AGGREGATE TESTING FOR TRANSPORTATION SYSTEMS

HIGHWAY TECHNICIAN CERTIFICATION PROGRAM
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PREFACE

The Wisconsin Department of Transportation (WisDOT) Certified Aggregate Technician for Transportation Systems course manual was prepared and developed by the Highway Technician Certification Program (HTCP) staff at the University of Wisconsin-Platteville, the HTCP program instructors, and other contributors from WisDOT and the highway industry. The intent of this manual is to provide AASHTO-based training as it applies to aggregate testing for WisDOT construction. It is the responsibility of the WisDOT Certified ATTS Technician to follow all current specifications when conducting work assignments.

The WisDOT Certified ATTS Technician course manual was developed with these resources:

- WisDOT Construction and Materials Manual (CMM)
- WisDOT Standard Specifications for Highway and Structure Construction, Highway Materials, Soils, and Concretes, by Harold N. Atkins
- The Aggregate Handbook
- Idaho State Department of Transportation
- American Association of State Highway and Transportation Officials (AASHTO)

ACKNOWLEDGEMENTS

The HTCP ATTS Technician Manual committee members have been instrumental contributors to the contents of this course manual. The committee members are:

- Robert Downing – WisDOT Bureau of Technical Services
- Dick Tracy – WisDOT Bureau of Technical Services
- Bob Jewell - The Kraemer Company
- Tom Brokaw – WisDOT Bureau of Technical Services
- Ray Spellman – University of Wisconsin-Platteville

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>TOPIC A</th>
<th>Course Overview</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOPIC B</td>
<td>Safety Considerations</td>
</tr>
<tr>
<td>TOPIC C</td>
<td>LA Wear (AASHTO T 96); 100 &amp; 500 Revolutions</td>
</tr>
<tr>
<td>TOPIC D</td>
<td>Sodium Sulfate Soundness (AASHTO T 104); R-4, 5 cycles</td>
</tr>
<tr>
<td>TOPIC E</td>
<td>Freeze/Thaw Soundness (AASHTO T 103); R-4, 16 cycles, Procedure B, for applicable counties/sources</td>
</tr>
<tr>
<td>TOPIC F</td>
<td>Fracture (WisDOT CMM 8.60)</td>
</tr>
<tr>
<td>TOPIC G</td>
<td>Liquid Limit (AASHTO T 89); using AASHTO T 146, Method A for prep of P-4 Plasticity (AASHTO T 90); using AASHTO T 146, Method A for prep of P-4</td>
</tr>
<tr>
<td>TOPIC H</td>
<td>Coarse Aggregate Specific Gravity &amp; Absorption (AASHTO T 85)</td>
</tr>
<tr>
<td>TOPIC I</td>
<td>Lightweight Pieces (AASHTO T 113); If chert is present</td>
</tr>
<tr>
<td>TOPIC J</td>
<td>Data Entry</td>
</tr>
</tbody>
</table>

## APPENDIX

- Worksheets
- QMP Award
- Corrections
- Course Evaluation
Aggregate Testing for Transportation Systems
Course Syllabus

8:00 - 8:15    Registration, Introductions, Course Objectives, and Course Syllabus
8:15 - 8:45    Safety Considerations
8:45 – 10:00   Los Angeles Wear (AASHTO T 96); 100 & 500 Revolutions

Break

10:15 – 12:00  Sodium Sulfate Soundness (AASHTO T 104): R-4, 5 Cycles
Noon – 1:00    Lunch
1:00 – 3:00    Freeze/Thaw Soundness (AASHTO T 103): R-4, 16 Cycles, Procedure B, for applicable counties/sources

Break

3:15 – 5:00    Fracture (WisDOT CMM Chapter 8.60)

DAY 2

8:00 – 10:00   Liquid Limit (AASHTO T 89); using AASHTO T 146, Method A for prep of P-4

Break

10:15 – 12:00  Plasticity (AASHTO T 90); using AASHTO T 146, Method A for prep of P-4
Noon – 1:00    Lunch
1:00 – 3:00    Coarse Aggregate Specific Gravity & Absorption (AASHTO T 85)

Break

3:15 – 5:00    Lightweight Pieces (AASHTO T 113); if chert is present
Data Entry

DAY 3

8:00 - 10:30   Review for Written Examination
10:30 - 12:00  Written Examination, Course Evaluation
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- Individual AASHTO standards may be requested from:
  AASHTO
  444 North Capitol Street, N.W.
  Suite 249
  Washington, D.C. 20001
  202.624.5800
  FAX 202.624.5806

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  P. O. Box 7129
  Boise, ID 83707-1129

- Wisconsin Department of Transportation Construction and Materials Manual
TOPIC A: Course Overview
Previous Process

Historically, aggregate quality testing was required at a minimum of every five years per source.

The samples were obtained by WisDOT personnel.

WisDOT personnel were responsible for all quality testing.

Samples had to be submitted at least 14 days prior to the intended use.

Why Has the Process Changed?

WisDot has been progressing toward having industry control their product and schedules.

WisDot personnel will take a “verification” role.

Staff reductions at WisDOT have contributed to a change in the process.

The Current Process

Aggregate samples will be obtained jointly by WisDOT and producer personnel.

A sample will be split with half the sample going to the producer and half the sample going to WisDOT.

The producer will have their split portion tested. The producer will submit a report from the testing lab indicating the results of the required tests, including all worksheets.

Required Tests

Tests required of the producer on their split portion are:

- LA Wear (AASHTO T 96); 100 & 500 revolutions
- Sodium Sulfate Soundness (AASHTO T 104); R-4, 5 cycles
- Freeze/Thaw Soundness (AASHTO T 103); R-4, 16 cycles, Procedure B, for applicable counties/sources
- Fracture (WisDOT CMM 8.60)
- Liquid Limit (AASHTO T 89); using AASHTO T 146, Method A for prep of P-4
- Plasticity (AASHTO T 90); using AASHTO T 146, Method A for prep of P-4
- Coarse Aggregate Specific Gravity & Absorption (AASHTO T 85)
- Lightweight Pieces (AASHTO T 113); if chert is present
Testing Laboratory Requirements

The testing lab must meet any of the following requirements:

- Testing must be performed by a WisDOT Qualified and an AASHTO Accredited Laboratory with accreditation in the tests being performed
- WisDOT qualified for the applicable tests above, and participating in AMRL’s Proficiency Sample Program for coarse aggregate ($250/year), if performing wear and soundness testing. A copy of AMRL’s data report for the lab shall be submitted to the WisDOT Quality Management Laboratory.

Department Testing

The Central Office Laboratory will test their portion of the split sample for the following situations:

- Random testing to verify results from each lab/producer (%)
- When requested by the producer
- When requested by the district/department
- When the source has a history of being close to specification limits for one of the tested properties

Frequency

The minimum frequency of source testing is:

- Every five (5) years for pits
- Every three (3) years for quarries

Any testing outside of these frequency requirements would be performed by WisDOT.
TOPIC B: SAFETY CONSIDERATIONS
SAFETY FIRST

1. Know your Safety Officer
   a. Emergency phone numbers
   b. Nearest hospital location

2. Safety Equipment
   a. First aid kit
   b. Fire extinguishers
   c. Fireproof gloves
   d. Eye protection
   e. Ear protection
   f. **STEEL TOE SHOES**
   g. Safety vest
   h. Hard hats
   i. Proper ventilation

3. Equipment Operators
   Always keep eye contact with operators when working close to heavy equipment.

4. Practice Proper Back Maintenance

5. Exercise extreme caution when using caustic chemicals.
Safety Considerations

Safety is prime importance while serving your occupational duty on Wisconsin Department of Transportation projects.

About 15% of all accidents are caused by unsafe mechanical or physical conditions. The other 85% of the accidents are caused by absentmindedness, negligence or ignorance. For each accident, 100 near misses occur.
Safety Considerations

**Crushing Machinery:**

Ample room should be provided for movement around equipment and use of tools.

Platforms should be provided for service and observation areas should be accessed without climbing on equipment.

Crushing feed chambers should be shielded to prevent fly-rock injury or accumulation of material on platforms.

Adjustment tools or hydraulic hoses should be kept off the floor area to prevent tripping of personnel.
Safety Considerations

Crushing Machinery:

- Properly designed mechanical devices should be provided to permit crusher service and maintenance to use safe procedures.
- Engineered and prefabricated guards for moving parts of machinery should be provided.

Screening Machinery:

- Walkways alongside and parallel to the screen slope should be provided to permit access to the clamping bar bolts and screen frame connections.
- Ample clearance should be provided to permit safe access around drive unit.
### Safety Considerations

#### Screening Machinery:
- Drive guards should be provided that permit easy access for changing drive parts.
- Safe access to screen decks is very important.

#### Conveyors:
- Walkways should be provided for service, inspection, and product sampling.
- Pinch points along conveyors need to be protected to prevent inadvertent access to these hazardous areas.
Safety Considerations

Conveyors:

- Pull cord or inside handrails should be provided at the idler height on conveyors with walkways or personnel access that are not visible to the plant operator.

- Cages or guards on return idlers must be provided if the area is accessible to personnel.

If conveyor inclination or material size could result in the roll back of materials, buffers need to be provided at sufficient points to eliminate the hazards of falling rock.
Safety Considerations

Stairways:

☆ All working levels of a plant building need stairway access if at all possible.
☆ Stairs should have a minimum width of 30 in. and be constructed at a slope of 30° to 35°, with a constant riser height.
☆ Landings should be provided at appropriate levels.

Ladders:

☆ Stairs are always preferable to ladders. Vertical stairs should be used at last resort.
☆ Where ladders are required, rungs should be spaced at 9 in. to 12 in. apart, and be at least 18 in. wide. Safety cages are required for ladders over 7 ft in height and should be designed to applicable regulations.
Safety Considerations

 Platforms:

★ Hand rails at a 42 in. height with mid-rails are required unless area is enclosed with mesh or plate.

♫ Toe boards around the edge of the floors should be a minimum of 4 in. high and may be placed 1 in. above the flooring.

Platforms:

♫ Flooring may be steel checkered plate, expanded metal grating or a variety of nonskid flooring products.

♫ Openings in the floor should be guarded by hand rails and toe boards, and the access openings should be protected.
Safety Considerations

Material Storage:

Open hoppers or bins that are in the plant working area should be covered and protected with proper handrails and toe boards.

When internal bin access is required, ladders should be provided as well as life belts or harness suspension facilities.
Essentials of Laboratory Safety

Safety Essentials

Safety matters
Safety:

It is important to always work safely while working in or around:

• Labs
• Loud noises
• Heavy machinery
• Heavy lifting

Before Lab Work, Get to Know:

• Hazards of materials & agents and their prescribed safety procedures
Also Get to Know:

- Emergency spill procedures, use of adsorbents and disinfectants
- Designated escape route and alternate
- Location of fire ext., eye wash, shower, first aid, and spill kits

While Working in the Lab:

- Shoes with full coverage and good grip soles
- Restrain long hair, loose clothing and jewelry
- Use appropriate eye, skin, and hand protection
Eye protection

- Protects against risk of flying objects or dust particles, splashes of hazardous materials or harmful rays

Safety Glasses

- Unbreakable lenses of plastic or tempered glass
- For light-to-moderate work
- Can be prescription lenses
- Do not interfere with contact lenses
Goggles

- Work with significant risk of splash of chemicals or projectiles
- Can be worn over prescription glasses

Face Shield

- Work with significant risk of splash on face or possible explosion
- Face shield protects face adequately but not eyes
Hand Protection

- Protects against risk of cuts, abrasions, burns, or exposure to hazardous materials.
- Requires selection of the appropriate chemical resistant gloves.

While Working in the Lab:

- Follow universal precautions
- Handle unknowns as if they were hazardous
While Working in the Lab:

Report **all:**

- **Accidents**
- **Injuries**
- **Fires**
- **Spills**
- **Close calls**

![Diagram showing statistics]

1 Disabling injury
10 Minor injuries
30 Property damage incidents
600 Close Calls

While Working in the Lab:

Protect yourself from hearing damage and loud noises.

Where:

- ✔ Ear plugs
- ✔ Ear muffs
Before Leaving the Lab:

Turn off:
- Gas
- Water
- Power supplies
- Vacuum lines
- Compression lines
- Heating apparatus

Before Leaving the Lab:

- Identify and package waste, dispose properly
- Lock/out and tag/out defective equipment
- Decontaminate work surfaces and equipment
Evaluating Lab Hazards

• Regular review of the types of hazards:
  • chemical
  • physical
  • biological
  • ergonomic
  • mechanical

Minor Variation in Procedure

Weekly Lab Checks

• Eye wash (purge)
• Fire extinguisher
• First Aid Kit
• Fume Hood
• Tubing, pressurized connections
• Chemical storage
Protect Your Ears:

It can be very loud while working around heavy machinery. You should always wear proper ear protection when working around noisy machinery and equipment.

• Ear plugs

• Ear muffs

Protect Your Feet:

While working near machinery it is important to protect your feet. Wear proper foot protective gear!

• Steel-toed shoes

• Safety shoes
While Performing Heavy Lifting

Wear proper safety gear when performing heavy lifting.

- Safety shoes or steel-toed boots
- Eye and face protection when lifting hazardous materials
- Hard hat when lifting near machinery

While Performing Heavy Lifting

Use the right technique and form when lifting heavy objects.

- Lift with your legs, not your back!
- Lift in a clear area free of tripping hazards.
- Lift all objects in a safe direction.
  - Point sharp objects or edges away from you.
Heavy Lifting Technique:

• Squat to lift and lower. Do not bend at the waist.
• Keep you low back bowed in while bending over.
• Keep the weight as close to you as possible.
• Bow your back in and raise up with your head first.
• If you must turn, turn with your feet, not your body.
• Never jerk or twist!
• Put the weight down by keeping your low back bowed in.
• Keep you feet apart, staggered if possible.
• Wear shoes with non-slip soles.

Source: http://www.vcu.edu/oehs/fire/safetytech.html

Credits:

• The material for the lab portion of this safety topic came from the University of Vermont's PowerPoint Presentation Library, the Wisconsin Department of Transportation's Work Safe, Truax Center Safe Operating Procedures Manual, and program staff and associates.

Source: http://www.vcu.edu/oehs/fire/safetytech.html
TOPIC C: LA Wear (AASHTO T 96)
Purpose: To measure the hardness of aggregates.

Estimated Time to Complete the Test: Two hours (start to finish)

Significance: Hardness (or resistance to wear) is important in many applications. It is important that the aggregates for pavement surfaces not become rounded or polished due to traffic, since they would become less skid resistant. Floors subjected to heavy traffic in industrial buildings also must be wear resistant. Aggregates in roadbeds are subjected to innumerable cycles of load application and removal. Particles that tend to break or powder will result in a change in gradation and other properties and reduced strength of the structure. Broken particles in concrete and asphalt pavements are also detrimental as these bits will not be cemented together as are the original particles and would have no tensile strength.

Resistance to degradation is also critical for the particles during transport, placing, and compaction operations. Soft particles may break, resulting in a material that no longer meets specifications.

Various tests are used to evaluate aggregates for this property. The most common is the test using the Los Angeles apparatus. The Los Angeles abrasion test is a commonly accepted measure of the hardness of aggregates. Aggregates are prepared and placed in a drum with a number of steel balls. The drum is rotated a specified number of times, and the loss of aggregates or the amount ground down is measured.

Theory: To measure the hardness of aggregates, a sample is placed in a drum with steel balls. The drum is rotated and the balls grind down the aggregate particles. Soft aggregates are quickly ground to dust, while hard aggregates lose little mass.

Apparatus: Los Angeles abrasion machine
sieves
balance (accurate to 1.0g)

Sample: Approximately 5000g of aggregate including 2500 ±10g of 19mm to 12.5 mm (3/4 in. to ½ in.) size and 2500 ± 10g of 12.5 mm to 9.5 mm (1/2 in. to 3/8 in.) size.

(Note: This sample specification is for aggregates graded mainly between the 19 mm and 9.5 mm size. Sample requirements for other aggregate gradations – 38.1 mm to 9.5 mm, 9.5 mm to 4.75 mm, and 4.75 mm to 2.36 mm – are given in the AASHTO standards.)
Procedure:
1. Wash, dry, and obtain mass of the sample.
2. Add the number of standard steel balls as required by the specific procedure.
3. Place the sample in the abrasion machine.
4. Rotate the drum 100 revolutions at 30-33 rpm.
5. Remove sample and sieve on #12, record wt. of matl. Retained
6. Place entire (including fines) sample back in drum
7. Rotate the drum for 400 revolutions (500 total) at 30-33 rpm.
8. Remove the sample. Sieve on a #12 (1.70 mm) sieve. Wash the sample over a #12 (1.70 mm) sieve. Dry sample to a constant mass at 230° ± 9° F (110° ± 5° C). Record the mass.

Results or Worksheet Example:

Mass of original sample ________________ g (A)
Mass of final sample ________________ g
Loss ________________ g (B)

Calculation:

% loss = B/A x 100 = ________________ %

Example:

Mass placed in abrasion machine 5005g
Mass of intact particles left after test 3891g

% loss = \( \frac{5005g - 3891g}{5005g} \) = 22.3%
Slide 1
aggregate sample, #12 sieve with coarse sieve for a breaker and steel ball bearings.

Slide 2
weighing sample fractions to specified mass, according to gradation of the sample.

Slide 3
Los Angeles Abrasion Machine
Slide 4: Placing ball bearings in LA wear machine before placing aggregate.

Slide 5: Securing cover on LA wear machine to prevent loss of fines during test. Run LA wear machine containing the sample and ball bearings 100 revolutions.

Slide 6: Dumping tested aggregate and steel balls out of LA wear machine.
Slide 7
Separating the steel ball bearings from the test sample prior to weighing.

Slide 8
Sieve tested aggregate over #12 sieve with a coarser breaker on top.

Slide 9
Weigh and record the weight of the sample retained on both sieves.
Combine both fines and coarse aggregate. Place aggregate in LA wear machine for 400 revolutions, then sieve and weigh as before.
TOPIC D: SODIUM SULFATE SOUNDNESS (AASHTO T104);
R-4, 5 CYCLES
Purpose: To measure the aggregates ability to withstand weathering

Key Words: Hydration: To combine with water.

Precipitate: To cause to separate from solution or suspension.

Estimated Time to Complete the Test: 5 Cycles = 5 Days

Steps of Procedure:
1. Set up
2. Cycles
3. Quantitative Examination – Two Hours

Significance:

Soundness indicates the aggregates ability to withstand weathering especially during cycles of freezing and thawing. Aggregates are porous, and, especially in pavements are exposed to water continuously. Water expands 9-10% when it freezes. Therefore, considerable pressure is exerted, and susceptible aggregates may fail. Pavement distresses that result from aggregate failures include:

Popouts- failure of a large aggregate particle near the surface, causing a lump of concrete to break away, leaving a hole in the surface.

D-cracking- formation of a series of adjacent cracks in the surface near joints in the concrete.

Map cracking- formation of a series of cracks over the whole surface of the concrete.

This traditional sodium sulfate soundness test was developed to measure the soundness of aggregates.¹

Theory: The sodium sulfate soundness test determines the aggregates resistance to disintegration by repeated immersions in saturated solutions of sodium sulfate. The sample is then oven dried to dehydrate the salt precipitated in permeable pore spaces. The internal, expansive force, derived from the rehydration of the salt, upon reimmersion, simulates the expansion of water on freezing ²

¹ Highway Materials, Soils, and Concretes/ Harold N. Atkins. --4th ed, p.302
Test Equipment:

The key to running a successful sodium sulfate soundness test is minimizing temperature variation.

Constant temperature water bath; sieves used to determine loss are the 1 ¼ " 5/8", 5/16", and No. 5; balances; thermometers; tank; hydrometers; drying ovens; bottom up washing apparatus.

<table>
<thead>
<tr>
<th>Size of Aggregate</th>
<th>Sieve Used to Determine Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>63 mm to 37.5 mm (2 ½ to 1 ½ in.)</td>
<td>31.5 mm (1 ¼ in.)</td>
</tr>
<tr>
<td>37.5 mm to 19.0 mm (1 ½ to ¾ in.)</td>
<td>16.0 mm (5/8 in.)</td>
</tr>
<tr>
<td>19.0 mm to 9.5 mm (3/4 to 3/8 in.)</td>
<td>8.0 mm (5/16 in.)</td>
</tr>
<tr>
<td>9.5 mm to 4.75 mm (3/8 in. to No. 4)</td>
<td>4.0 mm (No. 5)</td>
</tr>
</tbody>
</table>

Sample, Material Preparation, and Procedure:

The coarse aggregate sample will have all the material that passes the No. 4 sieve removed. The balance of the sample will conform to the ranges in the following table.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Mass in Grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1/2 in to 1-1/2 in</td>
<td>5000 +/- 300</td>
</tr>
<tr>
<td>Consisting of:</td>
<td></td>
</tr>
<tr>
<td>2 in. to 1-1/2 in</td>
<td>2000 +/- 200</td>
</tr>
<tr>
<td>2-1/2 in. to 2-in.</td>
<td>3000 +/- 300</td>
</tr>
<tr>
<td>1-1/2 in. to 3/4 in</td>
<td>1500 +/- 50</td>
</tr>
<tr>
<td>Consisting of:</td>
<td></td>
</tr>
<tr>
<td>1-in to 3/4 in.</td>
<td>500 +/- 30</td>
</tr>
<tr>
<td>1-1/2 in. to 1-in.</td>
<td>1000 +/- 50</td>
</tr>
<tr>
<td>3/4 in. to 3/8</td>
<td>1000 +/- 10</td>
</tr>
<tr>
<td>Consisting of:</td>
<td></td>
</tr>
<tr>
<td>1/2 in. to 3/8-in.</td>
<td>330 +/- 5</td>
</tr>
<tr>
<td>3/4 in. to 1/2 -in.</td>
<td>670 +/- 10</td>
</tr>
<tr>
<td>3/8 in. to No. 4</td>
<td>300 +/- 5</td>
</tr>
</tbody>
</table>
Soundness – Sodium Sulfate (T 104)

1. Gilson grade sample into appropriate sizes. (1", ¾", ½", 3/8", #4)
2. Wash separate sizes and dry to a constant mass
3. Weigh out quantities of different sizes according to Table 1 and record masses to the nearest gram.
4. Immerse the samples in solution for 16 to 18 hours so the solution covers them at least 12.5 mm (1/2 in.)
5. Cover containers.
6. Remove samples from solution.
7. Drain samples for 15 ± 5 minutes.
8. Place in drying oven – dry to constant mass.
9. Repeat steps 4 – 8 five times.
10. Proceed to quantitative examination.

Solution

Sodium sulfate solution may be used. The solution shall be at least five times the solid volume of the test samples. Add and dissolve salt in water at 77° F (25 °C) minimum to saturation so that salt crystals are present when the solution is ready for use. Keep container covered when access is not needed. Let solution cool to 68.5 to 71.5 °F (20.3 to 21.9 °C). Stir again and let stand for 48 hours prior to use. Before each use, break up the salt cake in the container and stir. The specific gravity should be between 1.154 and 1.171. AASHTO recommends the use of not less than 225g/liter of sodium sulfate.

Sample Preparation

Coarse aggregate will have the material that passes the 4.75 mm (No. 4) sieve removed. Sieve and separate the test sample to sizes corresponding to Table 1. Wash and dry samples to a constant mass at 230 ° ± 9 ° F (110 ° ± 5 ° C). Weigh out quantities as specified in Table 1 and place in sample containers. If the sample contains less than five percent of any size specified in Table 1, that size will not be tested.

Quantitative Examination

1. After final cycle, wash samples in their containers by introducing 110 ° ± 10 ° F (43 ° ± 6 ° C) water through the bottom of the samples, allowing the hot water to pass through the sample and overflow.

2. Check the sample cleanliness by adding a few drops of 0.2 molar barium chloride to a beaker of rinse water. The barium chloride turns cloudy when salt is present, while the barium chloride remains clear when sample is clean.

3. Dry the samples to a constant mass at 230 ° ± 9 ° F (110 ° ± 5 ° C).
4. Sieve, by hand, the sample over the designated sieve with effort only for undersized material to pass and not break up the particles to cause them to pass the sieves.

5. Subtract the amount retained from the initial mass and express the loss as a percentage of the initial mass.

Soundness Report

1. Calculate the weighted average for each fraction based on the sample grade by using T 27.

Example:

<table>
<thead>
<tr>
<th>As received Grade</th>
<th>% Retained on #4</th>
<th>Weighted Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot;</td>
<td>7/70 = 10%</td>
<td>27%</td>
</tr>
<tr>
<td>¾&quot;</td>
<td>12/70 = 17%</td>
<td></td>
</tr>
<tr>
<td>½ &quot;</td>
<td>70%</td>
<td>50%</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>21%</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>23%</td>
<td>23%</td>
</tr>
<tr>
<td>P4</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Start Mass</th>
<th>Ending Mass</th>
<th>Loss</th>
<th>% Loss</th>
<th>Weighted %</th>
<th>Weighted % Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.5 mm – 25.0 mm</td>
<td>1000g</td>
<td>1500g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25.0 mm – 19.0 mm</td>
<td>500g</td>
<td>1468</td>
<td>32</td>
<td>2.1</td>
<td>27 (35)</td>
<td>0.5</td>
</tr>
<tr>
<td>19.0 mm – 12.5 mm</td>
<td>670g</td>
<td>970</td>
<td>30</td>
<td>3</td>
<td>50 (45)(65)</td>
<td>1.5</td>
</tr>
<tr>
<td>12.5 mm – 9.5 mm</td>
<td>330g</td>
<td>970</td>
<td>30</td>
<td>3</td>
<td>50 (45)(65)</td>
<td>1.5</td>
</tr>
<tr>
<td>9.5 mm – 4.75 mm</td>
<td>300g</td>
<td>300g</td>
<td>278</td>
<td>22</td>
<td>7</td>
<td>3 (20)(35) 1.6</td>
</tr>
</tbody>
</table>

Soundness = 3.6 = 4

Parenthetical values are DOT weighted percentages.
Containers for samples. Section 3.2.

Washing samples during sample prep Section 6.2. Samples will then be dried at 230° ± 9 ° F (110 ° ± 5 ° C) to a constant mass.

Five-gallon buckets filled with soundness solution.
Slide 4

Taking the specific gravity of a solution with a hydrometer, which must be 1.154 to 1.171. Section 4.1.1.

Slide 5

Washing apparatus introduces water near the bottom and allows water to pass through the samples and overflow. Section 8.1.1.

Slide 6

Wash water is checked with 0.2 molar barium chloride. Section 8.1.1. Cloudiness indicates presence of salt.
Checking wash water for salt with 0.2 molar barium chloride. A milky cloud in the water indicates presence of salt. Ref. par. 4.2 in AASHTO T 104

Samples are sieved to determine loss after five cycles. Section 8.1.2
TOPIC E: FREEZE/THAW SOUNDNESS (AASHTO T 103)
R-4, 13 to 16 Cycles
Purpose: To measure the aggregates ability to withstand weathering

Estimated Time to Complete the Test:

Steps of Procedure:
1. Set up
2. Cycles
3. Quantitative Examination – Two Hours

Significance:

An aggregate particle disintegrates due to cycles of wetting and drying, heating and cooling, and especially, freezing and thawing. In concrete pavements, aggregate disintegration due to freezing and thawing is a major cause of distress. Aggregate particles have pores, which often become saturated. On freezing, the water expands as it turns to ice, opening the pore to a certain degree. On thawing, more water can seep in, further widening the crack.

Repeated cycles can cause the particles to break apart or flakes may come off of it. This is especially dangerous with particles from sedimentary rocks, which usually have planes of weakness between layers. Cycles of wetting and drying or heating and cooling may also cause disintegration, although the forces are less than those caused by freezing.¹

This test is only required in the State of Wisconsin for Sinnipee Group Geologic formations.

Theory: Certain aggregates tend to break up when subjected to cycles of freezing and thawing. Water soaks into pores in the particles; freezes, expanding about 9-10%; and opens the pores even wider. On thawing, more water can seep in, further widening the crack. After a number of cycles, the aggregate may break apart, or flakes may come off of it. This leads to disintegration of concrete and to weakening of base course layers.

Test Equipment:

Freezing equipment, sample containers, sieves, balance, drying oven, thawing tank, thermometer, vacuum chamber/pycnometer, methyl alcohol

<table>
<thead>
<tr>
<th>Size of Aggregate</th>
<th>Sieve Used to Determine Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>63 mm to 37.5 mm (2 ½ to 1 ½ in.)</td>
<td>31.5 mm (1 ¼ in.)</td>
</tr>
<tr>
<td>37.5 mm to 19.0 mm (1 ½ to ¾ in.)</td>
<td>16.0 mm (5/8 in.)</td>
</tr>
<tr>
<td>19.0 mm to 9.5 mm (3/4 to 3/8 in.)</td>
<td>8.0 mm (5/16 in.)</td>
</tr>
<tr>
<td>9.5 mm to 4.75 mm (3/8 in. to No. 4)</td>
<td>4.0 mm (No. 5)</td>
</tr>
</tbody>
</table>

Sample, Material and Preparation:

The coarse aggregate sample will have all the material that passes the No. 4 sieve removed. The balance of the sample will conform to the ranges in the following table.

<table>
<thead>
<tr>
<th>Passing to Retained</th>
<th>Sieve Size</th>
<th>Mass in Grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1/2 in to 1-1/2 in</td>
<td></td>
<td>5000 +/- 300</td>
</tr>
<tr>
<td>Consisting of:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 in. to 1-1/2 in</td>
<td>2000 +/- 200</td>
<td></td>
</tr>
<tr>
<td>2-1/2 in. to 2-in.</td>
<td>3000 +/- 300</td>
<td></td>
</tr>
<tr>
<td>1-1/2 in. to 3/4 in</td>
<td>1500 +/- 50</td>
<td></td>
</tr>
<tr>
<td>Consisting of:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-in to 3/4 in.</td>
<td>500 +/- 30</td>
<td></td>
</tr>
<tr>
<td>1-1/2 in. to 1-in.</td>
<td>1000 +/- 50</td>
<td></td>
</tr>
<tr>
<td>3/4 in. to 3/8</td>
<td>1000 +/- 10</td>
<td></td>
</tr>
<tr>
<td>Consisting of:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/2 in. to 3/8-in.</td>
<td>330 +/- 5</td>
<td></td>
</tr>
<tr>
<td>3/4 in. to 1/2 -in.</td>
<td>670 +/- 10</td>
<td></td>
</tr>
<tr>
<td>3/8 in. to No. 4</td>
<td>300 +/- 5</td>
<td></td>
</tr>
</tbody>
</table>
Freeze Thaw Procedures

Procedure A = Total Immersion-50 Cycles

1. Place sample in freeze/thaw container.
2. Add a sufficient amount of either 0.3 per cent NaCl and water solution or 0.5 per cent Methyl Alcohol and water solution to completely immerse the sample.
3. Soak the immersed sample for 24 ± 4 hrs. at a temperature of 23° ± 3°C (73° ± 5° F).
4. Freeze each sample until a temperature of -23° ± 3°C (-9° ± 5° F) is reached at the center of each sample. This temperature shall be held for a minimum of two hours.
5. Thaw by raising the center of the sample to a temperature of 21° ± 3°C (70° ± 5° F). The temperature shall be held for a minimum of 30 minutes. Continue for 50 freeze/thaw cycles.

Procedure B = Partial Immersion-16 Cycles

1. Place sample in vacuum chamber and vacuum sample to a pressure not over 34 kPa (25.4 mm of Mercury).
2. Break vacuum with a sufficient amount of a 0.5 percent (by mass) solution of ethyl alcohol and water to completely cover the sample.
3. Continue vacuuming for 15 minutes.
4. Remove sample from vacuum chamber and place sample one layer deep in freeze/thaw container with 6.4mm (1/4”) alcohol solution.
5. Freeze and thaw samples as in Procedure A. Continue for 16 freeze/thaw cycles.

Procedure C = Partial Immersion-25 Cycles

1. Vacuum sample as in Procedure B except that water is used instead of the alcohol water solution.
2. Freeze, then thaw samples as in Procedure A. Continue for 25 cycles.
Slide 1
1. Place aggregate in vacuum chamber/ pycnometer. #2. Apply vacuum.

Slide 2
2. The vacuum is broken by adding water (Procedure C) or a 0.5% water/alcohol solution. It is left in solution, totally covered for 15 minutes.
3. Set timer.

4. Samples are placed in freezer with ¼” of solution after being evacuated.
5. Additional alcohol solution may be required to be added to maintain ¼" immersion.

6. Samples are sieved to determine loss after required number of cycles.
TOPIC F: FRACTURE
Purpose: The intent of specifying a fractured face criterion is to provide a degree of stability and shear resistance due to mechanical interlock of aggregate particles.¹

Key Words:
Fractured face: At least one-fourth of the maximum cross sectional areas of the rock particle with a fragmented exposure when directly viewed.

Fractured particle: A rock particle with one or more fragmented faces.

Estimated Time to Complete Test:
Two hours. This time estimate includes preparation in conjunction with the Gilson screening and the AASHTO wash requirements.

Significance:
Many specifications require a minimum percentage of aggregate particles to be crushed. This percentage is expressed either by weight or by count. Crushed is usually defined as having one or two mechanically induced fractured faces. Some specifications require that the coarse aggregate be produced by crushing a feed material processed over a screen whose openings are larger than a specified size. More often compliance is based on subjectively separating particles into crushed, uncrushed, and perhaps uncertain categories by visual inspection. Personal judgment plays a big part in determining crushed faces.²

Theory:
Flat faces having sharp edges will be most effective in providing mechanical interlock of aggregate particles. This test method determines the percentage of a coarse aggregate sample that consists of fractured particles meeting the specified requirements. The percent of fractured particles is to be based on the count of fractured particles related to the total count of particles in the sample.

Test Equipment:
Splitting equipment, quartering equipment

¹ Construction and Materials Manual, 4-15-32, 4-25-50
² The Aggregate Handbook, November 2001, p. 3-49
Sample, Material and Preparation:

Sample the aggregate in accordance with CMM Chapter 8. The sample size table follows. Reduce the sample to the lab sample size in accordance with CMM Chapter 8. The reduction procedure follows.

Procedure:

1. Remove the material passing the No. 4 (4.75 mm) sieve. Aggregate particles retained on the No. 4 (4.75 mm) sieve from a washed sieve analysis can be used.
2. Further reduce the No. 4 (4.75) retained material sample until 400 or more individual aggregate particles remain.
3. 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 fracture 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.
4. Separate the sampled particles into categories based on whether a particle: a) has the required number of fractured faces, b) does not meet the specified fracture criteria, c) has a questionable or borderline face.
5. Following the division of all sampled particles into the categories, determine the count of particles in the fractured category, the count of particles in the questionable category, and the count of particles not meeting the specified fracture criteria.
6. Calculate and report the percentage of particles, by count, with the specified numbers of fractured faces to the nearest 1% in accordance with the following:

\[
P = \left( \frac{F + \frac{2}{Q}}{F + Q + N} \right) \times 100
\]

Where:

\(P\) = percentage of particles with the specified number of fractured faces,
\(F\) = count of particles with at least the specified number of fractured faces,
\(Q\) = count of particles in the questionable or borderline category,
\(N\) = count of particles in the uncrushed category not meeting the fracture particle criteria

If more than one number of fractured faces is specified (for example, 70% with one or more fractured faces and 40% with two or more fractured faces), repeat the calculation for each requirement.

7. Report the specified fracture criteria against which the sample was evaluated.
8. Report the total count of the coarse aggregate sample tested.
Slide 1
Split the representative sample according to T-248. Obtain a representative sample above the #4 sieve. The gravity sample may be used.

Slide 2
Sample should be dried and separated on the #4 sieve.

Slide 3
Separate aggregate into fracture, non-fractured, and questionable pieces.
Slide 4  Questionable aggregate. Aggregate is fractured, however, may be questionable to meet requirements.

Slide 5  Questionable fractured face.

Slide 6  No fractured face.
One fractured face.
TOPIC G: Liquid Limit and Plasticity
Atterberg Limits

A. Introduction

The Atterberg limits are the liquid limit, LL; the plastic limit, PL; and the shrinkage limit, SL. These limits are water contents which represent the dividing line between the liquid, plastic, semi-solid, and solid states of cohesive soils. The Atterberg limits are useful for classifying soils; identifying normally loaded vs. over consolidated soils; and generally comparing one soil to another.

The numerical difference between the liquid limit and the plastic limit is called the plasticity index. The plasticity index represents the range of water content over which a soil possesses plasticity. See Figure P-1 for a schematic representation of the Atterberg limits. As mentioned earlier, the Atterberg limits are water contents.

---

B. Liquid Limit Test

AASHTO Designation: T89-02
(The following notes are an adaptation of the AASHTO procedure)

1. Apparatus
   a. Porcelain mixing dish
   b. Four or five water content cans
   c. Spatula
   d. Water bottle filled with distilled water
   e. Liquid limit device as illustrated in Figure P-2
   f. Grooving tool with gage as illustrated in Figure P-2
   g. Balance sensitive to 0.01 g
   h. Drying oven set at 110 °C ± 5 °C
   i. Mortar and rubber tipped pestle
   j. Number 40 sieve
Table of Measurements

<table>
<thead>
<tr>
<th>Description</th>
<th>Liquid Limit Device</th>
<th>Grooving Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cup Assembly</td>
<td>Base</td>
</tr>
<tr>
<td>Dimension</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Radius of Cup</td>
<td>54</td>
<td>2.0</td>
</tr>
<tr>
<td>Thickness of Cup</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>Metric, mm</td>
<td>2.13</td>
<td>.079</td>
</tr>
<tr>
<td>Tolerance, mm</td>
<td>.08</td>
<td>.004</td>
</tr>
</tbody>
</table>

**Note:**
- Plate "H" may be designed for using 1 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.
- The metric units are the required dimension. The English units are approximate conversions

2. Adjustment of liquid limit device
   a. Inspect the device to see if the cup drops freely when the crank is turned.
   b. Measure drop of the cup when the crank is turned. The drop should be 10 ± 0.2 mm. The square end of the grooving tool is 10 ± 0.1 mm between parallel surfaces. This can be used as a gage when the liquid limit device is being calibrated.
3. Test Procedures  
   a. Grind up 100 to 200 grams of air dry soil with the mortal and pestle.  
   b. Sieve the soil through a No. 40 screen into the porcelain mixing dish.  
   c. Mix in a small amount of distilled water with a spatula until the soil is reasonably uniform and free of lumps. The soil should have the consistency of stiff peanut butter.  
   d. Place the soil in the liquid limit device using a spatula. The soil should be approximately level and 10 millimeter thick when the bottom of the cup rests on the black hard rubber base of the liquid limit device.  
   e. Make a groove in the soil as illustrated in Figure P-3.  
   f. Turn the crank allowing the cup to fall at a rate of 2 drops per second. Count the number of drops that caused the soil to flow together in the bottom of the groove for a continuous distance of ½ inch (13 mm).  
   g. Record the number of drops. Cut a sample of soil from the center of the liquid limit cup and place in a water content can. Weigh immediately and place in the drying oven.  
   h. Scrape soil from the cup back into the porcelain dish and change the water content by adding water if the sample is too dry. Wash and thoroughly dry the cup and grooving tool in preparation for the next trial.  
   i. Repeat steps d – g until enough data is obtained such that there is at least one test with the number of drops being between 15 and 25; another between 20 and 30; and a third between 25 and 35. A minimum of five trials should be conducted.  
   j. Remove water content samples from the drying oven and calculate the moisture content for each trial.  

4. Flow Curve  
The flow curve is a plot of the logarithm of the number of drops on the liquid limit device placed on the y axis and the water content placed on the x axis. The flow curve plots as a straight line on the above mentioned semi-log axes. Graphically select the point on the flow curve where the number of drops is 25. The corresponding water content is the liquid limit.
C. Plastic Limit Test  
AASHTO Designation: T90-00  
(The following notes are an adaptation of the AASHTO procedure)

1. Apparatus  
   a. Hard flat surface such as a glass plate or laboratory bench top  
   b. Three water content cans  
   c. Spatula  
   d. Porcelain mixing dish  
   e. Water bottle filled with distilled water  
   f. Balance sensitive to 0.01 g  
   g. Drying oven set at 110° C ± 5° C  
   h. Mortar and rubber tipped pestle  
   i. Number 40 sieve  
   j. Short length of 1/8 inch welding rod

2. Test Procedure  
   a. Grind up 30 to 50 grams  
   b. Sieve the soil through the number 40 sieve into the porcelain mixing dish  
   c. Mix in a small amount of distilled water with a spatula until the soil is reasonably uniform and free of lumps. The soil should be very stiff and easily shaped into a ball with fingers without sticking too much.
d. Take about 8 grams of the mixed up soil and roll it out into a thread on the laboratory bench top. The final diameter of the thread should be 1/8 inch (3.2 mm). A short piece of 1/8 inch welding rod can be used as a gage to approximate the diameter.

e. Usually the 1/8 inch thread will be easily formed on the first trial unless the soil is so wet that a coil cannot be formed at all. If too wet, let the soil air dry.

f. Once a 1/8 inch thread has been formed, cut it up into 6 to 8 pieces. Knead it together into a ball again and roll out another coil.

g. Repeat step (f) as many times as necessary until the thread crumbles just as it reaches the 1/8 inch size. Sometimes the very last trial will crumble the soil before reaching the required 1/8 inch thread. This is considered a satisfactory end to the rolling process.

h. Knead the soil into one last ball, place into a water content can, weigh immediately, and place in the drying oven.

3. Calculation
   a. The plastic limit is the average water content from the three trials in part two above.

D. Plasticity Index

   1. The plasticity index is obtained from the equation below:

      Plasticity Index = Liquid Limit – Plastic Limit
      or
      PI = LL – PL

   2. When the liquid limit or plastic limit tests cannot be performed, the soil should be reported as NP (non-plastic).

      Also, when the plasticity index is negative, the soil should be reported as non-plastic.
### ATTERBERG LIMITS

<table>
<thead>
<tr>
<th>Description of Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Plastic Limit**

<table>
<thead>
<tr>
<th></th>
<th>No. 1</th>
<th>No. 2</th>
<th>No. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Tin No.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight of Tin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet Wt. of Soil + Tin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Wt. of Soil + Tin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Content (3-4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Soil (4-2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic Limit (5/6) x100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(% moisture)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Liquid Limit**

<table>
<thead>
<tr>
<th></th>
<th>No. 1</th>
<th>No. 2</th>
<th>No. 3</th>
<th>No. 4</th>
<th>No. 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Tin No.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight of Tin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet Wt. of Soil +</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Wt. of Soil + Tin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Content (3-4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Soil (4-2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Moisture (5/6) x100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of Blows</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Liquid Limit from Flow Curve

**Plasticity Index**

\[
PI = LL - PL = \]

Name __________________________
Date __________________________
TOPIC H: COARSE AGGREGATE SPECIFIC GRAVITY & ABSORPTION (AASHTO T 85)
SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
FOR AASHTO T 85

Significance

Bulk specific gravity is a characteristic used for calculating the volume occupied by the aggregate or various mixtures containing aggregate, including portland cement concrete, bituminous mixes, and other materials that are proportioned or analyzed on an absolute volume basis. Specific gravity is the ratio of the mass of a material to the mass of an equal volume of water. Several categories of specific gravity are used relative to aggregate.

Bulk specific gravity (oven-dry), $G_{sb}$, is used for computations when the aggregate is dry. Bulk specific gravity (saturated surface dry, or SSD), $G_{sd}$ SSD, is used if the aggregate is wet. Apparent specific gravity, $G_{sa}$, is based solely on the solid material making up the constituent particles and does not include the pore space within the particles that is accessible to water.
Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for approximately 15 hours in water. Aggregates mined from below the water table may have a higher absorption, when used, if not allowed to dry. Conversely, some aggregates, when used, may contain an amount of absorbed moisture less than the 15 hours soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture can be determined by deducting the absorption from the total moisture content.

The pores in lightweight aggregates may or may not become filled with water after immersion for 15 hours. In fact, many such aggregates can remain immersed in water for several days without satisfying most of the aggregates’ absorption potential. Therefore, this method is not intended for use with lightweight aggregate.

**Scope**

This procedure covers the determination of specific gravity and absorption of coarse aggregate in accordance with AASHTO T 85. Specific gravity may be expressed as bulk specific gravity ($G_{sb}$), bulk specific gravity, saturated surface dry ($G_{sb} \text{ SSD}$), or apparent specific gravity ($G_{sa}$). $G_{sb}$ and absorption are based on aggregate after 15 hours soaking in water. This procedure is not intended to be used with lightweight aggregates.

**Terminology**

Absorption – the increase in the mass of aggregate due to water being absorbed into the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. The aggregate is considered “dry” when it has been maintained at a temperature of 110 ±5°C (230 ±9°F) for sufficient time to remove all water. (Dry to constant weight.)

Specific Gravity – the ratio of the mass, in air, of a volume of a material to the mass of the same volume of gas-free distilled water at a stated temperature.

Apparent Specific Gravity – the ratio of the mass, in air, of a volume of the impermeable portion of aggregate to the mass of an equal volume of gas-free distilled water at a stated temperature.

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

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

- Balance or scale
- Sample container, wire basket of 3.35 mm (No. 6) or smaller mesh, with a capacity of 4 to 7 L (1 to 2 gal) to contain aggregate with a nominal maximum size of 37.5 mm (1 1/2 in.) or smaller; larger basket for larger aggregates.
- Water tank, watertight and large enough to completely immerse aggregate and basket, equipped with an overflow valve to keep water level constant.
- Suspension apparatus: wire used to suspend apparatus shall be of smallest practical diameter.
- Sieves, 4.75 mm (No. 4), or other sizes as needed

Sample Preparation

1. Obtain the sample in accordance with AASHTO T 2.
2. Mix the sample thoroughly and reduce it in accordance with AASHTO T 248.

3. Reject all material passing the appropriate sieve by dry sieving and thoroughly washing to remove dust or other coatings from the surface. The minimum mass is given in Table 1.

<table>
<thead>
<tr>
<th>Nominal Maximum Size*, mm (in.)</th>
<th>Minimum Mass of Test Sample, kg (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 (1/2) or less</td>
<td>2 (4.4)</td>
</tr>
<tr>
<td>19.0 (3/4)</td>
<td>3 (6.6)</td>
</tr>
<tr>
<td>25.0 (1)</td>
<td>4 (8.8)</td>
</tr>
<tr>
<td>37.5 (1 1/2)</td>
<td>5 (11)</td>
</tr>
<tr>
<td>50 (2)</td>
<td>8 (18)</td>
</tr>
<tr>
<td>63 (2 1/2)</td>
<td>12 (26)</td>
</tr>
<tr>
<td>75 (3)</td>
<td>18 (40)</td>
</tr>
</tbody>
</table>

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.
Procedure

1. Dry the test sample to constant mass at a temperature of 230 ±9°F (110 ±5°C) and cool in air at room temperature for 1 to 3 hours.

2. Immerse the aggregate in water at room temperature for a period of 15 to 19 hours.

   Note: 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 then combine values obtained.

3. Place the basket into the water bath and attach to the balance. Inspect the immersion tank to insure the water level is at the overflow outlet height. Tare the balance with the basket attached in the water bath.

4. 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.

   Note: A moving stream of air may be used to assist in the drying operation, but take care to avoid evaporation of water from aggregate pores.

5. Determine the SSD mass of the sample, and record this and all subsequent masses to the nearest 1.0 g or 0.1 percent of the sample mass, whichever is greater. Designate this mass as “B”.

6. Re-inspect the immersion tank to insure the water level is at the overflow outlet height. Immediately place the SSD test sample in the sample container and weigh it in water maintained at 73.4 ±3°F (23.0 ±1.7°C). Shake the container to release entrapped air before recording the weight. Designate this submerged weight as “C”.

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

7. Dry the test sample to constant mass at a temperature of 230 ±9°F (110 ±5°C) and cool in air at room temperature for 1 to 3 hours. Designate this mass as “A”.
Calculations

Perform calculations and determine values using the appropriate formula below. In these formulas:

\[ A = \text{oven dry mass} \]
\[ B = \text{SSD mass} \]
\[ C = \text{weight in water}. \]

**Bulk specific gravity (\( G_{sb} \))**

\[ G_{sb} = \frac{A}{B-C} \]

\[ A = 2030.9 \text{ gm} \]
\[ B = 2044.9 \text{ gm} \]
\[ C = 1304.3 \text{ gm} \]

\[ G_{sb} = \frac{2030.9 \text{ gm}}{2044.9 \text{ gm} - 1304.3 \text{ gm}} = 2.742 \]

**Bulk specific gravity, SSD (\( G_{sb SSD} \))**

\[ G_{sb SSD} = \frac{B}{B-C} \]

\[ G_{sb SSD} = \frac{2044.9 \text{ gm}}{2044.9 \text{ gm} - 1304.3 \text{ gm}} = 2.761 \]

**Apparent specific gravity (\( G_{sa} \))**

\[ G_{sa} = \frac{A}{A-C} \]

\[ G_{sa} = \frac{2030.9 \text{ gm}}{2030.9 \text{ gm} - 1304.3 \text{ gm}} = 2.795 \]

**Absorption**

Absorption = \([ (B - A) / A ] \times 100\)

\[ A_{bs} = \frac{2044.9 \text{ gm} - 2030.9 \text{ gm}}{2030.9 \text{ gm}} \times 100 = 0.689\% \]
Sample Calculations

<table>
<thead>
<tr>
<th>Sample</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>B - C</th>
<th>A - C</th>
<th>B - A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2030.9</td>
<td>2044.9</td>
<td>1304.3</td>
<td>740.6</td>
<td>726.6</td>
<td>14.0</td>
</tr>
<tr>
<td>2</td>
<td>1820.0</td>
<td>1832.5</td>
<td>1168.1</td>
<td>664.4</td>
<td>651.9</td>
<td>12.5</td>
</tr>
<tr>
<td>3</td>
<td>2035.2</td>
<td>2049.4</td>
<td>1303.9</td>
<td>745.5</td>
<td>731.3</td>
<td>14.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample</th>
<th>$G_{\text{sb}}$</th>
<th>$G_{\text{sb SSD}}$</th>
<th>$G_{\text{sa}}$</th>
<th>Absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.742</td>
<td>2.761</td>
<td>2.795</td>
<td>0.689</td>
</tr>
<tr>
<td>2</td>
<td>2.739</td>
<td>2.758</td>
<td>2.792</td>
<td>0.687</td>
</tr>
<tr>
<td>3</td>
<td>2.730</td>
<td>2.749</td>
<td>2.783</td>
<td>0.698</td>
</tr>
<tr>
<td>Average</td>
<td>2.737</td>
<td>2.756</td>
<td>2.790</td>
<td>0.691</td>
</tr>
</tbody>
</table>

These calculations demonstrate the relationship between $G_{\text{sb}}$, $G_{\text{sb SSD}}$, and $G_{\text{sa}}$. $G_{\text{sb}}$ is always lowest, since the volume includes voids permeable to water. $G_{\text{sb SSD}}$ is always intermediate. $G_{\text{sa}}$ is always highest, since the volume does not include voids permeable to water. When running this test, check to make sure the values calculated make sense in relation to one another.
TOPIC I: LIGHTWEIGHT PIECES (AASHTO T 113)
Purpose: Determine the percentage of light weight pieces in aggregate

Key Words:
Chert: A fine-grained, hard rock composed of silica. Cherts range from hard, dense particles to light weight, porous particles that are white and chalky in appearance.

Significance:
The chert we find in Wisconsin is predominantly a white, chalky mineral.

Deleterious substances are those substances present in an aggregate that are harmful to the desired properties of the aggregate. Particles such as chert exhibit disruptive expansion. Deleterious substances should be minimized in aggregate used in construction. Cherts are the most frequent cause of popouts in Portland Cement Concrete.

Chert is widely distributed in certain areas of the Midwest and South, and is associated only with carbonate rocks. See map.¹

We only do the test when chert is identified in a sample.

Theory:
This method is used to determine the amount of lightweight material in aggregates. These lightweight particles are porous A heavy liquid is used to separate the aggregate particles.

Test Equipment:
Balance, containers for drying the material, skimmer, oven, sieves, hydrometer, heavy liquid with specific gravity (SP.GR.)

Sample, Material and preparation
Use a liquid with a SP.GR. of 2.40 as the heavy liquid.

Sample the aggregate in accordance with CMM Chapter 4. The sample size table follows. Reduce the sample to the lab sample size in accordance with CMM Chapter 4.

Dry the sample. Use a minimum test sample size that conforms to the quantities in the table.

¹ The Aggregate Handbook, November 2001, p. 3-12, 31
Nominal Maximum Size of Aggregate (Square-Opening Sieves)  | Minimum Mass of Sample, g
--- | ---
4.75 mm (No. 4)  | 200
19.0 mm (3/4 in.)  | 3000
37.5 mm (1 ½ in.)  | 5000
75 mm (3 in.)  | 10000

Procedure:

Coarse Aggregate – Allow the dried test specimen of coarse aggregate to cool to room temperature and sieve over a 4.75-mm sieve. Determine the mass of the material coarser than the No. 4 sieve to the nearest 1 g. and bring to a saturated surface-dry condition (Note 2) by means of the procedure specified in T 85; then introduce it into the heavy liquid in a suitable container. The volume of liquid shall be at least three times the absolute volume of the aggregate. Using the skimmer, remove the pieces that float to the surface, and save them. Repeatedly agitate the remaining pieces, and remove the floating pieces until no additional pieces rise to the surface. Wash the pieces that are skimmed off in an appropriate solvent to remove the heavy liquid. After the heavy liquid has been removed, allow the pieces to dry (Section 7.1.2). Dry the particles to constant mass at 110 ± 5°C to determine the value of \( W_1 \) used for the calculation in Section 8.2 (See Section 7.1.3).\(^1\) Determine the mass of the decanted pieces to the nearest 1 g.

Calculations, formulas:

Calculate the percentage of lightweight pieces (pieces floating on the heavy liquid) as follows:

\[
L = \left( \frac{W_1}{W_2} \right) \times 100
\]

\[
L = \frac{21 \text{ gm}}{3015 \text{ gm}} \times 100
\]

\[
L = 0.697\% (0.7\%, \text{ record to nearest } 0.1\%)
\]

where;

\( L \) = percentage of lightweight pieces
\( W_1 \) = dry mass of pieces that float,
\( W_2 \) = dry mass of portion of specimen coarser than the 4.75-mm (No. 4) sieve.
Slide 1  
Sample is washed and oven-dried and weighed. ($W_2$)

Slide 2  
Cover the sample with water for 15 to 19 hours.

Slide 3  
Pour off water after 15 to 19 hours.
Slide 4  
Place aggregate on a cloth and bring it to a SSD condition.

Slide 5  
Sample and equipment used for test; heavy liquid, flask, hydrometer, screen smaller than #4.

Slide 6  
Measure the specific gravity of the heavy liquid. Adjust specific gravity to 2.40.
Slide 7

Introduce SSD aggregate into heavy liquid. Remove pieces that float to the surface with a skimmer.

Slide 8

Example of pieces that float in the heavy liquid.

Slide 9

Removing pieces that float with a skimmer. All pieces will be washed to remove the heavy liquid, then oven-dried.
Slide 10

$W_1 =$ Dry Mass or pieces that float.
Note: Check the CMM link to verify the latest version

http://roadwaystandards.dot.wi.gov/standards/cmm/
TOPIC J: Data Entry

MATERIAL DATA REPORTING FOR QC, QA, QV, IA ON HIGHWAY CONSTRUCTION PROJECTS

Materials Reporting Systems Tutorials

**Materials Information Tracking**

MIT collects data on a wide range of Materials in an AASHTO and ASTM format for QA, QC, IA and Verification requirements. Also, collect Tester and Sampler certifications information.

[Watch Tutorial](#)

**Materials Reporting System**

**Hot Mix Asphalt**

MRSHMA effectively implements QMP by collecting field data entered by the contractor by lot and sublot for transmission to the State agency.

[Watch Tutorial](#)

**Materials Reporting System**

**Portland Cement Concrete**

MRSPCC effectively implements QMP by collecting field data entered by the contractor by lot and sublot for transmission to the State agency.

[Watch Tutorial](#)

The above is from the Atwood Systems website:

[http://www.atwoodsystems.com/resources/](http://www.atwoodsystems.com/resources/)
Atwood Systems
Software in use by Wisconsin Department of Transportation

<table>
<thead>
<tr>
<th>PRODUCT NAME</th>
<th>DESCRIPTION</th>
<th>USAGE</th>
<th>DEPLOYMENT TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td>NETWORK BASED REPORTING SYSTEMS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Tracking (PT)</td>
<td>Manages all phases of a project. FIT provides field data to this system.</td>
<td>WISDOT Staff.</td>
<td>WISDOT LAN</td>
</tr>
<tr>
<td>Materials Tracking (MTS)</td>
<td>Manages all materials testing and reporting. MIT provides field data to this system. Data collected is sent to Project Tracking via Atwood.</td>
<td>WISDOT Staff.</td>
<td>WISDOT LAN</td>
</tr>
<tr>
<td>FIELD BASED REPORTING SYSTEMS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Field Information Tracking (FIT) | Provides data collected from project sites and merged data from Field Manager. Data collected is sent to Project Tracking via Atwood. | WISDOT Staff. Contractors. | Field job sites
<p>| Materials Information Tracking (MIT) | Captures QV, QA, IA and Verification test reporting for a multitude of materials. | WISDOT Staff.       | Field job sites   |
| MATERI AL S REPORTING SYSTEM - QUALITY MANAGEMENT PROGRAM | | | |
| MRS Hot Mix Asphalt          | Asphalt QC data collection by Lot and Sub-lot by date. Used by Contractors. | Used by Contractors. | Field job sites   |
| MRS Portland Cement Concrete | Concrete pavement, structures (by lot / sub-lot and thickness QC data collection. | Used by Contractors. | Field job sites   |
| MRS International Roughness Index | Pavement smoothness QC / QA data collection. | WISDOT Staff. Contractors. | Field job sites   |
| WEB-BASED REPORTING SYSTEMS  |                                                                             |                     |                   |</p>
<table>
<thead>
<tr>
<th>System</th>
<th>Description</th>
<th>Responsible Party</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highway Quality Management System</td>
<td>Data management and reporting web site. Hosts all QMP data; materials reports.</td>
<td>WISDOT Staff. Contractors.</td>
<td>Atwood Web Site</td>
</tr>
<tr>
<td>Activity Reporting System</td>
<td>Reports on project activity and material test results.</td>
<td>WISDOT Staff.</td>
<td>Atwood Web Site</td>
</tr>
<tr>
<td>Data Management System</td>
<td>Manages data replication / synchronization from field sites to MTS and Project Tracking.</td>
<td>Atwood Systems</td>
<td>Atwood Systems</td>
</tr>
</tbody>
</table>
8-10.1 Control of Materials

8-10.1.1 Approval of Materials Used in Work

The service life of a highway is dependent upon the quality of the materials used in its construction, as well as the method of construction. Control of materials is discussed in standard spec 106.1. The spec provides that only materials conforming to the requirements of the contract must be used, and the contractor is responsible for furnishing materials meeting specified requirements. Only with permission of the engineer can the contractor provide materials that have not been approved, as long as the contractor can provide evidence that the material will be approved later. The department's intention is to hold payment of items until the required materials information is provided by the contractor.

The standard specs encourage recovered and recycled materials to be incorporated into the work to the maximum extent possible, consistent with standard engineering practice. Standard spec 106.2.2 and Wisconsin statute 16.754 require the use of American made materials to the extent possible. On federally funded projects, all steel products must be produced in the United States, and manufacturing and coating processes must be performed in the U.S. These "Buy America" requirements are discussed in CMM 2-28.

8-10.1.2 Contractor and Department Designated Materials Persons

Standard spec 106.1.2 requires the contractor to designate a dedicated materials person (CDMP) who will be responsible for submitting all contractor materials information to the engineer. The department should also designate a dedicated materials person (WDMP) who will be in direct contact with the contractor's designee.

Standard spec 106.1.2 requires the CDMP to communicate with all subcontractors to ensure that sampling, testing, and associated documentation conforms to the contract. The contract also makes the CDMP responsible for submitting materials information from the prime contractor and subcontractors to the WDMP, promptly reporting out-of-specification test results, collecting and maintaining all required materials certifications, and regularly communicating with the WDMP regarding materials issues on the contract.

The WDMP should provide a project-specific sampling and testing guide (E-Guide) to the contractor at the preconstruction conference. The E-Guide is created from the following site:

http://www.atwoodsysteams.com/sysportal.htm

Both the CDMP and WDMP should review and supplement the E-guide before work operations begin to ensure that testing methods, frequencies, and documentation requirements conform to the contract.

The CDMP and WDMP are charged with working together throughout the life of the contract to ensure that contract materials requirements are met and any issues that might arise related to either non-conformance or non-performance are dealt with promptly. The ultimate goal is to make sure that problems with materials are brought to light and timely corrective action taken before those materials problems compromise the quality or acceptability of the completed work.

The CDMP should coordinate contractor materials related activities and do the following:

- Establish methods and work expectations with the WDMP.
- Provide all QMP test data and control charts from the prime contractor and subcontractors.
- Deal with all materials-related concerns from the WDMP.

The WDMP is responsible for administration of the contract with regards to contract materials requirements and should do the following:

- Communicate or meet weekly with the CDMP to discuss outstanding materials issues on the contract.
- Monitor the submittals from the CDMP to ensure timeliness and completeness.
- Review contractor submittals to verify materials requirements are met.
- Inform the Project Leader of non-conforming materials issues and discuss actions to be taken.
- Prepare materials documentation for inclusion into the project files.
8-10.2 Approval of Materials
All materials used in a project are subject to the engineer's approval before incorporation into the work. Approval of materials is discussed in standard spec 106.3. Approval is generally accomplished by material tests and/or analysis. This can be done by using approved product lists, certification, or sampling and testing. Unless the contract specifies otherwise, the contractor must follow manufacturer's recommended procedures for products incorporated into the work. Refer to CMM 8-45 for details of acceptance types.

8-10.3 Quality Management Program
Sampling and testing on WisDOT projects is performed according to the Quality Management Program (QMP). QMP is presented in CMM 8-30 and the following CMM sections.

8-10.4 Independent Assurance Program
The Independent Assurance Program (IAP) is an element of the Quality Management Program intended to ensure that test data from project acceptance testing is reliable, including sampling procedures, testing procedures, and testing equipment. Quality verification (QV), quality assurance, (QA), and quality control (QC) are integral parts of the IAP. Further information about the Independent Assurance Program can be found in CMM 8-20.

8-10.4.1 Quality Verification (QV)
Quality verification (QV) sampling is done by a department representative, and is taken independently from the quality control samples to validate the quality of the material.

8-10.4.2 Quality Assurance (QA)
Under the quality assurance (QA) program, a department representative observes sampling and testing performed by the contractor, by testing split samples. Further detail about quality verification and quality assurance is provided in CMM 8-20.

8-10.4.3 Quality Control (QC)
Quality control for materials testing includes all contractor/vendor operational techniques and activities that are performed or conducted to fulfill the contract requirements.

8-10.5 Nonconforming Materials
8-10.5.1 General
The department does not want material not meeting contract specifications incorporated into the work. Standard spec 106.5 gives the engineer the authority to either reject nonconforming materials or to allow the nonconforming materials to remain in place. If materials are found to be unacceptable before or after placement into the work, the engineer may reject the materials, and the contractor must remove the materials from the site at no cost to the department. Materials that have been tested and approved at their source or otherwise previously approved, but have become damaged or contaminated before use in the work, are also subject to rejection by the engineer.

To ensure consistency in the decisions made for acceptance of non-conforming material or workmanship, the engineer should involve the region oversight engineer before finalizing any decision. This will help keep central office informed about contractor or material problems that may require action with a change in specifications or discipline of a contractor. If any technical questions remain about the acceptance or rejection of nonconforming materials refer to the appropriate technical expert in the Bureau of Technical Services.

8-10.5.2 Nonconforming Materials Allowed to Remain in Place
8-10.5.2.1 Deciding Whether or not to Allow Material to Stay in Place
Good engineering judgment is required when making decisions on nonconforming materials. The engineer may choose to approve nonconforming materials, allow them to remain in place, and adjust the contract price. When making the decision to direct the contractor to remove and replace the materials versus leave the materials in place, it's important to consider the following:

- Long-term consequences on quality and durability.
- Implications on the project's life cycle costs, service life, serviceability, and maintenance.
- Socioeconomic, environmental, and aesthetic considerations.
- Impacts on traffic, staging, and construction timeframes.

8-10.5.2.2 Deciding Whether or Not to Apply Price Reduction
After the engineer has decided to allow nonconforming materials to remain in place, he or she must carefully evaluate each situation in deciding whether to take a price reduction. The goal is to achieve consistency statewide in administering price reductions for nonconforming materials that are allowed to remain in place.
Results of retests and related quality tests should be considered. The following list includes some examples of the types of factors the engineer must consider to decide if a price reduction is warranted and how much it should be:

- Has the contractor been conscientious to provide quality by carefully controlling materials and construction operations?
- Has the contractor been proactive and made good use of QC data to maintain and improve quality?
- Did the engineer provide the contractor with non-conforming test results within the contractual timeframe, if specified?
- If timeframes are not specified, did the engineer provide non-conforming test results in time for the contractor to make process or materials corrections?
- Upon becoming aware of a materials quality problem, has the contractor responded quickly to correct it?
- Is the nonconforming test an isolated incident or a recurring situation?
- How does the nonconforming test compare to the rest of the project data:
  - Have material test results been well within specification requirements or consistently at the very limit of what is acceptable?
  - How many tests are nonconforming vs. how many tests have passed?
  - How far out of spec is the non-conforming test?

8-10.5.3 Price Reductions Specified in the Contract with Administrative Items

If price reductions are included in the specifications or special provisions for certain nonconforming items, the price reductions should be administered using the appropriate 800 series administrative items. Since the price reductions are included in the contract language, the engineer can add the 800 series items to the contract without going through the complete change order process. Approval by a DOT representative and contractor representative are not necessary, though it's good practice to communicate the changes to all parties. Further guidance on the 800 series administrative items is provided in CMM 2-38.

For payment of nonconforming items with associated administrative items, pay for the installed quantity and bid price of the work item under the original bid item. The pay reduction will be accounted for using the administrative item. Compute the price reduction by multiplying the quantity of nonconforming material by the original unit price and the percent price reduction. The pay units of all administrative items are DOL. Document all calculations, and pay for the (negative) total calculated price reduction as the pay quantity, with 1 dollar as the pay unit.

**Example 1**

- Contractor placed total of 19,000 SY of Concrete Pavement 9 inch
- 670 SY (12' x 500') is 1/8" - 1/2" under plan thickness
- Standard spec 415.5.2 directs to pay 80% contract price for this range (20% reduction)
- Bid unit cost is $35/SY

Using original bid item, pay 19,000 SY at $35/SY = $655,000
Compute price reduction = 670 SY x $35 x -0.20 = -$4,690
Add the administrative item 804.6005 Nonconforming Thickness Pavement to the contract, with unit price of $1.00
Pay quantity of -$4,690
Net pay = $655,000 - $4,690 = $650,310

Paying for nonconforming items this way allows for clean tracking of as-built quantities. The use of administrative items can easily be tracked to monitor specific items that are frequently the target of price reductions. This can help the department develop improved specifications and construction methods.

8-10.5.4 Price Reductions Not Specified in the Contract

If specific price reductions are not outlined in the contract specifications or special provisions, standard spec 106.5 gives the engineer the option to take a price reduction on nonconforming materials allowed to remain in place. The engineer has latitude to decide whether a price reduction is appropriate, and what amount the price reduction should be.

For payment of nonconforming items, use full quantity and bid price of the work item. Apply the price reduction by submitting a change order that creates a new item with the same bid item number but with the supplemental
8-45.1 Acceptance Procedures, Documentation, and Reporting

Documentation and reporting for materials acceptance is equal in importance to Item Record Account documentation. The basis of acceptance for contract materials is accomplished in several ways, depending on the material. The type of reporting and documentation is a function of the acceptance type.

Materials test reporting and documentation is to be done using the WisDOT electronic Materials Tracking System (MTS). The MTS is a computerized filing and reporting system for construction materials tests and documents. All construction materials tested and inspected for WisDOT projects are reported on the MTS. The overall MTS has three basic components, the MTS (LAN/WAN attached), Materials Information Tracking System (MIT), and the Materials Tracking website. Region and central office laboratory personnel can enter data directly into the Oracle database via a Local Area Network (LAN) attachment provided through the MTS. The MIT is used for entering tests from the field.

The engineer should follow these guidelines for material documentation:

- Inspect all manufactured products as soon as possible after delivery.
  - Include all approved lists, certified sources, and pre-qualified products.
  - Record in the project record relevant inspection information.

- Verify that products delivered match the certifications, approved list, etc.

- Review all Certifications of Compliance and Certified Reports of Test and Analysis.

- Reference all Certifications, shop inspection reports, and other external documents using the MTS/MIT prefix 900 report.

All materials documentation and reporting must be completed and entered in the MTS no more than 60 working days after the work completion date.

Manufactured products must be inspected at the job site as soon as possible after arrival for evidence of damage or noncompliance even though these materials are covered by prior inspection testing or certification.

Those materials normally source inspected, but which arrive at the job without appropriate marking, indicating that they have been accepted at the source, must be field inspected or tested and the basis for acceptance must be documented in the inspector’s diary.

8-45.1.1 Materials Testing and Acceptance Guide

The Materials Testing and Acceptance Guide, CMM 8-50 details many of the sampling, testing, and documentation requirements for various materials. The instructions shown in this guide are recommended minimum requirements. In many cases, it may be appropriate to increase the frequency and scope of certain testing and acceptance activities in order to properly administer the materials specifications. In all cases, it is appropriate to closely observe produced materials for visual evidence of changes in quality and to then adjust testing frequencies, as required, to adequately evaluate their quality.

Sampling and testing procedures of certain unique materials are described in the standard specs and other contract documents. The instructions in this guide are intended to supplement those in other contract documents.

8-45.1.2 E-Guide

E-Guide is an automated system that produces condensed sampling, testing and documentation guidance for material requirements for a project. It generates the guidance in two basic ways. For the project bid items, the system automatically generates guidance. For non-standard special provision (SPV) items, the system requires manual input of the SPV material requirements contained in the project proposal. CMM 8-50 should be cross checked when an E-Guide is developed since it contains detailed information and it breaks material information out by type. The E-Guide system for developing a project specific sampling and testing guide is available at:

http://www.atwoodsystems.com/syslinks.cfm

The WisDOT project material coordinator shall prepare the E-Guide and provide a copy to the contractor's material coordinator. Consult the region materials engineer or region person responsible for construction
materials for guidance when developing the E-Guide.

The E-Guide does not supersede material requirements in the Standard Spec or the CMM. The contractor is contractually bound to supply the information if required in the Standard Spec, CMM or Special Provisions.

The region materials engineer or region person responsible for this area must be consulted regarding doubts as to the adequacy of compliance of source inspected materials, need for field inspection and reports, waiver of testing, unlisted items, evaluation of certifications, or other questions regarding acceptance procedures.

Table 1 below defines the general documentation requirements for each materials acceptance type. Table 2 provides the MTS prefixes for all material types. Figure 1, Figure 2, and Figure 3 show example test reports.
Table 1 Documentation Requirements for Different Acceptance Types

<table>
<thead>
<tr>
<th>Documentation Required</th>
<th>Acceptance Type</th>
<th>MIT/MTS Document</th>
<th>MTS Documentation Time Line</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTS Report.</td>
<td>Verification tests- C.O. Laboratory</td>
<td>Various MTS prefixes as appropriate. See Table 2 for a list of prefixes.</td>
<td>No later than one week after completion of test.</td>
<td>Test entry by C.O. Lab personnel.</td>
</tr>
<tr>
<td>Materials Diary entry</td>
<td>Approved Product Lists- WisDOT</td>
<td>Reference on MTS prefix 900 or 155</td>
<td>No later than 60 days after contract work completion date.</td>
<td>Test entry by project personnel.</td>
</tr>
<tr>
<td>Materials Diary entry</td>
<td>Source or Shop Inspection</td>
<td>Reference on MTS prefix 900 or 155</td>
<td>No later than 60 days after contract work completion date.</td>
<td>Test entry by project personnel.</td>
</tr>
<tr>
<td>Materials Diary entry</td>
<td>Source sampled materials tested and reported by C.O. personnel (see verification tests C.O. Lab above).</td>
<td>Reference on MTS prefix 900 or 155</td>
<td>No later than 60 days after contract work completion date.</td>
<td>Test entry by project personnel.</td>
</tr>
<tr>
<td>Cert. of Compliance</td>
<td>Manufacturers Certification of Compliance</td>
<td>Reference on MTS prefix 900 or 155</td>
<td>No later than 60 days after contract work completion date.</td>
<td>See note below [1].</td>
</tr>
<tr>
<td>MTS reference report.</td>
<td>MTS reference report.</td>
<td>Reference on MTS prefix 900 or 155</td>
<td>No later than 60 days after contract work completion date.</td>
<td>See note below [1].</td>
</tr>
<tr>
<td>MTS reference report.</td>
<td>MTS reference report.</td>
<td>Reference on MTS prefix 900 or 155</td>
<td>No later than 60 days after contract work completion date.</td>
<td>See note below [1].</td>
</tr>
<tr>
<td>MTS reference report.</td>
<td>MTS reference report.</td>
<td>Reference on MTS prefix 900 or 155</td>
<td>No later than 60 days after contract work completion date.</td>
<td>See note below [1].</td>
</tr>
</tbody>
</table>
| Verification tests-MTS Report. | Field Sampling and Testing | Aggregates- MTS prefix 162, 217  
HMA- MTS prefix 254  
HMA Nuclear Density- MTS prefix 262  
Concrete Cylinders – MTS prefix 130  
Earth Work Density- MTS prefix 232 | No later than one week after completion of test. | All aggregate and HMA QV testing done must be entered by the qualified lab doing the testing.  
When QV and Companion Cylinder testing is done the data must be entered by the qualified laboratory doing the testing.  
Refer to Figure 1, Figure 2, and Figure 3 for examples of prefix 155 reports for verification of contractor QMP and QC testing. |
| Quality Management Program (QMP) Quality Control (QC) tests. | Field Sampling and Testing | MTS Report 155                                       | No later than 60 days after contract work completion date- prefix 155 data. | MRS data is to be input by the contractor as it is developed. |

\([1]\) Certifications must be evaluated promptly for adequacy, completeness, and compliance with the specifications. The certification reviewer must make appropriate notations, initial, and date the document when the review is completed.
DATA SHEET

ATTERBERG LIMITS

Name _________________________
Date _________________________

Description of Sample ________________________________________________

<table>
<thead>
<tr>
<th>Plastic Limit</th>
<th>No. 1</th>
<th>No. 2</th>
<th>No. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Moisture Tin No.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Weight of Tin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Wet Wt. of Soil + Tin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Dry Wt. of Soil + Tin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Water Content (3-4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Dry Soil (4-2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Plastic Limit (5/6) x100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(% moisture)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ave = _________________________

<table>
<thead>
<tr>
<th>Liquid Limit</th>
<th>No. 1</th>
<th>No. 2</th>
<th>No. 3</th>
<th>No. 4</th>
<th>No. 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Moisture Tin No.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Weight of Tin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Wet Wt. of Soil +</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Dry Wt. of Soil + Tin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Water Content (3-4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Dry Soil (4-2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 % Moisture (5/6) x100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 No. of Blows</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Liquid Limit from Flow Curve ____________________________________________

Plasticity Index

\[ PI = LL - PL = \] ____________________________________________
FREEZE-THAW WORKSHEET

Test No. 

Dates:  Started ______  Out ______  Completed ______

QUALITATIVE EXAMINATION

<table>
<thead>
<tr>
<th>Cycle</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date In</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time In</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date Out</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Out</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>Pieces</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1 1/2&quot; - R1&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1&quot; - R3/4&quot;</td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Cycle</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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</tr>
<tr>
<td>Time In</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date Out</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Out</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Size</td>
<td>Pieces</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1 1/2&quot; - R1&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1&quot; - R3/4&quot;</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Cycle</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date In</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time In</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date Out</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Time Out</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>Pieces</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1 1/2&quot; - R1&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1&quot; - R3/4&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Descriptive Terms: Nature of action (none, slight, moderate, heavy)
Effect of action (disintegration, splitting, crumbling, flaking, etc.)

QUANTITATIVE EXAMINATION

<table>
<thead>
<tr>
<th>Size</th>
<th>R-4 Basis Grad. %</th>
<th>Weight (gm)</th>
<th>Ret'd Wt. (gm)</th>
<th>Loss Wt. (gm)</th>
<th>Loss (%)</th>
<th>Weighted Ave., Corr. % Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 1/2&quot; - R1&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1&quot; - R3/4&quot;</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>P3/4&quot; - R1/2&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1/2&quot; - R3/8&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>P3/8&quot; - R#4</td>
<td></td>
<td></td>
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</tbody>
</table>

Soundness of Aggregates by Freezing and Thawing, Procedure B
16 cycles, AASHTO T103, Weighted Loss, %
AGGREGATE QUALITY

LA WEAR TEST

<table>
<thead>
<tr>
<th>Grading</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td># Steel Spheres</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample Mass, g</td>
<td></td>
<td></td>
</tr>
<tr>
<td># of Revolutions</td>
<td>100</td>
<td>500</td>
</tr>
<tr>
<td>Retained Mass, g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss, g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wear, %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ATTERBERG LIMITS

| Liquid Limit             |   |   |
| Plasticity Index         |   |   |

FRACTURED PARTICLES

| Uncrushed                |   |   |
| Questionable             |   |   |
| Fractured                |   |   |
| Total                    |   |   |
| % by count               |   |   |

LIGHTWEIGHT PIECES

| Total Dry                |   |   |
| Sample Mass, g           |   |   |
| Dry Mass of              |   |   |
| Pieces Floating, g       |   |   |
| Lightweight              |   |   |
| Pieces, %                |   |   |

AS RECEIVED GRADATION

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Mass, lbs</th>
<th>% Retained</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>3&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1/2&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1/4&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/4&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/2&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/8&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P #4</td>
<td></td>
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</tr>
<tr>
<td>TOTAL</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### SOUNDNESS

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Weighted Multiplier, %</th>
<th>Initial Mass, g</th>
<th>Retained Mass, g</th>
<th>Loss, g</th>
<th>Loss, %</th>
<th>Weighted Loss, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 1/2&quot; - R1&quot;</td>
<td>******</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>P1&quot; - R3/4&quot;</td>
<td>0</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>P3/4&quot; - R1/2&quot;</td>
<td>******</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>P1/2&quot; - R3/8&quot;</td>
<td>65</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>P3/8&quot; - R#4</td>
<td>35</td>
<td>*****</td>
<td>*****</td>
<td></td>
<td></td>
<td>****</td>
</tr>
</tbody>
</table>

Sodium Sulphate Soundness:
5 cycles, AASHTO T104, Weighted Loss %

### FREEZE-THAW

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Weighted Multiplier, %</th>
<th>Initial Mass, g</th>
<th>Retained Mass, g</th>
<th>Loss, g</th>
<th>Loss, %</th>
<th>Weighted Loss, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 1/2&quot; - R1&quot;</td>
<td>******</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
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<tr>
<td>P1&quot; - R3/4&quot;</td>
<td>0</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>P3/4&quot; - R1/2&quot;</td>
<td>******</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>P1/2&quot; - R3/8&quot;</td>
<td>65</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>P3/8&quot; - R#4</td>
<td>35</td>
<td>*****</td>
<td>*****</td>
<td></td>
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</tr>
</tbody>
</table>

Soundness of Aggregates by Freezing and Thawing:
Procedure B, 16 cycles, AASHTO T103, Weighted Loss, %

### COARSE AGGREGATE SPECIFIC GRAVITY

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Saturated Weight, g</th>
<th>Oven-Dry Weight, g</th>
<th>Weight in Water, g</th>
<th>Absorption, %</th>
<th>Bulk Specific Gravity</th>
<th>Bulk Specific Gravity, SSD</th>
<th>Apparent Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When complete, please e-mail this worksheet to: thomas.brokaw@dot.wi.gov

AASHTO T03, Weighted Loss, %
APPENDIX: QMP Award Nomination Form

The Quality Management Program Award recognizes outstanding certified highway materials technicians who have displayed exceptional leadership roles in developing quality materials used in highway construction projects.

These winners are chosen from contractors, consultants, and the Wisconsin Department of Transportation. It is this industry support and joint partnering that makes this program a success.

Some of the qualities attributed to the award winners include HTCP certification, HTCP promotion, development of cost savings, development of time savings, quality improvement, being a team player and possessing a positive attitude.
Quality Management Program Award
Nomination Application

This Outstanding Individual or Team is Nominated to Receive this Year’s “Quality Management Program Award”

Individual/Team: ___________________________ Employer: ___________________________
Address: ___________________________ Work Address: ___________________________
City/State/Zip: ___________________________ City/State/Zip: ___________________________
Telephone: ___________________________ Telephone: ___________________________
Fax: ___________________________
List individual or team nominated:

Identify outstanding individual or team achievement(s) that exemplify this nomination for the “Quality Management Program Award:

*Application submitted by: ___________________________ Date: ___________________________
Do you wish to remain anonymous? ☐ Yes ☐ No (* Required for nomination)

Please fax (608) 342-1982 or send completed application before November 1 of each year to Highway Technician Certification Program, University of Wisconsin-Platteville, 049 Ottensman Hall, 1 University Plaza, Platteville, WI 53818-3099.
Quality Management Program Award
Nomination Application

This Outstanding Individual or Team is Nominated to Receive this Year’s “Quality Management Program Award”

Individual/Team: ___________________________ Employer: ___________________________

Address: ___________________________ Work Address: ___________________________

City/State/Zip: ___________________________ City/State/Zip: ___________________________

Telephone: ___________________________ Telephone: ___________________________

Fax: ___________________________

List individual or team nominated:

Identify outstanding individual or team achievement(s) that exemplify this nomination for the “Quality Management Program Asphalt Award”:

*Application submitted by: ___________________________ Date: ___________________________

Do you wish to remain anonymous? ☐ Yes ☐ No

(* Required for nomination)

Please fax (608) 342-1982 or send completed application before November 1 of each year to Highway Technician Certification Program, University of Wisconsin-Platteville, 049 Ottensman Hall, 1 University Plaza, Platteville, WI 53818-3099.
Corrections
OOPS! Found an error?

Course Title: ____________________________

Please describe the error and the page or topic where you found it:

We might have questions. How can we reach you?

Name: ________________________________

E-Mail: ________________________________

Phone: ________________________________

Note to Development Team: Send updates to htcp@uwplatt.edu, or call 608.342.1545, or mail to HTCP, 1 University Plaza, University of Wisconsin-Platteville, Platteville, WI 53818.

THANK YOU!
Course Evaluation
The HTCP would appreciate your thoughtful completion of all items on this evaluation. Your comments and constructive suggestions will be carefully studied and will serve as a valuable resource to improve our course presentations:

Course: ________________________________

Date: ________________________________

1. **Overall rating of this program:**

<table>
<thead>
<tr>
<th></th>
<th>Outstanding</th>
<th>Above Average</th>
<th>Average</th>
<th>Below Average</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did the course meet your expectations?</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>How well were you satisfied with the quality and quantity of the course materials?</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Comments about course materials/visual aids: __________________________________________

2. **Instructor: ____________________________**

<table>
<thead>
<tr>
<th></th>
<th>Outstanding</th>
<th>Above Average</th>
<th>Average</th>
<th>Below Average</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness of course presentation:</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Responsiveness and interaction with students:</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Ability to communicate:</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Knowledge of course content:</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

3. **Please fill in and rate overall effectiveness of laboratory instructor(s)/guest lecturer(s):**

<table>
<thead>
<tr>
<th></th>
<th>Outstanding</th>
<th>Above Average</th>
<th>Average</th>
<th>Below Average</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
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<tr>
<td></td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Comments: Please make additional comments about individual laboratory instructor(s)/guests lecturer(s) quality of instruction: __________________________________________
4. Administrative Evaluation:

<table>
<thead>
<tr>
<th></th>
<th>Outstanding</th>
<th>Above Average</th>
<th>Average</th>
<th>Below Average</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Registration procedure:</td>
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<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Classroom atmosphere:</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Laboratory equipment:</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Parking</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Comments: Please make additional comments about registration procedures, classroom atmosphere, laboratory equipment, and parking: _______________________________

5. What did you like most about the course? _______________________________

6. What did you like least about the course? _______________________________

7. Please comment about overall course quality and length: _______________________________

8. The HTCP may wish to use your comments in our next brochure ________________

To use your comments, we must have your name and address:

Name: ________________________________

Title: ________________________________

Organization: __________________________

Address: ______________________________

City/State/Zip: _________________________ Phone: ________________