Transportation System Engineering 1 , 10601360

Chapter 5
Soil Engineering for Highway Design

AN-NAJAH NATIONAL UNIVERSITY
NABLUS, PALESTINE

Outline: Chapter 2

- 5.1 Soil Characteristics and Classification
- 5.2 Soil Investigation
- 5.3 Soil Compaction
- 5.4 California-Bearing Ratio CBR

5.1 Soil Characteristics and Classification

Soil Characteristics and Classification

- **Soil is mainly formed by weathering and other geologic processes that occur on the surface of the solid rock at or near the surface of the earth.**
- **Weathering** is the result of physical and chemical actions, mainly due to atmospheric factors that change the structure and composition of the rocks.
  - Physical (mechanical) weathering, causes the disintegration of the rocks into smaller particle sizes by the action of forces such as running water, wind, freezing and thawing.
  - Chemical weathering occurs as a result of oxidation, carbonation, and other chemical actions that decompose the minerals of rocks.

Soil Characteristics and Classification

- Soils may be described as
  - **Residual soils:** weathered in place and are located directly above the original material from which they were formed.
  - **Transported soils:** those that have been moved by water, wind, glaciers, etc and are located away from their parent materials.
- The geological history of any soil deposit has a significant effect on the engineering properties of the soils.

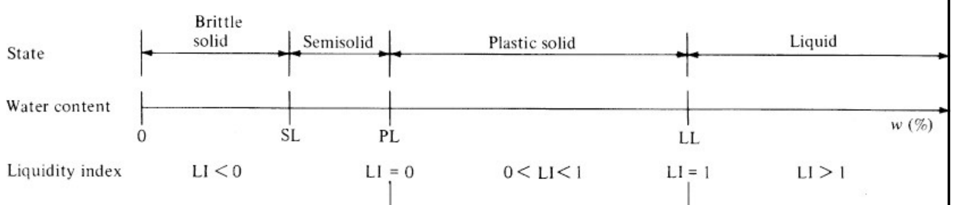
Soil Characteristics and Classification

- **Atterberg Limits:**
  - Clay soils with very low moisture content will be in the form of **solids**.
  - As the water content increases, the solid soil gradually becomes **plastic** (the soil easily can be molded into different shapes without breaking up).
  - Continuous increase of water content will bring the soil to a state where it can flow as a **viscous liquid**.

Atterberg limits: the water content levels at which the soil changes from one state to the other.

Soil Characteristics and Classification

- **Atterberg Limits:**
  - Shrinkage limit (**SL**),
  - Plastic limit (**PL**),
  - Liquid limit (**LL**).



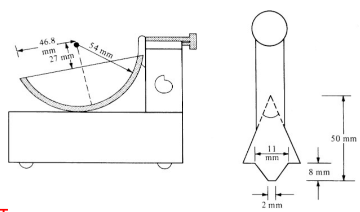
They are used in the classification of fine-grained soils and are extremely useful, since they correlate with the engineering behaviors of such soils.

Soil Characteristics and Classification

- **Atterberg Limits:**
  - **Shrinkage limit** (**SL**):
    - When a saturated soil is slowly dried, the volume shrinks. Continuous drying of the soil, however, will lead to a moisture content at which further drying will not result in additional shrinkage.
    - The volume of the soil will stay constant, and further drying will be accompanied by air entering the voids.
    - **The moisture content at which this occurs is the shrinkage limit** (**SL**)

Soil Characteristics and Classification

- **Atterberg Limits:**
  - **Plastic limit (PL):**
    - It is defined as the moisture content at which the soil crumbles when it is rolled down to a diameter of one-eighth of an inch.
  - **Liquid limit (LL):**
    - It is defined as the moisture content at which the soil will flow and close a groove of one-half inch within it after the standard LL equipment has been dropped 25 times.



T Figure 17.5 Schematic of the Casagrande Liquid Limit Apparatus

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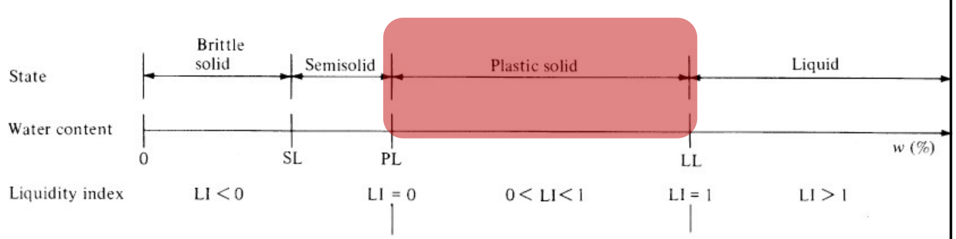
Soil Characteristics and Classification

- **Plasticity Index (PI)**: the range of moisture content over which the soil is in the plastic state.



$$PI = LL - PL$$

PI = plasticity index
LL = liquid limit
PL = plastic limit

Soil Classification

- Soil classification is a method by which soils are systematically categorized according to their probable engineering characteristics.
- It serves as a means of identifying suitable subbase materials and predicting the probable behavior of a soil when used as subgrade material.
  - this should not be regarded as a substitute for the detailed investigation of the soil properties.
- The most commonly use classification systems:

1. **AASHTO Soil Classification System**
2. **Unified Soil Classification System (USCS)**

Soil Characteristics and Classification

1. **AASHTO Soil Classification System**:

- The classification of a given soil is based on:
  - **Particle size distribution**,
  - **LL** (Liquid Limit)
  - **PI** (Plasticity Index)
- The group index (**GI**) of the soils

$$GI = (F - 35)[0.2 + 0.005(LL - 40)] + 0.01(F - 15)(PI - 10)$$

GI = group index
F = percent of soil particles passing 0.075 mm (No. 200) sieve in whole number based on material passing 75 mm (3 in.) sieve
LL = liquid limit expressed in whole number
PI = plasticity index expressed in whole number

Soil Characteristics and Classification

1. AASHTO Soil Classification System:

- A value of zero should be recorded when a negative value is obtained for the GI.
- Classifying soils under the AASHTO system will consist of:
  - **Determining the particle size distribution**
  - **Determining Atterberg limits of the soil**
  - **Reading Table 17.1 from left to right to find the correct group.**
- The correct group is the first one from the left that fits the particle size distribution and Atterberg limits

Example: A-2-4 (GI)

Soil Characteristics and Classification

1. AASHTO Soil Classification System:

Table 17.1 AASHTO Classification of Soils and Soil Aggregate Mixtures

General Classification	*Granular Materials (35% or Less Passing No. 200)*							*Silt-Clay Materials (More than 35% Passing No. 200)*			
	A-1			*A-2*							*A-7*
Group Classification	*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											
Percent 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 fraction passing 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 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			

*Plasticity index of A-7-5 subgroup ≤ LL − 30. Plasticity index of A-7-6 subgroup > LL − 30.
SOURCE: Adapted from *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 27th ed., Washington, D.C., The American Association of State Highway and Transportation Officials, copyright 2007. Used with permission.

Soil Characteristics and Classification

1. AASHTO Soil Classification System:

Table 17.1 AASHTO Classification of Soils a...

Granular soils | **Silt-Clay soils**

General Classification	Granular M...							Silt-Clay Materi...			
	A-1			A-2							A-7
Group Classification	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											
Percent 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 fraction passing No. 40:											
Liquid limit	—		—	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity inde	6 max.		N.P.	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.*
Usual types of significant constituent material	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			

*Plasticity index of A-7-5 subgroup ≤ LL − 30. Plasticity index of A-7-6 subgroup > LL − 30.
SOURCE: Adapted from *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 27th ed., Washington, D.C., The American Association of State Highway and Transportation Officials, copyright 2007. Used with permission.

Soil Characteristics and Classification

1. AASHTO Soil Classification System:

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	A-1			A-2							A-7
Group Classification	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											
Percent 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 fraction passing 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 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			

*Plasticity index of A-7-5 subgroup ≤ LL − 30. Plasticity index of A...
SOURCE: Adapted from *Standard Specifications for Transportat*... The American Association of State Highway and Transportation Officials, copyright 2007. Used ...

A-2-6 and A-2-7

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

Soil Characteristics and Classification

1. AASHTO Soil Classification System:

– In general, the suitability of a soil deposit for use in highway construction can be summarized as following. However firstly the definition of subgrade and subbase is shown below:

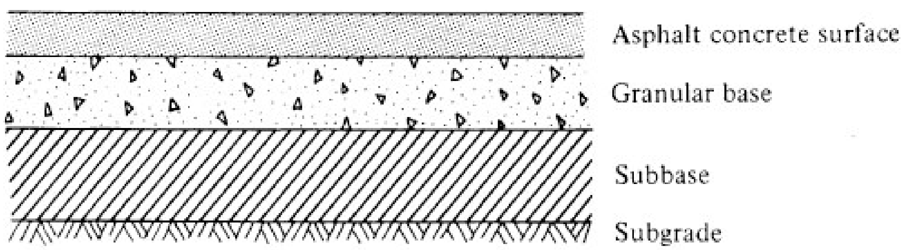


Figure 19.1 Schematic of a Flexible Pavement

Soil Characteristics and Classification

1. AASHTO Soil Classification System:

Table 17.1 AASHTO Classification of Soils and Soil Aggregate Mixtures

General Classification	Granular Materials (35% or Less Passing No. 200)							Silt-Clay Materials (More than 35% Passing No. 200)			
	A-1			A-							A-7
Group Classification	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											
Percent 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 fraction passing 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 of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey g avel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

*Plasticity
SOURCE: ... shington, D.C., The American Association of
State High

1) It can be used satisfactorily as subgrade or subbase material if properly drained

Soil Characteristics and Classification

1. AASHTO Soil Classification System:

Table 17.1 AASHTO Classification of Soils and Soil Aggregate Mixtures

General Classification	*Granular Materials (35% or Less Passing No. 200)*							*Silt-Clay Materials (More than 35% Passing No. 200)*			
	A-1			*A-2*							*A-7*
Group Classification	*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											
Percent 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 ma	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40:											
Liquid limit	—		—	40 max.	41 min.	40 ma	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		N.P.	10 max.	10 max.	11 mi	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 a[…]l sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

*Plasticity index of A-7-5 subgroup ≤ LL − 30. Plastic
SOURCE: Adapted from *Standard Specifications fo*
State Highway and Transportation Officials, copyright

2) It will require a layer of subbase material if used as subgrade.

Soil Characteristics and Classification

1. AASHTO Soil Classification System:

– When soils are properly drained and compacted, their value as subgrade material decreases as the GI increases.

As GI increases → **Become poor subgrade material**

Soil Characteristics and Classification

1. AASHTO Soil Classification System:

Example 17.3 Classifying a Soil Sample Using the AASHTO Method

The following data were obtained for a soil sample.

Mechanical Analysis

Sieve No.	*Percent Finer*	*Plasticity Tests:*
4	97	LL = 48%
10	93	PL = 26%
40	88	
100	78	
200	70	

Using the AASHTO method for classifying soils, determine the classification of the soil and state whether this material is suitable in its natural state for use as a subbase material.

Solution:

- Since more than 35% of the material passes the No. 200 sieve, the soil is either A-4, A-5, A-6, or A-7.
- LL > 40%, and therefore the soil cannot be in group A-4 or A-6. Thus, it is either A-5 or A-7.
- The PI is 22% (48 – 26), which is greater than 10%, thus eliminating group A-5. The soil is A-7-5 or A-7-6.
- (LL – 30) = 18 < PI (22%). Therefore the soil is A-7-6, since the plasticity index of A-7-5 soil subgroup is less than (LL – 30). The GI is given as:

$$(70 - 35)[0.2 + 0.005(48 - 40)] + 0.01(70 - 15)(22 - 10) = 8.4 + 6.6 = 15$$

The soil is A-7-6 (15) and is therefore unsuitable as a subbase material in its natural state.

Soil Characteristics and Classification

1. Unified Soil Classification System (USCS):

- Originally was developed during World War II for use in airfield construction.
- The fundamental premise is that the engineering properties of any **coarse-grained soil depend on its particle size distribution**, whereas those for a **fine-grained soil depend on its plasticity**.
- Thus, the system classifies **coarse-grained soils on the basis of grain size characteristics** and **fine-grained soils according to plasticity characteristics**.

Soil Characteristics and Classification

1. Unified Soil Classification System (USCS):

Table 17.2 USCS Definition of Particle Sizes

Soil Fraction or Component	*Symbol*	*Size Range*
1. Coarse-grained soils		
Gravel	G	75 mm to No. 4 sieve (4.75 mm)
Coarse		75 mm to 19 mm
Fine		19 mm to No. 4 sieve (4.75 mm)
Sand	S	No. 4 (4.75 mm) to No. 200 (0.075 mm)
Coarse		No. 4 (4.75 mm) to No. 10 (2.0 mm)
Medium		No. 10 (2.0 mm) to No. 40 (0.425 mm)
Fine		No. 40 (0.425 mm) to No. 200 (0.075 mm)
2. Fine-grained soils		
Fine		Less than No. 200 sieve (0.075 mm)
Silt	M	(No specific grain size—use Atterberg limits)
Clay	C	(No specific grain size—use Atterberg limits)
3. Organic soils	O	(No specific grain size)
4. Peat	Pt	(No specific grain size)

Gradation Symbols	*Liquid Limit Symbols*
Well graded, W	High LL, H
Poorly graded, P	Low LL, L

Soil Characteristics and Classification

1. Unified Soil Classification System (USCS):

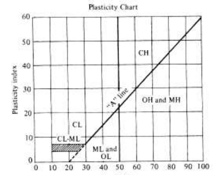
Table 17.3 Unified Soil Classification System

Table 17.3 Unified Soil Classification System

Major Divisions			*Group Symbols*	*Typical Names*	*Laboratory Classification Criteria*	
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM[a] d / u	Silty gravels, gravel-sand-silt mixtures	Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			GC	Clayey gravels, gravel-sand-clay mixtures	Atterberg limits below "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines	$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP	Poorly graded sands, gravelly sands, little or no fines	Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM[a] d / u	Silty sands, sand-silt mixtures	Atterberg limits above "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			SC	Clayey sands, sand-clay mixtures	Atterberg limits above "A" line with P.I. greater than 7	
Fine-grained soils (More than half material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity		
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays		
			OL	Organic silts and organic silty clays of low plasticity		
	Silts and clays (Liquid limit greater than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts		
			CH	Inorganic clays of high plasticity, fat clays		
			OH	Organic clays of medium to high plasticity, organic silts		
	Highly organic soils		Pt	Peat and other highly organic soils		

Laboratory classification criteria (coarse-grained soils): Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:
Less than 5 per cent — GW, GP, SW, SP
More than 12 per cent — GM, GC, SM, SC
5 to 12 per cent — *Borderline* cases requiring dual symbols[b]

Plasticity Chart



[a]Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterberg limits; suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.
[b]Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.

SOURCE: *The Unified Soil Classification System*, Annual Book of ASTM Standards, Vol. 4.08, American Society for Testing and Materials, West Conshohocken, PA, 2002.

Soil Characteristics and Classification

Table 17.4 Comparable Soil Groups in the AASHTO and USCS Systems

Table 17.4 Comparable Soil Groups in the AASHTO and USCS Systems

Soil Group in Unified System	Comparable Soil Groups in AASHTO System: Most Probable	Possible	Possible but Improbable
GW	A-1-a	—	A-2-4, A-2-5, A-2-6, A-2-7
GP	A-1-a	A-1-b	A-3, A-2-4, A-2-5, A-2-6, A-2-7
GM	A-1-b, A-2-4, A-2-5, A-2-7	A-2-6	A-4, A-5, A-6, A-7-5, A-7-6, A-1-a
GC	A-2-6, A-2-7	A-2-4, A-6	A-4, A-7-6, A-7-5
SW	A-1-b	A-1-a	A-3, A-2-4, A-2-5, A-2-6, A-2-7
SP	A-3, A-1-b	A-1-a	A-2-4, A-2-5, A-2-6, A-2-7
SM	A-1-b, A-2-4, A-2-5, A-2-7	A-2-6, A-4, A-5	A-6, A-7-5, A-7-6, A-1-a
SC	A-2-6, A-2-7	A-2-4, A-6, A-4, A-7-6	A-7-5
ML	A-4, A-5	A-6, A-7-5	—
CL	A-6, A-7-6	A-4	—
OL	A-4, A-5	A-6, A-7-5, A-7-6	—
MH	A-7-5, A-5	—	A-7-6
CH	A-7-6	A-7-5	—
OH	A-7-5, A-5	—	A-7-6
Pt	—	—	—

SOURCE: Adapted from T.K. Liu, *A Review of Engineering Soil Classification Systems—Special Procedures for Testing Soil and Rock for Engineering Purposes*, 5th ed., ASTM Special Technical Publication 479, American Society for Testing and Materials, Easton, MD, 1970.

5.2 Soil Investigation

Soil Investigation

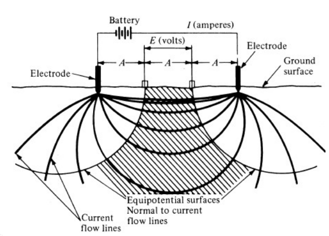
- Soil surveys for highway construction entail the investigation of the soil characteristics on the highway route and the identification of suitable **soils for use as subbase and fill materials**.
- Soil surveys are therefore normally an integral part of preliminary location surveys, since the soil conditions may significantly affect the location of the highway.
- The first step in any soil survey is in the collection of existing information on the soil characteristics of the area from geological and agricultural soil maps, existing aerial photographs, etc.
- The next step is to obtain and investigate enough soil samples along the highway route.

Soil Investigation

- **Geophysical Methods of Soil Exploration**:

1. **Resistivity Method**

2. **Seismic Method**



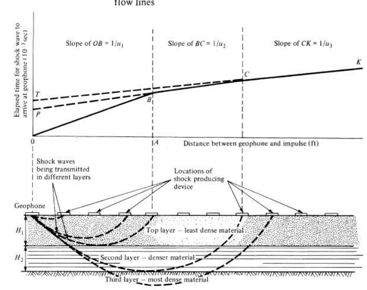


Figure 17.9 Soil Exploration by the Seismic Method

5.3 Soil Compaction

Soil Compaction

- When soil is to be used as embankment or subbase material in highway construction, it is essential that the material be placed in uniform layers and compacted to a high density.
- Proper compaction of the soil will reduce subsequent settlement and volume change to a minimum.
  - **Enhancing the strength of the embankment or subbase.**
- The strength of the compacted soil is directly related to the maximum dry density achieved through compaction.

Soil Compaction

– Compaction is achieved in the field by using hand-operated tampers, sheepsfoot , rubber-tired rollers, etc.

(a) Smooth wheel roll

Smooth wheel Roller

Rubber-tired Roller

Sheepsfoot Roller

Figure 17.16 Typical Sheepsfoot Roller

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Soil Compaction

– The relationship between dry density and moisture content for practically all soils takes the following form:

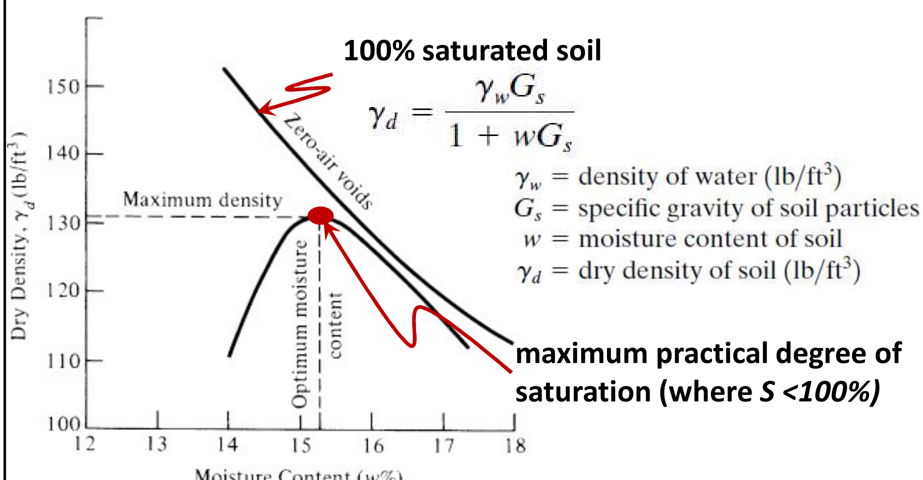

Figure 17.11 Typical Moisture-Density Relationship for Soils

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Soil Compaction

- The distance between **zero-air voids curve** and the **test moisture density curve** is of importance,
  - since this distance is an indication of the amount of air voids remaining in the soil at different moisture contents.
- The larger the distance, the more air voids remain in soil and the higher the likelihood of expansion or swelling if the soil is subjected to flooding.

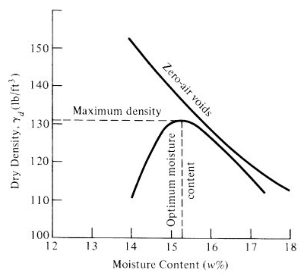


Figure 17.11 Typical Moisture-Density Relationship for Soils

Optimum Moisture Content

- **Two types of tests are commonly used:**
  - **The standard AASHTO**
  - The modified AASHTO
- **The standard AASHTO:**
  - Most highway agencies now use dynamic or impact tests to determine the optimum moisture content and maximum dry density.
  - Samples of the soil to be tested are compacted in layers to fill a specified size mold.
  - Compacting effort is obtained by dropping a hammer of known weight and dimensions from a specified height in a specified number of times for each layer.

Optimum Moisture Content

- Then we can determine:
  - **Moisture content** of the compacted material
  - **Dry density** from the measured weight of the compacted soil and the known volume of the mold.
- Then using another sample, the moisture content is then increased and the test repeated.
- The process is repeated until a reduction in the density is observed.

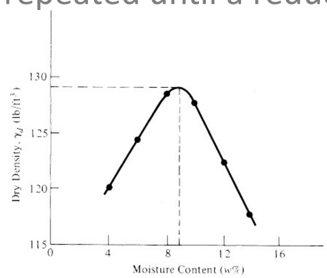


Figure 17.13 Moisture-Density Relationship for Example 17.7

Optimum Moisture Content

- Table 17.6 shows details for the standard AASHTO (designated T99) and the modified AASHTO (designated T180).

Table 17.6 Details of the Standard AASHTO and Modified AASHTO Tests

Test Details	*Standard AASHTO (T99)*	*Modified AASHTO (T180)*
Diameter of mold (in.)	4 or 6	4 or 6
Height of sample (in.)	5 cut to 4.58	5 cut to 4.58
Number of lifts	3	5
Blows per lift	25 or 56	25 or 56
Weight of hammer (lb)	5.5	10
Diameter of compacting surface (in.)	2	2
Free-fall distance (in.)	12	18
Net volume (ft^3)	1/30 or 1/13.33	1/30 or 1/13.33

Most transportation agencies use the standard AASHTO test.

Optimum Moisture Content

– Effect of Compacting Effort

- Compacting effort is a measure of the mechanical energy imposed on the soil mass during compaction.
- **Units**: In the laboratory: ft-lb/in.3 or ft-lb/ft3,
  - In the field: number of passes of a roller of know weight and type.
- Optimum moisture content and maximum dry density attained depend on the compactive effort used.
- As compactive effort increases, maximum dry density increases
- Compactive effort required to obtain a given density increases as the moisture content decreases

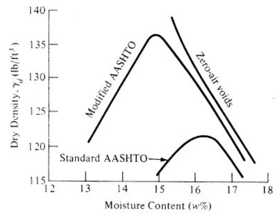


Figure 17.12 Effect of Compactive Effort in Dry Density

Field Compaction Procedures and Equipment

– Field Compaction Procedures:

- The first step in the construction of a highway embankment is **the identification and selection of a suitable material**.
- based on the AASHTO system of classification, materials classified as A-1, A-2-4, A-2-5, and A-3 are usually suitable embankment materials.
- In cases where it is necessary to use materials in other groups, special consideration should be given to the design and construction.
- The cost of transportation the embankment material to the construction site is an important factor.

Field Compaction Procedures and Equipment

– **Field Compaction Procedures:**

- After identifying the suitable materials, their optimum moisture contents and maximum dry densities are determined.
- **Fill material Formation**: It is formed by spreading thin layers of uniform thickness of the material and compacting each layer at or near the optimum moisture content.
  - Most states stipulate a thickness of **6 to 12 inches (20 cm)** for each layer, although the thickness may be increased to **24 inches** when the lower portion of an embankment consists mainly of large boulders.

Field Compaction Procedures and Equipment

– **Field Compaction Procedures:**

- **Fill Material Formation**: Table 17.7,gives commonly used relative density values for different fill heights.
  - **The relative density** is given as a percentage of the maximum dry density obtained from the standard AASHTO (T99) test.

Table 17.7 Commonly Used Minimum Requirements for Compaction of Embankments and Subgrades

	Minimum Relative Density		
	Embankments		
AASHTO Class of Soil	*Height Less Than 50 ft*	*Height Greater Than 50 ft*	*Subgrade*
A-1, A-3	≥ 95	≥ 95	100
A-2-4, A-2-5	≥ 95	≥ 95	100
A-2-6, A-2-7	> 95	—[a]	≥ 95[b]
A-4, A-5, A-6, A-7	> 95	—[a]	≥ 95[b]

[a]Use of these materials requires special attention to design and construction.
[b]Compaction at 95 percent of T99 moisture content.

Field Compaction Procedures and Equipment

– Control of Embankment Construction:

- The construction control of fill material entails frequent and regular checks of the dry density and the moisture content of materials being compacted.
- The bulk density is obtained directly **from measurements obtained in the field**,
  - dry density is then calculated from the bulk density and the moisture content.
  - The laboratory moisture-density curve is then used to determine whether the dry density obtained in the field is in accordance with the laboratory results.

Destructive Methods

Nondestructive Methods

Field Compaction Procedures and Equipment

– Control of Embankment Construction:

A) **Destructive Methods**: A cylindrical hole of about a four inch diameter and a depth equal to that of the layer is excavated

- The material obtained from the hole is immediately sealed in a container.
- **Total weight** of the excavated material and the **moisture content** (rapidly drying or facilitating evaporation by adding volatile solvent material) is determined.
- The compacted volume of the excavated material is then measured by determining the volume of the excavated hole.

Field Compaction Procedures and Equipment

– **Control of Embankment Construction:**

A) Destructive Methods:

- The volume of the excavated hole may be obtained by one of three methods: **sand replacement**, **oil**, or **balloon**.
- ***The destructive methods are all subject to errors.***

B) Nondestructive Methods: The direct measurement of the in site density and moisture content of the compacted soil, using **nuclear equipment**

- The density is obtained by measuring the scatter of gamma radiation by the soil particle
- The moisture content is obtained by measuring the scatter of neutrons emitted in the soil

Field Compaction Procedures and Equipment

– **Control of Embankment Construction:**

B) Nondestructive Methods:

Advantages

- Results are obtained speedily, which is essential if corrective actions are necessary
- More tests can be carried out, which facilitates the use of statistical methods in the control process

Disadvantages

- A relatively high capital expenditure is required to obtain the equipment
- The field personnel are exposed to dangerous radioactive material

Field Compaction Procedures and Equipment

– **Field Compaction Equipment:**

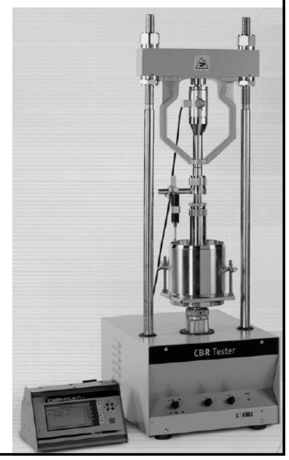
  – **Spreading Equipment**

  – **Compacting Equipment**

5.4 California-Bearing Ratio CBR

California-Bearing Ratio CBR

- It is a penetration test consists of measuring the relative load required to cause a standard (**3 square inch**) plunger to penetrate a saturated soil specimen at a specific rate to a specific depth.
- **The objective of the test is to determine the relative strength of a soil with respect to crushed rock.**
- The word "relative" is used since the actual load is compared to a standard load of crushed stone.



California-Bearing Ratio CBR

$$\text{CBR} = \frac{(\text{unit load for 0.1 piston penetration in test specimen})\ (\text{lb/in}^2.)}{(\text{unit load for 0.1 piston penetration in standard crushed rock})\ (\text{lb/in}^2.)}$$

$$\text{CBR} = \frac{\text{Actual Load (psi)}}{\text{Standard Load (psi)}} \times 100\%$$

Penetration mm	Standard Load KN
2.5	13.36
5.0	19.96

Penetration	Pressure
0.1 in. (2.5 mm)	1000 psi (6.9 MPa)
0.2 in. (5.0 mm)	1500 psi (10.4 MPa)
0.3 in. (7.6 mm)	1900 psi (13.1 MPa)
0.4 in. (10.2 mm)	2300 psi (15.9 MPa)
0.5 in. (12.7 mm)	2600 psi (17.9 MPa)

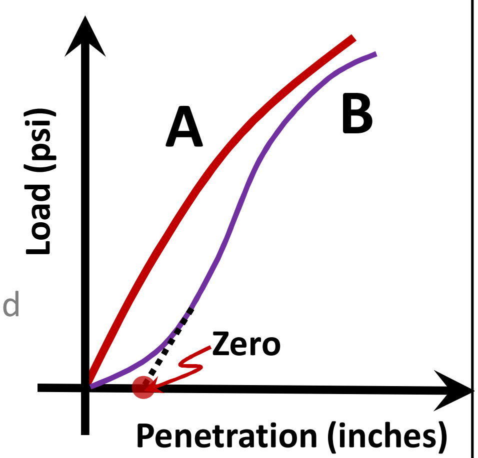
California-Bearing Ratio CBR

– The standard features of the test:

- Soaking the sample in water for a period of 4 days to saturate the soil.
- The use of surcharge weights during tests.
  - They are estimated to result in an intensity of pressure equal to that of the final pavement on the soil.
- The cylinder in which the soil is tested has a diameter of 6 inches
- The piston has a diameter a little under 2 inches.

California-Bearing Ratio CBR

- The resulting data will be in the form of inches of penetration versus load as shown below.
- If the plot is concave upward (curve B), the steepest slope is extended downward to the x-axis. This point is taken as zero penetration point and all penetration values adjusted accordingly.



California-Bearing Ratio CBR

- The unit load generally taken for design is at 0.1-inch penetration; however, in some cases other values are used.
- As general rule, **the CBR will decrease as the penetration depth increases**.
  - In some cases, the CBR at 0.2 inch penetration may be higher than that at 0.1 inch.
    - In this case the test is repeated, then the value at 0.2 inch penetration is used.

California-Bearing Ratio CBR

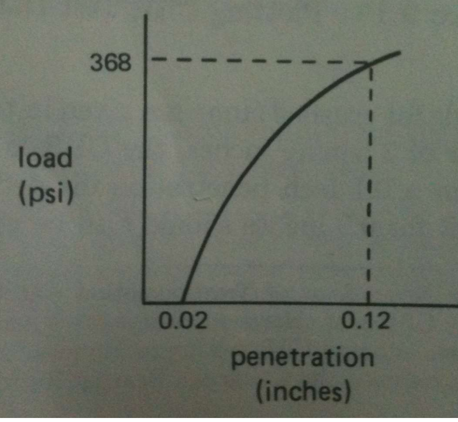
Disadvantages of CBR test:

- It does not correctly simulate the **shearing forces** imposed on subbase and subgrade materials as they support highway pavements.
- Example: It is possible to obtain a high CBR value for a soil containing rough or angular coarse and some clay if the coarse material resists penetration of the piston by keeping together in the mold.
  - The performance of the soil in highway construction may be poor, due to the lubrication of the soil mass by the clay, which reduces the shearing strength.

Example

– Find the CBR value

The following load data is collected for a 3 square inch plunger test.



penetration (inches)	load (psi)
0.025	20
0.050	130
0.075	230
0.100	320
0.125	380
0.150	470
0.175	530
0.200	600
0.250	700
0.300	830

Example

– **Solution**:

Upon graphing the data, it is apparent that a 0.02 inch correction is required. Therefore, the 0.1″ load is read from the graph as a 0.12 inch load.

$$CBR_{0.1} = \frac{(368)(100)}{1000} = 36.8 \text{ (percent omitted)}$$

$$CBR_{0.2} = \frac{(640)(100)}{1500} = 42.7$$

Since $CBR_{0.2}$ is greater than $CBR_{0.1}$, the test should be repeated.

Chapter 5
Soil Engineering for Highway Design

Thank You Very Much