Lab Manual for AASHTO M 145: Standard Specification for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes

1. Introduction

Purpose

The AASHTO M 145 standard provides a method for classifying soils and soil-aggregate mixtures used in highway construction based on laboratory testing of particle size distribution, liquid limit, and plasticity index.

General Application

- This classification system evaluates soil materials for use in highway construction, particularly in embankments, subgrades, subbases, and base layers.
- It helps in determining the suitability of soils for construction, improving decision-making for pavement design.

2. Objective

- The objective of the AASHTO M 145 test is to classify soils and soil-aggregate mixtures based on their particle size distribution, liquid limit, and plasticity index.
- This test aims to measure the soil's physical characteristics, enabling engineers to determine its suitability for use in highway construction projects.

Referenced Standards

The following referenced documents are relevant to the AASHTO M 145 testing standard:

- AASHTO R 58: Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test
- AASHTO T 11: Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- AASHTO T 27: Sieve Analysis of Fine and Coarse Aggregates
- AASHTO T 88: Particle Size Analysis of Soils
- AASHTO T 89: Determining the Liquid Limit of Soils
- AASHTO T 90: Determining the Plastic Limit and Plasticity Index of Soils
- AASHTO T 146: Wet Preparation of Disturbed Soil Samples for Test

3. Testing Materials

The following materials can be tested using the AASHTO M 145 standard:

Soil-Aggregate Mixtures: Mixtures of soils and aggregates commonly used in highway construction projects.

Figure 1: Representative Soil-Aggregate Mixture

- Fine-Grained Soils: Soils with high percentages of silt or clay, with relevant properties like plasticity and liquid limits.

Figure 2 Fine-Grained Soil Sample (Clay)

- Coarse-Grained Soils: Soils with high percentages of sand or gravel, characterized by particle size distribution.

Figure 3 Coarse-Grained Soil Sample (Gravel)

4. Apparatus and Equipment

The following equipment is used in the AASHTO M 145 test:

- Liquid Limit Device: Determines the liquid limit of fine-grained soils by repeatedly dropping a soil sample in a brass cup.

Liquid Limit Device

- Plastic Limit Rolling Plate: Used for determining the plastic limit of fine-grained soils by rolling soil samples into threads.

Plastic Limit Rolling Plate

- Balance: A precision instrument for weighing soil samples before and after testing, ensuring accuracy in moisture content and weight measurements

Balance

- Sieve Shaker: Used for particle size analysis, separating soil samples by size through a series of sieves.
- Sieve Set: A collection of sieves with various mesh sizes to perform gradation analysis. The following sieves are critical for particle size analysis in this test:

- 75 mm Sieve: Used for separating large particles, typically at the coarser end of the soil gradation spectrum.
- No. 4 Sieve (4.75 mm): Separates coarse-grained from finer particles.
- No. 10 Sieve (2.00 mm): Provides further separation of soil aggregates.
- No. 40 Sieve (425 µm): Used to classify finer materials from coarse sands.
- No. 200 Sieve (75 µm): Important for determining the percentage of fines (silt and clay) in the soil.

Sieve Shaker with Sieve Set

Sample Preparation

The following detailed steps outline the procedure for preparing test specimens according to AASHTO M 145 and relevant referenced standards:

1. Obtain a Representative Soil Sample:

   - Use field sampling methods to collect a soil sample representative of the field conditions. Ensure the sample is of sufficient quantity and homogeneity to meet testing requirements.
   - Follow AASHTO R 58 for dry preparation of disturbed soil and soil-aggregate samples.

2. Air-Dry or Oven-Dry the Sample:

   - Air-dry the soil sample if it contains excess moisture. If rapid drying is required, oven-dry at low temperatures (below 60°C).
   - Stir the sample occasionally to ensure even drying and avoid clumping.

3. Sieve the Soil Sample:

   - Perform a sieve analysis according to AASHTO T 27 (Sieve Analysis of Fine and Coarse Aggregates).
   - Use the appropriate sieves (75 mm, No. 4, No. 10, No. 40, and No. 200).
   - Record the weight of material retained on each sieve.

4. Wet Preparation of Fine Material (if required):

   - Use AASHTO T 146 to remove fine particles through wet sieving. Wash the material finer than the No. 200 sieve.

5. Weigh the Sample Accurately:

   - Weigh each fraction retained on the sieves to the nearest gram.
   - Ensure the total mass equals the initial weight of the sample.

Testing Procedures

The following steps outline the testing procedures for classifying soils according to AASHTO M 145:

1. Prepare the Soil Sample: Ensure the soil sample is representative and ready for testing following the preparation methods described earlier.
2. Sieve Analysis: Conduct sieve analysis using the No. 4, No. 10, No. 40, No. 200, and 75 mm sieves. Weigh the material retained on each sieve.
3. Perform Liquid and Plastic Limit Tests: Using AASHTO T 89 and AASHTO T 90, determine the liquid limit and plastic limit of the soil.
4. Perform data Analysis (Classification): Based on the results of the liquid limit, plastic limit, and particle size distribution, classify the soil according to the AASHTO M 145 standard , then calculate the group index

Examples of Sieve Analysis Results and Liquid/Plastic Limits

Example of Liquid and Plastic Limits:

- Liquid Limit (LL): 35%
- Plastic Limit (PL): 20%
- Plasticity Index (PI): LL - PL = 35% - 20% = 15%

Example Sieve Analysis (Total weight = 1000 grams)

- Sieve analysis is a practice or procedure used to assess the particle size distribution of a granular material. The data obtained from sieve analysis is critical for understanding material behavior in construction applications.
- The columns represent the following:
  1. Sieve Size (mm): The size of the sieve openings.
  2. Mass Retained (g): The mass of material retained on each sieve.
  3. Cumulative Mass Retained (g): The running total of mass retained on the sieves.

4. Cumulative % Retained: The cumulative mass retained divided by the total weight of the sample, multiplied by 100.
5. % Passing: 100 minus the cumulative % retained.

Sieve Size (mm)	Mass Retained (g)	Cumulative Mass Retained (g)	Cumulative % Retained	% Passing
75 mm	300	300	30.0	70.0
4.75 mm (No. 4)	250	550	55.0	45.0
2.00 mm (No. 10)	150	700	70.0	30.0
0.425 mm (No. 40)	150	850	85.0	15.0
0.075 mm (No. 200)	100	950	95.0	5.0
Pan	50	1000	100.0	0.0

- Sample Calculations

  Cumulative % Retained for 4.75 mm sieve:
  Cumulative Mass Retained = 550 g
  Total Sample Weight = 1000 g
  Cumulative % Retained = (550 / 1000) * 100 = 55.0%
  % Passing for 4.75 mm sieve:
  % Passing = 100 - Cumulative % Retained
  % Passing = 100 - 55.0 = 45.0%
  Similarly, these steps are followed for each sieve size to complete the table.

Data Collection

The following types of raw data should be collected during the testing process, which are essential for further calculations:

1. Mass Retained on Each Sieve: After conducting the sieve analysis, record the mass (in grams) retained on each sieve for further calculations of % passing.
2. Cumulative Mass Retained: The cumulative mass retained is required to calculate the total mass of the sample and to determine the % passing for each sieve size.
3. Liquid Limit (LL): Record the liquid limit of the soil, which represents the water content at which the soil changes from a plastic to a liquid state.
4. Plastic Limit (PL): Record the plastic limit, the water content at which the soil starts to exhibit plastic behavior.
5. Plasticity Index (PI): Calculate the plasticity index (PI = LL - PL) based on the collected LL and PL values.
6. Total Sample Mass: Ensure the total mass of the sample (in grams) is recorded to verify data accuracy during the % passing calculations.

Definitions of Gravel, Sand, and Silt-Clay

- Gravel: Material passing a sieve with 75-mm (3-in.) square openings and retained on the 2.00-mm (No. 10) sieve.

Gravel - 75-mm to 2.00-mm (No. 10) Sieve

- Coarse Sand: Material passing the 2.00-mm (No. 10) sieve and retained on the 0.425-mm (No. 40) sieve.
- Fine Sand: Material passing the 0.425-mm (No. 40) sieve and retained on the 75-µm (No. 200) sieve.

Sand - 2.00-mm (No. 10) to 0.425-mm (No. 40) Sieve

- Silt-Clay (Combined Silt and Clay): Material passing the 75-µm (No. 200) sieve.

Silt-Clay - Passing 75-µm (No. 200) Sieve

  - The term 'silty' is applied to fine material having a plasticity index of 10 or less,
  - The term 'clayey' is applied to fine material with a plasticity index of 11 or greater.

- Boulders and Cobbles: Materials retained on the 75-mm (3-in.) sieve should be excluded from the portion of the sample used for classification, but the percentage of such material, if any, should be recorded.

Boulders and Cobbles - Retained on 75-mm (3-in.) Sieve

AASHTO Soil Groups Classification

Granular Materials

Granular materials contain 35 percent or less passing the 75-µm (No. 200) sieve.

Silt-Clay Materials

Silt-clay materials contain more than 35 percent passing the 75-µm (No. 200) sieve.

Soil groups

- AASHTO Classifies soils into 7 main groups:
  - A-1 (Best for subgrade)
    - A-1-a
    - A-1-b
  - A-2
    - A-2-4 and A-2-5
    - A-2-6 and A-2-7
  - A-3
  - A-4
  - A-5
  - A-6
  - A-7 (Worst for subgrade)

A-1 Class (Granular Materials - Best Subgrade Soils)

- A-1-a (Stone Fragments, Gravel, and Sand):
  - Predominantly stone fragments or gravel, with or without binder.
  - Contains 50% or more of gravel and coarse fragments.
  - Less than 15% fines (passing the #200 sieve)
  - Uses: Excellent for highway subgrades due to high strength, good drainage, and minimal plasticity.

- A-1-b (Coarse Sand):
  - Predominantly coarse sand with or without binder
  - Contains 50% or more of coarse sand particles.
  - Less than 25% of fine particles.
  - Uses: Excellent for subgrades but slightly inferior to A-1-a due to the presence of more fines.

A-3 Class (Fine Sand - Marginal Subgrade Soils)

- Composed primarily of fine sand with very few fines or clay particles.
  - Typically, fine beach or desert sand
  - Less than 10% fines.
  - Uses: Generally poor for subgrade material, although it has good drainage. Suitable for lightly loaded or temporary roads.

A-4 Class (Silty Soils - Poor Subgrade Soils)

- Silty soil with moderate plasticity.
  - Liquid Limit (LL) < 40.
  - Usually with a high percentage passing the 0.075 mm sieve.
  - Uses: Not ideal for subgrades without stabilization. Prone to poor drainage and low strength, especially in wet conditions.

A-5 Class (High Liquid Limit Silty Soils)

- Similar to A-4 but with higher plasticity.
  - Silty soil with High plasticity.
  - Liquid Limit (LL) > 40.
  - Usually with a high percentage passing the 0.075 mm sieve.
  - Uses: Performs poorly as a subgrade due to high compressibility and poor load-bearing capacity. Requires stabilization for use.

A-6 Class (Clayey Soils - Very Poor Subgrade Soils)

- High plastic clay soil.
  - Liquid Limit (LL) < 40
  - Plasticity Index (PI) > 10.
  - Having a high percentage passing the 0.075 mm sieve.
  - Prone to shrink and swell with moisture content changes.
  - Materials in this group have a high-volume change between wet and dry states.
  - Uses: Very poor for subgrade material, often requiring chemical stabilization (lime or cement) to improve performance.

A-7 Class (Highly Plastic Clayey Soils - Worst Subgrade Soils)

- Similar to material described under group A-6 except that it has:
  - High liquid limit characteristic of group A-5.
  - May be elastic as well as subject to high volume change.
  - Subgroups:
    - A-7-5: Low to moderate plasticity.
    - A-7-6: Highly plastic clayey soils.
  - Uses: Poor subgrade material; must be stabilized for any significant use.

A-2 Class (Granular Materials with Fines - Variable Subgrade Soils)

- Includes a wide variety of granular materials which are borderline between the granular A-1 and A-3 groups and the silty clay materials of groups A-4 to A-7.

A-2-4 (Silty Gravel or Silty Sand)

- Composition:
  - Contains a moderate percentage of fine particles (10 - 35% passing the #200 sieve).
  - Typically has a higher gravel or coarse sand content.
  - Moderate plasticity, typically less than 10% fines.
  - LL < 40, PI < 10.
- Uses: Suitable for subgrade in lightly trafficked roads. Can be used in embankments and backfill applications.

A-2-5 (Clayey Gravel or Clayey Sand)

- Composition:
  - Similar to A-2-4 but with a higher clay content.
  - Contains 10-35% fines, with some clay particles contributing to plasticity.
  - Moderate to high plasticity.
  - LL typically between 25 - 40, PI between 7-12.
- Uses: Acceptable for subgrade, but caution is needed for heavily trafficked areas. Commonly used in structural fills and embankments with proper compaction.

A-2-6 (Clayey Sand)

- Composition:
  - Contains significant clay content, with 15-30% fines.
  - Characterized by its sandy texture with clay inclusions.
  - High plasticity, potentially problematic in wet conditions.
  - LL > 40, PI > 10.
- Uses: Generally not recommended for subgrade without treatment or stabilization. May be used in low-traffic areas with proper moisture control.

A-2-7 (Silty Clay)

- Composition:
  - Contains a high percentage of fines (30-50% passing the #200 sieve).
  - Predominantly clayey with silt.
  - Very high plasticity. LL > 40, PI > 12.
- Uses: Unsuitable for subgrade without extensive stabilization (lime, cement). Typically used in controlled environments or structures that can accommodate movement.

Group A-8

- Contains a significant amount of organic matter, highly plastic clays, or mixtures that lead to unpredictable engineering properties.
- Plasticity Index (PI) is often high due to the organic content.
- Behavior: Generally poor load-bearing capacity, high compressibility, and significant shrink-swell potential.
- Uses: Typically avoided for subgrade applications without significant treatment or stabilization.

Group Index

The group index is a supplementary value used to refine the classification of soils within each group under the AASHTO M 145 system. While the group symbol (e.g., A-6, A-7) provides the primary classification based on soil properties like particle size distribution, liquid limit, and plasticity index, the group index gives a numerical indication of the soil's suitability for use in road construction

Importance of Group Index in Classification:

- **Refines Classification:** The group index provides additional detail on the soil's behavior, particularly within the A-4, A-6, and A-7 groups, which helps engineers make better decisions on the soil's application.
- **Indicates Soil Quality:** A higher group index indicates poorer performance of the soil as a subgrade material, while a lower group index suggests better performance.
- **Aids in Decision-Making:** Engineers use the group index to assess whether soil stabilization (e.g., using lime or cement) is required to improve the material's properties for construction.

Calculation method :

The group index (GI) is calculated using the following formula:

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

Where:

- F = percentage passing the 75-µm (No. 200) sieve.
- LL = liquid limit.
- PI = plasticity index.

When calculating the group index of the A-2-6 and A-2-7 subgroups, only the PI portion of the formula is used. If the group index value is negative, it should be reported as zero. Group index values should always be shown in parentheses after the group symbol, e.g., A-6(12).

Examples of Group Index Calculations

1. Assume that an A-6 material has 55% passing the 75-µm (No. 200) sieve, a liquid limit of 40, and a plasticity index of 25. The group index is calculated as:

$$GI = (55 - 35)\,[0.2 + 0.005\,(40 - 40)] + 0.01\,(55 - 15)\,(25 - 10)$$

$$GI = 4.0 + 6.0 = 10$$

2. Assume that an A-7 material has 80% passing the 75-µm (No. 200) sieve, a liquid limit of 90, and a plasticity index of 50. The group index is calculated as:

$$GI = (80 - 35)\,[0.2 + 0.005\,(90 - 40)] + 0.01\,(80 - 15)\,(50 - 10)$$

$$GI = 20.3 + 26.0 = 46.3$$

3. Assume that an A-4 material has 60% passing the 75-µm (No. 200) sieve, a liquid limit of 25, and a plasticity index of 1. The group index is calculated as:

GI = (60 – 35) [0.2 + 0.005 (25 – 40)] + 0.01 (60 – 15) (1 – 10)

GI = 25 × (0.2 – 0.075) + 0.01 (45) (–9) = 3.1 – 4.1 = –1.0

Report as zero.

Data Analysis (Classification Procedures)

The following steps outline the procedure for classifying soils using the AASHTO system and calculating the Group Index:

1. **Perform Sieve Analysis:** Conduct a sieve analysis to determine the percentage of material passing each sieve. The critical sieve sizes for classification are the 75-mm (No. 200) sieve for fines and the 2.00-mm (No. 10) sieve for coarser materials.
2. **Determine Liquid and Plastic Limits:** Conduct tests to determine the Liquid Limit (LL) and Plastic Limit (PL) of the soil. These values will be needed for the Group Index calculation.
3. **Classify the Soil Based on Fines Content**: Based on the percentage of material passing the 75-µm (No. 200) sieve, classify the soil as a Granular Material (35% or less fines) or a Silt-Clay Material (more than 35% fines).
4. **Assign a Group and Subgroup:** For granular materials, assign groups A-1, A-2, or A-3 based on gradation and plasticity. For fine-grained materials, assign groups A-4, A-5, A-6, or A-7 based on plasticity and liquid limits.
5. **Calculate the Group Index (GI):** Use the formula to calculate the Group Index based on the percentage of fines, liquid limit, and plasticity index.

Example: Soil Classification and Group Index Calculation

Assume the following data for a soil sample:

- 45% passing the 75-µm (No. 200) sieve.
- Liquid Limit (LL) = 40
- Plastic Limit (PL) = 20
- Plasticity Index (PI) = LL – PL = 40 – 20 = 20

Step-by-step classification process:

1. Sieve Analysis: The soil has 45% passing the No. 200 sieve, so it is classified as a Silt-Clay Material.

    3. Calculate Group Index: Use the Group Index formula:

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

    GI = (45 – 35) [0.2 + 0.005 (40 – 40)] + 0.01 (45 – 15) (20 – 10) = GI = 2.0 + 3.0 = 5.0

Table 2—Classification of Soils and Soil-Aggregate Mixtures

General Classification	Granular Materials (35 Percent or Less Passing 75 µm)							Silt-Clay Materials (More Than 35 Percent Passing 75 µm)			
	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:											
2.00 mm (No. 10)	50 max	—	—	—	—	—	—	—	—	—	—
0.425 mm (No. 40)	30 max	50 max	51 min								
75 µm (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 0.425 mm (No. 40):											
Liquid limit	—		—	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity index	6 max		NP	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min[a]
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			

[a] Plasticity index of A-7-5 subgroup is equal to or less than $LL - 30$. Plasticity index of A-7-6 subgroup is greater than $LL - 30$. (See Figure 2.)

Results Reporting

The following key results should be reported for AASHTO soil classification:

- Sieve Analysis Data: The percentage passing each critical sieve size (e.g., No. 200, No. 40, No. 10, 75 mm).
- Liquid Limit (LL): The liquid limit of the soil, reported as a percentage.
- Plastic Limit (PL): The plastic limit of the soil, reported as a percentage.
- Plasticity Index (PI): The difference between the liquid limit and plastic limit, indicating the soil's plasticity.
- Group Classification: The assigned AASHTO soil classification group (e.g., A-1, A-2, A-6, A-7) based on the percentage passing the No. 200 sieve and plasticity.
- Group Index (GI): The calculated group index, presented in parentheses after the group classification (e.g., A-6(12)).

Specifications

The following are the Ministry of Public Works and Housing specifications applicable to the AASHTO M 145 test:

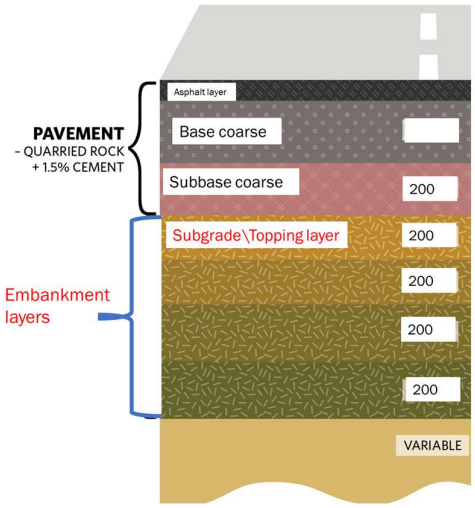
"Technical Specifications for the Construction of Rural and Secondary Roads" (1994)

- 3/2/3 - In the case of excavation, when reaching the level of the earth base (TOPPING), if the soil has a C.B.R greater than 10%, and after ensuring that the layer (with a thickness of 20 cm) beneath the earth base achieves a C.B.R of no less than 10% and is **classified as not falling under A-7 or A-6**, then the ground should be cleared of roots and vegetation, watered, and compacted to a degree of no less than 98% of the modified Proctor density. Subsequently, a layer of base materials is to be placed. If the materials for the layer beneath the earth base (20 cm thickness) do not meet the above specifications **or fall under A-6 or A-7**, then the work should be carried out according to item 3/2/3 (the minimum requirement).

- 3/2/3 - In the case of excavation, when reaching the level of the earth base and if the materials of this layer have a C.B.R of less than 15%, then this layer (with a thickness of 20 cm) should be removed. Subsequently, the materials beneath the earth base should be examined to a depth of 10 cm. If these materials have a C.B.R of less than 10% or are **classified as A-7 or A-6**, then these materials must be improved or replaced with materials that achieve a C.B.R of no less than 10% and are **not classified as A-7 or A-6.** (After that, materials for the earth base should be placed to meet the specifications provided in the attached table.)

"SPECIFICATIONS FOR HIGHWAY AND BRIDGE CONSTRUCTION" (2008)

- Topping shall consist **of selected borrow material** having
  - a 4-day soaked CBR of not less than 25% when tested in accordance with AASHTO T 193 when compacted at 100% of modified proctor AASHTO (T-180-**D**)
  - Having a maximum P.I. of 12%.
  - Gradation shall be reasonably smooth without gap grading.
  - All topping material shall pass 75 mm sieve
  - not more than 18% shall pass 0.075 mm (No. 200) sieve.
- Soil Suitable for Embankment
  - Maximum dry density not less than 1.7 (T-180D)
  - Organic matter not more than 5% (T-267)
  - No use of A-6, A-7 soil (AASHTO M-145)
  - Maximum size not more than 2/3 of the layer thickness
  - No use of high to medium expansive soil
  - C.B.R. should not be less than 8% (AASHTO T-193
- Soil Suitable for Embankment (OR)
  - or in the A-1, A-2-4, A-2-5 or A-3 "when confined" groups as in AASHTO M145 shall be used when available except for rock fill embankments.
  - If material of this character is not available,
  - then materials from A-2-6, A-2-7, A-4, A-5 groups (AASHTO M145)
  - or that specified under 'Special Specifications' may be used provided it complies with Table 2.1;
  - however, special attention should be given to the design and construction.
  - Materials classified as A-6 or A-7 shall not be used.
  - In areas subject to flooding and prolonged inundation of the embankment, such as at bridge and culvert sites, the material used in embankment are Rock, A-1-a, A-1-b, and A-2-4



Common Sources of Error and Impact

Error Source	Impact on Results	Troubleshooting Steps

Incorrect Sieve Size	Inaccurate gradation results, leading to misclassification	Verify that the correct sieve sizes are used and ensure proper calibration
Improper Drying of Soil Sample	Changes in moisture content can affect plasticity and sieve results	Ensure proper air drying or oven drying before testing begins
Incorrect Liquid or Plastic Limit Measurements	Leads to errors in calculating the Plasticity Index	Double-check all measurements and follow procedures for liquid and plastic limits

YouTube Videos

Video Title	**Direct Link**
Soil Classification by AASHTO Standards (English)	https://www.youtube.com/watch?v=ibNEvtrOONY&t=170s
FE Civil Exam Course - Soil classification AASHTO (English)	https://www.youtube.com/watch?v=Xo986QdTkt4
تصنيف التربة بطريقة الآشتو AASHTO Soil Classification I (Arabic)	https://www.youtube.com/watch?v=vAQDjTv6Fho
تصنيف التربة في الموقع طبقا للآشتو وبدون اختبارات | AASHTO Soil Classification	https://www.youtube.com/watch?v=Z8ywFunlwF4