Basic Soils Information

A. General Information

This section summarizes the basic soil properties and definitions required for designing pavement foundations and embankment construction. Basic soil classification and moisture-density relationships for compacted cohesive and cohesionless soil materials are included. The standard for soil density is determined as follows:

1. **Coarse-grained Soil:** The required minimum relative density and moisture range should be specified if it is a bulking soil.

2. **Fine-grained Soil:** The required minimum dry density should be specified; then the acceptable range of moisture content should be determined through which this density can be achieved.

3. **Inter-grade Soils:** The required minimum dry density or relative density should be specified, depending on the controlling test. Moisture range is determined by the controlling test.

B. Soil Types

1. **Soil:** Soils are sediments or other unconsolidated accumulation of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter. Soil has distinct advantages as a construction material, including its relative availability, low cost, simple construction techniques, and material properties which can be modified by mixing, blending, and compaction. However, there are distinct disadvantages to the use of soil as a construction material, including its non-homogeneity, variation in properties in space and time, changes in stress-strain response with loading, erodability, weathering, and difficulties in transitions between soil and rock.

   Prior to construction, engineers conduct site characterization, laboratory testing, and geotechnical analysis, design and engineering. During construction, engineers ensure that site conditions are as determined in the site characterization, provide quality control and quality assurance testing, and compare actual performance with predicted performance.

   Numerous soil classification systems have been developed, including geological classification based on parent material or transportation mechanism, agricultural classification based on particle size and fertility, and engineering classification based on particle size and engineering behavior. The purpose of engineering soil classification is to group soils with similar properties and to provide a common language by which to express general characteristics of soils.

   Engineering soil classification can be done based on soil particle size and by soil plasticity. Particle size is straightforward. Soil plasticity refers to the manner in which water interacts with the soil particles. Soils are generally classified into four groups using the Unified Soil Classification System, depending on the size of the majority of the soil particles (ASTM D 3282, AASHTO M 145).

   a. **Gravel:** Fraction passing the 3 inch sieve and retained on the No. 10 sieve.

- **b. Sand:** Fraction passing No. 10 sieve and retained on the No. 200 sieve.

- **c. Silt and Clay:** Fraction passing the No. 200 sieve. To further distinguish between silt and clay, hydrometer analysis is required. Manually, clay feels slippery and sticky when moist, while silt feels slippery but not sticky.
  - **1) Fat Clays:** Cohesive and compressible clay of high plasticity, containing a high proportion of minerals that make it greasy to the feel. It is difficult to work when damp, but strong when dry.
  - **2) Lean Clays:** Clay of low-to-medium plasticity owing to a relatively high content of silt or sand.

2. Rock: Rocks are natural solid matter occurring in large masses or fragments.

3. Iowa Soils: The three major soils distributed across Iowa are loess, glacial till, and alluvium, which constitute more than 85% of the surface soil.

- **a. Loess:** A fine-grained, unstratified accumulation of clay and silt deposited by wind.

- **b. Glacial Till:** Unstratified soil deposited by a glacier; consists of sand, clay, gravel, and boulders.

- **c. Alluvium:** Clay, silt, or gravel carried by running streams and deposited where streams slow down.

C. Classification

Soils are classified to provide a common language and a general guide to their engineering behavior, using either the Unified Soil Classification System (USCS) (ASTM D 3282) or the AASHTO Classification System (AASHTO M 145). Use of either system depends on the size of the majority of the soil particles to classify the soil.

1. USCS: In the USCS (see Table 6A-2.01), each soil can be classified as:
- Gravel (G)
- Sand (S)
- Silt (M)
- Clay (C)

2. AASHTO: In the AASHTO system (see Table 6A-2.02), the soil is classified into seven major groups: A-1 through A-7. To classify the soil, laboratory tests including sieve analysis, hydrometer analysis, and Atterberg limits are required. After performing these tests, the particle size distribution curve (particle size vs. percent passing) is generated, and the following procedure can be used to classify the soil.

A comparison of the two systems is shown in Table 6A-2.03.

Table 6A-2.01: Unified Soil Classification System Soil Classification Chart

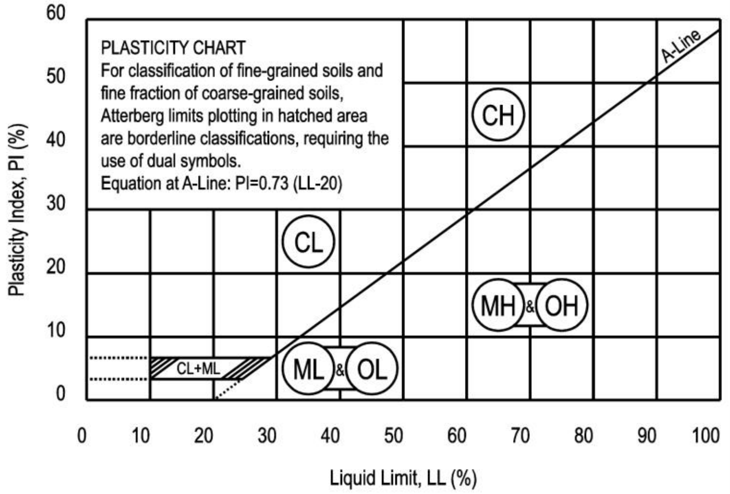
CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES ASTM D 2487 and D 2488 (Unified Soil Classification System)										
MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES	FIELD IDENTIFICATION PROCEDURES			CLASSIFICATION CRITERIA		
COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve*	GRAVELS 50% or 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 sizes 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* $C_z = \frac{(D_{30})^2}{D_{10} x D_{60}}$ *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	GH	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* $C_z = \frac{(D_{30})^2}{D_{10} x D_{60}}$ *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	
					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		

Table 6A-2.02: AASHTO Soil Classification Chart

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

Table 6A-2.03: Comparison of the AASHTO system with the Unified Soil Classification System

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

D. Moisture-Density Relationships for Soils

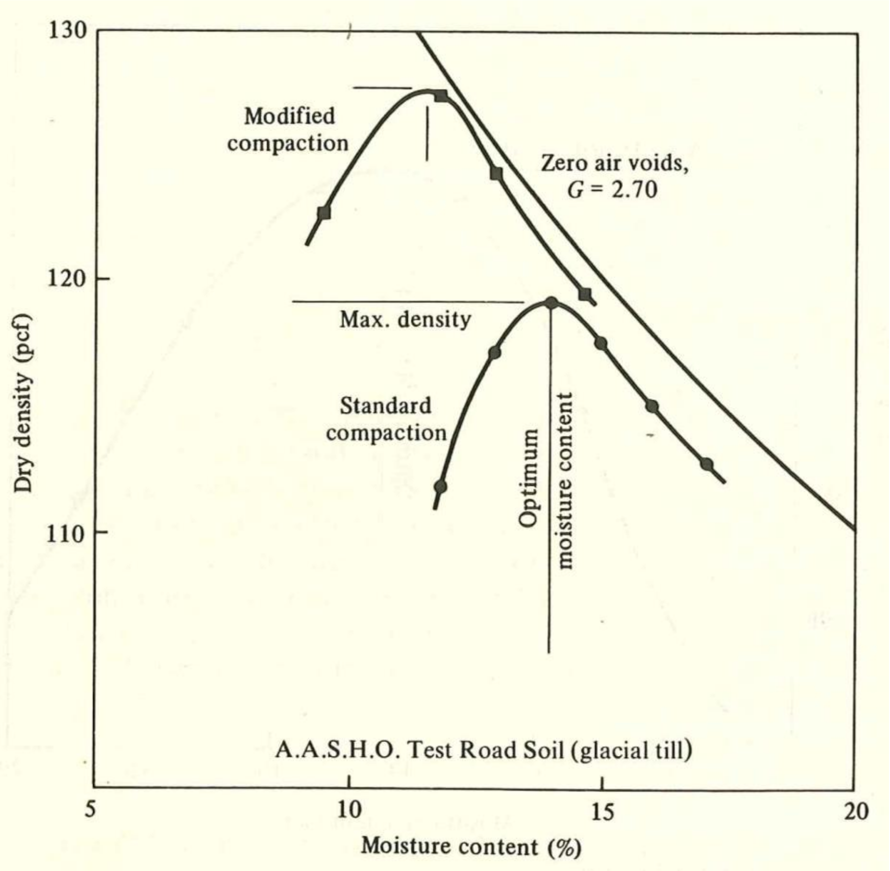
Compaction is the densification of soils by mechanical manipulation. Soil densification entails expelling air out of the soil, which improves the strength characteristics of soils, reduces compressibility, and reduces permeability. Using a given energy, the density of soil varies as a function of moisture content. This relationship is known as the moisture-density curve, or the compaction curve. The energy inputs to the soil have been standardized and are generally defined by Standard Proctor (ASTM D 698 and AASHTO T 99) and Modified Proctor (ASTM D 1557 and AASHTO T 180) tests. These tests are applicable for cohesive soils. For cohesionless soils, the relative density test should be used (ASTM D 4253 and ASTM D 4254). The information below describes the compaction results of both cohesive and cohesionless soils.

1. **Fine-grained (Cohesive) Soils:** The moisture-density relationship for fine-grained (cohesive) soils (silts and clays) is determined using Standard or Modified Proctor tests. Typical results of Standard Proctor tests are shown in Figure 6A-2.02, which represents the relationship between the moisture content and the dry density of the soil. At the peak point of the curve, moisture content is called the optimum moisture content, and the density is called the maximum dry density. If the moisture content exceeds the optimum moisture content, the soil is called wet of optimum. On the other hand, if the soil is drier than optimum, the soil is called dry of optimum.

   The compaction energy used in Modified Proctor is 4.5 times the compaction energy used in Standard Proctor. This increase in compaction energy changes the point-of-optimum moisture content and maximum dry density (see Figure 6A-2.02). In the field, the compaction energy is generally specified as a percentage of the Standard Proctor or Modified Proctor by multiplying the maximum dry density by this specified percent. Figure 6A-2.03 shows Proctor test results with a line corresponding to the specified percentage of the maximum dry density. The area between the curve and the specified percentage line would be the area of acceptable moisture and density.

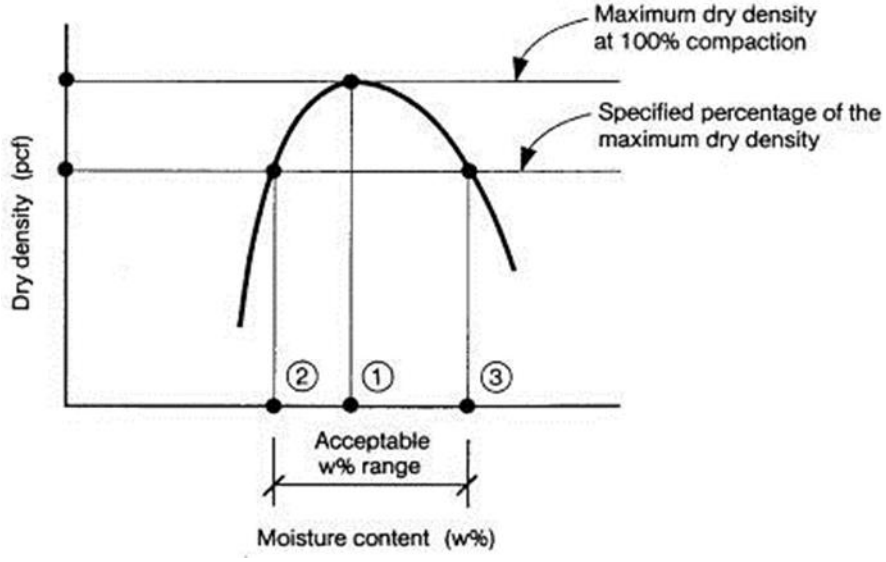
   Soils compacted on the dry side of optimum have higher strength, stability and less compressibility than the same soil compacted on the wet side of optimum. However, soils compacted on the wet side of optimum have less permeability and volume change due to change in moisture content. The question of whether to compact the soil on the dry side of optimum or on the wet side of optimum depends on the purpose of the construction and construction equipment. For example, when constructing an embankment, strength and stability are the main concern (not permeability); therefore, a moisture content on the dry side of optimum should be used. For contractors, compacting the soil on the wet side of optimum is more economical, especially if it is within 2% of the optimum moisture content. However, if the soil is too wet, the specified compaction density will not be reached.

Figure 6A-2.02: An Example of Standard and Modified Proctor Moisture-Density Curves for the Same Soil



Source: Spangler and Handy 1982

Figure 6A-2.03: Example Proctor Test Results with Specified Percentage Compaction Line



Source: Duncan 1992

2. **Coarse-grained (Cohesionless) Soils:** When coarse-grained, cohesionless soils (sands and gravels) are compacted using standard or modified Proctor procedures, the moisture-density curve is not as distinct as that shown for cohesive soils in Figure 6A-2.02. Figure 6A-2.04 shows a typical curve for cohesionless materials, exhibiting what is often referred to as a hump back or camel back shape. It can be seen that the granular material achieves its densest state at 0% moisture, then decreases to a relative low value, and then increases to a relative maximum, before decreasing again with increasing water content. A better way of representing the density of cohesionless soils is through relative density. Tests can be conducted to determine the maximum density of the soil at its densest state and the minimum density at its loosest state (ASTM D 4253 and D 4254). The relative density of a field soil, D_r, can be defined using the density measured in the field, through a ratio to the maximum and the minimum density of the soil, using Equation 6A-2.01.

$$D_r(\%) = \left[\frac{\gamma_{d(field)} - \gamma_{d(\min)}}{\gamma_{d(\max)} - \gamma_{d(\min)}}\right]\left[\frac{\gamma_{d(\max)}}{\gamma_{d(field)}}\right]$$ **Equation 6A-2.01**

where:

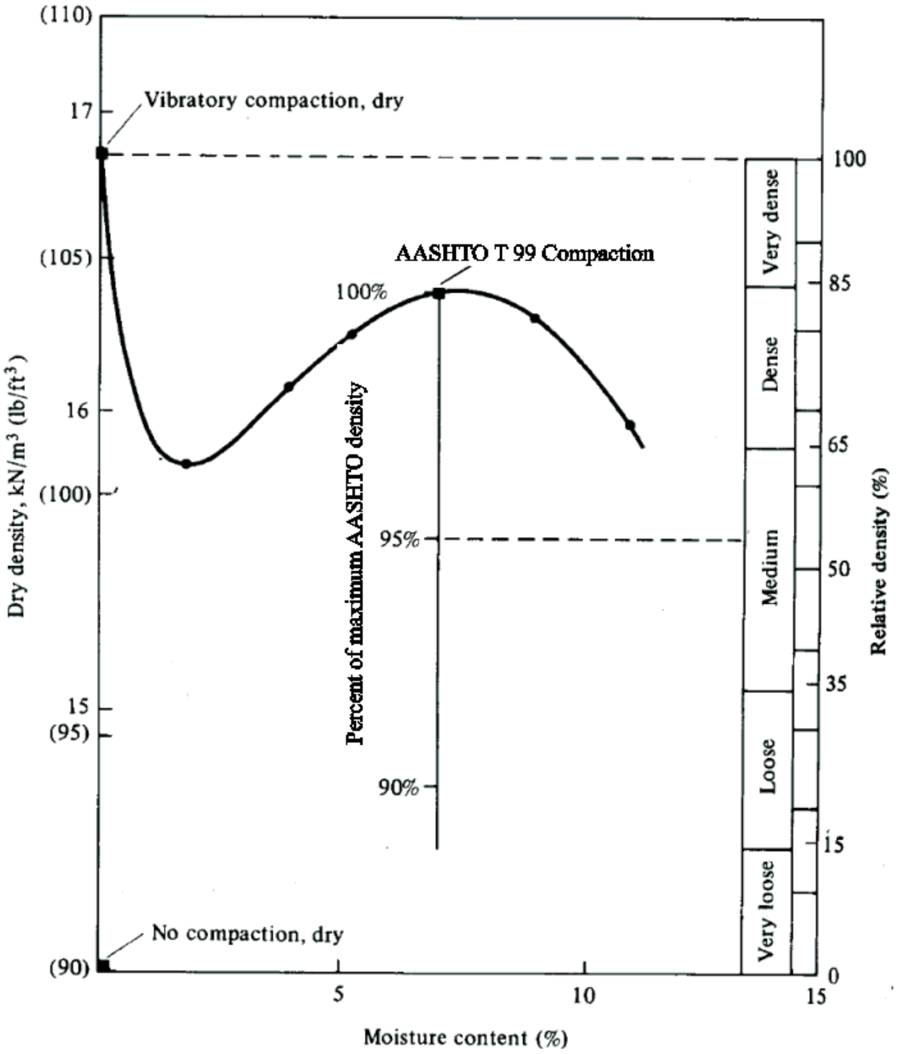
$\gamma_{d(field)}$ = field density

$\gamma_{d(\min)}$ = minimum density

$\gamma_{d(\max)}$ = maximum density

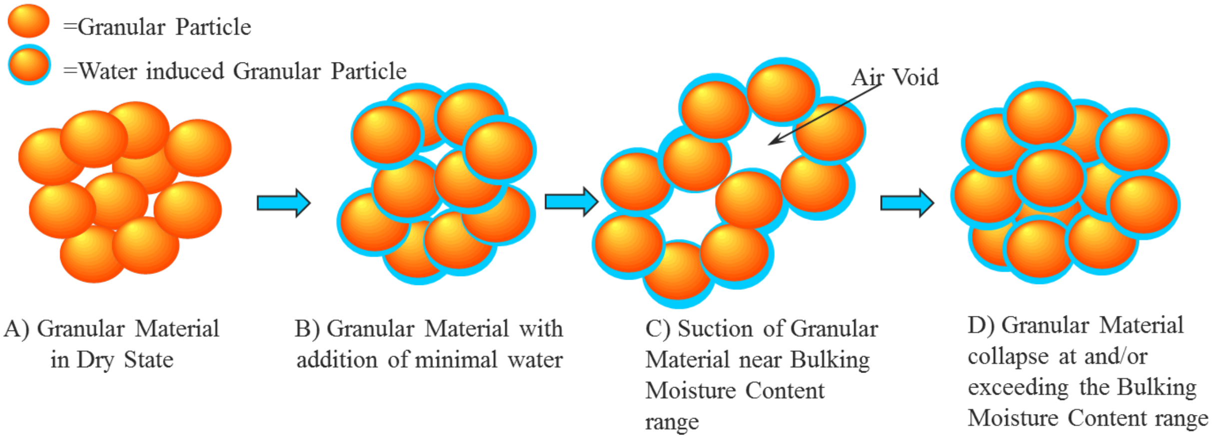
The maximum and minimum density testing is performed on oven-dry cohesionless soil samples. However, soils in the field are rarely this dry, and cohesionless soils are known to experience bulking as a result of capillary tension between soil particles. Bulking is a capillary phenomena occurring in moist sands (typically 3 to 5% moisture) in which capillary menisci between soil particles hold the soil particles together in a honeycomb structure. This structure can prevent adequate compaction of the soil particles and is also susceptible to collapse upon the addition of water (see Figure 6A-2.05). The bulking moisture content should be avoided in the field.

Figure 6A-2.04: Example of Relative Density vs. Standard Proctor Compaction



Source: Spangler and Handy 1982

Figure 6A-2.05: Example Showing the Processes of Collapse due to Bulking Moisture



Source: Schaefer et al. 2005

E. References

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