<table>
<thead>
<tr>
<th>Test Method No.</th>
<th>Title</th>
<th>Pages</th>
<th>Date of Publication or Revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT 200</td>
<td>Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test</td>
<td>pp 1-4</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 201</td>
<td>Sampling Roadway Materials</td>
<td>pp 1-7</td>
<td>Oct 2013</td>
</tr>
<tr>
<td>MT 202</td>
<td>Sieve Analysis for Fine and Coarse Aggregate</td>
<td>pp 1-9</td>
<td>Nov 2011</td>
</tr>
<tr>
<td>MT 203</td>
<td>Unit Weight of Aggregate</td>
<td>pp 1-6</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 204</td>
<td>Specific Gravity and Absorption of Fine Aggregate</td>
<td>pp 1-5</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 205</td>
<td>Specific Gravity and Absorption of Coarse Aggregate</td>
<td>pp 1-6</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 206</td>
<td>Terms Relating to Density and Specific Gravity of Solids, Liquids and Gases</td>
<td>pp 1-3</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 207</td>
<td>Centerline Soil Survey</td>
<td>pp 1-10</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 208</td>
<td>Determining the Liquid Limit, Plastic Limit, and Plasticity Index of Soils</td>
<td>pp 1-12</td>
<td>Aug 2014</td>
</tr>
<tr>
<td>MT 209</td>
<td>Los Angeles Abrasion (Wear Test)</td>
<td>pp 1-4</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 210</td>
<td>Moisture-Density Relations of Soils Using 5.5 lb. Rammer and 12 In. Drop</td>
<td>pp 1-8</td>
<td>Aug 2014</td>
</tr>
<tr>
<td>MT 211</td>
<td>Moisture-Density Relations of Soil-Cement Mixtures</td>
<td>pp 1-6</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 212</td>
<td>Determination of Moisture and Density of In-Place Materials</td>
<td>pp 1-5</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 213</td>
<td>Plastic Fines in Graded Aggregates (Sand Equivalent Test)</td>
<td>pp 1-8</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 214</td>
<td>The Classification of Soil and Soil-Aggregate Mixtures</td>
<td>pp 1-8</td>
<td>Dec 2004</td>
</tr>
<tr>
<td>MT 215</td>
<td>Optimized Aggregate Gradation for Hydraulic Cement Concrete Mix Designs</td>
<td>pp 1-6</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 216</td>
<td>Method of Sampling and Testing Cement Treated Base</td>
<td>pp 1-5</td>
<td>Oct 2013</td>
</tr>
<tr>
<td>MT 217</td>
<td>Method for Determining Percentage of Mechanically Fractured Particles</td>
<td>pp 1-5</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 218</td>
<td>Determining Relative Compaction and Percent Moisture</td>
<td>pp 1-2</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 219</td>
<td>Controlling Compaction Using a Control-Strip Test-Section Technique with Nuclear Gauges</td>
<td>pp 1-4</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 220</td>
<td>Specific Gravity of Soils</td>
<td>pp 1-5</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 221</td>
<td>Total Evaporable Moisture Content of Aggregate by Drying</td>
<td>pp 1-3</td>
<td>Jan 2006</td>
</tr>
<tr>
<td>MT 222</td>
<td>Method of Test for Determining the In-Place Moisture and Density of Soils by the Sand Cone Method</td>
<td>pp 1-5</td>
<td>Nov 2004</td>
</tr>
<tr>
<td>MT 223</td>
<td>Clay Lumps and Friable Particles in Aggregates</td>
<td>pp 1-3</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 224</td>
<td>Failing and Check Samples of Aggregates</td>
<td>pp 1-2</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 225</td>
<td>Terms Relating to Subgrade, Soil Agg and Fill Materials (formerly MT 511)</td>
<td>pp 1-2</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 226</td>
<td>Maximum Acceptable Deviations in Sieve Analysis of IA Samples</td>
<td>pp 1-7</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 227</td>
<td>Method of Test for Determination of Moisture Content of Soils</td>
<td>pp 1-2</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 228</td>
<td>Method of Establishing Field Target Density for Cement Treated Base</td>
<td>pp 1</td>
<td>Oct 2013</td>
</tr>
<tr>
<td>MT 229</td>
<td>Procedure for Solids-Water-Voids Relations of Soil Masses</td>
<td>pp 1-22</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 230</td>
<td>Moisture-Density Relation of Soils Using a 10 lb Rammer and 18 In. Drop</td>
<td>pp 1-8</td>
<td>June 2008</td>
</tr>
<tr>
<td>MT 231</td>
<td>Procedure for Correction for Coarse Particles in the Soil Compaction Test</td>
<td>pp 1-5</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 232</td>
<td>Soil Corrosion Test</td>
<td>pp 1-3</td>
<td>June 2004</td>
</tr>
<tr>
<td>MT 233</td>
<td>Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus</td>
<td>pp 1-6</td>
<td>July 2007</td>
</tr>
</tbody>
</table>
METHODS OF SAMPLING AND TESTING
MT 200-04
DRY PREPARATION OF DISTURBED SOIL AND SOIL AGGREGATE SAMPLES FOR TEST
(Modified AASHTO T 87)

1 Scope:

1.1 This method describes the dry preparation of soil and soil-aggregate samples, as received from the field, for mechanical analysis, physical tests, moisture-density relations test, and other tests as may be desired.

2 Apparatus:

2.1 Balance - A balance sensitive to 0.1 g for samples weighing approximately 110 g or less; for larger samples, the balance shall be sensitive to within 0.1 percent of the sample to be weighed.

2.2 Drying Apparatus - Any suitable device capable of drying samples at a temperature not exceeding 60 C (140 F).

2.3 Sieves - A series of sieves of the following sizes: 19.0 mm (¾ in.), 4.75 mm (No. 4), 2.00 mm (No. 10), 0.425 mm (No. 40) and others as required for preparing the sample for a specific test. The sieves shall conform to MT-405, Sieves for Testing Purposes.

Note 1 - A 50 mm (2 in.) sieve is required if the sample includes particles retained on the 10.0 mm (¾ in.) sieve and it is desired that the sample for moisture-density relations (AASHTO T 99 or T 180) contain material between 19.0 mm (¾ in.) and 4.75 mm (No. 4) sieve size to represent the fraction between 50 and 19.0 mm (2 in. and ¾ in.).

2.4 Pulverizing Apparatus - Either a mortar and rubber-covered pestle or a mechanical device consisting of a power-driven rubber-covered muller suitable for breaking up the aggregations of soil particles without reducing the size of the individual grains.

Note 2 - Other types of apparatus, such as a revolving drum into which the soil sample and rubber-covered rollers are placed and tumbled until soil aggregations are pulverized, are satisfactory if the aggregations of soil particles are broken up without reducing the size of the individual grains.

2.5 Sample Splitter - A suitable riffle sampler or sample splitter for proportional splitting of the sample and capable of obtaining representative portions of the sample without appreciable loss of fines. The width of the container used to feed the riffle sample splitter should be equal to the total combined width of the riffle chutes. Proportional splitting of the sample on a canvas cloth is also permitted.

Note 3 - The procedure for proportional splitting is described in MT 607, Reducing Field Samples of Aggregate to Testing Size.

3 Sample Size:

3.1 The amounts of soil material required to perform the individual tests are as follows:

3.1.1 Particle Size Analysis of Soils (AASHTO T 88) - For the particle size analysis material passing a 2.00 mm (No. 10) sieve is required in amounts equal to approximately 110 g for sandy soils and approximately 60 g of silty or clayey soils. A sufficient amount of material retained on either the 4.75 mm (No. 4) sieve or 2.00 mm (No. 10) sieve is required (Note 4) to obtain a representative gradation, and depending on the maximum particle size, shall not be less than the amount shown in the following table:
3 Sample Size: (continued)

<table>
<thead>
<tr>
<th>Diameter of Largest Particle, mm (in.)</th>
<th>Approximate Minimum Mass of Portion, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5 (3/8)</td>
<td>0.5</td>
</tr>
<tr>
<td>25.0 (1)</td>
<td>2.0</td>
</tr>
<tr>
<td>50 (2)</td>
<td>4.0</td>
</tr>
<tr>
<td>75 (3)</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Note 4 - The material for coarse sieve analysis may be separated by either of two alternate methods, 4.2.1 (2.00 mm sieve) or 4.2.2 (4.75 mm sieve). When only a small percentage of the material will be retained on the 4.75 mm or 2.00 mm sieve, a considerable total weight of sample will be required to provide the minimum quantity shown in the above table; consequently, if the material represented by the sample is not to be used in a base or sub-base course, select borrow, or other item having a requirement for coarse aggregate adherence to the minimum weight requirements in the above table may not be necessary.

3.1.2 Specific Gravity (AASHTO T 100) - For the specific gravity test performed in conjunction with AASHTO T 88, Mechanical Analysis, Soils, Material passing the 2.00 mm (No. 10) sieve is required in the amounts (oven-dry) of at least 25 g when the volumetric flask is used and at least 10 g when the stoppered bottle is used.

3.1.3 Physical Tests - For the physical tests, material passing the 0.425 mm (No. 40) sieve is required in the total amount of at least 300 g, allocated approximately as follows:

<table>
<thead>
<tr>
<th>Test (and AASHTO Designation)</th>
<th>Approx. Mass, g.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid limit (T 89)</td>
<td>100</td>
</tr>
<tr>
<td>Plastic limit (T 90)</td>
<td>20</td>
</tr>
<tr>
<td>Shrinkage factors (T 92)</td>
<td>30</td>
</tr>
<tr>
<td>Field moisture equivalent (T 93)</td>
<td>50</td>
</tr>
<tr>
<td>Check the referee tests</td>
<td>100</td>
</tr>
</tbody>
</table>

3.1.4 Moisture-Density Relations (MT-210) - For moisture-density relations test, the following approximate amounts of material are required:

<table>
<thead>
<tr>
<th>Soil Material Passing, Sieve</th>
<th>Approximate Quantity Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>mm</td>
</tr>
<tr>
<td>--------</td>
<td>----</td>
</tr>
<tr>
<td>A</td>
<td>4.75</td>
</tr>
<tr>
<td>B</td>
<td>4.75</td>
</tr>
<tr>
<td>C</td>
<td>3/4 Inch</td>
</tr>
<tr>
<td>D</td>
<td>3/4 Inch</td>
</tr>
</tbody>
</table>

3.1.5 Other Tests - For quantity of material required for testing, refer to the specific method of test.

4 Initial Preparation of Test Samples:

4.1 The soils sample as received from the field shall be dried thoroughly in air or the drying apparatus at a temperature not exceeding 60 C (140 F). A representative test sample of the amount required to perform the desired tests (Section 3) shall then be obtained with the sampler, or by splitting or quartering. The aggregations of soil particles shall then be broken up in the pulverizing apparatus in such a way as to avoid reducing the natural size of individual particles.

Note 5 - Samples dried in an oven or other drying apparatus at a temperature not exceeding 60 C (140 F) are considered to be air dried.
4 Initial Preparation of Test Samples: (continued)

4.2 The portion of the dried sample selected for particle size analysis and physical tests (including specific gravity) shall be weighed and that weight recorded as the weight of total sample uncorrected for hygroscopic moisture. This portion shall then be separated into fractions by one of the following methods:

4.2.1 Alternate Methods Using 2.00 mm (No. 10) Sieve - The dried sample shall be separated into two fractions using a 2.00 mm sieve. The fraction retained on the sieve shall be ground with the pulverizing apparatus until the aggregations of soil particles are broken into separate grains. The ground soil shall then be separated into two fractions using the 2.00 mm sieve.

4.2.2 Alternate Method Using 4.75 mm and 2.00 mm (No. 4 and No. 10) Sieves - The dried sample shall first be separated into two fractions using a 4.75 mm sieve. The fraction retained on this sieve shall be ground with the pulverizing apparatus until the aggregation of soil particles are broken into separate grains, and again separated on the 4.75 mm sieve. The fraction passing the 4.75 mm sieve shall be mixed thoroughly and, by the use of the sampler or by splitting and quartering, a representative portion adequate for the desired tests shall be obtained and weighed. This split-off portion shall then be separated on the 2.00 mm sieve, and processed as in 4.2.1. The material from the split-off fraction that is retained on the 2.00 mm sieve shall be weighed for later use in coarse sieve analysis computations.

5 Test Sample for Particle Size Analysis and Specific Gravity:

5.1 The fraction retained on the 2.00 mm (No. 10) sieve in 4.2.1 or that retained on the 4.75 mm (No. 4) sieve in 4.2.2, after the second sieving, shall be set aside for use in sieve analysis of the coarse material.

5.2 The fraction passing the 2.00 mm (No. 10) sieve in both sieving operations in 4.2.1 or 4.2.2 shall be thoroughly mixed together and, by the use of the sampler or by splitting or quartering, representative portions having approximate weights as follows shall be obtained: (1) for the hydrometer analysis and sieve analysis of the fraction passing the 2.00 mm sieve, 110 g for sandy soil and 60 g for silty or clayey soils; and (2) for specific gravity, 25 g when the volumetric flask is to be used and 10 g when the stoppered bottle is to be used.

6 Test Sample for Physical Tests:

6.1 The remaining portion of the material passing the 2.00 mm (No. 10) sieve shall then be separated into two parts by means of a 0.425 mm (N. 40) sieve. The fraction retained on the 0.425 mm (No. 40) sieve shall be ground with the pulverizing apparatus in such a manner as to break up the aggregations without fracturing the individual grains. If the sample contains brittle particles, such as flakes of mica, fragments of sea shells, etc., the pulverizing operation shall be done carefully and with just enough pressure to free the finer material that adheres to the coarser particles. The ground soil shall then be separated into two fractions by means of the 0.425 mm (N. 40) sieve and the material shall be reground as before. When repeated grinding produces only a small quantity of soil passing the No. 40 sieve, the material retained on the No. 40 sieve shall be discarded.

The several fractions passing the No. 40 sieve obtained from the grinding and sieving operations just described shall be thoroughly mixed together and set aside for use in performing the physical tests.

7 Test Sample for the Moisture Density Relations:

7.1 The portion of dried soil selected for the moisture-density relations test shall be separated by means of the required sieve as specified in Section 3.1.4. If necessary, the pulverizing apparatus shall be used to break up the soil aggregations retained on this sieve into separate grains. The
ground soil shall then be separated into two fractions using the required sieve.

7  Test Sample for the Moisture Density Relations: (continued)

7.2  The fraction retained on the sieve after the second sieving shall be saved, if required. The fractions passing the required sieve in both sieve operations shall be thoroughly mixed and used for the moisture-density test.
1 General:

1.1 Sampling for evaluation of potential aggregate sources should be performed by a responsible, trained and experienced person. Because of the wide variety of conditions under which sampling may be done, it is not possible to describe detailed procedures applicable to all circumstances.

1.2 The sample bags must be tightly-woven and durable so that the required amount of sample can be shipped without rupture of the bag or loss of fine material through the fabric. Also, when tied, as in 1.3, the bag must be sealed tightly enough to prevent loss or contamination of the material.

1.3 Samples shall be double tied as close to the gravel as possible with the necessary papers between the double tie. This procedure insures a good sample together with a legible laboratory sheet.

2 Referenced Documents:

2.1 MT Manual:
MT 101 Making and Curing Concrete Compressive and Flexural Strength Field Test Specimens
MT 202 Sieve Analysis of Fine and Coarse Aggregate
MT 207 Centerline Soil Survey
MT 210 Moisture Density Relation of Soils Using a 5.5 lb. Rammer
MT 218 Determining Relative Compaction and Percent Moisture
MT 230 Moisture Density Relation of Soils Using a 10 lb. Rammer
MT 601 Materials Sampling, Testing and Acceptance Guide
MT 607 Procedure for Reducing Filed Samples to Testing Size

3 Number of Samples:

3.1 The frequency of sampling as described in this procedure is the minimum required and more should be taken if deemed necessary.

4 Pre-construction Proposed Surfacing Sampling:

4.1 Proposed surfacing samples should represent a vertical cross-section of the proposed source.

4.1.1 Describe each site or area investigated with each test hole, boring or test pit clearly located (horizontally and vertically) with reference to some established coordinate system or permanent monument on an area map or sketch.

4.1.2 Log each test hole, boring, test pit or cut-surface exposure with the field description and location of each material encountered clearly shown by Montana Department of Transportation symbols and word descriptions used on Form 30. An example of Form 30 is in MT 207.

4.1.3 Each aggregate layer that is included in the sample should be noted along with the depth of the water table if it is encountered should be shown on the log of test holes.

4.2 Overburden or clay seams may be sampled separately.

4.3 Rocks larger than 6 inches (150mm) in diameter shall not be included in the sample. However, the estimated percentage of rock larger than 12 inches (300mm); between 6 and 12 inches (150 and 300mm); between 4 and 6 inches (100 and 150mm); and less than 4 inches (100mm) in diameter shall be shown on the Prospected Area Report.
4 Pre-construction Proposed Surfacing Sampling: (continued)

4.4 Representative samples shall be taken on the following basis:

4.4.1 Each sample shall be a minimum of 150 pounds (68 Kg).

4.4.2 Not less than 3 samples shall be taken from any proposed source.

4.4.3 Up to 50,000 cubic yards (38,230 cubic meters) - a minimum of 3 samples.

4.4.4 50,000 to 100,000 cubic yards (38,230 to 76,460 cubic meters) - 3 to 5 samples.

4.4.5 100,000 to 150,000 cubic yards (76,460 to 114,690 cubic meters) - 5 to 8 samples.

4.4.6 150,000 to 200,000 cubic yards (114,690 to 152,920 cubic meters) - 8 to 10 samples.

4.4.7 Providing the material is uniform, one sample may represent material from as many as ten test holes in large areas if provisions 4.4.1 through 4.4.6 above are met.

4.4.8 For large sources, a suggested sampling sequence is to take samples around the perimeter of the source with additional samples taken toward the middle to check for uniformity. Each proposed source is unique, however, and the final sampling sequence shall be determined by the District Materials Supervisor or Area Lab Supervisor.

4.5 The District or Area laboratory will determine the gradation, LL, PL, PI, soil class and 24-hour volume swell and submit to the Materials Bureau on a form 123. Also, a visual examination by the Materials Supervisor will be made. An interpretation of these results will determine if the material in the proposed source is worthy of further consideration.

4.5.1 Predominately Unacceptable - If the tests show the material to be predominately unsatisfactory and material of a better quality is available, no further consideration shall be given this source.

4.5.2 Uniformly Acceptable - If the tests indicate the material is uniformly satisfactory, at least one sample for every six tested in the District or Area laboratory (a minimum of three) shall be sent to the Materials Bureau. Each sample shall consist of 1-75 lb. (34 Kg) split for wear, gradation and other correlations (see note 1). Also, a 300 lb. composite sample for Mix design testing shall be submitted for these areas. Additionally, one 180 lb. (32 Kg) composite sample per source is required for Sodium Sulfate and Micro-Deval testing.

4.5.3 Spotty sources - If the tests indicate the material is spotty, at least one sample for every six tested in the District or Area laboratory (a minimum of one) for each of the areas (satisfactory, questionable, and unsatisfactory) shall be sent to the Materials Bureau for wear test, gradation check, evidence of disintegration, and other correlations. Also, a 300 lb. composite sample for Mix design testing shall be submitted for these areas. Additionally, one 180 lb. (32 Kg) composite sample per source is required for Sodium Sulfate and Micro-Deval testing.

### Number of Representative Pounds from Each Hole to Make Composite

<table>
<thead>
<tr>
<th>Holes</th>
<th>Sodium Sulfate</th>
<th>Micro Deval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lbs.</td>
<td>Kg</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>54</td>
</tr>
<tr>
<td>5</td>
<td>24</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>
4 Pre-construction Proposed Surfacing Sampling: (continued)

Note 1 - Each area within a source that exhibits different physical characteristics should be sampled completely as per 4.5.2. In a large volume area one sample may be a composite of a series of holes of uniform material (example: sample number 1 may be a composite of holes 1 through 6; sample number 2 - holes 7 through 12; sample number 3 - holes 13 through 20, etc.) The example cited above is to be used as a guide only.

4.5.4 Material for each portion of the composite sample shall be obtained by quartering, splitting, recombining and splitting again according to MT 607 so that a homogenous mix is obtained. The material will be split so that no more than 77 lbs. (35 Kg) are placed in one bag.

4.5.5 The Core Drill Section, under the direction of the Geotechnical Section, can be utilized in problem areas where conventional equipment is inadequate. Assistance, either geologic or drilling, can be provided usually within a period of a month or six weeks.

5 Laboratory Form No. 99:

5.1 The "Field Sample Analysis Report" Form No. 99 is to be used in reporting district or area laboratory tests. This information will be transferred to the "Available Surfacing Material Report" in Helena and will be available to prospective bidders, along with the usual Materials Bureau test results.

5.2 The District Materials Supervisor or Area Lab Supervisor is to use his experience and engineering judgment to give a summation of all information such as the past history of the source and his comments and recommendations regarding the laboratory test data which would include a statement as to which holes were represented by the Sodium Sulfate and Micro-Deval samples. This information will be placed on the bottom portion of Lab Form No. 99. However, the acceptance or rejection of the source will be the responsibility of the Materials Bureau in Helena when all testing is complete.

6 Laboratory Form No. 92:

6.1 The field information on Laboratory Form No. 92 shall include a correct legal description of the deposit. In some cases, it may be necessary to have a survey party retrace the boundary lines and make section line ties before right-of-way negotiations can be completed. Where deposits are located adjacent to the highway right-of-way, the boundary lines of the deposit should be tied to the centerline and shown on Laboratory Form No. 92 so that a legal description can be prepared without any further field work. Under some circumstances, the Department of Transportation will obligate by purchase or option surfacing material sources for future construction projects and maintenance use.

6.2 Form No. 92 "Prospected Area Report" must be completely filled out especially with reference to definite location, total yardage represented by the samples, ownership, and depth of overburden. The haul distance shall be reported to the nearest one-tenth mile over the shortest and most practical route from the deposit to a definite station on the project.

6.3 A sketch shall be attached Form No. 92 showing the boundary lines of the deposit with all dimensions and ties neatly plotted to a scale that is indicated on the sketch. All test holes shall be numbered and shown in their correct location.

6.4 In those cases where areas are being explored on which data has been previously submitted, a new "Prospected Area Report" shall accompany the new sampling showing any laboratory numbers previously assigned.
7 Reports on Proposed Surfacing Sources:

7.1 The Materials Bureau will issue a final report based on an evaluation of the district or area laboratory test data, the recommendations of the District Materials Supervisor or Area Lab Supervisor, and an interpretation of tests performed by the Materials Bureau.

8 Preconstruction Binder Samples:

8.1 Binder samples shall be taken incidental to all proposed gravel source exploration. A 25 lb. (11 Kg) sample from each distinct type proposed for use shall be taken and tested in the district or area laboratory. Binder samples need not be sent to the Materials Bureau unless an unusual problem arises.

9 Size of Samples: Required for District, Area and Materials Bureau Testing:

9.1 The sample size depends on 100% of the aggregate passing the specified sieve size. The amounts specified in the table below provide adequate material for routine testing (gradation, LL, PI, volume swell, etc.). Minimum Field Test sample sizes are in MT 202.

<table>
<thead>
<tr>
<th>SPECIFIED 100% PASSING SIEVE SIZE</th>
<th>MINIMUM WEIGHT OF SAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.75 mm (4 Mesh)</td>
<td>14 Kg (30 lb.)</td>
</tr>
<tr>
<td>9.5 mm (3/8 Inch)</td>
<td>14 Kg (30 lb.)</td>
</tr>
<tr>
<td>12.5 mm (1/2 Inch)</td>
<td>14 Kg (30 lb.)</td>
</tr>
<tr>
<td>16.0 mm (5/8 Inch)</td>
<td>14 Kg (30 lb.)</td>
</tr>
<tr>
<td>19.0 mm (3/4 Inch)</td>
<td>14 Kg (30 lb.)</td>
</tr>
<tr>
<td>25.0 mm (1 Inch)</td>
<td>35 Kg (77 lb.)</td>
</tr>
<tr>
<td>37.5 mm (1½ Inch)</td>
<td>35 Kg (77 lb.)</td>
</tr>
<tr>
<td>50 mm (2 Inch)</td>
<td>35 Kg (77 lb.)</td>
</tr>
<tr>
<td>63 mm (2½ Inch)</td>
<td>35 Kg (77 lb.)</td>
</tr>
</tbody>
</table>

Note 2 - The sample shall be obtained by quartering or splitting to insure a representative sample. If necessary, the representative sample shall be split again so that no more than 77 lbs. (35 Kg) are placed in two bags.

10 Sampling from Stockpiles:

10.1 When such sampling is necessary, every effort should be made to enlist the services of power equipment to develop a separate, small sampling pile composed of materials drawn from various levels and locations in the main pile after which several increments may be combined to compose the field sample.

10.2 Coarse Aggregate Stockpiles - Where power equipment is not available, samples from stockpiles should be made up of at least three increments taken from the top third, at the midpoint, and at the bottom third of the volume of the pile. A board shoved vertically into the pile just above the sampling point aids in preventing further segregation.

10.3 Fine Aggregate Stockpile - A suggested sampling procedure for fine aggregate would be to remove the outer layer, which may have become segregated and take the sample from the material beneath. Sampling tubes approximately 1¼ inches (30-mm) minimum by 6 feet (2-m) minimum in length may be inserted into the pile at random locations to extract a minimum of five increments of material to form the sample.
11 Production Sampling:

11.1 Production samples shall be taken in three equal increments from a stopped belt or with an automatic sampling device and combined to make the sample. Such samples shall be reduced to testing size, according to MT 607, Method A or Method B.

12 Windrow Sampling (Cement Treated Base and Cold In-Place Recycle):

12.1 Samples should be composed of a number of samples taken at various points along the windrow, combined and reduced to testing size according to MT 607, Method A or Method B.

13 Pug Mill - Mixed Aggregate Sampling:

13.1 Samples for gradation and fracture testing shall be taken from a minimum of three increments from the processed material on the roadway after lay down.

13.2 Samples for crushed cover material gradation and fracture will be taken at the most convenient point before application determined by the engineer.

13.3 Samples for other specified properties will be taken at the point of production.

14 Sampling from Roadway:

14.1 Samples from the roadway (minimum of three increments) should be taken for the full depth of the material, taking care to exclude any underlying material. Where necessary, place templates on the existing roadway to separate the underlying material from the sample. The sample shall be taken from the processed material on the roadway after laydown.

14.2 District or Area labs will determine the gradation, LL, PL, PI and soil class for Soil Survey "R" Value samples. The results will be reported on a form 123 which will accompany the sample to the Materials Bureau.

15 "Special Borrow":

15.1 District or Area labs will determine the gradation, LL, PL, PI and soil class for Special Borrow "R" Value samples. The results will be reported on a form 123 which will accompany the sample to the Materials Bureau.

16 Reduction of Sample Size by Quartering or Splitting:

16.1 The procedure for reducing the size of field sample of aggregate is described in MT 607.

17 Required Production Samples other than Aggregates for Plant Mix:

17.1 Field testing for Acceptance shall conform to the frequency as shown in MT 601, under "Aggregate Surfacing".

18 Independent Assurance Samples:

18.1 The District or Area laboratories shall take Independent Assurance samples in accordance with the frequency shown in MT 601. The same sample shall be tested by each lab, with all the material returned to the sample.

18.2 If discrepancies occur between the District or Area laboratory and the Acceptance samples, the District or Area laboratory will investigate and change any procedures or equipment found to be causing the differences.
18 Independent Assurance Samples: (continued)

18.3 If differences are found to exist between the District or Area laboratory and the Materials Bureau, the Materials Bureau will have the authority to investigate all of the testing procedures and make any changes found necessary.

19 Plant Mix Aggregates:

19.1 Sampling will be in accordance with the sample size and frequency described in MT 601 and the following:

19.2 WHEN STOCKPILED - In order to establish a stockpile average, the samples shall be secured and tested as the stockpile is being produced.

19.3 BATCH TYPE HOT PLANT - A representative sample of dried aggregate shall be provided by means of an approved sampling device.

19.4 DRYER DRUM HOT PLANT - A representative composite sample shall be provided, by means of an approved sampling device, at a point just prior to the aggregate entering the dryer drum mixer.

19.5 CONTINUOUS FLOW HOT PLANT - A representative sample of dried aggregate shall be provided by means of an approved sampling device.

20 Aggregates for Design:

20.1 MAINTENANCE MIX DESIGN - The amount of material submitted to the Materials Bureau for a proposed mix design shall be as follows: Plant Mix Aggregate - 300 lbs. (136 Kg), Seal and Cover Aggregate - 150 lbs. (68 Kg).

20.2 The sample shall be prepared in the district or area laboratory as described in 19.2 and 19.3.

20.3 Non-Quality Assurance Projects

20.3.1 When a satisfactory stockpile average has been established, a sieve analysis shall be performed, in the District or Area laboratory, on a representative sample of the stockpiled material.

20.3.2 Compare the sieve analysis obtained in paragraph 19.2 above, to the established stockpile average.

20.3.3 If the minus 4 mesh portion of the sample is within plus or minus 2% and the minus 200 mesh portion is within plus or minus 1% of the stockpile average, the sample may be submitted to the Materials Bureau for a mix design, without further preparation.

20.3.4 If the sample does not meet the above criteria, it will be necessary to adjust the gradation, in the District or Area laboratory, to allowable variations described in paragraph 20.2.3 above, before it is shipped to the Materials Bureau.

20.3.5 The stockpile average shall be shown on the laboratory work sheet that accompanies the sample.

21 Mineral Filler:

21.1 One 2.3 Kg (5 lb.) sample per project of mineral filler will be sampled and submitted to the Materials Bureau for testing and acceptance.
22Compaction Samples:

22.1 The District or Area laboratory shall run at least one sample from each different soil type using the methods described in MT 210 or MT 230. It will not be necessary to submit compaction samples to the Materials Bureau. If the material being sampled consists of fine material, 30 pounds (14 Kg) shall be obtained. If the material consists of coarse and fine material, the sample shall be large enough to yield 30 lbs. (14 Kg) of the fine material (minus 4 mesh).

23Field Density Tests:

23.1 Field density tests shall be taken in accordance with MT 601, under "Density Control, Embankment" and MT 218 (Determining Relative Compaction and Percent Moisture).

24Concrete Aggregates:

24.1 Concrete aggregate samples shall be submitted in accordance with MT 601.

25Concrete Test Specimens:

25.1 Concrete compressive and flexural strength test specimens will be made and cured in accordance with MT 101.

26Cement Treated Base:

26.1 Cement Treated Base shall be sampled in accordance Section 12.1 or Section 14.1, and MT 601.

27Field Construction Sampling:

27.1 Samples for soil classification and "R" value shall be obtained from the top 2 feet (0.6 meters) of the sub-grade. Sample frequency will be one sample every 1000 feet (305 meters) for projects with 3 or more cuts or fills per mile. If the project has fewer than 3 cuts or fills per mile the sample distance is extended to 2000 feet (610 meters).

27.2 District/Area lab personnel will determine the soil classification. If the soil class is not equal to or better than that used by the Surfacing Design Unit to determine the typical section, then samples for "R" value determination are to be submitted to the Materials Bureau in Helena.

27.3 Samples for soil classification and/or "R" value are not required when the top two feet of subgrade is constructed with Special Borrow tested and accepted at the borrow source. However, samples may be obtained from the roadway and tested to ensure the in-place material meets the contract requirements. Take samples whenever the material delivered to the roadway appears to differ from samples used for pit acceptance. Sample frequency is at the discretion of the Project Manager.

**NOTE:** These samples are as a design check only. Sampling every 1000 feet (305 meters) is a general guide and some discretion should be used. For example, it may be advisable to take more samples in fill sections than cut sections, or if there is an obvious change in the soil conditions or soil class, etc. No samples will be required for typical sections with a design "R" of 5 or less or for soils classified as A-6 or A-7.
METHODS OF SAMPLING AND TESTING
MT 202-11
SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES
(Modified AASHTO T 11 and T 27)

1 Scope:

1.1 This method covers the determination of the particle size distribution of fine and coarse aggregates by sieving.

1.2 Material passing the 4.75 mm (no. 4) sieve will be washed. Clay particles and other aggregate particles that are dispersed by the wash water, as well as water-soluble materials, will be removed from the aggregate during testing.

2 Referenced Documents:

2.1 AASHTO:
M231 Weighing Devises Used in the Testing of Materials
T11 Materials Finer Than 75-um (No. 200) Sieve in Mineral Aggregates by Washing
T27 Sieve Analysis of Fine and Coarse Aggregates

MT Manual:
MT 201 Sampling Roadway Materials
MT 405 Wire Cloth Sieves for Testing Purposes
MT 607 Reducing Field Samples of Aggregate to Testing Size

3 Definitions:

3.1 Constant Mass: Constant mass has been reached when there is less than a 0.1 percent change in mass over a monitored drying time. For an oven (110 ± 5° C (230 ± 9° F)), an additional 30 minutes of drying. For an uncontrolled heating source such as hot plates (an additional 20 minutes of drying) or microwaves (an additional 10 minutes of drying).

4 Apparatus:

4.1 Balance - The scale or balance for the coarse 4.75 mm (plus 4 mesh) material shall have a sensitivity of 0.01 pounds or 0.01 kilograms. The scale or balance for the fine 4.75 mm (minus 4 mesh) material shall have a sensitivity of 0.1 gram.

4.2 Sieves - The sieve cloth shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. Suitable sieve sizes shall be selected to furnish the information required by the specifications covering the material to be tested. The sieves shall conform to the requirements of MT 405, Wire Cloth Sieves for Testing Purposes.

4.2.1 Sieves—A nest of two sieves, the lower being a 75-um (No. 200) sieve and the upper being a sieve with openings in the range of 2.36 mm (No. 8) to 1.18 mm (No. 16), both conforming to the requirement of MT 405.

4.3 Container - A container sufficient in size to contain the sample covered with water and to permit vigorous agitation without inadvertent loss of any part of the sample or water.

4.4 Heat Source – A heat source capable of drying samples in accordance with Section 5.

4.5 Mechanical Sieve Shaker – A mechanical sieving device shall create motion of the sieves to cause the particles to bounce, tumble, or otherwise turn so as to present different orientations to the sieving surface. The sieving action shall be such that the requirement for sieving thoroughness as described in Section 7.3 is met within a reasonable amount of time.
5 Preparation of Samples:

5.1 Samples for sieve analysis shall be prepared in accordance with MT 607, Reducing Field Samples of Aggregates to Testing Size. The samples shall be the mass desired when dry. The selection of samples of an exact predetermined mass shall not be permitted.

5.2 Dry the sample to a constant mass. For control purposes, particularly where rapid results are desired, it is generally not necessary to dry coarse aggregate to a constant mass for the sieve analysis test. The results are insignificantly affected by the moisture content unless the nominal maximum size is smaller than 12.5 mm (½ in.), or the coarse aggregate contains appreciable material finer than 4.75 mm (No. 4); or the coarse aggregate is highly absorptive (a lightweight aggregate, for example). Samples may be dried at higher temperatures associated with the use of hot plates or other uncontrolled heat sources without affecting results, provided steam escapes without generating pressures sufficient to fracture the particles, and temperatures are not so great as to cause chemical breakdown of the aggregate.

Note 1 - Samples taken for Liquid Limit, Plastic Limit, and Plasticity Index shall be air dried or dried at a temperature no greater than 140°F or 60°C.

Note 2 – Air drying is an acceptable method.

5.3 Representative samples will be graded to determine the percentage of fine material adhering to the coarser fractions.

5.4 Fine Aggregate - The test sample of fine aggregate shall weigh, after drying, approximately the following amount:

| Aggregate with at least 95% passing a 2.36 mm (No. 8) sieve | . . . 100g |
| Aggregate with at least 85% passing a 4.75 mm (No. 4) sieve and more than 5% retained on a 2.36 mm (No. 8) sieve | . . . . . . . 500g |

5.5 Coarse Aggregate - The mass of the test sample of coarse aggregate shall conform with the following:

<table>
<thead>
<tr>
<th>Specified 100% Passing Sieve Size</th>
<th>Min. Field Test Sample Size*</th>
</tr>
</thead>
<tbody>
<tr>
<td>*9.5 (3/8) mm</td>
<td>Kg (lb)</td>
</tr>
<tr>
<td>*12.5 (1/2) mm</td>
<td>6.8 (15)</td>
</tr>
<tr>
<td>*19.0 (3/4) mm</td>
<td>6.8 (15)</td>
</tr>
<tr>
<td>*25.0 (1) mm</td>
<td>9.1 (20)</td>
</tr>
<tr>
<td>*37.5 (1 ½) mm</td>
<td>11.3 (25)</td>
</tr>
<tr>
<td>50 (2) mm</td>
<td>15 (33)</td>
</tr>
<tr>
<td>63 (2 ½) mm</td>
<td>20 (44)</td>
</tr>
<tr>
<td>100* mm</td>
<td>35 (77)</td>
</tr>
</tbody>
</table>

Note 3 - For cover material, concrete aggregate, and samples that require a wear, cleanliness value test, the sample size sent to Helena must be doubled.

5.6 Coarse and Fine Aggregate Mixtures - The mass of the test sample of coarse and fine aggregate mixtures shall be the same as for coarse aggregate.

6 Procedure for Calculating Clinging Fines:

6.1 Follow the procedure in Section 5 for the original test. Save the plus 4.75 mm (4 mesh) material.

6.2 Wash the plus 4.75 mm (4 mesh) material over a protected 75 μm (200 mesh) screen. In most cases it is not necessary to rewash the minus 4.75 mm (4 mesh) material. Dry and re-screen over the original sized screens. Use the original mass of sample taken for the calculation of the plus 4.75 mm (4 mesh) percentages.
6 Procedure for Calculating Clinging Fines: (continued)

6.3 Obtain the difference between the original plus 4.75 mm (4 mesh) material and the washed plus 4.75 mm (4) material. Record for use in calculations of the minus 4.75 mm (4 mesh) material. To convert from the pounds of minus 4 mesh material to grams, multiply by 453.6.

Example: (0.39 pounds) X (453.6) = 176.9 grams.

Use the percentage difference passing the 4.75 mm (4 mesh) divided by the before wash weight to get the reciprocal for multiplication.

Example: (1.55%)/176.9 g) = 0.00876

6.4 The total percent clinging fines is the difference in percent of the plus 4.75 mm (4 mesh) screen sizes.

Example: 55.61(dry) - 54.06(washed) = 1.55% (report as 1.6%)

7 Procedure for Aggregate without Clinging Fines:

7.1 The total sample as prepared in Section 5 shall be separated into a series of sizes. To determine compliance with the specifications for the material under test, avoid overloading the screens.

7.2 Coarse Aggregate: Plus 4.75 mm (4 Mesh) Material - The individual mass of the plus 4.75 mm (4 mesh) portion of the sample, retained on each screen, shall be determined and recorded to the nearest 0.01 of a pound or 0.01 kilogram.

7.2.1 The individual portions shall be saved until the entire plus 4.75 mm (4 mesh) portion of the sample has been screened, weighed and the weights recorded, before any of the material is discarded.

7.2.2 The total amount of material finer than the plus 4.75 mm (4 mesh) sieve may be determined by subtracting the total mass of material retained on the plus 4.75 mm (4 mesh) sieve from the total mass of the initial dry sample being tested.

7.3 Fine Aggregate: Minus 4.75 mm (4 Mesh) Material - At the completion of the sieving as described in Section 7.2, the entire minus 4.75 mm (4 mesh) portions shall be thoroughly mixed and reduced to a minimum of 500 grams.

7.3.1 After drying the sample to a constant mass and weighing, place the test sample in the container and add sufficient water to cover it. A detergent, dispersing agent, or other wetting solution may be added to the water to assure a thorough separation of the material finer than the 75 μm (No. 200) sieve from the coarser particles (Note 4). Agitate the sample with sufficient vigor to result in complete separation of all particles finer than the 75 μm (No. 200) sieve from the coarser particles, and to bring the fine material into suspension. Immediately pour the wash water containing the suspended and dissolved solids over the nested sieves, arranged with the coarser sieve on top. Take care to avoid, as much as feasible, the decantation of coarser particles of the sample.

*Note 4 – There should be enough wetting agent to produce a small amount of suds when the sample is agitated. The quantity will depend on the hardness of the water and the quality of the detergent. Excessive suds may overflow the sieves and carry some material with them.*

7.3.2 Add a second change of water (without wetting agent) to the sample in the container, agitate, and decant as before. Repeat the operation until the wash water is clear.

*Note 5 – If mechanical washing equipment is used, the charging of water, agitating, and decanting may be a continuous operation.*
7 Procedure for Aggregate without Clinging Fines: (continued)

Note 6 – A spray nozzle or a piece of rubber tubing attached to a water faucet may be used to rinse any of the material that may have fallen into the sieves. The velocity of the water, which may be increased by pinching the tubing, should not be sufficient to cause any splashing of the sample over the sides of the sieves.

7.3.3 Return all material retained on the nested sieves by flushing to the washed sample. Dry the washed aggregate to a constant mass.

7.3.4 Following the washing of the sample and flushing any materials retained on the 75 μm (No. 200) sieve back into the container, no water should be decanted from the container except through the 75 μm sieve, to avoid loss of material. Excess water from flushing should be evaporated from the sample in the drying process.

7.3.5 The individual weights of each size of the minus 4.75 mm (4 mesh) portion retained on each sieve shall be determined and recorded to the nearest 0.1 gram.

7.3.6 The individual portions shall be saved until the entire minus 4.75 mm (4 mesh) portion of the sample that was washed has been screened, weighed, and the weights recorded, before any of the material is discarded.

8 Sieving Procedure:

8.1 Nest the sieves in order of decreasing size of opening from top to bottom and place the sample, or portion of the sample if it is to be sieved in more than one increment, on the top sieve. Agitate the sieves by hand or by mechanical apparatus for a sufficient period, established by trial or checked by measurement on the actual test sample, to meet the criterion for adequacy of sieving described in Section 8.3.

8.2 Limit the quantity of material on a given sieve so that all particles have an opportunity to reach sieve openings a number of times during the sieving operation. Table 1 shows the maximum allowable quantity of material that can be retained on each individual sieve at the completion of the sieving operation. In no case shall the quantity retained be so great as to cause permanent deformation of the sieve cloth.

8.2.1 Prevent an overload of material on an individual sieve by splitting the sample into two or more portions, sieving each portion individually. Combine the masses of the several portions retained on a specific sieve before calculating the percentage of the sample on the sieve.

8.3 Continue sieving for a sufficient period and in such manner that, after completion, not more than 0.5 percent by mass of the total sample passes any sieve during one minute of continuous hand sieving. Perform as follows: Hold the individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand. Strike the side of sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute, turn the sieve about one sixth of a revolution at intervals of about 25 strokes. In determining sufficiency of sieving for sizes larger than the 4.75 mm (No. 4) sieve, limit the material on the sieve to a single layer of particles. If the size of the mounted testing sieves makes the described sieving motion impractical, use 203 mm (8 in.) diameter sieves to verify the sufficiency of sieving.

8.4 Unless a mechanical shaker is used, hand sieve particles obtained on the 75 mm (3 in) by determining the smallest sieve opening through which each particle will pass by rotating the particles, if necessary, in order to determine whether they will pass through the particular opening, however, do not force the particles to pass through an opening.
8 Sieving Procedure: (continued)

8.5 The efficiency of the mechanical shaker shall be checked periodically by comparing results with the hand method. This practice will help determine the length of time required for the mechanical shaker to adequately separate material sizes.

Table 1 – Maximum Allowable Quantity of Material Retained on a Sieve, Kg (lb)

<table>
<thead>
<tr>
<th>Nominal Dimensions of Sieve</th>
<th>8 in</th>
<th>10 in</th>
<th>12 in</th>
<th>14 x 14 in</th>
<th>16 x 24 in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve Opening Size</td>
<td>dia</td>
<td>dia</td>
<td>dia</td>
<td>dia</td>
<td>dia</td>
</tr>
<tr>
<td>125 mm (5 in)</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>67.4</td>
</tr>
<tr>
<td>100 mm (4 in)</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>30.6 (67.5)</td>
<td>53.9</td>
</tr>
<tr>
<td>90 mm (31/2 in)</td>
<td>a</td>
<td>a</td>
<td>15.1 (33.3)</td>
<td>27.6 (60.8)</td>
<td>48.5</td>
</tr>
<tr>
<td>75 mm (3 in)</td>
<td>a</td>
<td>8.6 (19.0)</td>
<td>12.6 (27.8)</td>
<td>23.0 (50.7)</td>
<td>40.5</td>
</tr>
<tr>
<td>63 mm (21/2 in)</td>
<td>a</td>
<td>7.2 (15.9)</td>
<td>10.6 (23.4)</td>
<td>19.3 (42.6)</td>
<td>34.0</td>
</tr>
<tr>
<td>50 mm (2 in)</td>
<td>3.6 (7.9)</td>
<td>5.7 (12.6)</td>
<td>8.4 (18.5)</td>
<td>15.3 (33.7)</td>
<td>27.0</td>
</tr>
<tr>
<td>37.5 mm (11/2 in)</td>
<td>2.7 (6.0)</td>
<td>4.3 (9.5)</td>
<td>6.3 (13.9)</td>
<td>11.5 (25.4)</td>
<td>20.2</td>
</tr>
<tr>
<td>25.0 mm (1 in)</td>
<td>1.8 (4.0)</td>
<td>2.9 (6.4)</td>
<td>4.2 (9.5)</td>
<td>7.7 (17.0)</td>
<td>13.5</td>
</tr>
<tr>
<td>19.0 mm (3/4 in)</td>
<td>1.4 (3.1)</td>
<td>2.2 (4.9)</td>
<td>3.2 (7.1)</td>
<td>5.8 (12.8)</td>
<td>10.2</td>
</tr>
<tr>
<td>12.5 mm (1/2 in)</td>
<td>0.89 (2.0)</td>
<td>1.4 (3.1)</td>
<td>2.1 (4.6)</td>
<td>3.8 (8.4)</td>
<td>6.7</td>
</tr>
<tr>
<td>9.5 mm (3/8 in)</td>
<td>0.67 (1.5)</td>
<td>1.1 (2.4)</td>
<td>1.6 (3.5)</td>
<td>2.9 (6.4)</td>
<td>5.1</td>
</tr>
<tr>
<td>4.75 mm (No 4)</td>
<td>0.33 (0.7)</td>
<td>0.54 (1.2)</td>
<td>0.80 (1.8)</td>
<td>1.5 (3.3)</td>
<td>2.6</td>
</tr>
</tbody>
</table>

* Sieves as indicated have less than 5 full openings and should not be used for sieve testing.

9 Calculations:

9.1 Calculate the cumulative weight passing and the percentages to the nearest 0.01 percent on the basis of the total mass of the initial dry sample.

9.2 Coarse Aggregate: Plus 4.75 mm (4 Mesh) Material – For each of the various sieves, the individual cumulative weights must be converted to total weight passing. The total weight passing is divided by the total weight of the initial dry sample multiplied by 100, which will result in the percent passing. (See the example on the following worksheets).

9.3 Fine Aggregate: Minus 4.75 mm (4 Mesh) Material - Calculating the percentages of the minus 4.75 mm (4 mesh) portion of the sample is simplified by using a reciprocal. The reciprocal is determined by dividing the percent of material passing the minus 4.75 mm (4 mesh) sieve by the weight of the minus 4.75 mm (4 mesh) sample before washing. This reciprocal, when multiplied by the various total weights passing, results in the percent passing, in relation to the total sample. (See the example on the following worksheets).

10 Report:

10.1 Unless otherwise required, the results of the sieve analysis shall be reported as the total percentages passing each sieve size and reported to the nearest whole number for all material coarser than the 75 µm (200 mesh) and reported to one tenth of one percent for the 75 µm (200 mesh). Percentages shall be calculated on the basis of the total mass of the initial dry sample, including any material finer than the 75 µm (200 mesh) sieve.

11 Hot Plant Mix Aggregates:

11.1 Plant mix aggregates shall be governed by the provisions of MT 202, except that sampling will be in accordance with MT 201, which provides that the samples be obtained by means of an approved sampling device.
### Constant Mass

<table>
<thead>
<tr>
<th>(500 gram sample):</th>
<th>Initial Wt.</th>
<th>Check Wt.</th>
<th>Second Check Wt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. of Sample Taken.</td>
<td>40.83 lbs.</td>
<td>518.6 grams</td>
<td>518.6 grams</td>
</tr>
<tr>
<td>Wt. Retained 4-Mesh</td>
<td>26.92 lbs.</td>
<td>65.93%</td>
<td>Wear %</td>
</tr>
<tr>
<td>Wt. Passing 4-Mesh.</td>
<td>13.91 lbs.</td>
<td>34.07%</td>
<td>Fracture %</td>
</tr>
</tbody>
</table>

**Before Wash** 518.6 **After** 425.3 **LBW** 93.3

<table>
<thead>
<tr>
<th></th>
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<td>1½”</td>
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</tr>
<tr>
<td>9.42</td>
<td>3/4”</td>
<td>31.41</td>
<td>77</td>
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</tr>
<tr>
<td>16.18</td>
<td>1/2”</td>
<td>24.65</td>
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<td>26.92</td>
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<td>13.91</td>
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<tr>
<td>146.5</td>
<td>8M/10M</td>
<td>372.1</td>
<td>24</td>
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<td>279.6</td>
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<td>239.0</td>
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<td>375.2</td>
<td>80M</td>
<td>143.4</td>
<td>9</td>
<td></td>
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<td>423.9</td>
<td>200M</td>
<td>94.7</td>
<td>6.2</td>
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<td></td>
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<tr>
<td>425.1</td>
<td>Pan Wt.</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0657</td>
<td>Reciprocal</td>
<td>0.04% is less than 0.3%</td>
<td></td>
<td></td>
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### Volume Swell

<table>
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<tr>
<th>Age</th>
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<th>%Swell</th>
<th>Spec. Condition</th>
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<table>
<thead>
<tr>
<th>Extrude Pressure</th>
<th>Expansion Pressure</th>
<th>Equilibrium</th>
</tr>
</thead>
</table>
| Micro-Deval / Sodium Sulfate

<table>
<thead>
<tr>
<th>Micro-Deval Loss</th>
<th>% Sodium Sulfate Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Adhesion</td>
<td>Bitumen</td>
</tr>
</tbody>
</table>

### Adhesion

<table>
<thead>
<tr>
<th>Checked &amp; Approved</th>
<th>Date</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

### Distribution List

- District Administrator
- District Lab Supervisor
- Area Lab Supervisor
- Engr Project Manager
- Maintenance Superintendent
- Construction
- Preconstruction
- County File
- Surfacing Design
- Helena
- Master Lab File

### Independent Assurance Comparison

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Field</th>
<th>Dist</th>
<th>Helena</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Calculations used on form F123-E

PLUS 4.75 mm (+4 MESH) MATERIAL - The total weight passing each sieve divided by the total weight of the initial sample taken (40.83 lbs.), multiplied by 100, results in the percent passing. EXAMPLE: 13.91 ÷ 40.83 = 0.34 X 100 = 34% The value is rounded and recorded to the nearest whole number.

MINUS 4.75 mm (-4 MESH) MATERIAL – (By Reciprocal Method). This sample is dried to a constant mass before and after washing. A reciprocal is determined by dividing the percent of material passing the 4 mesh (34.07%) by the mass of the minus 4 mesh sample (518.6 grams). This reciprocal (0.0657) is multiplied by the cumulative weight passing for each sieve size. EXAMPLE: 518.6 - 146.5 = 372.1; 372.1 x 0.0657 = 24.45% and is rounded down to and is recorded as 24%. The rounding is either up or down to the nearest whole number with the exception of the 200 mesh which is carried to one tenth of a percentage (6.2%). The result represents the percent passing in relation to the total sample.

The adjusted cumulative mass retained in the pan plus the Loss By Wash (LBW) mass should be within 0.3% of original dry mass of the total sample. EXAMPLE: 425.1+93.3=518.4, 518.6-518.4=0.2, (0.2/518.6)x100=0.04%
**Field Aggregate Chart - Sample for Clinging Fines**

<table>
<thead>
<tr>
<th>Project No.:</th>
<th>Contract No.:</th>
<th>Project Name:</th>
<th>Mat'l's. Suprv.:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Contract Item #</th>
<th>UPN:</th>
<th>Laboratory Pit No.:</th>
<th>Test For:</th>
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<tbody>
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</table>

<table>
<thead>
<tr>
<th>County:</th>
<th>Pit Location:</th>
<th>Section:</th>
<th>Township:</th>
<th>Range:</th>
</tr>
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<tbody>
<tr>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Lot No.</th>
<th>Date</th>
<th>Sampled By</th>
<th>Tested By</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<table>
<thead>
<tr>
<th>Stationing</th>
<th>Lift</th>
<th>Lane</th>
</tr>
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<tr>
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<table>
<thead>
<tr>
<th>Constant Mass</th>
<th>Wt. 1</th>
<th>Wt. 2</th>
<th>Wt. 3</th>
<th>Constant Mass</th>
<th>Wt. 1</th>
<th>Wt. 2</th>
<th>Wt. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. of Sample Taken</td>
<td>25.23 Lbs.</td>
<td>100%</td>
<td></td>
<td>Wt. of Orig. Sample Taken</td>
<td>25.23 Lbs.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wt. Retained 4-Mesh</td>
<td>11.59 Lbs.</td>
<td>45.94%</td>
<td></td>
<td>Difference in Weight Passing 4-Mesh</td>
<td>0.39 Lbs</td>
<td>1.55%</td>
<td></td>
</tr>
<tr>
<td>Wt. Passing 4-Mesh</td>
<td>13.64 Lbs.</td>
<td>54.06%</td>
<td></td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Before Wash</th>
<th>After Wash</th>
<th>LBW</th>
<th>Before Wash</th>
<th>After Wash</th>
<th>LBW</th>
</tr>
</thead>
<tbody>
<tr>
<td>520.5</td>
<td>448.0</td>
<td>72.5</td>
<td>176.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0%</td>
<td>3/4&quot;</td>
<td>25.23</td>
<td>100</td>
<td></td>
<td></td>
<td>0</td>
<td>0%</td>
<td>3/4&quot;</td>
<td>25.23</td>
<td>100</td>
<td>100</td>
<td>0%</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.29 lbs</td>
<td>1/2&quot;</td>
<td>23.94</td>
<td>94.89</td>
<td></td>
<td></td>
<td></td>
<td>1.22 lbs</td>
<td>1/2&quot;</td>
<td>24.01</td>
<td>95.16</td>
<td>95.16</td>
<td>1/2&quot;</td>
<td>0.27</td>
<td></td>
<td>1/2&quot;</td>
<td></td>
<td>1.55</td>
</tr>
<tr>
<td>4.69 lbs</td>
<td>3/8&quot;</td>
<td>20.54</td>
<td>81.41</td>
<td></td>
<td></td>
<td></td>
<td>4.43 lbs</td>
<td>3/8&quot;</td>
<td>20.80</td>
<td>82.44</td>
<td>82.44</td>
<td>3/8&quot;</td>
<td>1.03</td>
<td></td>
<td>3/8&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* 11.59 lbs</td>
<td>4 M</td>
<td>13.64</td>
<td>54.06</td>
<td></td>
<td></td>
<td></td>
<td>* 11.20 lbs</td>
<td>4 M</td>
<td>14.03</td>
<td>55.61</td>
<td>55.61</td>
<td>4 M</td>
<td>1.55</td>
<td></td>
<td>4 M</td>
<td></td>
<td>1.55</td>
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<tr>
<td>219.7 g</td>
<td>8/10 M</td>
<td>300.8</td>
<td>31.25</td>
<td></td>
<td></td>
<td></td>
<td>19.9 g</td>
<td>8/10 M</td>
<td>157.0</td>
<td>1.38</td>
<td>1.38</td>
<td>8/10 M</td>
<td></td>
<td></td>
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<tr>
<td>375.8 g</td>
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<td>48.4 g</td>
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<td>420.5 g</td>
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<td>90.0 g</td>
<td>80 M</td>
<td>86.9</td>
<td>0.76</td>
<td>0.76</td>
<td>80 M</td>
<td></td>
<td></td>
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<tr>
<td>447.9 g</td>
<td>200 M</td>
<td>72.6</td>
<td>7.54</td>
<td></td>
<td></td>
<td></td>
<td>174.9 g</td>
<td>200 M</td>
<td>2.0</td>
<td>0.02</td>
<td>0.02</td>
<td>200 M</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Pan/Total</td>
<td>Reciprocal</td>
<td>0.1039</td>
<td></td>
<td>Pan/Total</td>
<td>Reciprocal</td>
<td>0.0088</td>
<td></td>
<td>Pan/Total</td>
<td>Reciprocal</td>
<td>0.0088</td>
<td></td>
<td>Pan/Total</td>
<td>Reciprocal</td>
<td>0.0088</td>
<td></td>
<td>Pan/Total</td>
<td>Reciprocal</td>
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<table>
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<tr>
<th>Dust Ratio</th>
<th>Moisture</th>
<th>Fracture</th>
<th>Liquid Limit</th>
<th>Plasticity Index</th>
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<tbody>
<tr>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Checked by</th>
<th>Date</th>
<th>Entered by</th>
<th>Date</th>
<th>REMARKS: See the following page for a written explanation of calculations used for this form (F104C-E).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>
Calculations used on form F104C-E

PLUS 4.75 mm (+4 MESH) MATERIAL - The total weight passing each sieve divided by the total weight of the initial sample taken (25.23 lbs.), multiplied by 100, results in the percent passing.  EXAMPLE: 13.64 ÷ 25.23 = 0.5406 X 100 = 54.06%

MINUS 4.75 mm (-4 MESH) MATERIAL – (By Reciprocal Method). This sample is dried to a constant mass before and after washing. A reciprocal is determined by dividing the percent of material passing the 4 mesh (54.06%) by the mass of the minus 4 mesh sample (520.5 grams). This reciprocal (0.1039) is multiplied by the cumulative weight passing for each sieve size. EXAMPLE: 520.5 – 219.7 = 300.8; 300.8 x 0.1039 = 31.25% and is rounded down to and is recorded as 31%. The rounding is either up or down to the nearest whole number with the exception of the 200 mesh which is carried to one tenth of a percentage (7.5%). The result represents the percent passing in relation to the total sample.

For the Actual Grading % Passing of the +4 MESH, use the second gradation.

To calculate the % of Clinging Fines on each sieve (change in percentage), take the percent from the +4 MESH of the second gradation and subtract the percent from the +4 MESH of the first gradation.  EXAMPLE: 95.16 – 94.89 = 0.27%

In order to calculate the Actual Grading % Passing the MINUS 4.75 mm (-4 MESH), the percent passing in the second gradation is added to the percent passing the first gradation.  EXAMPLE: 31.25 + 1.38 = 32.63

The reciprocal for the second sieve analysis is calculated by taking the % of clinging fines on the +4 MESH and dividing it by the before wash weight of the second gradation.  EXAMPLE: 1.55 ÷ 176.9 = 0.0088

The adjusted cumulative mass retained in the pan plus the Loss By Wash (LBW) mass should be within 0.3% of original dry mass of the total sample.  EXAMPLE: 447.9 + 2.5 = 450.4, 450.5 – 450.4 = 0.1, (0.1/450.5) x 100 = 0.02%
METHODS OF SAMPLING AND TESTING

MT 203-04

METHOD OF TEST FOR UNIT WEIGHT OF AGGREGATE
(Modified AASHTO T 19)

1 Scope:

1.1 This method covers the determination of unit weight in a compacted or loose condition, and calculated voids in fine, coarse, or mixed aggregates based on the same determination. The method is applicable to aggregates not exceeding 6 in. [150 mm] in nominal maximum size.

Note 1 - Unit weight is the traditional terminology used to describe the property determined by this test method. Some believe the proper term is unit mass or density or bulk density, but consensus on this alternate terminology has not been obtained.

1.2 The values stated in either inch-pound units or acceptable metric units are to be regarded separately as standard, as appropriate for a specification with which this test method is used. An exception is with regard to sieve sizes and nominal size of aggregate, in which the metric values are the standard as stated in AASHTO M 92. Within the text, metric units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system must be used independently of the other, without combining values in any way.

2 Referenced Documents:

2.1 AASHTO:

M 92 Wire Cloth and Sieves for Testing Purposes
T 2 Sampling Aggregates
T 19 Bulk Density (“Unit Weight”) and Voids in Aggregate
T 84 Specific Gravity and Absorption of Fine Aggregate
T 85 Specific Gravity and Absorption of Coarse Aggregate

MT Manual:

MT 115 Weight per Cubic Foot, Yield and Air Content (Gravimetric) of Concrete
MT 204 Absorption of Fine Aggregate
MT 205 Specific Gravity and Absorption of Coarse Aggregate
MT 405 Specification for Wire-Cloth Sieves for Testing Purposes
MT 607 Procedure for Reducing Field Samples of Aggregate to Testing Size

3 Apparatus:

3.1 Balance - A balance or scale accurate within 0.3 percent of the test load at any point within the range of use. The range of use shall be considered to extend from the weight of the measure empty to the weight of the measure plus its contents at 100 pounds per cubic foot (1600 kilograms per cubic meter).

3.2 Tamping Rod - A round, straight steel rod, 3/8 in. (16 mm) in diameter and approximately 24 in. (600 mm) in length, having one end rounded to a hemispherical tip of the same diameter as the rod.

3.3 Measure - A cylindrical metal measure preferably provided with handles. It shall be watertight, with the top and bottom true and even, and sufficiently rigid to retain its form under rough usage. The measure should have a height approximately equal to the diameter, but in no case shall the height be less than 80% nor more than 150% of the diameter. The capacity of the measure shall conform to the limits in Table 1 for the aggregate size to be tested. The thickness of metal in the measure shall be as described in Table 2. The top rim shall be smooth and plane within 0.01 in. [0.25 mm] and shall be parallel to the bottom within 0.5° (Note 2).
### TABLE 1 Capacity of Measures

<table>
<thead>
<tr>
<th>Nominal Maximal Size of Aggregate</th>
<th>Capacity of Measure&lt;sup&gt;A&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>in.</td>
<td>mm</td>
</tr>
<tr>
<td>1/2</td>
<td>12.5</td>
</tr>
<tr>
<td>1</td>
<td>25.0</td>
</tr>
<tr>
<td>1½</td>
<td>37.5</td>
</tr>
<tr>
<td>3</td>
<td>75</td>
</tr>
<tr>
<td>4½</td>
<td>112</td>
</tr>
<tr>
<td>6</td>
<td>150</td>
</tr>
</tbody>
</table>

<sup>A</sup>The indicated size of measure shall be used to test aggregates of a nominal maximum size equal to or smaller than that listed. The actual volume of the measure shall be at least 95% of the nominal volume listed.

### TABLE 2 Requirements of Measures

<table>
<thead>
<tr>
<th>Capacity of Measure</th>
<th>Thickness of Metal. min</th>
<th>Thickness of Metal. min</th>
<th>Thickness of Metal. min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bottom</td>
<td>Upper 1½ in. or 38 mm of Wall&lt;sup&gt;A&lt;/sup&gt;</td>
<td>Remainder of Wall</td>
</tr>
<tr>
<td>Less than 0.4 ft³</td>
<td>0.20 in.</td>
<td>0.10 in.</td>
<td>0.10 in.</td>
</tr>
<tr>
<td>0.4 ft³ to 1.5 ft³, incl</td>
<td>0.20 in.</td>
<td>0.20 in.</td>
<td>0.12 in.</td>
</tr>
<tr>
<td>Over 1.5 to 2.8 ft³, incl</td>
<td>0.40 in.</td>
<td>0.25 in.</td>
<td>0.15 in.</td>
</tr>
<tr>
<td>Over 2.8 to 4.0 ft³, incl</td>
<td>0.50 in.</td>
<td>0.30 in.</td>
<td>0.20 in.</td>
</tr>
<tr>
<td>Less than 11 L</td>
<td>5.0 mm</td>
<td>2.5 mm</td>
<td>2.5 mm</td>
</tr>
<tr>
<td>11 to 42 L, incl</td>
<td>5.0 mm</td>
<td>5.0 mm</td>
<td>3.0 mm</td>
</tr>
<tr>
<td>Over 42 to 80 L, incl</td>
<td>10.0 mm</td>
<td>6.4 mm</td>
<td>3.8 mm</td>
</tr>
<tr>
<td>Over 80 to 133 L, incl</td>
<td>13.0 mm</td>
<td>7.6 mm</td>
<td>5.0 mm</td>
</tr>
</tbody>
</table>

<sup>A</sup>The added thickness in the upper portion of the wall may be obtained by placing a reinforcing band around the top of the measure.

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**Note 2 -** The top rim is satisfactorily plane if a 0.01 in. (0.25 mm) feeler gage cannot be inserted between the rim and a piece of ¼ in. (6 mm) or thicker plate glass laid over the measure. The top and bottom are satisfactorily parallel if the slope between pieces of plate glass in contact with the top and bottom does not exceed 0.87 percent in any direction.

**3.1.1** If the measure may also be used for testing for unit weight of concrete according to T 121, the measure should be made of steel or other suitable metal not readily subject to attack by cement paste.
3 Apparatus: (continued)

Note 3 - Reactive materials such as aluminum alloys may be used where, as a consequence of an initial reaction, a surface film is formed which protects the metal against further corrosion. Measures larger than nominal 1-ft³ (28-L) capacity should be made of steel for rigidity, or the minimum thicknesses of metal listed in Table 2 should be suitably increased.

3.4 Shovel or Scoop--A shovel or scoop of convenient size for filling the measure with aggregate.

3.5 Calibration Equipment--A piece of plate glass, preferably at least ¼ in. [6 mm] thick and at least 1 in. [25 mm] larger than the diameter of the measure to be calibrated. A supply of water pump or chassis grease that can be placed on the rim of the container to prevent leakage.

4 Sampling:

4.1 Sampling should generally be accomplished in accordance with MT 607, Procedure for Reducing Field Samples of Aggregate to Testing Size.

5 Sample:

5.1 The size of sample shall be approximately 125 to 200% of the quantity required to fill the measure, and shall be handled in a manner to avoid segregation. Dry the sample of aggregate to essentially constant mass, preferably in an oven at 230 ± 9°F (110 ± 5°C).

6 Calibration of Measure:

6.1 Fill the measure with water at room temperature and cover with a piece of plate glass in such a way as to eliminate bubbles and excess water.

6.2 Determine the mass of water in the measure using the balance described in 5.1.

6.3 Measure the temperature of water to determine its density from Table 3, interpolating if necessary.

6.4 Calculate the volume, V, of the measure by dividing the mass of water required to fill the measure by its density. Alternately, calculate the factor for the measure (1/volume) by dividing the density of the water by the mass required to fill the measure.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Density of Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>°F</td>
<td>°C</td>
</tr>
<tr>
<td>60</td>
<td>15.6</td>
</tr>
<tr>
<td>65</td>
<td>18.3</td>
</tr>
<tr>
<td>70</td>
<td>21.1</td>
</tr>
<tr>
<td>(73.4)</td>
<td>(23.0)</td>
</tr>
<tr>
<td>75</td>
<td>23.9</td>
</tr>
<tr>
<td>80</td>
<td>26.7</td>
</tr>
<tr>
<td>85</td>
<td>29.4</td>
</tr>
</tbody>
</table>
6 Calibration of Measure: (continued)

Note 4 - For the calculation of unit weight, the volume of the measure in acceptable metric units should be expressed in cubic meters, or the factor as 1/m³. However, for convenience the size of the measure may be expressed in liters (equal to m³/1,000).

6.5 Measures shall be recalibrated at least once a year or whenever there is reason to question the accuracy of the calibration.

7 Selection of Procedure:

7.1 The shoveling procedure for loose unit weight shall be used only when specifically stipulated. Otherwise, the compact unit weight shall be determined by the rodding procedure for aggregates having a nominal maximum size of 1½ in. [37.5 mm] or less, or by the jigging procedure for aggregates having a nominal maximum size greater than 1½ in. [37.5 mm] and not exceeding 6 in. (150 mm).

8 Rodding Procedure:

8.1 Fill the measure one-third full and level the surface with the fingers. Rod the layer of aggregate with 25 strokes of the tamping rod evenly distributed over the surface. Fill the measure two-thirds full and again level and rod as above. Finally, fill the measure to overflowing and rod again in the manner previously mentioned. Level the surface of the aggregate with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

8.2 In rodding the first layer, do not allow the rod to strike the bottom of the measure forcibly. In rodding the second and third layers, use vigorous effort, but not more force than to cause the tamping rod to penetrate to the previous layer of aggregate.

Note 5 - In rodding the larger sizes of coarse aggregate, it may not be possible to penetrate the layer being consolidated, especially with angular aggregates. The intent of the procedure will be accomplished if vigorous effort is used.

8.3 Determine the mass of the measure plus contents, and the mass of the measure alone and record the values to the nearest 0.1 lb (0.05 kg).

9 Jigging Procedure:

9.1 Fill the measure in three approximately equal layers as described in 10.1 compacting each layer by placing the measure on a firm base, such as a cement-concrete floor, raising the opposite sides alternately about 2 in. (50 mm), and allowing the measure to drop in such a manner as to hit with a sharp, slapping blow. The aggregate particles, by this procedure, will arrange themselves in a densely compacted condition. Compact each layer by dropping the measure 50 times in the manner described, 25 times on each side. Level the surface of the aggregate with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

9.2 Determine the mass of the measure plus contents, and the mass of the measure alone, and record the values to the nearest 0.1 lb (0.05 kg).

10 Shoveling Procedure:

10.1 Fill the measure to overflowing by means of a shovel or scoop, discharging the aggregate from a height not to exceed 2 in. (50 mm) above the top of the measure. Exercise care to prevent, so far as possible, segregation of the particle sizes of which the sample is composed. Level the
10 Shoveling Procedure: (continued)

of the aggregate with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

10.2 Determine the mass of the measure plus contents, and the mass of the measure alone, and record the values to the nearest 0.1 lb (0.05 kg).

11 Calculations:

11.1 Unit Weight--Calculate the unit weight for the rodding, jigging, or shoveling procedure as follows:

\[
M = \frac{(G - T)}{V} \quad (1)
\]

or

\[
M = (G - T) \times F \quad (2)
\]

where:

\[
M = \text{unit weight of aggregate, lb/ft}^3 [\text{kg/m}^3]
\]

\[
G = \text{mass of aggregate plus the measure, lb [kg]}
\]

\[
T = \text{mass of the measure, lb [kg]}
\]

\[
V = \text{volume of measure, ft}^3 [\text{m}^3]
\]

\[
F = \text{factor for measure, ft}^-3 [\text{m}^-3]
\]

11.1.1 The unit weight determined by this method is for aggregate in an oven-dry condition. If the unit weight in terms of saturated-surface-dry (SSD) condition is desired, use the exact procedure in this method, and then determine the SSD unit weight by the following formula:

\[
M_{SSD} = M \times [1 + (A/100)] \quad (3)
\]

where:

\[
M_{SSD} = \text{unit weight in SSD condition, lb/ft}^3 [\text{kg/m}^3]
\]

\[
A = \text{absorption, %, determined in accordance with AASHTO T84 or T 85.}
\]

11.2 Void Content--Calculate the void content in the aggregate using the unit weight determined by either the rodding, jigging, or shoveling procedure, as follows:

\[
\text{Voids, %} = 100 \left(\frac{(S \times W) - M}{S \times W}\right) \quad (4)
\]

where:

\[
M = \text{unit weight of aggregate, lb/ft}^3 [\text{kg/m}^3]
\]

\[
S = \text{bulk specific gravity (dry basis) as determined in accordance with AASHTO T 84 or T 85.}
\]

\[
W = \text{density of water, 62.3 lb/ft}^3 [998 \text{ kg/m}^3]
\]
12 Report:

12.1 Report the results for unit weight to the nearest 1 lb/ft³ [10 kg/m³] as follows:

12.1.1 Unit weight by rodding, or

12.1.2 Unit weight by jigging, or

12.1.3 Loose unit weight.

12.2 Report the results for void content to the nearest 1% as follows:

12.2.1 Voids in aggregate compacted by rodding, % or

12.2.2 Voids in aggregate compacted by jigging, %, or

12.2.3 Voids in loose aggregate, %.

13 Reproducibility of Results:

13.1 Results by an operator using the sample and procedure check within one percent.
METHODS OF SAMPLING AND TESTING
MT 204-04

METHOD OF TEST FOR SPECIFIC GRAVITY AND
ABSORPTION OF FINE AGGREGATE
(Modified AASHTO T 84)

1 Scope:

1.1 This method covers the determination of bulk and apparent specific gravity, 23/23°C 73.4/73.4°F, and absorption of fine aggregate.

1.2 This method determines (after 15 h in water) the bulk specific gravity and the apparent specific gravity as defined in MT-206, the bulk specific gravity on the basis of weight of saturated surface-dry aggregate, and the absorption as defined in MT-206.

1.3 The values stated in acceptable metric unit (SI units and units specifically approved in AASHTO R1 for use with SI units) are to be regarded as the standard.

1.4 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2 Referenced Documents:

2.1 AASHTO:
R 1 Metric Practice
T 133 Density of Hydraulic Cement

ASTM Standards:
C 125 Terminology Relating to Concrete and Concrete Aggregates
C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

MT Materials Manual:
MT 201 Sampling Roadway Materials
MT 205 Specific Gravity and Absorption of Coarse Aggregate
MT 206 Definitions of Terms Relating to Density and Specific Gravity of Solids, Liquids, and Gases
MT 607 Reducing Field Samples of Aggregate to Testing Size

3 Apparatus:

3.1 Balance - A balance having a capacity of 1 kilogram or more and sensitive to 0.1 gram or less.

3.2 Pycnometer - A flask or other suitable container into which the fine aggregate test sample can be readily introduced and in which the volume content can be reproduced with ± 0.1 cm³. The volume of the container filled to mark shall be at least 50 percent greater than the space required to accommodate the test sample. A volumetric flask of 500 capacity or a fruit jar fitted with a pycnometer top is satisfactory for a 500-g test sample of most fine aggregates. A Le Chatelier flask as described in AASHTO T 133 is satisfactory for an approximately 55-g test sample.

3.3 Mold - A metal mold in the form of a frustum of a cone with dimensions as follows: 40 ± 3 mm inside diameter at the top, 90 ± 3 mm inside diameter at the bottom, and 75 ± 3 mm in height, with the metal having a minimum thickness of 0.8 mm.
3 Apparatus: (continued)

3.4 Tamper - A metal tamper weighing 340 ± 15 g and having a flat circular tamping face 25 ± 3 mm in diameter.

4 Sampling:

4.1 Sampling shall be accomplished in general accordance with MT-201.

5 Preparation of Test Specimen:

5.1 Obtain approximately 1000 grams of the fine aggregate from the sample using the applicable procedures described in MT 607.

5.1.1 Dry it in a suitable pan or vessel to constant weight at a temperature of 110 ± 5°C (230 ± 9°F). Allow it to cool to comfortable handling temperature, cover with water, either by immersion or by the addition of at least 6 percent moisture to the fine aggregate and permit to stand for 15 to 19 hours.

5.1.2 As an alternative to Section 5.1.1, where the absorption and specific gravity values are to be used in proportioning concrete mixtures with aggregates used in their naturally moist condition, the requirement for initial drying to constant weight may be eliminated and, if the surfaces of the particles have been kept wet, the 15-h soaking may also be eliminated.

Note 1 - Values for absorption and for specific gravity in the saturated surface-dry condition may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with Section 5.1.1.

5.2 Decant excess water with care to avoid loss of fines, spread the sample on a flat nonabsorbent surface exposed to a gently moving current of warm air, and stir frequently to secure homogeneous drying. If desired, mechanical aids such as tumbling or stirring may be employed to assist in achieving the saturated surface-dry condition. Continue this operation until the test specimen approaches a free-flowing condition. Follow the procedure in Section 5.2.1 to determine whether or not surface moisture is present on the constituent fine aggregate particles.

5.2.1 Cone Test for Surface Moisture - Hold the mold firmly on a smooth nonabsorbent surface with the large diameter down. Place a portion of the partially dried fine aggregate loosely in the mold by filling it to overflowing and heaping additional material above the top of the mold by holding it with the cupped fingers of the hand holding the mold. Lightly tamp the fine aggregate into the mold with 25 light drops of the tamper. Each drop should start about 5 mm (0.2 in.) above the top surface of the fine aggregate. Permit the tamper to fall freely under gravitational attraction on each drop. Adjust the starting height to the new surface elevation after each drop and distribute the drops over the surface. Remove loose sand from the base and lift the mold vertically. If surface moisture is still present, the fine aggregate will retain the molded shape. When the fine aggregate slumps slightly, it indicates that it has reached a surface-dry condition. Some angular fine aggregate or material with a high proportion of fines may not slump in the cone test upon reaching a surface-dry condition. This may be the case if fines become airborne upon dropping a handful of the sand from the cone test 100 to 150 mm into a surface. For these materials, the saturated surface-dry condition should be considered as the point that one side of the fine aggregate slumps slightly upon removing the mold.
5 Preparation of Test Specimen: (continued)

Note 2 - The following criteria have also been used on materials that do not readily slump:

(1) Provisional Cone Test - Fill the cone mold as described in Section 5.2.1 except only use 10 drops of the tamper. Add more fine aggregate and use 10 drops of the tamper again. Then add material two more times using 3 and 2 drops of the tamper, respectively. Level off the material even with the top of the mold, remove loose material from the base; and lift the mold vertically.

(2) Provisional Surface Test - If airborne fines are noted when the fine aggregate is such that it will not slump when it is at a moisture condition, add more moisture to the sand, and at the onset of the surface-dry condition, with the hand lightly pat approximately 100 g of the material on a flat, dry, clean, dark or dull nonabsorbent surface such as a sheet of rubber, a worn oxidized, galvanized, or steel surface, or a black-painted metal surface. After 1 to 3 s, remove the fine aggregate. If noticeable moisture shows on the test surface for more than 1 to 2 s, then surface moisture is considered to be present on the fine aggregate.

(3) Calorimetric procedures described by Kandhal and Lee, Highway Research Record No. 307, p. 44.

(4) For reaching the saturated surface-dry condition on a single size material that slumps when wet, hard-finish paper towels can be used to surface dry the material until the point is just reached where the paper towel does not appear to be picking up moisture from the surfaces of the fine aggregate particles.

6 Procedure:

6.1 Make and record all weight determinations to 0.1 g.

6.2 Partially fill the pycnometer with water. Immediately introduce into the pycnometer 500 ± 10 g of saturated surface-dry fine aggregate prepared as described in Section 6, and fill with additional water to approximately 90 percent of capacity. Roll, invert, and agitate the pycnometer to eliminate all air bubbles. Adjust its temperature to 23 ± 1.7°C (73.4 ± 3°F), if necessary by immersion in circulating water, and bring the water level in the pycnometer to its calibrated capacity. Determine total weight of the pycnometer, specimen, and water.

Note 3 - It normally takes about 15 to 20 minutes to eliminate air bubbles. Dipping the tip of a paper towel into the pycnometer has been found to be useful in dispersing the foam that sometimes builds up when eliminating the air bubbles.

6.2.1 Alternative to Weighing in Section 6.2 - The quantity of added water necessary to fill the pycnometer at the required temperature may be determined volumetrically using a buret accurate to 0.15 mL. Compute the total weight of the pycnometer, specimen, and water as follows:

\[ C = 0.9975V_a + S + W \]

where:

\[ C \] = weight of pycnometer with specimen and water to calibration mark, g,

\[ V_a \] = volume of water added to pycnometer, mL

\[ S \] = weight of saturated surface-dry specimen, g, and

\[ W \] = weight of the pycnometer empty, g.
Procedure: (continued)

6.2.2 Alternative to the Procedure in Section 6.2 - Use a Le Chatelier flask initially filled with water to a point on the stem between the 0 and the 1 -mL mark. Record this initial reading with the flask and contents within the temperature range of 23 ± 1.7°C (73.4 ± 3°F). Add 55 ± 5 g of fine aggregate in the saturated surface-dry condition (or other weight as necessary to result in raising the water level to some point on the upper series of graduation). After all fine aggregate has been introduced, place the stopper in the flask and roll the flask in an inclined position, or gently whirl it in a horizontal circle so as to dislodge all entrapped air, continuing until no further bubbles rise to the surface. Take a final reading with the flask and contents within 1°C (1.8°F) of the original temperature.

6.3 Remove the fine aggregate from the pycnometer, dry to constant weight at a temperature of 110 ± 5°C (230 ± 9°F), cool in air at room temperature for 1 ± ½ h, and weigh.

6.3.1 If the Le Chatelier flask method is used, a separate sample portion is needed for the determination of absorption. Weigh a separate 500 ± 10 g portion of the saturated surface-dry fine aggregate, dry to constant weight, and reweigh.

Note 4 - In lieu of weighing the sample that has been removed from the pycnometer, a second 500 ± 10 g portion of the saturated surface-dry sample may be used to determine the dry weight.

6.4 Determine the weight of the pycnometer filled to its calibration capacity with water at 23 ± 1.7°C (73.4 ± 3°F).

6.4.1 Alternative to Weighing in Section 6.4 - The quantity of water necessary to fill the empty pycnometer at the required temperature may be determined volumetrically using a buret accurate to 0.15 mL. Calculate the weight of the pycnometer filled with water as follows:

\[ B = 0.9975 \times V + W \]

where:

\( B \) = weight of flask filled with water, g,
\( V \) = volume of flask, mL, and
\( W \) = weight of the flask empty, g.

7 Bulk Specific Gravity:

7.1 Calculate the bulk specific gravity, 23/23°C (73.4/73.4°F), as defined in MT-206 as follows:

\[ \text{Bulk sp gr} = \frac{A}{B + S - C} \]

where:

\( A \) = weight of oven-dry specimen in air, g,
\( B \) = weight of pycnometer filled with water, g,
\( C \) = weight of pycnometer with specimen and water to calibration mark, g, and
\( S \) = weight of saturated surface-dry specimen, g.
7.2 If the Le Chatelier flask method was used, calculate the bulk specific gravity, 23/23°C, as follows:

\[
\text{Bulk sp gr} = \frac{S_1(A/S)}{0.9975(R_2 - R_1)}
\]

where:

\(R_1\) = initial reading of water level in Le Chatelier flask,

\(R_2\) = final reading of water level in Le Chatelier flask, and

\(S_1\) = weight of saturated surface-dry specimen used in Le Chatelier flask, g.

8 **Bulk Specific Gravity (Saturated Surface-Dry Basis):**

8.1 Calculate the bulk specific gravity, 23/23°C (73.4/73.4°F), on the basis of weight of saturated surface-dry aggregate as follows:

\[
\text{Bulk sp gr (saturated surface-dry basis)} = \frac{A}{B+S-C}
\]

8.2 If the Le Chatelier flask method was used, calculate the bulk specific gravity, 23/23°C, on the basis of saturated surface-dry aggregate as follows:

\[
\text{Bulk sp gr (saturated surface-dry basis)} = \frac{S_1}{0.9975(R_2 - R_1)}
\]

9 **Apparent Specific Gravity:**

9.1 Calculate the apparent specific gravity, 23/23°C (73.4/73.4°F), as defined in MT-206 as follows:

\[
\text{Apparent sp gr} = \frac{A}{B+A-C}
\]

10 **Absorption:**

10.1 Calculate the percentage of absorption, as defined in ASTM C 125, as follows:

\[
\text{Absorption, %} = \left(\frac{S-A}{A}\right) \times 100
\]

11 **Report:**

11.1 Report specific gravity results to the nearest 0.01 and absorption to the nearest 0.1 percent. The Appendix gives mathematical interrelationships among the three types of specific gravities and absorption. These may be useful in checking the consistency of reported data or calculating a value that was not reported by using other reported data.

11.2 If the fine aggregate was tested in a naturally moist condition other than the oven dried and 15-h soaked condition, report the source of the sample and the procedures used to prevent drying prior to testing.
METHODS OF SAMPLING AND TESTING

METHOD OF TEST FOR SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATES
(Modified AASHTO T 85)

1 Scope:

1.1 This method covers the determination of specific gravity and absorption of coarse aggregate. The specific gravity may be expressed as bulk specific gravity, bulk specific gravity (saturated-surface-dry (SSD)), or apparent specific gravity. The bulk specific gravity (SSD) and absorption are based on aggregate after 15 h soaking in water. This method is not intended to be used with lightweight aggregates.

1.2 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2 Referenced Documents:

2.1 AASHTO:
M 43 Sizes of Aggregate for Road and Bridge Construction
M 92 Wire Cloth Sieves for Testing Purposes
R 1 Metric Practice

MT Materials Manual:
MT 201 Sampling Roadway Materials
MT 202 Sieve Analysis of Fine and Coarse Aggregates
MT 204 Specific Gravity and Absorption of Fine Aggregate
MT 206 Terms Relating to Density and Specific Gravity of Solids, Liquids and Gases
MT 607 Reducing Field Samples of Aggregate to Testing Size

¹This method agrees with ASTM C 127-88 except for differences in soaking time, accuracy of weighing, balance requirements, and water tank requirements.

2.2 ASTM Standards:
C 125 Terminology Relating to Concrete and Concrete Aggregates
C 670 Practice of Preparing Precision Statements for Test Methods for Construction Materials

3 Summary of Method:

3.1 A sample of aggregate is immersed in water for approximately 15 h to essentially fill the pores. It is then removed from the water, the water dried from the surface of the particles, and weighed. Subsequently the sample is weighed while submerged in water. Finally the sample is oven-dried and weighed a third time. Using the weights thus obtained and formulas in the method, it is possible to calculate three types of specific gravity and absorption.

4 Terminology:

4.1 Absorption - The increase in the weight of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry weight. The aggregate is considered "dry" when it has been maintained at a temperature of 110 ± 5°C for sufficient time to remove all uncombined water.
4 Terminology: (continued)

4.2 Specific Gravity - The ratio of the mass (or weight in air) of a unit volume of a material to the mass of the same volume of water at stated temperatures. Values are dimensionless.

4.3 Apparent Specific Gravity - The ratio of the weight in air of a unit volume of the impermeable portion of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

4.4 Bulk Specific Gravity - The ratio of the weight in air of a unit volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

4.5 Bulk Specific Gravity (SSD) - The ratio of the weight in air of a unit volume of aggregate, including the weight of water within the voids filled to the extent achieved by submerging in water for approximately 15 h (but not including the voids between particles) at a stated temperature, compared to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

Note 1 - The terminology for specific gravity is based on terms in MT-206 and that for absorption is based on that term in ASTM C 125.

5 Apparatus:

5.1 Balance - A balance having a capacity of 1 kilogram or more and sensitive to 0.1 gram or less.

5.2 Sample Container - A wire basket of 3.35 mm (No. 6) or finer mesh, or a bucket of approximately equal breadth and height, with a capacity of 4 to 7 L for 37.5-mm (1½-in.) nominal maximum size aggregate or smaller, and a larger container as needed for testing larger maximum size aggregate. The container shall be constructed so as to prevent trapping air when the container is submerged.

5.3 Water Tank - A watertight tank into which the sample and container are placed for complete immersion while suspended below the balance, equipped with an overflow outlet for maintaining a constant water level.

5.4 Sieves - A 4.75 mm (No. 4) sieve or other sizes as needed (see Sections 6.2, 6.3, and 6.4), conforming to M 92.

5.5 Suspended Apparatus - Wire suspending the container shall be of the smallest practical size to minimize any possible effects of a variable immersed length.

6 Sampling:

6.1 Sample the aggregate in accordance with MT-201.

6.2 Thoroughly mix the sample of aggregate and reduce it to the approximate quantity needed using the applicable procedures in MT 607. Reject all material passing a 4.75 mm (No. 4) sieve by dry sieving and thoroughly washing to remove dust or other coatings from the surface. If the coarse aggregate contains a substantial quantity of material finer than the 4.75 mm sieve (such as for Size No. 8 and 9 aggregates in M 43), use the 2.36 mm (No. 8) sieve in place of the 4.75 mm sieve. Alternatively, separate the material finer than the 4.75 mm sieve and test the finer material according to MT-204.
6 **Sampling:** (continued)

6.3 The minimum weight of test sample to be used is given below. In many instances it may be desirable to test a coarse aggregate in several separate size fractions; and if the sample contains more than 15% retained on the 37.5 mm (1½-in.) sieve, test the material larger than 37.5 mm in one or more size fractions separately from the smaller size fractions. When an aggregate is tested in separate size fractions, the minimum weight of test sample for each fraction shall be the difference between the weights prescribed for the maximum and minimum sizes of the fraction.

<table>
<thead>
<tr>
<th>Nominal Maximum Size, mm (in.)</th>
<th>Minimum Weight of Test Sample, kg (lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 (½) or less</td>
<td>2 (4.4)</td>
</tr>
<tr>
<td>19.0 (¼)</td>
<td>3 (6.6)</td>
</tr>
<tr>
<td>25.0 (1)</td>
<td>4 (8.8)</td>
</tr>
<tr>
<td>37.5 (1½)</td>
<td>5 (11)</td>
</tr>
<tr>
<td>50 (2)</td>
<td>8 (18)</td>
</tr>
<tr>
<td>63 (2½)</td>
<td>12 (26)</td>
</tr>
<tr>
<td>75 (3)</td>
<td>18 (40)</td>
</tr>
<tr>
<td>90 (3½)</td>
<td>25 (55)</td>
</tr>
<tr>
<td>100 (4)</td>
<td>40 (88)</td>
</tr>
<tr>
<td>112 (4½)</td>
<td>50 (110)</td>
</tr>
<tr>
<td>125 (5)</td>
<td>75 (165)</td>
</tr>
<tr>
<td>150 (6)</td>
<td>125 (276)</td>
</tr>
</tbody>
</table>

6.4 If the sample is tested in two or more size fractions, determine the grading of the sample in accordance with MT-202, including the sieves used for separating the size fractions for the determinations in this method. In calculating the percentage of material in each size fraction, ignore the quantity of material finer than the 4.75 mm (No. 4) sieve or 2.36 mm (No. 8) sieve when that sieve is used in accordance with Section 6.2.

7 **Procedure:**

7.1 Dry the test sample to constant weight at a temperature of 110 ± 5°C (230 ± 9°F), cool in air at room temperature for 1 to 3 h for test samples of 37.5 mm (1½-in.) nominal maximum size, or longer for larger sizes until the aggregate has cooled to a temperature that is comfortable to handle (approximately 50°C). Subsequently immerse the aggregate in water at room temperature for a period of 15 to 19 hours.

*Note 2 -When testing coarse aggregate of large nominal maximum size requiring large test samples, it may be more convenient to perform the test on two or more sub-samples, and the values obtained combined for the computation described in Section 8.*

7.2 Where the absorption and specific gravity values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement for initial drying to constant weight may be eliminated, and, if the surfaces of the particles in the sample have been kept continuously wet until test, the 15-h soaking may also be eliminated.

*Note 3 - Values for absorption and bulk specific gravity (SSD) may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with Section 7.1. This is especially true of particles larger than 75 mm (3 in.) since the water may not be able to penetrate the pores to the center of the particle in the prescribed soaking period.*

7.3 Remove the test sample from the water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually. A moving stream of air may be used to assist in the drying operation. Take care to avoid evaporation of water from aggregate pores during the operation of surface-drying. Weigh the test sample in the saturated surface-dry
7 Procedure: (continued)

condition. Record this and all subsequent weight to the nearest 1.0 g or 0.1% of the sample weight, whichever is greater.

7.4 After weighing, immediately place the saturated-surface-dry test sample in the sample container and determine its weight in water at 23 ± 1.7°C (73.4 ± 3°F), having a density of 997 ± 2 kg/m³. Take care to remove all entrapped air before weighing by shaking the container while immersed.

Note 4 - The container should be immersed to a depth sufficient to cover it and the test sample during weighing. Wire suspending the container should be of the smallest practical size to minimize any possible effects of a variable immersed length.

7.5 Dry the test sample to constant weight at a temperature of 110 ± 5°C (230 ± 9°F), cool in air at room temperature 1 to 3 h, or until the aggregate has cooled to a temperature that is comfortable to handle (approximately 50°C), and weigh. Use this weight for A in the calculations in section 8.

8 Calculations:

8.1 Specific Gravity:

8.1.1 Bulk Specific Gravity--Calculate the bulk specific gravity, 23/23°C (73.4/73.4°F), as follows:

\[
\text{Bulk sp gr} = \frac{A}{(B - C)}
\]

where:

- \(A\) = weight of oven-dry test sample in air, g,
- \(B\) = weight of saturated-surface-dry test sample in air, g, and
- \(C\) = weight of saturated test sample in water, g.

8.1.2 Bulk Specific Gravity (Saturated-Surface-Dry) - Calculate the bulk specific gravity, 23/23°C (73.4/73.4°F), on the basis of weight of saturated-surface-dry aggregate as follows:

\[
\text{Bulk sp gr (saturated-surface-dry)} = \frac{B}{(B - C)}
\]

8.1.3 Apparent Specific Gravity - Calculate the apparent specific gravity, 23/23°C (73.4/73.4°F), as follows:

\[
\text{Apparent sp gr} = \frac{A}{(A - C)}
\]

8.2 Average Specific Gravity Values - When the sample is tested in separate size fractions, the average value for bulk specific gravity, bulk specific gravity (SSD), or apparent specific gravity can be computed as the weighted average of the values as computed in accordance with Section 8.1 using the following equation:

\[
G = \frac{1}{\sum \frac{P_i}{100G_i}} + \frac{P_2}{100G_2} + \ldots + \frac{P_n}{100G_n}
\]

where:

- \(G\) = average specific gravity. All forms of expression of specific gravity can be averaged in this manner.
8 Calculations: (continued)

\[ G_1, G_2...G_n = \text{appropriate specific gravity values for each size fraction depending on the type of specific gravity being averaged.} \]

\[ P_1, P_2...P_n = \text{weight percentages of each size fraction present in the original sample.} \]

*Note 5 - Some users of this method may wish to express the results in terms of density. Density may be determined by multiplying the bulk specific gravity, bulk specific gravity (SSD), or apparent specific gravity by the weight of water (997.5 kg/m³ or 62.27 lb ft³ at 23°C). Some authorities recommend using the density of water at 4°C (1.000 kg/m³ or 1.000 Mg/m³ or 62.43 lb/ft³) as being sufficiently accurate. Results should be expressed to three significant figures. The density terminology corresponding to bulk specific gravity, bulk specific gravity (SSD), and apparent specific gravity has not been standardized.*

8.3 Absorption - Calculate the percentage of absorption, as follows:

\[ \text{Absorption, \%} = \left( \frac{(B - A)}{A} \right) \times 100 \]

8.4 Average Absorption Value - When the sample is tested in separate size fractions, the average absorption value is the average of the values as computed in Section 8.3, weighted in proportion to the weight percentages of the size fractions in the original sample as follows:

\[ A = (P_1A_1/100) + (P_2A_2/100) + . . . (P_nA_n/100) \]

where:

\[ A = \text{average absorption, \%.} \]

\[ A_1, A_2 ... A_n = \text{absorption percentages for each size fraction, and} \]

\[ P_1, P_2 ... P_n = \text{weight percentages of each size fraction present in the original sample.} \]

9 Report:

9.1 Report specific gravity results to the nearest 0.01, and indicate the type of specific gravity, whether bulk (saturated-surface-dry), or apparent.

9.2 Report absorption result to the nearest 0.1%.

9.3 If the specific gravity and absorption values were determined without first drying the aggregate, as permitted in Section 7.2, it shall be noted in the report.

10 Precision and Bias:

10.1 The estimates of precision of this test method listed in Table 1 are based on results from the AASHTO Materials Reference Laboratory Reference Sample Program, with testing conducted by this test method and ASTM C 127. The significant difference between the methods is that ASTM C 127 requires a saturation period of 24 ± 4 h, while MT-205 requires a saturation period of 15 h minimum. This difference has been found to have significant effect on the precision indices. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.
### TABLE 1 Precision

<table>
<thead>
<tr>
<th></th>
<th>Standard Deviation (IS)(^{\text{A}})</th>
<th>Acceptable Range of Two Results (D2S)(^{\text{A}})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single operator precision:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk specific gravity</td>
<td>0.009</td>
<td>0.025</td>
</tr>
<tr>
<td>(dry)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk specific gravity</td>
<td>0.007</td>
<td>0.020</td>
</tr>
<tr>
<td>(SSD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apparent specific gravity</td>
<td>0.007</td>
<td>0.020</td>
</tr>
<tr>
<td>Absorption(^{\text{B}},\ %)</td>
<td>0.088</td>
<td>0.25</td>
</tr>
<tr>
<td><strong>Multilaboratory precision:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk specific gravity</td>
<td>0.011</td>
<td>0.32</td>
</tr>
<tr>
<td>(SSD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apparent specific gravity</td>
<td>0.011</td>
<td>0.032</td>
</tr>
<tr>
<td>Absorption(^{\text{B}},\ %)</td>
<td>0.145</td>
<td>0.41</td>
</tr>
</tbody>
</table>

\(^{\text{A}}\) These numbers represent, respectively, the (IS) and (D2S) limits as described in ASTM C 670. The precision estimates were obtained from the analysis of combined AASHTO Materials Reference Laboratory reference sample data from laboratories using 15-h minimum saturation times and other laboratories using 24 ± 4-h saturation time. Testing was performed on normal weight aggregates, and started with aggregates in the oven-dry condition.

\(^{\text{B}}\) Precision estimates are based on aggregates with absorptions of less than 2%.
1 **Introduction:**

1.1 Attention is called to the Appendix for information concerning the definitions that follow. Their meanings and their relationships to scientific terms are briefly explained. Some standards in which they are used are compared with standards in which other definitions have been applied.

1.2 **Density** (of solids and liquids)—The mass of a unit volume of a material at a specified temperature. The units shall be stated, such as grams per milliliter, grams per cubic centimeter, pounds per cubic foot, or other. If the material is a solid, the volume shall be that of the impermeable portion. The form of expression shall be:

Density at \( x \) . . . .

where \( x \) is the temperature of the material.

1.3 **Density** (of gases)—The mass of a unit volume of a gas at a stated temperature and pressure. The units shall be stated. The form of expression shall be:

Density at \( x, y \) . . . .

where:

\( x = \) temperature of the gas; and

\( y = \) pressure of the gas.

1.4 **Density, Apparent** (of solids and liquids)—The weight in air of a unit volume of a material at a specified temperature. The units shall be stated. If the material is a solid, the volume shall be that of the impermeable portion. The form of expression shall be:

Apparent density at \( x \) . . . .

where \( x \) is the temperature of the material.

1.5 **Density, Bulk** (of solids)—The weight in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature. The unit shall be stated. The form of expression shall be:

Bulk density at \( x \) . . . .

where \( x \) is the temperature of the material.

*Note 1 - The accuracy of bulk density determinations is so low that corrections for air buoyancy and variations in the value for the acceleration of gravity are not warranted. Hence, this definition is based on weights in air.*
1.6 **Specific Gravity** (of solids and liquids)--The ratio of the mass of a unit volume of a material at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. If the material is a solid, the volume shall be that of the impermeable portion. The form of expression shall be:

\[
\text{Specific gravity } x/y°C . . . .
\]

where:

\( x = \) temperature of the material, and

\( y = \) temperature of the water.

*Note 2 - The term "relative density" with the same meaning as specific gravity is becoming more widely used.*

1.7 **Specific Gravity** (of gases) - the ratio of the density of a gas, under the observed conditions of temperature and pressure, to the density of dry air of normal carbon dioxide content, at the same temperature and pressure. The units shall be stated. The form of expression shall be:

\[
\text{Apparent specific gravity } x/y
\]

where:

\( x = \) temperature of the gas, and

\( y = \) pressure of the gas.

1.8 **Specific Gravity, Apparent** (of solids and liquids)--the ratio of the weight in air of a unit volume of a material at a stated temperature to the weight in air of equal density of an equal volume of gas-free distilled water at a stated temperature. If the material is a solid, the volume shall be that of the impermeable portion. The form of expression shall be:

\[
\text{Apparent specific gravity } x/y°C
\]

where:

\( x = \) temperature of the material, and

\( y = \) temperature of the water.

1.9 **Specific gravity, Bulk** (of solids)--the ratio of the weight in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of equal density of an equal volume of gas-free distilled water at a stated temperature. The form of expression shall be:

\[
\text{Bulk specific gravity } x/y°C
\]

where:

\( x = \) temperature of the material, and

\( y = \) temperature of the water.
Appendix: Discussion of Definitions and Relationship to Scientific Terms

2.1 In scientific terminology, mass is a measure of the quantity of material in a body, and is constant regardless of geographical location, altitude, or atmospheric conditions, so long as no material is added or taken away. Weight is the force with which a body is attracted to the earth and varies from place to place with the acceleration of gravity.

2.2 When an equal-arm balance is used to compare an object with standards of mass ("weights"), the effects of variations in the acceleration of gravity are self-eliminating and need not be taken into account, but the apparent mass of the object is slightly different from the true mass because of the buoyant effects of the surrounding air. Mass can then be computed from apparent mass by applying a correction for air buoyancy. When a spring balance is used, an additional correction accounting for the local value of the acceleration of gravity is required for the computation of mass.

2.3 For many commercial and industrial processes the rigorous scientific distinction between mass, apparent mass, and weight is of no practical consequence and is therefore ignored. The term "weight" in general practice has been accepted as being the value secured when an object is weighed in air. This "weight" or "weight in air" is often converted to "weight in vacuo" by the application of an air buoyancy correction, and is then considered as synonymous with mass.

2.4 All of the definitions listed above are based on either "mass" or "weight in air," the distinction being that air buoyancy corrections have been applied in the former case and not in the latter. Density and specific gravity are based on mass, and should be similarly constant. Apparent density, bulk density, apparent specific gravity, and bulk specific gravity are based on weight in air, and therefore are subject to change with atmospheric conditions, locality, and altitude. These changes may be negligible, depending upon the accuracy required for the particular application.

2.5 The definitions are intended as a guide for future standardization of terminology relating to density and specific gravity. They do not represent the terminology presently used in many existing AASHTO and ASTM standards, which has become diversified to an undesirable extent by the variety of materials, procedures, and trade practices involved.

2.6 Specific gravity definitions refer to the weight of a unit volume of the sample compared with the weight of a unit volume of water.

2.7 The definition of bulk density, like the previous definition of bulk specific gravity, specifies that the volume shall include both permeable and impermeable voids normal to the material. This requirement for the inclusion of all voids is completely satisfied whether the volume is computed from the measured dimensions of a solid, or whether it is found by placing the material in a container of predetermined capacity. It would be expected that all standards using either of the two methods would identify the results in like terms.

2.8 The terms "permeable" and "impermeable" cannot be rigidly defined for general application. The exact meaning in a particular application is the conventional one inferred by the procedure specified for determining the density or specific gravity of the material in question. In AASHTO T 84 and T 85, the spaces between grains or particles of granular aggregates are not included in the permeable voids mentioned in the definition for bulk specific gravity. On the other hand, in AASHTO T 166, the method of test is designed to include in the permeable voids the spaces between particles or substances in compacted bituminous paving mixtures or other bonded or cemented mixtures.
METHODS OF SAMPLING AND TESTING
MT 207-04
CENTERLINE SOIL SURVEY

1 Introduction:

1.1 A centerline soil survey is an essential part of preliminary highway engineering. Information on the engineering properties and distribution of soils, rock and groundwater must be obtained before a reasonable and economic highway design can be developed. A soil survey is not intended to take the place of a thorough Geotechnical Foundation investigation.

1.2 The soil survey work depends on many factors which include scope of the proposed project, types and variability of materials found on the project, groundwater conditions, adverse geologic features, etc. Often field conditions found during the soil survey will increase or decrease the amount of work needed to supply the necessary information for design. The soil survey and the geotechnical investigation must be coordinated in order to preclude duplication of effort.

2 Referenced Documents:

2.1 AASHTO:
T 190 Resistance R-Value and Expansion Pressure of Compacted Soils

MT Manual:
MT 210 Moisture-Density Relations of Soils Using a 5.5 lb. Rammer
MT 214 The Classification of Soil and Soil-Aggregate Mixtures
MT 230 Moisture-Density Relations of Soils Using a 10 lb. Rammer

3 Apparatus:

3.1 Equipment required to perform a soil survey may include but is not limited to the following items:

3.1.1 Sampling tools:
Hand shovels, picks, etc.
Hand augers, post hole diggers
Power augers and drills, etc.
Backhoes

3.1.2 Instruments:
Survey equipment
Nuclear moisture and density testing device
Camera & film

3.1.3 Miscellaneous:
Stakes and lath
Sample bags (17”X28” canvas 75 lb. capacity cloth)
Sealed containers (jars or plastic bags)
Field notebooks and forms

4 General Procedure:

4.1 General Procedure: Following is the general procedure which should be followed in conducting any soil survey. The complexity of the soil survey will depend upon many factors as discussed in 1.2 above.
4 General Procedure: (continued)

4.2 Reconnaissance: reconnaissance of the proposed project should be conducted with pertinent existing information in hand. Additional information available may include but is not limited to the following items:

- Maintenance records
- Construction records
- Topographic & geologic maps
- Historic use of the area
- U.S. Department of Agriculture Soil Conservation Service County soil survey reports
- Utility company maps & locations
- City and county plat maps
- City, county and state health department information
- Information from landowners and businesses
- Aerial photography

4.3 Preliminary Survey Plan:

4.3.1 A preliminary plan should be determined prior to fieldwork. This should be based upon available information and intended scope. Approximate sample site locations should be determined to enable proper soil profile determination and adequate sampling. This plan will likely change as information is gained during the actual construction of the test sites.

4.3.2 Boring records should be kept in a systematic manner and referred to new centerline stationing and elevations for each project. Such records should include and be recorded on Lab Forms 30 and 111.

- Describe each site or area investigated, with each test hole, boring, or test pit clearly located (horizontally and vertically) with reference to some established coordinate system or permanent monument.
- Log each test hole, boring, test pit, or cut-surface exposure with the field description and location of each material encountered clearly shown by Montana Department of Highways' symbols and word descriptions used on Form 30.

**Note** - Color photographs of samples, and exposed strata may be of considerable value to the Department. Each photograph should include a date and an identifying number or symbol.

- Identify all soils based on MT 214 Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purpose.
- Record seepage and water-bearing zones and free water-table depth found in each test hole, boring or test pit.
- Identify artifacts and items of cultural and historical significance.
- Note items concerning environmental hazards or other worthy notes.

4.3.3 Identify vertical and/or horizontal change of original ground where instability problems exist (landslides, subsidence, etc.).
4.4 Soil Profile Determination and Sampling:

4.4.1 Boring or test pits should be taken for laboratory analysis from all areas which may supply appreciable quantities of earthwork, and known borrow areas. Embankment areas should be tested for areas of swamp conditions or loosely compacted soils that will result in embankment settlements. The spacing of these investigations will depend upon the geologic complexity of the project area and upon the importance of soil and rock parameters to the project design. The depth should be a minimum of five feet below the proposed top of subgrade elevation or to borrow area depth.

4.5 Sampling:

4.5.1 Accurately identify each sample with the project identification, location, date, test site number and depth below reference ground surface from which it was taken. Place identification inside the container, secure close the container, protect it to withstand rough handling, and mark it with proper identification on the outside of the container. Keep samples for natural moisture determination in sealed containers to prevent moisture loss. When drying of samples may affect classification or engineering properties, protect them to minimize moisture loss.

4.5.2 Soil and water samples should be taken from the probable, proposed, or existing centerline of pipe, channel bottom and bridge locations as well as probable borrow areas, to determine pH, resistivity and sulfate (SO$_4$) content of the soil and water. In areas of bad soils (resistivity less than 500), additional samples should be taken.

Sample Size not less than 5 lbs. (2.3 Kg.)

Sample Size, Water 1 quart.

4.5.3 Evaluate performance of existing installations in the immediate vicinity of the proposed site, relative to their historical performance and environmental impact. Photos of relevant installations properly labeled are helpful.

4.5.4 Representative disturbed samples for laboratory classification tests of soil, rock, and local construction material should be supplemented by undisturbed specimens.

4.5.5 Standard traffic control is required while working on the PTW.

4.6 Testing:

4.6.1 Testing analysis should be performed on all samples for the following items and recorded on Form 111:
- Soil class by MT 214
- Liquid limit
- Plastic limit
- Percent of material passing the 10 mesh, 40 mesh, and 200 mesh sieve size.
- Maximum dry density and optimum moisture content by MT 230 for A-1 soils, MT 210 for all other soils
- In-place density and moisture content
- "R" value by AASHTO T190, all soils except A-6 and A-7's.
- Depth to water table

5 Field Procedure:

5.1 Overlay, New and Reconstruction Projects:

Survey data required for all projects is as follows:
5 Field Procedure: (continued)

The PTW should be cored at least 5’ into the subgrade and sampled in the driving lanes (not the shoulder) as frequently as necessary.

Typical sampling frequency is one per 1/2 mile, more or less as conditions dictate.

Note and log the mat thickness.

Note and log base thickness and subgrade. Sample and determine moisture content, record soil class (MT 214), moisture, density and "R" value (AASHTO T190).

Perform a culvert inspection, take chemical corrosion samples where necessary. Take photos at locations of bad pipe.

Review the existing project and record its past performance. A narrative summary should be provided with the soil survey.

Problem areas must be shown and recommendations for sub-excavation and the proposed depth of sub-excavation should be noted.

Anticipated borrow material should be sampled and tested for R values and corrosion.

Projects, where the intent is to overlay the existing plant mix, should be cored and the cores submitted to the Materials Bureau for evaluation. A typical sampling frequency is one (1) core per lane mile with a minimum of five (5) cores per project. The frequency can and should be adjusted as conditions warrant. The cores will be evaluated to determine the in-place condition of the PMS and a report issued to Surfacing Design.

5.2 New and Reconstruction Projects Only:

Additional survey data for new and reconstruction projects only are as follows:

Review planning reports and anticipate alignment and grades.

Test holes in the field should be located to provide engineering soil properties where appreciable quantities of excavation will occur. Depth will be determined by the new grade line with holes extending about five feet below the proposed subgrade line. Typical sampling frequency is one per 1/2 mile, more or less as conditions dictate.

Tests should include samples of each soil strata encountered and the in place moisture, the chemical-corrosive properties, soil class (MT 214), "R" value (AASHTO T190), and the specific gravity for each strata.

Determine in place densities for shrink and swell determinations if frozen conditions do not exist.

A log of the test holes should be kept and the test holes plotted on a profile sheet.

Data obtained should be reviewed to determine if additional test sites (i.e., areas of refusal, inadequate depth, or of questionable frequencies) are required.

Topsoil depth and availability should be noted.

Any anticipated borrow material should be sampled for "R" value, chemical-corrosive properties, and moisture density purposes.
5.2 **New and Reconstruction Projects Only:** (continued)

If centerline is following close to the PTW and material in present embankment will be used, additional R-values and chemical-corrosive properties should be taken beneath the PTW driving lanes.

Potential borrow areas that have better quality soils (A-4(0) or better) should be investigated to determine their use in the top 2’ of the subgrade especially in areas where surfacing materials are scarce.

6 **Interpretation of Results:**

6.1 Interpret the results of an investigation only in terms of actual findings and make every effort to collect and include all field and laboratory data from previous investigations in the same areas. Extrapolation of data into local areas not surveyed and tested can be done only where geologically uniform subsurface conditions of soil and rock are known to exist. Engineering properties of the soils and rocks encountered on important projects should not be predicted wholly on field identifications or classification but should be checked by laboratory and field tests made on samples collected.

6.2 The recommendations for design parameters can be made only by professionals who have specialized in the field of soils and foundations or highway engineering, and who are familiar with the problems for which the study is being made.

7 **Report:**

7.1 A soil survey investigation report should:

7.1.1 Locate the area investigated in terms pertinent to the project. This may include sketch maps or aerial photos on which the test holes, pits, and sample areas are located, as well as topographic items relevant to the determination of the various soil and rock types, such as contours, streambeds, sink holes, cliffs, etc. Where feasible, include a geologic map of the area investigated in the report.

7.1.2 Include copies of all borings, test-hole logs and laboratory test results.

7.1.3 Describe and relate the findings obtained by following the format of Section 4, General Procedure.

7.1.4 Provide preliminary shrink/swell recommendations. Shrink/swell information obtained from adjacent projects in the area should be included.

7.1.5 Provide recommendations relative to availability of better quality soils (A-4(0) or better) that could be used in the top 2’ of the subgrade to reduce more costly surfacing material and to improve drainage.

Provide recommendations for additional testing required by core drill, seismic, etc., for materials inaccessible because of depth, topography, etc.

7.1.6 Each soil survey shall be submitted and distributed as follows:

- 1 copy to Preconstruction Bureau
- 1 copy to Geotechnical & Materials Bureau
- 1 copy to Surfacing Design - Materials Bureau
- 2 copies to be retained by the District
DRAINAGE EVALUATION FORM
MT 207

This form should be submitted with each soil survey. Each area of concern on the project should be noted.

Project No.________________________ Designation:_____________________________________

Date_____________________ Submitted by:_______________________________________________

Station(s)________________________________________________________________________

Are the ditch lines clear of standing water? _______________________________________________

Are the ditch lines and pavement edges free from weed growth that may indicate a moisture concentration? _________________________________________________________________

After a rain,

a) Is there moisture standing in the joints or cracks?________________________________________

b) Is there any evidence of pumping?_____________________________________________________

c) Is there water standing at the outer edge of the shoulder?________________________________

d) Is there evidence that the water may pond on the shoulder?_________________________________

Are joint sealants or crack sealants in good condition and preventing water from entering the pavement? __

Are the cross drainage conduits closed by debris?___________________________________________

AC Pavements

Is there moisture related distress evident such as; Stripping, Rutting, Cracking in Wheelpath, Shoulder Dropoff/Heave, Pumping, Water Bleeding, Swelling?

____________________________________________________________________________________

____________________________________________________________________________________

PCC Pavements

Is there moisture related distress evident such as; Pumping, Faulting, Corner Break, D-Cracking, Edge Joint Opening, Shoulder Dropoff/Heave, Punchout (CRCP only), Swelling, Slab Cracking?

____________________________________________________________________________________

____________________________________________________________________________________

____________________________________________________________________________________
Is there evidence of springs and excessively wet areas?

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

Are there slides or slumps noted along the alignment?

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

Specific surface/subsurface drainage recommendations

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________
# Preconstruction Soil Survey Data

and Special Recommendations Relative to Subgrade and Road Surface Design

<table>
<thead>
<tr>
<th>Project Number</th>
<th>Designation</th>
<th>Length</th>
<th>County</th>
<th>Date</th>
</tr>
</thead>
</table>

Submitted by: [Signature]

Title: [Title]

District Materials Supervisor: [Signature]

District Engineer: [Signature]

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Date</th>
<th>Location of Boring</th>
<th>Depth</th>
<th>Representing Stationing</th>
<th>Soil Class (MT 214)</th>
<th>LL</th>
<th>PI</th>
<th>10 Mesh</th>
<th>40 Mesh</th>
<th>200 Mesh</th>
<th>In-place Density</th>
<th>Maximum Dry Density</th>
<th>Percent Natural Moisture</th>
<th>Percent Optimum Moisture</th>
<th>Depth to Water Table</th>
<th>TP Value (AASHTO T190)</th>
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</thead>
<tbody>
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</tbody>
</table>

Remarks:

[Signature]

[Signature]

MT 207-04 (06/01/04)
LOG OF BORING

Geotechnical Section

Project Name: EXAMPLE - ENGLISH

Borehole Location: STA. 13+95, 20.8 ft. LT. PTW Centerline

Drilling Equipment: CME 550

Borehole Number: EXAMPLE

Driller: A. Driller

Logger: A. Logger

Drilling Fluid: Water

Borehole Diameter (in): 8

Elevation and Datum: Ground: 3739.80

Casing:

Notes: Legal Description - 01S18E32DAC. Elevation and Station provided by District Survey.

MATERIAL DESCRIPTION

DEPTH (feet)

REMARKS

Sandy GRAVEL, coarse, subangular, damp, tan, medium dense.

Hollow stem auger with bullet bits.

CLAY, moist, gray, medium stiff, high plasticity, medium dry strength, slow dilatancy, medium toughness.

qu = 250 psf @ 10 ft.

SHALE, moderately fissile, slightly weathered, hard field hardness, black, horizontal bedding.

Switched to NW triple tube core barrel with surface set bit @ 16 ft.

Bottom of Hole Elevation = 3714.80 ft.

WATER LEVEL OBSERVATIONS

While Drilling $12.1$ ft

Upon Completion of Drilling $9.8$ ft

Time After Drilling

Depth To Water (feet)

Remarks: Water table at 9.8 ft.
### LOG OF BORING

**Geotechnical Section**

<table>
<thead>
<tr>
<th>Project Name:</th>
<th>SAMPLE - Metric</th>
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<tbody>
<tr>
<td>Borehole Location:</td>
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<tr>
<td>Drilling Equipment:</td>
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<td>Drilling Fluid:</td>
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<td>Elevation and Datum:</td>
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<tr>
<td>Ground:</td>
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<tr>
<td>Casing:</td>
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#### MATERIAL DESCRIPTION

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<tr>
<th>Operation Types:</th>
<th>Sampler Types:</th>
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<td>Auger</td>
<td>Split Spoon</td>
<td>Penetrometer</td>
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<td>Casing</td>
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<td>Core Barrel</td>
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<td>Drive Casing</td>
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#### WATER LEVEL OBSERVATIONS

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<th>While Drilling</th>
<th>Upon Completion of Drilling</th>
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<tr>
<td>m</td>
<td>m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time After Drilling</th>
<th>Depth To Water (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

**Remarks:**
Methods of Sampling and Testing

Method of Test for Determining the Liquid Limit of Soils
(Modified AASHTO T 89)

and

Method of Test for Determining
The Plastic Limit, and the Plasticity Index of Soils
(Modified AASHTO T 90)

1 Definition:

1.1 The Liquid Limit of a soil is that water content, as determined in accordance with the following procedure, at which the soil passes from a plastic to a liquid state.

1.2 The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off “to the nearest unit” in the last right-hand place of figures used in expressing the limiting value, in accordance with AASHTO R 11.

2 Referenced Documents:

2.1 AASHTO:
T 89 Determining the Liquid Limit of Soils
T 90 Determining the Plastic Limit and Plasticity Index of Soils

MT Materials Manual:
MT-200 Dry Preparation of Disturbed Samples for Test
MT-227 Laboratory Determination of Moisture Content of Soils

3 Apparatus:

3.1 Dish—A porcelain dish, preferably unglazed, or similar mixing dish, about 115 mm (4½ in.) in diameter.

3.2 Spatula—A spatula or pill knife having a blade about 75 mm (3 in.) in length and about 20 mm (¾ in.) in width.

3.3 Liquid Limit Device:

3.3.1 Manually Operated—A device consisting of a brass dish and carriage, constructed according to the plan and dimensions shown in Figure 1.

3.3.2 Mechanically Operated—A motorized device equipped to produce the rise and rate of shocks to a brass cup as described in sections 4.2 and 5.3 of this procedure, respectively. The cup and the critical dimensions of the device shall conform to those shown in Figure 1 of this procedure. The device shall give the same liquid limit values as obtained with the manually operated device.

3.4 Grooving Tool—A grooving tool conforming to the critical dimensions shown in Figure 1. The gage need not be part of the tool.

3.5 Gage—A gage, whether attached to the grooving tool or separate, conforming to the critical dimension “d” shown in Figure 1 and may be, if separate, a metal bar 10.0 ± 0.2 mm (0.394 ± 0.008 in.) thick and approximately 50 mm (2 in.) long.

3.6 Containers—Suitable containers made of material resistant to corrosion and not subject to change in weight or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing. One container is needed for each moisture content determination.
3 **Apparatus: (continued)**

3.7 *Balance*—A balance sensitive to 0.01 grams.

3.8 *Oven*—A thermostatically controlled drying oven capable of maintaining temperatures of $110 \pm 5 \, ^\circ C$ ($230 \pm 9 \, ^\circ F$) for drying moisture samples.

4 **Sample:**

4.1 A sample weighing about 100 g shall be taken from the thoroughly mixed portion of the material passing the 0.425 mm (No. 40) sieve which has been obtained in accordance with MT-200, Dry Preparation of Disturbed Soil and Soil Aggregate Sample for Test.

5 **Adjustment of Liquid Limit Device:**

5.1 The Liquid Limit Device shall be inspected to determine that the device is in good working order; that the pin connecting the cup is not worn sufficiently to permit side play; that the screws connecting the cup to the hanger arm are tight; that the points of contact on the cup and base are not excessively worn; that the lip of the cup is not excessively worn; and that a groove has not been worn in the cup through long usage. The grooving tool shall be inspected to determine that the critical dimensions are as shown in Figure 1 of this method.

---

<table>
<thead>
<tr>
<th>Dimension</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>N</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
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<td>150</td>
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<td>13.5</td>
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<td>0</td>
<td>1.5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>---</td>
</tr>
</tbody>
</table>

**Note:**
- Plate “H” may be designed for using (1) one securing screw (I).
- An additional wear tolerance of 0.1 mm shall be allowed for dimension “b” for used grooving tools.
- Feet for base shall be of resilient material.
- (*) Nominal dimensions.
- All tolerances specified are plus or minus (±) except as noted above.

**Figure 1**—Manual Liquid Limit Device
Note 3 - Wear is considered excessive when the point of contact on the cup or base exceeds approximately 13 mm (0.5 in.) in diameter, or when any point on the rim of the cup is worn to approximately ½ the original thickness. Although a slight groove in the center of the cup is noticeable, it is not objectionable. If the groove becomes pronounced before other signs of wear appear, the cup should be considered excessively worn. Excessively worn cups shall be replaced. A base which is excessively worn may be refinished as long as the thickness does not exceed the tolerance shown in Figure 1 by more than -2.5 mm (-0.1 in.) and the distance between the cup at the cam follower and the base is maintained within the tolerances specified in Figure 1.

5.2 Adjust the height of drop of the cup so that the point on the cup that comes in contact with the base rises to a height of 10 ± 0.2 mm (0.394 ± 0.008 in.). See Figure 2 for proper location of the gage relative to the cup during adjustment.

![Figure 2](image)

Note 4 - A convenient procedure for adjusting the height of drop is as follows: place a piece of masking tape across the outside bottom of the cup parallel with the axis of the cup hanger pivot. The edge of the tape away from the cup hanger should bisect the spot on the cup that contacts the base. For new cups, placing a piece of carbon paper on the base and allowing the cup to drop several times will mark the contact spot. Attach the cup to the device and turn the crank until the cup is raised to its maximum height. Slide the height gage under the cup from the front, and observe whether the gage contacts the cup or the tape. See Figure 2. If the tape and cup are both contacted, the height of drop is approximately correct. If not, adjust the cup until simultaneous contact is made. Check adjustment by turning the crank at two revolutions per second while holding the gage in position against the tape and cup. If a ringing or clicking sound is heard without the cup rising from the gage, the adjustment is correct. If no ringing is heard or if the cup rises from the gage, readjust the height of drop. If the cup rocks on the gage during this checking operation, the cam follower pivot is excessively worn and the worn parts should be replaced. Always remove tape after completion of adjustment operation.
6 Procedure:

6.1 The soil sample shall be placed in the mixing dish and thoroughly mixed with 15 to 20 ml of distilled or demineralized water by alternately and repeatedly stirring, kneading and chopping with a spatula. Further additions of water shall be made in increments of 1 to 3 ml. Each increment of water shall be thoroughly mixed with the soil as previously described before another increment of water is added. Once testing has begun, no additional dry soil should be added to the moistened soil. The cup of the Liquid Limit Device shall not be used for mixing soil and water. If too much moisture has been added to the sample, the sample shall either be discarded, or mixed and kneaded until natural evaporation lowers the closure point into an acceptable range.

Note 5 - Some soils are slow to absorb water, therefore, it is possible to add the increments of water so fast that a false liquid limit value is obtained. This can be avoided if more mixing and/or time is allowed. Tap water may be used for routine testing if comparative tests indicate no differences in results between using tap water and distilled or demineralized water. However, referee or disputed tests shall be performed using distilled or demineralized water.

6.2 When sufficient water has been thoroughly mixed with the soil to form a uniform mass of stiff consistency, a sufficient quantity of this mixture shall be placed in the cup above the spot where the cup rests on the base and shall be squeezed and spread with the spatula to level and at the same time trimmed to a depth of 10 mm at the point of maximum thickness. As few strokes of the spatula as possible shall be used, care being taken to prevent the entrapment of air bubbles within the mass. With the spatula the soil shall be leveled and at the same time trimmed to a depth of 10 mm at the point of maximum thickness. The excess soil shall be returned to the mixing dish. The soil in the cup of the device shall be divided by a firm stroke of the grooving tool along the diameter through the centerline of the cam follower so that a clean sharp groove of the proper dimensions will be formed as shown in Figure 3. To avoid tearing of the sides of the groove or slipping of the soil cake on the cup, up to six strokes from front to back or from back to front counting as one stroke, shall be permitted. The depth of the groove should be increased with each stroke and only the last stroke should scrape the bottom of the cup.

Figure 3—Liquid Limit Device With Soil Sample in Place
6 Procedure: (continued)

6.3 The cup containing the sample prepared as described in 6.2 shall be lifted and dropped by turning the crank F at the rate of approximately two revolutions per second until the two sides of the sample come in contact at the bottom of the groove along a distance of about 13 mm (0.5 in.). The number of shocks required to close the groove this distance shall be recorded. The base of the machine shall not be held with the free hand while the crank F is turned.

Note 6 - Some soils tend to slide on the surface of the cup instead of flowing. If this occurs, more water should be added to the sample and remixed, then the soil-water mixture placed in the cup, a groove cut with the grooving tool and 6.2 repeated. If the soil continues to slide on the cup at a lesser number of blows than 25, the test is not applicable and a note should be made that the liquid limit could not be determined.

6.4 A slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angles to the groove and including that portion of the groove in which the soil flowed together, shall be removed and placed in a suitable container. The container and soil shall then be weighed promptly and the weight recorded. The soil in the container shall be oven-dried to a constant weight at 110 ± 5 C (230 ± 9 F) and weighed. This weight shall be recorded and the loss in weight due to drying shall be recorded as the weight of water.

6.5 The soil remaining in the cup shall be transferred to the mixing dish. The cup and grooving tool shall then be washed and dried in preparation for the next trial.

6.6 The foregoing operations shall be repeated for at least two additional portions of the sample to which sufficient water has been added to bring the soil to a more fluid condition. The object of this procedure is to obtain samples of such consistency that at least one determination will be made in each of the following ranges of shocks: 25-35, 20-30, 15-25, so the range in the three determinations is at least 10 shocks.

7 Calculation:

7.1 The water content of the soil shall be expressed as the moisture content in the percentage of the weight of the oven-dried soil and shall be calculated as follows:

\[
\text{Percentage moisture} = \frac{\text{mass of water}}{\text{mass of oven dried soil}} \times 100
\]

7.1.1 Calculate the percentage of moisture to the nearest whole percent.

8 Preparation of Flow Curve:

8.1 A "Flow Curve" representing the relation between moisture content and corresponding number of shocks shall be plotted in a semi-logarithmic graph with the moisture contents as abscissae on the arithmetical scale, and the number of shocks as ordinates on the logarithmic scale. The flow curve shall be a straight line drawn as nearly as possible through the three or more plotted points.

9 Liquid Limit:

9.1 The moisture content corresponding to the intersection of the flow curve with the 25 shock ordinate shall be taken as the liquid limit of the soil. Report this value to the nearest whole number.
METHOD B

10 Sample:

10.1 A sample weighing about 50 g shall be taken as described in 4.1.

11 Procedure:

11.1 The procedure shall be the same as prescribed in Sections 6.1 through 6.5 except that the initial amount of water to be added in accordance with Section 6.1 shall be approximately 8 to 10 ml and the moisture sample taken in accordance with Section 6.4 shall be taken only for the accepted trial.

11.2 For accuracy equal to that obtained by the standard three-point method, the accepted number of blows for groove closure shall be restricted between 22 and 28 blows. After obtaining a preliminary closure in the acceptable blow range, immediately return the soil remaining in the cup to the mixing dish and, without adding any additional water, repeat as directed in Sections 6.2 and 6.3. If the second closure occurs in the acceptable range (22 – 28 inclusive) and the second closure is within two (2) blows of the first closure, secure a water content specimen as directed in Section 6.4.

11.3 Groove closures between 15 and 40 blows may be accepted if variations of ± 5 percent of the true liquid limit are tolerable.

12 Calculation:

12.1 The water content of the soil at the time of the accepted closure shall be calculated in accordance with Section 7.1.

13 Liquid Limit:

13.1 The liquid limit shall be determined by one of the following methods: the nomograph, Figure 4; the multicurve; Figure 5; the slide rule with a special "blows" scale, Figure 6, or by any other method of calculation that produces equally accurate liquid limit values. The standard three-point method shall be used as a referee test to settle all controversies.

13.2 The key in Figure 4 illustrates the use of the nomograph (mean slope).

13.3 The chart (multi-flow curve), Figure 5, is used by plotting on it a point representing the moisture content vs. number of blows for the accepted trial, and drawing a line through the plotted point parallel to the nearest chart curve. The moisture content corresponding to the intersection of this line with the 25-blow line shall be recorded as the liquid limit.

13.4 The special slide rule, Figure 6, is used by setting the hairline of the indicator slide coincident with the A-scale value of the moisture content for the accepted groove closure, and moving the special scale until the number of blows used for closure is also under the hairline. The liquid limit will then be found on the A-scale opposite the end index of the B-scale, or opposite the middle index of the B-scale, which in turn is directly in line with the 25-blow mark of the special scale.
Figure 4—Nomographic chart developed by the Waterways Experiment Station, Corps of Engineers, U.S. Army, to determine liquid limit using mean slope method.

Figure 5—Chart developed by Washington State Highway Department for the calculation of the liquid limit.
Figure 5—Chart Developed by Washington State Highway Department for the Calculation of the Liquid Limit

A - LOCATION OF SPECIAL SCALE (BLOWS) WITH RESPECT TO B SCALE OF SLIDE RULE

B - SLIDE RULE SET FOR 21.4 PERCENT MOISTURE AT 20 BLOWS, INDICATING CALCULATED LIQUID LIMIT OF 20.8
14  **Method to be Used:**

14.1 In making check or referee tests, Method A shall be used. The results of liquid limit tests are influenced by:

14.1.1 The time required to make the test.

14.1.2 The moisture content at which the test is begun.

14.1.3 The addition of dry soil to the seasoned sample.

15  **Procedure:**

15.1 Therefore, in making the liquid limit test for check, or referee purposes, the following time schedule shall be used:

15.1.1 Mixing of soil with water -- 5 to 10 minutes, the longer period being used for the more plastic soils.

15.1.2 Seasoning under a damp cloth -- 30 minutes.

15.1.3 Remixing before placing in the brass cup -- add 1 ml of water and mix for 1 minute.

15.1.4 Placing in the brass cup and testing -- 3 minutes.

15.1.5 Adding water and remixing -- 3 minutes.

15.2 No trial requiring more than 35 blows or less than 15 blows shall be recorded. In no case shall dried soil be added to the seasoned soil being tested.
METHODS OF SAMPLING AND TESTING
MT-208
METHOD OF TEST FOR DETERMINING
THE PLASTIC LIMIT, AND THE PLASTICITY INDEX OF SOILS
(Modified AASHTO T 90 )

1 Scope:

1.1 The plastic limit of a soil is the lowest water content determined in accordance with the following procedure at which the soil remains plastic. The plasticity index of a soil is the range in water content, expressed as a percentage of the mass of the oven-dried soil, within which the material is in a plastic state. It is the numerical difference between the liquid limit and plastic limit of the soil.

1.2 The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off “to the nearest unit” in the last right-hand place of figures used in expressing the limiting value, in accordance with AASHTO R 11.

2 Referenced Documents:

MT Materials Manual
MT-200 Dry Preparation of Disturbed Samples for Test
MT-208 Determining the Liquid Limit of Soils
MT 227 Laboratory Determination of Moisture Content of Soils

3 Apparatus:

3.1 Dish – A porcelain evaporating dish, or similar mixing dish about 115 mm in diameter.

3.2 Spatula – A spatula or pill knife having a blade about 75 mm in length and about 20 mm in width.

3.3 Surface for Rolling – A ground glass plate or piece of smooth, unglazed paper on which to roll the sample.

3.4 Containers - Suitable containers made of material resistant to corrosion and not subject to change in mass or disintegration on repeated heating and cooling. Containers shall have close fitting-lids to prevent loss of moisture from samples before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing. One container is needed for each moisture content determination.

3.5 Balance – The balance shall sufficient capacity and conform to AASHTO M 231, Class G1.

3.6 Oven – A thermostatically controlled drying oven capable of maintaining temperatures of 110 ± 5°C (230 ± 9°F) for drying samples.

4 Sample:

4.1 If the plastic limit only is required, take a quantity of soil weighing about 20 g from the thoroughly mixed portion of the material passing the 0.425 mm (No. 40) sieve, obtained in accordance with paragraph 3.1. Place the air-dried soil in a mixing dish and thoroughly mix with distilled or demineralized water until the mass becomes plastic enough to be easily shaped into a ball. Take a portion of this ball weighing about 8 g for the test sample.

Note 1 - Tap water may be used for routine testing if comparative tests indicate no differences in results between using tap water and distilled or demineralized water. However, referee or disputed tests shall be performed using distilled or demineralized water.

4.2 If both the liquid and plastic limits are required, take a test sample weighing about 8 g from the thoroughly wet and mixed portion of the soil prepared in accordance with the Standard Method of
Test for Liquid Limit for Soils (MT-208). Take the sample at any stage of the mixing process at which the mass becomes plastic enough to be easily shaped into a ball without sticking to the fingers excessively when squeezed. If the sample is taken before completion of the liquid limit test, set it aside and allow to season in air until the liquid limit test has been completed. If the sample taken during the liquid limit test is to dry to permit rolling to a 3 mm (1/8 in.) thread, add more water and remix.

5  **Procedure:**

5.1 Select a 1.5 to 2.0 g portion from the mass taken in accordance with Section 4. Form the selected portion into an ellipsoidal mass.

5.2 Use one of the following methods to roll the soil mass into a 3 mm diameter thread at a rate of 80 to 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position again.

5.2.1 **Hand Rolling Method** - Roll the mass between the fingers and the ground-glass plate (or a piece of paper laying on a smooth horizontal surface) with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length. The thread shall be further deformed on each stroke so that its diameter reaches 3 mm, taking no more than 2 min. The amount of hand or finger pressure required will vary greatly, according to the soil. Fragile soils of low plasticity are best rolled under the outer edge of the palm or at the base of the thumb.

5.2 When the diameter of the thread becomes 3 mm (1/8 in.), break the thread into six or eight pieces. Squeeze the pieces together between the thumbs and fingers of both hands into a uniform mass roughly ellipsoidal in shape and reroll. Continue this alternate rolling to a thread 3 mm (1/8 in.) in diameter, gathering together, kneading and rerolling, until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread. The crumbling may occur when the thread has a diameter greater than 3 mm (1/8 in.). This shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread 3 mm (1/8 in.) in diameter. The crumbling will manifest itself differently with the various types of soil. Some soils fall apart in numerous small aggregations of particles; others may form an outside tubular layer that starts splitting at both ends. The splitting progresses toward the middle, and finally, the thread falls apart in many small platy particles. Heavy clay soils require much pressure to deform the thread, particularly as they approach the plastic limit, and finally, the thread breaks into a series of barrel-shaped segments each about 6.4 to 9.5 mm (¼ to _ in.) in length. At no time shall the operator attempt to produce failure at exactly 3 mm (1/8 in.) diameter by allowing the thread to reach 3 mm (1/8 in.) diameter by allowing the thread to reach 3 mm (1/8 in.) then reducing the rate of rolling or the hand pressure, or both, and continuing rolling without further deformation until the thread falls apart. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal-shaped mass bearer to the required 3 mm (1/8 in.) final diameter.

5.3 Gather the portions of the crumbled soil together and place in a weighed container. Immediately cover the container.

5.4 Repeat the operations described in sections 5.1 through 5.3 until the 8 g specimen is completely tested. Determine the moisture content of the soil in the containers in accordance with MT-227, and record the results.
6  Calculations:

6.1 Calculate the plastic limit, expressed as the water content in percentage of the mass of the oven-dry soil, as follows:

\[
\text{Percentage moisture} = \frac{\text{mass of water}}{\text{mass of oven dried soil}} \times 100
\]

Report the plastic limit to the nearest whole number.

6.2 Calculate the plasticity index of a soil as the difference between its liquid limit and its plastic limit, as follows:

\[
\text{Plastic index} = \text{liquid limit} - \text{plastic limit}
\]

6.3 Report the difference calculated as indicated in 6.2 as the plasticity index, except under the following conditions:

6.3.1 When the liquid limit or plastic limit cannot be determined, report the plasticity index as NP (non-plastic).

6.3.2 When the plastic limit is equal to, or greater than, the liquid limit, report the plasticity index as NP.
METHODS OF SAMPLING AND TESTING

METHOD OF TEST FOR
RESISTANCE TO ABRASION OF SMALL SIZE COARSE AGGREGATE
BY USE OF THE LOS ANGELES MACHINE
(Modified AASHTO T 96)

1 Scope:

1.1 This method covers a procedure for testing sizes of coarse aggregate smaller than 37.5 mm (1½ in.) for resistance to abrasion using the Los Angeles testing machine.

Note 1 - A procedure for testing coarse aggregate larger than 19.0 mm (¾ in.) is covered in the Method of Test for Resistance to Abrasion of Large Size Coarse Aggregate by the Los Angeles Machine (ASTM C 535).

2 Referenced Documents:

2.1 AASHTO:
T 2 Sampling Aggregates
T 96 Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

MT Manual:
MT 202 Sieve Analysis of Fine and Coarse Aggregates
MT 405 Wire Cloth Sieves for Testing Purposes
MT 607 Reducing Field Samples of Aggregate to Testing Size

ASTM:
C 535 Test for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
C 670 Practice for Preparing Precision Statement for Test Methods for Construction Materials

3 Description of Terms:

3.1 Constant Mass—Test samples dried at a temperature of 110 ± 5°C (230 ± 9°F) to a condition such that it will not lose more than 0.1 percent moisture after 2 h of drying. Such a condition of dryness can be verified by weighing the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5°C (230 ± 9°F) for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.

4 Apparatus:

4.1 Los Angeles Machine—The Los Angeles abrasion testing machine equipped with a counter and conforming in all its essential characteristics to the design shown in AASHTO T 96 shall be used. The machine shall consist of a hollow steel cylinder, closed at both ends, having an inside diameter of 711 ± 5 mm (28 ± 0.2 in.) and an inside length of 508 ± 5 mm (20 ± 0.2 in.). The cylinder shall be mounted on stub shafts attached to the ends of the cylinder but not entering it, and shall be mounted in such a manner that it may be rotated with the axis in a horizontal position within a tolerance in slope of 1 in 100. An opening in the cylinder shall be provided for the introduction of the test sample. A suitable, dust-tight cover shall be provided for the opening with means for bolting the cover in place. The cover shall be so designed as to maintain the cylindrical contour of the interior surface unless the shelf is to located that the charge will not fall on the cover, or come in contact with it during the test. A removable steel shelf extending the full length of the cylinder and projecting inward 89 ± 2 mm (3.5 ± 0.1 in.) shall be mounted on the interior cylindrical surface of the cylinder, or on the inside surface of the cover, in such a way that a plane centered between the large faces coincides with an axial plane. The shelf shall be of such thickness and so mounted, by bolts or other suitable means, as to be firm and rigid. The
position

4 Apparatus: (continued)

of the shelf shall be such that the distance from the shelf to the opening, measured along the outside circumference of the cylinder in the direction of the rotation, shall not be less than 1.27 m (50 in.).

Note 2 - The use of a wear-resistant steel, rectangular in cross-section and mounted independently of the cover, is preferred. However, a shelf consisting of a section of rolled angle, properly mounted on the inside of the cover plate, may be used provided the direction of rotation is such that the charge will be caught on the outside face of the angle. If the shelf becomes distorted from its original shape to such an extent that the requirements given in A1.2 of the Appendix to this method are not met, the shelf shall either be repaired or replaced before additional abrasion tests are made.

4.1.1 The machine shall be so driven and so counterbalanced as to maintain a substantially uniform peripheral speed. (Note 3). If an angle is used as the shelf, the direction of rotation shall be such that the charge is caught on the outside surface of the angle.

Note 3 - Back-lash or slip in the driving mechanism is very likely to furnish test results which are not duplicated by other Los Angeles machines producing constant peripheral speed.

4.2 Sieves, conforming to the Specifications for Wire-Cloth Sieves for Testing Purposes (MT-405).

4.3 Balance-The balance shall have a capacity over 2,000 grams thru 5,000 grams, sensitive to 1.0 grams, and with an accuracy of 1.0 gram or 0.1%.

4.4 Oven-The oven shall be capable of maintaining a uniform temperature of 110 ± 5°C (230 ± 9°F).

4.5 Charge-The charge shall consist of steel spheres averaging approximately 1 27/32 in. (46.8 mm) in diameter and each weighing between 390 and 445 g. (Note 4)

4.5.1 The charge, depending upon the grading of the test sample as described in Section 8, shall be as follows:

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<th>Grading</th>
<th>Number of Spheres</th>
<th>Weight of Charge, g</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>12</td>
<td>5,000± 25</td>
</tr>
<tr>
<td>B</td>
<td>11</td>
<td>4,584± 25</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>3,330± 20</td>
</tr>
<tr>
<td>D</td>
<td>6</td>
<td>2,500± 15</td>
</tr>
</tbody>
</table>

Note 4 - Steel ball bearings 1 13/16 in. (46.0 mm) and 1 7/8 in. (47.6 mm) in diameter, weighing approximately 400 and 440 g each, respectively, are readily available. Steel spheres 1 27/32 in. (46.8 mm) in diameter weighing approximately 420 g may also be obtainable. The charge may consist of a mixture of these sizes conforming to the weight tolerances of Sections 4.5 and 4.5.1.

5 Sampling:

5.1 The field sample shall be obtained in accordance with T 2 and reduced to test portion size in accordance with T 248.

6 Test Sample:

6.1 The test sample shall be washed and oven-dried to a constant mass as described in Section 3 (Note 5), separated into individual size fractions, and recombined to the grading of Table 1 most nearly corresponding to the range of sizes in the aggregate furnished for the work. The weight of the sample prior to test shall be recorded to the nearest 1.0 g.
7 Procedure:

7.1 Place the test sample and the charge in the Los Angeles testing machine and rotate the machine at a speed of 30 to 33 rpm for 500 revolutions. After the prescribed number of revolutions, discharge the material from the machine and make a preliminary separation of the sample on a sieve coarser than the 1.70 mm (No. 12). Sieve the finer portion on a 1.70 mm sieve in a manner conforming to MT-202. Wash the material coarser than the 1.70 mm sieve (Note 5), oven-dry to a constant mass, and weigh to the nearest 1.0 g (Note 6).

Note 5 - If the aggregate is essentially free of adherent coatings and dust, the requirement for washing before and after test may be waived. Elimination of washing after test will seldom reduce the measured loss by more than about 0.2% of the original sample weight.

Note 6 - Valuable information concerning the uniformity of the sample under test may be obtained by determining the loss after 100 revolutions. This loss should be determined without washing the material coarser than the 1.70-mm sieve. The ratio of the loss after 100 revolutions to the loss after 500 revolutions should not greatly exceed 0.20 for material of uniform hardness. When this determination is made, take care to avoid losing any part of the sample; return the entire sample, including the dust of fracture, to the testing machine for the final 400 revolutions required to complete the test.

8 Calculation:

8.1 Express the loss (difference between the original weight and the final weight of the test sample) as a percentage of the original weight of the test sample. Report this value as the percent loss.

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Mass of Indicated Sizes, % Grading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passing</td>
<td>Retained on A</td>
</tr>
<tr>
<td>37.5 (1 1/2 in.)</td>
<td>25.0 (1 in.)</td>
</tr>
<tr>
<td>25.0 (1 in.)</td>
<td>19.0 (3/4 in.)</td>
</tr>
<tr>
<td>19.0 (3/4 in.)</td>
<td>12.5 (1/2 in.)</td>
</tr>
<tr>
<td>12.5 (1/2 in.)</td>
<td>9.5 (3/4 in.)</td>
</tr>
<tr>
<td>9.5 (3/4 in.)</td>
<td>6.3 (1/4 in.)</td>
</tr>
<tr>
<td>6.3 (1/4 in.)</td>
<td>4.75 (No. 4)</td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
<td>2.36 (No. 8)</td>
</tr>
</tbody>
</table>

Total: 5,000± 10  5,000± 10  5,000± 10  5,000± 10

Note 7 - The percent loss determined by this method has no known consistent relationship to the percent loss for the same material when tested by ASTM C 535.
APPENDIX

A1  Maintenance of Shelf

A1.1  The shelf of the Los Angeles Machine is subject to severe surface wear and impact. With use, the working surface of the shelf is peened by the balls and tends to develop a ridge of metal parallel to and about 32 mm (1¼ in.) from the junction of the shelf and the inner surface of the cylinder. If the shelf is made from a section of rolled angle, not only may this ridge develop but the shelf itself may be bent longitudinal or transversely from its proper position.

A1.2  The shelf should be inspected periodically to determine that it is not bent either lengthwise or from its normal radial position with respect to the cylinder. If either condition is found, the shelf should be repaired or replaced before further abrasion tests are made. The influence on the test result of the ridge developed by peening of the working face of the shelf is not known. However, for uniform test conditions, it is recommended that the ridge be ground off if its height exceeds 2 mm (0.1 in.).
1 Scope:

1.1 These methods of test are intended for determining the relation between the moisture content and density of soils compacted in a mold of a given size with a 5.5 lb. (2.5 kg) rammer dropped from a height of 12 in. (305 mm). Four alternate procedures are provided as follows:

- **Method A**—A 4 in. (101.60 mm) mold: soil material passing a 4.75 mm (No. 4) sieve Sections 3 and 4.
- **Method B**—A 6 in. (152.40 mm) mold: soil material passing a 4.75 mm (No. 4) sieve Sections 5 and 6.
- **Method C**—A 4 in. (101.60 mm) mold: soil material passing a 19.0 mm (¾ in.) sieve Sections 7 and 8.
- **Method D**—A 6 in. (152.40 mm) mold: soil material passing a 19.0 mm (¾ in.) sieve Sections 9 and 10.

1.2 This test method applies to soils mixtures that have 40 percent or less retained on the 4.75 mm (No. 4) sieve, when Method A or B is used and 30 percent or less retained on the 19.0 mm (¾ in.) sieve, when Method C or D is used. The material retained on these sieves shall be defined as oversized particles (coarse particles).

1.3 If the test specimen contains oversize particles, and the test specimen is used for field density compaction control, corrections must be made according to MT 231 to compare the total field density with the compacted field density. The person or agency specifying the method shall specify a minimum percentage of oversize particles below which correction for oversize need not be applied. If no minimum is specified, correction shall be applied to samples with more than five percent by mass of oversize particles.

1.4 If the specified oversized maximum tolerances are exceeded, other methods of compaction must be used.

**Note 1** – One method for the design and control of the compaction of such soils is to use a test fill to determine the required degree of compaction and a method to obtain that compaction. Then use a method specification to control the compaction by specifying the type and size of compaction equipment, the lift thickness and the number of passes.

1.5 The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off “to the nearest unit” in the last right-hand place of figures used in expressing the limiting value, in accordance with R11.

2 Referenced Documents;

2.1 **AASHTO**:
- T 99 Moisture-Density Relations of Soils Using a 5.5 lb. Rammer with a 12 Inch Drop
- M 92 Wire Cloth and Sieves for Testing Purposes
- R 11 Indicating Which Places of Figures Are to be Considered Significant in Specified Limiting Values
- T224 Coarse Particle Correction
2 Referenced Documents: (continued)

**MT Manual:**
- MT 203 Unit Weight of Aggregate
- MT 405 Wire Cloth Sieves for Testing Purposes
- MT 231 Coarse Particle Correction

3 Apparatus:

3.1 *Molds*—The molds shall be solid-wall, metal cylinders manufactured with dimensions and capacities given in 3.1.1. and 3.1.2 below. They shall have a detachable collar assembly approximately 2.375 in. (60 mm) in height, to permit preparation of compacted specimens of soil-water mixtures of the desired height and volume. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base plate made of the same material (Note 2).

Note 2 - Alternate types of molds with capacities as stipulated herein may be used, provided the test results are correlated with those of the solid-wall mold on several soil types and the same moisture-density results are obtained. Records of such correlation shall be maintained and readily available for inspection, when alternate types of molds are used.

3.1.1 A 4 in. (101.60 mm) Mold having a capacity of 1/30 (0.0333 ± 0.0003 cu. ft. (0.000943 ± 0.000008 m³) with an internal diameter of 4.000 ± 0.016 in. (101.6 ± 0.41 mm) and a height of 4.584 ± 0.005 in. (116.43 ± 0.13 mm).

3.1.2 A 6 in. (152.40 mm) Mold having a capacity of 1/13.33 (0.07500 ± 0.00075 cu. ft. (0.002124 ± 0.000021 m³) with an internal diameter of 6.000 ± 0.026 in. (152.4 ± 0.66 mm) and a height of 4.584 ± 0.005 in. (116.43 ± 0.13 mm).

3.1.3 *Molds Out of Tolerance Due to Use*—A mold that fails to meet manufacturing tolerances after continued service may remain in use provided those tolerances are not exceeded by more than 50 percent; and the volume of the mold, calibrated in accordance with Sec. 6 (Calibration of Measure) of MT-203, for Unit Weight of Aggregate, is used in the calculations.

3.2 *Rammer:*

3.2.1 *Manually Operated*—Metal rammer having a flat circular face of 2.000 ± 0.01 in. (50.80 ± 0.12 mm) diameter, a wear tolerance of 0.01 in. (0.25 mm) and weighing 5.50 ± 0.02 lb, (2.495 ± 0.009 kg). The rammer shall be equipped with a suitable guide-sleeve to control the height of drop to a free fall of 12.00 ± 0.06 (or 1/16) in. (305 ± 2 mm) above the elevation of the soil. The guide-sleeve shall have at least 4 vent holes, no smaller than 3/8 in. (9.5 mm) diameter spaced approximately 90 deg. (1.57 rad) apart and approximately ¾ in. (19 mm) from each end; and shall provide sufficient clearance so the free fall of the rammer shaft and head is unrestricted.

3.2.2 *Mechanically Operated*—A metal rammer which is equipped with a device to control the height of drop to a free fall of 12.00 ± 0.06 (or 1/16) in. (305 ± 2 mm) above the elevation of the soil and uniformly distributes such drops to the soil surface (Note 2). The rammer shall have a flat circular face 2.000 ± 0.01 in. (50.80 ± 0.127 mm) diameter, a wear tolerance of 0.01 in. (0.25 mm) and a manufactured mass of 5.50 ± 0.02 lb. (2.495 ± 0.009 kg). The mechanical rammer shall be calibrated by ASTM Method D 2168 to give the same moisture-density results as with a manually operated rammer.

Note 3 - It may be impractical to adjust the mechanical apparatus so the free fall is 12 in. (305 mm) each time the rammer is dropped, as with the manually operated rammer. To make the adjustment of free fall, the portion of loose soil to receive the initial blow should be slightly compressed with the rammer to establish the point of impact from which the 12 in. (305 mm) drop is determined. Subsequent blows on the layer of soil being compacted may all be applied
3.2 **Apparatus: (continued)**

*by dropping the rammer from a height of 12 in.*

3.2.3 **Rammer Face**—The circular face rammer shall be used but a sector face may be used as an alternative provided the report shall indicate type of face used other than the 2 in. (50.8 mm) circular face and it shall have an area equal to that of the circular face rammer.

3.3 **Sample Extruder**—A jack, lever, frame, or other device adopted for the purpose of extruding compacted specimens from the mold.

3.4 **Balances and Scales**—A balance or scale of at least 25 lb. capacity having a sensitivity and readability to 0.01 lb., or a balance or scale having a capacity of approximately 11.5 kg and a sensitivity and readability to 5 grams. (Note 3) Also, a balance of at least 1 kg capacity with a sensitivity and readability to 0.1 g.

*Note 4 - The capacity of the metric balance or scale should be approximately 11.5 kg when used to weigh the 6 in. (152 mm)mold and compacted, moist soil; however, when the 4-in. (102 mm) mold is used, a balance or scale of lesser capacity than the 11.5 kg may be used, if the sensitivity and readability is 5 g.*

3.5 **Drying Oven**—A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5º C (230 ± 9º F) for drying moisture samples.

3.6 **Straightedge**—A hardened-steel straightedge at least 10 in. (250 mm) in length. It shall have one beveled edge, and at least one longitudinal surface (used for final trimming) shall be plane within 0.01 in. per 10 in. (0.1 percent) (0.250 mm per 250 mm) of length within the portion used for trimming the soil (Note 5).

*Note 5 - The beveled edge may be used for final trimming if the edge is true within a tolerance of 0.001 in. per 10 in. (0.1 percent) (0.250 mm per 250 mm) of length; however, with continued use, the cutting edge may become excessively worn and not suitable for trimming the soil to the level of the mold. The straightedge should not be so flexible that trimming the soil with the cutting edge will cause a concave soil surface.*

3.7 **Sieves**—2-in. (50 mm), ¾-in. (19.0 mm), and No. 4 (4.75 mm) sieves conforming to the requirements of MT-405 (AASHTO M 92), Sieves for Testing Purposes.

3.8 **Mixing Tools**—Miscellaneous tools such as mixing pan, spoon trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

3.9 **Containers**—Suitable containers made of material resistant to corrosion and not subject to change in weight or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing. One container is needed for each moisture content determination.

**METHOD A**

4 **Sample:**

4.1 If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of drying apparatus such that the temperature of the sample does not exceed 60º C (140º F). Then thoroughly break up the aggregations in such a manner to avoid reducing the natural size of individual particles.

4.2 Sieve an adequate quantity of the representative pulverized soil over the No. 4 (4.75 mm) sieve. Discard the coarse material, if any, retained on the No. 4 (4.75 mm) sieve.
Sample: (continued)

4.3 Select a representative sample, with a mass of approximately 7 lb. (3 kg) or more, of the soil prepared as described in Sections 4.1 and 4.2.

Note 6 – When developing a compaction curve for free-draining soils, such as uniform sands and gravels, where seepage occurs at the bottom of the mold and base plate, taking a representative moisture content sample from the mixing bowl may be preferred in order to determine the amount of moisture available for compaction.

5 Procedure:

5.1 Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately four percentage points below optimum moisture content.

5.2 Form a specimen by compacting the prepared soil in the 4 in. (101.60 mm) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 5 in. (125 mm). Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a loose or fluffy state, using either the manual compaction rammer or a similar device having a face diameter of approximately 2 inches (50 mm). Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 12 in. (305 mm) above the elevation of the soil when a sleeve-type rammer is used, or from 12 in. (305 mm) above the approximate elevation of compacted soil when a stationary mounted type of rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid and stable foundation (Note 7).

Note 7 - Each of the following has been found to be a satisfactory base on which to rest the mold during compaction of the soil: A block of concrete, weighing not less than 200 lb. (90 kg), supported by a relatively stable foundation; a sound concrete floor; and for field application, such surfaces as found in concrete box culverts, bridges, and pavements.

5.2.1 Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge, and weigh the mold and moist soil in pounds, to the nearest 0.01 lb., or weigh in kilograms to the nearest 5 grams. For molds conforming to tolerances given in Section 3.1.1 and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 30, and record the result as the wet density, $W_1$, in pounds per cubic foot, of compacted soil. For molds conforming to tolerances given in Section 3.1.1 and masses recorded in kilograms, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 1060, and record the result as the wet density, $W_1$, in kilograms per cubic meter, of compacted soil. For used molds out of tolerance by not more than 50 percent (3.1.3), use the factor for the molds as determined in accordance with Section 6 (Calibration of Measure), MT-203.

5.3 Remove the material from the mold and slice vertically through the center. Take a representative sample of the material from one of the cut faces, weigh immediately, and dry in an oven at 110 ± 5°C (230 ± 9°F) for at least 12 hours, or to a constant mass to determine the moisture content. The moisture sample shall weigh not less than 100 g.

5.4 Thoroughly break up the remaining portion of the molded specimen until it will pass a No. 4 (4.75 mm) sieve as judged by eye, and add to the remaining portion of the sample being tested. Add water in sufficient amount to increase the moisture content of the soil by one or two percentage points, and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet unit mass, $W_1$, per cubic foot or cubic meter of the compacted soil (Note 6).
5 Procedure: (continued)

Note 8 - This procedure has been found satisfactory in most cases. However, in instances where the soil material is fragile in character and will reduce significantly in grain size due to repeated compaction, and in cases where the soil is a heavy-textured clayey material into which it is difficult to incorporate water, a separate and new sample shall be used in each compaction test. In these cases, separate samples shall be thoroughly mixed with amounts of water sufficient to cause the moisture contents of the samples to vary by approximately two percentage points. The moisture points selected shall bracket the optimum moisture content, thus providing samples which when compacted will increase in mass to the maximum density and then decrease in mass. The samples of soil-water mixtures shall be placed in covered containers and allowed to stand for not less than 12 hours before making the moisture-density test.

5.4.1 In instances where the soil material is fragile in character and will be reduced significantly in grain size by repeated compaction, a separate and new sample shall be used in each compaction test.

METHOD B

6 Sample:

6.1 Select the representative sample in accordance with 4.3, except that it shall have a mass of approximately 16 lb. (7 kg).

7 Procedure:

7.1 Follow the same procedure as described for Method A in Section 4, except for the following: Form a specimen by compacting the prepared soil in the 6-in. (152.4 mm) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 5 in. (125 mm), each layer being compacted by 56 uniformly distributed blows from the rammer. For molds conforming to tolerances in 3.1.2, and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 13.3, and record the result as the wet density, \( W_1 \), in lb. ft.\(^3\), of the compacted soil. For molds conforming to tolerances given in 3.1.2 and masses recorded in kilograms, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 471, and record the results as the wet density, \( W_1 \), in kg/m\(^3\), of compacted soil. For used molds out of tolerance by not more than 50 percent (3.1.3), use the factor for the mold as determined in accordance with Section 6 (Calibration of Measure), MT-203.

METHOD C

8 Sample:

8.1 If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of drying apparatus such that the temperature does not exceed 60° C (140° F). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles.

8.2 Sieve an adequate quantity of the representative pulverized soil over the 3/4 in. (19.0 mm) sieve. Discard the coarse material if any, retained on the 3/4 in. (19.0 mm) sieve (Note 7).

Note 9 - The use of the replacement method previously specified, where the oversized particles are replaced with finer particles, to maintain the same percentage of coarse material, is not considered appropriate to compute the maximum density.

8.3 Select a representative sample, having a mass of approximately 12 lb. (5 kg) or more, of the soil prepared as described in 8.1 and 8.2.
9 Procedure:

9.1 Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately 4 percentage points below optimum moisture content.

9.2 Form a specimen by compacting the prepared soil in the 4 in. (102.60 mm) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 5 in. (125 mm). Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a loose or fluffy state, using either the manual compaction rammer or a similar device having a face diameter of approximately 2 inches (50 mm). Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 12 in. (305 mm) above the elevation of the soil when a sleeve-type rammer is used, or from 12 in. (305 mm) above the approximate elevation of each finally compacted layer when a stationary mounted type rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid and stable foundation (Note 5).

9.2.1 Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge. Holes developed in the surface by removal of coarse material shall be patched with smaller size material. Weigh the mold and moist soil in pounds to the nearest 0.01 lb.; or weigh in kilograms to the nearest 5 grams. For molds conforming to tolerances given in Section 3.1.1, and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 30, and record the result as the wet density, \( W_1 \), in lb./ft.\(^3\), of compacted soil. For molds conforming to tolerances given in Section 3.1.1 and masses recorded in kilograms, multiply the mass of the compacted specimen and mold, minus the mass of the mold, by 1060, and record the result as wet density, \( W_1 \), in kg/m\(^3\), of compacted soil. For used molds out of tolerance by not more than 50 percent (3.1.3), use the factor for the mold as determined in accordance with Section 6 (Calibration of Measure), MT-203.

9.3 Remove the material from the mold and slice vertically through the center. Take a representative sample of the material from one of the cut faces, weigh immediately, and dry in an oven at 110 ± 5º C (230 ± 9º F) for at least 12 hours, or to constant mass, to determine the moisture content. The moisture content sample shall weigh not less than 500 g.

9.4 Thoroughly break up the remainder of the material until it will pass a 3/4 in. (19.0 mm) sieve and 90 percent of the soil aggregations will pass a 3/4 in. (4.75 mm) sieve as judged by eye, and add to the remaining portion of the sample being tested. Add water in sufficient amounts to increase the moisture content of the soil sample by one or two percentage points, and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet mass, \( W_1 \), per cubic foot or cubic meter of compacted soil (Note 8).

METHOD D

10 Sample:

10.1 Select the representative sample in accordance with 8.3 except that it shall have a mass of approximately 25 lb. (11 kg).

11 Procedure:

11.1 Follow the same procedure as described for Method C in Section 8 except for the following. Form a specimen by compacting the prepared soil in the 6 in. (152.4 mm) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 5 in. (125 mm), each layer being compacted by 56 uniformly distributed blows from the rammer. For molds conforming
Procedure: (continued)

to tolerances given in 3.1.2 and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 13.3, and record the results as the wet unit mass, $W_1$, in lb/ft³, of the compacted soil. For molds conforming to tolerances given in 3.1.2 and masses recorded in kilograms, multiply the mass of the compacted specimen and mold, minus the mass of the mold, by 471, and record the result as the wet unit mass, $W_1$, in kg/m³ of compacted soil. For used molds out of tolerance by not more than 50 percent (3.1.3), use the factor for the mold as determined in accordance with Section 6 (Calibration of Measure) MT-203.

CALCULATIONS AND REPORT

12 Calculations:

12.1 Calculate the moisture content and the dry unit mass of the soil as compacted for each trial, as follows:

$$w = \frac{A - B}{B - C} \times 100$$
and

$$W = \frac{W_1}{w + 100} \times 100$$

where:

- $w$ = percentage of moisture in the specimen, based on oven dry mass of soil.
- $A$ = mass of container and wet soil.
- $B$ = mass of container and dry soil.
- $C$ = mass of container.
- $W$ = dry mass, in pounds per cubic foot of compacted soil, or kilograms per cubic meter of compacted soil, and
- $W_1$ = wet density, in pounds, per cubic foot of compacted soil or kilograms per cubic meter of compacted soil.

13 Moisture-Density Relationship:

13.1 The calculation in 12.1 shall be made to determine the moisture content and corresponding oven-dry unit mass (density) in pounds per cubic foot or kilograms per cubic meter of the compacted samples. The oven-dry densities (unit weight) of the soil shall be plotted as ordinates and the corresponding moisture content as abscissas.

13.2 Optimum Moisture Content--When the densities and corresponding moisture contents for the soil have been determined and plotted as indicated in 13.1, it will be found that by connecting the plotted points with a smooth line, a curve is produced. The moisture content corresponding to the peak of the curve shall be termed the "optimum moisture-content" of the soil under the above compaction.

13.3 Maximum Density--The oven-dry density in pounds per cubic foot or kilograms per cubic meter of the soil at optimum moisture content shall be termed "maximum density" under the above compaction.
14 Report:

14.1 The report shall include the following:

14.1.1 The method used (Method A, B, C, or D),

14.1.2 The optimum moisture content, as a percentage, to the nearest whole number,

14.1.3 The maximum density in lbs. per cu. ft., to the nearest 0.1 lb/ft³ or in kilograms per cubic meter, the nearest 1 kg.,

14.1.4 In Methods C and D indicate if the material retained on the 19.0 mm sieve was removed or replaced.

14.1.5 Type of face if other than 2 in. (50.8 mm) circular.
METHODS OF SAMPLING AND TESTING
MT 211-04

METHOD OF TEST FOR
MOISTURE-DENSITY RELATIONS OF SOIL-CEMENT MIXTURES
(Modified AASHTO T 134)

1 Scope:

1.1 This method covers procedures for determining the relationship between the moisture content and the density of soil-cement mixtures when compacted before cement hydration as prescribed.

1.2 A 1/30 cu. ft. (0.9 liter) mold and a 5.5 lb. (2.5 kg) rammer dropped from a height of 12 in. (305 mm) are used and two methods, depending on soil gradation, are covered as follows:

1.2.1 Method A - Using soil material passing the 4.75 mm sieve. This method shall be used when 100 percent of the soil sample passes the 4.75 mm sieve, Sections 4 and 5.

1.2.2 Method B - Using soil sample passing the 19.0 mm sieve. This method shall be used when part of the soil sample is retained on the 4.75 mm sieve, Sections 6 and 7.

2 Referenced Documents:

2.1 AASHTO:
T 134 Moisture-Density Relations of Soil-Cement Mixtures

MT Manual:
MT-203 Unit Weight of Aggregate
MT-405 Wire Cloth Sieves for Testing Purposes

3 Apparatus:

3.1 Molds - The molds shall be solid-wall, metal cylinders manufactured with dimensions and capacities shown in 3.1.1. They shall have a detachable collar assembly approximately 2 3/4 in. (60 mm) in height, to permit preparation of compacted specimens of soil-cement mixtures of the desired weight and volume. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base plate made of the same material.

Note 1 - Alternate types of molds with capacities as stipulated herein may be used, provided the test results are correlated with those of the solid-wall mold on several soil types and the same moisture-density results are obtained. Records of such correlations shall be maintained and readily available for inspection when alternate types of molds are used.

3.1.1 A 4-inch mold having a capacity of 1/30 ± 0.0003 cu. ft. (944 ± 8.5 cm³) with an internal diameter of 4.000 ± 0.016 in. (101.6 ± 0.4 mm) and a height of 4.584 ± 0.005 in. (116.4 ± 0.1 mm).

3.1.2 Molds Out of Tolerance Due to Use - A mold that fails to meet manufacturing tolerances after continued service may remain in use provided those tolerances are not exceeded by more than 50 percent; and the volume of the mold, calibrated in accordance with Sec 6 (Calibration of Measure) of MT-203, Unit Weight of Aggregate, is used in the calculations:

3.2 Rammer:

3.2.1 Manually Operated - Metal rammer having a flat circular face of 2.000 ± 0.001 in. (50.8 ± 0.127 mm) diameter, a wear tolerance of 0.005 (0.127 mm) and weighing 5.50 ± 0.02 lb. (2.495 ± 0.009 kg) (Note 2). The rammer shall be equipped with a suitable guide-sleeve to control the height of drop to a free fall of 12.00 ± 0.06 (or 1/16 in.) (304.8 ± 1.524 mm) above the elevation of the soil.
3 **Apparatus:** (continued)

The guide-sleeve shall have at least 4 vent holes, no smaller than 3/8 in. (9.5 mm) diameter spaced approximately 90 deg. apart and approximately 3/4 in. (19 mm) from each end, and shall provide sufficient clearance so the free fall of the rammer shaft and head is unrestricted.

3.2.2 *Mechanically Operated* - A metal rammer which is equipped with a device to control the height of drop to a free fall of 12.00 ± 0.06 (or 1/16 in.) (304.8 ± 1.524 mm) above the elevation of the soil and uniformly distributes such drops to the soil surface. The rammer shall have a flat circular face 2.000 ± 0.001 in. (50.8 ± 0.127 mm) in diameter, a wear tolerance of 0.005 (0.127 mm) and a manufactured mass of 5.50 ± 0.02 lb. (2.495 ± 0.009 kg) (Note 2).

**Note 2** - The rammer apparatus shall be calibrated with several soil-cement mixtures and the mass of the rammer adjusted, if necessary, to give the same moisture-density results as with the manually operated rammer. It may be impractical to adjust the mechanical apparatus so the free fall is 12 in. (305 mm) each time the rammer is dropped, as with the manually operated rammer. To make the adjustment of free fall, the portion of loose soil to receive the initial blow should be slightly compressed with the rammer to establish the point of impact from which the 12 in. (305 mm) drop is determined. Subsequent blows on the layer of soil-cement may all be applied by dropping the rammer from a height of 12 in. (305 mm) above the initial-setting elevation, or when the mechanical apparatus is designed with a height adjustment for each blow, all subsequent blows should have a rammer free fall of 12 in. (305 mm) measured from the elevation of the soil as compacted by the previous blow.

3.2.3 **Rammer Face** - The circular face rammer shall be used but a sector face rammer may be used as an alternative provided the report shall indicate type of face used other than the 2 in. (50.8 mm) circular face and it shall have an area equal to that of the circular face rammer.

3.3 **Sample Extruder** - A jack, lever, frame, or other device adopted for the purpose of extruding compacted specimens from the mold.

3.4 **Balances and Scales** - A balance or scale of at least 25 lb. capacity having a sensitivity and readability to 0.01 lb., or a balance or scale having a capacity of approximately 11.5 kg. and a sensitivity and readability to 5 grams. Also, a balance of at least 1 kg capacity with a sensitivity and readability to 0.1 gram.

3.5 **Drying Oven** - A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5º C (230 ± 9º F) for drying moisture samples.

3.6 **Straightedge** - A hardened steel straightedge at least 10 in. (254 mm) in length. It shall have one beveled edge, and at least one longitudinal surface (used for final trimming) shall be plane within 0.01 in. per 10 in. (0.1 percent) of length within the portion used for trimming the soil (Note 3).

**Note 3** - The beveled edge may be used for final trimming if the edge is true within a tolerance of 0.01 in. per 10 in. (0.1 percent) of length; however, with continued use, the cutting edge may become excessively worn and not suitable for trimming the soil to the level of the mold. The straightedge should not be so flexible that trimming the soil surface with the cutting edge will cause concave soil surface.

3.7 **Sieves** - 50, 19.0, 4.75 mm sieves conforming to the requirements of MT-405, Sieves for Testing Purposes.

3.8 **Mixing Tools** - Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

3.9 **Container** - A flat, round pan for moisture absorption by soil-cement mixtures about 12 in. (300 mm) in diameter and 2 in. (50 mm) deep.
Method Application: (continued)

3.10 Moisture Containers - Suitable containers made of material resistant to corrosion and not subject to change in weight or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing. One container is needed for each moisture content determination.

3.11 Butcher Knife - A butcher knife approximately 10 in. (250 mm) in length, for trimming the top of the specimens.

Method A. Using Soil Material
Passing a 4.75 mm Sieve

4 Sample:

4.1 Prepare the sample for testing by breaking up the soil aggregations to pass the 4.75 mm sieve in such a manner as to avoid reducing the natural size of the individual particles. When necessary, first dry the sample until it is friable under a trowel. Drying may be accomplished by air drying or by the use of drying apparatus such that the temperature of the sample does not exceed 60º C (140º F).

4.2 Select a representative sample weighing approximately 6 lb. (2.72 kg) or more, of the soil prepared as described in 4.1.

5 Procedure:

5.1 Add to the soil the required amount of cement conforming to AASHTO M 85, Specifications for Portland Cement, or AASHTO M 240, Blended Hydraulic Cements. Mix the cement and soil thoroughly to a uniform color. When needed, add sufficient potable water to dampen the mixture to approximately four to six percentage points below the estimated optimum moisture content and mix thoroughly. At this moisture content, plastic soils, tightly squeezed in the palm of the hand, will form a cast that will fracture with only slight pressure applied by the thumb and fingertips; nonplastic soils will bulk noticeably. When the soil is a heavy-textured clayey material, compact the mixture of soil, cement, and water in the container to a depth of about 2 in. (50 mm) using the rammer described in 3.2.1 or a similar hand tamper. Cover, and allow to stand for not less than 5 min. but not more than 10 min. to aid dispersion of the moisture and to permit more complete absorption by the soil-cement. After the absorption period thoroughly break up the mixture, without reducing the natural size of individual particles, until it will pass a 4.75 mm sieve and then remix.

5.2 Form a specimen by compacting the prepared soil-cement mixture in the mold, with the collar attached, in three equal layers so as to give a total compacted depth of about 5 in. (127 mm). Compact each layer by 25 blows from the rammer dropping free from a height of 12 in. (305 mm) above the elevation of the soil-cement when a sleeve-type rammer is used, or from 12 in. (305 mm) above the approximate elevation of each finally compacted layer when a stationary-mounted type rammer is used. The blows shall be uniformly distributed over the surface of the layer being compacted. During compaction, the mold shall rest on a uniform, rigid foundation (Note 4). Following compaction, remove the extension collar, carefully trim the compacted mixture even with the top of the mold by means of the knife and straightedge, and weigh to the nearest 0.01 lb. (0.004 kg). Multiply the mass of the compacted specimen and mold, minus the mass of the mold by 30; record the results as the wet mass per cubic foot (kg/m³) W₁ of the compacted soil-cement mixture.
5 Procedure: (continued)

Note 4 - Each of the following has been found to be a satisfactory base on which to rest the mold during compaction of the soil; a block of concrete weighing not less than 200 lb. (90.8 kg), supported by a relatively stable foundation; a sound concrete floor; and for field application, such surfaces as found in concrete box culverts, bridges and pavements.

5.3 Remove the material from the mold and slice vertically through the center. Take a representative sample of the material, weighing not less than 100 grams, from the full height of one of the cut faces, weigh immediately, and dry in an oven at 230 ± 9°F (110 ± 5°C) for at least 12 hours or to constant mass. Calculate the moisture content of the sample as directed in Section 7. Record the results as the moisture content, w, of the compacted soil-cement mixture.

5.4 Thoroughly break up the remaining portion of the molded specimen until it will pass a 4.75 mm sieve as judged by eye, and add to the remaining portion of the sample being tested. Add water in sufficient amount to increase the moisture content of the soil-cement mixture by one or two percentage points, mix, and repeat the procedure given in 5.2 and 5.3 for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet mass per cubic foot (kg/m³) W¹ of the compacted soil-cement mixture.

Note 5 - This procedure has been found satisfactory in most cases. However, in instances where the soil material is fragile in character and will reduce significantly in grain size due to repeated compaction, a separate and new sample shall be used for each moisture-density determination.

METHOD B. USING MATERIAL PASSING A 19.0 mm SIEVE

6 Sample:

6.1 Prepare the sample for testing by segregating the aggregate retained on a 4.75 mm sieve and breaking up the remaining soil aggregations to pass the 4.75 mm sieve in such a manner as to avoid reducing the natural size of individual particles. When necessary, first dry the sample until it is friable under a trowel. Drying may be accomplished by air drying or by the use of drying apparatus such that the temperature of the sample does not exceed 60º C (140º F).

6.2 Sieve the prepared soil over the 75 mm (Note 6), 19.0 mm, and 4.75 mm sieves. Discard the material retained on the 75 mm sieve. Determine the percentage of material, by oven-dry mass, retained on the 19.0 mm and 4.75 mm sieves. Saturate the aggregate passing the 19.0 mm sieve and retained on the 4.75 mm sieve by soaking in potable water; surface-dry the material as required for later testing.

Note 6 - Most soil-cement construction specifications covering soil gradation limit maximum size material to 75 mm (3 in.) or less.

6.3 Select and maintain separate representative samples of soil passing the 4.75 mm sieve and of saturated, surface-dry aggregate passing the 19.0 mm sieve and retained on the 4.75 mm sieve so that the total sample will weigh approximately 11 lb. (5 kg) or more. The percentage, by oven-dry mass, of aggregate passing the 19.0 mm sieve and retained on the 4.75 mm sieve shall be the same as the percentage passing the 75 mm sieve and retained on the 4.75 mm sieve in the original sample.

7 Procedure:

7.1 Add to the portion of the soil sample passing the 4.75 mm sieve the amount of cement conforming to AASHTO M 85, Specifications for Portland Cement, AASHTO M 240. Blended Hydraulic Cement required for the total sample specified in 5.1. Mix the cement and soil thoroughly to a uniform color. When needed, add water to this soil-cement mixture and facilitate
moisture

7 Procedure: (continued)

dispersion as described for Method A in 4.1. After this preparation, add the saturated, surface-
dry aggregate to the soil-cement mixture passing the 4.75 mm sieve and mix thoroughly.

7.2 Form a specimen by compacting the prepared soil-cement mixture in the mod (with the collar
attached) and trim and weigh the compacted specimen as described for Method A in 5.2. During
the trimming operation remove all particles that extend above the top level of the mold. Correct
all irregularities in the surface by hand-tamping fine material into these irregularities and leveling
the specimen again with the straightedge. Multiply the mass of the compacted specimen and
mold, minus the mass of the mold, by 30; record the result as the wet mass per cubic foot, $W^\prime$, of
the compacted soil-cement mixture.

7.3 Remove the material from the mold and take a sample for determining the moisture content as
described for Method A in 5.3, except that the moisture sample shall weigh not less than 500g.
Record the result as the moisture content $w$, of the compacted soil-cement mixture.

7.4 Thoroughly break up the remainder of the material as before until it will pass a 19.0 mm sieve
and at least 90 percent of the soil particles smaller than a 4.75 mm sieve will pass a 4.75 mm
sieve, as judged by eye, and add all other material remaining after obtaining the moisture sample.
Add sufficient water to increase the moisture content of the soil-cement mixture by one or two
percentage points, mix, and repeat the procedure described in 7.2 and 7.3 for each increment of
water added. Continue this series of determinations until there is either a decrease or no change
in the wet mass per cubic foot ($kg/m^3$) $W^\prime$ of the compacted soil-cement mixture (Note 5).

CALCULATIONS AND REPORTS

8 Calculations:

8.1 Calculate the moisture content and oven-dry mass per cubic foot of the compacted soil-cement
mixture for each trial as follows:

$$w = \frac{A - B}{B - C} \times 100$$

$$W^\prime = \frac{W}{w + 100} \times 100$$

where:

- $w$ = percentage of moisture in the specimen,
- $A$ = mass of moisture can and wet soil-cement,
- $B$ = mass of moisture can and oven-dry soil cement,
- $C$ = mass of moisture can,
- $W$ = oven-dry mass in pounds per cubic foot ($kg/m^3$) of compacted soil-cement, and
- $W^\prime$ = wet mass in pounds per cubic foot ($kg/m^3$) of compacted soil-cement.

9 Moisture-Density Relationship:

9.1 The calculations in Section 8 shall be made to determine the moisture content and corresponding
oven-dry mass pounds per cubic foot ($kg/m^3$) (density) for each of the compacted soil-cement
samples. The oven-dry mass, pounds per cubic foot ($kg/m^3$) (densities) of the soil-cement
mixture shall be plotted as ordinates and the corresponding moisture contents as abscissas.
9 **Moisture-Density Relationship:** (continued)

9.2 *Optimum Moisture Content* - When the densities and corresponding moisture contents for the soil-cement mixture have been determined and plotted as indicated in 9.1, it will be found that by connecting the plotted points with a smooth line, a curve is produced. The moisture content corresponding to the peak of the curve shall be termed the "Optimum moisture content" of the soil-cement mixture under the compaction prescribed in these methods.

9.3 *Maximum Density* - The oven-dry mass, pounds per cubic foot (kg/m$^3$) of the soil cement mixture at "optimum moisture content" shall be termed "maximum density" under the compaction prescribed in these methods.

10 **Report:**

10.1 The report shall include the following:

10.1.1 The method used (Method A or B).

10.1.2 The optimum moisture content, and

10.1.3 The maximum density.
1 Scope:

1.1 This method of test is intended as a means of determining the moisture and/or density of in-place materials, either in the natural state or after compaction.

1.2 In-place moisture and density determinations shall be made by the use of nuclear density/moisture equipment. Moisture may be determined by oven drying or by the calcium carbide method, MT-215.

2 Referenced Documents:

2.1 MT Manual:
   MT-215 Moisture Content by Calcium Carbide Method
   MT-313 Procedure for Comparing Nuclear Gauge to Core Densities of Bituminous Paving Mixtures

2 Types of Equipment:

2.1 The types of equipment being used at the present time are:

2.1.1 A portable nuclear moisture/density gauge containing radioactive sources, electronics and rechargeable batteries

2.1.2 Standard Count Reference Block

2.1.3 AC Charger 115v/60Hz and DC Adapter 12v negative ground

2.1.4 Transport case designed and labeled for each specific gauge

2.1.5 Scraper Plate/Drill Rod Guide

2.1.6 Drill Rod and Drill Rod Extractor

2.1.7 Operators Manual and Gauge Booklet

2.2 The nuclear moisture/density gauges are calibrated by the Montana Department of Transportation for testing density of PCC and AC pavements. The gauges are also calibrated for both density and moisture of most soils and soil aggregate mixtures. The calibrations are stored electronically within the gauge.

2.3 Modes of density operation are backscatter and direct transmission (see Operator Manual). Direct transmission reduces surface roughness error and tests a larger volume of material resulting in increased precision. For these reasons, direct transmission is required whenever possible when testing soils and base gravels. Moisture may be tested with the source rod in any position.

3 Operating Instructions:

3.1 A manufacturer's instructional manual is furnished with each nuclear device and must be consulted for operational procedures. These procedures vary between gauges and must be
3 Operating Instructions: (continued)

followed carefully.

3.2 NUCLEAR GAUGES SHALL ONLY BE DISTRIBUTED TO PERSONNEL WHO HAVE RECEIVED THE REQUIRED 8 HOUR RADIATION SAFETY AND NUCLEAR GAUGE OPERATION COURSE. Upon successful completion of this training, the operator will be furnished a certification card which signifies that she/he is fully qualified to operate nuclear gauges. Additionally, gauge operators must attend a 2 to 4 hour refresher course at intervals not to exceed two years. This training will be provided by MDT.

3.3 District Materials Supervisors must ensure that each gauge operator has completed an approved operator training course, that their card is up to date and in their possession, and that a radiation monitoring device is properly utilized when handling nuclear gauges.

3.4 Some instructional procedures, which should be emphasized, are:

3.4.1 The operator should be very familiar with the Operator's Instruction Manual.

3.4.2 Always be aware of battery charge status and follow battery care instructions in Operator's Manual.

3.4.3 The gauge electronics must be turned on to warm up for a minimum of 15 minutes before taking the daily standard count or testing.

3.4.4 Standard counts shall be taken and recorded each day that gauges are put into use.

3.4.5 If the daily standard counts are more than 1% for density or 2% for moisture from the average of the previous four counts, procedures should be thoroughly examined and the counts taken again. If these counts also fail, problems with the gauge or procedure are indicated and the appropriate District or Area Laboratory should be contacted.

3.4.6 A Stability Test shall be performed:

3.4.6.1 Whenever the accuracy of the gauge is in doubt

3.4.6.2 Before gauge-core correlations

3.4.6.3 At least every two weeks during periods of routine testing.

STABILITY TEST

20 One-Minute Standard Counts
Use Actual Gauge Reading

3.4.6.4 Compute Average, (AVG.)

3.4.6.5 Compute Square Root of Avg., (AVG.)

3.4.6.6 Compute Standard Deviation, (ST.DEV.)

3.4.6.7 Compute Stability Ratio, ST.DEV = Stability Ratio

AVG.
3 Operating Instructions: (continued)

PASSING RATIOS:

<table>
<thead>
<tr>
<th>Moisture</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 3411-B</td>
<td>0.18-0.35</td>
</tr>
<tr>
<td>Model 3440</td>
<td>0.18-0.35</td>
</tr>
</tbody>
</table>

Note - If the ratio falls outside of the indicated ranges, procedures should be checked and the stability test taken again. If another failure occurs, contact the appropriate District or Area Lab.

3.4.7 Shovel, trowel or scraper and straightedge must be used to prepare the test site - **DO NOT USE THE STANDARD TEST BLOCK.**

3.4.8 Use minus No. 30 sieve size dry sand for seating the gauge base. Whenever available, this sand should be native to the project material.

3.4.9 A thin layer of sand should remain between the bottom of the gauge and the ground surface. Any unusual voids or air gaps can cause considerable decrease in density readings.

3.4.10 When testing soils, base gravel, pulverized plant mix materials, cement treated aggregates for acceptance, take two, one-minute counts in the direct transmission mode. Take the first count and record the moisture and density counts. Rotate the gauge 180° around the source rod and take the second count and record the moisture and density counts. The average of the two counts will constitute a test. A valid test consists of density counts in both gauge positions that are within 50 kg/m³ (3 lb/ft³).

3.4.11 When testing plant mix for density acceptance, four (one minute) tests at 90° intervals as in the pattern defined in MT-313 will be performed. All four one minute tests must be within 40 kg/m³ (2.5 lb/ft³). The average of the four tests will be the final test result.

3.4.12 Periodic comparison checks should be made using conventional methods.

4 Calculations:

4.1 Use Lab. Form No. 1000A for recording field determinations with Nuclear Devices. These forms are supplied through the Purchasing Services Bureau (Stores) upon request.

4.1.1 Wet density, dry density, and moisture, all in pounds per cubic foot, can be read directly from the gauge scales. Percent moisture can also be read directly.

4.1.2 \[ \text{Field Dry Density (lbs/ft}^3) \times 100 = \% \text{ compaction} \]

\[ \text{Proctor Dry Density} \]

4.1.3 \[ \text{Field Wet Density (lbs/ft}^3) \times 100 = \% \text{ compaction} \]

\[ \text{Marshall Density} \]

4.1.4 Compare field moisture to optimum moisture from the Proctor determination.

4.1.5 If problems occur on thin lift plant mix overlays, refer to pages 7 and 8 of this test procedure.
5 Radiological Considerations:

5.1 The use of nuclear devices is licensed by the Nuclear Regulatory Commission (NRC). The NRC requires a radiation monitoring system for individuals. They also require the leak testing of nuclear gauges every six months.

5.2 The Materials Bureau has subscribed to a quarterly TLD badge service. We distribute these badges to all District Materials Supervisors and collect them once a quarter. The District Materials Supervisors issue these badges and instruct each nuclear gauge operator on the following:

5.2.1 Each nuclear gauge operator must wear a TLD badge attached to the front of his clothing or belt at waist level.

5.2.2 These TLD badges must not be transferred from one operator to another.

5.2.3 Whenever badges are not being worn, they must be stored at least 30 feet from nuclear gauges, out of direct sunlight, and away from excessive heat or dampness. **BADGES LEFT NEAR GAUGES ARE ESPECIALLY SUSCEPTIBLE TO UNFOUNDED HIGH READINGS.**

5.2.4 Whenever a TLD badge has a high reading, the individual to whom the badge was issued will be notified and must fill out a report and submit it to the Materials Bureau within five days. It is important that all facts and details be presented accurately and conscientiously including diagrams, distances and times. Statements from supervisors and witnesses are also valuable.

5.2.5 The District Materials Supervisor will keep an up-to-date record consisting of the individual's name, the date the badge was issued, the individual's age, the serial number of the gauge they are using, and the project to which the gauge is assigned. This information, along with the TLD badges will be mailed to the Materials Bureau within ten days after the end of the quarter.

5.2.6 An Occupational Radiation History form (NRC Form 4) must be completed by every employee operating a nuclear gauge. The completed form must be sent to the Materials Bureau.

5.2.7 The leak testing of all nuclear gauges will be performed by personnel in the Materials Bureau or other individuals designated by the Radiation Safety Officer to perform such tests. An up-to-date record of the results of these tests shall also be maintained by the Materials Bureau.

6 NRC Licenses and Documents:

6.1 All personnel engaged in activities licensed by the NRC can examine the following documents at the Materials Bureau in Helena.

6.1.1 Publication 10 CFR-19, Notices, Instructions, and Reports to Workers and Inspectors.

6.1.2 Publication 10 CFR-20, Standards for Protection Against Radiation.

6.1.3 NCR License No. 25-11498-01, including all conditions and incorporated documents.

6.1.4 Operating procedures applicable to licensed activities.

6.2 A notice giving the location of the above documents will be inserted in the nuclear gauge operator's manual or posted in the shipping container. This notice and a map showing the location and telephone number of the regional offices of the NRC will be posted on the bulletin boards or other conspicuous places in each district laboratory and area laboratory. Montana is located in Region IV, telephone (817)860-8100.
6 NRC Licenses and Documents: (continued)

6.3 The District Materials Supervisors are responsible to see that each gauge operator has com-
blished training in radiation safety and nuclear gauge operations. Proper storage, transporting,
and distribution within the districts is also a part of this responsibility.

6.4 Inspections will be conducted by the Materials Bureau to verify compliance with the requirements
of the license.

7 Transportation, Storage and Maintenance:

7.1 These instruments require careful handling. The vehicle in which they are transported should be
able of keeping them dry and provide complete security from unauthorized personnel. It
should also be equipped with a carrying rack to which the instrument cases can be strapped and
locked. This is a precision instrument designed to give many years of good service providing it
has proper care.

7.2 Requirements for nuclear gauge storage.

7.2.1 Storage areas are to be locked and posted with radiation caution signs.

7.2.2 When the equipment is not being used, it should be stored in a separate dry room or garage.
The temperature in the storage area should be above freezing and the batteries in the device
should be fully charged. Never store a device in an area where personnel are working or will be
working. Radiation caution signs shall be posted at the entrance door of any storage area.

7.2.3 Radiation levels surrounding the storage area shall not exceed two millirems per hour. To help
ensure low radiation levels outside the storage area, a gauge should be stored as near the center
of the room as practical. Gauges should not be stored above, below or adjacent to a work area.
The best way to assure radiation safety is to limit the number of gauges in a storage area. The
largest number of gauges to be stored in one area is determined by the outside radiation level
which shall not exceed 2 millirems per hour. The Materials Bureau in Helena shall be called to
check the outside area to see if the radiation levels are acceptable.

7.2.4 Store the gauge fully charged. Battery charging during storage is not necessary but gauges
should be given a full charge prior to initial use at the beginning of the construction season.

7.3 Maintaining the Gauge:

7.3.1 The Materials Bureau should be notified immediately when any breakdowns occur. It will be
decided at that time whether the gauge should be sent to the Materials Bureau for repairs.

7.3.2 Clean and maintain the gauge regularly as recommended in the Operator's Manual.

7.4 The Nuclear Gauge Transport paper shall be kept with the nuclear gauge at all times. When
transporting a gauge, the certification shall be filled out, visible and within reach of the driver.

8 Theory of Operation:

8.1 For theory of operation and other detailed descriptions, consult the manufacturer's manual for the
particular model gauge that you are using.
METHODS OF SAMPLING AND TESTING

METHOD OF TEST FOR PLASTIC FINES IN GRADED AGGREGATES
AND SOILS BY USE OF THE SAND EQUIVALENT TEST
(Modified AASHTO T 176)

1 Scope:

1.1 This test is intended to serve as a rapid field test to show the relative proportions of fine dust or claylike material in soils or graded aggregates.

1.2 The following applies to all specified limits in this standard: For the purpose of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value.

2 Referenced Documents:

2.1 AASHTO: T 176 Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test

3 Apparatus:

3.1 A graduated plastic cylinder, rubber stopper, irrigator tube, weighted foot assembly, and siphon assembly, all conforming to their respective specifications and dimensions shown in Figure 1. Fit the siphon assembly to a 1 gal. (4 liter) bottle of working calcium chloride solution (see 2.8) placed on a shelf 36 ± 1 in. (915 ± 25 mm) above the work surface. In lieu of the specified 1 gal. (4 liter) bottle, a glass or plastic vat having a larger capacity may be used providing the liquid level of the working solution is maintained between 36 and 46 inches (915 to 1,170 mm) above the work surface.

Note 1 - An older model of weighted foot assembly has a guide cap that fits over the upper end of the graduated cylinder and centers the rod in the cylinder, and the foot of the assembly has a conical upper surface and three centering screws to center it loosely in the cylinder. The older model does not have the sand reading indicator affixed to the rod (Figure 1), but a slot in the centering screws of the weighted foot is used to indicate the sand reading. Apparatus with the sand reading indicator (Figure 1) is preferred for testing clayey materials.

3.2 A 3 oz. (85 ml) tinned box approximately 2¼ in. (57 mm) in diameter, with Gill style cover and having a capacity of 85 ± 5 ml.

3.3 A wide-mouthed funnel approximately 4 in. (100 mm) in diameter at the mouth.

3.4 A clock or watch reading in minutes and seconds.

3.5 A mechanical shaker as shown in Figure 3, having a throw of 8 ± 0.04 in. (203.2 ± 1.02 mm), and operating at 175 ± 2 cycles per minute (2.92 ± 0.03 Hz) (Note 2). Prior to use, fasten the mechanical sand equivalent shaker securely to a firm and level mount.

3.6 A manually operated shaker as shown in Figure 4, capable of producing an oscillating motion at the rate of 100 complete cycles in 45 ± 5 s, with a hand-assisted half stroke length of 5.0 ± 0.2 in. (127.00 ± 5.08 mm). The shaker shall be fastened securely to a firm and level mount by bolts or clamps if a large number of determinations are to be made.

Note 2 - The mechanical shaker shall be used when performing referee sand equivalent determinations. Either the mechanical or manually operated shaker should be used in lieu of the hand method whenever possible.
3 **Apparatus:** (continued)

3.7 Stock calcium chloride solution: Prepare the stock calcium chloride solution with the following:

- 454 g (1 lb.) technical grade anhydrous calcium chloride
- 2.050 g (1.640 ml.) USP glycerine
- 47 g (45 ml) formaldehyde (40 percent by volume solution)

3.7.1 Dissolve the calcium chloride in ½ gal. (1.89 liters) of distilled or demineralized water. Cool the solution, then filter it through Whatman No. 12 or equivalent filter paper. Add the glycerine and formaldehyde to the filtered solution, mix well, and dilute to 1 gal. (3.79 liters) with distilled or demineralized water.

3.8 Working calcium chloride solution: Prepare the working calcium chloride by diluting one measuring tin fill (85 ± 5 ml.) of the stock calcium chloride solution to 1 gal. (3.79 liters) with water. Use distilled or demineralized water for the normal preparation of the working solution. However, if it is determined that the local tap water is of such purity that it does not affect the test results, it is permissible to use in lieu of distilled or demineralized water except in the event of dispute.

3.9 A straightedge or spatula, suitable for striking off the excess soil from the tin measure.

3.10 A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5º C (230 ± 9º F).

4 **Control:**

4.1 The temperature of the working solution should be maintained at 22 ± 3º C (72 ± 5º F) during the performance of this test. If field conditions preclude the maintenance of the temperature range, frequent referee samples should be submitted to a laboratory where proper temperature control is possible. It is also possible to establish temperature correction curves for each material being tested where proper temperature control is not possible. However, no general correction curve should be utilized for several materials even within a narrow range of sand equivalent values. Samples that meet the minimums and equivalent requirement at a working solution temperature below the recommended range need not be subject to referee testing.
FIGURE 1 Sand Equivalent Test Apparatus
5 Sample Preparation:

5.1 The sand equivalent test shall be performed on soils or graded aggregate materials passing the 4.75 mm (No. 4) sieve. All aggregations of fine-grained soil material shall be pulverized to pass the 4.75 mm sieve, and all fines shall be cleaned from the particles retained on the 4.75 mm sieve and included with the material passing the 4.75 mm sieve.

5.2 Split or quarter enough of the original sample to yield slightly more than four 3-oz. (85 ml.) tin measures of material passing the 4.75 mm sieve. Use extreme care to obtain a truly representative portion of the original sample (Note 3).

Note 3 - Experiments show that as the amount of material being reduced by splitting or quartering is decreased, the accuracy of providing representative portions is reduced. It is imperative that the sample be split or quartered carefully. When it appears necessary, dampen the material before splitting or quartering, to avoid segregation or loss of fines.

5.3 Prepare the desired number of test samples by one of the following methods:

5.3.1 Alternate Method No. 1 - Air Dry.

5.3.1.1 Split or quarter enough material from the passing 4.75 portion to fill the 3 oz. (85 ml) tin measure so it is slightly rounded above the brim. While filling the measure, tap the bottom edge of the tin on the work table or other hard surface to cause consolidation of the material and allow the maximum amount to be placed in the tin. Strike off the tin measure level full with a spatula or straightedge.

5.3.2 Alternate Method No. 2 - Pre-Wet.

5.3.2.1 The sample must be in the proper moisture condition to achieve reliable results. This condition is determined by tightly squeezing a small portion of the thoroughly mixed sample in the palm of the hand. If the cast that is formed permits careful handling without breaking, the correct moisture range has been obtained. If the material is too dry, the cast will crumble and it will be necessary to add water and remix and retest until the material forms a cast. If the material shows any free water, it is too wet to test and must be drained and air dried, mixing it frequently to insure uniformity. This overly wet material will form a good cast when checked initially, so the drying process should continue until a squeeze check on the drying material gives a cast which is more fragile and delicate to handle than the original. If the moisture content of the original sample prepared in 5.2 is within the limits described above, the test sample may be obtained immediately. If the moisture content is altered to meet these limits, the altered sample should be placed in a pan, covered with a lid or with a damp cloth which does not touch the material, and allowed to stand for a minimum of 15 minutes.

5.3.2.2 After the minimum 15-minute tempering period, place the sample on the splitting cloth and mix by alternately lifting each corner of the cloth and pulling it over the sample toward the diagonally opposite corner, causing the material to be rolled. When the material appears homogeneous, finish the mixing with the sample in a pile near the center of the cloth.

5.3.2.3 Fill the 3 oz. (85 ml) tin measure by pushing it through the base of the pile while exerting pressure with the hand against the pile on the side opposite the measure. As the tin is moved through the pile, hold enough pressure with the hand to cause the material to fill the tin to overflowing. Press firmly with the palm of the hand, compacting the material and allowing the maximum amount to be placed in the tin. Strike off the tin measure level full with a spatula or straightedge.
5 Sample Preparation: (continued)

Note 4 - Moist test specimens produce lower sand equivalent values than the corresponding over-dry specimens with almost no exceptions, therefore, if a dual specification encompassing both the wet and dry methods of sample preparation is utilized, it will be necessary to determine the appropriate correction for each material since a standard correction does not appear possible. Either method can be employed with equal confidence, however.

5.3.3 Referee Method (Mechanical Shaker) - Obtain the 3 oz. (85 ml) tin measure of material by one of the alternate methods, 5.3.1 or 5.3.2, above, then dry the test sample to constant mass at 110 ± 5º C (230 ± 9º F), and cool to room temperature before testing.

6 Procedure:

6.1 Siphon 4 ± 0.1 in. (101.6 ± 2.5 ml) of working calcium chloride solution into the plastic cylinder. Pour the prepared test sample from the measuring tin into the plastic cylinder using the funnel to avoid spillage. Tap the bottom of the cylinder sharply on the heel of the hand several times to release air bubbles and to promote thorough wetting of the sample.

6.2 Allow the wetting sample to stand undisturbed for 10 ± 1 minutes. At the end of the 10-minute soaking period, stopper the cylinder, then loosen the material from the bottom by partially inverting the cylinder and shaking it simultaneously.

6.3 After loosening the material from the bottom of the cylinder, shake the cylinder and contents by any one of the following methods:

6.3.1 Mechanical Shaker Method (Referee Method) - Place the stoppered cylinder in the mechanical sand equivalent shaker, set the timer, and allow the machine to shake the cylinder and contents for 45 ± seconds.

6.3.2 Manual Shaker Method - Secure the stoppered cylinder in the three spring clamps on the carriage of the hand operated sand equivalent shaker and reset the stroke counter to zero. Stand directly in front of the shaker and force the pointer to the stroke limit marker painted on the backboard by applying an abrupt horizontal thrust to the upper portion of the right hand spring steel strap. Then remove the hand from the strap and allow the spring action of the straps to move the carriage and cylinder in the opposite direction without assistance or hindrance. Apply enough force to the right hand spring steel strap during the thrust portion of each stroke to move the pointer to the stroke limit marker by pushing against the strap with the ends of the fingers to maintain a smooth oscillating motion. The center of the stroke limit marker is positioned to provide the proper stroke length and its width provides the maximum allowable limits of variation. The proper shaking action is accomplished only when the tip of the pointer reverses direction within the marker limits. Proper shaking action can best be maintained by using only the forearm and wrist action to propel the shaker. Continue the shaking action for 100 strokes.

6.3.3 Hand Method - Hold the cylinder in a horizontal position as illustrated in Figure 7 and shake it vigorously in a horizontal linear motion from end to end. Shake the cylinder 90 cycles in approximately 30 seconds using a throw of 9 ± 1 in. (229 ± 25 mm). A cycle is defined as a complete back and forth motion. To properly shake the cylinder at this speed, it will be necessary for the operator to shake with the forearms only, relaxing the body and shoulders.

6.4 Following the shaking operation, set the cylinder upright on the work table and remove the stopper.

6.5 Irrigation Procedure - Insert the irrigator tube in the cylinder and rinse material from the cylinder walls as the irrigator is lowered. Force the irrigator through the material to the bottom of the cylinder by applying a gentle stabbing and twisting action.
6 Procedure: (continued)

while the working solution flows from the irrigator tip. This flushes the fine material into suspension above the coarser sand particles. Continue to apply the stabbing and twisting action while flushing the fines upward until the cylinder is filled to the 15 in. (381 mm) mark. Then raise the irrigator slowly without shutting off the flow so that the liquid level is maintained at about 15 in. (381 mm) while the irrigator is being withdrawn. Regulate the flow just before the irrigator is entirely withdrawn and adjust the final level to 15 in. (381 mm).

6.6 Allow the cylinder and contents to stand undisturbed to 20 minutes ± 15 seconds. Start the timing immediately after withdrawing the irrigator tube.

6.7 At the end of the 20-minute sedimentation period, read and record the level of the top of the clay suspension. This is referred to as the "clay reading." If no clear line of demarcation has formed at the end of the specified 20-minute sedimentation period, allow the sample to stand undisturbed until a clay reading can be obtained, then immediately read and record the level of the top of the clay suspension and the total sedimentation time. If the total sedimentation time exceeds 30 minutes, rerun the test using three individual samples of the same material. Read and record the clay column height of that sample requiring the shortest sedimentation period only.

6.8 After the clay reading has been taken, the "sand reading" shall be obtained by one of the following methods:

6.8.1 When using the weighted foot assembly having the sand indicator on the rod of the assembly place the assembly over the cylinder and gently lower the assembly toward the sand. Do not allow the indicator to hit the mouth of the cylinder as the assembly is being lowered. As the weighted foot comes to rest on the sand, tip the assembly toward the graduations on the cylinder until the indicator touches the inside of the cylinder. Subtract 10 inches (254 mm) from the level indicated by the extreme top edge of the indicator and record this value as the "sand reading."

6.8.2 If an older model weighted foot assembly having centering screws is used, keep one of the centering screws in contact with the cylinder wall near the graduations so that it can be seen at all times while the assembly is being lowered. When the weighted foot has come to rest on the sand, read the level of the centering screw and record this value as the "sand reading."

6.9 If clay or sand readings fall between 0.1 in. (2.5 mm) graduations, record the level of the higher graduation as the reading. For example, a clay reading of 7.95 would be recorded as 8.0 and a sand reading of 3.22 would be recorded as 3.3.

Note 5 - Samples obtained from aggregate proposed for use in hot asphalt paving mixtures shall be prepared by oven-drying if acceptance of the material is based on tests on material that has passed through a hot plant drier.

7 Calculations:

7.1 Calculate the sand equivalent (SE) to the nearest 0.1 using the following formula:

\[
\text{SE} = \left(\frac{\text{Sand Reading}}{\text{Clay Reading}}\right) \times 100
\]
7 Calculations: (continued)

7.2 If the calculated sand equivalent is not a whole number, report it as the next higher whole number, as in the following example:

\[
\frac{3.3}{8} \times 100 = 41.25, 
\]

which is reported as 42.

7.3 If it is desired to average a series of sand equivalent values, average the whole number values determined as described above. If the average of these values is not a whole number, raise it to the next higher whole number, as in the following example:

Calculated SE values: 41.2, 43.8, 40.9

After raising each to the next higher whole number, they become: 42, 44, 41

The average of these values is then determined:

\[
\frac{42 + 44 + 41}{3} = 42.3
\]

7.3.1 Since the average value is not a whole number, it is raised to the next higher whole number and the reported averages and equivalent value is reported as "43."

8 Precautions:

8.1 Perform the test in a location free of vibrations; vibrations may cause the suspended material to settle at a rate greater than normal.

8.2 Do not expose the plastic cylinders to direct sunlight any more than is necessary.

8.3 Removal of Organic Growth: Occasionally it may be necessary to remove an organic growth from the working calcium chloride solution container and from the inside of the flexible tubing and irrigator tube. This organic material can easily be seen as a slimy substance in the solution. To remove this growth, prepare a cleaning solvent by diluting sodium hypochlorite with an equal quantity of water (see Note 6). Fill the solution container with the prepared cleaning solvent, allow about a liter of the cleaning solvent to flow through the siphon assembly and irrigator tube, then place the pinch clamp on the end of the tubing to cut off the flow of solvent and to hold the solvent in the tube.

Note 6 - Chlorox or its equivalent has been found satisfactory for this purpose.

Refill the container and allow to stand overnight. After soaking, allow the cleaning solvent to flow out through the siphon assembly and irrigator tube. Remove the siphon assembly from the solution container and rinse both with clear water. The irrigator tube and siphon assembly can be rinsed easily by attaching a hose between the tip of the irrigator tube and water faucet and backwashing fresh water through the tube.

8.4 Occasionally the holes in the tip of the irrigator tube may become clogged by a particle of sand. If the obstruction cannot be freed by any other method, use a pin or other sharp object to force it out, using extreme care not to enlarge the size of the opening.
9 **Operator Qualifications:**

9.1 Before an operator is allowed to perform the sand equivalent test by either the manual method or the hand method, he must meet certain qualification requirements for that method. Although the qualification requirements are identical for both methods, an operator shall be permitted to use only that method for which he has qualified.

9.1.1 The operator must be capable of obtaining consistent sand equivalent test results on representative samples of any given material when the test is performed in accordance with the prescribed procedure for that particular method. An operator's test results are considered to be consistent if the individual results of three tests performed by him on representative samples of any given material do not vary by more than ± 4 points from the average of these tests.

8.1.2 The average of three tests by an operator on any given material must correspond within ± 4 points with the average of three tests on the same material when tested using the mechanical shaker method (Referee Method).

9.2 If an operator is not capable of obtaining consistent results with the manual shaker method, or if his results do not agree with results obtained by the mechanical shaker method, he is not to perform the sand equivalent test using the manual shaker until he has perfected his technique sufficiently to bring his test results into the specified limits without adjusting the required number of cycles.

8.3 If an operator is capable of obtaining consistent results when qualifying for the hand method, but the average of his results does not agree within the prescribed limits of the average of three results by the mechanical shaker method, he shall adjust the number of shaking cycles sufficiently to cause his results to agree with those by the mechanical shaker method. Determine the required adjustment in the shaking cycles by the following method:

9.3.1 Estimate the adjusted number of shaking cycles required. Increase the number of cycles to obtain a lower sand equivalent test result or decrease the number of cycles to obtain a higher sand equivalent test result. Perform three tests at the adjusted number of cycles. Strive to maintain the prescribed shaking rate of 180 cycles per minute. Compare the average of the three test results using the adjusted number of strokes with the average obtained by the mechanical shaker method. If necessary, readjust the number of shaking cycles until the average result of three tests at the adjusted number of cycles is within ± 4 points of the average obtained by the mechanical shaker.

9.4 The ± 4 points is a minimum qualification and should not be considered perfection. Each operator should strive to perfect his technique to obtain results equivalent to those of the mechanical shaker method.

8.5 Operators should be required to perform qualification test whenever their results tend to vary appreciably from those obtained using the mechanical shaker method. Qualification tests should be made at regular intervals to assure a reasonable degree of accuracy and standardization of test results.
METHODS OF SAMPLING AND TESTING
RECOMMENDED PRACTICE FOR THE CLASSIFICATION OF
SOILS AND SOIL-AGGREGATE MIXTURES
FOR HIGHWAY CONSTRUCTION PURPOSES
(Modified AASHTO M 145)

1 Scope:

This recommended practice describes a procedure for classifying soils into seven groups based on laboratory determination of particle-size distribution, liquid limit and plasticity index. Evaluation of soils within each group is made by means of a "group index," which is a value calculated from an empirical formula. The group classification, including group index, should be useful in determining the relative quality of the soil material for use in earthwork structures, particularly embankments, sub-grades, sub-bases, and bases. However, for the detailed design of important structures, additional data concerning strength or performance characteristics of the soil under field conditions will usually be required.

2 Referenced Documents:

2.1 AASHTO:
T 11 Materials Finer Than 75-µm (No. 200) Sieve in Aggregates by Washing
T 27 Sieve Analysis of Fine and Coarse Aggregates
T-88 Particle Size Analysis of Soils
M 145 Classification of Soil and Soil-Aggregate Mixtures for Highway Construction Purposes
T-146 Wet Preparation of Disturbed Soil Samples for Test

ASTM:
D 1140 Amount of Material in Soils Finer Than the No. 200 (75 μm) Sieve

MT Manual:
MT-200 Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test
MT-202 Sieve Analysis of Fine and Coarse Aggregates
MT-208 Determining the Plastic Limit and Plasticity Index of Soils
MT-208 Determining the Liquid Limit of Soils

Note 1 - Either AASHTO T 88, or T 11 and T 27, or ASTM D 1140 will be used to determine the particle size distribution of soils or soil-aggregate mixtures as a basis for classification.

3 Classification:

3.1 The classification is made by using the test limits and group index values shown in Table 1. If a more detailed classification is desired, a further subdivision of the groups shown in Table 1 may be made. An example of the classification with such subgroups as shown in Table 1 may be made. An example of the classification with such subgroups is shown in Table 2. The liquid limit and plasticity index ranges for the A-4, A-5, A-6, and A-7 soil groups are shown graphically in Figure 2.

3.2 Classification Procedure - With required test data available, proceed from left to right in Table 1 or Table 2 and the correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification. All limiting test values are shown as whole numbers. If fractional numbers appear on test reports, convert to nearest whole number for purposes of classification. Group index values should always be shown in parentheses after group symbol as: A-2(3), A-4(5), A-6(12), A-7-5(17), etc.
### TABLE 1 – Classification of Soils and Soil-Aggregate Mixtures

<table>
<thead>
<tr>
<th>General Classification</th>
<th>Granite Materials (35% or Less Passing No. 200)</th>
<th>Silt – Clay Materials (More than 35% Passing No. 200)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Classification</td>
<td>A-1</td>
<td>A-3$^a$</td>
</tr>
<tr>
<td>Sieve Analysis, percent passing:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.00 mm (No. 10)…………………</td>
<td>......</td>
<td>......</td>
</tr>
<tr>
<td>0.425 mm (No. 40)…………………</td>
<td>50 max.</td>
<td>51 min.</td>
</tr>
<tr>
<td>0.075 mm (No. 200)…………………</td>
<td>25 max.</td>
<td>10 max.</td>
</tr>
<tr>
<td>Characteristics of fraction passing No. 40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid Limit…………………</td>
<td>......</td>
<td>......</td>
</tr>
<tr>
<td>Plasticity Index…………………</td>
<td>6 max</td>
<td>NP</td>
</tr>
<tr>
<td>General rating as subgrade</td>
<td>Excellent to Good</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ The placing of A-3 before A-2 is necessary in the “left to right elimination process” and does not indicate superiority of A-3 over A-2.

$^b$ See Table 2 for values.

### TABLE 2 – Classification of Soils and Soil-Aggregate Mixtures

<table>
<thead>
<tr>
<th>General Classification</th>
<th>Granite Materials (35% or Less Passing the 0.075)</th>
<th>Silt – Clay Materials (More than 35% Passing No. 200)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Classification</td>
<td>A-1</td>
<td>A-2</td>
</tr>
<tr>
<td>Sieve Analysis, percent passing:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.00 mm (No. 10)…………………</td>
<td>50 max</td>
<td>......</td>
</tr>
<tr>
<td>0.425 mm (No. 40)…………………</td>
<td>30 max</td>
<td>50 max</td>
</tr>
<tr>
<td>0.075 mm (No. 200)…………………</td>
<td>15 max</td>
<td>25 max</td>
</tr>
<tr>
<td>Characteristics of fraction passing No. 40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid Limit…………………</td>
<td>......</td>
<td>......</td>
</tr>
<tr>
<td>Plasticity Index…………………</td>
<td>6 max</td>
<td>NP</td>
</tr>
<tr>
<td>Usual types of significant constituent materials</td>
<td>Stone fragments, gravel and sand</td>
<td>Fine sand</td>
</tr>
<tr>
<td>General rating as subgrade</td>
<td>Excellent to Good</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30. (See figure 2.)
4 Definitions of Gravel, Sand, and Silt-Clay:

4.1 The terms "gravel," "coarse sand," and "silt-clay," as determinable from the minimum test data required in this classification arrangement, and as used in subsequent word descriptions, are defined as follows:

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

4.1.2 **Coarse Sand** - Material passing the 2.00 mm (No. 10) sieve and retained on the 0.425 mm (No. 40) sieve.

4.1.3 **Fine Sand** - Material passing the 0.425 mm (No. 40) sieve and retained on the 0.075 mm (No. 200) sieve.

4.1.4 **Silt Clay (combined silt and clay)** - Material passing the 0.075 mm (No. 200) sieve.

4.1.5 **Boulders and Cobbles** [retained on 75 mm (3 in.) sieve] should be excluded from the portion of the sample to which the classification is applied, but the percentage of such material, if any, in the sample should be recorded.

*Note* - The revised specification is identified as Interim Specification M 149.91 l.

4.1.6 The term "silty" is applied to fine material having plasticity index of 10 or less and the term "clayey" is applied to fine material having plasticity index of 11 or greater.

5 Description of Classification Groups:

5.1 **Granular Materials** - Containing 35 percent or less passing 0.075 mm (No. 200) sieve, Note 2.

5.1.1 **Group A-1** - The typical material of this group is a well-graded mixture of stone fragments or gravel, coarse sand, fine sand and a nonplastic or feebly plastic soil binder. However, this group includes also stone fragments, gravel, volcanic cinders, etc. without soil binder.

5.1.1.1 **Subgroup A-1-a** includes those materials consisting predominantly of stone fragments or gravel, either with or without a well-graded binder of fine material.

5.1.1.2 **Subgroup A-1-b** includes those materials consisting predominantly of coarse sand either with or without a well-graded soil binder.

5.1.2 **Group A-3** - The typical material of this group is fine beach sand or fine desert blow sand without silty or clay fines or with a very small amount of nonplastic silt. The group includes also stream-deposited mixtures of poorly-graded fine sand and limited amounts of coarse sand and gravel.

5.1.3 **Group A-2** - This group includes a wide variety of "granular" materials which are border-line between the materials falling in Groups A-1 and A-3 and silt-clay materials of Groups A-4, A-5, A-6, and A-7. It includes all materials containing 35 percent or less passing the 0.075 mm (No. 200) sieve which cannot be classified as A-1 or A-3, due to fines content or plasticity, or both, in excess of the limitations for those groups.

5.1.3.1 **Subgroups A-2-4 and A-2-5** include various granular materials containing 35 percent or less passing the 0.075 mm (No. 200) sieve and with a minus 0.425 mm (No. 40) portion having the characteristics of the A-4 and A-5 groups. These groups include such materials as gravel and coarse sand with silt contents or plasticity indexes in excess of the limitations of Group A-1, and fine sand with nonplastic silt content in excess of the limitations of Group A-3.

5.1.3.2 **Subgroups A-2-6 and A-2-7** include materials similar to those described under Subgroups A-2-4 and A-2-5, except that the fine portion contains plastic clay having the characteristics of the A-6 or A-7 group.
5 Description of Classification Groups: (continued)

Note 2 - Classification of materials in the various groups applies only to the fraction passing the 75 mm (3-in.) sieve. Therefore, any specifications regarding the use of A-1, A-2, or A-3 materials in construction should state whether boulders retained on the 75 mm (3-in.) sieve are permitted.

5.2 Silt-Clay Materials - Containing more than 35 percent passing the 0.075 mm (No. 200) sieve.

5.2.1 Group A-4 - The typical material of this group is a nonplastic or moderately plastic silty soil usually having the 75 percent or more passing the 0.075 mm (No. 200) sieve. The group includes also mixtures of fine silty soil and up to 64 percent of sand and gravel retained on 0.075 mm (No. 200) sieve.

5.2.2 Group A-5 - The typical material of this group is similar to that described under Group A-4, except that it is usually of diatomaceous or micaeous character and may be highly elastic as indicated by the high liquid limit.

5.2.3 Group A-6 - The typical material of this group is a plastic clay soil usually having 75 percent or more passing the 0.075 mm (No. 200) sieve. The group includes also mixtures of fine clayey soil and up to 64 percent of sand and gravel retained on the 0.075 mm (No. 200) sieve. Materials of this group usually have high volume change between wet and dry states.

5.2.4 Group A-7 - The typical material of this group is similar to that described under Group A-6, except that it has the high liquid limits characteristic of the A-5 group and may be elastic as well as subject to high volume change.

5.2.4.1 Subgroup A-7-5 includes those materials with moderate plasticity indexes in relation to liquid limit and which may be highly elastic as well as subject to considerable volume change.

5.2.4.2 Subgroup A-7-6 includes those materials with high plasticity indexes in relation to liquid limit and which are subject to extremely high volume change.

Note 3 - Highly organic soils (peat or much) may be classified in an A-8 group. Classification of these materials is based on visual inspection, and is not dependent on percentage passing the 0.075 mm (No. 200) sieve, liquid limit or plasticity index. The material is composed primarily of partially decayed organic matter, generally has a fibrous texture, dark brown or black color and odor of decay. These organic materials are unsuitable for use in embankments and sub-grades. They are highly compressible and have low strength.

6 Group Index:

6.1 The group index is calculated from the following formula:

\[
\text{Group index} = (F-35)(0.2 + 0.005(LL-40)) + 0.01(F-15)(PI-10),
\]

in which,

\[
F = \text{percentage passing 0.075 mm (No. 200) sieve, expressed as a whole number. This percentage is based only on the material passing the 75 mm (3-in.) sieve.}
\]

\[
LL = \text{liquid limit}
\]

\[
PI = \text{plasticity index}
\]

6.1.1 When the calculated group index is negative, the group index shall be reported as zero (0).

6.1.2 The group index should be reported to the nearest whole number.

6.2 Figure 1 may be used in estimating the group index, by determining the partial group index due to liquid limit and that due to plasticity index, then obtaining the total of the two partial group indexes.
6 Group Index: (continued)

6.3 When calculating the group index of A-2-6 and A-2-7 subgroups, only the PI portion of the formula (or of Figure 1) shall be used.

6.4 The following are examples of calculations of the group index:

6.4.1 Assume that an A-6 material has 55 percent passing the 0.075 mm (No. 200) sieve, liquid limit of 40, and plasticity index of 25. Then,

\[
\text{Group} = (55-35)[0.2 + 0.005(40-40)] + 0.01(55-15)(25-10) = 4.0 + 6.0 = 10
\]

6.4.2 Assume that an A-7 material has 80 percent passing the 0.075 mm (No. 200) sieve, liquid limit of 90, and plasticity index of 50. Then,

\[
\text{Group index} = (80-35)[0.2 + 0.005(90-40)] + 0.01 (80-15)(50-10) = 20.3 + 26.0, \text{ or } 46.3
\]

6.4.3 Assume that an A-4 material has 60 percent passing the 0.075 mm (No. 200) sieve, liquid limit of 25, and plasticity index of 1. Then,

\[
\text{Group index} = (60-35)[0.2 + 0.005(25-40)] + 0.01 (60-15)(1-10) = 25 \times (0.2 - 0.075) + 0.01(45)(-9) = 3.1 - 4.1 = 4.1 = 1.0
\]

Report as 0.

6.4.4 Assume that an A-2-7 material has 30 percent passing the 0.075 mm (No. 200) sieve, liquid limit of 50, and plasticity index of 30. Then,

\[
\text{Group index} = 0.01(30-15)(30-10) = 3.0 \text{ or } 3 \text{ (Note that only the PI portion of formula was used.)}
\]
Group Index (GI) = (F - 35)(0.2 + 0.005(LL-40)) + 0.01(F-15)(PI-10)

where $F =$ Percent Passing 0.075-mm sieve, $LL =$ Liquid Limit,
and $PI =$ Plasticity Index.

When working with A-2-6 and A-2-7 Subgroups, the Partial Group Index (PGI)
is determined from the PI only.

When the combined Partial Group Indices are negative, the Group Index
should be reported as zero.

**Figure 1 – Group Index Chart**
The empirical group index formula devised for approximately within-group evaluation of the "clayey granular materials" and the "silt-clay materials" is based on the following assumptions:

7.1.1 Materials falling within Groups A-1-a, A-1-b, A-2-4, A-2-5, and A-3 are satisfactory as subgrade when properly drained and compacted under moderate thickness pavement (base and/or surface course) of a type suitable for the traffic to be carried, or can be made satisfactory by additions of small amounts of natural or artificial binders.

7.1.2 Materials falling within the "clayey granular" Groups A-2-6 and A-2-7 and the "silt-clay" Groups A-4, A-5, A-6, and A-7 will range in quality as sub-grade from the approximate equivalent of the good A-2-4 and A-2-5 sub-grades to fair and poor sub-grades requiring a layer of sub-base material or an increased thickness of base course over that required under 7.1.1 in order to furnish adequate support for traffic loads.

7.1.3 The assumed critical minimum percentage passing the 0.075 mm (No. 200) sieve is 35 neglecting plasticity, and 15 as affected by plasticity indexes greater than 10.

7.1.4 Liquid limits of 40 and above are assumed to be critical.

7.1.5 Plasticity indexes of 10 and above are assumed to be critical.

7.1.6 For soils that are non-plastic and when the liquid limit cannot be determined, the group index shall be considered zero (0).
7.2 There is no upper limit of group index value obtained by use of the formula. The adopted critical values of percentage passing the 0.075 mm (No. 200) sieve, liquid limit and plasticity index, are based on an evaluation of sub-grade, sub-base and base course materials by several highway organizations that use the tests involved in this classification system.

7.3 Under average conditions of good drainage and thorough compaction, the supporting value of a material as sub-grade may be assumed as an inverse ratio to its group index, that is, a group index of 0 indicates a "good" sub-grade material and a group index of 20 or greater indicates a "very poor" sub-grade material.
1 Scope:

1.1 This method outlines the procedure for analyzing combined aggregate gradations for optimized concrete mix designs.

2 Referenced Documents:

*MT Manual:*

MT 201 Sampling Roadway Materials
MT 202 Sieve Analysis for Fine and Coarse Aggregate

3 Apparatus:

3.1 The apparatus required for sampling aggregates and performing sieve analysis will be as stated in MT 201 and MT 202.

4 Procedure:

4.1 Submit sieve analysis reports showing the cumulative combined percent passing, the cumulative combined percent retained, and the combined percent retained as shown in the sieve analysis Table 4-1. Include in the report, each individual aggregate gradation starting with the largest appropriate sieve for that material and including all the consecutive smaller sieve sizes through the #200 (75-μm) sieve. They are to include: 1 1/2-in. (37.5-mm), 1-in. (25-mm.), 3/4-in. (19-mm), 1/2-in. (12.5-mm), 3/8-in. (9.5-mm), #4 (4.75-mm), #8 (2.3-mm), #16 (1.18-mm), #30 (60-μm), #50 (300-μm), #100 (150-μm), and #200 (75-μm) sieves. For coarse and intermediate aggregates, the #16 (1.18-mm) through #100 (150-μm) sieves may be determined mathematically.

4.2 Submit the following charts used to perform aggregate gradation analysis:

- Coarseness Factor Chart
- 0.45 Power Chart
- Percent Retained Chart

4.3 Perform a sieve analysis according to MT 202 for each aggregate that will be used in the optimized mix design. Complete a sieve analysis with the percent passing and the relative percent volume of each aggregate used in the proposed mix design as shown in Table 4-1.
### Table 4-1: Sieve Analysis

<table>
<thead>
<tr>
<th>% Passing Agg (P)</th>
<th>Coarse Aggregate</th>
<th>Mid</th>
<th>Fine Aggregate</th>
<th>Combined Aggregate</th>
<th>Each Sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3</td>
<td>1 1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sieve</td>
<td>% Passing</td>
<td>% Passing</td>
<td>% Passing</td>
<td>% Passing</td>
<td>% Passing</td>
</tr>
<tr>
<td>2 in.</td>
<td>100.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1 1/2 in.</td>
<td>100.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1 in.</td>
<td>100.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>3/4 in.</td>
<td>96.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1/2 in.</td>
<td>63.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>3/8 in.</td>
<td>28.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>95.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>No. 4</td>
<td>9.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>65.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>No. 8</td>
<td>2.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>3.0%</td>
<td>96.0%</td>
</tr>
<tr>
<td>No. 16</td>
<td>1.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>1.0%</td>
<td>76.0%</td>
</tr>
<tr>
<td>No. 30</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>45.0%</td>
</tr>
<tr>
<td>No. 50</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>17.0%</td>
</tr>
<tr>
<td>No. 100</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>6.0%</td>
</tr>
<tr>
<td>No. 200</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Pan</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Blend % (R)</td>
<td>55.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>9.0%</td>
<td>36.0%</td>
</tr>
</tbody>
</table>

#### Calculations:

**5.1** Calculate the cumulative combined percent passing each sieve using the following equation:

\[
C_P = \sum \{(P_A)(R_A)\}
\]

where:

- \(C_P\) = Cumulative Combined % Passing
- \(P_A\) = % Passing of Aggregate
- \(R_A\) = Relative % of Aggregate

**5.2** Calculate the cumulative combined percent retained on each sieve using the following equation:

\[
C_R = 100\% - C_P
\]

where:

- \(C_R\) = Cumulative Combined % Retained
- \(C_P\) = Cumulative Combined % Passing
5 Calculations: (continued)

5.3 Calculate the combined percent retained on each sieve using the following equation:

\[ C = C_R - C_{RX} \]

where:

\( C = \text{Combined \% Retained} \)
\( C_R = \text{Cumulative Combined \% Retained} \)
\( C_{RX} = \text{Cumulative Combined \% Retained of next larger sieve size} \)

6 Charts:

6.1 Coarseness Factor Chart—Use the cumulative combined sieve analysis to determine the coarseness and workability factors. Plot the coarseness and workability factors on the Coarseness Factor Chart (Figure 5-1).

Determine the coarseness factor using the following equation:

\[ CF = \left( \frac{S}{T} \right) \times 100 \]

where:

\( CF = \text{Coarseness Factor} \)
\( S = \text{Cumulative \% Retained on the 3/8 in. Sieve} \)
\( T = \text{Cumulative \% Retained on the No. 8 Sieve} \)

The workability factor is the cumulative combined percent passing the No. 8 sieve. Increase the workability factor by 2.5 percentage points for every 94 lb. per cubic yard of cementitious material used in excess of 564 lb. per cubic yard in the mix design. Decrease the workability factor by 2.5 percentage points for every 94 lb. per cubic yard of cementitious material used below 564 lb. per cubic yard in the mix design. Do not adjust the workability factor if the amount of cementitious material is 564 lb. per cubic yard.

The coarseness factor and workability factor must plot within the workability box defined as follows:

- coarseness factor must not be greater than 68 or less than 52
- workability factor must not be greater than 38 or less than 34 when the coarse factor is 52
- workability factor must not be greater than 36 or less than 32 when the coarseness factor is 68
6.2 0.45 Power Chart—The 0.45 Power Chart (Figure 5-2) is created by plotting the cumulative percent passing (y-axis) vs. the sieve sizes raised to the power of 0.45 (x-axis). The cumulative percent passing should generally follow the maximum density line and should not deviate beyond the maximum and minimum tolerance lines. There may be a “hump,” beyond the tolerance line and above the maximum density line around the No. 16 sieve. There will always be a dip below the maximum density line around the No. 30 sieve. These deviations are typical and should not be cause for rejection of a gradation unless results from trial batches indicate workability problems.

The maximum density line is a straight line calculated with the following equation:

\[ P = \left( \frac{d}{D} \right)^{0.45} \]

where:

- \( P \) = % Passing
- \( d \) = sieve size being considered
- \( D \) = nominal maximum sieve size

The nominal maximum sieve size is one sieve larger than the first sieve to retain ≥10%.

The tolerance lines are straight lines drawn on either side of the maximum density line. Draw the tolerance lines from the origin of the chart to 100% of the next sieve size smaller and larger than the maximum density sieve size.
6.3 **Percent Retained Chart**—Create the Percent Retained Chart (Figure 5-3) by plotting the combined percent-retained (y-axis) vs. the sieve sizes (x-axis). The sum of the percent retained on any two adjacent sieves, excluding the first and last sieve that retains material, must not be less than 13%.

![Percent Retained Chart](image-url)
Charts: (continued)

6.4 *MDT Optimized Gradation Worksheet* — May be used to perform the aggregate gradation analysis. It allows the user to input sieve analysis results and aggregate percentages, generating all of the previous charts.

6.5 *Selection of Optimized Aggregate Gradation* — Use the aggregate gradations and proportions that plot within the limits of the three charts described above as the basis for trial batches. Perform trial batches with varying aggregate proportions meeting the limits of the three previous charts to determine which concrete mix proportions meet contract requirements.

The Materials Bureau may allow the use of aggregate gradations and proportions that exceed the limits of the 0.45 Power Chart and the percent-retained chart. This may be permitted if the coarseness and workability factors plot within the workability box on the Coarseness Factor Chart and the trial batch results meet all contact requirements.

6.6 *Aggregate Gradation Monitoring and Aggregate Proportion Adjustment* — Monitor the aggregate gradation by plotting the results of each sieve analysis on the three previous charts. Perform sieve analysis on a lot by lot basis determined by MT 601.

Any adjustments to the aggregate proportions during concrete production to keep the coarseness factor and workability factor plotted within the workability box on the Coarseness Factor Chart are subject to the Project Manager’s approval.
METHODS OF SAMPLING AND TESTING

METHOD OF SAMPLING AND TESTING CEMENT TREATED BASE
(Montana Test Method)

1 Scope:

1.1 This method covers procedures for making, curing, and testing cylindrical specimens from representative samples of Cement Treated Base (CTB).

2 Referenced Documents:

2.1 AASHTO:
T134 Moisture-Density Relations of Soil-Cement Mixtures
T 231 Capping Cylindrical Concrete Specimens

ASTM:
D1633 Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders

MT Manual:
MT 201 Sampling Roadway Materials
MT 203 Unit Weight of Aggregate
MT 211 Moisture Density Relations of Soil-Cement Mixtures
MT 212 Determination of Moisture and Density of In-Place Materials
MT 228 Method of Establishing Field Target Density for Cement Treated Base Density Control
MT 405 Wire Cloth Sieves for Testing Purposes
MT 601 Materials Sampling, Testing and Acceptance Guide

3 Apparatus:

3.1 Molds - Use solid-wall, metal cylinders manufactured with dimensions and capacities shown in 3.1.1. They must have a detachable collar assembly approximately 2.375 in. (60 mm) in height, to permit preparation of compacted specimens of soil-cement mixtures of the desired weight and volume. The mold and collar assembly must be constructed so that it can be fastened firmly to a detachable base plate made of the same material.

Note 1 - Alternate types of molds with capacities as stipulated herein may be used, provided the test results are correlated with those of the solid-wall mold on several soil types and the same moisture-density results are obtained. Records of such correlations shall be maintained and readily available for inspection when alternate types of molds are used.

3.1.1 A 4 in. (101.6 mm) mold having a capacity of 1/30 ± 0.0003 cu. ft. (943 ± 8 cm³) with an internal diameter of 4.000 ± 0.016 in. (101.6 ± 0.41 mm) and a height of 4.584 ± 0.005 in. (116.43 ± 0.13 mm).

3.1.2 Molds Out of Tolerance Due to Use - A mold that fails to meet manufacturing tolerances after continued service may remain in use provided those tolerances are not exceeded by more than 50 percent; and the volume of the mold, calibrated in accordance with MT 203, Section 6 (Calibration of Measure), is used in the calculations.
Apparatus: (continued)

3.2 **Rammer:**

3.2.1 *Manually Operated* - Metal rammer having a flat circular face of 2.000 in. (50.8 mm) diameter, a manufacturing tolerance of ± 0.01 (0.25 mm) and weighing 5.50 ± 0.02 lb. (2.495 ± 0.009 kg). The in-service diameter of the flat circular face shall be not less than 1.985 in. (50.42 mm). Use a rammer equipped with a suitable guide-sleeve to control the height of drop to a free fall of 12.00 ± 0.06 in. (305 ± 2 mm) above the elevation of the soil. The guide-sleeve must have at least 4 vent holes, no smaller than ¾ in. (9.5 mm) diameter spaced approximately 90 degrees (1.57 radius) apart and approximately ¾ in. (19 mm) from each end, and provide sufficient clearance so the free fall of the rammer shaft and head is unrestricted.

3.2.2 *Mechanically Operated* - A metal rammer equipped with a device to control the height of drop to a free fall of 12.00 ± 0.06 in. (305 ± 2 mm) above the elevation of the soil and uniformly distributes such drops to the soil surface (Note 2). The rammer must have a flat circular face 2.000 in. (50.8 mm) diameter, a manufacturing tolerance of ± 0.01 (0.25 mm) and weighing 5.50 ± 0.02 lb. (2.495 ± 0.009 kg).

*Note 2 – Calibrate the rammer apparatus with several soil-cement mixtures. Adjust the mass of the rammer, if necessary, to give the same moisture-density results as with the manually operated rammer. It may be impractical to adjust the mechanical apparatus so the free fall is 12 in. (305 mm) each time the rammer is dropped, as with the manually operated rammer. To make the adjustment of free fall, the portion of loose soil to receive the initial blow should be slightly compressed with the rammer to establish the point of impact from which the 12 in. (305 mm) drop is determined. Subsequent blows on the layer of soil-cement may all be applied by dropping the rammer from a height of 12 in. (305 mm) above the initial-setting elevation, or when the mechanical apparatus is designed with a height adjustment for each blow, all subsequent blows should have a rammer free fall of 12 in. (305 mm) measured from the elevation of the soil-cement as compacted by the previous blow.*

3.2.3 **Rammer Face** – Use the circular face rammer. If necessary, use a sector face rammer as an alternative. Indicate the type of face used other than the 2 in. (50.8 mm) circular face in the report. The alternate must have an area equal to that of the circular face rammer.

3.3 **Sample Extruder** - A jack, lever, frame, or other device adopted for the purpose of extruding compacted specimens from the mold.

3.4 **Balances and Scales** - A balance or scale of at least 25 lb. (11.5 kg) capacity having sensitivity and readability to 0.01 lb. (5 grams). Also, a balance of at least 3 lb. (1 kg) capacity having sensitivity and readability to 0.003 oz. (0.1 gram). Use balances or scales of the same units shown in the contract.

3.5 **Heat Source** - Oven, hot plate or alternate heating source.

3.6 **Straightedge** - A hardened steel straightedge at least 10 in. (254 mm) in length. Use a straightedge with one beveled edge. At least one longitudinal surface (used for final trimming) must be plane within 0.01 in. per 10 in. (0.25 mm per 250 mm) (0.1 percent) of length within the portion used for trimming the soil. (Note 3)

*Note 3 - The beveled edge may be used for final trimming if the edge is true within a tolerance of 0.01 in. per 10 in. (0.25 mm per 250 mm) (0.1 percent) of length; however, with continued use, the cutting edge may become excessively worn and not suitable for trimming the soil to the level of the mold. The straightedge should not be so flexible that trimming the soil surface with the cutting edge will concave the soil surface.*
Apparatus: (continued)

3.7 Sieves – 2 in. (50 mm), ¾ in. (19.0 mm), No. 4 (4.75 mm) sieves conforming to the requirements of MT 405.

3.8 Mixing Tools - Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

3.9 Container - A flat, round pan for moisture absorption by soil-cement mixtures about 12 in. (305 mm) in diameter and 2 in. (50 mm) deep.

3.10 Moisture Containers - Suitable containers made of material resistant to corrosion and not subject to change in weight or disintegration on repeated heating and cooling. Use containers with close-fitting lids to prevent loss of moisture from samples before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing. One container is needed for each moisture content determination.

3.11 Butcher Knife - A butcher knife approximately 10 in. (250 mm) in length, for trimming the top of the specimens.

4 CTB Mix Design:

4.1 Verify that the contractor has submitted a cement treated base mix design to the Materials Bureau at least 10 business days before scheduled placement. Confirm with the Materials Bureau that the design is approved for use before allowing placement on the project.

5 Acceptance:

5.1 In-Place Densities - Test for compaction in accordance with Subsection 304.03.5. Determine in-place densities in accordance with MT 212. Establish a corrected moisture curve by correcting the nuclear moisture reading to oven-dry moisture contents.

5.2 Field-Made Compression Specimens – Mold a minimum of one set of compressive strength specimens for every 750 cubic yards (550 cubic meters) of CTB in accordance with MT 601. A set consists of three compressive strength specimens molded in accordance with Section 6 of this procedure. It is desirable that these specimens represent the material placed at the locations of the in-place densities so moisture-density comparisons can be made. Two specimens from each set will be tested at 7 days to determine strength acceptance. The remaining specimens will be broken at 28 days to identify strength gain. A copy of the sample record containing moisture content, cementitious material content, and density must accompany each set of compressive strength specimens in the shipping boxes.

5.3 Acceptance Samples of Aggregate - Sample for gradation analysis in accordance with Subsection 304.03.1.

6 Molding Specimens in the Field:

6.1 Sample the CTB mixture placed on the roadway from a representative location in accordance with MT 201. Obtain approximately one cubic foot of material and place in suitable container(s) lined with a plastic bag. Once the sample is complete, close the bag and place a lid on the container(s). This is done to reduce any possibility of moisture loss from the sample. Transport the sample to the place of molding as quickly as possible in order to minimize hydration (excessive hydration can reduce the lubrication properties and result in less than maximum density and therefore lower strengths). Remix the sample before and during molding to ensure uniformity and prevent segregation.
Molding Specimens in the Field: (continued)

6.2 Immediately form a specimen by compacting the mixture in the mold in accordance with MT 211, Section 5.2 (with the collar attached). Trim the specimen in accordance with MT 211, Section 7.2. Uniformly distribute the material by spading along the inside of the mold with a spatula for each lift placed in the mold and before compaction. After compaction of each lift, scarify or roughen the top of the layer in order to obtain a good bond between lifts.

6.3 During compaction, obtain a representative sample of the mixture, weighing not less than 500 grams. Weigh the sample immediately and dry until further drying does not alter the weight greater than 0.1 percent, constant mass. Determine the moisture content as a check against design moisture content.

6.4 Weigh the compacted specimen to check against design density before beginning the initial cure. (Note 4)

Note 4 - Once the specimen has been struck off to the required smoothness and weighed, cover the top of the mold with plastic and place the compaction collar back on the mold, leaving the plastic in place. Tighten the collar so that the plastic will make an airtight seal around the rim of the mold and the surface of the specimen. This is done to prevent moisture loss from the specimen during the initial cure. Once all specimens have been molded and sealed with plastic, place in a cure box to protect the specimens from temperature extremes and from direct sunlight. Maintain a temperature range of 60° F to 80° F during the initial cure in the field. The location for the initial cure must be horizontally level, rigid, and free from vibration or other disturbances.

6.5 Maintain a running average of densities and moistures in accordance with MT 228 to establish density control.

6.6 Form two additional specimens in the same manner as the first as rapidly as possible. Identify two specimens as 7-day compression specimens, and the third as a 28-day compression specimen. (Note 5)

Note 5 - A satisfactory method of identifying the specimens for the 7-day or 28-day breaks is to wrap a piece of masking tape around the specimen. Indicate on the masking tape the date made, stationing & lane, type of test, etc.

6.7 Cure the compacted specimens in the molds a minimum of 24 hours. Extract the specimens from the molds, place in the shipping box packed in damp sawdust, and transport to the Materials Bureau as soon as possible so that the final cure can be accomplished in the moist cure room for the remainder of the curing period.

7 Compressive Strength Determination:

7.1 Determine the diameter using two diameter measurements to the nearest 0.01 inches (0.25 mm) taken at 90 degrees to one another near mid height of the specimen. Prior to placing compressive strength specimens in the compression machine, verify that both ends of the specimen are plane to within 0.002 in (0.05 mm). If an end of the specimen is outside of the 0.002 in. (0.05 mm) tolerance, cap that end of the specimen in accordance with AASHTO T 231.

7.2 Determine the 7 day unconfined compressive strength in accordance with ASTM D1633 except as modified herein. Omit the requirement for immersing cured specimens in water for 4 hours prior to testing.

7.3 Maintain free moisture on the outsides of specimens to prevent drying until testing is complete (except for the ends of the specimens when sulfur capping). When capping with sulfur, be certain that the ends of the specimen are dry enough to prevent small pockets of steam from forming within the capping compound.
8 Calculation:

8.1 Calculate the unit compressive strength of the specimen by dividing the maximum load by the cross-sectional area.

\[ S = \frac{lbf}{\pi r^2} \]

Where:
- \( S \) = Strength
- \( lbf \) = Maximum Load
- \( r \) = Radius of Specimen

8.2 For purposes of this method, determine strength of specimens using a height (uncapped) divided by diameter ratio of 1.15. This is standard and is not to be corrected by a length to diameter correction factor.

9 Report:

9.1 The field technician is to report the following:

- Sample Date the cylinder was made
- Percent cement rounded to the nearest tenth
- Percent fly ash rounded to the nearest tenth
- Depth of material placed rounded to the nearest tenth of a ft (m)
- Station where sample was taken
- Density rounded to the nearest tenth of lbs per ft\(^3\) (kg per m\(^3\))
- Moisture content rounded to the nearest tenth of a percent

9.2 The lab technician is to report the following:

- Date the cylinder was broken
- Diameter of the cylinder rounded to the nearest hundredth of an inch (mm)
- Load rounded to the whole number in lbs per ft (kg per m)
- Compressive strength rounded to the nearest whole number in lbs per in\(^2\) (MPa)

Report the average strength of the two 7-day cylinders rounded to the nearest whole number.
METHODS OF SAMPLING AND TESTING

METHOD OF TEST FOR DETERMINING
PERCENTAGE OF MECHANICALLY FRACTURED PARTICLES

1 Scope:

1.1 This test method covers the determination of the percentage, by mass or by count, of a coarse aggregate sample that consists of fractured particles meeting specified requirements.

1.2 The values stated in SI units are to be regarded as the standard. The values in parentheses are provided for information only.

2 Referenced Documents:

2.1 ASTM:
D 5821 Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate

MT Manual:
MT 201 Sampling Roadway Materials
MT 202 Sieve Analysis for Coarse and Fine Aggregate
MT 405 Wire Cloth Sieves for Testing Purposes
MT 607 Procedure for Reducing Field Samples to Testing Size

WAQTC:
TM-1 Determining the Percentage of Fractured Particles in Coarse Aggregate

3 Terminology:

3.1 Fractured face, n – an angular, rough, or broken surface of an aggregate particle created by crushing, by other artificial means, or by nature.

3.2 Discussion – for this standard, a face will be considered a "fractured face" only if it has a projected area at least as large as one quarter of the maximum projected area (maximum cross-sectional area) of the particle and the face has sharp and well-defined edges; this excludes small nicks

3.3 Fractured particle, n – a particle of aggregate having at least the minimum number of fractured faces specified (usually one or two).

3.4 Nominal Maximum Size – One sieve size larger than the first sieve to retain more than 10 percent.

4 Significance and Use:

4.1 Some specifications contain requirements relating to percentage of fractured particles in coarse aggregates. One purpose of such requirements is to maximize shear strength by increasing inter-particle friction in either bound or unbound aggregate mixtures. Another purpose is to provide stability for surface treatment aggregates and to provide increased friction and texture for aggregates used in pavement surface courses. This test method provides a standard procedure for determining the acceptability of coarse aggregate with respect to such requirements.
4 Significance and Use: (continued)

4.2 Specifications differ as to the number of fractured faces required on a fractured particle, and they also
differ as to whether percentage by mass or percentage by particle count shall be used. If the
specification does not specify, use the criterion of at least one fractured face and calculate percentage
by mass.

5 Apparatus:

5.1 Balance - A balance or scale accurate and readable to within 0.1% of the test sample mass at any
point within the range of use.

5.2 Sieves - Sieves shall be of the woven wire type with square openings and shall conform to MT 405.

5.3 Splitter – A sample splitter suitable for dividing field samples into test portion sizes according to MT
607.

5.4 Spatula - A spatula or similar tool to aid in sorting aggregate particles.

6 Sampling:

6.1 Sample and reduce the aggregate in accordance with MT 201 and MT 607.

7 Sample Preparation:

7.1 Dry the sample sufficiently to obtain a clean separation of fine and coarse material in the sieving
operation. Sieve the sample in accordance with MT 202 over the 4.75 mm (No. 4) sieve, or other
specified sieve for retaining material for this test, and reduce the portion retained on the sieve using a
splitter in accordance with MT 607 to the appropriate size for test. This test size should be slightly
larger than shown in Table 1 to account for loss of fines through washing, if necessary.

Note - When individual sieve fracture determination is required, such as in the Special Provisions for a Grade
“S” mix design, the test sample size will be determined using Table 2.

7.2 For aggregate with a nominal maximum size of 19.0 mm (3/4 in.) or larger, where the fracture particle
content is to be determined for material retained on the 4.75 mm (No. 4) or smaller sieve, the test
sample may be separated on the 9.5 mm (3/8 in.) sieve. The portion passing the 9.5 mm (3/8 in.) sieve
may then be further reduced, in accordance with MT 607, to a minimum of 200 g (0.5 lbs.). This will
reduce the number of particles to be separated during the procedure. In this case, percent fractured
particles is determined on each portion; and a weighted average of fractured particles is calculated
based on the mass of each of the portions to reflect the total percentage of fractured particles in the
entire sample.
Combined Fracture Determination

TABLE 1

<table>
<thead>
<tr>
<th>Nominal Maximum Size Square Openings, mm (in.)</th>
<th>Minimum Test Sample Mass, grams (Approx. lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.75 (No.4)</td>
<td>200 (0.4)</td>
</tr>
<tr>
<td>9.5 (3/8)</td>
<td>400 (0.9)</td>
</tr>
<tr>
<td>12.5 (1/2)</td>
<td>700 (1.5)</td>
</tr>
<tr>
<td>19.0 (3/4)</td>
<td>1,000 (2.5)</td>
</tr>
<tr>
<td>25.0 (1)</td>
<td>1,500 (3.5)</td>
</tr>
<tr>
<td>37.5 (11/2)</td>
<td>2,500 (6)</td>
</tr>
<tr>
<td>50.0 (2)</td>
<td>4,000 (8.8)</td>
</tr>
<tr>
<td>63.0 (21/2)</td>
<td>7,500 (16.5)</td>
</tr>
<tr>
<td>75.0 (3)</td>
<td>10,000 (27)</td>
</tr>
<tr>
<td>90.0 (31/2)</td>
<td>15,000 (33)</td>
</tr>
</tbody>
</table>

Note - Nominal maximum size is one sieve size larger than the first sieve to retain more than 10 percent of the material.

Individual Sieve Fracture Determination

TABLE 2

<table>
<thead>
<tr>
<th>Nominal Maximum Size Square Openings, mm (in.)</th>
<th>Minimum Test Sample Mass, grams (Approx. lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.00 (No.10)</td>
<td>25 (0.1)</td>
</tr>
<tr>
<td>2.36 (No.8)</td>
<td>25 (0.1)</td>
</tr>
<tr>
<td>4.75 (No.4)</td>
<td>100 (0.4)</td>
</tr>
<tr>
<td>6.3 (¼)</td>
<td>100 (0.2)</td>
</tr>
<tr>
<td>9.5 (3/8)</td>
<td>200 (0.5)</td>
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<tr>
<td>12.5 (1/2)</td>
<td>300 (0.7)</td>
</tr>
<tr>
<td>16.0 (5/8)</td>
<td>500 (1)</td>
</tr>
<tr>
<td>19.0 (3/4)</td>
<td>700 (1.5)</td>
</tr>
<tr>
<td>25.0 (1)</td>
<td>1,000 (2.2)</td>
</tr>
<tr>
<td>31.5 (11/4)</td>
<td>1,500 (3.5)</td>
</tr>
</tbody>
</table>

8 Procedure:

8.1 Wash the sample, when necessary, over the sieve designated for determination of fractured particles to remove any remaining fine material, and dry to a constant mass in accordance with MT 202. Determine the mass of the test sample, and any subsequent determination of mass, to the nearest 0.1% of the original dry sample mass.

8.2 Spread the dried test sample on a clean flat surface large enough to permit careful inspection of each particle. To verify that a particle meets the criteria, hold the aggregate particle so that the face is viewed directly. If the face constitutes at least one quarter of the maximum cross sectional area of the rock particle, consider it a fractured face.

8.3 Using the spatula or similar tool, separate the test sample into three categories: (1) fractured particle based on whether the particle has the required number of fractured faces, (2) particles not meeting the specified criteria, and (3) questionable or borderline particles. If the required number of fractured faces is not given in the applicable specifications, the determination will be made on the basis of a minimum of one fractured face.
8 Procedure: (continued)

8.4 To aid in making the fracture determination, separate the sample into three categories. Determine the mass or count of particle in the fractured particle category, the mass or count of the questionable particles, and the mass or count of the particle not meeting the specified fracture criteria. Use mass to calculate percent fractured particles unless percentage by particle count is specified.

8.5 If more than one number of fractured faces is specified (for example, 90% with one or more fractured faces and 60% with two or more fractured faces), repeat the procedure on the same sample for each requirement.

8.6 If on any of the determinations, more than 15% of the total is placed in the questionable pile, repeat the determination until no more than 15% is present in that category. Use percent based on mass for this determination unless percent by particle count is specified. Also, if the sample has been divided into two test portions, the 15% criteria shall apply to each.

9 Report:

9.1 Report the mass percentage of fractured faces to the nearest 1% in accordance with the following:

\[ P = \frac{F + Q/2}{F + Q + N} \times 100 \]

- \( P \) = percentage of particle with the specified number of fractured faces,
- \( F \) = mass or count of fractured particles with at least the specified number of fractured faces,
- \( Q \) = mass of count of particles in the questionable or borderline category, and
- \( N \) = mass or count of particles in the uncrushed category not meeting the fractured particle criteria.

Example:

\[ F = 632.6 \text{ g}, \; Q = 97.6 \text{ g}, \; N = 352.3 \text{ g} \]

\[ P = \frac{(632.6 \text{ g} + 97.6 \text{ g}/2)(632.6 \text{ g} + 97.6 \text{ g} + 352.3 \text{ g})}{100} = 62.9\% \]

9.2 Report the specified fracture criteria against which the sample was evaluated.

9.3 Report the total mass in grams of the coarse aggregate sample tested.

9.4 Report the sieve on which the test sample was retained at the start of the test.

9.5 Report whether the percentage of fractured particles was determined by mass or by particle count.
A face will be considered a "Fractured Face" only if it has: \( A_r \geq 0.25 \times X_{\text{max}} \)

**FIG. 1 Schematic of a Fractured Particle with One Fractured Face**

Fig. 1 reprinted with the permission of the American Society for Testing Materials
METHODS OF SAMPLING AND TESTING

MT 218-04

METHOD OF TEST FOR

DETERMINING RELATIVE COMPACTION AND PERCENT MOISTURE

(Montana Test Method)

1 Scope:

1.1 This procedure is intended as a guide for comparing in-place moisture and density to optimum moisture and maximum density, respectively, in order to determine compliance with standard specifications and contract special provisions.

2 Referenced Documents:

2.1 MT Manual:
MT-210 Moisture-Density Relations of Soils Using a 5.5 lb. Rammer
MT-212 Determination of Moisture and Density of In-Place Materials
MT-230 Moisture-Density Relations of Soils Using a 10 lb. Rammer

3 In-Place Moisture and Density:

3.1 The in-place moisture and density shall be determined in accordance with MT-212.

4 Optimum Moisture and Maximum Density:

4.1 The optimum moisture and maximum density shall be determined in accordance with MT-210 or MT-230, Method A, B, C, or D, whichever is applicable, using the following criteria as a guide.

4.2 When the material under test is a soil or aggregate consisting of entirely minus 4 mesh (4.75 mm), Method A or B will be used.

4.3 When the material under test is a soil or aggregate with a maximum size of 3/4 inch (19.0 mm), Method C or D will be used.

4.4 When the material under test is a soil or aggregate with a maximum size of 2 inches (50 mm), Method D will be used.

4.5 When the material under test is a soil or aggregate with a maximum size of 4 inches (100 mm) and no more than 50% of the material under test is retained on the 4 mesh (4.75 mm), Method D will be used.

4.6 When the material under test is a soil or aggregate with a maximum size larger than 2 inches (50 mm) and more than 50% of the material under test is retained on the 4 mesh (4.75 mm), the material will not be required to meet 95% density within 2% optimum moisture.

4.6.1 A screen analysis must be provided on representative samples from each lift of the embankment area to prove that more than 50% of the material is retained on the 4 mesh (4.75 mm) sieve.

4.6.2 Nuclear M/D readings must be taken on each lift in the embankment area to demonstrate that uniform relative density has been achieved.

4.6.3 Notes must be made on the Summary of Compaction Data (Form 1006) showing the results obtained in paragraphs 4.1.5.1 and 4.1.5.2.
5 Calculation:

5.1 Determine the relative compaction by dividing the in-place density (pounds per cubic foot) by the maximum density (pounds per cubic foot) and multiplying by 100.

5.2 A direct comparison of the in-place moisture and the optimum moisture will determine compliance with specifications.

6 Family of Curves:

6.1 A "family of curves" is a term applied to a number of moisture-density curves which are plotted on one cross-section sheet, using the same ordinates and abscissas as dry weights pounds per cubic foot and moisture contents, respectively. The family of curves is plotted, initially, from values obtained by the sampling and testing of the various soil types during the Preconstruction Soils Survey and every effort must be made to sample and identify all of the various soil types that will be encountered on the project. Each new soil type, or mixture of soils, encountered on the project during construction, will be represented by a moisture-density curve, which is added to the "family".

Note 1 – New curves drawn through plotted one-point determinations shall not become a permanent part of the family of curves until verified by a full moisture-density relationship.

7 One Point Proctors:

7.1 A "one point Proctor" is an abbreviated standard Proctor compaction test and is used in conjunction with the family of curves. Rather than determining the moisture and density points for an entire curve, a single point is determined for the purpose of selecting the curve, which represents the soil being compacted, from the family of curves.

7.1.1 One-point Proctors shall be run whenever there is any doubt that the soil being compacted is from a location on the project, which is represented, by one of the curves in the family of curves.

7.1.2 Frequently soils may be mixed by heavy equipment excavating and hauling to the embankment site and a one-point Proctor may not fit any of the established curves. In these cases a new curve will have to be prepared from the mixture and added to the family of curves.

7.1.3 It is necessary to run the one-point Proctor as close to optimum moisture as possible. The point should be within plus or minus three percent of optimum on most curves and within plus or minus two percent of optimum on sharp breaking curves. If the point is established on either side of optimum and some distance from the peak of the curve, it may very well fit more than one curve in the family of curves, or none at all and it will be impossible to select the proper curve.

7.1.4 The moisture and density results obtained by the one-point Proctor are plotted on the family of curves and, when obtained near optimum, will fall near one of the curves in the family of curves, provided that particular type of soil or mixture of soils has been tested for optimum moisture and maximum density. The peak of the curve selected shall be considered the optimum moisture and maximum density of the material represented by the one-point Proctor.

Note 2 – If the one-point plotted within or on the family of curves does not fall in the 80 to 100 percent of optimum moisture range, compact another specimen, using the same material, at an adjusted moisture content that will place the one-point within this range.

8 Numbering Check Samples:
When a check sample is taken it will be assigned the same number as the sample being checked, with the addition of a letter suffix. For example, if sample number 38 failed to meet specifications, the first check sample would be numbered 38-A, the second check sample would be 38-B.
METHODS OF SAMPLING AND TESTING

METHOD OF TEST FOR
CONTROLLING THE COMPACTION OF SURFACING AGGREGATES
AND PLANT MIX PAVING

USING A CONTROL-STRIP TEST-SECTION TECHNIQUE WITH NUCLEAR GAUGES

(Montana Test Method)

1 Scope:

1.1 This test method is intended to control the density of compacted courses of surfacing aggregates and plant mix pavement using nuclear gauges.

2 Referenced Documents:

2.1 MT Manual:
MT-212 Determination of Moisture and Density of In-Place Materials
MT-230 Moisture-Density Relations of Soils using a 10 lb. Rammer
MT-311 Marshall Method for Field Control of Hot Mix Asphalt Paving

3 Definitions:

3.1 Control-Strip A - Surfacing Aggregates - A section approximately three hundred (300) feet long by the typical section width of two lanes on a firm sub-grade.

3.2 Control-Strip B - Plant Mix Paving - A section approximately three hundred (300) feet long by one paver width on a firmly compacted base. Please refer to table 1 on page 4 as a guide for maximum rolling times.

3.3 Test-Section Surfacing Aggregates - Individual sections each approximately two thousand (2000) feet long, as constructed, on which the surfacing aggregates will be placed, using the same layer thickness, compaction watering and procedures used in constructing the Control-strip A above.

3.4 Test-Section Plant Mix Paving - Individual sections each approximately two thousand (2000) feet long by one paver width on which plant mix material will be placed, using the same layer thickness, compaction and procedure used in construction the Control-strip B above.

4 Equipment:

4.1 Nuclear Moisture/Density Gauges - Refer to MT-212 of the Materials Manual for a description of the various types of devices.

5 Operational Procedures:

5.1 Control-Strip Surfacing Aggregates - At the beginning of compaction operations, the density requirements shall be determined by compacting a Control-Strip of an approved thickness. The procedure, MT-230 (Proctor Test) establishes the dry density for aggregates being used in the Control-strip. (Note 1)

Note 1 - The moisture-density of the control strip will be determined by the use of approved nuclear equipment under field conditions.

5.1.1 After each application of the roller, wet density and moisture determinations are made with the Nuclear device at a minimum of three (3) random locations. These locations may be marked with a small quantity of minus 30 mesh dry sand - the finer the better. This sand should be screened from the material that is being compacted and dried to constant weight. This sand serves to
5 Operational Procedures: (continued)

identify each test location and is an aid for seating the Nuclear device to preclude air voids between the bottom surface of the probe and the coarser aggregate particles that may be extruding above the surface of the lift. To avoid any errors in reading due to the build-up of sand beneath the Nuclear device, approximately the same quantity of sand is used at each of the three test locations. The test locations are marked so that the same locations are tested after each pass.

5.1.2 An average dry density is computed and plotted on a chart of dry density versus the number of roller passes. Rolling is discontinued when the curve plotted for dry density versus roller passes levels off. When the density plot levels off, density and moisture readings are taken at seven additional locations. Ten test sites in the 300 feet long Control-Strip are calculated to yield satisfactory statistical results. The average dry density is computed from the ten sets of readings and this serves as the standard of compaction. A new Control-Strip is required when the aggregate characteristics change appreciably, the aggregate is produced from a different source, or there has been a change in the rolling equipment or procedures used. Each new lift will require a new Control-Strip to determine if there is any change in Control-Strip density. If a different Nuclear device is used, a new Control-Strip might have to be established.

5.2 Test-Sections Surfacing Aggregates - The remainder of the project is divided into Test-Sections described above. After placing and compacting a lift of surfacing aggregate, employing the same thickness and procedures used in the Control-Strip, moisture and density readings are taken at ten randomly selected locations. Dry density determinations are made for each set of readings.

5.2.1 Whenever the minimum density results are not met, immediate corrective action must be taken by additional rolling or additional water and rolling. The densities of the completed Test-Sections must be determined without delay for applicable comparison (under the same conditions) with the Control-Strip density. (Note 2) Similarly, proper use of the most suitable roller can decrease time in attaining proper density in the Test-Section. The contractor should be encouraged to use various methods in establishing density in the Control-Strip.

Note 2 - (Not a specification requirement) The effective use of water and the method used in compacting the Control-Strip can influence the time and the compactive effort required to attain satisfactory density.

5.3 Control Strip Plant Mix Paving - All roller equipment will be approved by the engineer prior to the construction of the Control-Strip as specified in the Standard Specification. Whenever a Control-Strip is required on plant mix surfacing a comparison will be made between the established Control-Strip density and the Marshall density as determined by MT-311 (Marshall Method of Hot Mix Asphalt Paving). This should be done to ensure a reasonable Control-Strip density is established.

5.3.1 Three test sites will be randomly selected on the Control-Strip. Each site will be marked with minus 30 mesh dry seating sand used to seat the Nuclear gauge. This sand should be screened from the material that is being compacted and dried to constant weight. Compaction of the Control-Strip shall commence as soon as possible after placement of the bituminous mixture and be uniform over the entire Control-Strip before the temperature of the mix falls below 175 F. A test will be taken on each test site with a Nuclear gauge after each pass of the compaction equipment.

5.3.2 This procedure will continue until the density increase is less than one (1) pound per cubic foot at a temperature greater than 175 F. After completion of the rolling, then two more tests sites are established so that a total of five density tests are averaged for the Control-Strip density.

5.3.3 Each new lift will require a new Control-Strip to determine if there is any change in Control-Strip density. If a different Nuclear device is used, a new Control-Strip might have to be established.
5 Operational Procedures: (continued)

5.4 Test Section Plant Mix Paving - The remainder of the project is divided into 2000 ft. test sections. After placing and compacting a lift of Plant Mix Paving, employing the same thickness and procedures used in the Control-Strip, density readings are taken at five randomly selected locations. The average density of each test section will be evaluated based upon the results of five tests in each test section. Whenever the minimum density results are not met, immediate corrective action must be taken by additional rolling. The densities of the completed test sections must be determined without delay for applicable comparison (under the same conditions) with the Control-Strip density.

6 Forms and Reports:

6.1 The attached Lab. Form No. 1000-A is used for controlling the compaction of surfacing aggregates. This form may also be used for Control Strip paving.

6.2 Lab. Form No. 1006-A, Summary of Compaction Data for Surfacing, is applicable for all types of Nuclear devices. It is requested that the serial number of the device being used and the Laboratory Number of each pit, be entered on this form.

TABLE 1*

MAXIMUM AVAILABLE ROLLING TIMES

<table>
<thead>
<tr>
<th>Recommended Minimum Laydown Temperature</th>
<th>Mat Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Temp.°F</td>
<td>½&quot;</td>
</tr>
<tr>
<td>+35-40</td>
<td>-</td>
</tr>
<tr>
<td>+40-50</td>
<td>-</td>
</tr>
<tr>
<td>+50-60</td>
<td>-</td>
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<tr>
<td>+60-70</td>
<td>310</td>
</tr>
<tr>
<td>+70-80</td>
<td>300</td>
</tr>
<tr>
<td>+80-90</td>
<td>290</td>
</tr>
<tr>
<td>+90</td>
<td>280</td>
</tr>
</tbody>
</table>

Maximum Available Rolling time, minutes. 4 6 8 12 15 15

* Table from Superintendents Manual on Compaction of Hot Mix Asphalt Pavement

As an example: to illustrate the use of the table, assume we are placing a 1½" thick mat and the base temperature is between 50°F and 60°F. A laydown temperature of 295°F is needed to provide 12 minutes before the mat cools to an average temperature of 175°F. If it is a warmer day, with a base temperature of 70°F to 80°F, a laydown temperature of 280°F would provide 12 minutes of rolling time. On a day warm enough to have a base temp of 70°F to 80°F, the air temperature would probably be above 40°F and there would be some sunshine, so it would probably take 2 or 3 more minutes to cool to 175°F, probably 15 minutes.

Where dashes appear in the table, conditions are such that it is doubtful that specification density can be achieved so work would cease. The table has come to be known as "cessation requirements."
## Control Strip Density

<table>
<thead>
<tr>
<th>Test Site Number</th>
<th>Density Ref. Standard Count</th>
<th>Moisture Ref. Standard Count</th>
<th>Backscatter Count</th>
<th>Direct Tran. Count and Depth</th>
<th>Moisture Wet Density</th>
<th>Location</th>
<th>Distance Left or Right of Centerline</th>
<th>□ PCF</th>
<th>Percent Moisture</th>
<th>Dry Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
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</tbody>
</table>

**Remarks:**

Density as determined by this control strip \(\times 0.98 = \) (Mean density requirement)

Density as determined by this control strip \(\times 0.95 = \) (Individual density requirement)
METHODS OF SAMPLING AND TESTING
MT 220-04
SPECIFIC GRAVITY OF SOILS
(Modified AASHTO T100)

1 Scope:

1.1 This method covers determination of the specific gravity of soils by means of a pycnometer. When the soil is composed of particles larger than the 4.75 mm (No. 4) sieve, the method outlined in MT-205, Test for Specific Gravity and Absorption of Coarse Aggregate, shall be followed. When the soil is composed of particles both larger and smaller than the 4.75 mm sieve, the sample shall be separated on the 4.75 mm sieve and the appropriate test method used on each portion. The specific gravity value for the soil shall be the weighted average of the two values (Note 1). When the specific gravity value is to be used in calculations in connection with the hydrometer portion of AASHTO T 88, Particle-Size Analysis of Soils, it is intended that the specific gravity test be made on that portion of the soil that passes the 2.00 mm (No. 10) sieve.

1.2 The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off “to the nearest unit” in the last right-hand place of figures used in expressing the limiting value.

Note 1- The weighted average specific gravity should be calculated using the following equation:

$$G_{avg} = \frac{1}{R_1} + \frac{P_1}{100G_1 + 100G_2}$$

where:

- $G_{avg}$ = weighted average specific gravity of soils composed of particles larger and smaller than the 4.75 mm (No. 4) sieve,
- $R_1$ = percent of soil particles retained on the 4.75 mm sieve,
- $P_1$ = percent of soil particles passing the 4.75 mm sieve,
- $G_1$ = apparent specific gravity of soil particles retained on the 4.75 mm sieve as determined by MT-205, and
- $G_2$ = specific gravity of soil particles passing the 4.75 mm sieve as determined by this test method.

1.3 The values stated in acceptable metric units are to be regarded as the standard.

1.4 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.
2 Referenced Documents:

**AASHTO:**
- T 2  Sampling Aggregates
- T 88  Particle Size Analysis of Soils
- T 100  Specific Gravity of Soils

**ASTM:**
- C 670  Practice for Preparing Precision Statements for Test Methods for Construction Materials
- E 12  Definition of Terms Relating to Density and Specific Gravity of Solids, Liquids, and Gases

**MT Manual:**
- MT-200  Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Tests
- MT-205  Specific Gravity and Absorption of Coarse Aggregate
- MT-405  Wire Cloth Sieves for Testing Purposes
- MT-407  Reducing Field Samples of Aggregate to Testing Size

3 Definition:

3.1 *Specific Gravity*—the ratio of the mass in air of a given volume of a material at a stated temperature to the mass in air of the same volume of gas free distilled water at a stated temperature (per Definition E 12).

4 Apparatus:

4.1 *Pycnometer* - Either a volumetric flask having a capacity of at least 100 ml or a stoppered bottle having a capacity of at least 50 ml (Note 2). The stopper shall be of the same material as the bottle, and of such size and shape that it can be easily inserted to a fixed depth in the neck of the bottle, and shall have a small hole through its center to permit the emission of air and surplus water.

*Note 2 - The use of either the volumetric flask or the stoppered bottle is a matter of individual preference, but in general, the flask should be used when a larger sample than can be used in the stoppered bottle is needed due to maximum grain size of the sample.*

4.2 *Balance* - A balance having a capacity of 1 kilogram or more and sensitive to 0.001 gram or less.

4.3 *Oven* - A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5°C (230 ± 9°F).

4.4 *Thermometer* - A thermometer covering the range of 0-50°C (32-122°F), readable and accurate to 1°C (2°F).

5 General Requirements for Weighing:

5.1 When the volumetric flask is used in the specific gravity determination, all masses shall be determined to the nearest 0.01 g. When the stoppered bottle is used in the specific gravity determination, all masses shall be determined to the nearest 0.001 g.
6 Calibration of Pycnometer:

6.1 The pycnometer shall be cleaned, dried, weighed, and the mass recorded. The pycnometer shall be filled with distilled water (Note 3) essentially at room temperature. The mass of the pycnometer and water, \( W_a \), shall be determined and recorded. A thermometer shall be inserted in the water and its temperature, \( T_i \), determined to the nearest whole degree.

Note 3 - *Kerosine is a better wetting agent than water for most soils and may be used in place of distilled water for oven-dried samples.*

6.2 From the mass \( W_a \) determined at the observed temperature \( T_i \), a table of values of mass \( W_a \) shall be prepared for a series of temperatures that are likely to prevail when masses \( W_b \) are determined later (Note 4). These values of \( W_a \) shall be calculated as follows:

\[
W_a \text{ (at } T_x \text{)} = \left( \frac{\text{density of water at } T_x}{\text{density of water at } T_i} \right) \times (W_a \text{ (at } T_i) - W_f) + W_f
\]

where:

\( W_a = \) mass of pycnometer and water, in grams,

\( W_f = \) mass of pycnometer, in grams,

\( T_i = \) observed temperature of water, in degrees Celsius, and

\( T_x = \) any other desired temperature, in degrees Celsius.

Note 4 - *This method provides a procedure that is most convenient for laboratories making many determinations with the same pycnometer. It is equally applicable to a single determination. Bringing the pycnometer and contents to some designated temperature when masses \( W_a \) and \( W_b \) are taken, requires considerable time. It is much more convenient to prepare a table of masses \( W_a \) for various temperatures likely to prevail when masses \( W_b \) are taken. It is important that masses \( W_a \) and \( W_b \) be based on water at the same temperature. Values for the relative density of water at temperatures from 18 to 30 °C are given in Table 1.*

### TABLE 1 Relative Density of Water and Conversion Factor K for Various Temperatures

<table>
<thead>
<tr>
<th>Temperature, deg C</th>
<th>Relative Density of Water</th>
<th>Correction Factor K</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>0.9986244</td>
<td>1.0004</td>
</tr>
<tr>
<td>19</td>
<td>0.9984347</td>
<td>1.0002</td>
</tr>
<tr>
<td>20</td>
<td>0.9982343</td>
<td>1.0000</td>
</tr>
<tr>
<td>21</td>
<td>0.9980233</td>
<td>0.9998</td>
</tr>
<tr>
<td>22</td>
<td>0.9978019</td>
<td>0.9996</td>
</tr>
<tr>
<td>23</td>
<td>0.9975702</td>
<td>0.9993</td>
</tr>
<tr>
<td>24</td>
<td>0.9973286</td>
<td>0.9991</td>
</tr>
<tr>
<td>25</td>
<td>0.9970770</td>
<td>0.9989</td>
</tr>
<tr>
<td>26</td>
<td>0.9968156</td>
<td>0.9986</td>
</tr>
<tr>
<td>27</td>
<td>0.9965451</td>
<td>0.9983</td>
</tr>
<tr>
<td>28</td>
<td>0.9962652</td>
<td>0.9980</td>
</tr>
<tr>
<td>29</td>
<td>0.9959761</td>
<td>0.9977</td>
</tr>
<tr>
<td>30</td>
<td>0.9956780</td>
<td>0.9974</td>
</tr>
</tbody>
</table>
7 Sample:

7.1 The soil to be used in the specific gravity test may contain its natural moisture or be oven-dried. The mass of the test sample on an oven-dry basis shall be at least 25 g when the volumetric flask is to be used, and at least 10 g when the stoppered bottle is to be used.

7.2 Samples Containing Natural Moisture - When the sample contains its natural moisture, the mass of the soil, \( W_a \), on an oven-dry basis shall be determined at the end of the test by evaporating the water in an oven maintained at 110 ± 5°C (230 ± 9°F) (Note 5). Samples of clay soils containing their natural moisture content shall be dispersed in distilled water before placing in the flask, using the dispersing equipment specified in AASHTO T 88 (Note 6).

7.3 Oven-Dried Samples - When an oven-dried sample is to be used, the sample shall be dried for at least 12 h, or to constant mass, in an oven maintained at 110 ± 5°C (230 ± 9°F) (Note 5), cooled to room temperature, then weighed and transferred to pycnometer or transferred to pycnometer then weighed. Distilled water shall be added into pycnometer in an amount that will provide complete sample coverage. The sample shall then soak for at least 12 h.

Note 5 - Drying of certain soils at 110°C may bring about loss of moisture of composition or hydration, and in such cases drying shall be done, if desired, in reduced air pressure and at a lower temperature.

Note 6 - The minimum volume of slurry that can be prepared by the dispersing equipment specified in AASHTO T 88 is such that a 500-ml flask is needed as the pycnometer.

8 Procedure:

8.1 The sample as prepared in Section 7 shall have distilled water added to fill the volumetric flask about three-fourths full or the stoppered bottle about half full.

8.2 Remove entrapped air by either of the following methods: (1) subject the contents to a partial vacuum of 100 mm Hg or less absolute pressure or (2) boil gently for at least 10 min., while occasionally rolling the pycnometer to assist in the removal of the air. Subjection of the contents to reduced air pressure may be done either by connecting the pycnometer directly to an aspirator or vacuum pump, or by use of a bell jar. Some soils boil violently when subjected to reduced air pressure. It will be necessary in those cases to reduce the air pressure at a slower rate or to use a larger flask (Note 7). Samples that are heated shall be cooled to room temperature.

Note 7 - When using partial vacuum agitate the flask gently at intervals during the evacuation process. (A) Samples containing natural moisture with high plasticity may require 6 to 8 hours to remove air; samples with low plasticity may require 4 to 6 hours to remove air. (B) Oven-dried samples may require 2 to 4 hours to remove air.

8.3 Fill the pycnometer with distilled water to its calibrated capacity, clean the outside and dry with a clean, dry cloth. Determine the mass of the pycnometer and contents \( W_b \), and the temperature in degrees Celsius, \( T_x \), of the contents as described in Section 6.

9 Calculation and Report:

9.1 Calculate the specific gravity of the soil, based on water at a temperature \( T_x \), as follows:

\[
\text{specific gravity, } T_x/T_x = W_o/[W_o + (W_a - W_b)]
\]

where:

\( W_o \) = mass of sample of oven-dried soil in grams.

\( W_a \) = mass of pycnometer filled with water at temperature \( T_x \) (Note 8) in grams, and
9 Calculation and Report: (continued)

\[ T_x = \text{temperature of the contents of the pycnometer when mass } W_b \text{ was determined, in degrees Celsius.} \]

*Note 8 - This value shall be taken from the table of values of } W_a \text{, prepared in accordance with 7.2 for the temperature prevailing when mass } W_b \text{ was taken.}*

9.2 Unless otherwise required, specific gravity values reported shall be based on water at 20°C. The value based on water at 20°C shall be calculated from the value based on water at the observed temperature \( T_x \), as follows:

Specific gravity, \( T/J/20°C = K \times \text{specific gravity, } T/J/T_x \)

where:

\[ K = \text{a number found by dividing the relative density of water at temperature } T_x \text{ by the relative density of water at 20°C. Values for a range of temperatures are given in Table 1.} \]

9.3 When it is desired to report the specific gravity value based on water at 4°C, such a specific gravity value may be calculated by multiplying the specific gravity value at temperature \( T_x \) by the relative density of water at temperature \( T_x \).

9.4 When any portion of the original sample of soil is eliminated in the preparation of the test sample, the portion on which the test has been made shall be reported.

9.5 When using the volumetric flask to determine specific gravities, report results to at least the nearest 0.01.

9.6 When using the stoppered bottle to determine specific gravities, report results to at least the nearest 0.001.
METHODS OF SAMPLING AND TESTING
MT 221-06
TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING
(Modified AASHTO T 255)

1 Scope:

1.1 This test method covers the determination of the percentage of evaporable moisture in a sample of aggregate by drying both surface moisture and moisture in the pores of the aggregate. Some aggregate may contain water that is chemically combined with the minerals in the aggregate. Such water is not evaporable and is not included in the percentage determined by this test method.

1.2 The values stated in SI units are to be regarded as the standard. The values stated in parentheses are provided for information only.

2 Referenced Documents:

2.1 MT Materials Manual:
MT-201 Sampling Roadway Materials
MT-202 Sieve Analysis of Fine and Coarse Aggregate
MT-203 Unit Weight of Aggregate
MT-204 Specific Gravity and Absorption of Fine Aggregate
MT-205 Specific Gravity and Absorption of Coarse Aggregate

3 Apparatus:

3.1 Balance – The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better.

3.2 Source of Heat – A ventilated oven capable of maintaining the temperature surrounding the sample at 110 ± 5°C (230 ± 9°F). Where close control of the temperature is not required, other suitable sources of heat may be used, such as an electric or gas hot plate, electric heat lamps, or a ventilated microwave oven.

3.3 Sample Container – A container not affected by the heat, and of sufficient volume to contain the sample without danger of spilling, and of such shape that the depth of the sample will not exceed one-fifth of the least lateral dimension.

3.4 Precaution – When a microwave oven is used, the container shall be non-metallic.

Note1 – Except for testing large samples, an ordinary frying pan is suitable for use with a hot plate, or any shallow flat-bottomed metal pan with heat lamps or oven. Note precaution in Section 3.4.

3.5 Stirrer – A metal spoon or spatula of convenient size.

4 Sample:

4.1 Sampling shall be in accordance with MT-201, except the sample size may be as stated in Table 1.
4. Sample: (continued)

Table 1 – Sample Size for Aggregate

<table>
<thead>
<tr>
<th>Nominal Maximum size of Aggregate mm (1n.)</th>
<th>Mass of Normal Weight Aggregate Sample, Min. kg. (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.75 (No. 4)</td>
<td>0.5 (1.1)</td>
</tr>
<tr>
<td>9.5 (3/8)</td>
<td>1.5 (3.3)</td>
</tr>
<tr>
<td>12.5 (1/2)</td>
<td>2 (4)</td>
</tr>
<tr>
<td>19.0 (3/4)</td>
<td>3 (7)</td>
</tr>
<tr>
<td>25.0 (1)</td>
<td>4 (9)</td>
</tr>
<tr>
<td>37.5 (1 ½)</td>
<td>6 (13)</td>
</tr>
<tr>
<td>50 (2)</td>
<td>8 (18)</td>
</tr>
<tr>
<td>63 (2 ¼)</td>
<td>10 (22)</td>
</tr>
<tr>
<td>75 (3)</td>
<td>13 (29)</td>
</tr>
<tr>
<td>90 (3 ½)</td>
<td>16 (35)</td>
</tr>
<tr>
<td>100 (4)</td>
<td>25 (55)</td>
</tr>
<tr>
<td>150 (6)</td>
<td>50 (110)</td>
</tr>
</tbody>
</table>

4.2 Secure a sample of the aggregate representative of the moisture content in the supply being tested and having a mass not less than the amount listed in Table 1. Protect the sample against loss of moisture prior to determining the mass.

5. Procedure:

5.1 Determine the mass of the sample to the nearest 0.1 percent.

5.2 Dry the sample thoroughly in the sample container by means of the selected source of heat, exercising care to avoid the loss of any particles. Very rapid heating may cause some of the particle to explode, resulting in loss of particles. Use a controlled temperature oven when excessive heat may alter the character of the aggregate, or where more precise measurement is required. If a source of heat other than the controlled temperature oven is used, stir the sample during drying to accelerate the operation and avoid local overheating. When using a microwave oven, stirring of the sample is optional.

5.2.1 Caution: When using a microwave oven, occasionally minerals are present in aggregates that may cause the material to overheat and explode. If this occurs, it can damage the microwave oven.

5.3 The sample is thoroughly dry when further heating causes, or would cause, less than 0.1 percent additional loss in mass.

5.4 Determine the mass of the dried sample to the nearest 0.1 percent after it has cooled sufficiently not to damage the balance.

6. Calculation:

6.1 Calculate total evaporable moisture content as follows:

\[
P = 100\frac{(W - D)}{D}
\]

where:

\[
P = \text{total evaporable moisture content of sample, percent;}
\]
6 Calculation: (continued)

\[ W = \text{mass of original sample, g}; \]
\[ D = \text{mass of dried sample, g}. \]

6.2 Surface moisture content is equal to the difference between the total evaporable moisture content and the absorption, with all values based on the mass of a dry sample.

*Note 2 - Absorption may be determined in accordance with MT-204, Specific Gravity and Absorption of Fine Aggregate, and MT-205, Specific Gravity and Absorption of Coarse Aggregate.*
1 **Scope:**

1.1 This method of test is intended for determining the in-place density of soils. The apparatus described herein is restricted to tests in soils containing particles not larger than 50 mm (2 in.) in diameter.

1.2 The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off “to the nearest unit” in the last right hand-place of figures used in expressing the limiting value, in accordance with AASHTO R 11.

2 **Referenced Documents:**

**AASHTO Standards:**
R 11 Indicating Which Place of Figures are to be Considered Significant in Specified Limiting Values.

**MT Materials Manual:**
MT 203 Unit Weight of Aggregate
MT 210 Moisture-Density Relations of Soils Using a 5.5 LB. Rammer and 12 Inch Drop
MT 215 Moisture content by Calcium Carbide Method
MT 227 Laboratory Determination of Moisture Content of Soils

3 **Apparatus:**

3.1 *Density Apparatus with Base Plate*—The density apparatus shall consist of a 4 liter (1 gal.) jar and a detachable appliance consisting of a cylindrical valve with an orifice 12.7 mm (2 in.) in diameter and having a small funnel continuing to a standard G mason jar top on one end and a large funnel on the other end. The valve shall have stops to prevent rotating the valve past the completely open or completely closed positions. The apparatus shall conform to the requirements shown in Figure 1. The apparatus described here represents a design that has proven satisfactory. Other apparatus of similar proportions will perform equally well so long as the basic principles of the sand-volume determination are observed. The base plate is required for calibrations and testing.

3.2 *Calibration Container*—A sturdy cylindrical container of known volume \(V_c\). The container shall be dimensionally approximate the largest test hole that will be dug. The container shall be calibrated according to MT 203.

**Note 1** – The internal diameter of the container shall be equal to or slightly less than the diameter of the opening of the base plate used with the sand cone.

3.3 *Sand*—Any clean, dry, free-flowing, uncedmented sand having few, if any, particles passing the 0.075 mm or retained on the 2.00 mm sieves. In selecting a sand for use, several bulk density determinations should be made using the same representative sample for each determination. To be acceptable the sand shall not have a variation in bulk density greater than 1 percent.

3.4 *Balances*—A balance or scale of 10 kg. capacity accurate to 1.0 g. and a balance of 500 g. capacity accurate to 0.1 g.
3. Apparatus: (continued)

3.5 **Drying Equipment**—Stove or oven or other suitable equipment for drying moisture content samples.

3.6 **Miscellaneous Equipment**—Small pick, chisels, or spoons for digging test hole; 254 mm (10 in.) frying pan or any suitable container for drying moisture samples; buckets with lids, seamless tin cans with lids, canvas sacks or other suitable containers for retaining the density sample, moisture sample or density sand respectively; thermometer for determining the temperature of water; small paint-type brush, slide rule, notebook, etc.

![Density Apparatus Diagram](image)

**FIGURE 1** Density Apparatus

<table>
<thead>
<tr>
<th>Metric Equivalents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In.</strong></td>
</tr>
<tr>
<td>1/2</td>
</tr>
<tr>
<td>3/4</td>
</tr>
<tr>
<td>1 1/8</td>
</tr>
<tr>
<td>5 3/8</td>
</tr>
</tbody>
</table>
4 Cone Correction and Bulk Density Factors:

4.1 Filling the apparatus:

4.1.1 Place the empty apparatus upright on a firm level surface, close the valve and fill the funnel with sand.

4.1.2 Open the valve and keep the funnel at least half full with sand during filling. When the sand stops flowing into the apparatus, close the valve sharply and empty the excess sand (Note 2).

Note 2 – Vibration of the sand during any mass-volume determination may increase the bulk density of the sand and decrease the accuracy of the determination. Appreciable time intervals between the bulk density determination of the sand and its use in the field may result in change in the bulk density caused by a change in the moisture content or effective gradation.

4.1.3 Determine and record the mass of the apparatus filled with sand ($m_1$).

4.2 Determine the mass of sand required to fill the funnel and base plate (Cone Correction, $C_c$).

4.2.1 Place the base plate on a clean, level, plane surface. Invert the sand-cone filled with sand and seat the funnel in the recess of the base plate.

4.2.2 Open the valve fully, and allow the sand to flow until the sand stops flowing (Note 2).

4.2.3 Close the valve sharply, remove the apparatus and determine the mass of the apparatus and the remaining sand ($m_2$).

4.2.4 The mass of the sand required to fill the cone and base plate is calculated by the difference between the initial mass (4.1.3), and the final mass (4.2.3). Record this mass as the cone correction ($C_c = m_1 - m_2$) (Note 3).

Note 3 – For each container/bag of sand there will be a unique cone correction and sand calibration factor. Each sand-cone and matched base plate will also have a set of unique cone corrections and bulk sand densities. If more than one sand-cone apparatus is available, the sand-cone and base plate should be marked and the associated correction/density factors recorded.

4.3 Determining the bulk density of sand ($D_B$) to be used in the field test.

4.3.1 Replace the sand removed in the funnel determination according to section 4.1, close the valve, and determine the mass of the apparatus and sand ($m_3$).

4.3.2 Position the calibration container on a clean, level, plane surface. Place the base plate on the calibration container (Note 1). Invert the apparatus and seat the funnel in the recess of the base plate.

4.3.3 Open the valve and keep open until the sand stops flowing (Note 2).

4.3.4 Close the valve sharply, remove the apparatus and determine the remaining mass of the apparatus and sand ($m_4$).

4.3.5 Calculate the mass of the sand needed to fill the container, funnel and base plate. Subtract the final mass (4.3.5) from the initial mass (4.3.1).

4.3.6 The mass of the sand needed to fill the container only is determined by subtracting the mass of the cone correction (4.2.4) from the total mass required to fill the container with the funnel and base plate (4.3.5).
4 Cone Correction and Bulk Density Factors: (continued)

4.3.7 Determine the bulk density of the calibration sand (sand calibration factor). Divide the mass of the sand needed to fill the container (4.3.6), by the volume of the calibration container as determined according to MT 203.

\[ D_B = \frac{m_3 - m_4 - C_c}{V_c} \]

4.3.8 Record this factor for future reference (Note 3).

5 Procedure:

5.1 Fill the apparatus with sand according to Section 4.1. Record the total mass \( m_5 \).

5.2 Prepare the surface of the location to be tested so that it is a level plane.

5.3 Seat the base plate on the prepared surface. Dig the test hole inside the opening of the base plate, being very careful to avoid disturbing the soil that will bound the hole. Soils that are essentially granular require extreme care. Place all loosened soil in a container, being careful to avoid losing any material. Care must be taken to avoid moisture loss during excavation.

5.4 Place the apparatus on the base plate, open the valve. After the sand has stopped flowing, close the valve (Note 2).

5.5 Weigh the apparatus with remaining sand \( m_6 \) and record..

5.6 Weigh the moist material that was removed from the test hole.

5.7 Mix the material thoroughly and secure and weigh a representative sample for moisture determination.

5.8 Dry and weigh the soil sample for moisture content determination in accordance with MT 227. Calculate the moisture content to the nearest 0.1 percent.

5.9 The minimum test hole volumes suggested determining the in-place density of soil mixtures are given in Table 1. The table shows the suggested minimum mass of the moisture content sample in relation to the maximum particle size in soil mixtures.

<table>
<thead>
<tr>
<th>Maximum Particle Size</th>
<th>Minimum Test Hole Volume</th>
<th>Minimum Moisture Content Sample, g.</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>Alternate</td>
<td>cm³</td>
</tr>
<tr>
<td>4.75</td>
<td>No. 4 sieve</td>
<td>710</td>
</tr>
<tr>
<td>12.5</td>
<td>½ in.</td>
<td>1415</td>
</tr>
<tr>
<td>25.0</td>
<td>1 in.</td>
<td>2125</td>
</tr>
<tr>
<td>50.0</td>
<td>2 in.</td>
<td>2830</td>
</tr>
</tbody>
</table>
6 Calculations:

6.1 Calculate the volume of the test hole \((V_H)\):

\[ V_H = \frac{(m_5 - m_6 - C_c)}{D_B} \]

Where:

\( V_H \) = volume of test hole,

\( m_5 \) = initial mass of apparatus and sand,

\( m_6 \) = final mass of the apparatus and sand,

\( C_c \) = Cone Correction, and

\( D_B \) = bulk density of the sand.

6.1.1 Calculate the volume of the test hole to the nearest 1 cm\(^3\) (0.0001 ft\(^3\)).

6.2 Calculate the dry mass of the material removed from the test hole as follows:

\[ M_{DS} = \frac{M_{WS}}{1 + \left(\frac{w}{100}\right)} \]

where:

\( M_{DS} \) = dry mass of the material removed from the hole,

\( M_{WS} \) = moist mass of the material removed from the test hole, and

\( w \) = percentage of moisture, in the material removed from the test hole.

6.2.1 Calculate the dry mass of the material to the nearest 1 g (0.01 lb).

6.3 Calculate the in-place dry density for the material removed from the test hole as follows:

\[ D_D = \frac{M_{DS}}{V_H} \]

where:

\( D_D \) = in-place dry density of the material removed from the hole,

\( M_{DS} \) = dry mass of the material removed from the test hole (Section 5.2), and

\( V_H \) = volume of the test hole (Section 5.1).

6.3.1 Calculate the in-place dry density to the nearest 1 Kg/m\(^3\) (0.1 lb/ft\(^3\)).

*Note 4 – 0.001 g/cm\(^3\) = 1 Kg/m\(^3\)*

*Note 5 – It may be desired to express the in-place density as a percentage of some other density, for example, the laboratory maximum density determined in accordance with MT-210. This relationship can be determined by dividing the in-place density by the maximum density and multiplying by 100.*
METHODS OF SAMPLING AND TESTING
MT 223-04

METHOD OF TEST FOR CLAY LUMPS AND FRIABLE PARTICLES IN AGGREGATES
(Modified AASHTO T 112)

1 Scope:

1.1 This method covers the approximate determination of clay lumps and friable particles in natural aggregates.

1.2 This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2 Referenced Documents:

2.1 **AASHTO:**
    T 112 Clay Lumps and Friable Particles in Aggregate

**MT Manual:**
    MT 202 Sieve Analysis of Fine and Coarse Aggregate
    MT-405 Sieves for Testing Purposes

3 Apparatus:

3.1 **Balances** - Balances or scales for determining the mass of the test samples shall be sensitive to 0.1 percent of the mass of the sample. The residue (Section 5) shall be weighed on a balance or scale sensitive to 0.02 percent of the mass of the original test sample.

3.2 **Containers** - Rust-resistant containers of a size and shape that will permit the spreading of the sample on the bottom in a thin layer.

3.3 **Sieves** - Sieves conforming to MT-405, Sieves for Testing Purposes.

3.4 **Oven** - Oven capable of maintaining a temperature of 230 ± 9°F (110 ± 5°C).

4 Samples:

4.1 The aggregate shall be dried to substantially constant mass at a temperature of 230 ± 9°F (110 ± 5°C).

4.2 Test samples of fine aggregate shall consist of particles coarser than a 1.18 mm (No.16 ) sieve and shall weigh not less than 450 grams.

4.3 Test samples of coarse aggregate shall be separated into different sizes, using the following sieves: 4 Mesh (4.75 mm), 3/8 in. (9.5 mm), 3/4 in. (19.0 mm), and 1½ in. (37.5 mm). The test sample shall weigh not less than indicated in the following table:
4  **Samples:** (continued)

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Mass of Test Sample, Min. g.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-M to 3/8 in. (4.75 to 9.5 mm)</td>
<td>1000</td>
</tr>
<tr>
<td>3/8 to 3/4 in. (9.5 to 19.0 mm)</td>
<td>2000</td>
</tr>
<tr>
<td>3/4 to 1½ in. (19.0 to 37.5 mm)</td>
<td>3000</td>
</tr>
<tr>
<td>Over 1½ in. (37.5 mm)</td>
<td>5000</td>
</tr>
</tbody>
</table>

4.4  If the grading of the original sample provides less than 5% of any of the sizes indicated in Section 4.3, do not test that size.

4.5  In the case of aggregate which is composed of substantial amounts of both fine and coarse aggregate sizes, separate the material into two sizes at the 4.75 mm (No. 4) sieve, and prepare the samples of fine and coarse aggregate in accordance with sections 4.3 and 4.4. Any aggregate containing 50 percent or more material retained on the 4.74 mm (No. 4) sieve is considered to be coarse aggregate.

*Note 1 – In most cases, only the plus 4.75 mm (No. 4) fraction of coarse aggregate needs to be evaluated by this test, regardless of the amount of minus 4.75 mm (No. 4) material present. However, the amount of 1.18 mm (No. 16) to 4.75 mm (No. 4) material present shall be included in the weight of the test sample in Section 5.1 when calculating the percent of clay lumps and friable particles.*

5  **Procedure:**

5.1  Weigh the test sample and spread it in a thin layer on the bottom of the container, cover it with water, and allow it to soak for a period of 24 ± 4 hours. Roll and squeeze particles individually between the thumb and forefinger to attempt to break particles into smaller sizes. Do not use fingernails to break up particles, or press particles against a hard surface or each other. Any particles that can be broken with the fingers into fines removable by wet sieving shall be classified as clay lumps or friable particles. After all discernible clay lumps and friable particles have been broken, separate the undersized material from the remainder of the sample by wet sieving over the sieve prescribed in the following table.

<table>
<thead>
<tr>
<th>Size of Particles Making up Test Sample</th>
<th>Size of Sieve for Removing Residue of Clay Lumps and Friable Particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Aggregate retained on 16-M (1.18 mm)</td>
<td>20-M (0.850 µm)</td>
</tr>
<tr>
<td>4-M to 3/8 in. (4.75 to 9.5 mm)</td>
<td>8-M (2.36 mm)</td>
</tr>
<tr>
<td>3/8 to 3/4 in. (9.5 to 19.0 mm)</td>
<td>4-M (4.75 mm)</td>
</tr>
<tr>
<td>3/4 to 1½ in. (19.0 to 37.5 mm)</td>
<td>4-M (4.75 mm)</td>
</tr>
<tr>
<td>Over 1½ in. (37.5 mm)</td>
<td>4-M (4.75 mm)</td>
</tr>
</tbody>
</table>

Wet sieve is to be accomplished by passing water over the sample through the sieve while manually agitating the sieve until all undersize material has been removed.

5.2  The retained particles shall be carefully removed from the sieve and dried to substantially
constant mass at a temperature of $230 \pm 9^\circ$F ($110 \pm 5^\circ$C), allowed to cool, and weighed to an accuracy of 0.02 percent, based on the original mass of the test sample.

6 Calculations

6.1 Calculate the percent of clay lumps and friable particles in fine aggregate or individual sizes of coarse aggregate as follows:

$$P = \left[\frac{(M - R)}{M}\right] \times 100$$

where:

$P$ = percent of clay lumps and friable particles,

$M$ = mass of test sample [for fine aggregate the mass of the portion coarser than the 16-m (1.18 mm) sieve as described in Sec. 4.2, and

$R$ = mass of particles retained on designated sieve, as determined in accordance with Section 5.2.

6.2 For coarse aggregates, the percent of clay lumps and friable particles shall be an average based on the percent of clay lumps and friable particles in each sieve size fraction weighed in accordance with the grading of the original sample before separation or, preferably the average grading of the supply represented by the sample. Should the aggregate contain less than 5 percent of the material in a given size, that size shall be considered to contain the same percent of clay lumps and friable particles as the next larger or next smaller size, whichever is present.
1 Scope:

1.1 These definitions cover terms used in descriptions and specifications of materials occurring as or employed in the construction of sub-grades, soil-aggregate base and surface courses and fills.

2 Definitions of Rock and Soil:

2.1 Rock - Natural solid mineral matter occurring in large masses of fragments.

2.2 Soil - Sediment or other unconsolidated accumulation of solid particles produced by the physical and chemical disintegration of rocks and which may or may not contain organic matter.

2.3 Broken Rock - Angular fragments of rock which will be retained on a 3-inch sieve.

2.4 Boulders - Rounded fragments of rock, which will be retained on a 3-inch sieve.

3 Definitions of Soil- Aggregate and its Components:

3.1 Soil – Aggregate (Dense-Grade Aggregate) - Natural or prepared mixtures consisting predominately of stone, gravel, or sand and containing silt-clay (minus No. 200 material).

3.2 Stone - Crushed or naturally angular particles or rock which will pass a 3-inch sieve and be retained on a No. 10 sieve.

3.2.1 Coarse Stone - Stone passing the 3-inch sieve and retaining on the 1-inch sieve.

3.2.2 Medium Stone - Stone passing the 1-inch sieve and retaining on the 3/8-inch sieve.

3.2.3 Fine Stone - Stone passing the 3/8-inch sieve and retaining on the No. 10 sieve.

3.3 Gravel - Rounded particles of rock, which will pass a 3-inch sieve and be retained on a No. 10 sieve.

3.3.1 Coarse Gravel - Gravel passing the 3-inch sieve and retaining on the 1-inch sieve.

3.3.2 Medium Gravel - Gravel passing the 1-inch sieve and retaining on the 3/8-inch sieve.

3.3.3 Fine Gravel - Gravel passing the 3/8-inch sieve and retained on the No. 10 sieve.

3.4 Sand - Granular material resulting from the disintegration, grinding, or crushing of rock and which will pass the No. 10 sieve and be retained on the 200 sieve.

3.4.1 Coarse Sand - Sand passing the No. 10 sieve and retaining on the No. 40 sieve.

3.4.2 Fine Sand - Sand passing the No. 40 sieve and retaining on the No. 200 sieve.
Definitions of Soil-Aggregate and its Components: (continued)

3.5  **Silt-Clay (minus No. 200)** - Fine soil particles which will pass the No. 200 sieve.

3.5.1 **Silt Fraction** - Material passing the No. 200 sieve and larger than .005 mm.

3.5.2 **Clay Fraction** - Materials smaller than .005 mm.

3.6 **Colloids** - Materials smaller than .001 mm.

Definitions of Pavement Substructure Components:

4.1 **Embankment Foundation** - The material on which an embankment is placed.

4.2 **Embankment (Fill)** - A raised structure of soil, soil-aggregate, or rock.

4.3 **Sub-grade** - The prepared and compacted soil immediately below the pavement system and extending to such depth as will affect the structural system.

4.4 **Sub-base** - The layer used in pavement system between the sub-grade and the base course.

4.5 **Base** - The layer used in a pavement system to reinforce and protect the sub-grade or sub-base.
1 SCOPE:

1.1 This method defines the procedures for obtaining check samples and directs the necessary corrective action required to return failing material to acceptable limits.

1.2 It is a training requirement for new personnel sampling or testing aggregate to view the Safety and Training Bureau’s slide and audio presentation, “Aggregate Gradation Testing”, prior to performing this test.

2 Referenced Documents:

2.1 MT Manual:
MT-201 Sampling Roadway Materials

3 Production Samples:

3.1 In general, a sample from a moving belt or a sampling device can be represented by a check sample only if the original sample has been split with a portion designated for use as a check sample. Samples taken at a later time cannot be designated as check samples since considerable production may have occurred between the time of testing the failing sample and testing of the next sample. Therefore, the second sample simply becomes another Acceptance sample and is numbered consecutively.

3.1.1 If the second sample, taken after further production, also fails, steps must be taken to halt the production of aggregate until an explanation for the failure has been found and corrective action can be taken.

3.1.2 A few examples of the possible causes for failing tests are listed below:

A hole in one or more screens in the plant.

An unrepresentative sample.

An error in the testing procedure.

An error in calculating the test results.

Testing equipment not in calibration or not meeting specifications.

A change in the physical characteristics of the material in the pit (in the case of a crushing operation).

Stockpile contamination.

A plugged feeder or plugged bins.

4 Road and Windrow Samples:

4.1 Test results from a sample of material that has been placed on the roadway can easily be checked by obtaining another sample of the material from the same location on the roadway and in the same manner as the failing sample. Check for possible causes of the failing tests as in 3.1.2, where applicable. (See MT-201, Sampling Roadway Materials). If the check samples also fail to meet specifications, an investigation must be conducted to determine the extent and seriousness of the problem.
4  **Road and Windrow Samples:** (continued)

*Note 1 - A single check sample is not a satisfactory indication that the production of aggregate has returned to acceptable limits. At least two passing check samples must be taken.*

5  **Stockpile Samples:**

5.1 Refer to MT-201, Section 10, for the procedure in sampling a stockpile. The most satisfactory method of determining a stockpile average is to sample and test the material at the time of crushing. If tests of stockpiled material do not meet specifications, the same investigation should be conducted as described in paragraph 3.1.2. Check samples on material taken during production of a stockpile must be a split of the original sample. Existing stockpiles can be re-sampled at a later time and that sample can be designated as a check sample.

6  **Plant Mix Aggregate:**

6.1 Production test numbering will begin and continue as long as the sample is from material being incorporated into the work. These are acceptance samples.

6.2 Tests which are run to monitor operations adjustments, while the material being sampled is not to be incorporated into the work, shall be labeled and numbered as "Non-production #1," "Non-production #2," etc. Only those tests run a split of the same sample

6.3 Only those tests run on a split of the same sample will be designated as check samples.

7  **Numbering Check Samples:**

7.1 When a check sample is taken it will be assigned the same number as the sample being checked, with the addition of a letter suffix. For example, if sample number 38 failed to meet specifications, the first check sample would numbered 38-A, the second check sample would be 38-B, etc.

8  **Other Samples:**

8.1 Usually check tests on the materials not listed above are covered in the specific methods for the materials being tested.

9  **Remarks:**

9.1 The person with the responsibility for sampling and testing aggregates shall, in the case of failing tests, remark on the work sheet, or summary, the corrective action taken to resolve the problem.
METHODS OF SAMPLING AND TESTING
MT 226-04

MAXIMUM ACCEPTABLE DEVIATIONS
IN THE SIEVE ANALYSIS OF INDEPENDENT ASSURANCE SAMPLES
(MONTANA METHOD)

1 Scope:

1.1 The charts included in this method shall serve as a guide in evaluating the maximum acceptable deviations in the sieve analysis of Independent Assurance samples. If the individual grading percentages vary from the group average percentages by more than the amounts listed, the cause must be determined and the error remedied. Deviation percentages are based on the weight of the total sample.

2 References:

2.1 *MT Manual:*
MT 201 Preparing the Three-way Split Samples for Test and the Responsibility for Investigating Discrepancies.
MT 602 The Federal Highway Administration Policy and Procedure for Sampling and Testing Independent Assurance and Final Record Samples.
MT 607 Procedure for Reducing Field Samples of Aggregate to Testing Size

*Note 1 - The specifications apply to the material while the permissible deviation is used only to compare sieve analysis obtained in the field, division or area laboratory and Materials Bureau.*

<table>
<thead>
<tr>
<th>Fine Aggregate for Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percentage by Weight Passing Square Mesh Sieves</strong></td>
</tr>
<tr>
<td>Sieve Size</td>
</tr>
<tr>
<td>3/8&quot; (9.5 mm)</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
</tr>
<tr>
<td>No. 8 (2.36 mm)</td>
</tr>
<tr>
<td>No. 16 (1.18 mm)</td>
</tr>
<tr>
<td>No. 30 (0.600 μm)</td>
</tr>
<tr>
<td>No. 50 (0.300 μm)</td>
</tr>
<tr>
<td>No. 100 (0.150 μm)</td>
</tr>
<tr>
<td>No. 200 (0.075 μm)</td>
</tr>
</tbody>
</table>
# Coarse Aggregate for Concrete

## Percentage by Weight Passing Square Mesh Sieves

<table>
<thead>
<tr>
<th>GRADATION</th>
<th>No. 1</th>
<th>No. 2</th>
<th>No. 3</th>
<th>No. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve Size</td>
<td>1 1/2” to No. 4</td>
<td>3/4” to No. 8</td>
<td>1 1/2” to 3/8”</td>
<td>1/2” to No. 8</td>
</tr>
<tr>
<td>2” (50 mm)</td>
<td>100 - 2%</td>
<td>100 - 2%</td>
<td>90 - 100 ± 3%</td>
<td>100 ± 2%</td>
</tr>
<tr>
<td>1 1/2” (37.5 mm)</td>
<td>95 - 100 ± 3%</td>
<td>90 - 100 ± 3%</td>
<td>0 - 15 ± 3%</td>
<td>100 - 2%</td>
</tr>
<tr>
<td>1” (25 mm)</td>
<td>100 - 2%</td>
<td>20 - 55 ± 3%</td>
<td>0 - 15 ± 3%</td>
<td>90 - 100 ± 3%</td>
</tr>
<tr>
<td>3/4” (19 mm)</td>
<td>35 - 70 ± 3%</td>
<td>90 - 100 ± 3%</td>
<td>0 - 15 ± 3%</td>
<td></td>
</tr>
<tr>
<td>1/2” (12.5 mm)</td>
<td></td>
<td>90 - 100 ± 3%</td>
<td></td>
<td>3/8” (9.5 mm)</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>0 - 5 ± 2%</td>
<td>0 - 10 ± 2%</td>
<td>0 - 15 ± 2%</td>
<td></td>
</tr>
<tr>
<td>No. 8 (2.36 mm)</td>
<td>0 - 5 ± 2%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

# Selected Surfacing

## Percentage by Weight Passing Square Mesh Sieves

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
<th>Grade 4</th>
<th>Grade 5</th>
<th>Grade 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>4” (100 mm)</td>
<td>100 - 2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3” (75 mm)</td>
<td></td>
<td>100 - 2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 1/2” (63 mm)</td>
<td></td>
<td>100 - 2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2” (50 mm)</td>
<td></td>
<td></td>
<td>100 - 2%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1/2” (37.5 mm)</td>
<td></td>
<td></td>
<td></td>
<td>100 - 2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1” (25 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100 - 2%</td>
<td></td>
</tr>
<tr>
<td>No. 200 (75 µm)</td>
<td>15 max ± 1.5%</td>
<td>15 max ± 1.5%</td>
<td>15 max ± 1.5%</td>
<td>15 max ± 1.5%</td>
<td>15 max ± 1.5%</td>
<td>15 max ± 1.5%</td>
</tr>
</tbody>
</table>
**SAND SURFACING**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
<th>Grade 4</th>
<th>Grade 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1/2&quot; (37.5 mm)</td>
<td>100 - 2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&quot; (25.0 mm)</td>
<td></td>
<td>100 - 2%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/4&quot; (19.0 mm)</td>
<td></td>
<td></td>
<td>100 - 2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/2&quot; (12.5 mm)</td>
<td></td>
<td></td>
<td></td>
<td>100 - 2%</td>
<td></td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100 - 2%</td>
</tr>
<tr>
<td>No. 10 (2.00 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 200 (75 µm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CRUSHED TOP SURFACING, TYPE “A”**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
<th>Grade 4</th>
<th>Grade 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot; (25 mm)</td>
<td>100 - 2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/4&quot; (19.0 mm)</td>
<td></td>
<td></td>
<td></td>
<td>100 - 2%</td>
<td></td>
</tr>
<tr>
<td>5/8&quot; (16.0 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100 - 2%</td>
</tr>
<tr>
<td>1/2&quot; (12.5 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100 - 2%</td>
</tr>
<tr>
<td>3/8&quot; (9.5 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100 - 2%</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>40 - 70</td>
<td>40 - 70</td>
<td>40 - 70</td>
<td>40 - 70</td>
<td>50 - 80</td>
</tr>
<tr>
<td>No. 10 (2.00 mm)</td>
<td>25 - 55</td>
<td>25 - 55</td>
<td>25 - 55</td>
<td>25 - 60</td>
<td>35 - 70</td>
</tr>
<tr>
<td>No. 200 (75 µm)</td>
<td>2 - 8</td>
<td>2 - 8</td>
<td>2 - 8</td>
<td>2 - 8</td>
<td>2 - 8</td>
</tr>
</tbody>
</table>
### CRUSHED TOP SURFACING, TYPE “B”

#### PERCENTAGE BY WEIGHT PASSING SQUARE MESH SIEVES

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1/2” (37.5 mm)</td>
<td>100 - 2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1” (25 mm)</td>
<td></td>
<td>100 - 2%</td>
<td></td>
</tr>
<tr>
<td>3/4” (19.0 mm)</td>
<td></td>
<td></td>
<td>100 - 2%</td>
</tr>
<tr>
<td>1/2” (12.5 mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>40 - 80 ± 2%</td>
<td>40 - 80 ± 2%</td>
<td>40 - 80 ± 2%</td>
</tr>
<tr>
<td>No. 10 (2.00 mm)</td>
<td>25 - 60 ± 2%</td>
<td>25 - 60 ± 2%</td>
<td>25 - 60 ± 2%</td>
</tr>
<tr>
<td>No. 200 (75 μm)</td>
<td>5 - 20 ± 1.5%</td>
<td>5 - 20 ± 1.5%</td>
<td>5 - 20 ± 1.5%</td>
</tr>
</tbody>
</table>

### CRUSHED BASE COURSE, TYPE “A”

#### PERCENTAGE BY WEIGHT PASSING SQUARE MESH SIEVES

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grade 5A Target Limits</th>
<th>Job Mix Tolerance</th>
<th>Grade 6A Target Limits</th>
<th>Job Mix Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2” (50 mm)</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1/2” (37.5 mm)</td>
<td>97</td>
<td>±3%</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>3/4” (19.0 mm)</td>
<td>78 - 80</td>
<td>±8%</td>
<td>82 - 88</td>
<td>±8%</td>
</tr>
<tr>
<td>3/8” (9.5 mm)</td>
<td>58 - 62</td>
<td>±8%</td>
<td>52 - 64</td>
<td>±12%</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>42 - 50</td>
<td>±8%</td>
<td>36 - 48</td>
<td>±12%</td>
</tr>
<tr>
<td>No. 40 (425 μm)</td>
<td>14 - 22</td>
<td>±8%</td>
<td>16 - 24</td>
<td>±10%</td>
</tr>
<tr>
<td>No. 200 (75 μm)</td>
<td>3 - 5</td>
<td>±3%</td>
<td>3 - 5</td>
<td>±3%</td>
</tr>
</tbody>
</table>
### CRUSHED BASE COURSE, TYPE “B”

**PERCENTAGE BY WEIGHT PASSING SQUARE MESH SIEVES**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2” (50 mm)</td>
<td>100 - 2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1/2” (37.5 mm)</td>
<td></td>
<td>100 - 2%</td>
<td></td>
</tr>
<tr>
<td>1” (25 mm)</td>
<td>50 - 80 ± 2%</td>
<td>25 - 55 ± 2%</td>
<td>100 - 2%</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>20 - 50 ± 2%</td>
<td>30 - 60 ± 2%</td>
<td></td>
</tr>
<tr>
<td>No. 10 (2.00 mm)</td>
<td></td>
<td>20 - 50 ± 2%</td>
<td></td>
</tr>
<tr>
<td>No. 200 (75 μm)</td>
<td>8 max ± 1.5%</td>
<td>8 max ± 1.5%</td>
<td>8 max ± 1.5%</td>
</tr>
</tbody>
</table>

### COVER MATERIAL

**PERCENTAGE BY WEIGHT PASSING SQUARE MESH SIEVES**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grade 1A</th>
<th>Grade 2A</th>
<th>Grade 3A</th>
<th>Grade 4A</th>
<th>Grade 5A</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/8” (16.0 mm)</td>
<td>100 - 2%</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1/2” (12.5 mm)</td>
<td></td>
<td>100 - 2%</td>
<td>100 - 2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/8” (9.5 mm)</td>
<td>33 - 55 ± 2%</td>
<td>40 - 90 ± 2%</td>
<td>95 - 100 ± 2%</td>
<td>100 - 2%</td>
<td>100 - 2%</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>0 - 15 ± 2%</td>
<td>0 - 15 ± 2%</td>
<td>0 - 30 ± 2%</td>
<td>0 - 30 ± 2%</td>
<td>9 - 50 ± 2%</td>
</tr>
<tr>
<td>No. 8 (2.36 mm)</td>
<td>0 - 5 ± 2%</td>
<td>0 - 5 ± 2%</td>
<td>0 - 15 ± 2%</td>
<td>0 - 15 ± 2%</td>
<td>2 - 20 ± 2%</td>
</tr>
<tr>
<td>No. 200 (75 μm)</td>
<td>2 max ± 1.5%</td>
<td>2 max ± 1.5%</td>
<td>2 max ± 1.5%</td>
<td>2 max ± 1.5%</td>
<td>2 max ± 1.5%</td>
</tr>
</tbody>
</table>
### Aggregate for Cement-Treated Base

**Percentage by Weight Passing Square Mesh Sieves**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Job Mix Target Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4&quot; (19.0 MM)</td>
<td>100 - 2%</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>40 - 70 ± 2%</td>
</tr>
<tr>
<td>No. 10 (2.00 mm)</td>
<td>25 - 55 ± 2%</td>
</tr>
<tr>
<td>No. 200 (75 μm)</td>
<td>4 - 12 ± 1.5%</td>
</tr>
</tbody>
</table>

### Filter Material

**Percentage by Weight Passing Square Mesh Sieves**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Gradation No. 1</th>
<th>Gradation No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2&quot; (50 mm)</td>
<td></td>
<td>100 - 2%</td>
</tr>
<tr>
<td>11/2&quot; (37.5 mm)</td>
<td></td>
<td>95 - 100 ± 3%</td>
</tr>
<tr>
<td>3/4&quot; (19.0 mm)</td>
<td></td>
<td>35 - 70 ± 3%</td>
</tr>
<tr>
<td>3/8&quot; (9.5 mm)</td>
<td>100 - 2%</td>
<td>10 - 30 ± 2%</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>95 - 100 ± 2%</td>
<td>5 max ± 2%</td>
</tr>
<tr>
<td>No. 8 (2.36 mm)</td>
<td>80 - 100 ± 2%</td>
<td></td>
</tr>
<tr>
<td>No. 16 (1.18 mm)</td>
<td></td>
<td>50 - 85 ± 2%</td>
</tr>
<tr>
<td>No. 30 (600 μm)</td>
<td>25 - 60 ± 2%</td>
<td></td>
</tr>
<tr>
<td>No. 50 (300 μm)</td>
<td>5 - 30 ± 2%</td>
<td></td>
</tr>
<tr>
<td>No. 100 (150 μm)</td>
<td></td>
<td>10 max ± 1.5%</td>
</tr>
</tbody>
</table>
# PLANT MIX SURFACING

## PERCENTAGE BY WEIGHT PASSING SQUARE MESH SIEVES

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grade A</th>
<th>Job Mix Tolerance</th>
<th>Grade B</th>
<th>Job Mix Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target Limits</strong></td>
<td><strong>Tolerance</strong></td>
<td><strong>Target Limits</strong></td>
<td><strong>Tolerance</strong></td>
<td></td>
</tr>
<tr>
<td>3/4&quot; (19.0 mm)</td>
<td>100</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>1/2&quot; (12.5 mm)</td>
<td>87 - 93</td>
<td>±8%</td>
<td>86 - 90</td>
<td>±7%</td>
</tr>
<tr>
<td>3/8&quot; (9.5 mm)</td>
<td>77 - 83</td>
<td>±8%</td>
<td>75 - 79</td>
<td>±7%</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>52 - 58</td>
<td>±7%</td>
<td>51 - 57</td>
<td>±7%</td>
</tr>
<tr>
<td>No. 10 (2.00 mm)</td>
<td>36 - 41</td>
<td>±6%</td>
<td>32 - 40</td>
<td>±6%</td>
</tr>
<tr>
<td>No. 40 (0.425 mm)</td>
<td>19 - 21</td>
<td>±5%</td>
<td>14 - 16</td>
<td>±4%</td>
</tr>
<tr>
<td>No. 200 (75 μm)</td>
<td>6 - 8</td>
<td>±2%</td>
<td>4.5 – 6.5</td>
<td>±1.5%</td>
</tr>
</tbody>
</table>

# PLANT MIX SURFACING

## PERCENTAGE BY WEIGHT PASSING SQUARE MESH SIEVES

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grade D</th>
<th>Job Mix Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target Limits</strong></td>
<td><strong>Tolerance</strong></td>
<td></td>
</tr>
<tr>
<td>3/4&quot; (19.0 mm)</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>1/2&quot; (12.5 mm)</td>
<td>79 - 83</td>
<td>±7%</td>
</tr>
<tr>
<td>3/8&quot; (9.5 mm)</td>
<td>68 - 72</td>
<td>±7%</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>44 - 50</td>
<td>±7%</td>
</tr>
<tr>
<td>No. 10 (2.00 mm)</td>
<td>27 - 33</td>
<td>±6%</td>
</tr>
<tr>
<td>No. 40 (0.425 mm)</td>
<td>12 - 15</td>
<td>±4%</td>
</tr>
<tr>
<td>No. 200 (75 μm)</td>
<td>4.5 – 6.5</td>
<td>±1.5%</td>
</tr>
</tbody>
</table>

# BEDDING MATERIAL
<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>4&quot; (100 mm)</td>
<td>100 - 2%</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>25 - 60 ± 2%</td>
</tr>
<tr>
<td>No. 200 (75μm)</td>
<td>0 - 12 ± 1.5%</td>
</tr>
</tbody>
</table>
METHODS OF SAMPLING AND TESTING
MT 227-04

METHOD OF TEST FOR LABORATORY DETERMINATION
OF MOISTURE CONTENT OF SOILS
(MODIFIED AASHTO T 265)

1 Scope:

1.1 This method covers the laboratory determination of the moisture content of soils.

1.2 The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with AASHTO R 11.

2 Referenced Documents:

2.1 AASHTO:
T 265 Laboratory Determination of Moisture Content of Soils

3 Definition:

3.1 Moisture or Water Content of Soil – The ratio, expressed as a percentage, of the mass of water in a given mass of soil to the mass of the solid particles. Practical application is to determine the mass of water removed by drying the moist soil to a constant mass in a drying oven controlled at 110 ± 5°C (230 ± 9°F) and to use this value as the mass of water in the given soil mass. The mass of the soil remaining after oven drying is used as the mass of the solid particles.

4 APPARATUS:

4.1 Drying Oven – thermostatically controlled, preferably of the forced-draft type, capable of being heated at a temperature of 110 ± 5°C (230 ± 9°F).

4.2 Balance – The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of AASHTO M 231.

4.3 Containers – Suitable containers made of material resistant to corrosion and not subject to change in mass or disintegration on repeated heating and cooling. Containers shall have close fitting-lids to prevent loss of moisture from samples before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing. One container is needed for each moisture content determination.

5 Test Sample:

5.1 Select a representative quantity of moist soil in the amount indicated in the method of test. If no amount is indicated, the minimum mass of the sample shall be in accordance with the following table:

<table>
<thead>
<tr>
<th>Maximum Particle Size</th>
<th>Minimum Mass of Sample, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.425-mm (No. 40 sieve)</td>
<td>10</td>
</tr>
<tr>
<td>4.75-mm (No. 4 sieve)</td>
<td>100</td>
</tr>
<tr>
<td>12.5-mm (1/2 in.)</td>
<td>300</td>
</tr>
<tr>
<td>25.0-mm (1 in.)</td>
<td>500</td>
</tr>
<tr>
<td>50-mm (2 in.)</td>
<td>1000</td>
</tr>
</tbody>
</table>
6 Procedure:

6.1 Weigh a clean, dry container with its lid, and place the moisture content sample in the container. Replace the lid immediately, and weigh the container, including the lid and moist sample. Remove the lid and place the container with the moist sample in the drying oven maintained at a temperature of 110 ± 5°C (230 ± 9°F) and dry to a constant mass (Notes 1 and 2). Immediately upon removal from the oven, place the lid on the container and allow the sample to cool to room temperature. Weigh the container including the lid and the dried sample (Notes 3 and 4).

Note 1 – Checking every moisture content sample to determine that it is dried to a constant mass is impractical. In most cases, drying of a moisture content sample overnight (15 or 16 hours) is sufficient. In cases where there is no doubt concerning the accuracy of overnight drying, drying should be continued until the mass after two successive periods of drying indicates no change in mass. Samples of sand may often be dried to constant mass in a period of several hours. Since dry soil may absorb moisture from wet samples, dried samples should be removed before placing wet samples in the oven.

Note 2 – Oven-drying at 110 ± 5°C (230 ± 9°F) does not result in reliable moisture content values for soil containing gypsum or other minerals having loosely bound water from hydration or for soil containing significant amounts of organic material. Reliable moisture content values for these soils can be obtained by drying in an oven at approximately 60°C (140°F), or by vacuum desiccation at a pressure of approximately 10 mm Hg and at a temperature not lower than 23°C (73°F).

Note 3 – A container without a lid may be used provided the moist sample is weighed immediately after being taken and providing the dried sample is weighed immediately after being removed from the oven or after cooling in a desiccator.

Note 4 – Moisture content samples should be discarded and should not be used in any other tests.

7 CALCULATION:

7.1 Calculate the moisture content of the soil as follows:

\[
W = \frac{W_1 - W_2}{W_2 - W_c} \times 100
\]

where:

\[
\begin{align*}
W & = \text{moisture content, percent,} \\
W_1 & = \text{moisture content and moist soil, g,} \\
W_2 & = \text{mass of container and oven-dried soil, g, and} \\
W_c & = \text{mass of container, g.}
\end{align*}
\]

7.2 Calculate the percent of moisture content to the nearest 0.1 percent.
METHODS OF SAMPLING AND TESTING
MT 228-13
METHOD OF ESTABLISHING FIELD TARGET DENSITY FOR CEMENT TREATED BASE
DENSITY CONTROL

1 Scope:

1.1 This method is the procedure for establishing the field target density and moisture for compaction control of cement treated base (CTB).

2 Referenced Documents:

2.1 *MT Materials Manual:*
MT 211 Moisture-Density Relations of Soil-Cement Mixtures
MT 216 Method of Sampling and Testing Cement Treated Base

3 Procedure:

3.1 At the start of CTB production, use the maximum density and optimum moisture determined by MT 211 and provided in the mix design as the target for compaction control.

3.2 When samples for MT 216 have been taken, use the specimens molded for compressive strength to determine density. Use the average density of the three specimens to represent each sample. Use additional material taken for MT 216 to determine moisture content. Once the field density and moisture have been determined for two samples, average the results. If the average results in an increase of 1.0 pounds per cubic foot (16.0 kg per cubic meter) or greater or a decrease of 1.5 pounds per cubic foot (24.0 kg per cubic meter) or greater, calculate a new maximum density and optimum moisture in accordance with MT 211 for the material produced. Apply the new maximum density retroactive to the start of CTB production on the project. Do not change the target moisture unless a new optimum moisture is determined by MT 211.

3.3 When field densities on four samples have been completed, average the four test values. If the average results in an increase of 0.5 pound per cubic foot (8.0 kg per cubic meter) or greater or a decrease of 1.0 pound per cubic foot (16.0 kg per cubic meter) or greater, calculate a new maximum density and optimum moisture in accordance with MT 211 for the material produced. Apply the new maximum density to all subsequent CTB produced. Do not change the target moisture unless a new optimum moisture is determined by MT 211.

3.4 As each additional field density and moisture is completed, add the results to the results of the previous three densities and moistures, and average. If the average results in an increase of 0.5 pound per cubic foot (8.0 kg per cubic meter) or greater or a decrease of 1.0 pound per cubic foot (16.0 kg per cubic meter) or greater, calculate a new maximum density and optimum moisture in accordance with MT 211 for the material produced. Apply the new maximum density to all subsequent CTB produced. Do not change the target moisture unless a new optimum moisture is determined by MT 211.
METHOD OF SAMPLING AND TESTING
MT 229-04
PROCEDURE FOR SOLIDS - WATER - VOIDS RELATIONS
OF SOIL MASSES
(Zero-Air Voids)

1 Scope:

1.1 This method covers the compaction of soils by using the solids-water-voids (zero-air voids) chart. This method usually applies to the north central, eastern and southeastern areas of Montana but may apply to other areas of the state. It will be the responsibility of the District Materials Supervisor to monitor the applicability of this method.

2 Referenced Documents:

2.1 AASHTO:
   T 100 Specific Gravity of Soils

2.2 MT Materials Manual:
   MT-210 Moisture Density Relations of Soils Using a 5.5 Lb. Rammer and a 12 Inch Drop
   MT-220 Specific Gravity of Soils
   MT-230 Moisture Density Relations of Soils Using a 10 Lb. Rammer and a 18 Inch Drop

3 Procedure:

3.1 Air voids are another method used to determine the compaction of soils. The zero-air voids method will usually apply to soils classified from A-4 to A-7. When the zero-air voids method is not applicable, the 95% of maximum density and ±2% of optimum moisture will be used.

3.2 In order for this method to be accurate, it is necessary to find the specific gravity for the soils proposed for use. The most logical time to determine the specific gravity is during the pre-construction soil survey. However, due to the excavation process, which may result in a mixture of various soil strata, it may become necessary to perform additional specific gravity tests once the project is under contract. The specific gravity of soils is determined in accordance with MT-220, (AASHTO Designation T 100). (An average specific gravity is determined for the soil samples secured within any individual project.)

3.3 Individual proctor tests determined during the pre-construction soil survey are plotted on the zero-air voids chart. If the plot of the peaks from the family of proctor curves from the preliminary soil survey falls on a line roughly parallel to the zero-air voids, the zero-air voids method should work. Tests that fall to the left of the 10% air voids line are generally single size granular particle soils or excessively wet condition type soils. With these soils, the 95% of maximum density and ±2% of optimum moisture will be used.

3.5 Tests taken in the field that lie outside, or to the right of the 0% air voids line, not within the band, should be reviewed and treated as a failing test or possibly a bad reading by the density gauge. However, it is unusual to get tests that fall to the right of the 0% line. If tests consistently fall to the right of the 0% line, a specific gravity on the soil in question should be determined in accordance with MT-220, (AASHTO T100). Special Provision covers Proctor tests that plot outside the zero-air voids chart under compaction control. All proctor tests must be plotted on a zero-air voids chart to see if each test fits the zero-air voids chart.
4 Calculations:

4.1 Formula for calculating % voids:

\[ \% \text{ Voids} = 100 - \left( \frac{d \left( 1 + \frac{G_s (m/100)}{W} \right)}{G_s W} \right) \times 100 \]

Where:

**US Standard**

\( d = \text{Dry Density in lb/ft}^3 \)

\( G_s = \text{Specific Gravity} \)

\( m = \% \text{ moisture} \)

\( W = \text{wt of water in lb/ft}^3 \text{ or } 62.42796 \)

**Metric**

\( d = \text{Dry Density in Kg/m}^3 \)

\( G_s = \text{Specific Gravity} \)

\( m = \% \text{ moisture} \)

\( W = \text{wt of water in Kg/m}^3 \text{ or } 1000 \)
2.6 Specific Gravity, Zero Air Voids

16.0% Air Voids, 2.6 Specific Gravity
Dry Density, kg/m³

Moisture, Percent

- 2.7 Specific Gravity, Zero Air Voids
- 16.0% Air Voids, 2.7 Specific Gravity
Moisture, Percent

Dry Density, kg/m³

2.75 Specific Gravity, Zero Air Voids
16.0% Air Voids, 2.75 Specific Gravity
METHODS OF SAMPLING AND TESTING

METHOD OF TEST FOR THE MOISTURE-DENSITY RELATIONS OF SOILS USING A 10 LB. (4.54 KG) RAMMER AND A 18 IN. (457 MM) DROP
(Modified AASHTO T180)

1 Scope:

1.1 These methods of test are intended for determining the relation between the moisture content and density of soils compacted in a mold of a given size with a 10 lb. (4.54 kg) rammer dropped from a height of 18 in. (457 mm). Four alternate procedures are provided as follows:
Method A—A 4 in. (101.60 mm) mold: soil material passing a 4.75 mm (No. 4) sieve Sections 3 and 4.
Method B—A 6 in. (152.40 mm) mold: soil material passing a 4.75 mm (No. 4) sieve Sections 5 and 6.
Method C—A 4 in. (101.60 mm) mold: soil material passing a 19.0 mm (¾ in.) sieve Sections 7 and 8.
Method D—A 6 in. (152.40 mm) mold: soil material passing a 19.0 mm (¾ in.) sieve Sections 9 and 10.

1.2 The method to be used should be indicated in the specifications for the material being tested. If no method is specified, the provisions of Method A shall govern.

1.3 This test method applies to soil mixtures that have 40 percent or less retained on the 4.75 mm (No. 4) sieve, when Method A or B is used and 30 percent or less retained on the 19 mm (¾ in.) sieve, when Method D or C is used. The material retained on these sieves shall be defined as oversize particles (coarse particles).

1.4 If the test specimen contains oversize particles, and the test specimen is used for field density compaction control, corrections must be made according to MT-231 to compare the total field density with the compacted specimen. The person or agency specifying this method shall specify a minimum percentage of oversize particles below which correction for oversize need not be applied. If no percentage is specified, correction shall be applied to samples with more than five percent by mass of oversize particles.

1.5 If the specified oversized maximum tolerances are exceeded, other methods of compaction control must be used.

Note 1 – One method for the design and control of the compaction of such soils is to use a test fill to determine the required degree of compaction and a method to obtain that compaction. Then use a method specification to control the compaction by specifying the type and size of compaction equipment, the lift thickness and the number of passes.

1.6 The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off “to the nearest unit” in the last right hand place of figures used I expressing the limiting value, in accordance with AASHTO R 11.

2 Referenced Documents:

2.1 AASHTO:

T180 Moisture-Density Relations of Soils Using a 10 lb. Rammer with a 18 Inch Drop
T224 Coarse Particle Correction
M92 Wire Cloth Sieves for Testing Purposes
2 Referenced Documents: (continued)

MT Manual:
MT-203 Unit Weight of Aggregate
MT-231 Coarse Particle Correction
MT-405 Wire Cloth Sieves for testing Purposes

3 Apparatus:

3.1 Molds--The molds shall be solid-wall, metal cylinders manufactured with dimensions and capacities given 3.1.1 and 3.1.2 below. They shall have a detachable collar assembly approximately 2 3/8 in. (60 mm) in height, to permit preparation of compacted specimens of soil-water mixtures of the desired height and volume. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base plate made of the same material (Note 2).

Note 2 - Alternate types of molds with capacities as stipulated herein may be used, provided the test results are correlated with those of the solid-wall mold on several soil types and the same moisture-density results are obtained. Records of such correlation shall be maintained and readily available for inspection, when alternate types of molds are used.

3.1.1 A 4 in. Mold having a capacity of 1/30 (0.0333) ± 0.0003 cu. ft. (0.000943 ± 0.000008 m³) with an internal diameter of 4.000 ± 0.016 in. (101.6 ± 0.41 mm) and a height of 4.584 ± 0.005 in. (116.43 ± 0.13 mm).

3.1.2 A 6 in. Mold having a capacity of 1/13.33 (0.07500 ± 0.00075 cu. ft. (0.002124 ± 0.000021 m³) with an internal diameter of 6.000 ± 0.026 in. (152.40 ± 0.66 mm) and a height of 4.584 ± 0.005 in. (116.43 ± 0.13 mm).

3.1.3 Molds Out of Tolerance Due to Use--A mold that fails to meet manufacturing tolerances after continued service may remain in use provided those tolerances are not exceeded by more than 50 percent; and the volume of the mold, calibrated in accordance with par 4 (Calibration of Measure) of MT-203, for Unit Weight of Aggregate, is used in the calculations.

3.2 Rammer:

3.2.1 Manually Operated--Metal rammer having a flat circular face of 2.000 ± 0.01 in. (50.80 ± 0.25 mm) diameter, a wear tolerance of 0.01 in. (0.25 mm) and weighing 10.00 ± 0.02 lb. (4.536 ± 0.009 kg). The rammer shall be equipped with a suitable guide-sleeve to control the height of drop to a free fall of 18.00 ± 0.06 (or 1/16) in. (457 ± 2 mm) above the elevation of the soil. The guide-sleeve shall have at least 4 vent holes, no smaller than 3/8 in. (9.5 mm) diameter spaced approximately 90 deg. (1.57 rad) apart and approximately ¾ in. (19 mm) from each end; and shall provide sufficient clearance so the free fall of the rammer shaft and head is unrestricted.

3.2.2 Mechanically Operated--A metal rammer which is equipped with a device to control the height of drop to a free fall of 18.00 ± 0.06 (or 1/16) in. (457 ± 2 mm) above the elevation of the soil and uniformly distributes such drops to the soil surface. The rammer shall have a flat circular face 2.000 ± 0.01 in. (50.80 ± 0.25 mm) diameter, a wear tolerance of 0.01 in. (0.25 mm) and a manufactured mass of 10.00 ± 0.02 lb. (4.536 ± 0.009 kg) (Note 2). The mechanical rammer shall be calibrated, by ASTM Method D 2168, to give the same moisture-density results as with a manually operated rammer.

Note 3 - It may be impractical to adjust the mechanical apparatus so the free fall is 18 in. (457 mm) each time the rammer is dropped, as with the manually operated rammer. To make the adjustment of free fall, the portion of loose soil to receive the initial blow should be slightly compressed with the rammer to establish the point of impact from which the 18 in. (457 mm) drop is determined. Subsequent blows on the layer of soil being compacted may all be applied by dropping the
3.2.1 **Apparatus:** (continued)

*rammer from a height of 18 in.*

3.2.3 **Rammer Face**—The circular face rammer shall be used but a sector face may be used as an alternative provided the report shall indicate type of face used other than the 2 in. (50.8 mm) circular face and it shall have an area equal to that of the circular face rammer.

3.3 **Sample Extruder**—A jack, lever, frame, or other device adopted for the purpose of extruding compacted specimens from the mold.

3.4 **Balances and Scales**—A balance or scale of at least 25 lb. capacity having a sensitivity and readability to 0.01 lb., or a balance or scale having a capacity of approximately 11.5 kg and a sensitivity and readability to 5 grams. (Note 3) Also, a balance of at least 1 kg capacity with a sensitivity and readability to 0.1 g.

*Note 4 - The capacity of the metric balance or scale should be approximately 11.5 kg when used to weigh the 6 in. (152 mm) mold and compacted, moist soil; however, when the 4-in. (102 mm) mold is used, a balance or scale of lesser capacity than the 11.5 kg may be used, if the sensitivity and readability is 5 g.*

3.5 **Drying Oven**—A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5°C (230 ± 9°F) for drying moisture samples.

3.6 **Straightedge**—A hardened-steel straightedge at least 10 in. (250 mm) in length. It shall have one beveled edge, and at least one longitudinal surface (used for final trimming) shall be plane within 0.01 in. per 10 in. (0.1 percent) of length within the portion used for trimming the soil (Note 4).

*Note 5 - The beveled edge may be used for final trimming if the edge is true within a tolerance of 0.25 mm per 250 mm (0.001 in. per 10 in.) (0.1 percent) of length; however, with continued use, the cutting edge may become excessively worn and not suitable for trimming the soil to the level of the mold. The straightedge should not be so flexible that trimming the soil with the cutting edge will cause a concave soil surface.*

3.7 **Sieve**—2-in. (50 mm), ¾-in. (19.0 mm), and No. 4 (4.75 mm) sieves conforming to the requirements of MT-405, (AASHTO M 92), Sieves for Testing Purposes.

3.8 **Mixing Tools**—Miscellaneous tools such as mixing pan, spoon trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

3.9 **Containers**—Suitable containers made of material resistant to corrosion and not subject to change in weight or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing. One container is needed for each moisture content determination.

**METHOD A**

4 **Sample:**

4.1 If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of drying apparatus such that the temperature of the sample does not exceed 60 C (140 F). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles.

4.2 Sieve an adequate quantity of the representative pulverized soil over the No. 4, (4.75 mm) sieve. Discard the coarse material, if any, retained on the No. 4, (4.75 mm) sieve.
4 Sample: (continued)

4.3 Select a representative sample, with a mass of approximately 7 lb. (3 kg) or more, of the soil prepared as described in Sections 4.1 and 4.2.

Note 6 – When developing a compaction curve for the free draining soils, such as uniform sands and gravels, where seepage occurs at the bottom of the base plate, taking a representative moisture content sample from the mixing bowl may be preferred in order to determine the amount of moisture available for compaction.

5 Procedure:

5.1 Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately four percentage points below optimum moisture content.

5.2 Form a specimen by compacting the prepared soil in the 4 in. (101.60 mm) mold (with collar attached) in five approximately equal layers to give a total compacted depth of about 5 in. (125 mm). Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a loose or fluffy state, using either the manual compaction rammer or a similar device having a face diameter of approximately 2 inches (50 mm). Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 18 in. (457 mm) above the elevation of the soil when a sleeve-type rammer is used, or from 18 in. (457 mm) above the approximate elevation of compacted soil when a stationary mounted type of rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid and stable foundation (Note 5).

Note 7 - Each of the following has been found to be a satisfactory base on which to rest the mold during compaction of the soil: A block of concrete, weighing not less than 200 lb. (90 kg), supported by a relatively stable foundation; a sound concrete floor; and for field application, such surfaces as found in concrete box culverts, bridges, and pavements.

5.2 Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge, and weigh the mold and moist soil in pounds, to the nearest 0.01 lb., or weigh in kilograms to the nearest 5 grams. For molds conforming to tolerances given in Section 2.1.1 and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 30, and record the result as the wet density, $W_1$, in pounds per cubic foot, of compacted soil. For molds conforming to tolerances given in Section 2.1.1 and masses recorded in kilograms, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 1060, and record the result as the wet density, $W_1$, in kilograms per cubic meter, of compacted soil. For used molds out of tolerance by not more than 50 percent (2.1.3), use the factor for the molds as determined in accordance with Section 6 (Calibration of Measure), MT-203.

5.3 Remove the material from the mold and slice vertically through the center. Take a representative sample of the material from one of the cut faces, weigh immediately, and dry in an oven at 110 ± 5°C (230 ± 9°F) for at least 12 hours, or to a constant mass to determine the moisture content. The moisture sample shall weigh not less than 100 g.

5.4 Thoroughly break up the remaining portion of the molded specimen until it will pass a No. 4, (4.75 mm) sieve as judged by eye, and add to the remaining portion of the sample being tested. Add water in sufficient amount to increase the moisture content of the soil by one or two percentage points, and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet unit mass. $W_1$, per cubic foot or cubic meter of the compacted soil (Note 7).
5 Procedure: (continued)

Note 8 - This procedure has been found satisfactory in most cases. However, in instances where the soil material is fragile in character and will reduce significantly in grain size due to repeated compaction, and in cases where the soil is a heavy-textured clayey material into which it is difficult to incorporate water, a separate and new sample shall be used in each compaction test. In these cases, separate samples shall be thoroughly mixed with amounts of water sufficient to cause the moisture contents of the samples to vary by approximately two percentage points. The moisture points selected shall bracket the optimum moisture content, thus providing samples which when compacted will increase in mass to the maximum density and then decrease in mass. The samples of soil-water mixtures shall be placed in covered containers and allowed to stand for not less than 12 h before making the moisture-density test.

5.4.1 In instances where the soil material is fragile in character and will be reduced significantly in grain size by repeated compaction, a separate and new sample shall be used in each compaction test.

METHOD B

6 Sample:

6.1 Select the representative sample in accordance with 3.3, except that it shall have a mass of approximately 16 lb. (7 kg).

7 Procedure:

7.1 Follow the same procedure as described for Method A in Section 5, except for the following: Form a specimen by compacting the prepared soil in the 6-in. (152.40 mm) mold (with collar attached) in five approximately equal layers to give a total compacted depth of about 5 in. (125 mm), each layer being compacted by 56 uniformly distributed blows from the rammer. For molds conforming to tolerances in 2.1.2, and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 13.33, and record the result as the wet density, \( W_1 \), in lb. ft.\(^3\), of the compacted soil. For molds conforming to tolerances given in 2.1.2 and masses recorded in kilograms, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 471, and record the result as the wet density, \( W_1 \), in kg/m\(^3\), of compacted soil. For used molds out of tolerance by not more than 50 percent (3.1.3), use the factor for the mold as determined in accordance with Section 6 (Calibration of Measure), MT-203.

METHOD C

8 Sample:

8.1 If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of drying apparatus such that the temperature does not exceed 60 C (140ºF). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles.

8.2 Sieve an adequate quantity of the representative pulverized soil over the \( \frac{3}{4} \)-in., (19.0 mm) sieve. Discard the coarse material if any, retained on the \( \frac{3}{4} \)-in., (19.0 mm) sieve (Note 9).

Note 9 The use of the replacement method previously specified, where the oversized particles are replaced with finer particles, to maintain the same percentage of coarse material, is not considered appropriate to compute the maximum density.

8.3 Select a representative sample, having a mass of approximately 12 lb. (5 kg) or more, of the soil prepared as described in 8.1 and 8.2.
9.1 Thoroughly mix the selected representative sample with sufficient water to dampen it to
approximately 4 percentage points below optimum moisture content.

9 Procedure: (continued)

9.2 Form a specimen by compacting the prepared soil in the 4 in. (101.60 mm) mold (with collar
attached) in five approximately equal layers to give a total compacted depth of about 5 in. (125
mm). Compact each layer by 25 uniformly distributed blows from the rammer dropping free from
a height of 18 in. (457 mm) above the elevation of the soil when a sleeve-type rammer is used, or
from 18 in. (457 mm) above the approximate elevation of each finally compacted layer when a
stationary mounted type rammer is used. During compaction, the mold shall rest firmly on a
dense, uniform, rigid and stable foundation (Note 7).

9.2.1 Following compaction, remove the extension collar, carefully trim the compacted soil even with
the top of the mold by means of the straightedge. Holes developed in the surface by removal of
coarse material shall be patched with smaller size material. Weigh the mold and moist soil in
pounds to the nearest 0.01 lb.; or weigh in kilograms to the nearest 5 grams. For molds
conforming to tolerances given in Section 2.1.1, and masses recorded in pounds, multiply the
mass of the compacted specimen and the mold, minus the mass of the mold, by 30, and record
the result as the wet density, \( W_1 \), in lb./ft.\(^3\), of compacted soil. For molds conforming to
tolerances given in Section 2.1.1 and masses recorded in kilograms, multiply the mass of the compacted
specimen and mold, minus the mass of the mold, by 1060, and record the result as wet density,
\( W_1 \), in kg/m\(^3\), of compacted soil. For used molds out of tolerance by not more than 50 percent
(3.1.3), use the factor for the mold as determined in accordance with Section 6 (Calibration of
Measure), MT-203.

9.3 Remove the material from the mold and slice vertically through the center. Take a representative
sample of the material from one of the cut faces, weigh immediately, and dry in an oven at 110 ±
5 C (230 ± 9ºF) for at least 12 hours, or to constant mass, to determine the moisture content.
The moisture content sample shall weigh not less than 500 g.

9.4 Thoroughly break up the remainder of the material until it will pass a ¾-in., (19.0 mm) sieve and
90 percent of the soil aggregations will pass a No. 4, (4.75 mm) sieve as judged by eye, and add
to the remaining portion of the sample being tested. Add water in sufficient amounts to increase
the moisture content of the soil sample by one or two percentage points, and repeat the above
procedure for each increment of water added. Continue this series of determinations until there
is either a decrease or no change in the wet mass, \( W_1 \), per cubic foot or cubic meter of
compacted soil (Note 8).

METHOD D

10 Sample:

10.1 Select the representative sample in accordance with 8.3 except that it shall have a mass of
approximately 25 lb. (11 kg).

11 Procedure:

11.1 Follow the same procedure as described for Method C in section 9 except for the following. Form
a specimen by compacting the prepared soil in the 6 in. (152.40 mm) mold (with collar attached)
in five approximately equal layers to give a total compacted depth of about 5 in. (125 mm), each
layer being compacted by 56 uniformly distributed blows from the rammer. For molds conforming
to tolerances given in 2.1.2 and masses recorded in pounds, multiply the mass of the compacted
specimen and the mold, minus the mass of the mold, by 13.33, and record the results as the wet
unit mass, \( W_1 \), in lb./ft.\(^3\), of the compacted soil. For molds conforming to tolerances given in 2.1.2
and masses recorded in kilograms, multiply the mass of the compacted specimen and mold,
minus the mass of the mold, by 471, and record the result as the wet unit mass, \( W_1 \), in kg/m\(^3\) of
compacted soil. For used molds out of tolerance by not more than 50 percent (3.1.3), use the
7 of 8

CALCULATIONS AND REPORT

12 Calculations:

12.1 Calculate the moisture content and the dry unit mass of the soil as compacted for each trial, as follows:

\[
\frac{A - B}{B - C} \times 100
\]

and

\[
\frac{W_1}{W} \times 100
\]

where:

\( w \) = percentage of moisture in the specimen, based on oven dry mass of soil.

\( A \) = mass of container and wet soil.

\( B \) = mass of container and dry soil.

\( C \) = mass of container.

\( W \) = dry mass, in pounds per cubic foot of compacted soil, or kilograms per cubic meter of compacted soil, and

\( W_1 \) = wet mass, in pounds, per cubic foot of compacted soil or kilograms per cubic meter of compacted soil.

13 Moisture-Density Relationship:

13.1 The calculation in 11.1 shall be made to determine the moisture content and corresponding oven-dry unit mass (density) in pounds per cubic foot or kilograms per cubic meter of the compacted samples. The oven-dry densities (unit weight) of the soil shall be plotted as ordinates and the corresponding moisture content as abscissas.

13.2 Optimum Moisture Content--When the densities and corresponding moisture contents for the soil have been determined and plotted as indicated in 12.1, it will be found that by connecting the plotted points with a smooth line, a curve is produced. The moisture content corresponding to the peak of the curve shall be termed the "optimum moisture-content" of the soil under the above compaction.

13.3 Maximum Density--The oven-dry density in pounds per cubic foot or kilograms per cubic meter of the soil at optimum moisture content shall be termed "maximum density" under the above compaction.

14 Report:

14.1 The report shall include the following:
14 Report: (continued)

14.1.1 The method used (Method A, B, C, or D)

14.1.2 The optimum moisture content, as a percentage, to the nearest whole number

14.1.3.1 The maximum density in lbs. per cu. ft., to the nearest 0.1 lb/ft³ or in kilograms per cubic meter, to the nearest 1 kg.

14.1.3.2 In Methods C and D indicate if the material retained on the 19.0 mm sieve was removed or replaced.

14.1.5 Type of face if other than 2 in. (50.8 mm) circular.
METHOD OF SAMPLING AND TESTING

PROCEDURE FOR CORRECTION FOR COARSE PARTICLES
IN THE SOIL COMPACTION TEST
(Modified AASHTO T 224)

1 Scope:

1.1 This method describes a procedure for adjusting the densities of soil and soil aggregate mixtures to compensate for differing percentages of coarse particles retained on either the 4.75-mm (No. 4) or 19.0-mm (3/4 in.) sieve. This is necessary to adjust either the field wet density to a dry density of the material passing these sieves or the reverse, by adjusting the lab density to the field density when doing compaction control testing. Comparisons are made by comparing the field densities with the maximum dry density as determined by MT-210 (AASHTO T 99) or MT-230 (AASHTO T 180).

1.2 Two methods are available for correction, either, lab to field or field to lab density. The method specified in Section 4.1 adjusts the compacted lab density to the field density. The method specified in Section 4.2 adjusts the field wet density to dry density of the fine fraction and compares its results with the compacted lab density.

1.3 This test method applies to soil mixtures that have 40 percent or less retained on the 4.75-mm (No. 4) sieve, when Method A or B of MT 210 (AASHTO T 99) or MT 230 (AASHTO T 180) is used, or mixtures that have 30 percent or less retained on the 19.0-mm (3/4 in.) sieve, when Method C or D of MT 210 (AASHTO T 99) or MT 230 (AASHTO T 180) is used. The material retained on these sieves shall be defined as oversize particles (coarse particles).

1.4 This method applies to soils with any percentage of oversize particles as specified in Section 1.3. However, the correction may not be of practical significance for soils with only a small percentage of oversize particles. The person or agency specifying this method shall specify a minimum percentage of oversize particles below which the method need not be applied. If a minimum percentage is not specified, this method shall be applied to samples with more than 5 percent by weight of oversize particles.

1.5 The following applies to all specified limits in this standard: For the purpose of determining conformance with these specifications, an observed value or a calculated value shall be rounded off to the nearest 10kg/m³ (1 pcf), according to R 11, Recommended Practice for Indicating Which Places of Figures Are to Be considered Significant in Specified Limiting Values.

1.6 The values in SI units are to be considered as the standard.

2 Reference Documents:

2.1 AASHTO Standards:
R 11 Recommended Practice for Indicating Which Places of Figures Are to Be Considered Significant in Specified Limiting Values
T 85 Specific Gravity and Absorption of Coarse Aggregate
T 99 The Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
T 180 Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in) Drop
T 217 Determination of Moisture in Soils by Means of a Calcium Carbide Gas Pressure Moisture Tester
T 255 Total Moisture Content of Aggregate by Drying
T 272 Family of Curves-One Point Method
Outline of Method:

3.1 When method A or B of MT-210 or MT-230 is employed, the total field wet density is compared with the dry density of the soil particles passing the 4.75-mm (No. 4) sieve.

3.2 When method C or D of MT-210 or MT-230 is employed, the total field wet density is compared with the dry density of the soil particles passing the 19.0-mm (3/4 in) sieve.

3.3 Significant figures are as follows:

3.3.1 Adjusted wet density of the fine material passing the 4.75-mm (No. 4) sieve, Methods A and B; or 19.0-mm (3/4 in.) sieve, Methods C and D; (D_f) 1 kg/m³ (0.1pcf).

3.3.2 Bulk specific gravity of the coarse material retained on the 4.75-mm (No. 4) sieve, Methods A and B; or 19-mm (3/4 in.) sieve, Methods C and D; (G_m) 0.01.

3.3.3 Percent by mass, of coarse and fine particles, of material retained and passing the 4.75-mm (No. 4) sieve, Methods A and B; or 19.0-mm (3/4 in.) sieve, Methods C and D; (P_c) and (P_f) 0.1 percent.

3.3.4 In-place (field) wet density of the total sample (D) 1 kg/m³ (0.1 pcf).

Adjustment Equation:

4.1 Compacted Laboratory Dry Density Corrected to Field Dry Density

4.1.1 This section corrects the laboratory density obtained by either MT-210 or MT-230 for the moisture content and density of the material retained on the 4.74-mm (No. 4) sieve, Methods A and B; or the material retained on the 19.0-mm (3/4 in.) sieve, Methods C and D. The maximum laboratory dry density, adjusted for oversized particles and total moisture content are compared with the field dry density and field moisture content. This method is limited to field samples containing 40 percent or less of material retained on the 4.75-mm (No. 4) sieve, Methods A and B, or 30 percent or less of material retained on the 19.0-mm (3/4 in.) sieve, Methods C and D.

4.1.2 Determine the moisture content of the fine particles and oversize particles of the material used during compaction. The moisture contents can be determined by T 265, T 217, or T 255. The moisture content of the oversize material retained on the sieve can be assumed to be two (2) percent for most construction applications. If the moisture content of the oversized material is generally known, substitute the moisture content in the calculations. If drying equipment is available, determine the actual moisture contents. Calculate the moisture contents according to the calculations specified in T 265.

4.1.3 Calculate the dry mass of the coarse and fine particles as follows:

\[ M_D = \frac{M_M}{1 + MC} \]

where:

\[ M_D = \text{mass of dry material (fine or oversize particles).} \]

\[ M_M = \text{mass of moist material (fine or oversize particles).} \]

\[ MC = \text{moisture content of respective fine or oversized particles, expressed as a decimal.} \]
4.1.4 Adjustment Equation: (continued)

Calculate the percentage of the fine particles and oversized particles by dry weight of the total sample as follows:

\[ P_f = \frac{100 \cdot M_{DF}}{M_{DF} + M_{DC}} \]

and

\[ P_C = \frac{100 \cdot M_{DC}}{M_{DF} + M_{DC}} \]

where:

- \( P_f \) = percent of fine particles, of sieve used, by weight.
- \( P_C \) = percent of oversized particles, of sieve used, by weight.
- \( M_{DF} \) = mass of dry particles and
- \( M_{DC} \) = mass of oversize particles.

4.1.5 Calculate the corrected moisture content and corrected dry density of the total sample (combined fine and oversized particles) as follows:

\[ M_{CT} = \frac{(M_C P_f + M_C P_C)}{100} \]

where:

- \( M_{CT} \) = corrected moisture content of the combined fine and oversized particles, expressed as a decimal.
- \( M_C \) = moisture content of the fine particles, expressed as a decimal.
- \( M_C \) = moisture content of oversized particles, expressed as a decimal.

and

\[ D_d = \frac{100 \cdot D_f k}{(D_f P_C + k P_f)} \]

where:

- \( D_d \) = corrected total dry density (combined fine and oversized particles) kg/m³ (pcf).
- \( D_f \) = dry density of the fine particles kg/m³ (pcf).
- \( P_C \) = percent of oversized particles, of sieve used, by weight.
- \( P_f \) = percent of fine particles, of sieve used, by weight.
- \( k = 1,000 \cdot \text{Bulk Specific Gravity (Gₘ)} \) (oven dry basis) of coarse particles (kg/m³),
  Or 62.4* \( \text{Bulk Specific Gravity(Gₘ)} \) (oven dry basis) of coarse particles (pcf).

\[ K = 1,000 \cdot \text{Bulk Specific Gravity (Gₘ)} \] (oven dry basis) of coarse particles (kg/m³),
Or 62.4* \( \text{Bulk Specific Gravity(Gₘ)} \) (oven dry basis) of coarse particles (pcf).

**Note 1** – *If the specific gravity has been determined, this value may be used in the calculations. Determine the Bulk Specific Gravity according to T 85. For most construction activities the specific gravity can be assumed to be 2.60.*
4 Adjustment Equation: (continued)

4.2 Field Wet Density Corrected to Compacted Laboratory Density

4.2.1 The in-place total (field) wet density is corrected to a dry density of the sample passing the 4.75-mm (No. 4) sieve or the sample passing the 19.0-mm (3/4 in.) sieve. The adjusted dry density is compared with the maximum dry density obtained by methods T 99 or T 180.

4.2.2 Determine the moisture content of the total sample and for the material retained on the sieve used during compaction. Moisture content can be determined by either T 265, T 217 or T 255. If using the nuclear moisture/density gauge, read the moisture content directly from the gauge for the total moisture content. The moisture content of the oversize material retained on the sieve can be assumed to be two (2) percent for most construction applications. If the moisture content of the oversize material is generally known, substitute the moisture content in the calculations. If drying equipment is available, determine the actual moisture contents. Calculate the moisture contents according to the calculations specified in T 265.

4.2.3 Calculate the moisture content of the fine particles of the field sample as follows:

$$MC_T = (100MC_T-MC_CP_C)/P_f$$

where:

MC_T = moisture content of the fine particles, expressed as a decimal.

MC_T = moisture content of total field sample, expressed as a decimal.

MC_C = moisture content of the oversize particles, expressed as a decimal.

P_C = percent of oversize particles, of sieve used, by weight.

P_f = percent of fine particles, of sieve used, by weight.

4.2.4 Calculate the dry field density of the sample as follows:

$$D_d = D/(1+MC_T)$$

where:

D_d = dry field density of total sample, kg/m³ (pcf).

D = total field wet density, kg/m³ (pcf).

MC_T = moisture content of total field sample, expressed as a decimal.

4.2.5 Calculate the dry field density of the fine particles of the field sample as follows:

$$D_f = D_dP_f/(100-((D_dP_C)/k)))$$

where:

D_f = adjusted dry density of the fine particles, kg/m³ (pcf).

D_d = total field dry density, kg/m³ (pcf).
4 Adjustment Equation: (continued)

\[ P_f = \text{percent of fine particles, of sieve used, by weight.} \]

\[ P_C = \text{percent of oversize particles, of sieve used, by weight.} \]

\[ k = 1,000 \times \text{Bulk Specific Gravity (G_M)(oven dry basis)} \text{ of coarse particles (kg/m}^3\text{),} \]

\[ \text{or } 62.4 \times \text{Bulk Specific Gravity (G_M)(oven dry basis)} \text{ of coarse particles (pcf), (Note 1).} \]

5 Precision:

5.1 Since this correction for coarse particles involves no testing but instead utilizes the results of other tests and mathematically combines the results, determination of the precision and accuracy is not applicable.

APPENDIX:

A1 NOTES:

A1.1 These methods, described for coarse particle correction, are applicable to one type of soil and soil-aggregate material only. If the characteristic of the material changes, then a moisture/density relationship (T 99 or T 180) test is performed to determine a new maximum density.

A1.2 T 272 describes the methods for determining different maximum densities of soil and soil-aggregate materials which reveal certain similarities and trends characteristic of the material type and source.

A1.3 UTILIZATION OF A FAMILY OF CURVES – When using the One Point Method (T 272), Note 3 does not apply. The percentage of oversize particles, when performing the density of soil and soil-aggregate in-place, must be determined to adjust the T 99 or T 180 maximum density to compensate for this percentage.
1. **Scope:**

1.1 This test method covers procedures and apparatus for determining the pH, conductivity and sulfate content of a soil in corrosion testing.

1.2 The principle use of these tests is to supplement soil-resistivity measurements and thereby identify conditions under which the corrosion of metals in soil may be accentuated.

2. **Apparatus:**

2.1 **Sieves** – A series of sieves of the following sizes: 1/4 in. (6.3 mm), No. 4 (4.75 mm), No. 10 (2.00 mm) and a pan.

2.2 **Balance** – A balance readable to 0.1 percent of the sample mass, or better, and conforming to the requirements of AASHTO M 231.

2.3 **Drying Apparatus** – A suitable device capable of drying samples at a temperature of 140°F (60°C).

2.4 **Pulverizing Apparatus** – Either a mortar and a rubber-covered pestle or any device suitable for breaking up the aggregations of soil particles without reducing the size of the individual grains.

2.5 **Sample Splitter** – A suitable riffle sample splitter or sample splitter for proportional splitting of the sample and capable of obtaining representative portions of the sample without appreciable loss of fines. The width of the container used to feed the riffle splitter should be equal to the total combined width of the riffle chutes. Proportional splitting of the sample on a canvas cloth is also acceptable.

2.6 **pH Meter** – With electrodes suitable for laboratory analysis.

2.7 **Standard Buffer Solutions** – Buffer solutions with known pH values of 4.0, 7.0, 10.0.

2.8 **Beakers** – 100 ml and 250 ml wide mouth glass beakers with a watch glass for cover.

2.9 **Glass stirring rods.**

2.10 **Conductivity Meter** - Suitable for laboratory or field analysis.

2.11 **Muffle Furnace** – The muffle furnace shall be capable of operation at the temperatures required and shall have an indicating pyrometer accurate within ±25°C, as corrected, if necessary, by calibration.

2.12 **Platinum Crucible** – Platinum crucibles for ordinary chemical analysis should preferably be made of pure unalloyed platinum of 15 to 30-ml capacity. Where alloyed platinum is used for greater stiffness or to avoid sticking of crucible and lid, the alloyed platinum should not decrease in mass by more than 0.2 mg when heated at 1200°C for one hour.

2.13 **Filter Paper** – Fast filter paper (Whatman #41) and slow filter paper (Whatman #42).

3. **Sample Preparation:**

3.1 The sample as received shall be in a moist condition for pH purposes. If the sample is too wet, it may be dried to a moist condition in air or a drying apparatus not to exceed 140°F (60°C) prior to sample selection (Note 1). A representative test sample to perform the pH test shall then be obtained with a sampler or by splitting or quartering.
3 Sample Preparation: (continued)

Note 1 – Samples dried in an oven or other drying apparatus at a temperature not exceeding 140°F (60°C) are considered to be air dried.

3.2 The portion of the sample selected for pH testing shall be separated into fractions by one of the following methods:

4. Determination of pH:

4.1 Place sufficient soil into a 100 ml glass beaker or other suitable container to fill to the 80 ml mark.

4.2 Stir a sufficient amount of distilled water into the sample to produce a soil slurry and then cover with a watch glass.

4.3 Let the sample stand for a minimum of one hour, stirring every 10 to 15 minutes. This is to allow the pH of the soil slurry to stabilize.

4.4 Measure the temperature of the soil and adjust the temperature controller of the pH meter to that of the sample temperature. This adjustment should be done just prior to testing.

4.5 Stabilize the pH meter by means of the standard solutions provided.

4.6 Stir the sample with a glass rod immediately before immersing the electrode into the soil slurry solution and gently turn the beaker or container to make good contact between the solution and the electrode. DO NOT place the electrode into the soil, only into the soil slurry solution.

4.7 Immerse the electrode in the solution for at least 30 seconds to allow the meter to stabilize. If the meter has an auto read system, it will automatically signal when stabilized.

4.8 Read and record the pH value to the nearest tenth of a whole number.

4.9 Rinse the electrode well with distilled water, then dab lightly with tissues to remove any film formed on the electrode. Caution: Do not wipe the electrode as this may result in polarization of the electrode and consequent slow response.

4.10 Add approximately 1 gram of calcium carbonate (CaCO₃) to the soil slurry and set aside for approximately 24 hours and determine the marble pH according to sections 4.4 to 4.9.

5. Determination of Conductivity:

5.1 Place a sufficient amount of soil on a 100 mm watch glass to completely cover the watch glass and let stand overnight to allow the sample to dry.

5.2 Sieve the dry sample over a No. 10 sieve (2.00 mm) and then pulverize with a mortar and pestle in such a manner so as to break up the aggregations without fracturing the individual grains. If the sample contains brittle particles, pulverize carefully and with just enough pressure to free the finer material that adheres to the coarser particles.

5.3 Place a portion of the soil in a 100 ml beaker and add distilled water at a ratio of 1 part soil to 2 parts water and let stand for 30 minutes.

5.4 After conditioning, pour the water from the beaker into the sample container of the conductivity meter and determine the conductivity to the nearest 0.01 m. mhos.

6. Determination of Sulfate Content:

6.1 Place 3 grams of the remaining soil from the watch glass into a 500 ml Erlenmeyer flask.
6. **Determination of Sulfate Content:** (continued)

6.2 Add 150 ml of distilled water, stopper the flask and shake to mix.

6.3 Centrifuge the sample for 30 minutes.

6.4 Decant the liquid into a 250 ml beaker and add 2 ml of dilute Hydrochloric acid (50% strength), to flocculate the suspended particles, cover with a watch glass and place onto a hot plate until the sample boils.

6.5 Remove the beaker from the hot plate and immediately filter through a **fast** filter paper (Whatman #41).

6.6 Add 10 ml of a 10% Barium Chloride (BaCl₂·2H₂O) solution to this sample to determine the presence of sulfate. *(The liquid will become milky in the presence of sulfate).*

6.7 Cover the beaker with a watch glass and return to the hot plate to boil.

6.8 Immediately filter through a slow filter paper (Whatman #42) and wash with several hot water rinses.

6.9 Place the filter paper in a tared 30 ml platinum crucible, place the crucible into a muffle furnace and slowly raise the temperature to 1000°C to burn off filter paper.

6.10 Remove from the muffle furnace and desiccate until cool. Weigh to the nearest 0.0001 grams and record.

7. **Sulfate Calculation:**

\[
\left( \frac{W \times 0.4115}{S} \right) \times 100 = \text{______} \% \text{ Sulfate (SO}_4\text{)}
\]

where:

\( W = \text{Sulfate wt.} \)

\( S = \text{Soil sample wt.} \)

8. **Report:**

pH - ______________________

Marble pH - __________________

Sulfate - _________________% SO₄

Conductivity - ________________ m. mohs
METHODS OF SAMPLING AND TESTING
MT 233-07

METHOD OF TEST FOR RESISTANCE OF COARSE AGGREGATE TO DEGRADATION BY ABRASION IN THE MICRO-DEVAL APPARATUS
(Modified AASHTO T 327)

1 Scope:

1.1 This method covers a procedure for testing coarse aggregate for resistance to abrasion using the Micro-Deval apparatus.

1.2 The text of this method references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the test method.

2 Referenced Documents:

2.1 AASHTO:
T 327 Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus

MT Materials Manual:
MT 202 Sieve Analysis of Fine and Coarse Aggregates
MT 405 Wire-Cloth Sieves for Testing Purposes

3 Summary of Test Method:

3.1 The Micro-Deval Test is a measure of abrasion resistance and durability of mineral aggregates resulting from a combination of actions including abrasion and grinding with steel balls in the presence of water. A sample with standard grading is initially soaked in water for a minimum of 15 hours. The sample is then placed in a jar mill with 2.0 L of water and an abrasive charge consisting of 5000 grams of 9.5 mm diameter steel balls. The jar, aggregate, water and charge are revolved at 100 rpm for two hours depending on the particle size. The sample is then washed and oven-dried. The loss is the amount of material passing the 1.18 mm sieve, expressed as a percent by mass of the original sample.

4 Significance and Use:

4.1 The Micro-Deval abrasion test is a test of coarse aggregates to determine abrasion loss in the presence of water and an abrasive charge. Many aggregates are more susceptible to abrasion when wet than dry, and the use of water in this test incorporates this reduction in resistance in degradation, in contrast to some other tests that are conducted on dry aggregate. The test results are helpful in evaluating the toughness/abrasion resistance of coarse aggregate subject to abrasion when adequate information is not available from service records.

4.2 The Micro-Deval abrasion test is a useful test for detecting changes in properties of aggregate produced from an aggregate source as part of a quality control or quality assurance program.

5 Terminology:

5.1 Constant mass – Test samples dried at a temperature of 230 ± 9°F (110 ± 5°C) to a condition such that it will not lose more than 0.1 percent moisture after 2 hours of drying. Such a condition of dryness can be verified by weighing the sample before and after successive two hour drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 230 ± 9°F (110 ± 5°C) for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading condition of the oven.
6 **Apparatus:**

6.1 *Micro-Deval Abrasion Machine* – A jar rolling mill capable of running at 100 ± 5 rpm.

*Note 1 – Micro-Deval abrasion machine fitted with a counter may be used if the test is conducted on the basis of number of revolutions (Clause 9.4).*

6.2 *Containers* – Stainless steel Micro-Deval abrasion jars having a 5-L capacity with a rubber ring in the rotary locking cover, an external diameter of 194 to 202 mm, and an internal height of 170 to 177 mm. The inside and outside surfaces of the jars shall be smooth and have no observable ridges or indentations. (Figure 1)
6 Apparatus: (continued)

6.3 **Abrasive Charge** – Magnetic steel balls are required. These shall have a diameter of 9.5 ± 0.5 mm. Each jar requires a charge of 5000 ± 5 g of balls.

6.4 **Sieves** – Sieves with square openings, and of the following sizes conforming to AASHTO M 92 specifications: 3/4 inch (19.0 mm), 5/8 inch (16.0 mm), 1/2 inch (12.5 mm), 3/8 inch (9.5 mm), 1/4 inch (6.3 mm), No. 4 (4.75 mm), No. 16 (1.18 mm).

6.5 **Oven** – The oven shall be capable of maintaining a temperature of 230 ± 9°F (110 ± 5°C).

6.6 **Balance** - A balance or scale accurate to 1.0 gram.

7 Reference Aggregate:

7.1 **Laboratory Reference Aggregate**: A supply of standard “Brechin Quarry No. 2” coarse aggregate available from the Soils and Aggregates Section, Materials Engineering and Research Office, Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario, Canada M3m, 1J8.

7.2 **Calibration Aggregate** – An adequate supply of aggregate, established by the laboratory to use for calibration of the test method (see Section 11.1).

8 Test Sample:

8.1 The test sample shall be washed and oven dried at 230 ± 9°F (110 ± 5°C) to constant mass, separated into individual size fractions in accordance with MT-202, and recombined to meet the grading as shown in Section 8.2.

8.2 Aggregate for the test shall normally consist of material passing the 3/4 inch (19.0 mm) sieve, retained on the 3/8 inch (9.5 mm) sieve. An oven dried sample of 1500 ± 5 grams shall be prepared as in Table 1.

| Table 1 – Preparation of an Oven-Dried Sample of 3/4" (19.0 mm) |
|---|---|---|
| Passing | Retained | Mass |
| 3/4 " (19.0 mm) | 5/8 " (16.0mm) | 375 g |
| 5/8" (16.0 mm) | 1/2 " (12.5 mm) | 375 g |
| 1/2 " (12.5 mm) | 3/8 " (9.5 mm) | 750 g |

8.3 In a case where the maximum nominal size of the coarse aggregate is 1/2 " (12.5 mm) or less, a sample of 1500 ± 5 g shall be prepared as in Table 2:

| Table 2 – Preparation of an Oven-Dried Sample of Less Than 5/8" (16.0 mm) |
|---|---|---|
| Passing | Retained | Mass |
| 1/2 " (12.5 mm) | 3/8 " (9.5mm) | 750 g |
| 3/8 " (9.5mm) | 1/4 " (6.3 mm) | 375 g |
| 1/4 " (6.3 mm) | No. 4 (4.75 mm) | 375 g |
8 Test Sample: (continued)

8.4 In a case where the maximum nominal size of the coarse aggregate is 3/8 “ (9.5 mm) or less, a sample of 1500 ± 5 g shall be prepared as in Table 3:

| Table 3 – Preparation of an Oven-Dried Sample of Less Than 1/2” (12.5 mm) |
|-----------------|-----------------|-------|
| Passing         | Retained        | Mass  |
| 3/8 “ (9.5 mm)  | 1/4 “ (6.3 mm)  | 750 g |
| 1/4 “ (6.3 mm)  | No. 4 (4.75 mm) | 750 g |

9 Test Procedure:

9.1 Prepare a representative 1500 ± 5 g sample. Determine the mass “A” and record to the nearest 1.0 g.

9.2 Immerse the sample in 2.0 ± 0.05 liters of tap water at a temperature of 68 ± 9ºF (20 ± 5ºC) for a period of 15 to 19 hours either in the Micro-Deval container or some other suitable container.

9.3 Place the sample in the Micro-Deval abrasion container with 5000 ± 5 g of steel balls and the water used in section 9.2 to saturate the sample. Install the cover and place the container in the Micro-Deval machine.

9.4 Run the machine at 100 ± 5 rpm for 12,000 ± 100 revolutions for the grading shown in Section 8.2; for 10,500 ± 100 revolutions for the grading shown in Section 8.3; and for 9,000 ± 100 revolutions for the grading shown in Section 8.4.

Note 2 – Some equipment is not capable of measuring the total number of revolutions of the drum. If desired, instead of using revolutions, time can be used as follows:

Run the Micro-Deval machine at 100 ± 5 rpm for two hours ± 1 minute for the grading shown in Section 8.2. For the grading shown in Section 8.3, run the machine for 105 ± 1 minutes. For the grading shown in Section 8.4, run the machine for 95 ± 1 minutes.

9.5 Carefully pour the sample and steel balls over a No. 4 (4.75 mm) sieve superimposed on a No. 16 (1.18 mm) sieve. Take care to remove the entire sample from the stainless steel jar. Wash and manipulate the retained material on the sieves with water using a hand held water hose and the hand until the washings are clear and all the material smaller than No. 16 (1.18 mm) passes that sieve. Remove the stainless steel balls using a magnet or other suitable means.

9.6 Combine the material retained on the No.4 (4.75 mm) and No. 16 (1.18 mm) sieves, being careful not to lose any material.

9.7 Oven dry the sample to a constant mass at 230 ± 9ºF (110 ± 5ºC).

9.8 Weigh the sample to the nearest 1.0 g and record as mass “B”.

10 Calculations:

10.1 Calculate the Micro-Deval abrasion loss, as follows, to the nearest 0.1 percent.

\[
Percent\ Loss = \frac{(A - B)}{A} \times 100
\]
11 Use of the Calibration Aggregate:

11.1 Calibration Aggregate – The laboratory will establish an adequate supply of material to use for calibration of the test method. A suitable material with a loss of between 5 and 15 percent shall be established. From this material 10 sample will be taken randomly and tested. At the same time 10 samples of the reference aggregate from Brechin Quarry No.2 (see Section 7.1) shall also be tested. Provided the mean loss and variation of the Brechin Quarry No. 2 aggregate is within allowed tolerance of Section 11.1.1, the mean value obtained with the supply of in-house calibration aggregate shall be used thereafter. At any time a new supply is required, the calibration procedure shall be conducted.

11.1.1 The mean loss of the Brechin Quarry No. 2 reference aggregate (see Section 7.1) in multilaboratory study of the Micro-Deval Test is 19.1 percent. For continued acceptance of data, in-house calibration aggregate test data must fall within the range 5 to 15 percent loss for 95 percent of the time.

11.1.2 When test data of the calibration aggregate is outside the limits, an investigation as to the probable cause shall be conducted. The equipment shall be re-calibrated and the testing technique re-examined to detect non-conformance with the test procedure.

11.2 Every 10 samples, but at least every week in which a sample is tested, a sample of the calibration aggregate shall be tested. The material shall be taken from a stock supply and prepared according to section 8. When 20 samples of calibration aggregate have been tested, and the results show satisfactory variation, the frequency of testing may be changed to a minimum of one sample every month.

11.3 Trend Chart Use – The percent loss of the last 20 samples of calibration aggregate shall be plotted on a trend chart in order to monitor the variation in results (Figure 2).
12 Report:

12.1 The report shall include the following:

12.1.1 The maximum size of the aggregate tested and the grading used;

12.1.2 The percent loss of the test sample to one decimal place;

12.1.3 The percent loss of the calibration aggregate, tested closest to the time at which the aggregate was tested, to the nearest 0.1 percent; and

12.1.4 The percent loss of the last twenty samples of calibration material on a trend chart.