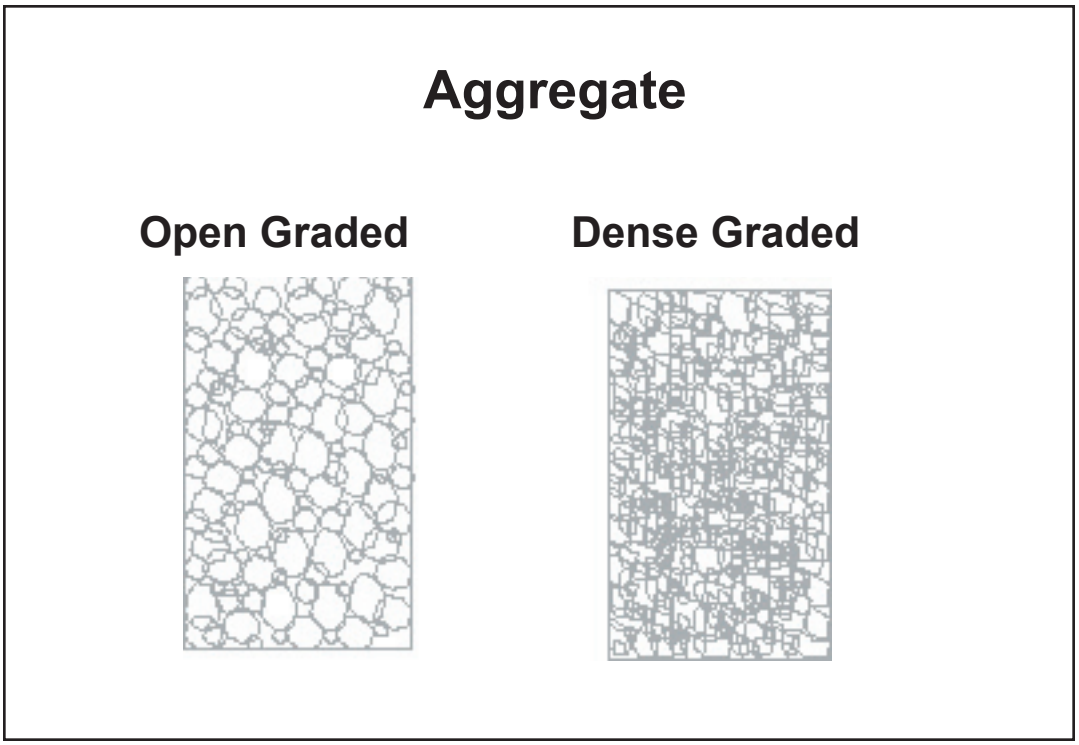


Figure 1.1 Sieve Analysis

Some materials are designed to be densely graded--that is: most of the voids are filled with particles. Open graded aggregates are sized so that they leave a lot of open space in between. Because of this, open graded aggregates are difficult to compact, and therefore, are generally not used as an aggregate base course, but are good as a drainage blanket or in underdrains.



Dense Gradation compared to Open Gradation

Most of the aggregates used in aggregate base courses are dense graded, since a dense gradation gives the material more strength to support a structure. There may be instances where a better quality material is needed to cap the subgrade to provide better support for the pavement but does not have to be of as high a quality as an aggregate base material. In this case, a select material (see Table II-6) would be used.

VDOT Specifications for Select Material and Dense Graded Aggregates are shown in the tables below.

Specification Reference: TABLE II-9
Design Range for Dense Graded Aggregates

Amounts Finer Than Each Laboratory Sieve (Square Openings*) (% by Weight)

Size No.	2″	1″	3/8″	No. 10	No. 40	No. 200
21A	100	94-100	63-72	32-41	14-24	6-12
21B	100	85-95	50-69	20-36	9-19	4-7
22	---	100	62-78	39-56	23-32	8-12

* In inches, except where otherwise indicated. Numbered sieves are those of the U.S. Standard Sieve Series.

Specification Reference: TABLE II-6
Select Material Design Range

	% by Weight of Material Passing				
	3″ Sieve	2″ Sieve	No. 10 Sieve	No. 40 Sieve	No. 200 Sieve
Type I	100	95-100	25-55	16-30	4-14
Type II		Min. 100			Max. 25
Type III[1]	Min. 100				Max. 20

[1] A maximum of 25% of material retained on the No. 200 sieve will be allowed for Type III if the liquid limit is less than 25 and the plasticity index is less than 6.

Particles passing the No. 200 Sieve are known as fines. A soil that contains a high percentage of fines is more affected by water than one with a low percentage of fines. Exactly how that soil will react with water can be predicted by the use of a test called the Atterberg Limits.

ATTERBERG LIMITS

Soil may exist in several states depending on its moisture content. At low moisture a soil will behave as a solid, with increasing moisture it becomes plastic and with excess moisture it flows like a liquid. The moisture content of the soil has a big effect on how well the soil will work as an embankment material or under a pavement.

The Atterberg Limits are determined by a laboratory test that will define the moisture limit consistency of fine grained soils. The test is done on the material that is finer than the openings of the No. 40 sieve.

Atterberg Limits are moisture content limits where a soil goes from one moisture state to another moisture state. In each moisture state a soil will generally react and perform differently in construction work. The effect of moisture on a soil's performance is more evident for soils with fines (minus No. 200) that have clay minerals. The greater the amount of clayey fines, the greater the effect. A material which does not have clayey fines, such as a clean sand or an aggregate which has fines resulting from crushing (stone dust), would not exhibit the same problems as a material with clayey fines. The following figure illustrates the different moisture states and the limits of each state.

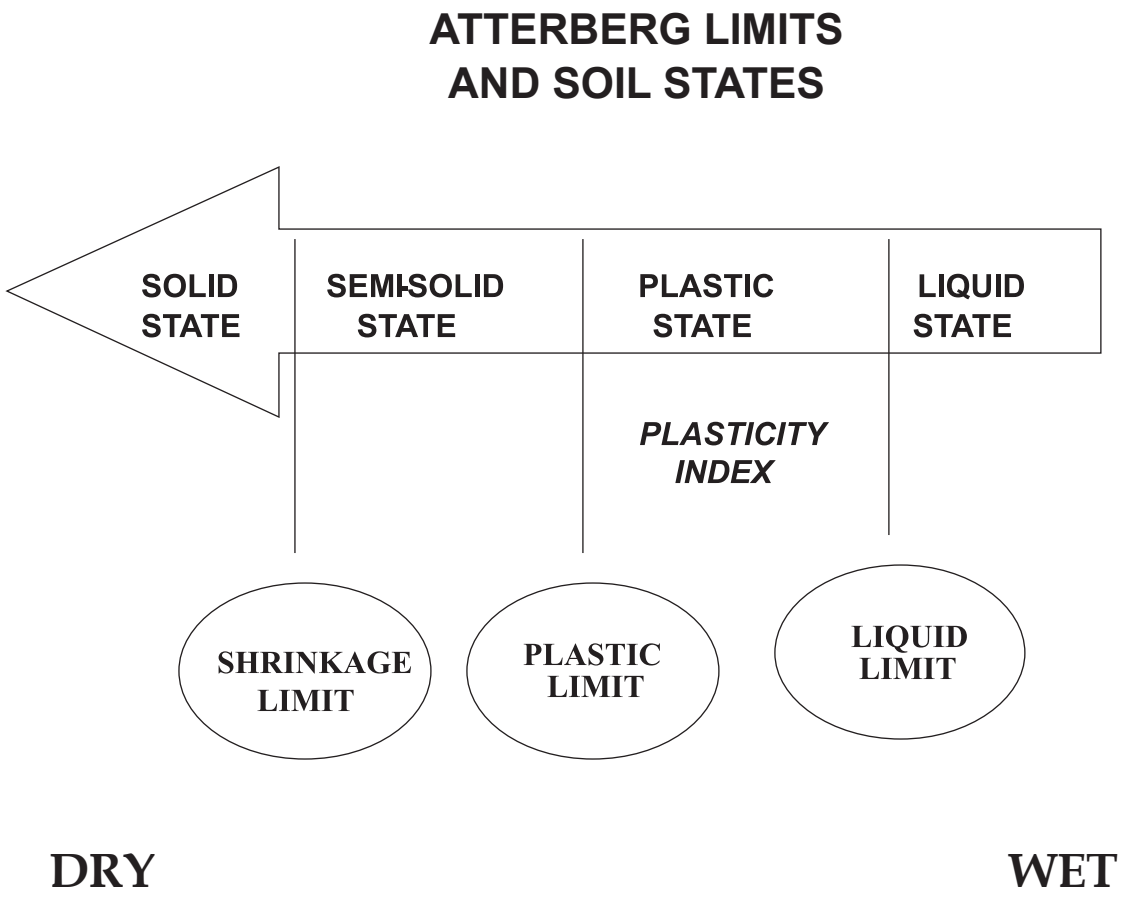


Illustration of Atterberg Limits' Relationship to Water Content

The amount of water in a soil is defined as the water content and expressed in percentage of the dry weight of the soil:

$$w(\%) = \frac{\text{weight of water}}{\text{weight of solids}} = \frac{Ww}{Ws} \times 100$$

On a test report, the Atterberg Limits are expressed as a number, not a percent. Even so, they do represent moisture content.

The Atterberg limits are the liquid limit, the plastic limit, and the shrinkage limit.

The liquid limit is defined as the moisture content at which the soil changes from a plastic state to a liquid state. The plastic limit is defined as the moisture content at which the soil changes from a semi-solid state to a plastic state. The shrinkage limit is defined as the moisture content at which the soil changes from a solid state to a semi-solid state.

Not all soils have a plastic limit. Many sands, for instance, have no moisture content at which they are plastic. A material with no plastic state is called non-plastic and this will be noted on the test report you receive as "NP".

The numerical difference between the liquid limit and the plastic limit (LL-PL) is the plasticity index. This is the moisture content range over which the soil will behave in a plastic state.

The difference between the Shrinkage Limit and the Plastic Limit is the SHRINKAGE INDEX. In this range of water contents, as the material loses water it will lose volume. This is not a good characteristic of a construction material as it will be too dry to properly compact.

If a soil is 100 percent saturated, that is, all the voids are full of water, AND has a high moisture content, this is an indication that the void space is large and the soil is loosely compacted. If, on the other hand the soil is 100 percent saturated and has a LOW moisture content, this indicates that the void space is small, and it is compact.

In the field, the Atterberg limits can be used as a guide as to how much a soil is likely to settle or consolidate under load. Find the field moisture content and compare it to the Atterberg Limits--if the Field Moisture is near the Liquid Limit, a lot of settlement is likely. The opposite is true if the field moisture is near or below the plastic limit.

On the next page are the specification requirements for Atterberg Limits for Select Material Type 1. They are based on a statistical quality acceptance program, which will not be covered here. The values on the table should give you an idea what range of Atterberg Limits values are typical for the material.

Specification Reference: TABLE II-8
Atterberg Limits: Select Material Type I

No. Tests	Max. Liquid Limit	Max. Plasticity Index
1	25.0	6.0
2	23.9	5.4
3	23.2	5.1
4	23.0	5.0
8	22.4	4.7

Atterberg Limits for Select Material Type II and III are:

Type	Max. Liquid Limit	Max. Plasticity Index
II	30	9
III	30	9

Specifications Reference: TABLE II-11
Atterberg Limits

	Max. Liquid Limit	Max. Plasticity Index	
No. Tests	Subbase and Aggregate Base Type I and II	Subbase Sizes No.21A, 22 and Aggregate Base Type II	Aggregate Base Type I and Sub-base Size No. 19
1	25.0	6.0	3.0
2	23.9	5.4	2.4
3	23.2	5.1	2.1
4	23.0	5.0	2.0
8	22.4	4.7	1.7

Atterberg Limits for Aggregate Subbase and Base (Section 208)

Using the Atterberg Limits and the results from the sieve analysis, the soil can now be classified.

CLASSIFICATION

Soil classification systems are based on the properties of the soil grains themselves instead of the intact material as found in nature. Although the behavior of soil during and after construction primarily depends on the properties of the intact soil, valuable information concerning the general characteristics of a soil can be inferred from its proper classification according to one of the standard systems available to the practitioners. As mentioned earlier VDOT uses both AASHTO and Unified Soil Classification System (USCS) depending on the specific use in its design and construction operations. AASHTO classification is mostly used for the highway and pavement whereas Unified Soil Classification System is widely used for foundation. Both of these classifications are based on gradation analysis (grain size distribution) and consistency as determined by Atterberg Limits.

Unified Soil Classification System

Unified soil classification system divides soils into two broad groups depending on percent materials passing the No. 200 sieve. When 50% or more passes the No. 200 sieve, the soil is considered as fine-grained whereas soil with more than 50% retained on the No. 200 sieve is classified as coarse grained. These large groups are further subdivided into smaller groups.

Coarse-grained soils are divided into two groups based on 50% particles on the No. 4 sieve: Gravel and Sand with symbols of G and S, respectively. Again, the gravels and sands are each subdivided into four groups:

i. Well-graded and fairly clean material (symbol W);
ii. Well-graded with excellent clay binder (symbol C);
iii. Poorly-graded but fairly clean material (symbol P);
iv. Coarse materials containing fines but does not show binding effect like clay (symbol M);

Fine-grained soils are divided into three groups: Silt (inorganic silt and fine sand), Clay (inorganic) and Organic Soils (silts and clays) with symbols M, C, and O, respectively. Each of these groups are again subdivided into two groups according to its Atterberg Limits as shown in Figure 1.2: soils with low compressibility (symbol L) and soils with high compressibility (symbol H).

Highly organic soils are classified as peat (symbol Pt) on the basis of visual classification. These are usually fibrous organic matter such as peat and swamp soils of very high compressibility with a dark brown to black color and an organic odor.

Table 1-3 summarizes unified soil classification system for proper identification of dual group symbols in a laboratory.

AASHTO Classification

AASHTO classification system also uses two broad categories of soils: granular material (less than 35% passing the No. 200 sieve) and silt-clay material (more than 35% passing the No. 200 sieve). The classification (further grouping) procedure based on gradation analysis and Atterberg Limits is given in Table 1-4. The inorganic soils are classified into seven groups corresponding to A-1 to A-3 for granular materials and A-4 through A-7 for silt-clay materials. These groups are further subdivided into a total of 12 sub-groups based on gradation and Atterberg Limits. Similar to USCS, highly organic soils are grouped in one classification as A-8. Any soil containing fine-grained materials is further rated with a Group Index (a number calculated from materials passing the No. 200 sieve, liquid limit and plasticity index). The higher the Group Index, the less suitable the soil as subgrade material. If this number is near 20 or more, then the subgrade support is usually considered poor because of the presence of a high percentage of fines with moisture sensitivity.

Table 1-3 – Unified Soil Classification System

Major Division		Group Symbol	Laboratory Classification Criteria: Percent finer than 0.075 mm (No. 200) sieve	Laboratory Classification Criteria: Supplementary Requirements	Soil Description
Coarse-grained (over 50% by weight retained on the 0.075 mm (No.200) sieve)	Gravelly soils (over half of coarse fraction retained on #4 sieve	GW	0 to 5	C_u greater than 4; C_c between 1 and 3	Well-graded gravels, sandy gravels
		GP	0 to 5	Not meeting above gradation requirements for GW	Gap-graded or uniform gravels, sandy gravels
		GM	12 or more	PI less than 4 or below A-line	Silty gravels, silty sandy gravels
		GC	12 or more	PI greater than 7 and above A-line	Clayey gravels, clayey sandy gravels
Fine-grained (over 50% by weight passing the 0.075 mm No. 200) sieve)	Sandy soils (over half of coarse fraction passing #4 sieve)	SW	0 to 5*	C_u greater than 4; C_c between 1 and 3	Well-graded, gravelly sands
		SP	0 to 5*	Not meeting above gradation requirements for SW	Gap-graded or uniform sands, gravelly sands
		SM	12 or more*	PI less than 4 or below A-line	Silty sands, silty gravelly sands
		SC	12 or more*	PI greater than 7 and above A-line	Clayey sands, clayey gravelly sands
	Low compressibility (liquid limit less than 50)	ML	Plasticity Chart (Figure 1.2)		Silts,very fine sands, silty or clayey fine sands, micaceous silts
		CL	Plasticity Chart (Figure 1.2)		Low plasticity clays, sandy or silty clays
		OL	Plasticity Chart (Figure 1.2), organic odor or color		Organic silts and clays of low plasticity
	High compressibility (liquid limit more than 50)	MH	Plasticity Chart (Figure 1.2)		Micaceous silts, diatomaceous silts, volcanic ash
		CH	Plasticity Chart (Figure 1.2)		Highly plastic clays and sandy clays
		OH	Plasticity Chart (Figure 1.2), organic odor or color		Organic silts and clays of high plasticity
Soils with fibrous organic matter		Pt	Fibrous organic matter; will char, burn or glow		Peat, sandy peats and clayey peat

- Note: For soils having 5 to 12 percent passing the 0.075 mm (No. 200) sieve, use dual symbol (e.g. GW-GC)

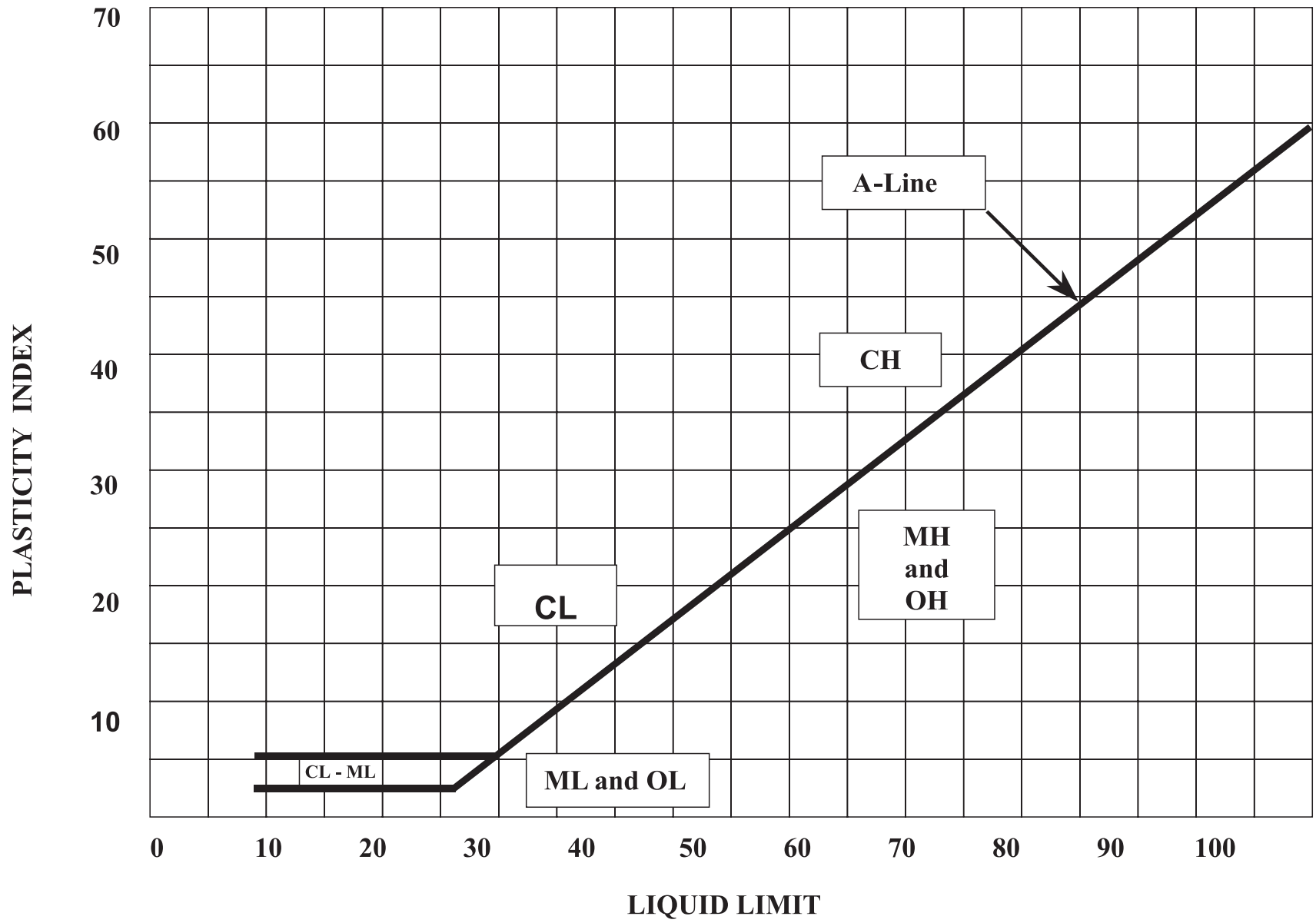


Figure 1.2 – Unified Liquid and Plasticity Index Ranges for Silt-Clay Materials

TABLE 1-4 - AASHTO Classification of Soils and Soil-Aggregate Mixtures

General Classification	Granular Materials (35 Percent or Less Passing 0.075 mm (No. 200) Sieve)							Silt-Clay Materials (More than 35 Percent Passing 0.0075 mm (No. 200) Sieve)			
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				
Sieve Analysis, percent passing 2.00 mm (No. 10) 0.425 mm (No. 40) 0.075 mm (No. 200)	50 max 30 max 15 max	- 50 max 25 max	- 51 min 10 max	- - 35 max	- - 35 max	- - 35 max	- - 35 max	- - 36 min	- - 36 min	- - 36 min	- - 36 min
Characteristics of fraction passing 0.425 mm (No. 40) sieve Liquid Limit Plasticity Index	- 6 max		- N.P.	40 max 10 max	41 min 10 max	40 max 11 min	41 min 11 min	40 max 10 max	41 min 10 max	40 max 11 min	41 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			

Note: 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. See Figure 1.1.

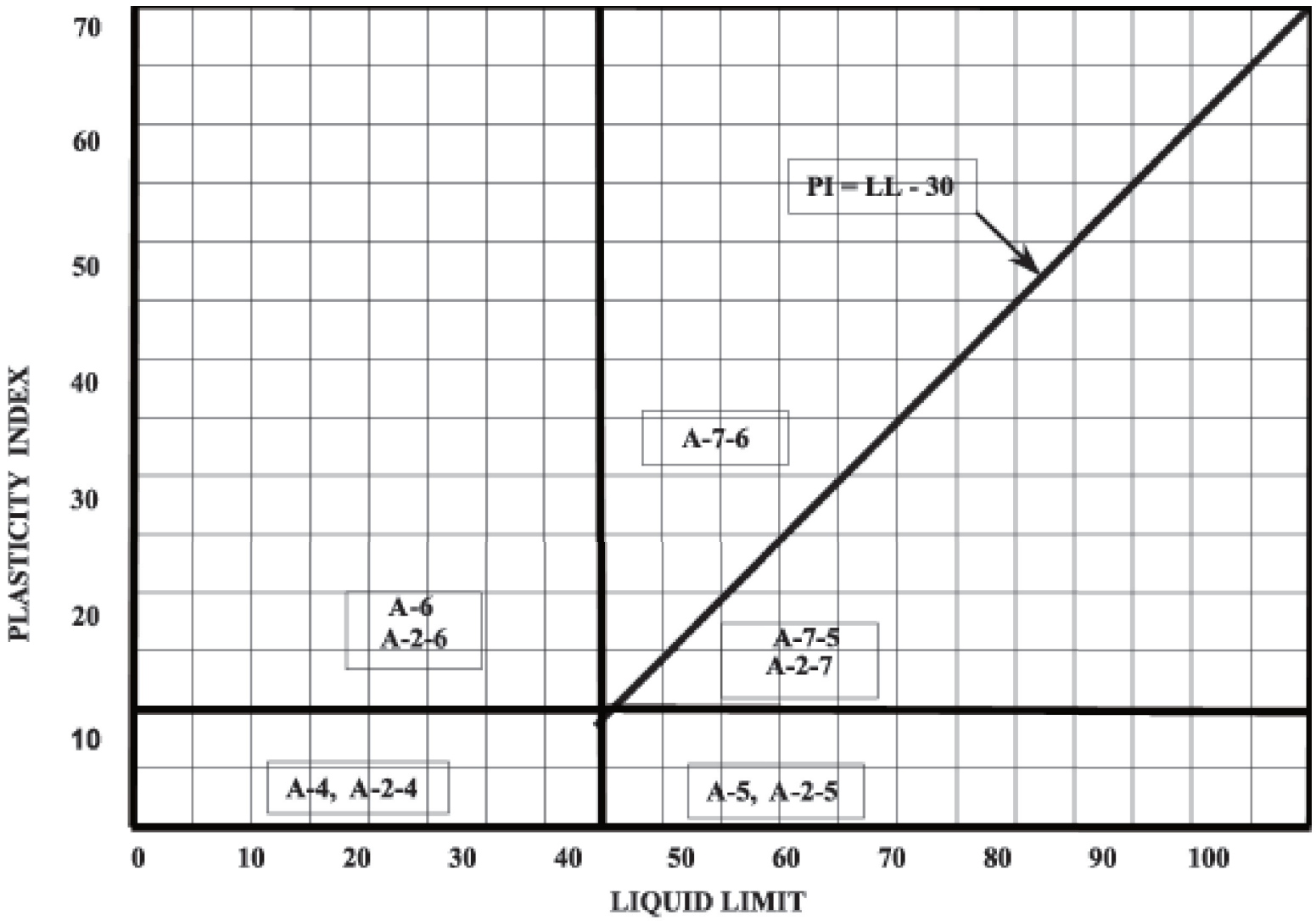


Figure 1.3 – AASHTO Liquid and Plasticity Index Ranges for Silt-Clay Materials

TABLE 1-5
COMPARISON OF AASHTO & USCS SOILS CLASSIFICATION SYSTEMS

SOIL GROUP IN AASHTO SYSTEM	COMPARABLE SOIL GROUPS IN UNIFIED SYSTEM			SOIL GROUP IN USCS SYSTEM	COMPARABLE SOIL GROUPS IN AASHTO SYSTEM		
	MOST LIKELY	POSSIBLE	POSSIBLE BUT NOT LIKELY		MOST LIKELY	POSSIBLE	POSSIBLE BUT NOT LIKELY
A-1-a	GW, GP	SW, SP	GM, SM	GW	A-1-a	-----	A-2-4 A-2-5 A-2-6 A-2-7
A-1-b	SW, SP GM, SM	GP	-----	GP	A-1-a	A-1-b	A-3, A-2-4 A-2-5 A-2-6 A-2-7
A-3	SP	-----	SW, GP	GM	A-1-b A-2-4 A-2-5 A-2-7	A-2-6	A-4, A-1-a A-5, A-7-5 A-6, A-7-6
A-2-4	GM, SM	GC, SC	GW, GP SW, SP	GC	A-2-6 A-2-7	A-2-4 A-6	A-4 A-7-5 A-7-6
A-2-5	GM, SM	-----	GW, GP SW, SP	SW	A-1-b	A-1-a	A-3, A-2-4 A-2-5 A-2-6 A-2-7
A-2-6	GC, SC	GM, SM	GW, GP SW, SP	SP	A-3 A-1-b	A-1-a	A-2-4 A-2-5 A-2-6 A-2-7
A-2-7	GM, GC SM, SC	-----	GW, GP SW, SP	SM	A-1-b A-2-4 A-2-5 A-2-7	A-4 A-5 A-2-6	A-6 A-1-a A-7-5 A-7-6
A-4	ML, OL	CL, SM SC	GM, GC	SC	A-2-6 A-2-7	A-4 A-6 A-2-4 A-7-6	A-7-5
A-5	OH, MH ML, OL	-----	SM, GM	ML	A-4 A-5	A-6 A-7-5	-----
A-6	CL	ML, OL SC	GC, GM SM	CL	A-6 A-7-6	A-4	-----
A-7-5	OH, MH	ML, OL CH	GM, SM GC, SC	OL	A-4 A-5	A-6 A-7-5 A-7-6	-----
A-7-6	CH, CL	ML, OL SC	OH, MH GC, GM SM	MH	A-5 A-7-5	-----	A-7-6
				CH	A-7-6	A-7-5	-----
				OH	A-5 A-7-5	-----	A-7-6
				PT	-----	-----	-----

LABORATORY CLASSIFICATION EXAMPLES:

1. A soil has the following properties:

Percentage passing No. 4	100
Percentage passing No. 10	80
Percentage passing No. 40	55
Percentage passing No. 200	30
Liquid limit (LL)	42
Plastic limit (PL)	33

<u>USCS Procedure</u>:

1. PI (plasticity index) = LL – PL = 42 – 33 = 9
2. In the chart (Table 1-3), it is COARSE-GRAINED soil since 30% (less than 50%) passes the No. 200 sieve.
3. Now check the percentage of soil passing No. 4 sieve. Since it is more than half (100% passing), it would be classified as SAND.
4. Again passing no. 200 is more than 12% so it will be either SC or SM material.
5. The plasticity index of this soil is 9 and it falls below line-A in Figure 1.2.
6. Although it satisfies the plasticity index requirement of SC (greater than 7) but it falls below line-A in Figure 9.
7. As it satisfies one of the requirements for SM soil (below line-A), it will be classified as SM.

2. Another soil has the following properties:

Percentage passing No.10	90
Percentage passing No. 40	65
Percentage passing No. 200	55
Liquid limit (LL)	54
Plastic limit (PL)	36

<u>USCS Procedure</u>:

1. PI (plasticity index) = LL – PL = 54 – 36 = 18
2. This soil is classified as FINE-GRAINED in the chart (Table 1.3) because the materials passing No. 200 is more than 50%.
3. Since the LL is greater than 50, it is highly compressible.
4. The LL of 54 and PI of 18 classifies this soil as elastic silt (MH) according to Figure 1.2 since it is below line-A and LL is greater than 50 (high compressibility, H).

Table 1-5 on Page 1-17 is a guide to the materials constituting the soils in each classification.

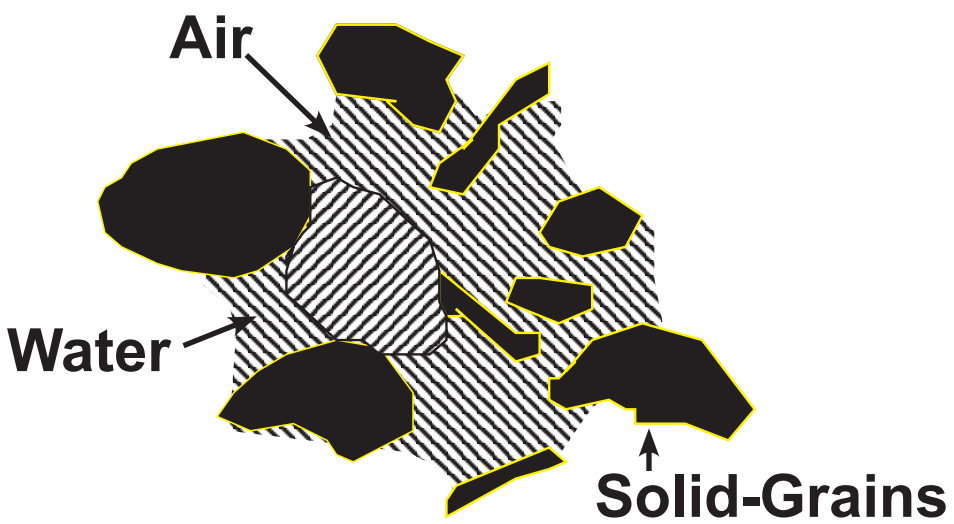
At this point we have seen how two laboratory tests, gradation or sieve analysis and the Atterberg Limits, can be used along with the Classification table to get a general idea of how the particular soil will behave. When you have a lab report for a soil on your project, the classification will have already been done.

The next characteristic of soil we will examine gives the relationship of soil moisture and density achieved by compaction. As soil is compacted in the field, the void content gets smaller. That is, the compaction equipment makes the soil denser by pushing all the particles closer together. Although having too much water in a soil will prevent proper compaction, there needs to be some water in the soil to get good compaction. The water not only adds a little density, but lubricates the soil particles so that they can move during compaction to the tightest arrangement possible.

SOIL MOISTURE RELATIONSHIP

To illustrate the states that soils can be found in nature, the following schematic diagram of soil is used. The components of a soil mass are shown by the mineral grains of solids, the water or moisture, and the air or gases. Each block illustrates that each component is a solid unit and not a heterogeneous mixture as in nature. Weight of a mass of soil is only due to the weight of the solids and the water in the soil, while volume is due to the solids, water and air. The void between the solids of a mass of soil are filled with water and/or air as shown below.

These relationships are illustrated below:



Natural State of Soil

Figure 1.4

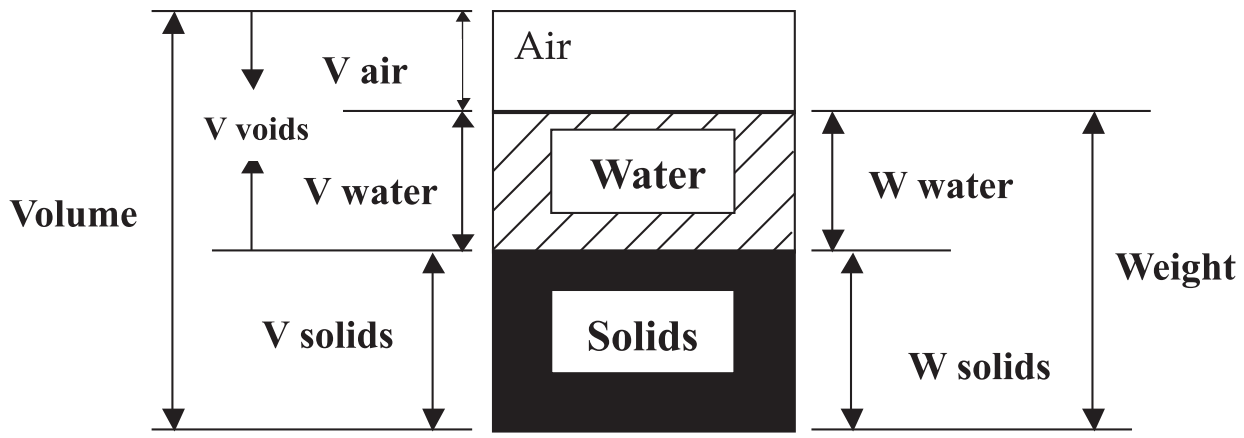


Figure 1.5 Wet Soil Weight and Volume Relationships
(Phase Diagram)

The volume of the voids is filled with air and water. The total weight is due to the weight of the solids and water. This is the most common state found in construction. The compaction tests run by the inspector is this same comparison of weight and volume.

HOW DO WE RELATE SOIL MOISTURE RELATIONSHIPS TO CONSTRUCTION DENSITY

What is Density?

Density is the ratio of the mass of an object to its volume (pounds per cubic feet, pfc)
Density of soil or aggregate

- Maximum Theoretical Density (lab or field)
  - AASHTO T99 & T180
  - VTM 1
- Field Density
  - Nuclear Gauge
  - Sand Cone

$$Density = \frac{Weight}{Volume}$$

$$Wet\ Density = \frac{Weight}{Volume}$$

$$Moisture\ Content\ (w) = \frac{W\ water}{W\ solids} x100$$

$$Dry\ Density = \frac{W\ solids}{Volume} = \frac{WetDensity}{1+(w/100)}$$

Compaction of a material in construction is measured by comparing its field unit weight or field density with its maximum dry density. The density of a soil is defined as the weight of the soil in one unit of volume, or pounds per cubic foot.

$$\%\ Compaction = \frac{Field\ Dry\ Density}{Max.\ Theoretical\ Dry\ Density} x100$$

Now that general characteristics of soil have been addressed, the next section will cover characteristics as determined by tests, and what this tells you about how a soil will respond to compactive efforts.

LABORATORY PROCTOR

In order to know how well the contractor is compacting the soil in question, we must know how dense the soil would become under the best possible conditions. The lab test used to determine this is the Proctor. (The "Standard Proctor" Density Test is the most commonly used. There is also a "Modified Proctor" Density Test, but it will not be discussed here).

The test consists of making a soil mold of compacted soil at different moisture contents. The object is to find the OPTIMUM MOISTURE CONTENT--the moisture content at which the soil compacts best, and the MAXIMUM DENSITY-- the density achieved at optimum moisture.

On the curve below, you can see that as water is added, the density of the soil in the mold increases until the optimum moisture content is reached. Where the water content is low, w1, there is too little water to "lubricate" the soil particles. The friction of the dry soil particles will be enough to retard compaction. As water is added, it does lubricate the soil and the compactive effort becomes more efficient. After this, the density decreases because water starts replacing soil in the mold (water is lighter than soil).

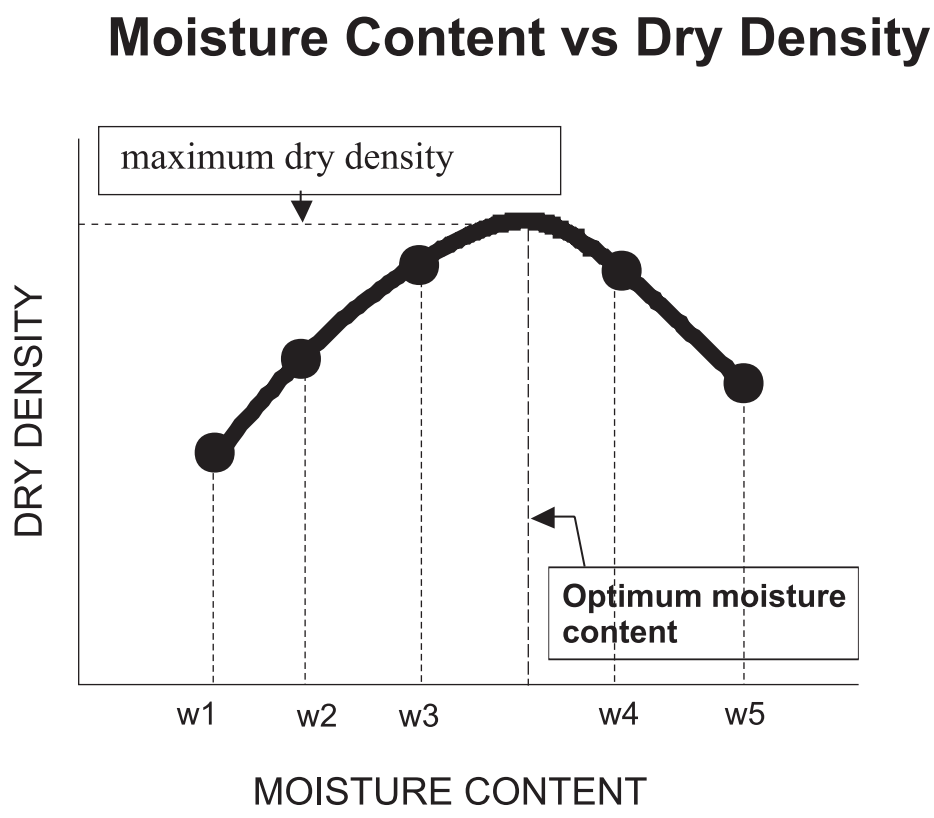


Figure 1.6

Curve from Laboratory Proctor showing Maximum Dry Density vs. Optimum Moisture.

Moisture Density Curve

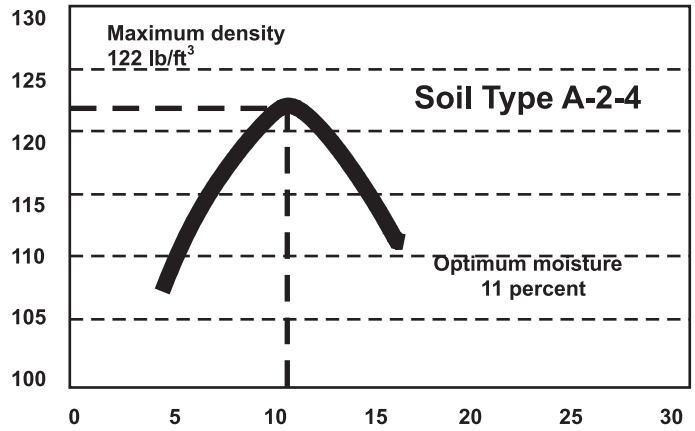


Figure 1.7

Curve showing the determination of optimum moisture and maximum density, and their actual values.

Moisture Density Curve

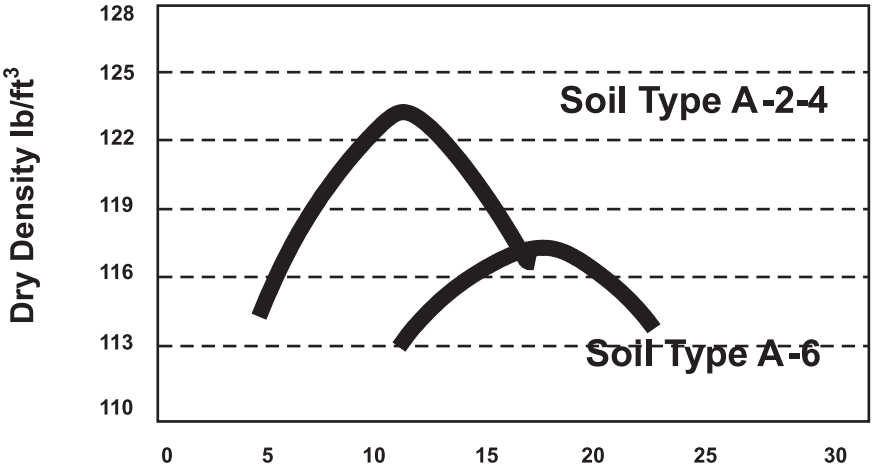


Figure 1.8

Curve comparing how two different soil types compact.

The soil designated A-2-4 (silty sand) will reach a higher maximum dry density than the A-6 (clayey soil). These are the soils represented on the moisture density curves above.

The A-2-4 is a soil with less fines (35 percent max) and the moisture density curve is relatively steep on both sides of the optimum moisture content. The A-6 is a soil with more fines (36 percent minimum) and the moisture density curve is relatively flat on both sides of the optimum moisture content. Therefore, the moisture control during compaction in the field will require stricter control for the A-2-4 silty sand (steep curve) than the A-6 clayey soil.

The chart below will help you see the relationship between the optimum moisture/maximum density and the Specifications. This curve has VDOT Specification acceptance ranges blocked in. It is presented in this form to make it clear how the specification relates to the proctor, and what the areas on the curve mean. If you are working on a compaction and the values from the densities being run start falling out of the passing range, seeing where they fall on a graph like this may indicate to you where the problem is (for example, too much or too little moisture in the soil).

Moisture Density Curve - Soil Moisture Content ± 20%

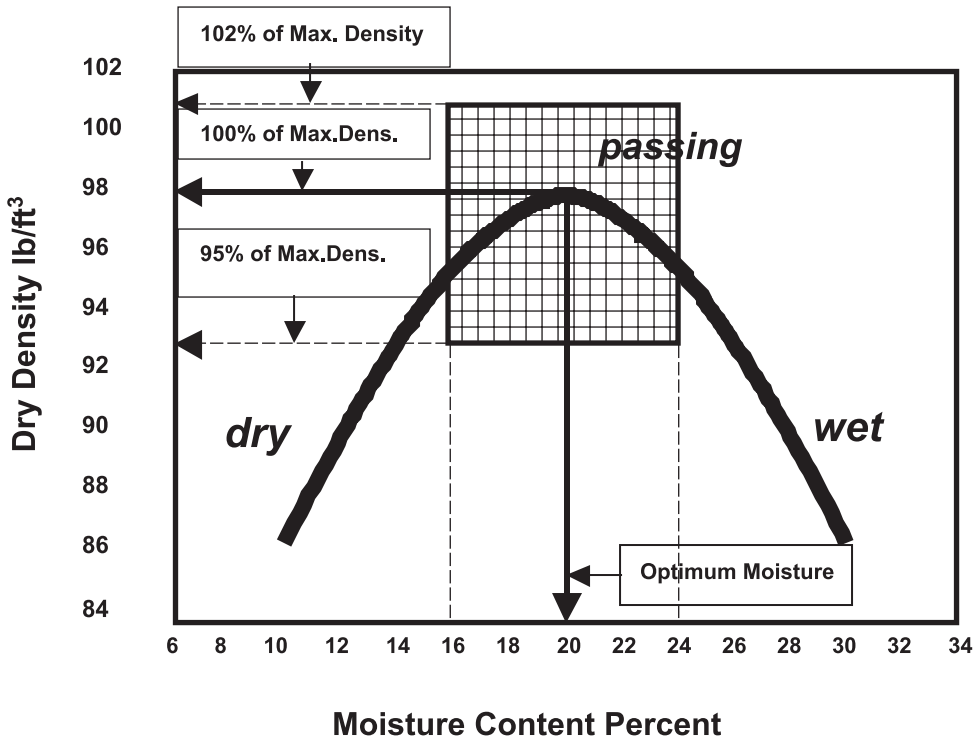


Figure 1.9

Moisture Density Curve - Aggregate Moisture Content ± 2 Percentage Points

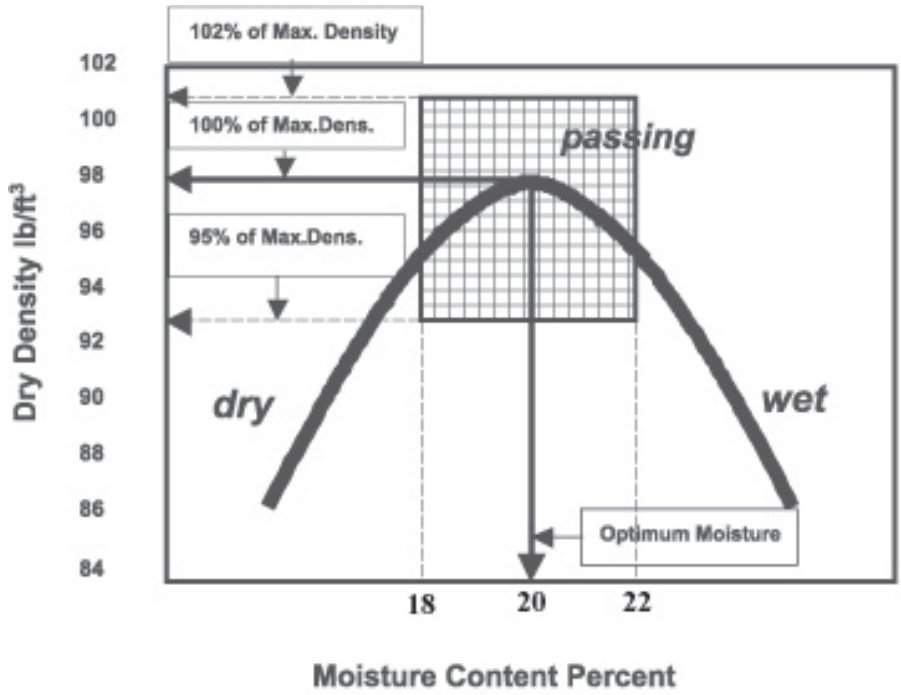


Figure 1.10

If, during construction, the density results either change suddenly, or simply don't make sense to you, these suggestions may help you determine what's happening:

1) Check your math, and the test itself.

2) If you used the sandcone, was the sand properly calibrated or was there vibration nearby (passing trucks) ?

3) If the nuclear method was used, check closely the area around the pin for either rocks or voids of some sort. Also, make sure the Standard Counts for that day are within the expected ranges (Moisture and Density).

Once you have checked these things, other reasons for unexpectedly changing densities are:

-Temperature--if you are working in very cold temperatures, a drop in temperature can cause a reduction in maximum dry density, especially in clayey soils. (Soil shall not be placed or compacted at temperatures below freezing).

-Lift thickness--if for reasons of uneven subgrade, uneven application of material, or constructing a grade, the lift being compacted is uneven across its section, this can cause unevenness (change) in density/compaction.

-When excavated material consists predominantly of soil, embankment shall be placed in successive uniform layers not more than 8 inches in thickness before compaction over the entire roadbed area. Each layer shall be compacted at optimum moisture, within a tolerance of plus or minus 20 percent of optimum, to a density of at least 95 percent as compared to the theoretical maximum density.

-More compactive effort--either a change in the number of rollers, or a change in the haul route so the fill is being compacted additionally by the haul trucks.

-Moisture control--A change in the moisture of the material, this is especially likely on dry, hot and windy days.

-A CHANGE IN THE MATERIAL. This is the most common reason for density results to either change quickly or stop making sense. ALWAYS be aware of the type of material being compacted and alert to changes. The possibility that you have run into soil that is not represented by a lab report that you have does exist.

CHAPTER 1
Study Questions

1. True or False. The voids in a saturated soil are partly filled with water and partly filled with air.

2. VDOT uses _____ Classification Systems to classify soils.

3. The mutual attraction of particles due to molecular forces and the presence of moisture is called _____.

4. The degree of adhesion between soil particles is called _____.

5. Silt and clay are made up of particles that are smaller than the _____ sieve.

6. The _____ is the distribution of various particle sizes within the material.

7. _____ means that the particles in a mixture are sized so that they fill most of the voids; there is very little space in between soil or stone particles.

8. The moisture content at which a soil begins to behave like a liquid is called the _____.

9. The behavior of a material where the material deforms under load and does not go back to its original shape is called _____.

10. The moisture content at which a soil can be compacted to its maximum dry density with the least amount of compactive effort is called the _____.

11. True or False. A soil that contains a high percentage of fines is more affected by water than one with a low percentage of fines.

12. True of False. Open graded aggregates are used in a pavement to give the structure more strength.

13. Name four items to check if your density tests are not passing.