Chapter 200
Soils – 24

This chapter is not part of the Project specifications but is a guide for project personnel in interpreting CDOT specifications, understanding ASTM, AASHTO, and Colorado test procedures, and for completing CDOT forms.

Pavements and structures built on the soils rely on engineered soil properties because soils are the foundation for transportation construction. Soil placement is vital to construction quality. The quality of the pavement mix, design, and construction is meaningless if the soils below the pavement settle, heave, or slide.

Soil and embankment inspectors and testers need to understand basic information about soils, testing procedures to classify soils, and how different soil types behave when they are used as an engineered material (i.e., compaction, drainage, stability, etc.). Testers working on a CDOT project are required to be certified with or under the guidance of a tester certified with the Western Alliance for Quality Transportation Construction (WAQTC) and CDOT's Soils, Excavation, & Embankment Inspection. Because these certifications cover testing in detail, this chapter provides a summary of basic soil mechanics, laboratory testing procedures, and field-testing procedures used to determine soil and engineering properties used during construction. Additional information can be found in the WAQTC Embankment & Base In-Place Density Participant Workbook and the CDOT Soils, Excavation, & Embankment Inspection Manual.

GENERAL SOIL PROPERTIES

There are three divisions of particle sizes that are determined from a gradation analysis: gravel, sand (coarse and fine), and fines (silt and clay). Sand and gravel are granular soils that are non-cohesive with particles that are visible to the naked eye. Soils composed primarily of sand and gravel have high strength, a high porosity (i.e., good drainage), and are not prone to long-term post-construction settlement. These soils are also easier to work with to gain adequate compaction during construction. Soils composed primarily of sand; however, are highly erodible.

Natural deposits of granular soils are described based on their in-situ density using the following terms: very loose, loose, medium dense, dense, and very dense. The denser the soil deposit, the higher the strength. This information is collected with field tests during a subsurface exploration program.

Silt and clay are classified as "fines" and pass the No. 200 sieve for a gradation analysis. These particles are not distinguishable by the naked eye. The terms used to describe silty and clayey soils refer to their "consistency" or "cohesiveness": very soft, soft, medium stiff, stiff, very stiff, and hard.

Silt is the coarser portion of the fines content (particle sizes varying from 0.002 mm to 0.075 mm). Soils composed primarily of silt are non-cohesive and are characterized by low plasticity. Soils composed primarily of silt are also highly erodible.

Clay is cohesive and can have high variability in plasticity, depending on the mineralogy of the clay particles present. Clay represents particles smaller than 0.002 mm, or 2 microns (µm) in a soil sample. The cohesion of clay soil is an indication of its strength, and softer clay soils are characterized by a lower cohesion or lower strength. This information is also collected with field tests during a subsurface exploration program.

Both silt and clay soils are characterized by low permeability (i.e., water does not flow through these soils quickly and they do not drain well). They have lower strength than sand and gravel, and they can be prone to long-term post-construction settlement. These soils are more difficult to work with during construction to achieve adequate compaction. Because of their low permeability, it is more difficult to moisture condition these soils uniformly to achieve near-optimum moisture conditions for adequate compaction. Silts and clays are also more sensitive to frost heave.

An elevated presence of fines within sandy or gravelly soils results in a decrease in strength, a decrease in permeability, and an increase in the likelihood of post-construction settlement. The percentage of fines and granular material determined in the soils and fills shall meet the project specifications.

LABORATORY TESTS

The following summarizes the testing that may be required during construction. Refer to the plans and specifications for your project to determine what tests are required.

Gradation

A gradation analysis is a method used to quantitatively determine the distribution of particle sizes in soils, aggregate, or soil-aggregate mixtures. Colorado Procedure (CP) 21 describes the procedure to run this test. This test is also referred to as a grain size analysis, particle size analysis, or sieve analysis. A sufficient amount of soil needs to be sampled to run a representative gradation test. The minimum mass of material required is dependent on the Nominal Maximum Size of aggregate or particle in the sample.

Atterberg Limits

The Atterberg limits define the range of moisture contents in which soil behaves as a plastic. As the moisture content of clayey soil increases, the material behavior will change from a solid to a semi-solid, to plastic, and eventually to a liquid. The specific moisture contents that need to be determined for AASHTO M-145 soil classification are:

- Plastic Limit (PL) and Plasticity Index of Soils - AASHTO T 90
- Liquid Limit (LL) of Soils - AASHTO T 89

The liquid limit is the moisture content at which the soil behavior changes from a plastic to a liquid state. The range of moisture contents that a soil behaves as plastic is referred to as the plasticity index (PI) and is taken as the difference between the liquid limit moisture content and the plastic limit moisture content (PI = LL – PL).

Soils that do not exhibit plastic behavior (clean granular soils) will have a value of zero for the PI, are referred to as Non-Plastic (NP) and will have No Value (NV) prescribed for their liquid limit and plastic limit. Soils with higher clay content are characterized by higher liquid limits and higher plasticity indices. If the soil can be rolled into 1/8-inch (3 mm) diameter threads after moisture is added, then the material is considered plastic. If the material cannot be easily rolled, it is likely non-plastic.

AASHTO Soil Classification

The inspector needs to familiarize themselves with this soil classification system. Project specifications will often require specific soil types to be used for various types of backfill (i.e. retaining wall backfill, embankment fill, pipe bedding, etc.).

The AASHTO Soil Classification system classifies soils into eight major groups based on their grain size distribution and Atterberg limits. These groups are designated A-1 through A-8. Soils that fall within the lower-numbered groups are granular (sands and gravels), contain less than 35 percent fines, and tend to be either non-plastic or low plasticity (A-1, A-2, and A-3 soils). Soils that classify within the higher numbered groups have higher fines content (silt and clay-sized particles) and are generally characterized by higher plasticity (A-4, A-5, A-6, and A-7 soils). Peat classifies as an A-8 soil and is characterized by an organic content of 15 percent or more.

To classify a soil using AASHTO M-145, gradation information and the Atterberg limits of the soil must be determined. The sieves used for this classification system must include the No. 10, No. 40, and No. 200 sieves. To use this classification system, an individual can determine the correct soil classification by the process of elimination.

In addition to the major groups and subgroups listed above, additional classification using the liquid limit, plasticity index, and percent fines can be conducted to determine a soil’s partial group index. A partial group index is a number placed in parentheses after an AASHTO group number: Example A-6 (5) indicates an A-6 group soil with a partial group index of 5. This number indicates the percent fines a soil contains, the level of plasticity of the fines, and indicates the quality of the soil as subgrade material. Higher partial group indices indicate poorer quality soil (i.e., an A-6 with a partial group index of 30 is a poorer quality soil than an A-6 with a partial group index of 5).

Unstable Soils as Determined by R-Value

Soil shall be analyzed for resistance to deformation (stability). The testing shall be Resistance R-Value and Expansion Pressure of Compacted Soils or Aggregates using Hveem Stabilometer per AASHTO T 190. Soil is unstable when the following criteria are met (see FIGURE 200-1):

- The decrease of the R-value from 400 psi to 300 psi is 10 or greater, and
- The optimum moisture of AASHTO T 99 or T 180 is greater than the exudation moisture at 300 psi.

The statement: "This material meets the criteria as unstable" will be written in the notes section on Soils Test Report in CAR for CDOT Form 323.

The use of unstable soil in projects should be minimized and carefully monitored. Potential remediation alternatives for unstable soil may include the following:

- Construction of a test section and proof rolling to verify construction methods.
- The unstable soil should be compacted at a moisture content of 1% to 2% below optimum moisture.
- Mechanical improvement, including the use of geosynthetics such as geotextile or geo-grid.
- Chemical treatment such as cement, fly ash, or cement/fly ash combination.

Region Materials should be contacted when unstable soils are encountered on a project.

Swelling Soils/Heaving Bedrock

Swelling soils are clay-rich soils that exhibit a volume change with increases or decreases in their moisture content. These soils are derived from weathering of certain claystone bedrock formations. Heaving bedrock operates by the same mechanism but is differentiated because the swelling occurs from intact bedrock layers rather than from unconsolidated soil deposits. This expansion can increase the volume of a deposit by more than 20 percent and the swelling action can exert thousands of pounds of force onto overlying structures.

Once a pavement or structure is placed over an expansive soil, natural evaporation is restricted which can cause moisture to build up in the subsurface. Also, if pavement cracks develop through time and allow water infiltration into the subsurface, an increase in moisture content can occur. The underlying soils expand causing buckling and differential heave to occur in the overlying structures.

Problems due to swelling soils and heaving bedrock most often occur in cut areas where dry claystone bedrock or residual soils are exposed and in transitions from cut to fill areas. Swelling soils can cause problems in, fill areas if soils with expansion potential are used as embankment fill.

Remedial measures to address swelling soil include:

- The crown of the roadway is generally sloped to promote runoff and eliminate ponding water.
- Construct drainage ditches below the subgrade level in low areas and are graded to allow rapid runoff of surface water.
- Over-excavation and replacement of potential expansive layers.
- Chemical treatment of the subgrade soils with lime, fly ash, or combinations of these materials. It should be noted that chemical soil treatment using lime or other cement agents can result in a different type of heave for soils characterized by a high sulfate content. Sulfate can react with the lime (or other calcium-based products) resulting in the growth of ettringite and/or thaumasite crystals in the soil. The growth of these crystals in the soil also results in volume expansion and heave to overlying structures. Soils shall be tested and meet the chemical requirements per Subsection 203.03 of the Standard Specifications.

The soil inspector needs to be aware of swelling soils that are encountered within a corridor; and what, if any, mitigation measures were specified to address these soils during construction. The Region Materials Engineer should be contacted when expansive soils are encountered on a project. Table 200-1 presents suggested treatment depths of the subgrade where swelling soils are present.

SOIL SURVEYS & SIMILARIZATION

There are two types of soil surveys: Preliminary Soil Surveys and Soil Surveys of Constructed Roadbeds. The preliminary soil surveys are conducted before new alignments and most road widening projects as part of the pavement design process. The purpose of soil surveys is to identify the various soil types within the existing and proposed roadway at elevations above and below the profile grade. The extent of each soil type is noted, and each type is identified by the AASHTO classification method. The condition of sub-soils upon which embankments will be constructed is evaluated. This involves moisture content, density, groundwater distribution, and other material properties that may impact the pavement before, during, and after construction. Detailed information on Preliminary Soil Surveys procedures and applications can be found in the Pavement Design Manual.

Soil Surveys of Constructed Roadbeds are to be performed per the OA Frequency Guide and CP 24. A sample should be taken for each soil encountered except for the material that may be used as topsoil. If the same soil is found in more than one hole, it may be ***Similarized*** to a soil already sampled. Similarization is the process of combining or eliminating samples from nearby locations that exhibit similar physical properties such as color, grain size, gradation, plasticity, roundness, etc. Similarizing increases productivity and efficiency while reducing costs for sample shipment and laboratory analysis. Care should be exercised in similarizing soils and additional samples should be taken where doubt exists. Similarization will be limited to one mile. Soil samples taken in each boring will be visually classified and similarized in the Region by certified inspectors and testers before submittal for laboratory analysis.

RIPPABILITY

Some bedrock can be broken down by the process of ripping. Ripping is the process of drawing a heavy metal tooth through the bedrock by a piece of construction equipment. The measurement of how easy it is to rip down the rock by a certain piece of equipment is rippability. The rippability is different for different types of bedrock and how the bedrock was formed. To assist in determining what equipment should be used for ripping the bedrock on a project, references are available such as the Caterpillar's Handbook of Ripping or similar manuals. These manuals associate construction equipment with seismic velocities to help plan what equipment should be used.

ITEM 203, EMBANKMENT

The foundation soils and the materials used to construct embankments must be properly constructed to improve stability, increase the strength of the soils, reduce the likelihood of post-construction settlement, and increase the long-term performance of the roadway. Embankment strength is dependent upon three basic conditions:

1. Compaction
2. Moisture Content
3. Soil Characteristics

Embankment material must be accurately classified using the AASHTO method and that soil samples tested truly represent the material being used in construction.

Proper compaction of embankments is necessary to provide a stable base for roadway pavement. It must be understood that the foundation soil directly beneath the embankment must be strong enough to support it. Insufficient strength of foundation soil could cause damage by shear failure, slip-outs, or displacement of underlying soft material by outward plastic flow. Highly compressible soil in the foundation could result in excessive settlement.

Compaction is, the densification of soil by the removal of air/void space through mechanical energy. To adequately compact any soil with conventional construction equipment, water must be regulated within the soil to maximize the degree of compaction that can be achieved. Water allows soil particles to slip over one another and move into a denser configuration. If too much water is added, the soil begins to behave as a liquid. The soil will simply pump or deform with compactive effort, and an increase in densification can no longer be achieved. The moisture content at which the maximum density of soil can be attained is referred to as the “optimum moisture content”. When soil is compacted at its optimum moisture content, it can be compacted to its maximum density.

Optimum moisture and maximum density values are determined according to either AASHTO T 99 (Standard) or AASHTO T 180 (Modified) as called for in the plans or specifications. It is the responsibility of the Engineer to assure the optimum moisture and maximum density of the in-place embankment material meet the requirements in Subsection 203.07 of the Standard Specifications.

Construction Procedure Summary

Roadway embankment material must be placed in horizontal layers. Material placed in lifts shall not exceed 8 inches for soil and rock embankment and 18 inches for rock fill. Rocks larger than the lift thickness shall be separated to allow for compaction equipment to operate in between the rocks. Rocky material should be uniformly distributed throughout the embankment to assure thorough consolidation.

Field Equipment

The type of compaction equipment to be used by the Contractor is optional unless otherwise specified on the plans. The Contractor, however, must meet density and percent moisture requirements. Common types of compaction equipment used are:

- **Sheep-foot Roller -** Used with cohesive (clayey and silty) soils.
- **Smooth-Wheel Rollers -** Used with base coarse materials and for finishing operations.
- **Vibratory Rollers -** Used with granular (sandy and gravely) soils.

When "Roller Hours" is specified on a project, estimated yardage (volume) shall be documented on the CP 80aa Template in Site Materials Manager. The estimated yardage (volume) shall be placed in the appropriate section of the template and shall be marked "for information only". In-place density tests should be taken for documentation when practical. A brief statement on the type, weight (mass), and effectiveness of the roller should be included under "Remarks" along with the "Roller Hours".

Field Tests

Field testing shall be performed per the OA and IA Frequency Guide Schedules as stated in this Field Materials Manual. Changes in embankment material may require additional testing. The results of these field tests must be recorded and retained in project Files.

Zero Air Voids Density

The Zero Air Voids Density Tabulation shown in this Chapter represents the dry density that would be obtained at the various moisture contents if there were no air voids present (i.e., when all voids between soil particles are filled with moisture). At a given moisture content and specific gravity, the zero air voids density represents the maximum density that can be obtained in the given soil.

Report the in-place dry density and the in-place moisture from the test results on CP 80aa. These results should be checked against the zero air voids density. For cohesive materials (clays and silts), a specific gravity of 2.70 may be used while 2.65 may be used for non-cohesive materials (sands and gravels). The in-place dry density should never exceed the zero air voids density of a material's in-place moisture and specific gravity as presented in the Zero Air Voids Density Tabulation (Table 200-2). If it does, some of the data is erroneous. To avoid using incorrect density values, the tester should check the Zero Air Voids Density Tabulation (Table 200-2) whenever a percent relative compaction figure of 105% or more is calculated.

ITEM 206, STRUCTURE BACKFILL

Section 206 of the Standard Specifications lists four classes of Structure Backfill in subsection 206.02:

- Structural Backfill Class 1, which is graded, granular material meeting the requirements of subsection 703.08 (a).
- Structural Backfill Class 2 shall be composed of suitable material developed on the project meeting the requirements of subsection 703.08 (b).
- Flow-Fill, which is a self-leveling, low strength concrete material as outlined in subsection 206.02(a) 2.
- Imported Structural Backfill for Pipes, as outlined in subsection 206.02(a) 3.

Field personnel shall indicate which method of determining maximum density (AASHTO T 99 or T 180) applies to the material submitted. The moisture and density required for Class 1 Structure Backfill will meet Subsection 206.03 of the Standard Specifications. More information on Structure Backfill, Class 1 appears in Chapter 300 of this Manual.

The moisture and density required for Class 2 Structure Backfill shall conform to Subsection 206.03 and unless otherwise designated, the type of compaction shall be the same as that specified for the project. In the event a contractor elects to substitute aggregate base course for Class 2 Structure Backfill, the maximum density determination and percent relative compaction will be the same as for Class 1 Structure Backfill per Subsection 206.03. The CDOT Tester and Project Engineer should discuss the compaction requirements if this type of substitution is being considered.

Structural Backfill shall meet the chemical testing requirements for sulfates, chlorides, pH, and resistivity per Subsection 206.02.

Note: When using Class 2 Structure Backfill that is composed of an appreciable amount of plus No. 4 material, Subsection 206.03 on uniform distribution and placement of maximum 6-inch layers should be strictly adhered to. See also Subsection 703.08(b) for further requirements when plus No. 4 material is present. This is very important in order not to cause any damage to the structure. Class 1 Backfill material should be used if there is any doubt about placing Class 2 material in the required 6-inch lift. The use of "too rocky to test" in place of the actual testing should be used very sparingly; therefore, it may apply when more than 50% of the material is retained on the ¾" sieve. Almost all Class 2 Backfill should be tested.

ITEM 206, FILTER MATERIAL

A protective filter is a pervious material that will allow the free infiltration of water but will prevent the entrance of soil into the filter. Specifications 206, 605, and 703 should be referenced concerning soil and drain material properties and placement. Much of the problem of selecting the right aggregate(s) for drainage systems stems from the need of satisfying two conflicting requirements:

- The aggregates must have pores that are large enough to permit water to flow readily through the layer.
- Drainage layers in contact with the soil must be fine enough to prevent the trench soil from washing through the pores of the aggregate which would result in clogging of the system. Usually, the pores will not clog if the 15% size of the filter is not more than 5 times the 85% size of the soil.

Meeting both requirements with one material sometimes can be nearly impossible. If it should become necessary to choose between one requirement or the other, the aggregate pore size should have precedence. One solution in difficult cases is the use of graded filters having two or more layers. One layer or zone of aggregate should be fine enough to hold the soil in place. Also, one or more than one of the coarser layers may be used to provide the needed water removing capacity. Graded filters of two or more layers are very common in dams. However, a desire to simplify construction has led to the widespread use of a single layer for most pavement drainage. Further guidance can be found in the Pavement Design Manual, Regional Materials Residency, or the Regional Hydraulic Engineer. Table 200-3 presents recommended filter classes.

Region Soil Survey Sampling Checklist

Soil Survey of Constructed Roadbeds
(Refer to CP 24 for details)

New & Widened Roadways and Sampling of Boring Materials

1. Borings will be drilled in the final subgrade before pavement overlay.
2. A minimum of one boring per 1,000 linear feet of completed 2-lane roadway will be done.
3. A minimum depth of 2 feet below the finished subgrade is required.
4. Take one sample per soil type containing at least 33 lbs. (15 kg) of minus No. 4 screen materials for ***classification.***

Materials Ownership and Documentation

1. ***Field*** or ***Region Lab*** will use CP 20, CP 21, and Form 564 to complete the soil classification.
2. ***Field*** **or** ***Region*** will follow CP 24 and mathematically scalp the gradation on the appropriate sieve and determine if there are significant variations in the material from the preliminary soil survey.
3. **If there are significant variations from the preliminary soil survey,** all +3/8, plus No. 4 screen, and minus #4 screen materials will be separated and retained in separate bags.
4. The sample material should be submitted through Site Manager Materials with a Form 157 requesting an R-value will be sent to the Region Lab (*) or Central Lab.
5. The soil classification on Form #564 will also be sent to the Region Lab or Central Lab.
6. If ***no*** significant variations are found, record them on Form 219 for project documentation.

<u>Borrow Pits</u>
(Refer to Standard Specifications for Road & Bridge Construction for details)

Contractor Source:
The cost of complying with Section 106.02 (b) *Contractor Source* requirements, including sampling, testing, and corrective action by the Contractor, shall be included in the work.
CDOT reserves the right to verify the contractor's source.

Materials Ownership, Sampling, and Forms (FMM OA Schedule)

1. If the embankment will support concrete pavement or be chemically stabilized, during production one soil sample per 2,000 yds^3 or fraction thereof will be tested for sulfate from the designated source by CDOT project or Region personnel.
2. Results will be documented on Forms 157 and 323.
3. During the qualification of a borrow source, one 5 lb. sample of soil, per soil type, will be submitted to the Chemical Unit of the Central Laboratory for sulfate content.

Notes:

1. Region Lab/Soils Program will perform the classification of soils.
2. Chemical Unit will perform a chemical analysis of soil samples for sulfates.
3. Chemical Unit will provide the Project with the chemical analysis on the qualification of the borrow sources.
4. For the preliminary soil survey, the Chemical Unit will provide the Region Materials Program with the chemical analysis reports and forward the results to the Soils Program.
5. The Soils Program will input the chemical results onto the electronic Form 555 and forward the completed preliminary soil survey to the Region Materials Program.
6. Chemical Unit will perform chemical analysis of soil samples for corrosion tests and will provide test results to the Region for pipe material type selection.

(*) If the Region Lab can perform AASHTO T 190 then no sample needs to be sent to the Central Lab.

Region Soil Survey Drilling Checklist

Reconnaissance of Drill Site

#	Question	Yes	No	N/A
1.	Was a reconnaissance survey of the area to be drilled performed?	☐	☐	☐
2.	Have landowner clearances and locates been obtained?	☐	☐	☐
3.	Have temporary easements been obtained?	☐	☐	☐
4.	Have drilling methods been determined?	☐	☐	☐
5.	Have roadway conditions and types of pavements been noted?	☐	☐	☐
6.	Have rock outcrops been noted?	☐	☐	☐
7.	Have survey cross-sections or profiles been performed?	☐	☐	☐
8.	Is there drilling for the existing roadway?	☐	☐	☐
9.	Is there drilling for new or extension of the roadway surface?	☐	☐	☐
10.	Have structures and culverts been identified?	☐	☐	☐
11.	Has the Soil Survey Field Report, Form 554 been completed?	☐	☐	☐
12.	Have sulfate/corrosion resistance samples been taken?	☐	☐	☐

If suspicious material is encountered during drilling

- **Stop Drilling**
- **Do not move the drill rig.**
- **Secure area and provide traffic control if necessary.**
- **Contact Region Environmental and/or Region Safety Coordinator**

FIGURES AND TABLES

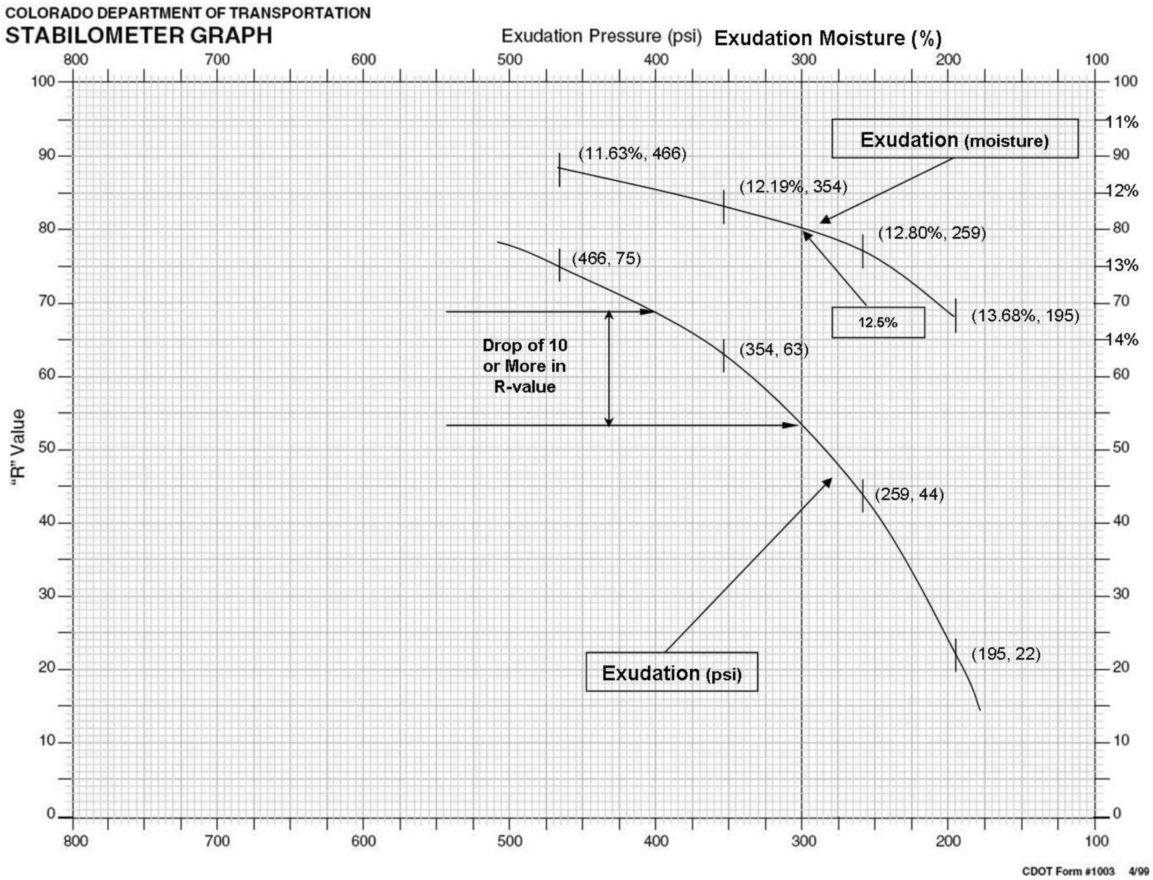

FIGURE 200-1

TABLE 200-1. SUGGESTED TREATMENT BELOW NORMAL SUBGRADE ELEVATION FOR PROJECTS

Plasticity Index	Depth of Treatment	
	Interstate And Primary System	Secondary And State Systems
10 to 20	2 feet	2 feet
20 to 30	3 feet	2 feet
30 to 40	4 feet	3 feet
40 to 50	5 feet	3 feet
*Over 50	6 feet	4 feet

TABLE 200-2. ZERO AIR VOIDS DENSITY TABULATION

	Dry Density (ZAVD)					
Moisture,	@ 2.65 SP. GR.		@ 2.70 SP. GR.		@ 2.75 SP. GR.	
% of Dry Wt.	lb./ft^3	kg/m^3	lb./ft^3	kg/m^3	lb./ft^3	kg/m^3
9.0	133.5	2138.4	135.5	2170.5	137.6	2204.1
9.5	132.1	2116.0	134.1	2148.1	136.1	2180.1
10.0	130.7	2093.6	132.7	2125.6	134.6	2156.1
10.5	129.4	2072.8	131.3	2103.2	133.2	2133.6
11.0	128.3	2055.1	129.9	2080.8	131.7	2109.6
11.5	126.7	2029.5	128.6	2060.0	130.3	2087.2
12.0	125.5	2010.3	127.3	2039.1	129.0	2066.4
12.5	124.2	1989.5	126.0	2018.3	127.7	2045.5
13.0	123.0	1970.3	124.7	1997.5	126.4	2024.7
13.5	121.8	1951.0	123.5	1978.3	125.1	2003.9
14.0	120.6	1931.8	122.3	1959.0	123.9	1984.7
14.5	119.5	1914.2	121.1	1939.8	122.7	1965.4
15.0	118.3	1895.0	120.0	1922.2	121.5	1946.2
15.5	117.2	1877.3	118.8	1903.0	120.3	1927.0
16.0	116.1	1859.7	117.7	1885.4	119.2	1909.4
16.5	115.1	1843.7	116.6	1867.7	118.0	1890.2
17.0	114.0	1826.1	115.5	1850.1	117.0	1874.1
17.5	113.0	1810.1	114.4	1832.5	115.8	1854.9
18.0	112.0	1794.0	113.4	1816.5	114.8	1838.9
18.5	111.0	1778.0	112.4	1800.5	113.7	1821.3
19.0	110.0	1762.0	111.4	1784.4	112.7	1805.3
19.5	109.0	1746.0	110.4	1768.4	111.7	1789.2
20.0	108.1	1731.6	109.4	1752.4	110.7	1773.2
20.5	107.2	1717.2	108.5	1738.0	109.7	1757.2
21.0	106.2	1701.1	107.5	1722.0	108.8	1742.8
21.5	105.3	1686.7	106.6	1707.6	107.8	1726.8
22.0	104.5	1673.9	105.7	1693.1	106.9	1712.4
22.5	103.6	1659.5	104.8	1678.7	106.0	1697.9
23.0	102.7	1645.1	103.9	1664.3	105.1	1683.5
23.5	101.9	1632.3	103.1	1651.5	104.2	1669.1
24.0	101.1	1619.5	102.2	1637.1	103.4	1656.3
24.5	100.3	1606.6	101.4	1624.3	102.5	1641.9
25.0	99.5	1593.8	100.6	1611.4	101.7	1629.1
25.5	98.7	1581.0	99.8	1598.6	100.9	1616.2
26.0	97.9	1568.2	99.0	1585.8	100.1	1603.4
26.5	97.2	1557.0	98.2	1573.0	99.3	1590.6
27.0	96.4	1544.2	97.4	1560.2	98.5	1577.8
27.5	95.7	1533.0	96.7	1549.0	97.7	1565.0
28.0	94.9	1520.1	96.0	1537.8	97.0	1553.8
28.5	94.2	1508.9	95.2	1524.9	96.2	1541.0
29.0	93.5	1497.7	94.5	1513.7	95.5	1529.7
29.5	92.8	1486.5	93.8	1502.5	94.7	1516.9
30.0	92.1	1475.3	93.1	1491.3	94.0	1505.7
30.5	91.4	1464.1	92.4	1480.1	93.3	1494.5
31.0	90.8	1454.5	91.7	1468.9	92.6	1483.3
31.5	90.1	1443.2	91.0	1457.7	91.9	1472.1
32.0	89.5	1433.6	90.4	1448.1	91.3	1462.5
32.5	88.8	1422.4	89.7	1436.8	90.6	1451.3
33.0	88.2	1412.8	89.1	1427.2	90.0	1441.6
33.5	87.5	1401.6	88.5	1417.6	89.3	1430.4
34.0	87.0	1393.6	87.8	1406.4	88.7	1420.8
34.5	86.4	1384.0	87.2	1396.8	88.1	1411.2
35.0	85.8	1374.4	86.6	1387.2	87.4	1400.0
35.5	85.2	1364.8	86.0	1377.6	86.8	1390.4

TABLE 200-3. RECOMMENDED FILTER CLASSES

Sieve Size or Designation	Percentage of soil passing designated sieves (1)		
	Use Class 1, B or C (2)	Use Class B or C (2)	Use Class C
No. 10 No. 40	less than 85, & less than 25	less than 85	more than 85

(1) Based on the minus 3-inch (75 mm) portion of the soil adjacent to the filter material.
(2) To drain large quantities of water, use the most open grading recommended.

This table is based on the following criteria: The D_{15} size of the filter should not be more than five times the D_{85} size of the soil.

DEFINITIONS

Alluvial Fan - Deposit formed at the base of a steep valley or canyon wall by steep gradient tributary action. The material usually consists of heterogeneous angular rock and soil.

Angle of Internal Friction - An angle whose tangent is equal to the frictional shear strength of soil divided by the confining stress exerted on that soil. Cohesion-less soils tend to exhibit high Angle of Internal Friction (∅) values.

Boulders - All rocks larger than 10 inches in diameter.

Clay - A very fine-grained soil, which passes the No. 200 screen and has a Plastic Index of 11 or more.

Cobbles - Rocks, which range from 3 to 10 inches in diameter.

Cohesion - The capacity of sticking or adhering together. That part of a soil's shear strength does not depend on inter-particle friction. Cohesion is the major factor contributing to the shear strength of clay soils.

Compaction - The process of increasing the density of a material by mechanical means, such as tamping, rolling, vibration, etc.

Consolidation - The process of decreasing the thickness of a soil layer by applying a vertical load.

Degree of Saturation - The ratio of the volume of water to the void volume in each soil mass.

Density - The mass of a substance per unit volume, usually expressed in pounds per cubic foot (pcf).

Embankment - A raised structure, consisting of soil, aggregate, or rock. Usually, the material is compacted and is used to support roadway pavement.

Erosion - The removal and transportation of soil or rock by water, ice, and gravity.

Escarpment - A steep face terminating highlands abruptly.

Glacial Moraine - Deposit of heterogeneous material left by glacial action. Material ranges in size from clay to large boulders.

Gradation - Indicates the range and relative distribution of particles in soil or aggregate.

Gravel - A granular material, which is retained on the No. 10 screen and has a maximum particle size of 3 inches.

Hygroscopic Moisture – Hygroscopic material is soil that readily absorbs water usually from the atmosphere; therefore, hygroscopic moisture is the moisture absorbed from the atmosphere. In most cases, the water can be removed from the material by heating.

Internal Friction - The property of individual soil particles to resist movement along adjacent surface areas.

Landforms - Distinct shapes of the earth's surface that have been formed by erosion and deposition of rock or soil. Common examples are stream terraces, alluvial fans, glacial moraines, and sand dunes.

Liquid Limit - The moisture content at which a soil changes from the plastic state of consistency to the liquid state of consistency.

Loess Deposit - A homogeneous, un-stratified accumulation of windblown silt with subordinate amounts of very fine-grained sand.

Maximum Density - The unit dry weight (pounds per cubic foot, (pcf)) of a soil compacted at optimum moisture and at a specific compactive effort.

Optimum Moisture - Percent moisture of a soil, which will yield a maximum dry unit weight for a specified compactive effort.

Permeability - The rate at which a material allows transmission of water.

pH – A measure of the activity of hydrogen ions in a solution. When in balance (pH 7) the soil is said to be neutral. The pH scale covers a continuum ranging from 0 (very acidic) to 14 (very alkaline or basic).

Plastic Index - The numerical difference between the liquid limit and the plastic limit of a soil.

Plasticity - Property of material to be remolded without crumbling under certain moisture conditions.

Plastic Limit - The moisture content at which a soil changes from the semi-solid state of consistency to the plastic state of consistency.

Poorly Graded - Particle sizes of a soil mass that are not evenly distributed.

Pore Water Pressure - The stress imparted by water against soil particles within a saturated soil mass.

Porosity - The ratio of the void space of a material to the total volume of its mass, usually expressed as a percent.

Rock - Any naturally formed consolidated aggregate or mass of minerals, which cannot be excavated by manual methods alone. (Pieces of rock, which pass the No. 4 screen, are considered soil particles.)

Sand - A granular soil, which passes the No. 10 screen and is retained on the No. 200 screen.

Sand Dunes - Ridges of mounds formed by windblown sand. These deposits of sand consist of clean, uniform sand grains.

Silt - A very fine-grained soil, which passes the No. 200 screen and has a Plastic Index of 10 or less.

Residual Soil - Material that is produced by the weathering of bedrock and accumulates or remains in contact with parent rock.

Similarization - The process of combining or eliminating samples from nearby locations that exhibit similar physical properties such as color, grain size, gradation, plasticity, roundness, etc. Similarization will be limited to one mile. Soil samples taken in each boring will be visually classified and similarized in the Region by certified inspectors and testers before submittal for laboratory analysis.

Soil - A loosely cemented, heterogeneous, earthen material, which is composed of particles surrounded by voids of various sizes. Voids may be filled with air, water, gas, or any combination of the same. Particles of soil are produced by the physical or chemical disintegration of rock.

Specific Gravity (Absolute) - The ratio of the unit weight of solid matter in the soil to that of distilled water at 68°F (20°C).

Specific Gravity (Apparent) - The ratio of the weight of soil particles (including permeable and impermeable voids) to that of water.

Specific Gravity (Bulk) - The ratio of the weight of a specific volume of soil particles to the same volume of water.

Stream Terrace - Mostly granular material, which has been deposited by stream action to form a level, topped surface with an escarpment on one side.

Stratified - Soil deposited in layers with different and distinct characteristics.

Swelling Soil – Material, which exhibits the ability to increase in volume with an increase in water content. Soils with high swell potential usually contain montmorillonite.

Testable Material – Soils and rock mixtures having 50% or more by weight, at field moisture content, of minus 4 material and the top size material being less than 6 inches in diameter.

Transported Soil - Accumulation of material, which has been transported from its parent rock by water, wind, or ice.

Void Ratio - The ratio of the volume of void space to the total volume of the particles within a mass.

CDOT Materials Forms - Applicable for Soils

https://www.codot.gov/library/forms/form-numbers-broken-down

Materials Forms, Instructions & Examples Chapter

NOTE: Use the relevant example forms from the electronic version of the 2018 FMM.