Concrete Strength Tester

HIGHWAY TECHNICIAN CERTIFICATION PROGRAM
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PREFACE

The WisDOT Certified Concrete Strength Tester Course Manual was prepared and developed by the Highway Technician Certification Program (HTCP) staff, the HTCP instructors, and other contributors from the Wisconsin Department of Transportation (WisDOT) and the highway industry. The information contained in this course manual is to be exclusively used to train WisDOT and industry Quality Management Program (QMP) concrete strength testers. The intent of this manual is to provide AASHTO-based training as it applies to the compressive strength cylinder testing procedures. It is the responsibility of the WisDOT Certified Concrete Strength Tester to follow all current WisDOT specification parameters and procedures in accordance when conducting work assignments for the Wisconsin Department of Transportation.

The WisDOT Certified Concrete Strength Tester course manual was developed with these valuable resources:

1. AASHTO T 231 Capping Cylindrical Concrete Specimens
2. ASTM C 1231 Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders
3. AASHTO T 22 Compressive Strength of Cylindrical Concrete Specimens (Modified)
4. AASHTO T 24 Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
5. AASHTO T 97 Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
6. AASHTO T 198 Splitting Strength of Cylindrical Concrete Specimens
7. AASHTO T 23 Making and Curing Concrete Test Specimens in the Field

ACKNOWLEDGMENTS

The HTCP Portland Cement Concrete Technical Manual Committee members have been instrumental contributors to the contents of this course manual. The committee members are:

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**TOPIC C:** AASHTO T 22 – Compressive Strength of Cylindrical Concrete Specimens

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Certified Concrete Strength Technician

8:00 – 8:15  Registration, introduction, course objectives and course syllabus

8:15 – 9:15  AASHTO T 231 – Capping Cylindrical Concrete Specimens

9:15 – 10:00  ASTM C 1231 – Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders

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Noon – 1:00  Lunch

1:00 – 1:15  AASHTO T 24 – Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

1:15 – 2:00  AASHTO T 97 Flexural Strength of Beams and

2:00 – 2:30  AASHTO T 198 Tensile Strength of Cylindrical Concrete Specimens

2:30 – 3:15  Laboratory Demonstration of Flexure Strength and Splitting Tensile Testing

3:15 – 3:30  Break

3:30 – 5:00  WRITTEN EXAMINATION

ADJOURN
Introduction

The Highway Technician Certification Program (HTCP) welcomes you to the Certified Compressive Strength Tester I course. This course requires eight hours of classroom attendance. The course content will cover capping cylindrical specimens, using unbonded (Neoprene) caps in determination of compressive strength of hardened concrete cylinders, and obtaining and testing drilled cores and sawed beams of concrete.

Course Prerequisites

None required. A person may earn 0.8 continuing education units (CEU’s) upon successful completion of this course.

Certification Requirements

The written examination will be limited to a maximum duration of two (2) hours. The written examination will be “open book and open notes” and will consist of true/false questions, multiple-choice questions, and essay problems. A student will be required to obtain a passing score of 70 percent to be certified as a Concrete Strength Technician I.

Recertification Requirements

Recertification is mandatory every three (3) years. The HTCP will send a recertification notice to each certified technician and the firm or agency before the expiration date of the highest certification level(s) of certification obtained. The certified technician must apply for recertification before the expiration date of the highest level(s) obtained. Each certified technician is responsible for obtaining his/her recertification.

Revocation/Suspension of Certification

Upon written request from any individual, firm, agency, or contractor associated with the HTCP, the HTCP director will provide technical assistance in investigating any alleged report(s) of either certified technician incompetence or act(s) of malfeasance. The HTCP director will then notify WisDOT of the report findings concerning certified technician incompetence or misconduct.

Highway Technician Certification Program Goal

The principal goal of the Highway Technician Certification Program (HTCP) is to certify that individuals have demonstrated the abilities to engage in quality control/quality assurance activities in highway work contracted by the Wisconsin Department of Transportation (WisDOT).
Introduction of Course Participants

At this time, you will be asked to introduce yourself, company name, years of service to the Portland cement concrete industry, and your present occupational duty.

What do you expect from this Training Course?

This is your opportunity, as a course participant, to ask the course instructor to cover any other topics related to the Concrete Strength Tester I course. Please list and identify topics below:

___________________________________________________________________________

___________________________________________________________________________

Duties and Responsibilities of a Certified Concrete Strength Tester I

The duties and responsibilities of a Certified Concrete Strength Tester I:

- Know how to perform the practice for providing plane surfaces on the ends of freshly made and hardened cylinders or drilled cores.
- Know the calibration frequency and required load rates for cylinder compression testing.
- Know the appropriate test methods for obtaining, preparing, and testing drilled cores for axial compression testing.
- Know how to apply a compressive axial load to a hardened cylindrical test specimen at a prescribed rate until failure occurs.
- Know how to calculate the hardened concrete cylinder compressive strengths and report test data results.
- Know the safety, handling, and storage requirements for the equipment.
- Know which project personnel to contact to obtain specification requirements, evaluate the test results in relation to these specifications, and report results to the appropriate persons.
- Be able to maintain records in an organized manner and document sampling and testing performed and actions taken as a result of sampling and testing required by specification.
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- Be able to maintain records in an organized manner and document sampling and testing performed and actions taken as a result of sampling and testing required by specification.
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A.1 Significance and Use

This procedure provides plane surfaces on the ends of hardened and freshly-molded concrete cylinders or drilled concrete cores to deliver an even distribution of the force applied by a compression machine to the ends of a cylindrical specimen.

A.2 Equipment

1. Capping Plates shall be at least 1 in. greater than diameter of specimen
   a. ¼" glass plate, or
   b. ½ in. machines metal plate, or
   c. polished plate of granite at least 3 inches thickness
2. 12-inch Carpenter’s Square
3. Alignment Devices or bull’s eye level
4. Melting pot for sulfur mortars and extra Sulfur Mortar material
5. Thermometer (reads to at least 300°F)
6. Exhaust hood
7. Ladle
8. Silicon spray lubricant or mineral oil
9. Cloth if using mineral oil
10. Dead-blow hammer (lead shot in head)
11. 0.002 in. leaf-type feeler gage
12. Machined straight edge
13. Calipers to check dimensions on capping plates
14. Metal implement to find hollow areas
15. Three-gang brass mold with special cover plate

A.3 Capping Materials

A.3.1 Three Types of Capping Materials:
   1. Neat hydraulic cement paste – Portland or blended cement mixed with water only
   2. High-strength gypsum cement paste – white gypsum cement mixed with water only (“Ultracal” is typically utilized.)
   3. Sulfur mortar – ceramic material cast in a molten state that gains strength as it cools
A.3.2 Strength and thickness requirements for all three capping materials:

For Normal Strength Concrete: 500 – 7000 psi

1. Minimum Strength of Capping Material
   a. 5000 psi
   b. OR cylinder strength if it is greater than 5000 psi

2. Cap Thickness (measured after cylinder has been tested)
   a. 0.25 in. (1/4 in.) maximum average
   b. 0.31 in. (5/16 in.) maximum of any part

If concrete strengths greater than 7000 psi are anticipated, see Table 1 of AASHTO T 231 for strength and thickness requirements of capping materials.

The strength of capping material should be conducted on receipt of new lot or at an interval not to exceed three months. Compressive strength tests of 2 in. cubes performed in accordance with AASHTO T 106 will be used to verify capping material strength.

A.4 Neat Hydraulic Cement Paste

A.4.1 General Requirements

1. A paste made from a mix of water and cements conforming to AASHTO M 85 Types I, II, or III.
2. Conduct qualification tests prior to use for capping to establish relationship between water-cement ratio and compressive strength of 2-inch cubes.
3. Only acceptable method for capping Freshly Molded Cylinders.
4. This capping method is rarely used.

Optimum consistency is generally produced at the following water cement ratios:

   TYPE I & II  = 0.32 - 0.36
   TYPE III     = 0.35 - 0.39

A.4.2 See AASHTO T 231 Sections 5.2 & 6 for mixing and capping procedures

A.5 High-Strength Gypsum Cement Paste

A.5.1 Strength Requirements

1. Optimum water-gypsum cement ratio is generally produced between 0.26 and 0.30. The recommended water-gypsum cement ratio should produce strengths exceeding 5000 psi.
2. Qualification tests shall be determined for the water-gypsum cement ratio and age required for compressive strength of 2 in. cubes.

A.5.2 Mixing Procedure

1. Mix the next gypsum cement paste at the desired water-gypsum cement ratio and use the mixture immediately. The mixture will tend to set rapidly.

2. The material is ready to be cast in cubes for strength testing or cast as a cap on a cylindrical specimen or a masonry unit.

A.5.3 Capping Procedure

1. Mix paste and do not exceed water-cement ratio determined from qualification tests.

2. Place a mound of pre-mixed capping compound on the appropriate capping plate.

3. Lower the specimen, using a bull’s eye level, on top of the cylinder specimen or guide bar within 1/8 inch in 12 inches.

4. Generally, capping plates may be removed within 45 minutes with Gypsum cement pastes.

A.6 Sulfur Mortar

A.6.1 Strength Requirements

1. Qualification tests shall be performed for compressive strength using 2 inch cubes to determine the relationship of strength to age.

2. Prepare and test specimens using 2-inch gang cubes and the metal cover conforming to test methods of AASHTO T 106.

3. Sulfur mortar must be allowed to cool at least two hours before testing for concrete with strength less than 5000 psi. “At least” means a longer cooling time is acceptable.
4. For concrete strengths greater than 5000 psi, cubes and possibly caps may have to harden at least 16 hours before testing. Qualification tests using cubes can be performed at varying ages to allow a shorter time.

A.6.2 Mixing Procedure and Casting Cubes

1. Warm-up all parts of the testing apparatus to a temperature between 68° to 86°F (20° to 30°C).

2. Lightly coat the surfaces within contact with sulfur mortar with mineral oil on a cloth or silicon spray.

3. Utilize an exhaust hood when heating molten sulfur mortar to a temperature of about 265°F (129°C) and stir frequently. (Note: plan ahead as it may take up to four or more hours to melt mortar.)

4. Using a suitable pouring device, quickly fill all three mortar compartments of the brass cube molds (with special cover plate) until reaching top of filling hole.

5. Wait approximately 15 minutes and refill the three compartments once again to allow for shrinkage during cooling.

6. Once the cubes have cooled sufficiently, carefully remove them from their molds.

7. Remove oil, sharp edges, and fins from all mortar cubes. Do not remove the knob formed from the filling hole.

8. After two hours, test cubes in compression machine by AASHTO T 106 and calculate the compressive strength.

A.6.3 Capping Procedure

1. End condition – perpendicular plane through highest point on the uncapped cylinder shall be less than 1/8 in. (0.125 in.) from any point on the end of the cylinder. If not, cut, lap, or grind the cylinder prior to capping.

2. Prepare sulfur mortar as specified to 265°F and add sulfur mortar materials to ensure the oldest material in the pot has not been used more than five (5) times. Place sulfur mortar pot underneath exhaust hood.

3. Warm the capping plate to ensure a slow rate of hardening and enable the production of thin caps.
4. Lightly apply release agent to the capping plate with mineral oil or silicon spray. Stir sulfur mortar immediately prior to pouring each cap.

5. Ensure cylinder specimens are free from oil or resins and dry at time of capping to reduce the risk of steam, foam pockets, or air voids forming larger than 1/4 inch (0.25 in.).

6. Then using the vertical device, pour mortar on the surface of the capping plate.

7. Lift the cylinder above the capping plate, being careful not to drop it on capping plate (could cause severe burns), and contacting the cylinder with the guides, carefully slide the cylinder (pressing against the guide) onto the capping plate. Be careful not to hesitate too long, thick sulfur cylinder caps can cause low measured cylinder strengths.

8. The cylinder should remain on the capping plate until the sulfur mortar has hardened.

9. Each day, check the planeness of the caps on at least three specimens representing the start, middle, and end of the run. Use a straight edge and feeler gauge, making a minimum of three measurements at different diameters to ensure that the surfaces are within 0.002 inch.

10. Also, tap surface lightly with a metal implement to see whether surface is solid or hollow. A coin or other metal instrument works well for identifying holly caps. Caps with hollow voids larger than ¼ in. must be replaced.

11. The cap shall not have gouges, grooves or indentations greater than 0.01 in. deep or greater than 0.05 in.² in surface area.

A.7 Protection of Specimens After Capping

Maintain moist cured specimens in a moist condition between the completion of capping and time of testing with a double layer of wet burlap. Do not store specimens with gypsum caps immersed in water or for more than four hours in a moist room. Protect plaster caps from dripping water.

For sulfur mortar compounds, allow at least two hours of time upon completion of capping before compression testing. Gypsum cement caps cannot be tested until the following day.
A.8 Field-Cured vs. Laboratory-Cured Testing

Field-Cured Cylinders – test cylinders that are left at the job site for curing should, as nearly as practicable, be maintained in the same manner as the concrete in the structure. This will indicate when supporting forms may be removed, additional construction loads may be imposed, or the structure may be placed in service.

Laboratory-cured cylinders – test cylinders stored on the job site in a temperature range between 60\(^\circ\) to 80\(^\circ\)F while shielded from the direct rays of the sun and radiant heating devices. From age 48 ± 4 hours they are transported from the job site to the laboratory where they are moist-cured at 73 ± 3\(^\circ\)F until tested.

The goal of the lab-cured testing is to determine the quality of the concrete mixture without the influence of construction workmanship or environmental conditions on the project site. Field-cured testing attempts to simulate the compressive strength of concrete in the structure. Field-cured test results are not typically used to accept or reject the concrete. Only lab-cured specimens are used to determine if the concrete meets compressive strength specifications. It is important that lab-curing procedures are followed closely.
TOPIC B:  ASTM C 1231 (WisDOT Modified)
Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders

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Reuse of Pads................................................................................... B-4
B.1 Test Method Summary

This test method covers requirements for using unbonded caps for compression testing concrete cylinders. The most commonly used material for use in unbonded caps and retaining rings (or retainers) is neoprene and steel respectively. However, the test method allows the use of other materials.

Unbonded caps are not be used for acceptance testing of concrete with compressive strength below 1500 psi or above 12,000 psi.

<table>
<thead>
<tr>
<th>B.2 Equipment List</th>
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<tbody>
<tr>
<td>1. Two Retaining Rings</td>
</tr>
<tr>
<td>2. Elastomeric (neoprene) pads – 50, 60, or 70 durometer hardness</td>
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<tr>
<td>3. 0.20 in. (5 gauge) – diameter heavy wire</td>
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<tr>
<td>4. 0.002 in. leaf-type feeler gage</td>
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<tr>
<td>5. Machined straight edge</td>
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<tr>
<td>6. Calipers to check gouges on retainers</td>
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<tr>
<td>7. 12 in. carpenter’s square modified to fit around a retainer</td>
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B.3 Equipment and Apparatus

B.3.1 Elastomeric Pads

Elastomeric materials will accommodate surface irregularities in ends of the cylinders. The dimensions of the pad shall be 1/2 in. ± 1/16 in. thick with a diameter not more than 1/16 in. smaller than the inside diameter of the retainer.

Data indicates that 50 durometer pads may be appropriate for cylinder strengths from 1500 psi to 6000 psi. The use of 60 durometer pads is appropriate for 2500 psi 7000 psi. The appropriate strength range for using 70 durometer pads is 4000 psi 12000 psi.
B.3.2 Retaining Rings

The Retaining Rings are used to restrain the elastomeric pad from excessive lateral spreading as the load is applied. They are made from steel and some made of aluminum alloys have also been found acceptable. Once placed in the rings, the neoprene pads should not fall out when tipped upside-down.

The inside diameter of the retaining rings shall be within 102% to 107% of the diameter of the cylinder. Minimum wall thickness and minimum bearing surface thickness in the ASTM procedure. The outside surfaces of the metal retainer that contact the compression machine bearing blocks shall be machined plane to within a tolerance of 0.002 in free of gouges, or dents larger than 0.01 in. depth or 0.05 in² surface area. Protrusions are not allowed. These requirements should be regularly checked.

B.4 Test Specimens

Neither end of cylinder specimens shall depart from perpendicularity to the axis by more than 0.5° [approximately equivalent to 1/8” in 12”]. Check cylinder perpendicularity with a small 12” square.

Diameter measurements shall not differ by more than 2%. A minimum of two diameter measurements will be obtained.

Depressions or protrusions shall be plane within 0.20 in. (1/5 in.) under a straight edge measured with a round wire gauge. If the cylinder ends do not meet this tolerance, the cylinder shall not be tested unless irregularities are corrected by sawing or grinding.

B.5 Unbonded Cap Procedure

1. AASHTO states that unbonded caps may be used on either end or both ends of the specimen during testing. WisDOT has modified the procedure to exclude this option when running compression tests for their projects. To be consistent, the capping procedure should be the same on both ends.

2. Examine pads for excessive wear or damage. Discard the pads if they show excessive wear or have cracks or splits longer than 3/8 in. regardless of depth.

3. Center unbonded cylinder caps (retainer with pad inserted) on each end of the cylinder.

4. Place the cylinder on the lower bearing block of the testing machine. Carefully center the cylinder under the upper spherically-seated bearing block.
5. While bringing the retainer in contact with the upper block, rotate the upper bearing block gently to align it parallel to the retainer for uniform contact.

6. After a load has been applied, but not more than 10% of the anticipated failure load:
   a. Check to see that the cylinder is vertical in the machine to a tolerance of not more than 1/8 in. in 12 in.
   b. Check that the cylinder is centered in both of the retaining rings.
   c. A pause in applying the load to perform these checks is permissible, but not required.
   d. If these requirements are not met: release the load, realign the cylinder or retaining rings and reapply the load performing this check again.

7. Complete load application as specified in AASHTO T 22 making sure the test is run until complete failure has occurred.

8. Neoprene caps may cause a cylinder to rupture more intensely than cylinders tested using sulfur-mortar caps. A protective cage on the compression machine will enhance safety.

9. Each neoprene cap shall not be used to test more than 100 cylinders. It’s a good idea to turn the pads over at 50 uses.

B.6 Qualification of Unbonded Capping Systems and Verification of Reuse of Pads

The maximum number of reuses of a pad is 100 unless the user of the pads demonstrates the pad to be acceptable through ASTM C1231.

Many reusable caps are manufactured from materials other than neoprene and Retaining Rings of metals other steel. Verification tests outlined in ASTM C1231 should be performed to confirm that the pads are satisfactory for compression testing. Many laboratories find this is not economical to do.
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Blank Worksheets can be found at the end of this Topic.
C.1 Test Method Summary

This test method consists of applying a compressive axial load to molded cylinder specimens or cores at a rate that is within a prescribed range until failure occurs. The compressive strength of the cylinder specimen is calculated by dividing the maximum load attained during the test procedure by the cross-sectional area of the specimen. This test procedure is limited to concrete having a unit weight in excess of 50 lb/ft³.

C.2 Equipment

1. Compression testing machine - rate of loading 35 ± 7 psi/sec
2. Calipers with 3.5 in. long jaws
3. Ruler to measure length to 0.1” increments
4. Stopwatch
5. Cleaning brush or cloth
6. Machined straight edge
7. Water Storage Tank or Moist-cure Room
8. Hydrated lime
9. Recording thermometer

C.3 Compression Testing Machine

This testing machine must apply the load continuously without shock. For compression testing machines of either screw type or hydraulic-operated machines, the load should be applied at a rate of movement on the specimen within a range of 35 ± 7 psi/s. The designated rate of movement shall be maintained at least during the latter half of the anticipated loading range.

C.4 Verification of Calibration

Calibration of a compression testing machine must be verified at a 12 month interval (WisDOT Modified) in accordance with AASHTO T 67. The accuracy of the load must be within 1.0% for any value displayed within the verified loading range.
C.5 Bearing Blocks

The compression machine shall be equipped with two steel bearing blocks, upper and lower, with hardened surfaces. Bearing faces of the blocks shall have a minimum dimension of at least 3% greater than the diameter of the specimen to be tested.

The bearing surface must be within planeness of 0.001 in. in any 6 inches of blocks 6 inches in diameter or larger or by more than 0.001 inches in the diameter of any smaller block. New blocks shall be manufactured within one half of this tolerance.

C.6 Bottom Bearing Blocks

The bottom bearing block may be fastened to the platen of the testing machine. The horizontal dimension shall be at least 3% greater than the diameter of the specimen to be tested. The top and bottom surfaces must be parallel to each other. The bottom block shall be at least 1 in. thick when new and at least 0.9 in. thick after any resurfacing operation.

C.7 Upper (Spherically Seated) Bearing Block

<table>
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<tr>
<th>Diameter of Test Specimens, in.</th>
<th>Maximum Diameter of Bearing Face, in.</th>
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<tbody>
<tr>
<td>2</td>
<td>4</td>
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<td>3</td>
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</table>

The maximum diameter of the upper bearing block bearing face for a 6 in. diameter of test specimens is 10 in. Square bearing surfaces are permissible, provided the diameter of the largest possible inscribed circle does not exceed the above diameter.

C.8 Centering Cylinder Specimen

Final centering must be made in reference to the upper spherical block. When the lower bearing block is used to assist in centering the cylinder specimen, the center of concentric rings must be directly below the center of the spherical head.
C.9 Load Indication

If a load dial is used on a compression-testing machine, the dial should be on a graduated scale that can be read to the nearest 0.1% of the full scale. The scale should include a graduation line equal to zero and be so numbered. The dial pointer shall be long enough to reach the graduation markings.

Each dial should be easily accessible so the zero adjustment may be made easily and indicate within 1% accuracy the maximum load applied to the specimen.

If the compression testing machine is supplied with a numerical display, then the display must be large enough to be easily read.

C.10 Cylindrical Specimens

The ends of the cylindrical specimens should not be off by more than 0.5° [approximately 1/8 inch in 12 inches]. The ends of compression test specimens that are not within planeness shall be capped in accordance with AASHTO T 231, sawed, or ground to meet that tolerance.

Cylindrical specimens shall not be tested if any individual diameter of the same cylinder is more than 2%. This may be caused by single use molds that are damaged or deformed during manufacturing.

The diameter used to calculate the cross-sectional area of the test specimen shall be determined to the nearest 0.01 in. by averaging two diameters measured at right angles to each other at mid height of the specimen.

Measure each cylinder tested.
The length of the cylinder shall be measured to the nearest 0.05 inch diameter when the length to diameter ratio is less than 1.8 or more than 2.2.

C.11 Calculation of Concrete Cylindrical Specimen Strength

The diameter used to calculate the cross-sectional area of the test specimen shall be determined to the nearest 0.01 in. by averaging two diameters measured at right angles to each other at mid-height of the specimen.

C.12 Cylinder Compression Procedure

1. AASHTO M 201 outlines procedures for maintaining moist storage rooms and water storage tanks.

2. The compression test of moist-cured specimens shall be made as soon as possible after removal from moist storage.

3. Test specimens shall be kept moist by any convenient method during the period between removal from moist storage and testing. They shall be tested in the moist condition.

4. All test specimens for a given test age shall be broken within the permissible time allowances (seven day test age within six hours and for 28 days within 20 hours).

5. Wipe clean the surfaces of both lower and upper bearing surfaces. Place the specimen on the lower bearing plate and center specimen directly under upper bearing block.

6. Apply the rate of loading continuously and without shock. During the application of the first half of the test load, the rate may be at a higher rate up to one-half of the anticipated load.

7. Loads shall be applied at the specified loading rates for screw and hydraulically-operated machines during the second half of the anticipated loading.

Example hydraulic rate of movement calculation for a 6" x 12" cylinder:

\[
\frac{28 \text{ (lbs)}}{\text{(sq.in.) (sec)}} \times 28.27 \text{ (sq.in.)} = 792 \frac{\text{lbs}}{\text{sec}}
\]

\[
\frac{42 \text{ (lbs)}}{\text{(sq.in.) (sec.)}} \times 28.27 \text{ (sq.in.)} = 1,187 \frac{\text{lbs}}{\text{sec}}
\]

Note: 28.27 sq.in. is the calculated cross-sectional area of a 6.00" dia. concrete cylinder.
8. Apply the load until the specimen fails and record the maximum load carried by the specimen during the test procedure. Note the type of test failure and the appearance of the concrete.

**C.13 Compressive Strength Calculation**

Calculate the compressive strength of the cylindrical specimen by dividing the maximum load applied to the test specimen and by the average cross-sectional area. Round off the results to the nearest 0.10 psi.

**C.14 Formulas**

\[
\text{Average Diameter} = \frac{D_1 + D_2}{2}
\]

\[
\text{Area} = \pi \frac{D^2}{4}, \quad \pi = 3.14 \text{ or use a calculator key.}
\]

**Compressive Strength = Maximum Load**

\[
\frac{\text{Ave. Cross-sectional Area}}{}
\]

**C.15 Report**

The report should include:

- Specimen identification number
- Diameter (and length if outside 1.8 to 2.2 x diameter)
- Cross-sectional area
- Age of specimen
- Date of test*
- Time of test*
- Rate of loading*
- Maximum load*
- Compressive strength calculated to 0.10 psi
- Type of fracture, if other than the usual cone
- Defects in either specimen or caps

*Test machine must be capable of automatically recording these four items.
C.15 Student Problem:

Compressive Strength Example

The diameters of a concrete cylinder specimen are measured as 6.04” and 5.98” and the maximum load sustained in a compression test is 99,000 pounds.

a) Calculate the average diameter.

b) Calculate the cross-sectional area.

c) Calculate the compressive strength of the cylinder.

Solution can be found on the Page C-9 of this Topic.
C.16 Rate of Loading Calculation

For each 28-day compressive strength test used to determine if specifications are met the rate of loading shall be calculated. Simply providing a graph of Load vs. Time is not enough. It must be determine if the rate of loading 35 ± 7 psi/sec has been met.

1. The rate of loading is the slope of the line on a Load vs. Time plot.
   \[
   \text{Rate of Loading} = \frac{(\text{Increase in Load})}{(\text{Increase in Time}) \times (\text{Cross-sectional Area})}
   \]

2. Select two points on the line where it’s easy to pick numbers off the chart.
   a. At 20 seconds the load was 40,000 pounds.
   b. At 60 seconds the load was 80,000 pounds.

3. Rate of Loading = \( \frac{80,000 - 40,000 \text{ lbs}}{(60 - 20 \text{ sec}) \times (28.35 \text{ sq in})} = \frac{40,000 \text{ lbs}}{40 \text{ sec} \times 28.35 \text{ sq in}} = 35.3 \text{ psi/sec} \)
Student Problem: Answer

Compressive Strength Example

The diameters of a concrete cylinder specimen are measured as 6.04” and 5.98", and the maximum load sustained in a compression test is 99,000 pounds.

a) Calculate average diameter.

\[
\text{Average Diameter} = \frac{D_1 + D_2}{2}
\]

\[
\text{Average Diameter} = \frac{6.04 + 5.98}{2}
\]

\[
\text{Average Diameter} = 6.01 \text{ (Note: WisDOT always rounds number next to “5” up.)}
\]

b) Calculate the cross-sectional area

\[
\text{Area} = \frac{\pi D^2}{4}
\]

\[
\text{Area} = \frac{\pi (6.01)^2}{4}
\]

\[
\text{Area} = 28.35 \text{ sq. inches}
\]

c) Calculate the compressive strength of the cylinder.

\[
\text{Compressive Strength} = \frac{\text{Maximum Load}}{\text{Ave. Cross-sectional Area}}
\]

\[
\text{Compressive Strength} = \frac{99,000 \text{ lbs}}{28.35 \text{ sq. inches}}
\]

\[
\text{Compressive Strength} = 3492.1
\]
# COMpressive Strength – T 22

## Concrete Data

<table>
<thead>
<tr>
<th>Date Cast</th>
<th>Set Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date Tested:</td>
<td>Age:</td>
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## Test Data

<table>
<thead>
<tr>
<th>Cylinder A</th>
<th>Cylinder B</th>
<th>Cylinder C</th>
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</thead>
<tbody>
<tr>
<td>Diameter (0.01”)</td>
<td>Diameter (0.01”)</td>
<td>Diameter (0.01”)</td>
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<td>Sum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Diameter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area (0.01 sq in)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Load (lb)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comp. Strength (psi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ave. Comp. Strength (10 psi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fracture Type</td>
<td></td>
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</tr>
</tbody>
</table>

## Reference Information

\[
\text{Average Diameter} = \frac{D_1 + D_2}{2} \\
\text{Average Area} = \frac{\pi D^2}{4} \\
\text{Compressive Strength} = \frac{\text{Peak Load}}{\text{Ave. Area}}
\]

**Fracture Types:**

- Cone (a)
- Cone and Split (b)
- Cone and Shear (c)
- Shear (d)
- Columnar (e)
- Crumbling (f)
- ¼ Crushing (g)
COMPRESSIVE STRENGTH – T 22

CONCRETE DATA

Date Cast: __________________________  Set Number: __________
Date Tested: __________________________  Age: _________________

TEST DATA

<table>
<thead>
<tr>
<th>Cylinder A</th>
<th>Cylinder B</th>
<th>Cylinder C</th>
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<tbody>
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<td>Diameter (0.01&quot;)</td>
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<td>__________</td>
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<tr>
<td>Diameter (0.01&quot;)</td>
<td>__________</td>
<td>__________</td>
</tr>
<tr>
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<tr>
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<td>Area (0.01 sq in)</td>
<td>__________</td>
<td>__________</td>
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<td>Peak Load (lb)</td>
<td>__________</td>
<td>__________</td>
</tr>
<tr>
<td>Comp.Strength (psi)</td>
<td>__________</td>
<td>__________</td>
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<tr>
<td>Ave. Comp. Strength (10 psi)</td>
<td>__________</td>
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</tr>
<tr>
<td>Fracture Type</td>
<td>__________</td>
<td>__________</td>
</tr>
</tbody>
</table>

REFERENCE INFORMATION

\[ \text{Average Diameter} = \frac{D_1 + D_2}{2} \]
\[ \text{Average Area} = \frac{\pi D^2}{4} \]

Compressive Strength = \frac{\text{Peak Load}}{\text{Ave. Area}}

Fracture Types:

- Cone (a)
- Cone and Split (b)
- Cone and Shear (c)
- Shear (d)
- Columnar (e)
- Crumbling (f)
- ¼ Crushing (g)
1. Conical Bond or Cone – Type (a) ........................................................ D-2
2. Combination Conical & Splitting – Type (b) ........................................... D-2
3. Combination Conical & Shear – Type (c) ............................................. D-2
4. Shear (Long Plane) – Type (d) ............................................................. D-3
5. Shear (Short Plane) – Type (d) ............................................................. D-3
   Reducing the Occurrence of Short Shear Fractures............................. D-3
6. Columnar or Splitting – Type (e) .......................................................... D-4
7. Crushing or Crumbling – Shall we call it Type (f)............................... D-4
8. Crushing at Upper Quarter of Specimen – Shall we call it Type (g).... D-4
D.1 Types of Fractures in Concrete Test Cylinders

1. Conical Bond or Cone – Type (a)

This is by far the most common type of failure. There may be some fractured aggregate particles along the shear faces, but most of the failure occurs at the contact surface of the mortar and aggregates.

2. Combination Conical & Splitting – Type (b)

This is typical of the many combinations of the various types of failure that may occur. The fracture may, or may not, be significant and the cylinder should, therefore, be visually examined.

3. Combination Conical & Shear – Type (c)

This is typical of the many combinations of the various types of failure that may occur. The fracture may, or may not, be significant and the cylinder should, therefore, be visually examined.
4. Shear (Long Plane) – Type (d)

The fracture plane is usually on about a 60-degree angle with the horizontal. This type of failure is common with high strength concretes where failure is more or less instantaneous rather than a gradual crushing.

5. Shear (Short Plane) – Type (d)

This type of fracture also usually occurs on a 60-degree plane and is more common with high strength concretes. It differs from number four in that it is restricted to a portion of the cylinder. A fracture of this type may indicate a faulty specimen or cap, particularly with test results less than 5000 psi. The cylinder and caps should, therefore, be carefully examined for defects, as the compressive strength may not be representative of the concrete in the structure.

Reducing the Occurrence of Short Shear Fractures
1. Smooth trowel cylinder when casting.
2. Prevent concave or out-of-round end.
3. Be conscious of using sulfur mortar capping methods when specimen end conditions exceed 0.5°.
4. Limit the number of pad uses to C 1231 specifications
5. Do not use nicked or warped retaining cups
6. Rotate spherical-seated bearing block as specimen contacts cap to provide a uniform load.
7. Check alignment of specimen at approximately 10% of anticipated load.
8. Annually dismantle, clean, and lightly lubricate (SAE 10) spherical seat on upper bearing block.
9. Do not allow water from cylinders to migrate under pads in lower retainer.
10. Consider using cornstarch or talcum powder on pads and cylinder ends.
11. Run test until cylinder has completely failed.
6. Columnar or Splitting – Type (e)

This type of failure is generally associated with relatively weak concrete. Failure occurs throughout the length of the specimen without the formation of any definite shear plane or cone.

7. Crushing or Crumbling: Shall we call it – Type (f)?

This is typical of weak concrete. It is similar to a cone-type fracture except the bond is so poor that the concrete crumbles over the entire cross-section of the cylinder. It may also be the result of poor quality aggregate, segregation of aggregate, or void spaces at the point of fracture. Loose aggregate particles and the ability to break off pieces of the concrete in hand indicate weak concrete. A defect in the aggregate or in casting of the cylinder will be rather obvious. It takes a mechanical defect of considerable magnitude to seriously affect the test result, however.

8. Crushing at Upper Quarter of Specimen: Shall we call it – Type (g)?

This type of failure normally indicates a defect in the specimen or the cap. It is a common result when the concrete has been frozen or shows excessive carbonation (indicated by light colored chalky deposits on the top of the surface of the specimen, usually in the form of small dome-like projections). It may also be the result of damage to the cylinder before testing or a weak or otherwise defective cap. The cylinder should be closely inspected after testing to determine whether any defects are evident. Failures of this type may have compressive strengths that are not representative of the concrete in the structure and the defect should, therefore, be noted.
Test Method Summary .................................................................................................................. E-2
Equipment List ............................................................................................................................ E-2
Sampling ........................................................................................................................................ E-2
Core Drilling .................................................................................................................................. E-2
Length of Drilled Core Specimens ............................................................................................... E-2
Compressive Strength of Drilled Cores ......................................................................................... E-3
Splitting Tensile Strength ............................................................................................................. E-5
Sawed Beams (Flexural Strength) ................................................................................................ E-5
E.1 Test Method Summary

This test method covers obtaining, preparing, and testing: (1) cores drilled from concrete for length or compressive or splitting tensile strength determinations, and (2) beams sawed from concrete for flexural determinations.

E.2 Equipment List

1. Core Drill – Used to obtain cylindrical core specimens.
2. Saw – Used to cut beam specimens to size for flexural tests.

E.3 Sampling

A sample must not be extracted until concrete becomes hard enough not to disturb the bond between the mortar and the aggregates. As a general rule, concrete should not be removed until being cured for 14 calendar days. Discard the sample if it displays abnormal defects or was damaged during the sampling and extraction process. Also, samples containing embedded reinforcement for determining compressive strength may cause inconsistent compressive test values. Embedded reinforcement should be avoided if possible to prevent inaccurate compressive strengths.

E.4 Core Drilling

Any core specimen taken perpendicular to the bed of concrete should be taken from the middle of the unit when possible. Avoid coring samples near formed joints or obvious edges.

E.5 Length of Drilled Core Specimens

1. The minimum diameter for a core sample shall be 3.75 in.

2. The procedure for length determination should be measured in accordance with AASHTO T 148.
E.6 Compressive Strength of Drilled Cores

1. Test Specimens
   The diameter of core specimens for determination of compressive strength should be at least three times the nominal maximum size of the coarse aggregate in the core sample but no less than 3.75 in.

2. Specimen Length After Capping
   a. Should be 1.8 to 2.1 times the diameter. No correction necessary.
   b. Between 0.95 to 1.8 diameters a strength correction factor shall be applied to the metered compressive strength.
   c. Shorter than 0.95 diameters **before** capping should not be tested.
   d. Longer than 2.1 diameters **after** capping should be shortened.

3. End Preparation
   Ends of the core specimens for compression must be smooth, perpendicular to the longitudinal axis, and the same diameter as the body.
   End preparation should be made if:
   a. Projections extend more than 0.2 in. above end surfaces.
   b. Surface departs from longitudinal axis by more than five degrees (5°)
   c. Diameters of ends differ by more than 0.1 in. from the average diameter.

4. Moisture Conditioning
   a. If Saturated – Specimens are immersed in lime-saturated water at 73.4 ± 3.0°F for at least 40 hours immediately prior to compression testing.
   b. If Air Cured – Specimens are air cured 7 days at an ambient temperature between 60° to 80°F and greater than 70 percent humidity until they are tested in compression.

5. Capping
   Capping shall be performed according to AASHTO T 231.

6. Measurement
   Length shall be measured to the nearest 0.1 in. This length should be used to compute the length-to-diameter ratio. The diameter should be measured with two measurements at right angles to each other at mid height. Measure diameters to the nearest 0.01 in. whenever possible, but at least to 0.1 in. (AASHTO T 148).
7. Testing
Conduct the testing of the specimen in accordance with the test provisions of Test Method T 22.

8. Calculation
Calculate the compressive strength of each specimen using the computed cross-sectional area based on the average diameter of the specimen. If the length-to-diameter ratio of the specimen falls between 1.94 and 2.10, no correction is necessary. Refer to the AASHTO T 24 table below.

<table>
<thead>
<tr>
<th>Ratio of Length of Cylinder to Diameter l/d</th>
<th>Strength Correction Factor *</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.75</td>
<td>0.98</td>
</tr>
<tr>
<td>1.50</td>
<td>0.96</td>
</tr>
<tr>
<td>1.25</td>
<td>0.93</td>
</tr>
<tr>
<td>1.00</td>
<td>0.87</td>
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</table>

*These correction factors apply to lightweight concrete weighing between 100 and 120 lb/ft³ and to normal weight concrete. They are applicable to concrete dry or soaked at the time of loading. Values not given in the table shall be determined by interpolation. The correction factors are applicable for nominal concrete strengths from 2000 to 6000 psi. (Correction factors depend on various conditions such as strength and elastic moduli. Average values are given in the table.)

9. Report
The report should include:
   a. Length of test specimen after capping,
   b. Compression strength to the nearest 10 psi when diameter is measured to nearest .01 in and to the nearest 50 psi when the diameter is measured to the nearest 0.1 in.
   c. Direction of load application with respect to horizontal plane.
   d. Moisture condition at time of testing whether saturated or air-dried.
   e. Nominal maximum of concrete aggregate.

10. ACI 318 Chapter 5 Requirements:
   a. 85% average of 3 cores
   b. 75% minimum per core
E.7 Splitting Tensile Strength

1. Sampling and moisture conditioning is the same as for compression testing of strength specimens.

2. Bearing Surfaces
   The line of contact between the specimen and each bearing strip shall be straight and clear of any projections or depressions of 0.01 in. Do not use projections or depressions greater than 0.01 in.

3. Testing and Calculation
   The splitting tensile test should be conducted in accordance with AASHTO T 198.

E.8 Flexural Strength of Sawed Beams

1. Test Specimen
   A beam specimen for the determination of flexural strength shall, in general, have a cross section of 6 by 6 in. The specimen shall be at least 21 in. in length.

2. Moisture Conditioning
   The lab curing of beams is the same curing applied to cylindrical compressive strength specimens used for acceptance testing.

3. Testing and Reporting
   Test and report specimen in accordance with AASHTO T 97.
Topic F: Flexural Strength
Test Method Summary ........................................................................................................F-2
Equipment ......................................................................................................................F-2
Flexure Testing Machine ...............................................................................................F-3
Verification of Calibration .........................................................................................F-3
Bearing Blocks .............................................................................................................F-3
Test Specimen ...............................................................................................................F-4
Flexural Testing Procedure .........................................................................................F-5
Measurements after the Test .......................................................................................F-6
Calculations ..................................................................................................................F-7
Report ............................................................................................................................F-8
Blank Worksheets can be found at the end of this Topic.
F.1 Test Method Summary

This procedure covers determination of the flexural strength of concrete specimens in accordance with AASHTO T 97 using two load-applying blocks placed at the third points of a simply supported concrete beam. This specimen should be molded, cured, and stored according to AASHTO T 23.

Background Information regarding Flexure Testing:

- Commonly performed on projects involving Airport Runways/Taxiways.
- Currently only used only on WisDOT pilot projects.
- More applicable to pavement design than compression testing.

F.2 Equipment

1. Testing machine with third-point flexural loading apparatus
   - rate of loading 125 to 175 psi/min
2. Leaf-type feeler gauges: 0.002 in., 0.004 in., and 0.015 in.
3. Machined straight edge
4. Four Leather shims: ¼ in. thick by 1 to 2 in. wide & as long as specimen is wide
5. Calipers
6. Ruler to measure length to 0.1” increments
7. Stopwatch
8. Small 12” carpenter’s square
9. Magic Marker
10. Water spray bottle or Wet burlap
11. Water Storage Tank or Moist-cure Room
12. Hydrated lime
13. Recording thermometer
F.3  Flexure Testing Machine

This testing machine must apply the load continuously without shock. Although hydraulic machines are mostly used, hand operated machines that can apply a continuous load at a rate of movement within a range of 125 to 175 psi/minute are acceptable. Standard compression machines can be fitted with the bearing blocks used for this testing.

F.4  Verification of Calibration

Calibration of the testing machine used for flexure testing must be verified at a 12 month interval (WisDOT Modified) in accordance with AASHTO T 67. The accuracy of the load must be within 1.0% for any value displayed within the verified loading range.

F.5  Bearing Blocks

The flexure machine shall be equipped with four steel bearing blocks, two upper load applying blocks, and two lower support blocks. The distance between the load applying blocks and between the support blocks shall maintained within 0.05 in. The jig containing the support blocks may be fastened to the testing machine. Lower jigs are not usually fastened to the machine.

The bearing surface must be within planeness of 0.002 in. in any 6 inches of blocks.
F.6 Test Specimen

The most common beams cast for flexure testing is 6" by 6" by 21" long made in accordance with AASHTO T 23. Each specimen should be molded, cured, and stored according to AASHTO T 23.

The span length between the lower support blocks shall be within 2% of three times the depth of the beam. The specimen surfaces must be smooth and free of scars, indentations, holes or inscribed marks.

Turn the specimen on its side with respect to molding when preparing to perform the test. Mark the bottom 1st.

1. Though not required by AASHTO, WisDOT has modified the procedure to include marking the specimen using a magic marker in a minimum of four locations:
   a. Once for each of the two load-applying blocks and once for each of the two support blocks.
   b. These marks will help when centering the specimen in the testing machine.
2. Four optional magic marker lines are recommended:
   a. Two lines defining the center third of the tension (bottom) surface.
   b. Two lines marking 5% outside the middle third of the tension surface.
   c. These marks will aid in identifying the correct formula to use when calculating test results.
3. Also place four tick marks on each side of the beam at the bearing block location.

Marks on Top of Beam:

Marks on Bottom of Beam:
F.7 Flexural Testing Procedure

1. AASHTO M 201 outlines procedures for maintaining moist storage rooms and water storage tanks. Concrete beams should be lab-cured in the same fashion as concrete cylinders.
   a. Beams should be stood on end in water tanks or moist storage.
   b. Beams kept in moist-cure rooms shall be placed in a water tank for a minimum of 20 hours prior to testing (See AASHTO T 23).

2. The flexure test of moist-cured specimens shall be performed as soon as possible after removal from moist storage.

3. Test specimens shall be kept moist by any convenient method during the period between removal from moist storage and testing. They shall be tested in the moist condition. A water spray bottle is suggested to mist the sample if necessary to keep it moist.

4. After centering the specimen and the loading system in relation to the applied force, apply a load of 3 to 6% of the anticipated ultimate load to provide a snug contact between the specimen and the blocks.

5. Check for gaps between the specimen and all four bearing blocks.
   a. Use a 0.004” leaf-type feeler gauge to search for a 1” or larger gap.
   b. If no gap is found, continue the test using this setup.
   c. If a ≥1” gap is found, use a 0.015” leaf-type feeler gauge to search for a 1” or larger gap.
   d. If no gap is found, release the load, place one shim under all four bearing blocks and continue the test.
   e. If a ≥1” gap is found, grind or cap the specimen before performing the test.
   f. Try to minimize grinding the specimen. It might be helpful to use a Carborundum Stone (mason’s stone) on the top lip of the specimen at the time of demolding.
   g. Capping is typically done using high strength gypsum cement.
6. Apply the load continuously at a rate of 125 to 175 psi/min until failure.
   a. This load rate is extremely slow and may require running a test on an extra sample to adjust the testing machine correctly.
   b. Loading Rate: \( r = \frac{Sbd^2}{L} \) where \( S = \) Rate of stress increase, \( b = \) width, \( d = \) depth, \( L = \) span
   c. 125 psi/min = \( \frac{125 \times 6 \times 6^2}{18} = 1,500 \) lbs per minute.
   d. 175 psi/min = \( \frac{175 \times 6 \times 6^2}{18} = 2,100 \) lbs per minute.

7. Some common flexural testing errors include:
   - Placing the specimen in the machine with the incorrect side to the top.
   - Improper Load Rates used.
   - Specimen allowed to dry out inducing tensile loading due to shrinkage.
   - Incorrect formula used for calculations.

F.8 Measurements after the Test

After the test, measure the width and depth at the fractured face. Take three measurements for each, one at each edge and one in the center for a total of six measurements. Calculate the average width and depth of the specimen at the failure plane.

If the fracture passes through capping material used to create a plane surface, include the thickness of the cap in the measurements.

If the fracture occurs outside of the middle third of the tension surface, take three measurements from the fracture to the nearest support block. Take a measurement at each edge and one in the center.
F.9 Calculations

1. If the fracture occurs in the middle third of the tension surface of the specimen, use this equation:

   \[ R = \frac{PL}{bd^2} \]

   - \( R \) = Modulus of Rupture (Flexure) rounded to 5 psi
   - \( P \) = Maximum Load, lbs
   - \( L \) = Span Length, in.
   - \( b \) = Average Width measured to 0.05 in. or smaller
   - \( d \) = Average Depth measured to 0.05 in. or smaller

2. If the fracture occurs outside the middle third of the tension surface of the specimen by not more than 5% (0.9 in.) of the span length, then use this equation:

   \[ R = \frac{3Pa}{bd^2} \]

   - \( R \) = Modulus of Rupture (Flexure) rounded to 5 psi
   - \( P \) = Maximum Load, lbs
   - \( a \) = Average distance from the fracture to the nearest support, in. (i.e. the bottom bearing block)
   - \( b \) = Average Width measured to 0.05 in. or smaller
   - \( d \) = Average Depth measured to 0.05 in. or smaller

   Note: “a” can vary from 5.1” to 6.0”.

3. If the fracture occurs outside the middle third of the tension surface by more than 5% of the span length, then discard the test results.
F.10  Report

The report should include:

- Specimen identification number
- Peak Load, lbs
- Average Width, (0.05" or better)
- Average Depth, (0.05" or better)
- Span Length, in.
- Date of test
- Time of test
- Age of specimen
- Curing History
- Rate of loading
- Modulus of Rupture calculated to nearest 5 psi
- Location of fracture & which equation was used
- Whether the sample was molded or sawed
FLEXURE STRENGTH OF CONCRETE – T 97

CONCRETE DATA

Date Cast: ___________________________  Set Number: _________________
Date Tested: ___________________________  Age: _________________________

TEST DATA

<table>
<thead>
<tr>
<th></th>
<th>Beam A</th>
<th>Beam B</th>
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</tr>
<tr>
<td>Width (0.05” or better)</td>
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<td>Width (0.05”)</td>
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<td>Width (0.05”)</td>
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<tr>
<td>Average Width (0.05”)</td>
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<tr>
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<tr>
<td>Depth (0.05”)</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Sum</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Average Depth (0.05”)</td>
<td>______</td>
<td>______</td>
</tr>
</tbody>
</table>

| Modulus of Rupture (5 psi) | ______ | ______ |

REFERENCE INFORMATION

NOTE: Width and Depth should be measured to the nearest 0.01” if possible.

\[
\text{Average Width} = \frac{B_1 + B_2 + B_3}{3} \quad \text{Average Depth} = \frac{D_1 + D_2 + D_3}{3}
\]

\[
\text{Case 1: Modulus of Rupture} = \frac{PL}{bd^2} \quad \text{Case 2: Modulus of Rupture} = \frac{3Pa}{bd^2}
\]
## FLEXURE STRENGTH OF CONCRETE – T 97

### CONCRETE DATA

Date Cast: ___________________________  Set Number: __________________

Date Tested: _________________________  Age: ________________________

### TEST DATA

<table>
<thead>
<tr>
<th></th>
<th>Beam A</th>
<th>Beam B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Load (lb)</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Width (0.05” or better)</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Width (0.05”)</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Width (0.05”)</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Sum</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Average Width (0.05”)</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Depth (0.05” or better)</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Depth (0.05”)</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Depth (0.05”)</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Sum</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Average Depth (0.05”)</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Modulus of Rupture (5 psi)</td>
<td>______</td>
<td>______</td>
</tr>
</tbody>
</table>

### REFERENCE INFORMATION

**NOTE:** Width and Depth should be measured to the nearest 0.01” if possible.

\[
\text{Average Width} = \frac{B_1 + B_2 + B_3}{3} \quad \text{Average Depth} = \frac{D_1 + D_2 + D_3}{3}
\]

\[
\text{Case 1: Modulus of Rupture} = \frac{PL}{bd^2} \quad \text{Case 2: Modulus of Rupture} = \frac{3Pa}{bd^2}
\]
Test Method Summary ........................................................................................................G-2
Equipment .........................................................................................................................G-2
Dimetral Marking Jig ..........................................................................................................G-3
Measurements before the Test ..........................................................................................G-3
Splitting Tensile Testing Procedure ................................................................................G-4
Calculations ........................................................................................................................G-5
Report ................................................................................................................................G-5
Blank Worksheets can be found at the end of this Topic.
G.1 Test Method Summary

This procedure covers determination of the splitting tensile strength of concrete specimens in accordance with AASHTO T 198 using an aligning jig to apply a force along the dimetral plan of a concrete cylinder. The application of this force splits the cylinder in half down it entire length. The specimen should be molded, cured, and stored according to AASHTO T 23.

G.2 Equipment

1. Testing machine with aligning jig containing a bearing bar
   - Rate of loading 100 to 200 psi/min
2. Jig for marking dimetral lines on cylinder
3. Plywood bearing strips: 1/8 in. thick by 1 in. wide & longer then cylinder
4. Calipers with 3.5 in. long jaws
5. Ruler to measure length to 0.1” increments that is 14 in. or longer
6. Stopwatch
7. Magic Marker
8. Water Storage Tank or Moist-cure Room
9. Hydrated lime
10. Recording thermometer
G.3 Dimetral Marking Jig

Draw dimetral lines on the each end of the cylindrical specimen using the dimetral marking jig to ensure that the lines are in the same axial plane. Connect the lines on the ends of the specimen with a line along the side of the cylinder in the same dimetral plane.

A dimetral marking jig shall be used to mark the ends of the cylinder. It is not optional.

A ruler that is at least 14 in. long should be used to connect the dimetral lines on the ends of the cylinder.

G.4 Measurements before the Test

Before performing the test, measure the diameter near each end and the middle of the specimen to the nearest 0.01 in. The measurements should be taken on the dimetral plane such that each jaw on the caliper is touching a magic marker line. Average the three measurements. Take two length measurements to the nearest 0.1 in., one at each edge of the specimen on the dimetral plane. Calculate the average length of the specimen.
G.5 Splitting Tensile Testing Procedure

1. AASHTO M 201 outlines procedures for maintaining moist storage rooms and water storage tanks. Concrete cylinders should be lab-cured in the same fashion as compressive strength concrete cylinders.

2. Place the aligning jig in the testing machine.
   a. Position a one-time use plywood bearing strip on the jig.
   b. Position the cylinder using the dimetral lines on the cylinder in reference to the horizontal guide plate, and the openings in the jig.
   c. Place another plywood bearing strip on the cylinder.
   d. Position the bearing bar. Some jigs have locking screws that hold the bar up until it’s released to lower down onto the bearing strip on the specimen.

3. Apply the load continuously at a rate of 100 to 200 psi/min until failure.
   a. This load rate is extremely slow and may require running a test on an extra sample to adjust the testing machine correctly.
   b. Loading Rate: \( P = \frac{\pi S l d}{2} \)
      
      \( S = \) Loading Rate, \( \pi = 3.14 \), \( l = \) average length, \( d = \) average diameter
      
      c. 100 psi/min = 100 x 3.14 x 12 x 6 / 2 = 11,300 lbs per minute
      d. 200 psi/min = 200 x 3.14 x 12 x 6 / 2 = 22,600 lbs per minute

4. Run the test to complete failure. Record the maximum load. Note the type of fracture regarding whether it was splintered or not. Also note the proportion of coarse aggregate that was fractured during the test.
G.6 Calculations

Use this equation to calculate the splitting tensile strength:

\[ T = \frac{2P}{\pi ld} \]

- \( T \) = Splitting Tensile Strength rounded to 5 psi
- \( P \) = Maximum Load, lbs
- \( l \) = Average Specimen Length measured to 0.1 in.
- \( d \) = Average Diameter measured to 0.01 in.

G.7 Report

The report should include:

- Specimen identification number
- Average diameter, (0.01”)
- Average length, (0.1”)
- Date of test
- Time of test
- Age of specimen
- Curing history
- Rate of loading
- Maximum load
- Splitting Tensile Strength calculated to nearest 5 psi
- Type of fracture
- Estimate of proportion of coarse aggregate fractured during the test
- Defects in the specimen
- Type or size of specimen
# SPLITTING TENSILE STRENGTH – T 198

## CONCRETE DATA

<table>
<thead>
<tr>
<th>Date Cast</th>
<th>Set Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date Tested:</td>
<td>Age:</td>
</tr>
</tbody>
</table>

## TEST DATA

<table>
<thead>
<tr>
<th></th>
<th>Cylinder A</th>
<th>Cylinder B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (0.01&quot;)</td>
<td></td>
<td></td>
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<tr>
<td>Diameter (0.01&quot;)</td>
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<tr>
<td>Diameter (0.01&quot;)</td>
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<td></td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ave. Diameter (0.01 sq in)</td>
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<td></td>
</tr>
<tr>
<td>Length (0.1&quot;)</td>
<td></td>
<td></td>
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<tr>
<td>Length (0.1&quot;)</td>
<td></td>
<td></td>
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<tr>
<td>Sum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Length (0.1&quot;)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Load (lb)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Splitting Strength (5 psi)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## REFERENCE INFORMATION

\[
\text{Average Diameter} = \frac{D_1 + D_2 + D_3}{3} \quad \text{Average Length} = \frac{L_1 + L_2}{2}
\]

\[
\text{Splitting Tensile Strength} = \frac{2P}{\pi LD}
\]
### SPLITTING TENSILE STRENGTH – T 198

#### CONCRETE DATA

<table>
<thead>
<tr>
<th>Date Cast</th>
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</thead>
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<td></td>
<td></td>
</tr>
<tr>
<td>Ave. Diameter (0.01 sq in)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Splitting Strength (5 psi)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### REFERENCE INFORMATION

- **Average Diameter**
  
  \[ \text{Average Diameter} = \frac{D_1 + D_2 + D_3}{3} \]

- **Average Length**
  
  \[ \text{Average Length} = \frac{L_1 + L_2}{2} \]

- **Splitting Tensile Strength**
  
  \[ \text{Splitting Tensile Strength} = \frac{2P}{\pi LD} \]
Note: Check the CMM link to verify the latest version

http://roadwaystandards.dot.wi.gov/standards/cmm/
MATERIAL DATA REPORTING FOR QC, QA, QV, IA ON HIGHWAY CONSTRUCTION PROJECTS

Materials Reporting Systems Tutorials

<table>
<thead>
<tr>
<th>Materials Information Tracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Materials Reporting System Hot Mix Asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRSHPMA effectively implements QMP by collecting field data entered by the contractor by lot and sublot for transmission to the State agency.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Materials Reporting System Portland Cement Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRSPCC effectively implements QMP by collecting field data entered by the contractor by lot and sublot for transmission to the State agency.</td>
</tr>
</tbody>
</table>

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>
<tr>
<td>Field Information Tracking (FIT)</td>
<td>Provides data collected from project sites and merged data from Field Manager. Data collected is sent to Project Tracking via Atwood.</td>
<td>WISDOT Staff. Contractors.</td>
<td>Field job sites</td>
</tr>
<tr>
<td>Materials Information Tracking (MIT)</td>
<td>Captures QV, QA, IA and Verification test reporting for a multitude of materials.</td>
<td>WISDOT Staff.</td>
<td>Field job sites</td>
</tr>
<tr>
<td>MATERIALS REPORTING SYSTEM - QUALITY MANAGEMENT PROGRAM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRS Hot Mix Asphalt</td>
<td>Asphalt QC data collection by Lot and Sub-lot by date. Used by Contractors.</td>
<td>Used by Contractors.</td>
<td>Field job sites</td>
</tr>
<tr>
<td>MRS Portland Cement Concrete</td>
<td>Concrete pavement, structures (by lot / sub-lot and thickness QC data collection.</td>
<td>Used by Contractors.</td>
<td>Field job sites</td>
</tr>
<tr>
<td>MRS International Roughness Index</td>
<td>Pavement smoothness QC / QA data collection.</td>
<td>WISDOT Staff. Contractors.</td>
<td>Field job sites</td>
</tr>
</tbody>
</table>

WEB-BASED REPORTING SYSTEMS
<table>
<thead>
<tr>
<th>System</th>
<th>Description</th>
<th>Owner</th>
<th>Source</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.atwoodsystems.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. Source sampled materials tested and reported by C.O. personnel (see verification tests C.O. Lab above).</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. Source sampled materials tested and reported by C.O. personnel (see verification tests C.O. Lab above).</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>Cert. Report of Test</td>
<td>Certified Report of Test</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>Verification tests-MTS Report.</td>
<td>Field Sampling and Testing</td>
<td>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</td>
<td>No later than one week after completion of test.</td>
<td>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.</td>
</tr>
<tr>
<td>Quality Management Program (QMP) Quality Control (QC) tests.</td>
<td>Field Sampling and Testing</td>
<td>MTS Report 155</td>
<td>No later than 60 days after contract work completion date-prefix 155 data.</td>
<td>MRS data is to be input by the contractor as it is developed. Refer to Figure 1, Figure 2, and Figure 3 for examples of prefix 155 reports for verification of contractor QMP and QC testing.</td>
</tr>
</tbody>
</table>

![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.
Appendix:

1) Understanding Concrete Core Testing, NRMCA Publication No. 185, by Bruce A. Suprenant, Part III, pgs. 13-16.

2) Field Curing of Beams

3) Beam Data

4) Beam Mark Up

5) Lab Exam

6) QMP Award

7) Corrections

8) Evaluation
Part III - Factors Affecting Core Strength

Many factors influence the compressive strength of cores, but some are not well known. These factors include the practical considerations of obtaining and testing cores. Before making the final decision of accepting or rejecting concrete, consider all the factors that influence concrete core test results.

Effect of drilling

The drilling operation can damage some of the bond between the cut aggregate-paste interface or dislodge coarse aggregate, possibly reducing the core's compressive strength. Occasionally, some damage is apparent when drilling immature or inherently weak concrete, but normally it is not possible to see any damage on the cut surface of the core. ASTM C42 (Reference 7) recommends waiting 14 days before drilling cores to minimize bond damage between the cut aggregate and paste.

Two investigations tested sleeved cylinders, cast integrally within the concrete slab, and cores of the same size and shape as the cylinders. Campbell and Tobin (Reference 36) cast 6-inch (150 mm) diameter metal sleeves in each of four 12-inch (300 mm) thick slabs. At 28, 56, and 91 days, the strength of pairs of sleeved cylinders was compared with the strength of pairs of cores of the same size and shape. On average, the sleeved cylinders had strength 5% greater than the strength of the cores.

Similar tests were conducted by Bloem (Reference 33). Pairs of slabs were cast from each of three concrete mixes, one being well cured and one poorly cured. Each slab was cast with 36 plastic inserts to enable cylinder removal for testing at six different ages. The results were compared with those of 36 corresponding cores taken from each slab. The compressive strength of the sleeved cylinders averaged 7% greater than the corresponding core strength.

Field core-drilling equipment and techniques can be quite different from those used in the research laboratory. Because of this, consider research laboratory studies on the effect of drilling as low-end values. In practice, cores severely damaged during drilling are not usually tested. This follows an ASTM C42 requirement that states "samples that show abnormal defects or samples that have been damaged in the process of removal shall not be used."

Wet versus dry

ASTM C42 requires cores to be moisture conditioned by placing the test specimens in lime-saturated water for at least 40 hours just prior to testing. This ASTM standard, however, does allow a specifying authority to designate a different moisture conditioning process. Occasionally, contractors and testing labs wrongly interpret themselves as the "specifying authority."

ACI 318 (Reference 1) and ACI 301 (Reference 37) conditioning requirements are based upon the anticipated service environment for the structure. Cores should be conditioned by drying or soaking for dry or wet service environments. Unfortunately, ACI 318 defines a wet service environment as "concrete that will be more than superficially wet." This vague definition is disappointing in a specification document and ACI 318 should, at least, address this issue in the Commentary.

The measured strength of a core depends upon its moisture condition. The compressive strength ratio of wet-versus-dry cores varies. The ACI 318-63 Commentary (Reference 38) states that dry cores may be 15% to 20% stronger than wet cores. Some studies show a lower and others a higher strength difference than that suggested by ACI 318-63.

Suprenant (Reference 39) presented core strengths from bridge decks. The average dry-core compressive strength was 30% stronger than the average wet-core compressive strength. Mehta (Reference 40) also indicates that a 30%
strength difference is possible. Bloem (References 12 and 33) found a strength difference between dry and wet cores of 20% for normal-weight concrete and 7% to 10% for structural lightweight concrete. Campbell and Tobin (Reference 36) found a 7.5% difference between dry and wet cores for lightweight concrete.

Akers and Miller (Reference 41) found strength differences varying from 0% to 25%. The strength difference between dry and wet cores decreased with time. Cores tested at 300 days had a much smaller strength difference than cores tested at 56 and 28 days.

Because the strength variation can be as much as 30%, the choice of testing wet or dry is very important. Testing cores dry, rather than wet, can alter the acceptance or rejection of concrete based on ACI 318 criteria. In practice, cores from interior or protected concrete are usually tested dry since the concrete is expected to be in a dry service environment. Cores from exterior concrete, including foundations, are tested wet because of the possible exposure to a wet environment. Exterior walls are more controversial. Some engineers believe that exterior walls never absorb enough moisture to be saturated. The rain or snow stops, the wall drys, thus cores should be tested dry. Other engineers believe that if the wall is exterior, exposed to rain or snow, that cores should be tested wet.

One rule of thumb is to test air-entrained concrete wet and non-air-entrained concrete dry. It's anticipated that entrained air is used in the concrete because of the potential for a wet, freezing environment. However, entrained air is added for a variety of reasons, including workability, which does not always indicate a wet environment.

If cores are to be tested dry, ACI 318 requires seven days at 70 °F (22 °C) as the drying time. On some high-rise construction projects, one week of drying is equivalent to building another story. Time is money, so a drying time of seven days at 70 °F (22 °C) may need reexamination. Pettersons (Reference 14) indicates that 3- and 4-inch (75 to 100 mm) diameter cores need only two to three days of drying to achieve their ultimate dry strength. A very practical and advantageous procedure is to remove cores on Friday, dry them over the weekend, and test on Monday.

Length-to-diameter ratio

Core strength increases as the ratio of its length-to-diameter (l/d) decreases. While this general concept has been accepted, the amount by which the compressive strength of the core increases is still debated.

According to ASTM C 42, the l/d ratio of a capped core specimen should not exceed 2.10 nor be less than 1.00. If l/d is between 1.94 and 2.10, no correction factor is necessary. Interpolation between the correction factors given in the table is permitted. The ASTM l/d correction factors are applicable for lightweight concrete with densities ranging from 100 to 120 pcf, normal weight concrete, and for wet or dry cores with strengths ranging from 2000 to 6000 psi (13.8 to 41.4 MPa).

Meininger et al. (Reference 34) tested cores to determine the effect of length-to-diameter ratio. The test variables included strength levels ranging from 2000 to 7500 psi (13.8 to 51.7 MPa), cores tested wet and dry, and different l/d ratios. His work serves as the basis for the current provisions in ASTM C 42. Table 3 shows length-to-diameter ratios recommended by other investigators.

Some studies have been performed for l/d less than 1. For instance, Chung (Reference 44) proposed an equation for l/d correction factors from 2.0 to 0.4. Occasionally, cores with an l/d less than 1.0 are tested, making Chung's equation useful. However, this would not be in strict accordance with ASTM C 42 requirements.

Chung's equation is:

**Correction Factor =** \( \frac{1}{1 + 0.8 \times (1 - 0.5 \times \lambda)^2} \)

where: \( \lambda = \frac{\text{length}}{\text{diameter}} \)
TABLE 3. Length to Diameter Correction Factors for Cores

<table>
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<tr>
<th>l/d</th>
<th>0.50</th>
<th>--</th>
<th>--</th>
<th>0.59</th>
<th>--</th>
<th>0.53</th>
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<td>1.00</td>
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<td>0.80</td>
<td>0.81</td>
<td>0.82</td>
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<tr>
<td>1.25</td>
<td>0.93</td>
<td>0.87</td>
<td>--</td>
<td>--</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>1.50</td>
<td>0.96</td>
<td>0.92</td>
<td>0.92</td>
<td>0.98</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td>1.75</td>
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<td>0.99</td>
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</tr>
<tr>
<td>2.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>3.00</td>
<td>--</td>
<td>--</td>
<td>16</td>
<td>43</td>
<td>44</td>
<td></td>
</tr>
</tbody>
</table>

Reference 7 42 16 43 44

ASTM BSI Lewandowski Sangha Chung

Volume effect
Many investigators have shown that concrete strength increases as the cylinder specimen size decreases. For instance, 4 x 8-inch (100 x 200mm) cylinders are about 5% stronger than 6 x 12-inch (150 x 300 mm) cylinders. Meininger (Reference 21) found the ratio of compressive strengths of 4- to 6-inch (100 to 150 mm) diameter cores to be 0.98. Because the effect of volume on core strength is so small, it is usually ignored. This is appropriate considering all the other factors that influence core strength.

Core diameter
ASTM C 42, Section 6.1, provides requirements for minimum core diameter:

"The diameter of core specimens for the determination of compressive strength should preferably be at least three times the nominal maximum size of the coarse aggregate used in the concrete, and must be at least twice the maximum nominal size of the coarse aggregate in the core sample."

For concrete with a 1-inch (25 mm) maximum coarse aggregate size, Section 6.1 dictates a preferred core diameter of 3 inches (75 mm) but would accept a core diameter of 2 inches (50 mm).

Section 5 of ASTM C 42 indicates that the core specimen must be a minimum of 4 inches in diameter to determine the specimen length. In practice, this requirement is generally considered to address only thickness measurements for pay determination and not as an additional requirement for minimum core size when determining compressive strength.

Very often, practical constraints prohibit large-diameter cores. On a recent project with 3/4-inch (75 mm) maximum aggregate, 1-inch (25 mm) diameter cores were removed to prevent any damage to adjacent prestressing strands. The cores were tested in compression to evaluate the effects of fire damage.

The difference between small, 2-inch (50mm), and large, 4-inch (100 mm), core diameters has been addressed by many investigators (References 15, 45; 46, 47, 48, 49). The general conclusions from these studies are:

1. The volume effect on compressive strength between 2-inch (50 mm), 3-inch (75 mm) and 4-inch (100 mm) core diameters is not significant.
2. Core diameters as low as 1.6 times the maximum nominal aggregate size can yield the same mean compressive strength as larger-diameter cores.
3. The testing error increases as the diameter of the core decreases.

These conclusions suggest that engineers may use smaller-diameter cores to evaluate the concrete compressive strength, but a greater number of smaller cores need to be tested. Keiller (Reference 15) reported the average coefficient of variation for 4-inch (100 mm), 3-inch (75 mm), and 2-inch (50 mm) cores as 4%, 6%, and 8%, respectively. To obtain the same degree of testing certainty as three 4-inch (100 mm) diameter cores, test six 3-inch (75 mm) diameter cores or twelve 2-inch (50 mm) diameter cores (to calculate these numbers use the equation described in "Why Three Cores?" Part I).

**Embedded reinforcement**

If possible, cores containing reinforcing steel should be avoided. Use a magnetic rebar locator to find steel and other metallic embedment, especially electrical conduit that poses a threat to the core driller's safety. ASTM C 42 indicates that cores containing embedded reinforcement can yield either higher or lower values than cores without embedded steel. They suggest avoiding these cores or, if possible, trimming the cores to eliminate the reinforcement, provided a length-to-diameter ratio of 1.00 or greater is attained. Gaynor (Reference 50) recommends trimming the cores to remove transverse steel if the length-to-diameter ratio can be maintained above 1.5.

Gaynor (Reference 51) tested a total of 66 cylinders, some reinforced. Some were reinforced with one bar and others with two perpendicular bars. All bars were perpendicular to the direction of casting. The particular location of the bars was found to have little effect on the cylinder strength. The average compressive strength reduction for one bar was about 8% and, for two bars, about 12%.

A series of tests conducted in Germany (Reference 16) involved more than 300 cores removed vertically from slabs. The cores were 6 inches (150 mm) high and 4 inches (100 mm) in diameter. The testing variables included percentage of reinforcement, the number of bars, the position of bars, and concrete strength. The results indicate that the volume of reinforcement had little effect on the measured strength, the maximum reduction being 3%.

**Tension versus compression**

Although not found in the literature, the author's experience indicates that cores drilled from tension and compression regions of a continuous beam may have different strengths. On one project, cores were drilled vertically from the compression zone of a beam. The cores' compressive strengths were used to determine the anchorage length of inserts placed in the tension side of the beam. On proof loading, the anchors pulled out.

For this project, the beams were cracked and excessive deflection had occurred. Removing the cores from the tension zone would have provided a more realistic estimate of the surrounding concrete strength and the required anchorage length. For new construction, concrete microcracking occurs due to construction loading of early-age members.

A correction factor is not possible, so drill cores from a compression region when evaluating low-strength concrete. Cores drilled from the tension region or a high-shear diagonal tension region of a member should be so noted on the test report.
### HIGHWAY TECHNICIAN CERTIFICATION PROGRAM
THE UNIVERSITY OF WISCONSIN - PLATTEVILLE

**CONCRETE STRENGTH TESTER**

**QUALIFYING LABORATORY EXAM**

<table>
<thead>
<tr>
<th>AREA OF QUALIFICATION</th>
<th>PASS/FAIL</th>
<th>INSTRUCTOR</th>
</tr>
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<tbody>
<tr>
<td>A. Sulfur Cap Concrete Cylinder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Test Concrete Cylinder to failure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Explain AASHTO # T-97 Beam, Flexure, 3rd Pt.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Explain AASHTO # T-198 Tensile, Strength</td>
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<td>Competencies to Demonstrate or Explain</td>
<td>Measurable Quantifiable Activity</td>
<td>Pass (P)/Fail (F)</td>
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</tr>
<tr>
<td><strong>Sulfur Cap Concrete Cylinder</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Identify capping material</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Strip cylinder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Cap cylinder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Perform hollowness check</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Perpendicularity-end condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Perpendicularity-diameter measure</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Test Concrete Cylinder to failure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Load machine with cylinder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Sulfur cap/neoprene-Check with square</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Describe rate of loading-Calculate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Perpendicularity-in machine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Test to failure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Describe break</td>
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<tr>
<td>7. Fill out report</td>
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<td><strong>Explain AASHTO # T-97, Beam, Flexure, 3rd Pt.</strong></td>
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<tr>
<td>1. Describe the required equipment</td>
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<tr>
<td>2. Describe the procedure</td>
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<td>3. Describe the report</td>
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<td><strong>Explain AASHTO # T-198, Tensile, Strength</strong></td>
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<td>3. Describe the report</td>
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</table>
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.
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>
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<th>Average</th>
<th>Below Average</th>
<th>Unacceptable</th>
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<td>3</td>
<td>2</td>
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<tr>
<td>How well were you satisfied with the quality and quantity of the course materials?</td>
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<td>4</td>
<td>3</td>
<td>2</td>
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Comments about course materials/visual aids: ____________________________________________________________

2. **Instructor:** ____________________________

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<th>Below Average</th>
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<td>Ability to communicate:</td>
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<tr>
<td>Knowledge of course content:</td>
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3. **Please fill in and rate overall effectiveness of laboratory instructor(s)/guest lecturer(s):**

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<th>Below Average</th>
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<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Comments: Please make additional comments about individual laboratory instructor(s)/guests lecturer(s) quality of instruction: ____________________________________________________________