CONSTRUCTION INSPECTOR'S REFERENCE MANUAL

SOILS COMPACTION AND TESTING 2015

Technical Training & Certification Program

Table of Contents

SPECIFICATIONS

GS-12005
Oct. 14, 2014

Section 2102. Roadway and Borrow Excavation

2102.01 DESCRIPTION.
Excavate, haul, place, compact, and shape construction materials.

2102.02 MATERIALS.

A. Class 10.
Includes:
- Normal earth materials such as loam, silt, gumbo, peat, clay, soft shale, sand, and gravel.
- Fragmentary rock or boulders handled in the manner normal to this class of excavation.
- Any combination of the above described materials and any other material not classified as Class 12 or Class 13.

B. Class 12.
Includes:
- Granite, trap, quartzite, chert, limestone, sandstone, hard shale, or slate in natural ledges or displaced masses.
- Rock fragments or boulders which occur on the surface or in subsurface deposits mixed with earth, sand, or gravel when their size, number, or location prevents them from being handled in a manner normal to Class 10 excavation.

C. Class 13.
Includes all materials included under the definitions of Classes 10 and 12 and any other material encountered, regardless of its nature.

D. Material Suitability.

1. Select Treatment Material.

a. Cohesive Soils.
Meet all of the following requirements:
1) 45% or less silt size fraction.
2) 110 pcf (1750 kg/m^3) or greater density (AASHTO T 99 Proctor Density or Materials I.M. 309).
3) Plasticity index greater than 10.
4) A-6 or A-7-6 soils of glacial origin.

b. Granular Soils.
Meet all of the following requirements:
1) 15% or less silt and clay.
2) 110 pcf (1750 kg/m^3) or greater density (AASHTO T 99 Proctor Density or Materials I.M. 309).
3) Plasticity index, 3 or less.
4) A-1, A-2, or A-3 (0).

c. Special Backfill Material.
Meet the requirements of Section 4132.

d. Modified Subbase Material.
Meet the requirements of Section 4123.

2. Suitable Soils.

a. Ensure all soils provided for the construction of embankments meet the requirements below. They are suitable when moisture control or moisture and density control is designated.
1) 95 pounds per cubic foot (1500 kg/m^3) or greater density (AASHTO T 99 Proctor Density or Materials I.M. 309).
2) AASHTO M 145 index of less than 30.
3) Liquid Limit (LL) less than 50.

b. Soils not meeting these requirements are considered unsuitable soils, regardless of classification.

c. When placing soil below water, use clean granular material.

3. Unsuitable Soils.
Place in the work only as specified by Standard Road Plan EW-102. Use in the work will be according to the definitions in Table 2102.02-1:

Table 2102.02-1: Uses for Unsuitable Soils

Definition	Use
1. Peat or Muck. **2.** Soils with a plasticity index of 35 or greater. **3.** A-7-5 or A-5 having a density less than 85 pcf (1350 kg/m^3) (AASHTO T 99 Proctor Density or Materials I.M. 309).	Slope Dressing Only.
1. All soils other than A-7-5 or A-5 having	

a density of 95 pcf (1500 kg/m^3) or less (AASHTO T 99 Proctor Density or Materials I.M. 309). **2.** All soils other than A-7-5 or A-5 containing 3.0% or more carbon.	Type C placement placed 3 feet (1 m) below top of subgrade in fills.
1. A-7-6 (30 or greater). **2.** Residual clays (overlaying bedrock), Paleosols, gumbo, and gumbotils regardless of classification.	Type B placement placed 5 feet (1.5 m) below top of subgrade in fills.
1. Shale. **2.** A-7-5 or A-5 soils having a density greater than 86 pcf (1351 kg/m^3) but less than 95 pcf (1500 kg/m^3) (AASHTO T 99 Proctor Density or Office or Materials I.M. 309).	Type A placement placed in layers 5 feet (1.5 m) below top of subgrade in fills (Alternate layers to consist of suitable soils or Type C placement soils).

E. Selected Backfill Material.
Shown in the contract documents.

F. Special Backfill Material.
Meet the requirements of Section 4132.

2102.03 CONSTRUCTION.

A. General.

1. Prepare the site and construct the embankment according to Section 2107.

2. Remove materials as indicated in the contract documents and from borrow pits, exclusive of that designated as channel excavation.

3. Remove material necessary to provide suitable approaches from intersecting highways and private entrances.

4. Shape and slope materials for construction of the roadbed, slopes, gutters, and inlet and outlet ditches according to these specifications and the alignment, grade, and cross sections shown in the contract documents or established by the Engineer.

5. Before beginning construction, remove grass, weeds, other herbaceous vegetation, and rubbish as provided in Article 2102.03, G.

6. Work around utility poles if it is impractical to remove them before excavation or embankment construction.

B. Classification of Excavation.

1. **Class 10 Excavation.**
Excavate Class 10 material.

2. **Class 12 Excavation.**
Excavate Class 12 material.

3. **Class 13 Excavation.**
   a. Excavate Class 13 material. This classification covers work commonly referred to as "Unclassified Excavation". Use or remove Class 13 material as provided for in the contract documents.
   b. The contract documents will specify the limits for Class 13 excavation. Excavation within these limits will not be classified as Class 10 or Class 12 excavation.

C. Removal and Placement of Boulders.

1. Remove or bury boulders. Remove, where necessary, surface collections of boulders within the limits of the work for satisfactory completion of the work.

2. After completion of excavation operations, collect loose boulders and rocks. Also collect pieces of broken PCC that have a vertical projection 4 inches (100 mm) or more above the surface or the ground, or have a minimum diameter of 6 inches (150 mm) and that appear during the finishing operation.

3. Boulders, except those handled in a way normal to Class 10 excavation, will be classified as Class 12 excavation. Unless otherwise specified, place boulders in any of the following ways:
   a. Boulders too large to be loaded and hauled with available equipment may be buried in locations where they

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Section 2107. Embankments

2107.01 DESCRIPTION.

A. Prepare the site.

B. Place and compact excavated materials.

2107.02 MATERIALS.
Specified in the contract documents.

2107.03 CONSTRUCTION.

A. General.

1. Prepare the site, and place and compact excavated materials to the required elevation and cross section shown in the contract documents.

2. If the type of compaction is not specified, Type A compaction will be required.

B. Equipment.
Use equipment that meets the requirements of Section 2001 and the following:

1. **Compaction Equipment.**
   - a. When compaction with moisture and density control is not specified, use equipment that meets the requirements of Article 2001.05, A. Other types of compacting equipment may be used as provided in Article 2107.03, G. → Sheepsfoot roller
   - b. For compaction of sand or other granular material, use either a:
     - Self propelled pneumatic roller meeting the requirements of Article 2001.05, C, or
     - Self propelled vibratory roller meeting the requirements of Article 2001.05, F.
   - c. Compact special backfill material with equipment meeting the requirements of Article 2001.05, Paragraphs B, C, D, F, or other types of compacting equipment as provided in Article 2107.03, G.
   - d. When compaction with moisture and density control is specified, any type of equipment which will produce the desired results may be used for compaction.

2. **Equipment for Applying Water.**
   Apply Article 2001.09.

C. Preparation of the Site.

1. Where the height of proposed embankment at the center line is 5 feet (1.5 m) or less, remove sod (after thorough disking) from the area. Place the sod on the area to be occupied by the outer portion of the embankment as provided in Article 2107.03, D.

2. When an embankment is placed on or against an existing slope which is generally steeper than 3 horizontal to 1 vertical and is more than 10 feet (3 m) high, cut the slope into steps as the construction of the new embankment progresses. Assure that sod or other potential sliding surfaces are removed. Cut each step or series of steps to approximate horizontal planes with vertical slope cut dimensions of no less than 3 feet (1 m).

D. Depositing Embankment Material. 8" loose lifts

1. Comply with the following:
   - a. Except for rock fills and granular blankets, deposit embankments in horizontal layers not over 8 inches (200 mm) in loose thickness.
   - b. Keep the outer portion lower than its center.
   - c. When construction will be suspended for a period during which rain is likely to occur, smooth the surface to produce a smooth and compact surface to shed water.
   - d. Deposit soils containing quantities of roots, sod, or other vegetable matter outside of the shoulder line and within the outer 3 feet (1 m) of the embankment.
   - e. Do not deposit tree stumps and other large woody objects in embankments.
   - f. Alternate layers of drier soils with wetter soils whenever it is practical to do so without an increase in average haul.
   - g. Do not construct embankments on frozen ground. Do not use frozen material to construct embankments.

2. Apply the following where Type A or Type B compaction operations are to be used:
   - a. When the width at the attained height is 30 feet (10 m) or more, divide the area upon which the layer is to be placed into separate and distinct dump areas having widths no less than 15 feet (5 m). If hauling

equipment is operated within a dump area, disk the area with a least one pass of a tandem axle disk or two passes with a single axle disk prior to compaction.

b. During compacting operations, keep hauling equipment off dump areas of embankments 36 feet (11 m) wide or more. Empty hauling units may travel on the dump area during compaction operations as necessary to pass loaded hauling units if:

- Within 36 feet (11 m) of a bridge or other limiting structure.
- The width of the embankment is less than 36 feet (11 m) at the attained height.

c. If the design width of embankment is less than 30 feet (10 m) at the attained height, hauling units will be allowed to travel through areas where compaction operations are in progress. Ensure hauling equipment passing through compaction operations does not force water, disking, and compacting equipment to deviate from their intended paths.

d. Deposit the material over the dump area as a separate and distinct operation. If the material, as deposited, contains an average of more than 1 lump per square yard (square meter) large enough to have at least one dimension greater than 12 inches (0.3 m), disk the area with at least one pass of a tandem axle disk or two passes of a single axle disk. Use a disk designed and operated to cut and stir to the full depth of the layer.

3. After depositing and disking (if required), smooth the material to a uniform depth using a suitable motor patrol, bulldozer, or self propelled sheepsfoot type roller with a blade attachment. In addition to the initial smoothing, continue smoothing and leveling during compaction as necessary to provide a surface area free from ruts and other objectionable irregularities. The self propelled, sheepsfoot type roller with blade attachment may be used under the following conditions:

a. Leveling is completed according to the prescribed rolling pattern.
b. Compaction is the major function of this unit.
c. Power drums are prevented from spinning.

4. When, in the Engineer's opinion, the unit cannot satisfactorily accomplish both leveling and rolling, use a separate dozer or motor patrol for the leveling operation prior to initiation of compaction.

E. Type A Compaction.

1. Type A compaction refers to compaction requiring a minimum of one rolling per inch (25 mm) depth of each lift. A further requirement is that the roller continues operation until it is supported on its feet, or the equivalent.

2. After smoothing the surface of the layer and before depositing material for the next layer, compact the layer with at least one pass of the sheepsfoot type roller for each inch (25 mm) of loose thickness of the layer. Compact until the roller is supported entirely on its feet. This occurs when the tamping feet penetrate no more than 3 inches (75 mm) into an 8 inch (200 mm) lift or 33% of the depth of the layer being placed.

Roller walk-out

3. Determine if the moisture content of the material is excessive or suitable for satisfactory compaction. The Contractor may elect to start rolling operations immediately after the smoothing operation, or may elect to delay rolling operations, and instead, aerate the material in preparation for rolling. Proceed with aeration and compaction operations in an orderly fashion without unreasonable and unnecessary delay. Rolling operations made prior to any aeration operations for a lift will not be counted as any of the required coverages.

4. Should the material be dry to the extent that it is likely to fail to be satisfactorily compacted by rolling, the Contractor may moisten the material. The Engineer may order the material to be moistened uniformly before compacting. Authorization may be given for the use of water in the final finishing of the roadbed.

5. Compensation will not be allowed for delays occasioned by the ordering of moistening or by drying.

6. The Contractor may request approval of other methods and equipment according to Article 2107.03, G.

Approval of other methods + equipment

F. Type B Compaction.

1. Type B compaction refers to compaction requiring a specified number of diskings and roller coverages, or the equivalent.

2. After smoothing the surface of the layer and before depositing the next layer, compact or smooth and compact the layer.

3. If the entire weight (mass) of the roller is supported on its feet after one pass of the roller for each inch (25 mm) of loose thickness of the layer, no further compacting is necessary. A roller will be considered to be supported entirely on its feet when the feet penetrate no more than 3 inches (75 mm) into an 8 inch (200 mm) lift or 33% of the depth of the layer being placed.

4. If the soil in the layer is too wet when it is deposited to compact to the degree that the entire weight (mass) of the roller is supported on its feet, the Engineer may require one disking per 2 inches (50 mm) of loose thickness of the layer in addition to the disking required in the smoothing operation. A disking consists of a complete coverage of the layer with either a tandem axle disk or a single axle disk. Use a disk designed and operated to cut and stir to the full depth of the layer. The Engineer may require an interval no longer than 2 hours between successive diskings. After the disking has been completed, compact the layer with one pass of a sheepsfoot type roller per inch (25 mm) of loose thickness of the layer.

5. The manipulation and compaction specified above is incidental to Class 10 or Class 13 excavation. The Engineer may require additional manipulation and compaction as extra work. If the soil is so dry that it will fail to be satisfactorily compacted by rolling, the Engineer may require the Contractor to moisten the material uniformly before it is compacted.

6. Compensation will not be allowed for delays caused by the ordering of moistening or by disking.

7. The Contractor may substitute Type A compaction at no additional cost to the Contracting Authority where Type B compaction is specified, by written notification to the Engineer, or the Contractor may request approval of other methods and equipment according to Article 2107.03, G. Approval of other methods + equipment

G. Compaction by Other Methods and Equipment.

1. Other methods of compaction may be used. Demonstrate they will obtain suitable compaction of a variety of soil types and moistures normally encountered. Compaction will be considered suitable if the resulting density, with adequate moisture, is both:
   - Reasonably uniform throughout the compacted lift.
   - At least 95% of maximum density, determined according to Materials Laboratory Test Method No. Iowa 103.

2. Other types of compacting equipment may be used. Demonstrate they will obtain equivalent compaction results using a variety of soil types and moistures normally encountered. Demonstrations are to be such that results can be compared.

3. For Type A compaction, equivalent compaction must be recognizable by roller penetration or other significant characteristic.

4. For other methods or other equipment, a definite approval will be necessary, including any limitations the Engineer deems advisable.

5. Use of other methods and equipment prior to approval, except for demonstration tests, must provide 6 inch (150 mm) compacted lifts at 95% of maximum density, during which moisture is maintained no drier than 3 percentage points below optimum moisture.

H. Compaction with Moisture and Density Control.

1. The contract documents will show areas in which embankments shall be constructed with moisture and density control. The contract documents will also show the distance below the elevation of the completed grading work to which such methods are to be applied.

2. Where construction with moisture and density control is indicated in cut sections:
   - **a.** Excavate the roadbed below proposed subgrade elevation to a plane 6 inches (150 mm) above the elevation shown for the bottom of the moisture and density control section.
   - **b.** Thoroughly scarify the remaining 6 inch (150 mm) layer.
   - **c.** Increase or reduce the moisture content as necessary to bring the moisture throughout this 6 inch (150 mm) layer within the moisture limits specified.
   - **d.** Compact this 6 inch (150 mm) layer to no less than 90% of maximum density determined according to Materials Laboratory Test Method No. Iowa 03.
   - **e.** Deposit the remainder of the cut section to the completed grade elevation in layers according to Article 2107.03, D. Loose 8" lifts
   - **f.** Uniformly moisten each layer as necessary to bring to within the specified moisture limits.
   - **g.** Compact each layer to no less than 95% of maximum density.

3. Where construction with moisture and density control is indicated in embankment sections outside cuts:
   - **a.** Deposit in layers, according to Article 2107.03, D, all material in fill above the designated elevation for compaction with moisture and density control. Loose 8" lifts
   - **b.** Uniformly moisten or dry as necessary to bring each layer within the specified moisture limits.
   - **c.** Compact the first layer placed with moisture and density control to no less than 90% of maximum determined according to Materials Laboratory Test Method No. Iowa 103.
   - **d.** Compact each succeeding layer to no less than 95% of maximum density.

4. Prior to compaction, bring the moisture content of each layer of earth to be compacted with controlled moisture

and density to within the specified limits of the optimum moisture content. After field tests determine that a layer is within the specified moisture limits, begin compaction and continue until the required density is obtained. If compaction is interrupted or delayed on a layer, bring the moisture of the layer to within the specified limits before resuming compaction.

I. Compaction with Moisture Control.

1. The contract documents will show:
   a. Areas in which embankments are to be constructed with moisture control.
   b. The distance below the elevation of the completed grading work to which such methods are to be applied.
   c. The moisture limits.

2. Where construction with moisture control is indicated in cut sections:
   a. Excavate the roadbed below proposed subgrade elevation to a plane 6 inches (150 mm) above the elevation shown for the bottom of the moisture control section.
   b. Thoroughly scarify the remaining 6 inch (150 mm) layer.
   c. Increase or reduce the moisture content as necessary to bring the moisture throughout this 6 inch (150 mm) layer within the moisture limits specified.
   d. Compact this 6 inch (150 mm) layer as specified in Article 2107.03, E. Type A compaction
   e. Deposit the remainder of the cut section in layers according to Article 2107.03, D. 8" loose lifts
   f. Uniformly moisten or dry as necessary to bring each layer within the specified moisture limits.
   g. Compact each succeeding layer as specified in Article 2107.03, E. Type A Compaction

3. Where construction with moisture control is indicated in embankment sections outside cuts:
   a. Deposit in layers, according to Article 2107.03, D, all material in fill above the designated elevation for compaction with moisture control. 8" loose lifts
   b. Uniformly moisten or dry as necessary to bring each layer within the specified moisture limits.
   c. Compact layers placed with moisture control as specified in Article 2107.03, E. Type A Compaction

4. Prior to compaction, bring the moisture content of each layer of earth to be compacted with controlled moisture within the specified limits of the optimum moisture content. After field tests determine that a layer is within the specified moisture limits, begin compaction and continue unit the requirements of Article 2107.03, E, are obtained. If compaction is interrupted or delayed for more than 1 hour on a layer, bring the layer within the specified moisture limits before resuming compaction.
   Type A compaction

J. Rock Fills.

1. When the excavated material consists of rock fragments too large to be placed in layers of the thickness prescribed without further breaking them down, it may be placed in the embankment in horizontal layers 4 feet (1.2 m) or less in thickness. Place each layer to avoid future water entrapment. In most cases, this will require placement to full embankment width, except for topsoil on the foreslope. Level each layer with a suitable dozer. Smooth each layer by choking the surface of the rock with spalls and finer fragments or earth.

2. Do not construct the 4 foot (1.2 m) lifts above an elevation 2 feet (0.6 m) below the finished grade line. The next foot (0.3 m) of embankment height may be placed in one layer using rock spalls and finer fragments which may be satisfactorily consolidated by the dozer and tractor. For the last foot (0.3 m) below the finished grade line, use either:
   - Earth smoothed and placed in layers not exceeding 8 inches (200 mm) thickness and rolled as described above, or
   - Special backfill material placed as shown in the contract documents.

3. Conduct operations in such a way that the Engineer is given the opportunity to take cross sectional measurements required before the earth cover is placed.

K. Granular Blankets.

1. Where a granular blanket is specified, spread material meeting the requirements of Section 4133 to the width and thickness shown in the contract documents. Do not use compaction equipment. The blanket may be constructed in several lifts. Do not incorporate foreign material from hauling equipment or other sources.

2. In areas requiring both granular blanket and subdrain backfill material, the sequence of operations will be the option of the Contractor. Ensure that contact areas between porous backfill material, granular material for subdrains, and granular blankets are free from clay or silt.

L. Rebuilding Embankments.

1. Do not place a pavement partly on an old and partly on a newly constructed embankment. Remove the part of

the old embankment that would be under the pavement as below grade excavation to the natural ground line, or to a depth of 5 feet (1.5 m) below the proposed grade line, whichever is higher. Rebuild as prescribed for new embankments.

Preparation of the site

2. Rebuild embankments according to Article 2107.03, C, unless otherwise specified in the contract documents. Compact the material according to Article 2107.03, E. Type A Compaction

3. At locations where the width of embankment widening is less than 4 feet (1.2 m), widening material may be placed and shaped to the bottom of pavement or base elevation without compaction other than that obtained with wheels of motor graders and hauling equipment. Placement and compaction may be accomplished in 8 inch (200 mm) lifts parallel to the finished slope, provided the existing slope has been roughened by disking or scarification.

4. In all cases of embankment widening, remove surface vegetation from slopes against which the widening material is to be placed. Deposit this material according to Article 2107.03, D. 8" loose lifts

M. Compacting Trench Bottom. Note: this is not referring to a sewer trench.

When designated in the contract documents, excavate the roadbed for the width shown to 1 foot (0.3 m) below subgrade elevation. Scarify the next 6 inch (150 mm) depth and compact as for Type B compaction, unless otherwise specified. When the bottom of the trench has been compacted, place suitable backfill material in the excavation and compact. If the type of compaction is not specified for this upper 1 foot (0.3 m), Type A compaction will be required on Primary projects and Type B compaction on Secondary projects.

N. Use of Unsuitable Soils.

1. Unsuitable soils may be used in embankments according to Standard Road Plan EW-102. This Std. Rd. plan Shows placement of unsuitable material.

2. Unless otherwise specified, when used in embankments, spread unsuitable material in uniform layers no more than 8 inches (200 mm) in loose thickness. Cover each layer with a layer or layers of suitable material.

O. Embankments Adjacent to Culverts and Structures.

1. When the contract documents require embankment construction adjacent to a bridge, culvert, or other structure, construct the compacted embankment to the height shown and to the full width of the roadway. Secure material for constructing these embankments from within the right-of-way or authorized borrow area as directed by the Engineer. Waste the material from within the waterway of bridges or culverts which is too wet to be suitable for compaction. Do not place this material in the embankment.

2. Place embankments adjacent to bridges, culverts, and structures with the same precautions and methods described in Article 2402.03, H. The contract documents may require moisture control.

→ placing backfill material for structures

3. Use mechanical or pneumatic tampers for compaction in areas occupied by embankments which are too narrow for the operation of rollers. The Contractor may elect to enlarge the area in which the embankment is to be constructed by cutting down the elevation of the old fill to permit rolling equipment to operate efficiently. When old fill is removed for this purpose, step it up to its original height such that each step has a horizontal dimension no less than 3 feet (1 m) with a vertical rise.

4. Flowable mortar may be placed as backfill material adjacent to bridges, culverts, and structures, at no additional cost to the Contracting Authority. Place this backfill material according to Section 2506. Developmental specs deleted &

P. Quality Control Program (Embankment Construction). → Added in 4/15/14 GS-12004.

On projects where the Department is the Contracting Authority:

1. Provide and maintain a Quality Control Program (Embankment Construction). This is defined as process control sampling, testing, and inspection as described in Materials I.M. 540 for construction of embankments with moisture control, or moisture and density control.

2. Provide a Quality Control Technician who is responsible for all process control sampling, testing, and inspection. The Quality Control Technician shall obtain Soils Technician certification through the Iowa DOT Technical Training and Certification Program (TTCP).

3. Provide a laboratory facility and necessary calibrated equipment to perform required tests.

4. Notify the Engineer when a moisture content falls outside specified control limits or density falls below required minimum. If a moisture content falls outside control limits, fill material in this area will be considered unacceptable for compaction. Perform corrective action(s) to bring uncompacted fill material within control limits. If material has been compacted, disk it, bring to within control limits, and re-compact. When project has a density

requirement, if an in-place density does not meet the requirements, compacted fill material in this area will be considered unacceptable. Perform corrective action(s) to material to meet density requirements. Compensation will not be allowed for delays resulting from moistening, disking, or re-compacting.

2107.04 METHOD OF MEASUREMENT.

A. Measurement will be as provided in Article 2102.04. The following will be included in Class 10 excavation:

1. Excavation in preparation for constructing embankment by compaction with moisture control.
2. Excavation in preparation for constructing embankment by compaction with moisture and density control.
3. Excavation in preparation for compacting trench bottom.
4. Excavation in preparation for rebuilding embankment.

B. Embankment construction will not be measured separately for payment except as follows:

1. **Compaction with Moisture and Density Control.**
Cubic yards (cubic meters) shown on the contract documents as determined by the template fill volume. Shrinkage will not be included in moisture and density control quantity.

2. **Compaction with Moisture Control.**
   a. Cubic yards (cubic meters) shown on the contract documents as determined by the template fill volume. Shrinkage will not be included in moisture control quantity.
   b. When moisture control is required adjacent to culverts and stockpasses (Article 2107.03, O) the volume will be computed using the formula in Article 2107.04, B, 4. When moisture control is required adjacent to pipe culverts, the volume will be computed as provided in Article 2402.04.

3. **Compacting Trench Bottom.**
Stations (meters) shown on the contract documents as determined along the center line of the roadbed.

4. **Compacting Backfill Adjacent to Bridges, Culverts, or Structures.**
The quantity of backfill material placed and compacted by the grading contractor adjacent to bridges, box culverts, or structures or their extensions will be the quantity obtained by the following formula:

English

$$Q = \frac{(4\text{ ft.} \times L \times H)}{27}$$

Metric

$$Q = (1.2\text{ m} \times L \times H)$$

Where:

Q = quantity of compacted backfill material in cubic yards (cubic meters);

L = (1) length in feet (meters) of the culvert or stock pass from back to back of parapet, or
(2) length in feet (meters) from back of existing parapet to back of parapet of the extension;

H = nominal height of structure opening, feet (meters).

5. **Granular Material for Blanket and Subdrain.**
Cubic yards (cubic meters) according to Article 2312.04, A.

6. **Water for Embankment Construction.**
Except when compaction with control of moisture and density or moisture is specified, water for embankment construction required for moistening materials to be placed in embankment will be measured in thousands of gallons (kiloliters) by gauging the contents of the transporting vehicle or by metering the supply. Authorized water for finishing the roadbed will not be measured for payment if a period in excess of 2 calendar days has elapsed between final compaction of a dump area and final finishing of the same area.

2107.05 BASIS OF PAYMENT.

A. Payment for embankment construction will be contract unit price as for Embankment-In-Place according to Article 2102.05, with the following additions:

1. **Compaction with Moisture and Density Control.**
   a. Per cubic yard (cubic meter).

b. Payment is full compensation for the work of drying material, furnishing and applying water, controlling moisture content of the materials, and compacting the materials to the specified density.
c. On projects where the Department is the Contracting Authority, payment includes process control sampling, testing, and inspection.

2. **Compaction with Moisture Control.**
a. Per cubic yard (cubic meter).
b. Payment is full compensation for the work of drying material, furnishing and applying water, controlling moisture content of the materials, and compacting the materials, as specified.
c. On projects where the Department is the Contracting Authority, payment includes process control sampling, testing, and inspection.

3. **Compacting Trench Bottom.**
a. Per station (meter).
b. Payment is full compensation for the work of scarifying, drying material, furnishing and applying water, controlling moisture content of the materials, and compacting the materials, as specified.

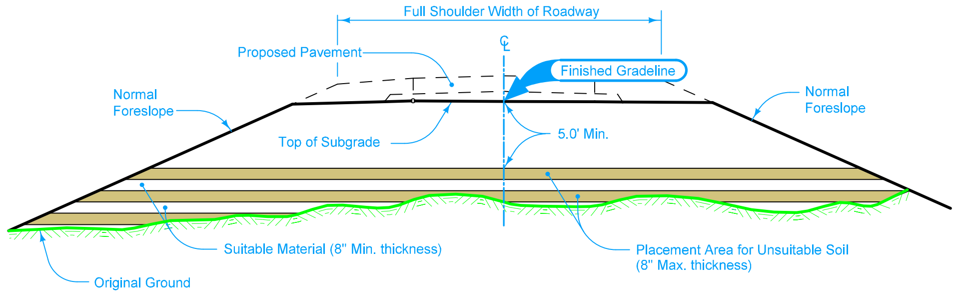
4. **Compacting Backfill Adjacent to Bridges, Culverts, or Structures.**
Per cubic yard (cubic meter).

5. **Granular Material for Blanket and Subdrain.**
Per cubic yard (cubic meter).

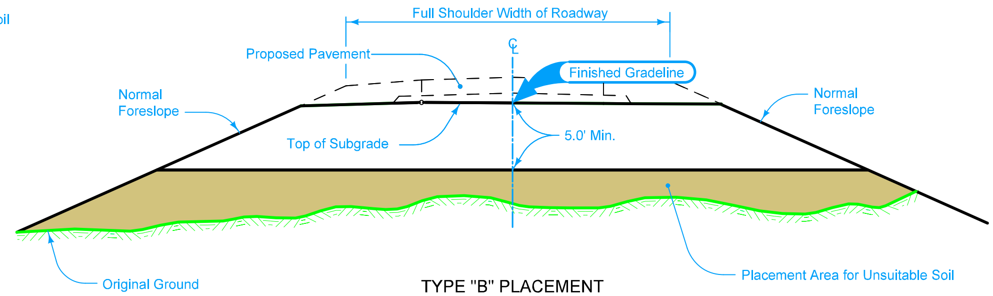
6. **Water for Embankment Construction.**
a. Except when compaction with moisture and density control or moisture control is specified, payment for water for embankment construction added at the Engineer's direction will be the contract unit price per 1000 gallons (kiloliter).
b. In case the contract does not contain a unit price for water, and moistening of the material is authorized or ordered, payment for water will be as extra work at the rate of $12.00 per 1000 gallons ($3.20 per kiloliter).
c. When Type A compaction or compacting embankments with moisture and density control or moisture control is specified, manipulation necessary to incorporate water or work necessary to dry the material will be considered as incidental work and will not be paid for separately.
d. When Type B compaction is specified, manipulation necessary to incorporate water will be considered incidental to other work. Work performed at the Engineer's direction to dry or compact the material, in excess of that obtained by the maximum number of diskings and roller coverages specified for Type B compaction, will be paid for as extra work according to Article 1109.03, B.

B. Payment for Compaction with Moisture and Density Control, Compaction with Moisture Control, Compacting Trench Bottom, and Compacting Backfill Adjacent to Culverts and Stockpasses will be for plan quantities in conjunction with quantities shown in the contract documents described in Article 2102.04 and under the conditions described therein.

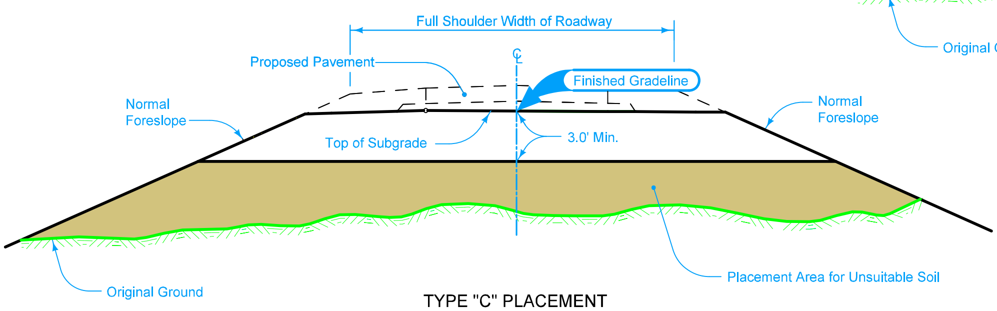
STANDARD
ROAD PLANS



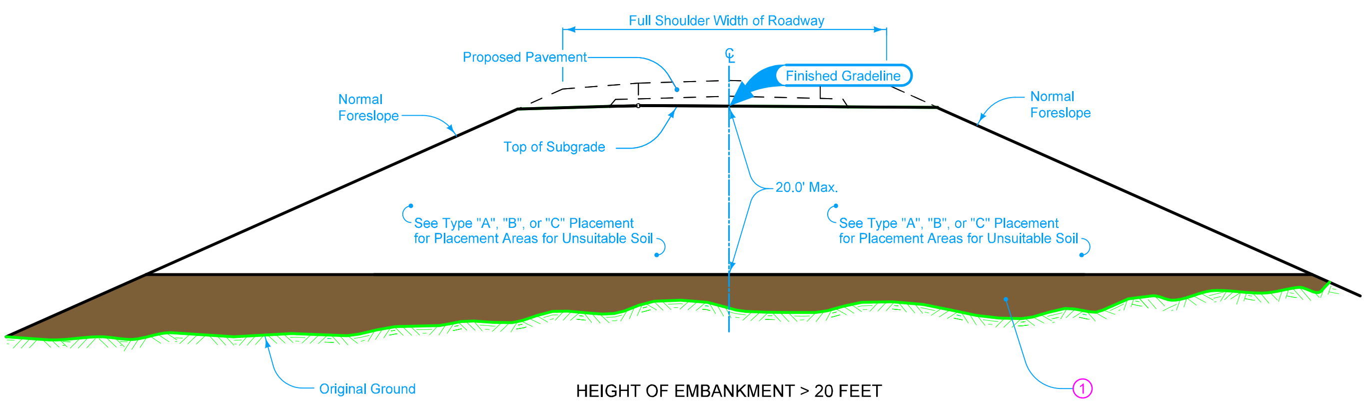
TYPE "A" PLACEMENT



TYPE "B" PLACEMENT



TYPE "C" PLACEMENT



HEIGHT OF EMBANKMENT > 20 FEET

Place unsuitable soil as detailed for the particular type of soil described in Section 2102 of the Standard Specifications. Project plan details or specific directions of the Engineer may require placement of topsoil or other unsuitable soil by methods other than those shown. Refer also to plan cross sections and soil survey sheets for additional information.

1 In new embankments greater than 20 feet in height, only Select, Suitable Class 10, or Type 'C' Unsuitable material will be allowed below that 20 foot depth.

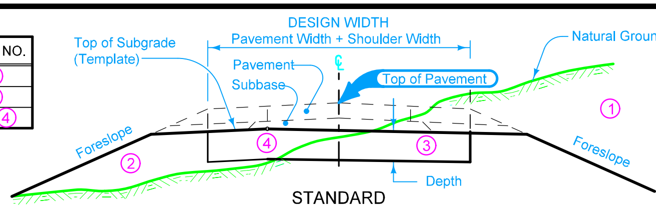
IOWA DOT STANDARD ROAD PLAN	REVISION	
	1	10-21-14
	EW-102	
	SHEET 1 of 1	

REVISIONS: Added HEIGHT OF EMBANKMENT > 20 FEET drawing and circle note 1.

Brian Smith
APPROVED BY DESIGN METHODS ENGINEER

ALLOWABLE PLACEMENT OF UNSUITABLE SOIL IN EMBANKMENTS

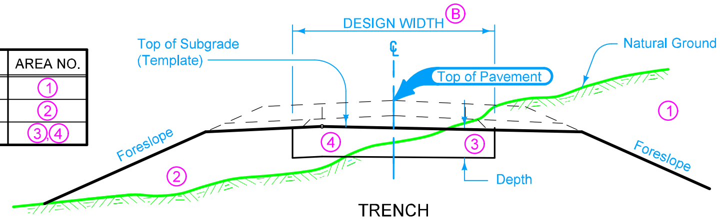
TYPE OF WORK	AREA NO.
Excavation	1
Embankment	2
Subgrade Treatment	3 4



AREA NO.	TYPE OF ADJUSTMENTS TO TEMPLATE QUANTITY
1	None
2	None
3	+ Cut
4	- Fill

STANDARD
SUBGRADE TREATMENT

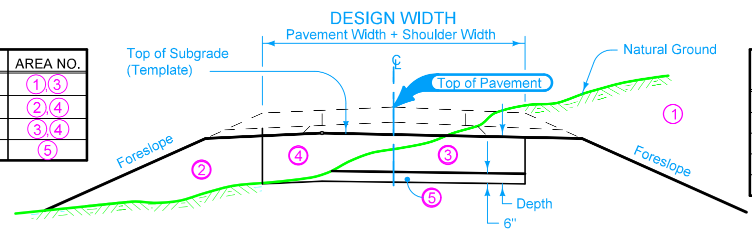
TYPE OF WORK	AREA NO.
Excavation	1
Embankment	2
Subgrade Treatment	3 4



AREA NO.	TYPE OF ADJUSTMENTS TO TEMPLATE QUANTITY
1	None
2	None
3	+ Cut
4	- Fill

TRENCH
SUBGRADE TREATMENT

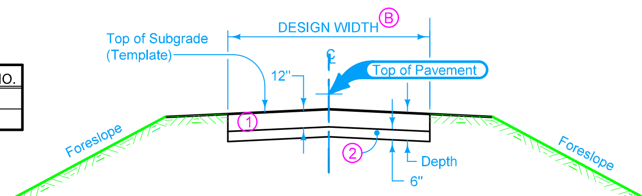
TYPE OF WORK	AREA NO.
Excavation	1 3
Embankment	2 4
M & D Embankment	3 4
Scarify with M & D Embank.	5



AREA NO.	TYPE OF ADJUSTMENTS TO TEMPLATE QUANTITY
1	None
2	None
3	+ Cut + Fill
4	None
5	None

MOISTURE CONTROL OR
MOISTURE AND DENSITY CONTROL

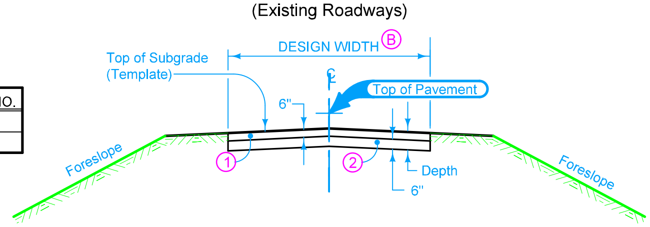
TYPE OF WORK	AREA NO.
Excavation	1
Scarify	2



AREA NO.	TYPE OF ADJUSTMENTS TO TEMPLATE QUANTITY
1	+ Cut + Fill
2	None

TRENCH BOTTOM COMPACTION
(Existing Roadways)

TYPE OF WORK	AREA NO.
Excavation	1
Scarify	2



AREA NO.	TYPE OF ADJUSTMENTS TO TEMPLATE QUANTITY
1	None
2	None

SPECIAL COMPACTION
(Existing Roadway)

The pay quantity for Subgrade Treatment will be in either tons or cubic yards. The volume will be based on specified depth, the treatment type, and includes the quantity for shrinkage.

The pay quantity for "Compaction with Moisture and Density Control" or "Compaction with Moisture Control" will be the absolute volume for the specified depth and subgrade width.

B Design width equals pavement width plus 3.0 feet on each side.

Possible Contract Items:

- Compaction with Moisture and Density Control
- Compaction with Moisture Control
- Compacting Trench Bottom
- Special Compaction of Subgrade

Possible Tabulations:

- 103-1
- 103-3
- 103-6

Iowa Department of Transportation

STANDARD ROAD PLAN

REVISION	
New	10-15-13

EW-103

SHEET 1 of 1

REVISIONS: New. Replaces RL-2A.

Brian Smith
APPROVED BY DESIGN METHODS ENGINEER

EMBANKMENT SUBGRADE TREATMENT, MOISTURE DENSITY CONTROL AND SPECIAL COMPACTION

IM 309
PROCTOR DENSITY

April 16, 2013 Matls. IM 309
Supersedes April 17, 2012

DETERMINING STANDARD PROCTOR MOISTURE DENSITY RELATIONSHIP OF SOILS

SCOPE

This test is used to determine the relationship between the moisture content and density of soils or base materials compacted according to a modification of standard procedure, AASHTO T-99, Method C. This test method is the field procedure for Laboratory Test Method 103. The sampling procedure to obtain soils used for this test is given in IM 312.

PROCEDURE

A. Apparatus

1. Cylindrical metal mold 4-in. in diameter and 4.584 in. high having a capacity of 1/30 cubic foot with base plate and collar.
2. Scale, capable of weighing at least 5000 grams and sensitive to 0.5 grams
3. Manual compaction device complying with AASHTO T99. Compaction should be performed on a rigid, uniform, and stable concrete foundation or base.
4. A rigid steel straight edge, 9-in. long, with one beveled cutting edge
5. Drying equipment, such as an oven capable of maintaining a temperature of 230°F ± 9°F, a microwave, or a hot plate.
6. Mixing equipment. A stainless steel mixing (dish) pan, long handled spoon, rubber or rawhide mallet, putty knife, graduate, and tared weighing scoop
7. Sample extruder, lever or hydraulic type
8. Tared moisture pans

B. Calibration

Check the rammer diameter (2.00 ± 0.01 in.) and the free-dropping-height of the rammer (12.00 ± 0.06 in.) by measurement with a 0.01-in. steel rule. Visually check the condition of the rammer.

1. Check the internal diameter of the mold (4.00 ± 0.02 in.) and the height of the mold (4.58 ± 0.01 in.) with the 0.01-in. steel rule.

C. Sample Preparation

1. Quarter the field sample to a representative sample of about 5000 grams. Spread out and allow to dry to a moisture content at least 5% below the estimated optimum moisture content.

2. Screen the sample over a 3/4-inch sieve and replace the aggregate retained with an equal weight of No. 4 to 3/4 in. aggregate from the same source, or break up the material larger than ¾" to pass the ¾" sieve and return it to the sample.

D. Test Procedure

1. Pulverize the prepared sample so that at least 90% of all non-aggregate material will pass the No. 4 sieve. Place the sample in the mixing pan and sprinkle sufficient water to dampen it to approximately 4% below optimum moisture content. The sample is ready for test when, after thorough mixing, a handful of soil squeezed tightly in the palm will barely hold together when pinched between the fingers.

2. Form a specimen by compacting the prepared soil in the mold in three approximately equal layers. Weigh in a tared scoop, and place loose soil in the assembled mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a loose state. Place the mold under the hammer for compaction. Deliver twenty-five uniformly distributed blows. Measure to determine if there is a deviation from the needed 1/3 height in the mold. Adjust the weight of soil taken for the second layer as needed to give the desired height, and compact the same as with the first layer. Following compaction of each of the first two layers, any soil adjacent to the mold walls that has not been compacted or extends above the compacted surface shall be trimmed. Repeat this process for a third layer. During this entire operation, do not allow sample to accumulate on the bottom of the hammer. After compaction of the final layer, the sample should extend 0.1 to 0.4 in. above the height of the mold.

3. Move the mold and contents to a table, remove the collar with a twisting motion and cut off the excess sample in thin layers with the straightedge. If the soil projects more than 0.4 in. above the mold or if the mold is not completely filled, the compactive effort is incorrect and the compacted specimen must be extruded, pulverized, and returned to the mixing pan. After remixing, adjust the weight for each layer as needed and recompact by the same procedure. Replace any small aggregate, which are pulled from the surface with finer hand tamped material. Leave in place large, well-embedded aggregate, and finish the top to arrive at a surface that will average level full.

4. Detach the mold from the base plate and determine the mass of the mold and compacted soil. Extrude the specimen from the mold. Slice vertically through the center of the specimen. Place into a weighted pan at least a 500 gram moisture sample from one of the cut faces. Follow IM 335 to determine moisture content. Pulverize the remaining portion of the specimen and return to the mixing pan.

5. Sprinkle the sample with water, not to exceed 2% of the remaining sample weight, and thoroughly mix until moisture uniformity is reached. The compaction and moisture determination for this moisture content is the same as for the first. Repeat this procedure of adding water, compacting a specimen and taking a moisture sample while increasing the moisture content until a compacted weight is reached that is no more than 20 grams higher than the preceding one. This signifies that the resultant moisture density curve is past the optimum percent moisture. Since the proctor curve is based on dry density, each 2% moisture increase is the equivalent of approximately 30 grams for a proctor specimen. Thus if the last specimen is only 20 grams heavier than the previous (2% drier) point, this will show a reduced dry density.

E. Calculations

$$\%\,\text{Moisture} = \frac{(\text{Wet soil} + \text{pan}) - (\text{Dry soil} + \text{pan})}{(\text{Dry soil} + \text{pan}) - (\text{pan})}(100)$$

Example:

$$\%\,\text{Moisture} = \frac{500 - 460}{460 - 170}(100) = 13.8\%$$

Compacted Dry Density for kg/m^3

$$\frac{\text{Net Wet Mass compacted soil x } 0.06614}{(\%\,\text{Moisture} + 100)}(100)$$

Example:

Compacted Dry Density for lb./ft.^{3}

$$\frac{(1983)(0.06614)}{(13.8 + 100)}(100) = 115.2\ \text{lb./ft.}^3$$

F. Moisture-Density Relationship

1. Make the preceding calculations for each compacted specimen at each corresponding moisture content.

2. Using these results, plot points with densities (dry weight per cubic foot) as ordinates (vertical) and percent of moisture as abscissas (horizontal).

3. Use the resulting points to draw a smooth curve. The peak of the curve will give the maximum, or Proctor density and the corresponding optimum moisture content.

G. One-Point Procedure

1. Grade material other than crushed stone, gravel, black soils, or soils containing a considerable amount of aggregate may be tested for maximum density and optimum moisture according to this procedure. Those excluded above shall be run as in "D", "E", and "F" above.

2. Moisten a representative sample of approximately 3000 grams to an estimated moisture content of two to three percentage points below Proctor optimum moisture.

3. Following the procedure outlined in D2 through D4, compact and obtain net wet weight of a single specimen at the moisture content in G2. Determine the moisture content and wet density (in pounds per cubic foot) for this single compacted specimen.

4. In the family of curves, plot the point of intersection of the above wet weight and moisture. If the plotted point falls outside the "Range of Confidence," recompact another specimen at an adjusted moisture content that will place the plot within these bounds.

5. Using the number of the nearest curve, obtain the dry Proctor density and optimum moisture values from the attached table.

H. Calculations for One-Point Test

Calculate the moisture content and wet weight of sample per cubic foot as follows:

$$w = \frac{A - B}{B - C} \times 100 \qquad W_2 = W_1 (0.06614^3)$$

<u>Where:</u>

w = Percentage of moisture in the specimen, based on oven dry weight of soil.

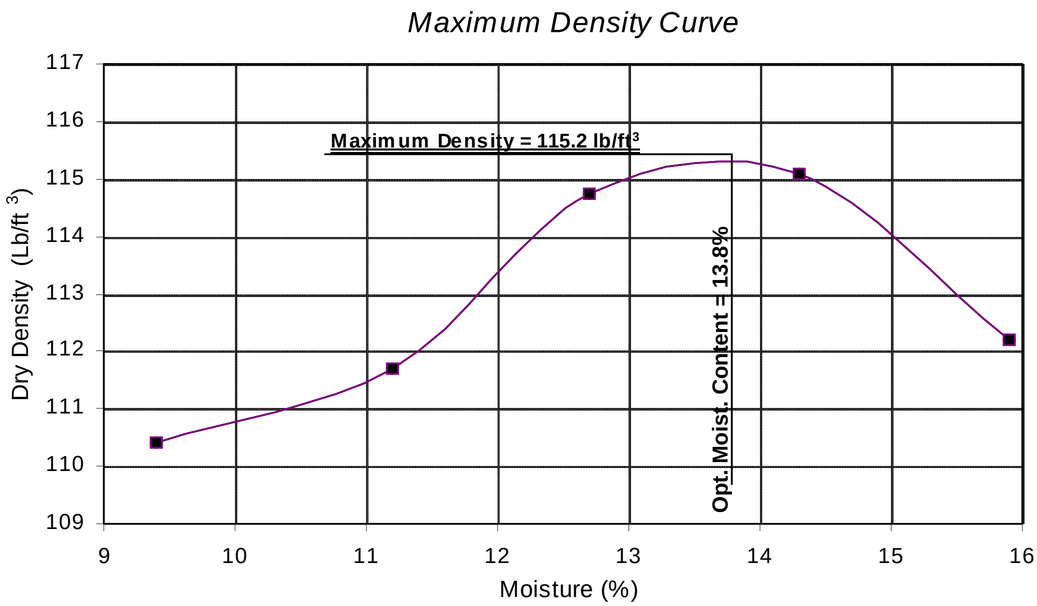
A = Weight of moisture pan plus wet soil.

B = Weight of moisture pan plus dry soil.

C = Weight of moisture pan.

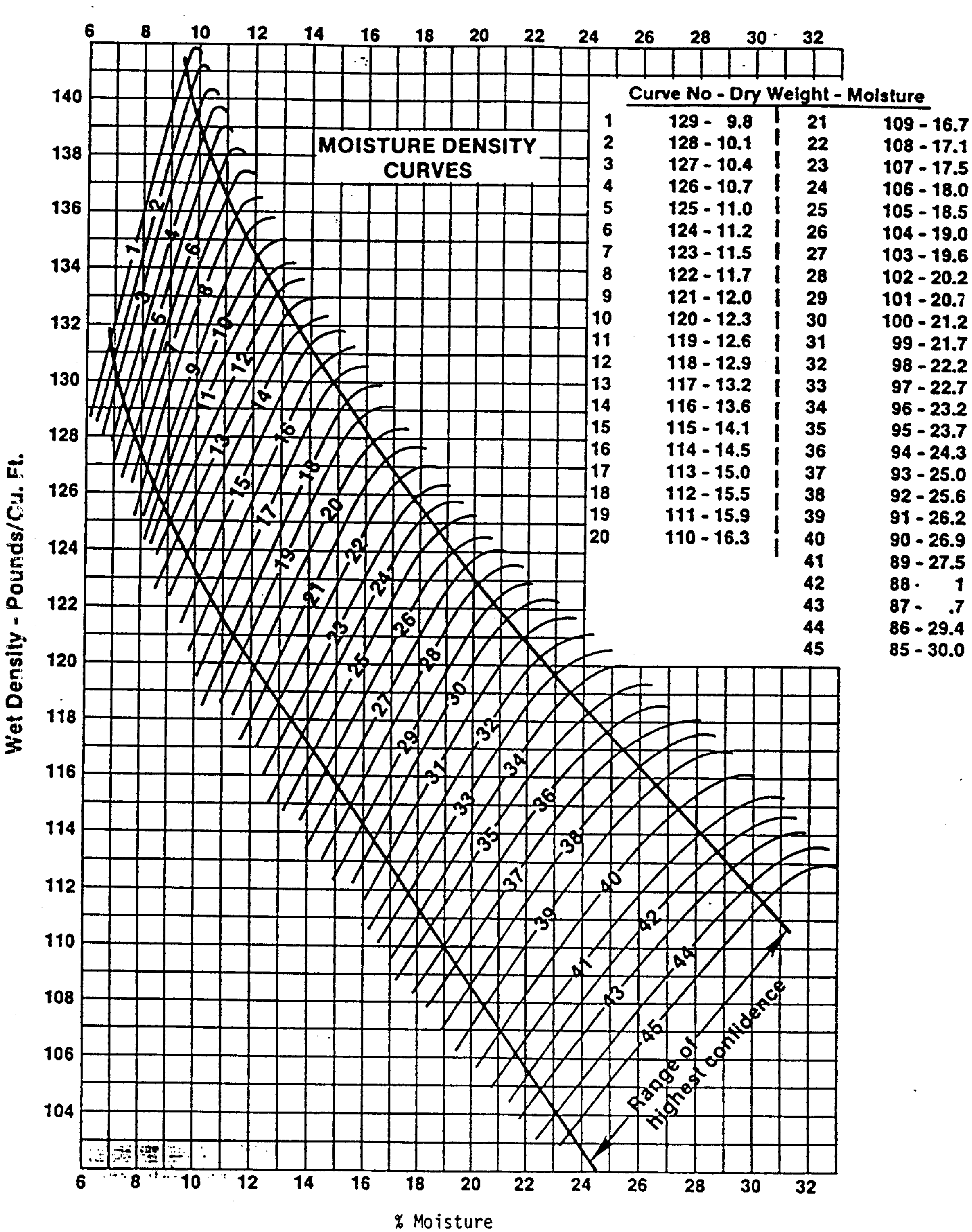
W_1 = Wet weight, in grams, of compacted specimen.

W_2 = Wet weight, in pounds per cubic foot of compacted specimen.


Maximum Density Curve
Maximum Density = 115.2 lb/ft³
Opt. Moist. Content = 13.8%
Dry Density (Lb/ft ³)
Moisture (%)
117
116
115
114
113
112
111
110
109
9
10
11
12
13
14
15
16

PROCTOR DENSITY CURVES

Curve No.	Dry Wt.	% Moisture
1	129	9.8
2	128	10.1
3	127	10.4
4	126	10.7
5	125	11.0
6	124	11.2
7	123	11.5
8	122	11.7
9	121	12.0
10	120	12.3
11	119	12.6
12	118	12.9
13	117	13.2
14	116	13.6
15	115	14.1
16	114	14.5
17	113	15.0
18	112	15.5
19	111	15.9
20	110	16.3
21	109	16.7
22	108	17.1
23	107	17.5
24	106	18.0
25	105	18.5
26	104	19.0
27	103	19.6
28	102	20.2
29	101	20.7
30	100	21.2
31	99	21.7
32	98	22.2
33	97	22.7
34	96	23.2
35	95	23.7
36	94	24.3
37	93	25.0
38	92	25.6
39	91	26.2
40	90	26.9
41	89	27.5
42	88	28.1
43	87	28.7
44	86	29.4
45	85	30.0


MOISTURE DENSITY CURVES
Curve No - Dry Weight - Moisture
1 129 - 9.8
2 128 - 10.1
3 127 - 10.4
4 126 - 10.7
5 125 - 11.0
6 124 - 11.2
7 123 - 11.5
8 122 - 11.7
9 121 - 12.0
10 120 - 12.3
11 119 - 12.6
12 118 - 12.9
13 117 - 13.2
14 116 - 13.6
15 115 - 14.1
16 114 - 14.5
17 113 - 15.0
18 112 - 15.5
19 111 - 15.9
20 110 - 16.3
21 109 - 16.7
22 108 - 17.1
23 107 - 17.5
24 106 - 18.0
25 105 - 18.5
26 104 - 19.0
27 103 - 19.6
28 102 - 20.2
29 101 - 20.7
30 100 - 21.2
31 99 - 21.7
32 98 - 22.2
33 97 - 22.7
34 96 - 23.2
35 95 - 23.7
36 94 - 24.3
37 93 - 25.0
38 92 - 25.6
39 91 - 26.2
40 90 - 26.9
41 89 - 27.5
42 88 - 1
43 87 - .7
44 86 - 29.4
45 85 - 30.0
Range of highest confidence
Wet Density - Pounds/Cu. Ft.
% Moisture

IM 312
SAMPLING

****THIS IS A NEW IM. – PLEASE READ CAREFULLY.****

SAMPLING OF SOILS FOR CONSTRUCTION PROJECT

GENERAL

This method describes the procedure for sampling soils on construction sites. The obtained sample will be used for the proctor test (IM 309), for the measurement of moisture content (IM 335), or nuclear gauge moisture correction (IM 334).

The intent of sampling is to obtain a suitable amount of soils from the earth with as little disturbance as possible to the natural density, moisture content, and structural arrangement of the particles. A representative sample of soil shall be a combination of the various particles in the same proportion as they exist in the natural ground, roadway or pit. Representative samples should also contain only materials of like color and texture, and should not be a composite of materials apparently different in character.

Soil samples can be collected by using a spade, shovel, or auger, depending on the terrain, the soil type, and the depth of material below the surface.

SAMPLING PROCEDURE FOR THE PROCTOR TEST

The sample consists of a composite of four approximately equal volume samples from select locations within the area under investigation. The recommended minimum sample size is 25 pounds which is sufficient for a four-point test in field.

- Select four representative locations within the sampling area.
- Identify the layer of soils needed to be sampled.
- Remove soils above the sampling layer.
- Take approximately a quarter of the sample from each the selected locations by using a proper tool.
- Place the four obtained samples into a bag or other acceptable container. These samples will be combined into a composite sample.
- Label the sample with a proper ID.

SAMPLING PROCEDURE FOR THE MOISURE TEST

The recommended minimum sample size is 3.0 pounds.

- Select a random location in the sampling area. Sample will be comprised of soil from three locations at this station, the center and the ¼ points from each side of the center.
- Identify the layer of soils needed to be sampled.
- Remove soils above the sampling layer.
- Take approximately one-third of the sample from each the selected locations by using a spade or shovel.
- Composite the soils taken from these three locations.

- Before performing the test, reduce the sample size to 1.1 lbs by quartering or other acceptable method.
- Place the obtained sample in a proper bag or container to prevent moisture loss if the test is not immediately performed.
- Label the sample with a proper ID.

Because moisture content may vary significantly over a project site, several samples and tests may be needed in order to obtain more realistic result of moisture content.

DETERMINING MOISTURE CONTENT OF SOILS

SCOPE

This method describes several field procedures for determining moisture content of soil. The sampling procedure to obtain soils used for this test is given in IM 312.

PROCEDURE A – DETERMINATION OF MOISTURE CONTENT OF SOIL BY DIRECT HEAT

A. Apparatus

1. Balance having a capacity of at least 5,000 grams accurate to at least 0.5 grams.

2. Direct heat source – hot plate, electric or gas stove or burner, or other heat source. Direct application of heat by open flame to specimen is not appropriate.

3. Containers – suitable container made of material resistant to corrosion and not subject to change in mass or disintegration upon repeated heating, cooling, or cleaning.

4. Miscellaneous (as needed) – Mixing tools such as spatula, spoons, etc. for cutting and stirring the specimen.

B. Preparation of Test Sample

1. Obtain a test sample of at least 500 grams.

2. To avoid moisture loss due to evaporation, the weighing should be done immediately after obtaining the test sample. Also avoid any excessive manipulation of the soil, prior to weighing, which could cause a loss of moisture.

C. Test Procedure

1. Weigh a clean, dry container, and record mass.

2. Place the moisture content sample in the container, and immediately determine and record the mass of soil and container.

3. Apply heat to the soil specimen and container, taking care to avoid localized overheating. Continue heating while stirring and breaking up the specimen to obtain even heat distribution. Continue application of heat until the specimen first appears dry. (Note: A piece of dry, light-weight paper or tissue placed on the surface of the apparently dry soil will curl or ripple if the soil still contains significant water or a mirror will fog up when placed over the sample.)

4. After initial heating period has been completed and soil appears dry, remove the container and soil from the heat source. Determine and record the mass of the soil and container.

5. Return the container and soil to the heat source for an additional application of heat.

6. With a small spatula or knife, continue to carefully stir and mix the soil, taking care not to lose any soil.

7. Repeat above steps 3 to 6 until the change between the two consecutive mass determinations would have an insignificant effect on the calculated water content. A change of 0.1% or less of the initial wet mass of the soil should be acceptable for most specimens.

8. Use the final dry mass determination in calculating water content.

D. Calculation

1. Calculate the moisture content, to the nearest 0.1 percent as follows:

$$\%\,\text{Moisture} = \frac{(\text{Wet soil} + \text{pan}) - (\text{Dry soil} + \text{pan})}{(\text{Dry soil} + \text{pan}) - (\text{pan})}\,(100)$$

<u>PROCEDURE B – DETERMINATION OF MOISTURE CONTENT BY MICROWAVE</u>

A. Apparatus

1. Balance having a capacity of at least 5,000 grams accurate to at least 0.5 grams.

2. Microwave oven.

3. Containers – suitable container made of nonmetallic, nonabsorbent material resistant to thermal shock, and not subject to changes in mass or disintegration upon repeated heating, cooling, or cleaning. Porcelain evaporating dishes and standard borosilicate glass dishes perform satisfactorily.

4. Heat Sink – a material or liquid placed in the microwave to absorb energy and avoid overheating the specimen after the moisture has been driven from test specimen (e.g. glass beaker filled with water).

5. Miscellaneous (as needed) – Mixing tools such as spatula, spoons, etc. for cutting and stirring the test specimen. Glass rods have been found useful for stirring and may be left in specimen container during the testing, reducing the possibility of specimen loss due to adhesion to stirring tool.

B. Preparation of Test Sample

1. Obtain a test sample of at least 500 grams mass.

2. To avoid moisture loss due to evaporation, the weighing should be done immediately after

obtaining the test sample. Also avoid any excessive manipulation of the soil, prior to weighing, which could cause a loss of moisture.

C. Test Procedure

1. Weigh a clean, dry container, and record mass.

2. Place the moisture content sample in the container, and immediately determine and record the mass of soil and container.

3. Place the soil and container in a microwave oven with the heat sink and turn the oven on for 3 minutes. If experience with a particular soil type, specimen size, or microwave oven indicates shorter or longer initial drying times can be used without overheating, the initial and subsequent drying times may be adjusted.

4. After the set time has elapsed, remove the container and soil from the microwave oven. Determine and record the mass of the soil and container.

5. With a small spatula or knife or glass rod, carefully stir and mix the soil, taking care not to lose any soil.

6. Return the container and soil to the microwave oven and reheat for 1 minute.

7. Repeat above steps 4 to 6 until the change between the two consecutive mass determinations would have an insignificant effect on the calculated water content. A change of 0.1% or less of the initial wet mass of the soil should be acceptable for most specimens.

8. Use the final dry mass determination in calculating water content

D. Calculation

1. Calculate the moisture content, to the nearest 0.1 percent as follows:

$$\%\,\text{Moisture} = \frac{(\text{Wet soil} + \text{pan}) - (\text{Dry soil} + \text{pan})}{(\text{Dry soil} + \text{pan}) - (\text{pan})}(100)$$

PROCEDURE C – DETERMINATION OF MOISTURE CONTENT BY DRYING OVEN

A. Apparatus

1. Balance having a capacity of at least 5,000 grams accurate to at least 0.5 grams
2. Drying oven – thermostatically controlled, capable of being heated continuously at a temperature of 230°F ± 9°F (110 °C ± 5°C).
3. Containers – suitable container made of material resistant to corrosion, and not subject to change in mass or disintegration upon repeated heating, cooling, or cleaning.

B. Preparation of Test Sample

1. Obtain a test sample of at least 500 grams.
2. To avoid moisture loss due to evaporation the weighing should be done immediately after obtaining the test sample. Also avoid any excessive manipulation of the soil, prior to weighing, which could cause a loss of moisture.

C. Test Procedure

1. Weigh a clean, dry container, and record mass.
2. Place the moisture content sample in the container, and immediately determine and record the mass of soil and container.
3. Place the soil and container in a drying oven overnight (at least 16 hours).
4. Remove the container and soil from the oven. Determine and record the mass of the soil and container.
5. Use the final dry mass determination in calculating water content.

D. Calculation

1. Calculate the moisture content, to the nearest 0.1 percent as follows:

$$\%\,\text{Moisture} = \frac{(\text{Wet soil} + \text{pan}) - (\text{Dry soil} + \text{pan})}{(\text{Dry soil} + \text{pan}) - (\text{pan})}(100)$$

****THIS IS A NEW IM. – PLEASE READ CAREFULLY.****

QUALITY MANAGEMENT & ACCEPTANCE - EMBANKMENT CONSTRUCTION

GENERAL

This IM describes the Quality Control Program (Embankment Construction) and quality assurance procedures for soils used in embankment construction that require moisture control or moisture and density control.

SAMPLING

The Contractor shall sample the soil per Materials IM 312.

TESTING

The Contractor shall use test procedures per Materials IM 204, Appendix A.

A. Proctor

The Contractor shall determine optimum moisture content and maximum density by Proctor testing for each type of excavated or mixed soil which varies as to change the expected AASHTO classification, or if directed by the Engineer.

With Engineer's approval, and for soils that can be identified during excavation, the Contractor may use the optimum moisture content and maximum density as shown on the soils 'Q' sheets in the contract documents. In lieu of using values from the 'Q' sheets, the Contractor may choose to determine optimum moisture and maximum density from a field sample.

If the Engineer deems the optimum moisture and maximum density of material being excavated and/or mixed is not represented by that shown on the 'Q' sheets, the Contractor shall determine optimum moisture and maximum density from a field sample.

When determined from a field sample at the option of the Contractor or at the Engineer's request, the optimum moisture and maximum density values from the field sample prevail over that shown on the 'Q' sheets.

B. Moisture Content and Density

The Contractor shall test and verify that moisture content of material placed is within optimum moisture content range and if required, greater than or equal to required minimum density. Upper and lower control limits for field moisture content of embankment material will be shown in the contract documents.

C. Frequency.

The Contractor shall test for proctor optimum moisture content and embankment moisture content and density at minimum frequencies in Materials IM 204, Appendix A. Samples will be randomly selected.

If source of excavation and moisture have been consistent and within moisture control limits and density has been greater than or equal to minimum density (if required), testing of each lift will be waived for areas less than 1300 cubic yards (1000 m^3), or for embankment placed as median dikes or safety dikes. Where testing per lift is waived, the contractor shall test randomly selected samples at a minimum frequency of one test per compacted volume of 1300 cubic yards (1000 m^3).

DOCUMENTATION

The Contractor shall document changes in soil type, fill placement procedures/locations, and test results on a weekly basis. Submit copies of field moisture and density tests and corresponding proctor tests to the Engineer weekly. Submit original testing records (raw field and lab data sheets) to the Engineer in a neat and orderly manner within five calendar days after completion of the project.

QUALITY ASSURANCE.

A. Required Testing.

The Contractor shall retain split samples of Materials IM 309 testing when requested by the Engineer. The Engineer may select any or all Contractor-retained split samples for independent assurance testing.

The Engineer will determine the random location of moisture and (if required) density verification tests and will test at the minimum frequencies in Materials IM 204, Appendix A. The Contractor shall obtain a sample at the same location as directed by the Engineer and provide results to the Engineer. Verification test results will be provided to the Contractor within one working day after the Contractor's quality control test results have been reported.

The Engineer will periodically witness field testing being performed by the Contractor. If the Engineer observes quality control field tests are not being performed according to the applicable test procedures, the Engineer may stop production until corrective action is taken. The Engineer will notify the Contractor of observed deficiencies, promptly, both verbally and in writing. The Engineer will document witnessed testing.

B. Verification and Independent Assurance Testing.

The Contractor’s quality control test results will be validated by the Engineer’s verification test results using the criteria in Materials IM 216. If Engineer’s verification test results validate the Contractor’s test results, the Contractor’s results will be used for material acceptance.

In the event that the Contractor's results cannot be validated, Engineer will investigate the reason immediately. Engineer's investigation may include:

- Testing of other locations,
- Observations of Contractor's testing procedures and equipment, and
- Comparison of test results of Contractor with those of the Engineer.

Personnel and laboratories performing tests used in acceptance of material shall participate in the independent assurance program covered in Materials IM 205.

C. Referee Testing.

If a difference in procedures for sampling and testing and/or test results exists between the Contractor and the Engineer which they cannot resolve, the Iowa DOT's Central Materials Laboratory will provide referee testing. The Engineer and Contractor will abide by results of referee testing.

ACCEPTANCE

The Engineer will base final acceptance of tests and materials on results of the Contractor's quality control testing as verified by Engineer's quality assurance.

OTHER IM’S

Other IM’s

I. IM 204 Appendix A – Roadway & Borrow Excavation & Embankments

II. IM 208 – Materials Laboratory Qualification Program (pages with soils items)

III. IM 213 Appendix D – Soils Technician Duties

IV. IM 216 – Guidelines for Determining the Acceptability of Test Results

V. IM 326 – Determining the Density of Undisturbed Soil Cores by Displacement

VI. IM 334 – Determining Moisture Content & Density of Soils, Bases & Subbases with a Nuclear Gauge

IM 204
Appendix A

Sampling & Testing Guide-Minimum Frequency

ROADWAY & BORROW EXCAVATION & EMBANKMENTS

Section 2102 & 2107

MATERIAL OR CONSTRUCTION ITEM	TESTS	METHOD OF ACCEPTANCE & RELATED IMs	QUALITY CONTROL					INDEPENDENT ASSURANCE & VERIFICATION S&T						REMARKS
			SAMPLE BY	FREQ.	SAMPLE SIZE	TEST BY	REPORT	S&T TYPE	SAMPLE BY	FREQ.	SAMPLE SIZE	TEST BY	REPORT	
SOURCE INSPECTION														
Special Backfill, Crushed Stone (4132.02), Gravel (4132.03)		AS 209												
Crushed Concrete (4132.02), RAP (2303.02)		209,210												
Granular Backfill (4133, 4134)	Quality	AS 209												
Engr. Fabric (4196)	Quality	AS 496.01												
Contractor Furnished Borrow		545	CONTR	IM 545	IM 545	CONTR	IM 545 & Cert	V	RCE/ CONTR	1/10 QC tests	35 lb.	CTRL	Test Report	Note 4
GRADE INSPECTION														
Moisture Control, (QC by Contractor) Note 1	Proctor	309	CONTR	1/ soil class	25 lb	CONTR	Field Book & Test Report	V (7) IA (4)	CONTR/ RCE CONTR/ DME	1/ 10 req'd QC tests (min. 1)(5) 1/proj.	25 lb. 25 lb.	RCE/ DME CTRL	Field Book Test Report	
	Moisture	335, 334	CONTR	1/lift/1500 ft (for max of 1300 cy) (6)	3 lb	CONTR	Field Book & Test Report	V (7) IA (4)	RCE (2) DME	1/ 10 req'd QC tests (min. 1)(5) Witness 1/proj.	3 lb.	RCE	Field Book	
Moisture & Density Control, including Special Compaction of Subgrade (2109.03C), (QC by Contractor) Note 1	Proctor	309	CONTR	1/ soil class	25 lb	CONTR	Field Book & Test Report	V (7) IA (4)	CONTR/ RCE CONTR/ DME	1/ 10 req'd QC tests (min. 1)(5) 1/proj.	25 lb. 25 lb.	RCE/ DME CTRL	Field Book Test Report	
	Moisture	335, 334	CONTR	1/lift/1500 ft.(for max of 1300 cy) (6)	3 lb	CONTR	Field Book & Test Report	V (7) IA (4)	RCE (2) DME	1/ 10 req'd QC tests (min. 1)(5) Witness 1/proj.	3 lb.	RCE	Field Book	
	In-place Density	326 & 334, ASTM D2937, D2167, D1556, & AASHTO T191 & T233	CONTR	1/lift/1500 ft (for max of 1300 cy) (6)	As req'd by test	CONTR	Field Book & Test Report	V (7) IA (4)	RCE/ DME DME	1/10 req'd QC tests (min. 1)(5) Witness 1/proj.		RCE/ DME	Field Book	Note 3

AS-Approved Source
ASD-Approved Shop Drawing
S&T-Sampling & Testing

Cert- Certification Statement

RCE-Resident Construction Engineer/Project Engineer
DME-District Materials Engineer
CTRL-Central Materials Office
CONTR-Contractor

IA-Independent Assurance
V-Verification

Note 1: When Contractor QC testing is not required in the contact documents. The RCE will perform verification testing at the frequency listed for QC.
Note 2: RCE will direct the Contractor to take a moisture sample beside the RCE verification sample location.
Note 3: If testing is done with a portable moisture-density gauge, the gauge calibration will be verified on the ValiDator block.
Note 4: For earthwork quantities of less than 50,000 Yd^3, no IA will be required.
Note 5: If no QC tests are required, then no verification or independent assurance tests are required.
Note 6: If source of excavation and moisture have been consistent and within moisture control limits and density has been greater than or equal to minimum density (if required), testing of each lift will be waived. Minimum frequency will be 1 per 1300 Yd^3.
Note 7: For earthwork quantities of less than 1300 Yd^3, no verification tests will be required.

IM 208

April 16, 2013
Supersedes October 19, 2010

Matls. IM 208

MATERIALS LABORATORY QUALIFICATION PROGRAM

GENERAL

The FHWA has outlined a Laboratory Qualification Program in the Federal-Aid Policy Guide update published as 23 CFR 637 on June 29, 1995. The updated guide has requirements for laboratories performing testing on Federal-Aid highway projects.

In order to avoid an appearance of a conflict of interest, any qualified non-DOT laboratory shall perform only one of the following types of testing on the same project: Verification testing, quality control testing, IA testing, or dispute resolution testing.

LABORATORIES TO BE QUALIFIED

The following laboratories are included in the qualification program for all Federal-Aid projects:

Central Materials Laboratory
6 District Laboratories
District Area Laboratories
Resident Construction Laboratories*
Aggregate Producer Laboratories
Soils Field Laboratories*
* May be qualified at the time of a project.

Ready Mix Laboratories
PCC Contractor Laboratories
HMA Contractor Laboratories
Consultant and Commercial Laboratories *
City and County Laboratories *

LABORATORY QUALIFICATION PROCESS

A two-level qualification system is required by the FHWA. Laboratories are either accredited or qualified. The accreditation process is more rigorous than the qualification process.

Accredited Laboratory Process

The Central Materials Laboratory and the six District Laboratories will be accredited as outlined in the 23 CFR 637 guide. The Central Materials Laboratory is accredited through the AASHTO Materials Reference Laboratory Program. The District Materials Laboratories will be accredited by using the Central Materials Staff and equipment to check testing and testing procedures and by using the same calibration and training documentation process. Laboratories will be accredited for a two-year period. In addition, an annual review will be made by the Central Office Staff. Appendix A contains the procedures for accrediting the District Materials Laboratories.

Qualified Laboratory Process

The remaining laboratories will be qualified as outlined below:

The District Materials Offices will qualify laboratories. Laboratories will be qualified for a two-year period. In addition, an annual review will be made by District Staff. Appendix B contains the procedures for qualifying materials laboratories.

Four laboratory types will be qualified, aggregate laboratories, PC Concrete laboratories, soils field laboratories, and Hot Mix Asphalt laboratories.

Qualified laboratories will have the following:

1. Current manuals and test methods to perform the qualified testing available

2. A technician certified by the Iowa DOT to perform the qualified testing

3. Proper equipment to perform the qualified testing (calibrated or checked annually according to Appendix B)

4. Satisfactory project and proficiency test results

5. Documentation of equipment calibrations, equipment checks, and proficiency results

The District may elect to accept qualifications, accreditations, or inspections from other government agencies or Laboratory inspection agencies. The AASHTO Materials Reference Laboratory (AMRL) and Cement and Concrete Reference Laboratory are 2 common Laboratory inspection programs. The links are:

http://www.amrl.net/amrlsitefinity/default/aap/r18labs.aspx

http://www.ccrl.us/Lip/LabListReport.pdf

ADMINISTRATION OF THE PROCESS

The Central Materials Laboratory will be responsible for implementation and operation of the Laboratory Qualification Program. The Central Materials Laboratory will accredit the District Laboratories. The District Materials Offices will qualify laboratories.

NON-COMPLIANCE/DISPUTE RESOLUTION

A laboratory that does not meet the requirements of the IM is subject to elimination from the qualification program.

Disputes concerning calibration and correlation of equipment will be resolved by the office responsible for the qualification. For disputes that cannot be resolved at the District, the Central Materials Laboratory will be the final authority.

LABORATORY QUALIFICATION PROGRAM

The District Materials Office will qualify the other laboratories and maintain records of the qualification for three years. The District Staff will check the following prior to qualifying a laboratory:

1. Establish the type of laboratory (Aggregate, Hot Mix Asphalt, Soils Field, PC Concrete).
2. Check for current manuals and test procedures covering the qualified testing.
3. Check the certification of the testing personnel.
4. Document that proper equipment is available to perform qualified testing.
5. Check documentation system.

Scheduling of the qualification review will be discussed with the laboratories seeking qualification. The District staff performing the qualification review should have the appropriate certification (IM 213) for the type of laboratory and tests being reviewed. The District Materials Engineer should be contacted for laboratories that have been qualified in other states. The District Materials Office may qualify a laboratory based on an acceptable qualification report and qualification program from another state transportation agency.

Table 1 and the pages following cover the list of items to be reviewed.

An oral close out on any deficiencies will be held with the testing personnel. Written notice will be sent within two weeks of the inspection. District personnel will re-inspect after correction of any deficiencies.

A form showing the laboratory type, the date qualified, and the expiration date will be issued by the District Materials Engineer.

The list of Qualified Laboratories will be maintained on a database accessible by authorized Materials Personnel.

NON-COMPLIANCE/DISPUTE RESOLUTION

A laboratory that does not meet the requirements of the IM is subject to elimination from the qualification program.

The office responsible for the qualification will resolve disputes concerning calibration and correlation of equipment. For disputes that cannot be resolved at the District level, the Central Materials Laboratory will be the final authority.

Table 1 - Laboratory Qualification Checklist

	√	Calib./Verif. Interval	Calib./Verif. Procedure
Tester Qualifications-Proper Iowa DOT certifications			
Current Test Procedures			
Current Calibration Procedures & Records			

Documentation of correlation results and corrective actions taken for previous construction season.			
Soils Field Laboratory			
Balances		12 months	Iowa 917
Sieves- wear, tear, size		12 months	
Mold, Base, and rammer condition		(a)	IM 309
Aggregate Laboratory			
Balances		12 months	Iowa 917
Sieves- wear, tear, size, and opening size		12 months	Iowa 1506
Splitter- condition		12 months	(Visual)
Mechanical Shakers- condition (if used)		12 months	Iowa 1502
HMA Laboratory			
Balances- and water bath		12 months	Iowa 917
Sieves- wear, tear, size, and opening size		12 months	Iowa 1506
Splitter- condition		12 months	(Visual)
Mechanical Shakers- condition (if used)		12 months	Iowa 1502
Rice equipment- vacuum and flask		12 months	IM 350
Thermometers		12 months	Iowa 1607
Ovens- temperatures		12 months	Iowa 1501
Gyratory Compactor and molds		12 months	Iowa 1522
PCC Laboratory			
Balances		12 months	Iowa 917
Sieves- wear, tear, size, and opening size		12 months	Iowa 1506
Splitter- condition		12 months	(Visual)
Mechanical Shakers- condition (if used)		12 months	Iowa 1502
Air Meter		12 months	IM 318
Slump Cone and equipment-condition		12 months	
Flexural Strength Apparatus		12 months	Central Lab
(a) The mold, base or rammer should be checked if the condition warrants.			

LABORATORY ITEMS

PCC Portable Paving Plant

The following list contains, as a minimum, what is required for a qualified PCC paving plant laboratory. The test equipment to perform each of the required tests is contained in the respective IM.

- Field Lab of suitable size for workspace, space to perform tests, and sample storage. Locate the Field Lab so it is convenient to the plant, but outside the influence of plant vibration.

  Air-conditioned
  Personal computer

Iowa Department of Transportation

SOILS FIELD LABORATORY INSPECTION
QUALITY CONTROL CHECKLIST

Contractor/Producer: ____________________ Location: ____________________

Certified Technician: ____________________ Certification No: ____________

		Yes	No
Balances	(Iowa Test Method 917)		
	Updated balance calibration records available?	____	____
	Check balance using 500 gm & 1000 gm calibrated weights?	____	____
	Is balance accurate to 0.1%?	____	____
Sieves			
	Are the sieves in good condition (no loose frames, holes, or tears)?	____	____
Mold, Base, and Rammer (IM 309)			
	Are they in good condition. Mold round and the base flat? If not, check the dimensions for out-of-tolerance.	____	____
Rigid Foundation			
	Do they have a concrete pad or floor or other rigid foundation to compact the specimen on?	____	____

Comments ____

cc:Materials Engineer
Contractor/Producer
Ames
File

Inspected By: ____________________

Date Inspected: ____________________

IM 213
Appendix D

SOILS TECHNICIAN DUTIES

A certified Soils Technician is required for all projects with Compaction with Moisture Control, Compaction with Moisture and Density Control, or Special Compaction of Subgrade (including for Recreation Trails). Refer to contract documents for Contractor QC testing requirements. Duties of the Soils Technician consist of, but are not limited to the following:

A. Sampling: Obtain samples at required frequencies per IM 204.

B. Proctor Testing

C. Other Testing as Required

   1. For projects with Compaction with Moisture Control: Determine moisture content per frequencies in IM 204.

   2. For projects with Compaction with Moisture and Density Control or Special Compaction of Subgrade: Determine moisture content and in-place density per frequencies in IM 204.

D. Sampling & Testing Equipment

   1. Clean and check testing sieves for defects.

   2. Assure scale accuracy.

   3. Check and maintain other testing equipment.

E. Evaluate the test data.

   1. For projects with Compaction with Moisture Control: Confirm soils are being placed within required moisture content range.

   2. For projects with Compaction with Moisture and Density Control or Special Compaction of Subgrade: Confirm soils are being placed within required moisture content range and soil is compacted to density equal to or greater than density requirement.

F. Documentation and Communication

   1. Document test data. A copy is sent to the Project Engineer.

   2. Relay test results to appropriate supervisory personnel.

   3. Notify the Project Engineer if any test results do not meet contract requirements and assure corrective actions are taken.

IM 216

April 15, 2014 Matls. IM 216
Supersedes April 16, 2013

GUIDELINES FOR DETERMINING THE ACCEPTABILITY OF TEST RESULTS

GENERAL

Criteria for determining the acceptability of test results is an integral part of the Quality Assurance Program. The comparison between two different operator's results is used in the independent assurance program and sometimes in the validation process. The tolerances in this IM are for comparing individual test results except in the case of the profile index where averages are used. When criteria for comparing tests results is not established in this IM or any other IM, use of the AASHTO or ASTM test procedure precision criteria is appropriate for determining acceptability of test results.

When the tolerances are exceeded, an immediate investigation must be made to determine possible cause so that any necessary corrections can be made. Below are some steps that may be used to identify the possible cause:

1. Check all numbers and calculations.
2. Review past proficiency and validation data.
3. Review sampling and testing procedures.
4. Check equipment operation, calibrations and tolerances.
5. Perform tests on split samples or reference samples.
6. Involve the Central Materials Laboratory.

TOLERANCES

TEST NAME	TEST METHOD	TOLERANCE
Slump of PC Concrete		
1" or less on IA or Verification	IM 317	1/4 in. (6 mm)
More than 1" on IA or Verification		3/4 in. (18 mm)
Air Content of PC Concrete	IM 318	0.4%
Length of Concrete Cores	IM 347	0.10 in. (2 mm)
Free Moisture in Aggregate, by Pycnometer	IM 308	0.2%
Specific Gravity of Aggregate, by Pycnometer	IM 307	0.02
Moisture in Aggregate, by Hot Plate		0.3%
Moisture in Soil	IM 335, IM 334	1.5%
Proctor Optimum Moisture Content	IM 309	2.0%
Proctor Maximum Dry Density	IM 309	5.0 lb./ft^3 (80 kg/m^3)
In-Place Wet Density, Soils & Bases	IM 334, 326,	2.0 lb./ft^3 (32 kg/m^3)

	other approved	
G_{mm} Maximum Specific Gravity	IM 350	0.010
G_{mb} Density of HMA Concrete, by Displacement	IM 321	0.020
G*/Sin Delta	T315	10% of mean
% Binder, Ignition Oven	IM 338	0.3%
G_{sa} Apparent Specific Gravity	IM 380	0.010
G_{sb} Bulk Specific Gravity	IM 380	0.028
Percent Absorption	IM 380	0.37%
Fine Aggregate Angularity	T304	2.0%
Sand Equivalency	T176	10 % of mean
Pavement Profile Index (0.2” blanking band)	IM 341	
Verification Profile Index Test Result		
Inches/mile (mm/km)		
6.0 (95) or less		1.0 in./mi. (16 mm/km)
6.1 to 20.0 (96 to 315)		2.0 in./mi. (32 mm/km)
20.1 to 40.0 (316 to 630)		3.0 in./mi. (47 mm/km)
More than 40.0 (630)		5.0 in./mi. (79 mm/km)
Pavement Profile Index (0.0” blanking band)	IM 341	
Verification Profile Index Test Result		
Inches/mile (mm/km)		
25.0 (395) or less		3.0 in./mi. (47 mm/km)
25.1 to 40.0 (396 to 630)		4.0 in./mi. (63 mm/km)
More than 40.0 (630)		5.0 in./mi. (79 mm/km)
Bridge Profile Index (0.2” blanking band)	IM 341	
Verification Profile Index Test Result		
Inches/mile (mm/km)		
6.0 (95) or less		2.0 in./mi. (32 mm/km)
6.1 to 20.0 (96 to 315)		3.0 in./mi. (47 mm/km)
20.1 to 40.0 (316 to 630)		4.0 in./mi. (63 mm/km)
More than 40.0 (630)		6.0 in./mi. (95 mm/km)
Pavement International Roughness Index (IRI)	IM 341	
Verification IRI Test Result		
Inches/mile		
50.0 or less		10.0% of mean
50.1 to 150.0		8.0% of mean

IM 326

DETERMINING THE DENSITY OF UNDISTURBED SOIL CORES BY DISPLACEMENT

SCOPE

This method of test is intended to determine the density of cohesive soils in the natural state or after compaction by measuring the weight, volume and moisture content of the undisturbed sample. This test method is the field procedure for Laboratory Test Method 102.

PROCEDURE

A. Apparatus

1. Core sampling device consisting of a bit, bit head, rod, driving head and driver
2. Balance accurate to 0.5 gram
3. Graduate, 500 ml
4. 1 gallon (4 liter) can
5. Supply of liquid. May be either kerosene or No. 2 diesel fuel.
6. Volume-measuring device, consisting of a 9 1/2 in. high by 5 1/2 in. (241.3 mm x 139.7 mm) diameter brass tube and a 9 1/2 in. by 2 in. (241.3 mm x 50.8 mm) diameter brass tube connected near their base by a 1 in. (25.4 mm) diameter cross tube. The 20 in. (50.8 mm) diameter tube acting as a surge tank has an anti-siphoning overflow outlet near its top.
7. Core carrier
8. Trimming knife
9. Waxed paper or cellophane
10. Extruding pedestal
11. Suitable containers for transporting the sample
12. Stove or other suitable device for drying sample

B. Sample Procedure

1. Hold the sampling device in a vertical position and drive to the bottom of the lift of material to be tested. Do not overdrive as this will compact and disturb the sample. During this driving procedure exercise care to keep the four cap screws and the screwed joints on each end of the rod tight to prevent damage to the threads.

2. Rotate the driving head in a circular motion to break the core loose. It can then be lifted out easily.

3. After disconnecting the bit from the bit head, remove the core by pushing it on through the top of the bit head using the extruding pedestal.

4. Wrap the sample in cellophane or waxed paper to maintain its moisture content until tested.

5. Place the wrapped specimen with proper identification in a suitable container for transporting.

C. Test Procedure

1. Trim the moisture test sample from the sides of the core leaving a representative sample for the full depth of the lift of material to be tested. The moisture test sample obtained in this manner should be of a size equal to between 3 and 4 grams per lineal millimeter of core.

2. Immediately weigh the moisture test sample, dry to a constant mass (weight), and reweigh the dried sample to determine the moisture content of the specimen.

3. Weigh the remainder of the core.

4. Place the core carrier in the volume-measuring device and fill with liquid until the overflow is running freely. After the overflow cuts off, place the 500-ml. graduate (or larger container if needed) under the outlet.

5. Remove the core carrier, place the core in it and carefully lower into a 1 gallon (4 liter) can containing sufficient liquid to cover the specimen. Soak the core in liquid until the air bubbles cease, indicating the filling of air voids. Remove the sample and allow the excess liquid to drain from the sides of the specimen.

6. Carefully lower the core carrier and sample into the volume-measuring device. Do not allow any liquid to run over the top of the device during this procedure.

7. Allow the displaced liquid to run into the 500-ml. graduate (or a larger container, if needed, and then measure in the graduate) until it stops. The volume of this displaced liquid is the volume of the sample.

8. Make certain that no portion of the samples extends above the level of the liquid at the time the liquid stops flowing.

D. Calculations

1. $\%M = \dfrac{(W - D)(100)}{D}$

   Where:

   W = Wet mass (weight) of moisture test sample
   D = Dry mass (weight) of moisture test sample
   M = Moisture content, in percent

2. $D_w = \dfrac{A}{V}$

   Where:

   A = Wet mass (weight) of density sample
   V = Volume of displaced liquid.
   D_w = Wet density of soil (kg/m^3)

3. $D_D = \dfrac{D_w(100)}{1 + \dfrac{M}{100}}$

   Where:

   D_D = Dry density of soil in kilograms per cubic meter (pounds per cubic foot).

   Example:

   Wet mass (weight) of moisture sample (W) = 500 g.
   Dry mass (weight) of moisture sample (D) = 447 g.
   Wet mass (weight) of density sample (A) = 1400 g.
   Volume of liquid displaced (V) = 695 ml.

   $$M = \frac{500 - 447}{447} \text{ x } 100 = 11.9\%$$

   $$D_w = \frac{1400}{695} = 2.01 \text{g/ml}$$

   $$D_D = \frac{2.01(100)}{1 + \frac{11.9}{100}} 1796.2 \text{ kg/m}^3$$

Figure 1. Volume-measuring Device

IM 334

DETERMINING MOISTURE CONTENT & DENSITY OF SOILS, BASES & SUBBASES WITH A NUCLEAR GAUGE

SCOPE

This test method describes the procedure used in determining the in-place density and moisture content of soils, cold-in-place recycled asphalt pavement, soil aggregate sub-base, soil lime sub-base, and cement treated granular base or sub-base by the use of nuclear method.

OPERATOR QUALIFICATION

In addition to complying with IM 206, an operator, to determine the moisture content and density of soils, bases, and sub-bases with a nuclear gauge, must first demonstrate knowledge and proficiency in various related areas that may affect the test result. The specific areas will be determined by and demonstrated to the satisfaction of the District Materials Engineer or an authorized representative.

PROCEDURE

A. Apparatus

1. A recognized nuclear moisture-density gauge containing a radioisotope, detectors and related circuitry. The gauge shall be capable of determining densities by either the backscatter or direct transmission methods.
2. A reference standard for the purpose of taking standard counts, and for checking equipment operation.
3. A drill rod and combination guide-scraper plate for preparing the testing site.
4. Manufacturer Instructional Manual.

B. Standard Counts

1. Place the reference standard in a position recommended by the manufacturer to obtain standard counts.
2. Allow the gauge to warm up as suggested by the manufacturer.
3. Take one automatic four-minute standard count per manufacturer instructions. This count should be within 1% of the latest standard count established for the gauge. In the event the standard count varies by more than 1%, make a note of that number, reject that count on the gauge and then obtain another standard count. The two standard count numbers just obtained should be within 1% of each other <u>and</u> within 2% of the latest established standard count. If so, retain and record the last standard count taken.
4. If the day-to-day shift in the standard count varies more than 2% for moisture or 1% for density, reset the gauge on the standard and repeat the procedure in B3.

5. Keep a log of the gauge standard counts.

6. Standard counts should be taken twice a day to detect any shift during daily use.

C. Site Preparation

1. Select a random location in the testing area. Test will be run at three locations at this station, the center and the ¼ points from each side of the center. Moisture and density determinations will be based on the average of the readings from the three locations. Test locations should be such that the gauge will be a least 6 in. (150 mm) away from any vertical projection. Be sure the vehicle is at least 10 ft. (3 m) away from the test site.

2. Remove all loose and disturbed material, and remove additional material as necessary to reach the top of the compacted lift to be tested.

3. Prepare a horizontal area, sufficient in size to accommodate the gauge, using the scraper plate supplied with the gauge; by planing to a smooth condition so as to obtain maximum contact between the gauge and material being tested. Make sure the gauge sits solidly on the site without rocking.

4. The maximum depressions beneath the gauge shall not exceed 1/8 in. (3 mm). Use native fines or fine sand to fill voids and level the excess with the scraper plate. The total area thus filled with native fines or sand should not exceed ten percent of the bottom area of the gauge.

D. Moisture Determination

1. Prepare test site as described in C.

2. Obtain a one-minute moisture count.

3. The moisture measurement is based upon the thermalization of fast neutrons by hydrogen atoms. Because some materials may contain hydrogen other than free water or may contain thermalizing elements other than hydrogen, not less than ten moisture samples should be oven dried to correct the calibration data. If the gauge reading is higher than the values obtained by oven dry samples, the error is due to hydrogen containing materials, and the correction may be made by subtracting a constant value from the gauge reading. If the gauge reading is lower than that obtained by oven drying, the error is likely due to materials which absorb thermalized neutrons. In this case, the error is not a constant offset, but varies directly with the moisture content. The compensation is made by adding the full error at moisture contents used to obtain the error data and reducing the added value at lower moisture contents. At zero moisture, the error would be zero.

E. Density Determination - Direct Transmission

1. Place the guide plate on the site for the moisture determination and drive the drive pin through the guide to a depth at least 2 in. (50 mm) below the depth of material to be measured. Remove the drive pin by pulling straight up in order to avoid disturbing the access hole.

2. Place the gauge over the access hole and push the index handle down until the source has reached the desired depth.

3. With the source at the desired depth, pull the gauge so that the probe is in contact with the near side of the hole, take and record a one-minute wet density count.

4. Generally no corrections for density need be made due to soil compositional error, however, if a soil has a mean atomic weight higher than limestone, the gauge may indicate a high density. If it is felt that the gauge is indicating an unrealistic high density, two undisturbed soil cores shall be obtained. These two cores should be sent to the Central Materials Laboratory and be tested for density using Iowa Test Method 102. A correction factor should be obtained based on the density measured by the Central Materials Laboratory. This factor should be applied to the field nuclear densities.

F. Calculations

1. When determining the moisture correction described in D4, use the oven dry percent of moisture and the gauge wet density to calculate the moisture content in kilograms per cubic meter (pounds per cubic foot) as follows:

$$\text{Moisture Content [kg/m}^3\text{ (lbs./cu.ft.)]} = \frac{\%\text{Moisture x Wet Density}}{\%\text{Moisture} + 100}$$

2. Calculate the dry density as follows:

$$\text{Dry Density} = \text{Wet Density - Moist. Content [kg/m}^3\text{ (lbs./cu. ft.)]}$$

3. Calculate the percent moisture as follows:

$$\%\text{ Moisture} = (\text{Moisture Content x 100})/(\text{Dry Density})$$

G. General Notes

1. Do not attempt to operate a nuclear gauge before thoroughly reading the Instruction Manual.

2. Do not attempt to operate a nuclear gauge before thoroughly reviewing the radiological safety precautions described in Office of Materials IM 206, "Nuclear Test Equipment."

DOCUMENTATION

Field Moisture Test

Line No.: ____________

Item Code: ____________

Description: ____________

Project No.: ____________

Page No.: ____________

Category No.: ____________

Contract ID: ____________

Date	Test Section Location (Sta. to Sta.)	Sample Location (Sta.)	Material Type	Wet Wt. (g)	Dry Wt. (g)	Difference (g)	Moisture (%)	Opt. MC (%)	Source of Proctor (Type & Location)[1]	Contr. or QA MC (%)	Remarks (e.g. Pass/Fail or Verified)	By

Note 1: MP = Multi point proctor, 1P = One point proctor, Q = Q sheets, SD = Soils Data Sheets

Proctor Tests (I.M. 309)

Line No.: ____________

Item Code: ____________ **Page No.:** ____________

Description: ____________ **Category No.:** ____________

Project No.: ____________ **Contract ID:** ____________

Trial No.	1	2	3	4	5	6	7
Proctor Mold + Soil Wt. (g)							
Proctor Mold Wt. (g)							
Speciman Wet Wt. (g)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sample Wet + Pan Wt. (g)							
Sample Dry + Pan Wt. (g)							
Pan Wt. (g)							
Moisture Loss (g)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Moisture Content (%)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Wet Density (lbs./cu. ft.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dry Density (lbs./cu. ft.)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

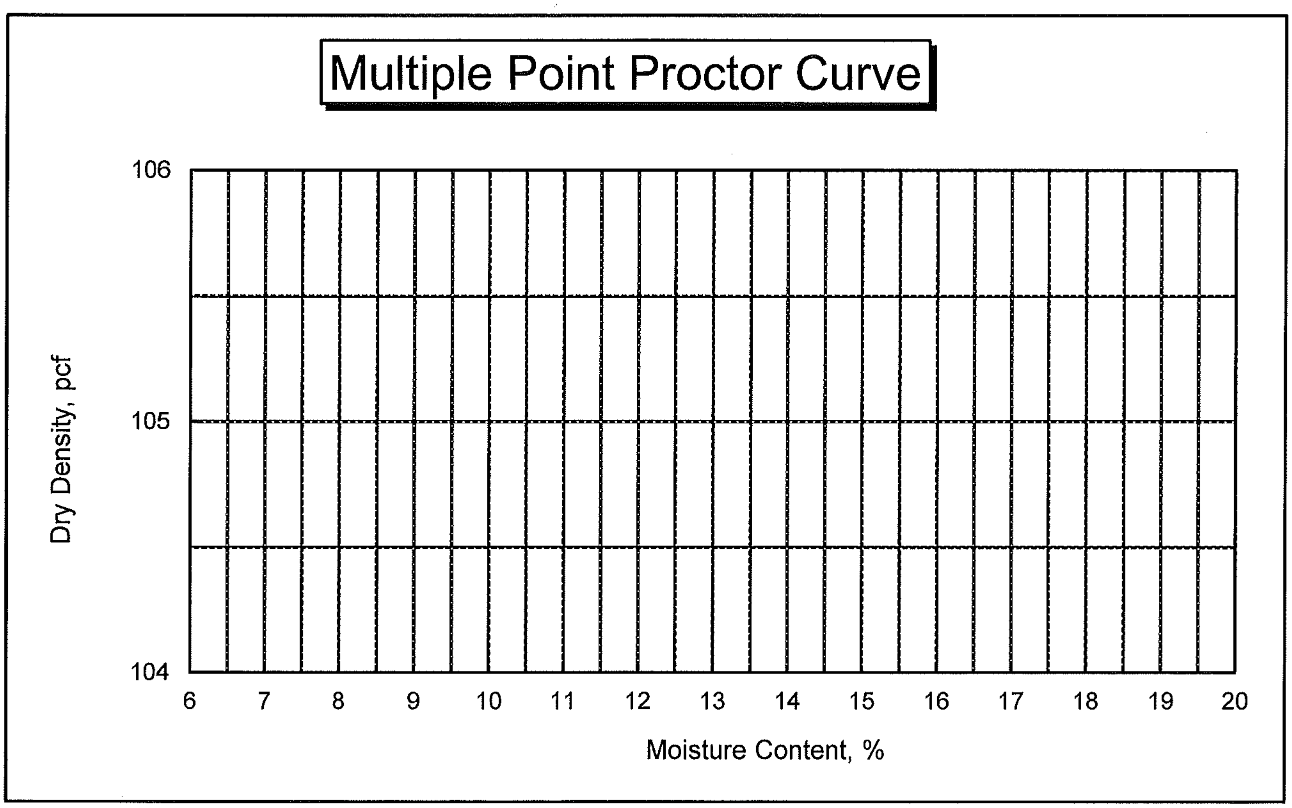
*** One Point Test:** ____________

One Point Wet Density: 0.0 **lbs./cu. ft.** **Date:** ____________

One Point Moisture: 0.0 **%** **Sample Location:** ____________

Maximum Density: ____________ **lbs./cu. ft.** **Soil Type:** ____________

Optimum Moisture: ____________ **%** **Soil Color:** ____________



Entries By: ____________

* Place an " X " in the blank if performing a one point test.

Form 821258
09-13

Iowa Department of Transportation

NUCLEAR TEST REPORT
MOISTURE & DENSITY EMBANKMENT CONSTRUCTION

County ____________________
Project No. ____________________
Contractor: ____________________ Contract No. ____________________
Resident Engineer ____________________ Report No. ____________________

TEST NUMBER	1	2	3	4	5
1. Date					
2. Station					
3. Offset					
4. Elevation					
5. Depth of Measurement (in.)					
6. Soil Type					
7. Proctor Density (pcf)					
8. Optimum Moisture Content (%)					
9. Nuclear Gauge Make & Model					
10. Nuclear Gauge No.					
11. Density Standard Count – Gauge Reading					
12. Density - Gauge Reading (pcf)					
13. Moisture Standard Count – Gauge Reading					
14. Moisture - Gauge Reading (pcf)					
15. % Moisture – Gauge Reading (%)					
16. Dry Density – Gauge Reading (pcf)					
17. % Compaction – Gauge Reading or calculated (%) (#16 / #7 x 100)					
18. Moisture Correction Factor used*					
*See gauge instruction manual and Materials IM 334					

REMARKS:

Distribution: RCE, DME

Signed: ____________________
Inspector

Proctor Density Calculation Worksheet

Mass of wet soil + Pan, A, in grams					
Mass of dry soil + Pan, B, in grams					
Mass of Pan, C, in grams					
Mass of dry soil, D = B-C, in grams					
Mass of water, E = A-B, in grams					
Moisture Content, F = 100 x E/D, in %					
Proctor Mold mass, G, in grams					
Soil and Mold mass, H, in grams					
Soil mass, I = H-G, in grams					
Wet Density, J = I x 0.06614, in pcf					
Dry Density, L = J/(1 + F/100), in pcf					

Mass of wet soil + Pan, A, in grams					
Mass of dry soil + Pan, B, in grams					
Mass of Pan, C, in grams					
Mass of dry soil, D = B-C, in grams					
Mass of water, E = A-B, in grams					
Moisture Content, F = 100 x E/D, in %					
Proctor Mold mass, G, in grams					
Soil and Mold mass, H, in grams					
Soil mass, I = H-G, in grams					
Wet Density, J = I x 0.06614, in pcf					
Dry Density, L = J/(1 + F/100), in pcf					

Mass of wet soil + Pan, A, in grams					
Mass of dry soil + Pan, B, in grams					
Mass of Pan, C, in grams					
Mass of dry soil, D = B-C, in grams					
Mass of water, E = A-B, in grams					
Moisture Content, F = 100 x E/D, in %					
Proctor Mold mass, G, in grams					
Soil and Mold mass, H, in grams					
Soil mass, I = H-G, in grams					
Wet Density, J = I x 0.06614, in pcf					
Dry Density, L = J/(1 + F/100), in pcf					

Random Sampling Worksheet (English)
Embankments

Project No.: ______________________
Contract ID No.: ______________________

Note: Enter Stations with a decimal (Example: Enter Sta. 14+10 as 14.10)

Random Number Generator : (press F9 to generate new random number) 0.055

Test No.	Date	Elevation (ft.)	Beginning Station of Test Section (Sta.)	Length of Test Section (ft.) (not to exceed 1500 ft.)	Enter Random Number	Location of Test (Sta.)
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
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						0.00
						0.00
						0.00

Iowa Department of Transportation

SOILS FIELD LABORATORY INSPECTION QUALITY CONTROL CHECKLIST

Contractor/Producer: ____________________ Location: ____________
Certified Technician: ____________________ Certification No: ________

		Yes	No
Balances	(Iowa Test Method 917)		
	Updated balance calibration records available?	____	____
	Check balance using 500 gm & 1000 gm calibrated weights?	____	____
	Is balance accurate to 0.1%?	____	____
Sieves			
	Are the sieves in good condition (no loose frames, holes, or tears)?	____	____
Mold, Base, and Rammer (IM 309)			
	Are they in good condition. Mold round and the base flat? If not, check the dimensions for out-of-tolerance.	____	____
Rigid Foundation			
	Do they have a concrete pad or floor or other rigid foundation to compact the specimen on?	____	____

Comments ____
____
____
____

cc: Materials Engineer
Contractor/Producer
Ames
File

Inspected By: ____________________

Date Inspected: ____________________

Rev 9/13

Form E107

Field Moisture Test

Line No.: Sample

Item Code: ____

Description: ____

Project No.: ____

Page No.: ____

Category No.: ____

Contract ID: ____

Date	Test Section Location Sta.)	Sample Location (Sta.)	Material Type	Wet Wt. (g)	Dry Wt. (g)	Difference (g)	Moisture (%)	Opt. MC (%)	Source of Proctor (Type & Location)[1]	Contr. or QA MC (%)	Remarks (e.g. Pass/Fail or Verified)	By
10/03/13	1+50 to 16+50	5+63	Yellow-brown sandy loam	563.4	512.8	50.6	9.9	10.5	Q- Borrow A Sta. 3641+00	--	Pass	MS
10/04/13	16+50 to 31+50	29+12	Brown sandy loam	542.9	488.1	54.8	11.2	12.3	1 pt - Sta. 22+50	12.8	Pass and verified	MS
10/04/13	31+50 to 40+50	34+90	Brown sandy loam	536.5	480.3	56.2	11.7	12.3	1 pt - Sta. 22+50	--	Pass	MS

Note 1: MP = Multi point proctor, 1P = One point proctor, Q = Q sheets, SD = Soils Data Sheets

2014

Construction and Materials Review

Roadway & Borrow Excavations and Embankments

Project No.: 0 ______________________ Contract No.: 0 ______________________

Refer to IM 204, Appendix A

Job Control Tests (Construction)

Contract Item No.			**Required**	**Documented**
	Q/C Proctor Tests	1 / soil class		
	Verification Proctor Tests	1 / 10 req'd QC tests		
	Q/C Moisture Tests	1 / lift / 1500 ft (for max 1300 cy)		
	Verification Moisture Tests	1 / 10 req'd QC tests		
	Q/C In-Place Density Tests	1 / lift / 1500 ft (for max 1300 cy)		
	Verification Density Tests	1 / 10 req'd QC tests		

Independent Assurance Tests --- Materials will furnish report(s)

Proctor Test	1 / project or systems approach		
Moisture Test Witness	1 / project or systems approach		
In-Place Density Test Witness	1 / project or systems approach		

Comments: ____

AASHTO NUCLEAR METHOD INFO

IN-PLACE DENSITY AND MOISTURE CONTENT OF SOIL AND SOIL-AGGREGATE BY NUCLEAR METHODS (SHALLOW DEPTH)

AASHTO T 310

Developed
by
Multi-Regional Soils & Certification Group
Revised 2006

TABLE OF CONTENTS

In-Place Density and Moisture Content of Soil and Soil-Aggregate In-Place by Nuclear Methods (Shallow Depth)

Density is a function of mass (weight) divided by volume. The more closely pressed together the individual particles of a quantity of material are, the more dense it is. The farther apart they are, separated by air spaces (voids), the less dense the material is. When the individual particles of the same mass (weight) of material are pressed tightly together (compacted), the mass (weight) takes up less volume than when the particles are farther apart.

In order to ensure that the embankment, base course, or other earthwork structure will be strong enough to support its intended design load, it must be compacted, made dense. Most specifications will require that the field earthwork be compacted to a specified percent of a target density called maximum density. The nuclear device is one device that is used to determine if the earthwork in the field has met this requirement (in-place density).

To determine the dry density of a soil in-place it is necessary to also determine the moisture content of the soil.

Nuclear Device

The nuclear device is a portable source containing a radioactive source, electronics and rechargeable battery packs. The device uses radiation (a gamma source and a gamma detector) to obtain several different readings. These readings are then calculated to acquire a number for in-place or dry density for soils and soil-aggregate mixtures. Density readings for depths between 50mm and 300mm (2 in. and 12 in.) (depending upon the method used) can be determined.

Summary of Testing

Since a density reading and a moisture reading are required to determine dry density, both values have to be determined. A separate radioactive source is necessary for each technique. The nuclear device may have a radioactive source at the tip of its probe or source rod and another source located in the body of the device. Some devices may have both sources located in the probe. At the back of the device, at opposite ends from the probe are detector tubes (Geiger-Muller tubes). Once the test is underway, these detector tubes pick up or count the gamma rays that travel through the material to them and relay this count to the master controls inside the body of the device . A certain percentage of gamma rays emitted by the source is absorbed by the soil, a certain percentage is scattered in the material and a certain percentage will pass through the material. The detector counts the rays that pass through the material and this count is relayed to the master control, called a scaler, by means of electrical impulses. The number of rays counted depends on the density of the material. The higher the density of the material the lower the gamma ray count.

Moisture

The nuclear gauge uses a fast neutron source and a thermal neutron detector which determines the intensity of slow or moderated neutrons. Moisture is determined by the relationship of nuclear count to mass of water per unit volume of soil. The moisture content is used in conjunction with the density measurement to determine dry density.

Density Testing

Three methods for determining density are covered by AASHTO T238: Method A, or Backscatter mode, Method B, Direct Transmission, and Method C, Air Gap. Each method uses a different test geometry (the geometric space of the test area changes) and should be used where appropriate. Generally, backscatter is used when the properties of the first few inches are concerned (such as density of hot mix asphalt), and direct transmission is used when the properties of 50mm - 30mm (2 in.-12 in.) are concerned (such as 150mm (6 in.) lifts of compacted backfill).

Air Gap

The air gap method which some older gauge models utilized has now been antiquated by technology.

Direct Transmission

To determine in-place density with a nuclear device, you will first prepare a smooth area on which to place the device. You will then place the nuclear device on the prepared surface and check to be sure that it is solidly seated with maximum contact between the device and the surface of the material being tested. Then place the device to the side and drill a small hole through the layer or lift being tested. Replace the device in the prepared area, in the same orientation as before, with the probe directly over the hole. Insert the probe into the hole and operated the device in accordance with the manufacturer’s instructions.

Backscatter

To determine in-place density in the backscatter mode, perform the test in the same manner as described under Direct Transmission, with the exception of drilling the hole and lowering the probe. Operate the device in backscatter mode in accordance with the manufacturer's instructions.

Special considerations when reporting density measurements as determined by the nuclear gauge: It should be noted that the volume of soil or soil-aggregate represented in the measurements is indeterminate and will vary with the source - detector geometry of the equipment used and with the characteristics of the material tested. In general, and with all other conditions constant, the more dense the material, the smaller the volume involved in the measurement. The density so determined is not necessarily the average density within the volume involved in the measurement. For the usual density conditions, the total count is largely determined by the upper 75 mm to 100 mm (3 to 4 inches) of soils and soil aggregates.

Common Testing Errors

Test results may be affected by:

- Soil chemical composition
- Soil not homogenous
- Equipment not calibrated properly
- Surface texture
- Testing to close to a vertical wall or other mass (e.g., cars, construction equipment, body of water, large pipe)
- Groups of observers gathered too close to device during operation
- Presence of asphaltic materials, recycled Pcc, cement, lime, flyash, etc. in soil materials

Safety

The device used for density testing is like any other tool you use on the job. It is there to make your job of taking accurate density readings easier and more efficient. It can be dangerous if used improperly. However, this device is different in that the danger it poses is invisible. Radiation poisoning is very serious. This is why taking proper safety precautions is so vital when dealing with this machine at any level. The following safety rules are simple to follow and will cause you very little inconvenience. If you follow them correctly, the nuclear device will be one of the safest tools you use.

There are two important facts to remember when working with nuclear devices. One, the device is radioactive and, two, the device is very expensive. It must always be handled carefully and treated with the utmost respect. It is important to take care of the nuclear device, but it is also important to take care of yourself while you are using it. This section will give guidelines on how to handle the devices with a minimum amount of radiation exposure.

You should not be afraid of radiation, but should have a healthy respect for it. By realizing the dangers involved, you will know the importance of following safety regulations carefully.

PRINCIPLES OF RADIATION SAFETY

There are several principles of radiation safety with which you should be familiar before you handle the nuclear device. These principles are known as the ALARA concept: keep radiation exposure As Low As Reasonably Achievable. The first principle is distance. The further someone is from the device the less the radiation exposure. The amount of radiation a person will receive when around a radioactive source is influenced by three factors: the intensity of the source, the person's distance from the source and the length of time the person is exposed to it. The intensity of radiation is inversely proportional to the square of the distance from the source. This is called the Inverse Square Law. This means, for example, that a certain radiation intensity at 3 m (10 ft) from a source will have 1/4 the intensity that it has 1.5 m (5 ft) from the source. Remember, the device is always radioactive. The on/off switch does not turn off the radiation.

The second principle is time. You must keep your exposure to a minimum. The third principle is shielding. Shielding is a very important part of radiation safety. Even though shielding is built into our equipment, any objects between you and the source help to cut down on the amount of radiation received. We will discuss each of these principles in more detail.

DISTANCE

Distance from the radiation source is the most effective way to keep exposure to a minimum because alpha and beta particles travel only short distances through matter, and gamma rays become less intense as the distance is increased. Doubling the distance from a radioactive source reduces the exposure to one-fourth the original value.

For this reason, place the device in the back of the vehicle when transporting it. Also, it is a good precaution to store the device at least 7.5 meters (25 ft) away from working areas whenever possible. The device must be properly marked with the radioactive symbol and kept locked when not in use. This means that the device itself must be locked and kept inside the storage case. The room in which the device is stored must also be kept locked. A closet, storage room or a cabinet may be used as the storage area if it meets the criteria described. Ideally, the storage area should have only one door and no windows. The door must have a lock. If storage cabinets are selected as the storage site, the cabinet must be securely and permanently attached to the structure of the facility. Store the nuclear device in its appropriate case.

Designate the area selected as the authorized storage location by installing a permanent sign in clear view, preferably on the access door. The sign is yellow in color, and bears the official symbol and the words "CAUTION - RADIOACTIVE MATERIALS." If a radioactive source is lost or stolen, immediately notify your gang supervisor. There must also be a “Notice To Employees” sign posted where the device is stored.

TIME

Time of exposure must be monitored carefully so anyone working with the device is checked for exposure to radiation. Each operator or handler of radioactive devices should wear a TLD (Thermoluminescent Dosimetry) badge or similar device, on his or her outer clothing when using or transporting these devices. The amount of radiation to which the wearer has been exposed is indicated by these badges. The badge is checked regularly for radiation exposure. It is replaced by a new badge. The badges are never reused.

Badges are not interchangeable between operators. The badge you are issued is numbered for identification; you must always wear your own badge. Be careful with your badge because it is the means by which your exposure to radiation is measured. Your badge should not be exposed to radiation when you are not wearing it. This means that you should not store your badge in or near the nuclear equipment box. Also, you should not keep your badge on the dashboard of your vehicle. The sun can melt the holder, and ruin the badge. If your badge measures exposure, you want to be sure it came from the device, and not some other source. Wear your badge on the upper torso, somewhere between the beltline and the top of the head. Ideally, your badge should be worn in the chest area.

SHIELDING

Proper shielding also reduces exposure. The source encapsulation and shielding stop any alpha and beta particles that are produced by the source because the source is well protected. The radioactive sources in most devices are classified as special form, encapsulated sealed sources. With normal device use, no extra shielding methods are required or necessary. However, anything placed between you and a radiation source is a deterrent to radiation penetration. Never attempt to remove the source. As long as the source is intact, it is safe.

You will be required to transport your nuclear device to various sites where testing is needed. The device is to be transported to the testing site in a truck, carry-all or station wagon. The device is to be kept securely in its case whenever it is not in use.

It must not be jarred. The mechanical and electronic parts of the device are very durable, but the radiation detectors contain fine wires with glass and ceramic seals that can be damaged by severe jarring. Damage to these parts can cause the device to malfunction. During transport, it must be padded and supported to prevent damage. If transported in a truck, the carrying case shall be secured by lock and chain to the truck. Therefore, be careful to never drop the device, leave it in the way of construction equipment, or transport it unsecured.

The most important thing to remember is use common sense. Follow these guidelines for safe operation of the nuclear device:

- Do not attempt to use the equipment unless you have been authorized to do so and have been properly trained.
- Keep the source in a “safe” or stored position when not in use.
- Always wear your safety badge when using the nuclear device.
- Never exchange your badge or loan it to another operator.
- All unauthorized personnel should be kept out of the operating area.
- Keep the nuclear device locked when not in use.
- Never leave the nuclear device unattended, except when properly stored.
- Return the nuclear device to its proper storage location when not in use.

Security

Security must always be maintained at 3 levels:

- Lock on device
- Device in locked case
- Device in locked case in locked storage area or locked transport vehicle.

CLEANING

The nuclear device must be kept as clean as possible at all times. Dirt and dust from the field can build up and cause delicate mechanisms within the machine to malfunction. The device must be cleaned before and after use. When cleaning, put the source rod in the safe storage position. This safe position is obtained by making sure that the index rod is pulled up to the top position and that the trigger button is released. To clean the outside of the device, use mild soap and water on a damp cloth. Before use, wipe the bottom of the device with a long handled brush to remove any dust and moisture. Turn the bottom away from you when doing this. Do the same when you are finished taking your reading. Make sure to clean off the device before it is stored in its case.

More extensive cleaning may be required if you encounter any of the following problems:

- Difficulty in lowering/raising the source rod. This may indicate a need to replace the scraper ring. The device is designed with a scraper ring on the bottom plate to keep the area of the source rod free of material that could cause damage to the vertical bearings inside the cavity above the bottom plate. Regular cleaning of this cavity will assure a long trouble-free working life. Cleaning frequency can vary from everyday - when testing wet soils, sands, etc., to a maximum of 2 weeks for normal conditions. Replacement of the scraper ring is recommended as needed. If the source rod is cleaned with a long handle brush when working with materials that stick to the rod, the cavity will only need cleaning once or twice a year.

- When the source rod is raised to the “safe” position, no “click” is heard from the tungsten shield striking the back of the shield cavity.

- Erratic density or moisture standard counts.

Occasionally, bottom shield removal is required to clean the cavity beneath the source. Cleaning that requires removal of the shield should be done by authorized personnel only, wearing a badge, and following all safety precautions. If the source rod cannot be retracted into the safe position, isolate the device and call your supervisor immediately. Clean and lubricate in accordance with manufacture’s instructions.

If the device has been out in extremely wet or humid weather, or if you have been in a cold environment and store the device in a heated space, condensation may form on the inside of the device. Normally, this is not a problem as condensation from the latter condition is so minimal that it dissipates overnight, reducing moisture accumulation in the interior. A hair dryer may also be used to dry out the inside of a wet device. If the gaskets are not tight, wet and very humid conditions are another problem because humidity inside may cause erratic or fluctuating moisture readings as well as possible damage to electronic equipment.

MAINTENANCE

Authorized personnel will perform all maintenance, except when removal of the source from the device is required. For this type of maintenance, the device must be returned to the manufacturer. There are two tests performed on the device every six months, the leak test and inspection of the equipment. The leak test ensures that the source materials remain sealed so that the equipment and the areas around the source are not contaminated. The inspection test includes inspecting all radioactive labels for readability, operation of the shutter, presence of two locks on the equipment and the physical condition of the equipment.

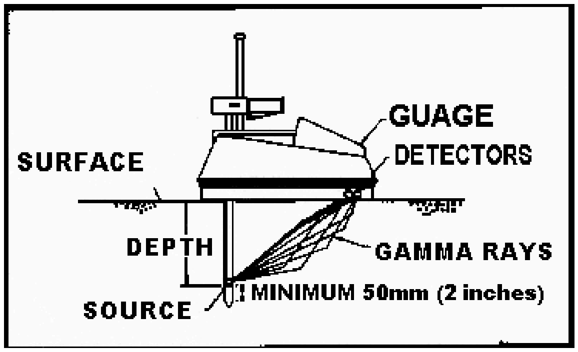
Both tests must be done on or before the due date of the leak test. In the event the device cannot be leak tested on or before the due date, the device must be taken out of use on this date and stored in a protected and secure location until the test can be performed. Follow the standard regulations and procedures for you organization. If the device or any part of it is lost or stolen, follow the regulations and procedures of your organization.

These methods utilize "radioactive materials which may be hazardous to the health of users unless proper precautions are taken.[1]" The Federal Government "strongly recommends that users of this equipment become completely familiar with possible safety hazards and that they establish effective operator instruction and use procedures together with routine safety procedures such as routine source-leak tests, the routine recording and evaluation of film badge data, the use of survey meters, etc. In connection with the operation of equipment of this type.[2]"

Methodology

Equipment

- A Nuclear Gauge (Figure 2).



- Reference standard – A block of material used for checking gauge operation, correction of source decay, and to establish conditions for a reproducible reference count rate.

- Site preparation device - A plate, straightedge or other suitable leveling tool which may be used for planing the test site to the required smoothness, and in the Direct Transmission Method, guiding the drive pin to prepare a perpendicular hole.

- Drive Pin – A pin not to exceed the diameter of the rod in the Direct Transmission gauge by more than 6mm (1/4 in.), or as recommended by the gauge manufacturer, used to prepare a hole in the material under test for inserting the rod.

  A slide hammer, with drive pin attached, may also be used both to prepare a hole in the material to be tested and to extract the pin without distortion to the hole.

- Drive Pin Extractor – A tool that may be used to remove the drive pin in a vertical direction so that the pin will not distort the hole in the extraction process

- Operator's manual

Calibration of Gauge

Newly acquired gauges are calibrated initially by the manufacturer. Existing gauges must be calibrated after repairs that may affect the gauge geometry. Existing gauges are calibrated to re-establish calibration curves, tables, or equivalent coefficients if the gauge does not meet specified tolerances in the verification process. If the owner does not establish a verification procedure, the gauge shall be calibrated at least once every 24 months.

Existing gauges must be verified at a minimum frequency of 12 months. The verification process and resultant tolerances obtained over the depths that the gauge will be operated must be formally recorded and documented. If the verification process indicates a variance beyond the specified tolerances, the gauge must be calibrated.

Calibration or verification of the gauge is conducted on blocks of material with known density and moisture content. Calibration or verification procedures are typically conducted by the manufacturer or an independent vendor, but may be conducted by your agency. It is usually not the responsibility of the inspector.

Standardization of Gauge.

All nuclear density/moisture gauges are subject to long-term aging of the radioactive sources, detectors, and electronic systems, which may change the relationship between count rates and the material density and water content. To offset this aging, gauges are calibrated as a ratio of the measurement count rate to a count rate made on a reference standard or to an air-gap count (for the backscatter/air-gap ratio method).

Standardization of the gauge on the reference standard is required at the start of each day's use and a permanent record of these data shall be retained. The standardization shall be performed with the gauge at least 10m (30 ft.) away from other nuclear density/moisture gauges and clear of large masses of water or other items which may affect the reference count rates. Standard counts should be taken in the same environment as the actual measurement counts.

The following procedure should be used to take the daily standard count:

1. Turn on the gauge and allow for stabilization according to the manufacturer's recommendations. If the gauge is to be used either continuously or intermittently during the day, it is best to leave it in the "power on" condition to prevent having to repeat the stabilization (refer to manufacturer recommendations). This will provide more stable, consistent results.

2. Using the reference standard, take at least four repetitive readings at the normal measurement period and calculate the average count. If available on the gauge, one measurement of four or more times the normal period is acceptable. This constitutes one standardization check.

3. Use the procedure recommended by the gauge manufacturer for determining compliance with the gauge calibration curves. Without specific recommendations, use the procedure provided below.

$$N_S = N_0 \pm 1.96\sqrt{(N_0/F)}$$

where:
N_S = value of current standardization count,
N_0 = average of the past four values of NS taken for prior usage, and
F = factory pre-scale factor (contact gauge manufacturer for the factor).

4. If the mean of the four repetitive reading is outside the limits set by the equation below, repeat the standardization check. If the second standardization check satisfies the equation, the gauge is considered in satisfactory operating condition. If the second check does not satisfy the equation, the gauge needs to be verified as outlined in “Gauge Calibration”. If the verification shows that there is no significant change in the calibration curve, a new reference standard count, N_O, should be established. If the verification check shows that there is a significant difference in the calibration curve, the gauge will needed to be repaired and recalibrated.

Procedure

1. Select a location where the gauge will be at least 150mm (6 in.) away from any vertical projection. If closer than 600mm (24 in.) to a vertical mass, such as in a trench, follow gauge manufacturer correction procedures.

Note about Trench Correction
When within 600mm (24 in.) of a wall in a trench the gauge might read the hydrogen contained in the wall as well as the material under test. In such a situation use the trench correction program contained within the gauge or other manufacturer correction procedure. The procedure will likely instruct you to place the standard block in the trench and then take a second reference count which will be compared to the standard, at which point adjustments (if necessary) will be made.

2. Remove all loose and disturbed material and additional material as necessary to expose the top of the material to be tested.

Note
The volume of material that you wish to be tested with the gauge should be considered when determining the depth at which the gauge is to be seated.

3. Prepare a horizontal area sufficient in size to accommodate the gauge, by planning the area to a smooth condition so as to obtain maximum contact between the gauge and material being tested.

4. The maximum void space beneath the gauge shall not be more than 3mm (1/8 in.). Use native fines or fine sand to fill these voids and smooth the surface with a rigid plate or other suitable tool. The depth of the filler should not exceed approximately 3mm (1/8 in.).

Note
The placement of the gauge on the surface of the material to be tested is critical to the successful determination of density. The optimum condition is total contact between the bottom surface of the gauge and the surface of the material being tested. When optimal conditions are not present, correct surface irregularities by the use of sand or similar filler material. The total area filled should not exceed 10 percent of the bottom area of the gauge. Several trial seatings may be required to achieve these conditions.

5. Turn on and allow the gauge to stabilize (warm up) according to the manufacturer's recommendations.

6. Continue by using either the steps listed under the "Backscatter or Backscatter/Air-Gap Ratio Method", or the "Direct Transmission Method" depending on the method selected for your test.

Backscatter or Backscatter/Air-Gap Ratio Method

7. Seat the gauge firmly.

8. Keep all other radioactive sources at least 10m (30 ft.) away from the gauge to avoid affecting the measurement.

9. Set the gauge in the Backscatter (BS) position.

Note
As a safety precaution, do not extend a rod containing radioactive sources out of its shielded position prior to placing on the test site. Always align the gauge so as to allow placing the rod directly into the test position from the shielded position.

10. Secure and record one or more one-minute readings. When using the backscatter/air-gap ratio method, follow the manufacturers instructions regarding gauge set up. Take the same number of readings for the normal measurement period in the air-gap position as in the standard backscatter position. Determine the air-gap ratio by dividing the counts per minute obtained in the air-gap position by the counts per minute obtained in the standard position. Many gauges have built-in provisions for automatically calculating the air-gap ratio and wet density.

11. Determine the in-place wet density by use of the calibration curve previously established or read the gauge directly if so equipped.

Direct Transmission Method

7. Select a test location where the gauge in test position will be at least 150mm (6 in.) away from any vertical projection.

8. Make a hole perpendicular to the prepared surface using the guide and the hole-forming device. The hole shall be a minimum of 50mm (2 in.) deeper than the desired measurement depth and of an alignment that insertion of the probe will not cause the gauge to tilt from the plane of the prepared surface.

9. Mark the test area to allow the placement of the gauge over the test site and to allow the alignment of the source rod to the hole. Follow manufacturer recommendations if applicable.

10. Remove the hole forming device carefully to prevent the distortion of the hole, damage to the surface, or loose material to fall into the hole.

11. Place the gauge on the material to be tested, making sure of maximum surface contact as described in Step 4.

12. Lower the source rod into the hole to the desired test depth. Pull gently on the gauge in the direction that will bring the side of the probe to face the center of the gauge so that the probe is in intimate contact with the side of the hole in the gamma measurement path.

Note
As a safety precaution, do not extend a rod containing radioactive sources out of its shielded position prior to placing on the test site. Always align the gauge so as to allow placing the rod directly into the test hole from the shielded position.

13. Keep all other radioactive sources at least 10m (30 ft.) away from the gauge to avoid affecting the measurement.

14. If the gauge is so equipped, set the depth selector to the same depth as the probe before recording the automated (gauge computed densities, moisture contents, and weights) values.

15. Secure and record one or more one-minute readings. The gauge may be rotated about the axis of the probe to obtain additional readings.

16. Determine the in-place wet density by use of the calibration curve previously established or read the gauge directly if so equipped.

Moisture Content Procedure

Unless your gauge simultaneously tests for wet density and moisture content, once the wet density has been determined and before moving the gauge, set the controls to the MOISTURE MODE and take a series of one or more one-minute readings. The unit will now display the unit weight of water measured. Pressing a control button on most gauges will result in the dry density being displayed automatically. See the manufacturer's instructions to operate your individual unit.

NOTE:
The nuclear device reads hydrogen ions as water. It also can be affected by minerals or chemicals that are neutron absorbers (e.g., boron, cadmium). Because of this, the mineral composition of a soil may cause the moisture content determined by a nuclear device to be inaccurate. Since density and moisture content bear a direct relationship to each other an inaccurate moisture content will yield an inaccurate density reading. To guard against this type of error, you should always clear the moisture content from the nuclear device for a given soil or soil-aggregate with AASHTO T 265 before relying on the nuclear moisture.

Calculation of Results

If dry density is required, the in-place water content may be determined by using the nuclear methods described above, by obtaining samples and testing in the laboratory, or by other approved methods.

If the water content is determined by nuclear methods, use the gauge readings directly, or, subtract the kg/m^3 (lbm/ft^3) of moisture from the kg/m^3 (lbm/ft^3) of wet density, and obtain dry density in kg/m^3 (lbm/ft^3).

If the water content is determined by other methods, and is in the form of percent, calculate the dry density using the following equation:

$$d = 100/(100+w) \times m$$

d = Dry density in kg/m^3 (lbm/ft^3),
m = wet density in kg/m^3 (lbm/ft^3), and
w = water as a percent of dry mass

Percent Compaction

It may be desired to express the in-place density as a percentage of some other density, for example, the laboratory densities determined in accordance with AASHTO Test Methods T 99 and T 180. This relation can be determined by dividing the in-place density by the laboratory density and multiplying by 100. Calculations for determining relative density are provided in ASTM D 4253 or D 4254. Corrections fro oversize material, if required , should be performed in accordance with AASHTO T 224 or ASTM D 4718.

If representative samples of material are to be taken for purposes or correlation with other test methods or rock correction, the volume measured can be approximated by a 200mm (8 in.) diameter cylinder located directly under the center line of the radioactive source and detector(s). The height of the cylinder to be excavated will be the depth setting of the source rod when using the Direct Transmission method or approximately 75mm (3 in.) when using the Backscatter method.

An alternate to the correction for oversize particles that can be used with mass density methods or minimal oversize situations, involves multiple tests. Three tests may be take at adjacent location and results averaged to get a representative value.

Comparisons need to be made to evaluate whether the presence of a single large rock or void in the soil is producing unrepresentative values of density. Whenever values obtained are questionable, the test volume site should be excavated and visually examined to determine whether or not the material tested was representative of the laboratory density sample.

Glossary

Background Count - The naturally occurring radiation from lights, the sun and many other sources.

Heterogeneity - Differing in structure, quality, etc.; dissimilar.

Fast Neutron Detector - An electronic device that counts Neutrons as they pass through a special gas.

Fast Neutron Source - Each atom has a nucleus comprised of varying numbers of Protons and Neutrons. When a high-energy electron strikes a nuclei, one or more Protons or Neutrons are released. These neutrons are used to measure moisture content by a nuclear gauge.

Gamma Detector - An electronic device that converts electronic pulses caused by high energy electrons, passing through a special gas enclosed in a tube, into a numerical count.

Gamma Source - A radioactive material that emits high energy electron radiation, similar to x-rays commonly used in hospitals. The radiation is invisible and capable of passing through many millimeters of wood, soil or other material.

Indeterminate - Indefinite or vague.

Radioisotope - Radioactive isotope of a chemical element.

Scaler - A device that converts electric pulses into numerical counts and displays the results.

Spatial - Existing in differing space, or relationships of space.