# NOTICE

# UDOT-TTQP

UDOT "TTQP" manual included; Long Form Versions listed.

- "WAQTC/TTQP" Certifications are listed as a 5 day course.
- 3 min. days of "Training" (completed outside of certification days).
- 2 days of "Certification" (completed at UDOT Central unless otherwise specified).

3 training + 2 certifying = 5 days!

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## GUIDANCE FOR COURSE EVALUATION FORM

The Course Evaluation Form on the following page is very important to the continuing improvement and success of this course. The form is included in each Participant Workbook. During the course introduction, the Instructor will call the participants' attention to the form, its content, and the importance of its thoughtful completion at the end of the course. Participants will be encouraged to keep notes, or write down comments as the class progresses, in order to provide the best possible evaluation. The Instructor will direct participants to write down comments at the end of each day and to make use of the back of the form if more room is needed for comments.

On the last day of the course, just prior to the written examination, the Instructor will again refer to the form and instruct participants that completion of the form after their last examination is a requirement prior to leaving. Should the course have more that one Instructor, participants should be directed to list them as A, B, etc., with the Instructor's name beside the letter, and direct their answers in the Instructor Evaluation portion of the form accordingly.

# UTAH DEPARTMENT OF TRANSPORTATION TTQP
# COURSE EVALUATION FORM

The UDOT Transportation Technician Qualification Program would appreciate your thoughtful completion of all items on this evaluation form. Your comments and constructive suggestions will be an asset in our continuing efforts to improve our course content and presentations.

Course Title: _____

Location: _____

Dates: _____

Employer: _____

Instructor(s) _____

Please circle your responses to the following questions, where 1 is the lowest and 5 is the highest rating. If you wish to make comments, do so in the space provided at the end of the form.

**COURSE MATERIALS**

1. Were the manuals written so that instructional material was clearly presented?

   1 2 3 4 5

2. Did the review questions at the ends of the Field Operating Procedures help you understand the information presented in the manuals?

   1 2 3 4 5

3. How effective were the PowerPoint review presentations in helping you understand the study materials?

   1 2 3 4 5

4. How effective was the sample test in helping you prepare for the written examinations?

   1 2 3 4 5

**CLASSROOM INSTRUCTION**

5. Were the instructors knowledgeable, and did they clearly communicate the information?

   Instructor #1 Name: _____ 1 2 3 4 5

   Instructor #2 Name: _____ 1 2 3 4 5

6. Did the instructors create an open atmosphere in which to ask questions, and give adequate attention in answering them?

   Instructor #1 Name: _____ 1 2 3 4 5

   Instructor #2 Name: _____ 1 2 3 4 5

7. Did the instructors clearly explain the format and rules of the examinations prior to testing?

1 2 3 4 5

8. How would you rate the quality of the classroom (physical layout, ability to hear instructors, see presentations, etc.?

1 2 3 4 5

**PRIOR TRAINING AND STUDY**

9. Did you receive an adequate amount of technical and hands-on training from your employer prior to attending the qualification course, to adequately prepare you for the scope of course material?

1 2 3 4 5

10. How confident are you in your ability to perform all the tests in this qualification module?

1 2 3 4 5

11. How many days in advance did you obtain a copy of the manual (before coming to class)?

0-7 8-14 15-21 22-28 More than 28

12. How many hours did you spend studying the written materials in the manual?

0-5 6-10 11-15 16-20 21-25 More than 25

**GENERAL COMMENTS**

General comments on the course, content, materials, presentation method, facility, registration process, etc. Suggestions for additional Tips!

_____

_____

_____

_____

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# COURSE OBJECTIVES AND SCHEDULE

## Learning Objectives

Instructional objectives for this course include:

- Becoming proficient in the following test procedures:

  MANDATORY BACKGROUND INFORMATION

  AASHTO T 23
  Making and Curing Concrete Test Specimens in the Field

  AASHTO T 22
  Compressive Strength of Cylindrical Concrete Specimens

  AASHTO T 97
  Flexural Strength of Concrete

  AASHTO T 231
  Capping Concrete Test Specimens

  ASTM C 1231
  Use of Unbonded Caps in Compressive Strength

The overall goals of this course are to understand the basics of concrete strength testing and to be competent with specific quality control test procedures identified for the Utah Department of Transportation (UDOT) Transportation Technician Qualification Program (TTQP).

It is assumed that the student has previously obtained a copy of the manual, and has adequately prepared for the qualification by studying and receiving training from a senior trainer.

## Course Outline and Suggested Schedule

### Day One

| | |
|---|---|
| 0900 | Welcome<br>Introduction of Instructors |
| 0915 | Presentations |
| 1200 | Lunch |
| 1300 | Presentations. Distribute copies of Sample Exams |

### Day Two

| | |
|---|---|
| 0800 | Review Sample Exam and answer questions from the Previous Day |
| 0900 | Start of Written Exams |
| Varies | Practical Exams (After successful completion of written exam) |

# MANDATORY BACKGROUND INFORMATION

02

## Scope

This section of the manual provides mandatory background information that supplements the Field Operating Procedures (FOP's) that follow.

The following AASHTO standard test procedures, practices, and specifications are covered:

03

**AASHTO T 24** - Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

**AASHTO R 39** - Making and Curing Test Specimens in the Laboratory

**AASHTO M 201** - Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

**AASHTO M 205** - Molds for Forming Concrete Test Cylinders Vertically

Each of these will be treated in summary form. Reference to the source documents is recommended when a more complete understanding of the information is required for conducting testing required by the governing agency.

04

## Significance

A working knowledge of the critical elements of each of the previously mentioned procedures, practices, and specifications is required for persons conducting strength testing of concrete specimens.

In several cases, information not otherwise provided by strength-testing procedures is included that is required for properly preparing specimens for testing.

05 ## AASHTO T 24 – Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

06 ### Introduction

AASHTO T 24 includes procedures for obtaining cores for the purpose of thickness measurements and splitting tensile strength as well as for compressive strength. It also describes procedures for obtaining and preparing sawed beams for flexural strength testing.

A description of cores for measurement of thickness or determination of splitting tensile strength **is not** included in this manual. Refer to the source documents in the current AASHTO publications for these procedures.

07 ### Apparatus

- Cutting edges must prevent overheating or shock to the specimens. Core drills with a diamond cutting edge for cylindrical specimens are required. Saw blades having either a diamond or silicon carbide cutting edge are permitted.

08 ### Sampling

**General:** Concrete must be sufficiently hardened to avoid damage during cutting and handling. Concrete must generally be at least 14 days old.

Specimens that contain obvious defects or that have been damaged shall not be used.

Specimens used for determining compressive or flexural strength may not contain embedded reinforcement.

09 **Core Drilling:** Locations for obtaining cores should avoid formed joints and obvious edges of a unit of deposit. Ideally, cores should be drilled such that the axis is perpendicular to the bed of the concrete as placed.

Where cores must be drilled perpendicular to a vertical surface or from a surface with a batter, locations should be selected near the middle of a

unit of deposit.

10 **Slab Removal:** Slabs must be large enough to yield the required number and sizes of specimens while avoiding cracked, spalled, undercut, or otherwise damaged areas.

11 ## Cores for Compressive Strength

- **Test Specimens**: Minimum nominal diameter shall be 3.75 inches unless it is not possible to maintain a length to diameter ratio (L/D) ≥ 1.0 for compressive strength determinations. When the concrete contains aggregate larger than 1½" the core diameter should preferably be three times, but in no case less than two times the nominal maximum aggregate size.

  The preferred ratio of L/D after capping should be 1.90 to 2.10. Trim longer cores to achieve that ratio. Cores with L/D equal to or less than 1.75 require correction to the measured strength. In no case shall a specimen be tested when L/D is less than 0.95 prior to capping or less than 1.00 after capping.

12 - **End Preparation:** Ends of cores should be smooth, perpendicular to the axis, and of the same diameter as the remainder of the core. Projections may not exceed 0.2 inches beyond the end.

- **Dimensional Tolerance:** Ends shall not depart from perpendicularity to the axis by a slope greater than 1:8*d*, where *d* equals the average core diameter (inches). End diameter shall not depart by more than 0.1 inch from the mean core diameter.

13 - **Moisture Conditioning:** To increase reproducibility and minimize the effects of moisture gradients, cores are to be moisture conditioned.

  After cores have been drilled, surface-dry the specimen by wiping with a cloth and allow surface moisture to evaporate. Within 1 hr of drilling, when surfaces appear dry, seal in separate plastic bags or other non-absorbent containers. Maintain at ambient temperature and

protect from direct sunlight.

14 Keep cores in sealed containers at all times except during end preparation. A maximum of 2 hours is allowed to permit capping before testing. If water is used during sawing or grinding, complete this as soon as practicable, but no later than two days after drilling. Wipe off surface moisture from sawing or grinding, allow to air dry, and reseal in plastic bags or non-absorbent containers. Minimize exposure to water during end preparation.

Cores should remain in sealed containers a minimum of five days after last being wetted before testing to reduce moisture gradients caused during drilling, sawing, or grinding.

At the discretion of the specifying agency, other moisture conditions may be required. Consult agency guidelines. Report alternate moisture conditioning when necessary.

15
- **Capping:** Cap according to the applicable provisions of the FOP for AASHTO T 231 (presented later).
- **Measurement:** Measure diameter to the nearest 0.01 inch, and length after capping to the nearest 0.1 inch. Diameter measurements shall be taken at mid-height of the specimen and shall be the average of two measurements at right angles to each other. Do not test cores when the difference between the largest and smallest diameters exceeds 5 percent of their average. Determine cross-sectional area.

16
- **Testing:** Test according to the FOP for AASHTO T 22. Test within 7 days of obtaining the core unless otherwise specified.

17
- **Calculations:** Calculate compressive strength of each specimen, dividing the maximum load by the cross-sectional area. If the ratio of length to diameter (L/D) is 1.75 or less, correct the result by applying the appropriate correction factor from Table 1.

**Table – 1 Strength Correction Factors Based on L/D** 18

| Ratio of Length to Diameter (L/D) | Strength Correction Factor |
|---|---|
| 1.75 | 0.98 |
| 1.50 | 0.96 |
| 1.25 | 0.93 |
| 1.00 | 0.87 |

19 The correction factors are applicable for lightweight concrete with density of 100 to 120 lb/ft$^3$ and normal weight concrete. They apply to both dry and wet specimens for strengths of 2000 to 6000 psi. For high-strength concrete (above 10000 psi) correction factors may be higher than those shown and caution should be exercised in their application.

20 **Report**

- Report as for the FOP for AASHTO T 22 but including the following additional items:
- Specimen length as drilled.
- Specimen length before and after capping.
- Direction of load application in relation to the horizontal plane of the concrete as placed.
- Moisture conditioning history.
- Any deviations from this test method.
- Nominal maximum aggregate size.

**Sawed Beams**

21 - **Test Specimens**: Beam specimens should normally have nominal width and depth of 6 x 6 inches. Length shall be at least 21 inches. In some cases, other dimensions of width and depth may be dictated by aggregate size and slab thickness from which the specimens were obtained. Consult agency requirements for such conditions.

22 Sawed surfaces shall be smooth, plane and free of steps, ridges and grooves. Take care in handling to avoid cracking or chipping edges.

23 - **Moisture Condition**: Beams shall be subjected to a minimum of 40 hours soaking in lime-saturated water prior to testing. Testing shall be conducted immediately after removal from moist storage, and surfaces shall be kept continuously moist up to the time of testing.

  When the agency permits or requires, moisture condition other than that described may be used prior to testing.

24 - **Capping:** Refer to the FOP for AASHTO T 97 to determine if capping is required. If it is required, do so according to the FOP for AASHTO T 231.

25 - **Testing:** Test according to the FOP for AASHTO T 97. Since sawing may greatly reduce flexural strength, whenever possible orient the specimen for testing with a formed or finished surface as the tension face.

### Report

- Report according to T 97 but include the following additional items:
- Moisture condition at time of testing.

Orientation of the specimen's finished, sawed, and tension faces as positioned in the testing apparatus.

26 ## AASHTO R 39 – Making and Curing Concrete Test Specimens in the Laboratory

27 ### Introduction:

AASHTO R 39 includes procedures for making specimens for many tests other than strength (creep, freeze thaw resistance, bond, length change, etc.).

This manual restricts the discussion to making specimens for compressive strength and flexural strength.

28 Much of the methodology described is the same as for molding strength specimens in the field (AASHTO T 23). Duplication of information will be avoided when possible except where clarity would be sacrificed.

## Apparatus

- **Molds**: Molds shall comply with the applicable testing procedures under which specimens will be tested. Cylinder molds shall comply with AASHTO M 205. Beam molds shall comply with AASHTO T 97. Note that laboratory-molded beam specimens may use molds with cross-section less than six by six inches when allowed by the governing agency. Consult agency specifications for guidance regarding mold dimensions.

- **Tamping Rods**: Large rod: 5/8" diameter, approximately 24 inches in length with a hemispherical tip. Small rod: 3/8" diameter, approximately 12 inches in length with a hemispherical tip.
- **Mallets:** Mallet with a rubber or rawhide head weighing 1.25 ±0.50 pounds.
- **Vibrators:** Internal vibrators shall operate at a minimum of 7000 vibrations per minute, shall have a length at least 3 inches greater than the concrete layer being consolidated, and shall have a diameter not greater than one-fourth cylinder diameter or beam width.

  Table or plank vibrators shall operate at a minimum of 3600 vibrations per minute, and must permit secure clamping of the mold(s) to the apparatus.

- **Small Tools**: Shovels, scoops, trowels, etc. necessary for remixing and handling mixtures.
- **Slump Apparatus**: Conforming to AASHTO T 119.
- **Wet Sieving Apparatus**: Conforming to AASHTO T 141.

- **Air Content Apparatus:** Conforming to AASHTO T 152 or T 196.
- **Scales**: Accurate to 0.3% of the quantity of material being weighed.

***Note 1:*** Avoid using scales of large capacity to weigh small material quantities. The smallest quantity weighed should generally be 10% or more of scale capacity, or accuracy of batch proportions may suffer.

- **Temperature Measuring Device:** Conforming to the requirements of the FOP for T 309.
- **Concrete Mixers:** Power operated mixer of the revolving drum, revolving pan, or revolving paddle type. Use size and type of mixer most suitable for the type and slump of mixture being produced (pan mixers may be more suitable for very low slumps for example).

36

## Specimens

- **General:** Diameter of cylinders or least dimension of beams shall be at least three times the nominal maximum aggregate size. Hand pick occasional oversize pieces from the concrete, or wet sieve according to T 141.
- **Cylindrical Specimens:** Minimum two-inch diameter by four-inch length. When correlation or comparison testing is desired for specimens cast in the field, 6 by 12 inch specimens shall be considered the standard. Specimens shall be cast and hardened in an upright orientation.
- **Flexural Specimens:** Form with long axes horizontal and meet requirements of T 97.
- **Number of Specimens:** Mold at least three specimens from each batch for each test age. Consult agency guidelines for required test ages and series of mixtures required.

37

## Preparation of Materials

- **Temperature**: Bring temperature of concrete materials to room temperature (68 to 86° F) prior to mixing.
- **Cement:** Keep cement dry. Remove lumps by passing through a No. 20 screen. Place cement on clean plastic sheet, mix thoroughly, and return to sample containers.

- **Aggregates:** For coarse aggregates, separate into individual size fractions and recombine according to aggregate grading.

  For fine aggregate, keep in a damp condition to prevent segregation unless it will be divided into separate sizes.

  Prepare the aggregate such that a uniform moisture condition is achieved for each aggregate. Absorption of the aggregates must be determined according to AASHTO T 84 and T 85 to permit accurate adjustment of mix water to maintain desired water/cement ratio.

38 ## Aggregate Proportioning

Determine batch weights by one of the following:

1. Low absorption coarse and fine aggregates (less than 1%): Determine mass of aggregates in a "room dry" condition and make allowance for the quantity of moisture that will be absorbed during the mixing process.
2. Weigh increments of coarse aggregates and immerse for 24 hours prior to use. Decant excess water such that no pond or puddle occurs, and calculate combined aggregate and water weights required for the batch.

39

3. Bring coarse and fine aggregates to at least saturated-surface-dry (SSD) condition with the presence of a small amount of surface moisture such that excess water does not drain down from the aggregates. Determine moisture content of the aggregates and make adjustments to the batch to account for free moisture.
4. Bring coarse and fine aggregates to a SSD condition until batched for use. Avoid drying during weighing and use.

40 **Lightweight Aggregates:** Follow well-established procedures for acceptable handling and moisture conditioning of lightweight aggregates. Moisture condition of these aggregates may have important effects on slump loss, strength, etc. of the concrete.

In general it is desirable to assure at least partial saturation of the permeable pore spaces to prevent undesirable properties during and immediately after mixing.

41 **Admixtures:** Insoluble powdered admixtures not containing hygroscopic salts may be incorporated with the cement when batching. Those insoluble powdered admixtures containing hygroscopic salts should be incorporated into the sand when batched.

Liquid admixtures should be added in the mixing water. Adjustment to batch water should be made to account for the liquid contained in the admixtures.

42 Pozzolans and other insoluble materials exceeding 10 percent by weight of cement should be batched as separate ingredients.

It is important to consult the admixture manufacturer to determine sequencing of admixture addition, or to determine whether some incompatibility exists between admixtures, as undesirable effects may be noted in the concrete.

43 ## Procedure – Mixing Concrete

Only machine mixing is described. AASHTO R 39 also describes hand mixing for small quantities (less than ¼ cubic foot).

- **General:** Mix concrete of sufficient quantity so at least 10 percent excess remains after casting specimens. Do not vary the mixing procedure from batch to batch unless that is the parameter being studied. Unless otherwise specified, use the following procedure:

44 1. Butter the mixer with a batch of similar proportions and discard the butter batch taking care that an excess of concrete does not remain in the mixer.
2. Add some of the mixing water, coarse aggregate, and the liquid admixture to the mixer.
3. Start the mixer and add the fine aggregate, cement, and remaining water.

***Note 2***: An experienced operator may add the final mix water incrementally to adjust to the desired slump.

45 4. Mix all ingredients for three minutes after addition of the final ingredient. Allow the concrete to rest for three minutes, covering the mixer to prevent evaporation. Restart the mixer and mix for two more minutes.

46 - **Mixed Concrete:** Select portions of the batch to be used in tests and molding specimens to be representative of the proportions and condition of the concrete. Keep container covered except when remixing or obtaining portions for testing.

47 - **Slump, Air Content, Density, Temperature:** Determine according to AASHTO T 119, T 152 or T 196, T 121, and T 309 respectively.
- **Making Specimens**: Mold cylinders and beams according to AASHTO T 23 and R 39 using the number of layers and method of consolidation specified.

48 - **Curing**

  **Protection:** Keep specimens covered to avoid loss of moisture. If wet burlap is used, prevent it from contacting the fresh concrete surfaces.

  **Removal From Molds:** Remove from molds within 24 ±8 hours after casting.

  **Curing Environment:** Unless otherwise required, continuously moist cure at 73.4 ±3° F until tested. Storage for the first 48 hours shall be in a location free of vibration.

  **Flexural Strength Specimens:** Cure as described above, but immerse in lime-saturated water for at least the final 20 hours prior to testing.

49 ## AASHTO M 201 – Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

50 ### Introduction

AASHTO M 201 covers the specification for mixing rooms, moist cabinets, moist rooms and water storage tanks for curing hardened concrete specimens up to the time of testing.

51 ### Terminology

- **Mixing rooms** have controlled temperature and relative humidity where cement paste and mortar specimens are prepared.
- **Moist cabinets** are moderately sized storage facilities in which temperature and moisture conditions are closely controlled.
- **Moist rooms** are larger "walk-in" storage facilities also with closely controlled temperature and humidity.

52 ### Requirements for Cement Mixing Rooms

- Air temperature maintained at 73.4 ±7°F, relative humidity not less than 50%.
- Mixing water temperature used to prepare cement paste and mortar specimens shall be 73.4 ±3°F.

53 ### Requirements for Moist Rooms & Cabinets

- **General Requirements for Moist Rooms and Moist Cabinets**: The atmosphere must have a temperature of 73.4 ±3°F and a relative humidity of at least 95 percent. The humidity must be sufficient that all exposed surfaces of test specimens have free moisture on them.

  Records of temperature must be maintained using a recording thermometer, calibrated at a maximum interval of six months or whenever accuracy is suspect. (Verification of the recording thermometer shall be performed using a reference thermometer accurate and

readable to 0.9° F.)

54 Verification shall be made according to the following procedure:

1. Position reference thermometer as close as possible to the sensor of the recording thermometer.
2. Close the door to the moist cabinet or room for at least five minutes.
3. Record both the temperature reading of the reference thermometer and the recording thermometer (Take the readings in the moist cabinet or room immediately upon opening the door).

55

4. Compare the results of the two readings. If the difference is greater than 1.8°F the recording thermometer must be adjusted to within 0.9°F of the reference thermometer reading.
5. Archive the recordings of the recording thermometer to document that proper control over curing temperature is being exercised.

Shelves on which fresh specimens are placed must be level.

56 Air temperature must be positively controlled by either heating or cooling as required according to one of the following two methods:

1. Thermostatically control the air inside the storage facility (thermostat must be inside the facility).
2. Thermostatically control the air surrounding the facility and manually control the air temperature inside the facility.

57

- **Moist Cabinets**: Moist cabinets must be constructed of durable materials with a tight-fitting door. They must have at least one or more fog sprays, water sprays, or curtains of water on the inner walls such that water discharge will be collected in a pool near the bottom.

58

- **Moist Rooms**: Walls must be constructed of

durable materials with tight-fitting doors, and windows, if any.

Humidity may be achieved in any convenient way (fog sprays, atomizing humidifiers, etc.)

Moist rooms used in cement testing must have durable shelving manufactured in such a way as to prevent droplets of water from falling on freshly made specimens.

Moist rooms used in concrete testing shall maintain atmospheric conditions such that free moisture is maintained on all exposed specimen surfaces. Specimens may not be exposed to running or dripping water.

- **Water Storage Tanks**: Tanks must be constructed of non-corroding material. Each tank not contained in a room capable of maintaining the required temperature range shall be equipped with positive temperature controls to maintain 73.4 $\pm 3^{o}$ F, and shall have a recording thermometer with the sensor immersed in the storage water.

  Recording thermometers shall be calibrated at an interval not exceeding six months. The calibration thermometer shall be placed adjacent to the sensor of the recording thermometer and the temperatures compared. If the recording thermometer indicates a temperature more than 1.8°F different from that of the calibration thermometer, the recording thermometer shall be adjusted such that the readings agree within 0.9°F.

  Water in the storage tanks shall be saturated with calcium hydroxide such that excess calcium hydroxide is present. This requires use of high-calcium hydrated lime, not calcium carbonate (limestone). Water in the tanks shall be stirred at least monthly and shall be refilled with fresh solution at intervals not exceeding 24 months (The solution must contain at least 3g/L of calcium hydroxide).

  To prevent leaching of minerals from test specimens, do not use continuously running water or demineralized water in storage tanks.

62 ## AASHTO M 205 – Molds for Forming Concrete Test Cylinders Vertically

63 ### Introduction

AASHTO M 205 covers the specification for single-use and reusable cylinder molds. Sizes include those with nominal diameters from 2 to 36 inches. The most commonly used sizes for concrete testing have nominal diameters of four and six inches. Cylinder molds are those for forming cylindrical specimens vertically (having an open top for filling with concrete).

64 ### General Requirements

Molds shall be right circular cylinders constructed of materials that do not react with portland cement or other hydraulic cements. Molds must be water tight and strong enough to resist crushing, tearing, or otherwise deforming.

The nominal inside height shall be twice the diameter. Height, consisting of the average of two measurements 180 degrees apart, shall not differ from the nominal height by more than 2%.

65 Diameter at the top of the mold shall not differ by more than 1% from the nominal diameter. Planes of the top and bottom may not deviate from perpendicularity to the axis by more than 0.5 degrees (1/8” in 12”). No diameter of a mold may differ from any other diameter by more than 2%. The bottom inside surface of the mold may not depart from a plane by more than 1% of the mold diameter (approximately 1/16” in 6”).

66 - **Reusable Molds**

  Molds must be made of non-absorptive materials. Many materials are satisfactory provided they meet the requirements. Alloys of aluminum and magnesium are not permitted since they may react with some constituents of portland cement concrete. Molds must be tested for water leakage and strength after every 50 uses or every 6 months, whichever

comes first.

Molds must have a base at right angles to the axis. They may be constructed of a single piece, or made from castings with separate
67 detachable base.

If an inside fillet is used at the bottom of the sidewall, the vertical and horizontal legs may not have lengths exceeding 1/8” and 3/16” respectively. Molds must be either coated or manufactured of material that will prevent adherence to concrete. Molds must be watertight at time of use.

68 • **Single-Use Molds**

**General:** Single-use molds may be made of sheet metal, plastic, or other materials. Paper molds shall not be used.

Molds shall be equipped with tightly fitting top
69 caps (lids) to maintain the circular shape at the top of the cylinder, and to provide a clearance above the finished concrete surface. Metal caps are required for sheet metal molds; plastic caps are required for plastic molds.

Physical requirements – When tested for water leakage, they shall show no visible leakage.

70 • **Sheet Metal Molds**:

**Metal thickness** of sidewalls shall be equivalent to can-making blackplate with a minimum metal thickness of approximately 0.0118 in. Minimum metal thickness of the bottom shall be 0.009 in.

**Bottom design –** The bottom shall be flush with the bottom of the sidewall within 1/16 in. If used, the inside crimp shall produce an indentation not to exceed 3/16 in. horizontally or 1/8 in. vertically.

**Top edge –** Curled or beaded to strengthen the mold and protect the user from cuts. If the curl or bead extends inside the mold it shall not make an indentation exceeding 1/8” either horizontally or vertically.

**Coating –** If material used in manufacture will rust or corrode, it must have a protective coating (lacquer or other suitable material).

71

- **Plastic Molds**:

  **Wall thickness** shall be sufficient to meet the strength and dimensional tolerances outlined under **"General Requirements"** above.

  **Bottom design –** Flush with the bottom of the sidewall within 1/16 in. If used, an inside fillet may not result in an indentation greater than 1/8 in. vertically or 3/16 in. horizontally. The bottom must be sufficiently rigid to produce specimens complying with the applicable provisions of T 23 and R 39.

72

  **Material –** Maximum water absorption of 0.5% in 24 hours as tested by ASTM D 570; Izod impact toughness of at least 2.2 ft-lb per inch of notch for 1/8 in. thick specimen as tested by ASTM D 256; after holding at 10$^{o}$F, for 24 hours the plastic shall not fracture when subjected to tapping and jarring considered to be typical when specimens are being molded.

73

## Test Methods for Molds

- **Test Procedure for Molds**: Subject all molds to the dry rodded coarse aggregate test to evaluate damage during use. After the dry-rodded test, subject molds to the test for leakage. Verify dimensional requirements for all types of molds.

74

  **Samples –** Select at least three molds for reusable or single-use molds from each shipment. For single-use molds, do not reuse or retest when conducting the following test methods.

75

  **Dry-Rodded Coarse Aggregate Test –** Fill the mold with either No. 57 (1" to No. 4) or No. 67 (3/4" to No. 4) crushed coarse aggregate. Use the method of compaction, number of layers, and strokes of the rod as required by AASHTO T 23. After rodding the final layer, empty the material from the mold, wipe the inside of the mold with a dry cloth,

**Note:** It will probably not be possible to completely penetrate each layer during the rodding process. The effort given in the rodding attempt will suffice for the requirements of this procedure.

and inspect for physical damage.

76 **Water Leakage for Single-use Molds –** After the dry-rodded test, empty the aggregate from the mold and wipe lightly with a dry cloth. Examine mold for damage. Fill molds to a depth of 90 to 95% of the height. Three hours after filling, examine for leakage.

77 **Water Leakage for Assembled Reusable Molds –** Assemble molds with sealant if required. Fill molds to a depth of 90 to 95% of the height and subject the mold to tapping and jarring equivalent to that of molding specimens according to T 23. One hour after jarring and tapping, examine for leakage.

78 ## Dimensional Measurements

Determine dimensions for the following:

- Diameter
- Length
- Perpendicularity of ends to longitudinal axis
- Planeness of ends

79 ## Sampling and Rejection

- At least three single-use and reusable molds shall be randomly selected from each shipment by the purchaser to conduct specified tests for compliance with this specification.
- Failure of any one of the three molds shall be basis for rejection of the shipment.

80 **Report**

- Brand and source of mold.
- Shipment or lot number.
- Date sampled and date tested.
- General mold description: Nominal dimensions, type of mold, materials from which constructed.
- Test results: damage and water leakage.
- For failed molds report the following (if
81 applicable):
    - Average diameter or height, in.
    - Maximum and minimum diameters or lengths, in.
    - Nonconformance with perpendicularity of rim or base to axis
    - Apparent reaction between mold materials and concrete or mortar

# METHOD OF MAKING AND CURING CONCRETE TEST SPECIMENS IN THE FIELD

## FOP FOR AASHTO T 23

**Typical Strength Specimens**

### Significance

02 Concrete is specified primarily on the basis of strength. Standard specimens are made and subsequently tested to determine the acceptability of

03 concrete. Concrete strength test specimens are made in accordance with a standard procedure to produce results that are reliable and tests that can be reproduced by someone else with the same concrete, following the same procedures.

04 Specimens are molded according to standard procedures and then cured under proper temperature and moisture conditions. Deviation from the standard procedures can cause significant differences in strength results. For example, specimens improperly cured between 90º and 100°F will develop strength at a different rate than specimens cured at the specified temperature range of 60º to 80°F required by this method. Ultimate strength is also affected.

This FOP pertains to specimens cast for the purpose of acceptance. Agencies sometimes specify curing practices other than those presented here. (To determine adequacy of protection or when a structure may be placed in service for example.)

### Scope

This procedure covers the method for making, initially curing, and transporting concrete test specimens in the field in accordance with AASHTO T 23.

**Apparatus, Cylinders**

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## Apparatus and Test Specimens

- Concrete cylinder molds: Conforming to AASHTO M 205 with a length equal to twice the diameter. Standard specimens shall be 6 in. by 12 in. cylinders. Mold diameter must be at least three times maximum aggregate size unless wet sieving is conducted according to FOP for WAQTC TM 2. Agency specifications may allow cylinder molds of 4 in. by 8 in. size when the nominal maximum aggregate size does not exceed 1 in..
- Beam molds: Rectangular in shape with ends and sides at right angles to each other. Must be sufficiently rigid to resist warpage. Surfaces must be smooth. Molds shall produce length no more than 1/16” shorter than that required (greater length is allowed). Maximum variation from nominal cross section shall not exceed 1/8 in. Ratio of width to depth may not exceed 1.5; the smaller dimension must be at least 3 times maximum aggregate size. Unless otherwise noted in specifications, beam molds for casting specimens in the field shall result in specimens having width and depth of not less than 6 inches. Specimens shall be cast and hardened with the long axes horizontal.
- Standard tamping rod: 5/8 in. diameter and approximately 24 in. long, having a hemispherical tip for preparing 6 in. x 12 in. cylinders.
- Small tamping rod: 3/8 in. diameter and approximately 12 in. long, having a hemispherical tip for preparing 4 in. x 8 in. cylinders
- Vibrator: At least 7000 vibrations per minute, diameter no more than one fourth the diameter or width of the mold and at least 3 in. longer than the section being vibrated for use with low slump concrete.
- Scoop
- Trowel or Float
- Mallet: With a rubber or rawhide head having a mass of 1.25 ±0.5 lb.

- Rigid base plates and cover plates: metal, glass, or plywood.
- Initial Curing Facilities: Temperature controlled curing box or enclosure capable of maintaining the required range of 60º to 80°F during the entire initial curing period (for concrete with compressive strength of 6000 psi or more, the temperature shall be 68º to 78ºF. As an alternative, sand or earth for initial cylinder protection may be used provided that the required temperature range is maintained and the specimens are not damaged.
- Thermometer: Capable of registering both maximum and minimum temperatures during the initial cure.

07

## Procedure – Making Specimens – General

1. Obtain the sample according with the FOP for WAQTC TM 2.

   Wet Sieving per the FOP for WAQTC TM 2 is required when concrete contains aggregate with a nominal maximum size greater than 2 in. for specimen's with a 6 in. diameter, or greater than 1 in. for specimen's with a 4 in. diameter.

2. Remix the sample after transporting to testing location.

08

3. Begin making specimens within 15 minutes of obtaining the sample.

4. Set molds upright on a level rigid base in a location free from vibration and relatively close to where they will be stored.

5. Fill molds in the required number of layers. In placing the final layer, try to add an amount of concrete that will exactly fill the mold after consolidation. Add or remove concrete prior to completion of consolidation to avoid a deficiency or excess of concrete.

09

6. There are two methods of consolidating the concrete – rodding and internal vibration. If the slump is greater than 1 in., consolidation may be by rodding or vibration. When the slump is 1 in. or less, consolidation must be accomplished by internal vibration. Agency specifications may dictate when rodding or vibration will be used.

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## Procedure – Making Cylinders – Rodding

1. For the standard 6 in. by 12 in. specimen, fill each mold in three approximately equal layers, moving the scoop or trowel around the perimeter of the mold to evenly distribute the concrete. For the 4 in. by 8 in. specimen, fill the mold in two layers. When filling the final layer, slightly overfill the mold.

11

2. Consolidate each layer with 25 strokes of the appropriate tamping rod, using the rounded end. Distribute strokes evenly over the cross section of the concrete. Rod the first layer throughout its depth without forcibly hitting the bottom. For subsequent layers, rod the layer throughout its depth penetrating approximately 1 in. into the underlying layer.

12

3. After rodding each layer, tap the sides of each mold 10 to 15 times with the mallet (reusable steel molds) or lightly with the open hand (single-use light-gauge molds).

4. Strike off the surface of the molds with tamping rod, or straightedge and begin initial curing.

**Consolidation of concrete in cylinder by rodding**

***Note 1:*** Floating or troweling is permitted instead of striking off with rod or straightedge

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## Procedure – Making Cylinders – Internal Vibration

1. Fill the mold in two layers.

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2. Insert the vibrator at the required number of different points for each layer (two points for 6 in. diameter cylinders; one point for 4 in. diameter cylinders). When vibrating the bottom layer, do not let the vibrator touch the bottom or sides of the mold. When vibrating the top layer, the vibrator shall penetrate into the underlying layer approximately 1 in.

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3. Remove the vibrator slowly, so that no air pockets are left in the material.

***Note 2:*** Continue vibration only long enough to achieve proper consolidation of the concrete. Over vibration may cause segregation and loss of appreciable quantities of intentionally entrained air.

4. Strike off the surface of the molds with tamping rod, or straightedge and begin initial curing.

**Vibrating cylinder specimens**

## Procedure – Making Flexural Beams – Rodding

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Making a flexural beam, rodding

17

1. Fill the mold in two approximately equal layers with the second layer slightly overfilling the mold.
2. Consolidate each layer with the tamping rod once for every 2 $in^2$ using the rounded end. Rod each layer throughout its depth taking care to not forcibly strike the bottom of the mold when compacting the first layer. Rod the second layer throughout its depth, penetrating approximately 1" into the lower layer.

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3. After rodding each layer, strike the mold 10 to 15 times with the mallet and spade along the sides and end using a trowel.
4. Strike off to a flat surface using a trowel and begin initial curing.

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## Procedure – Making Flexural Beams – Vibration

Making Beams
Internal Vibration

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1. Fill the mold to overflowing in one layer.
2. Consolidate the concrete by inserting the vibrator vertically along the centerline at intervals not exceeding 6 in. Take care to not over vibrate, and withdraw the vibrator slowly to avoid large voids. Do not contact the bottom or sides of the mold with the vibrator.

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3. After vibrating, strike the mold 10 to 15 times with the mallet.
4. Strike off to a flat surface using a trowel and begin initial curing.

22

## Procedure – Initial Curing

- When moving cylinder specimens made with single use molds, support the bottom of the mold with trowel, hand or other device.

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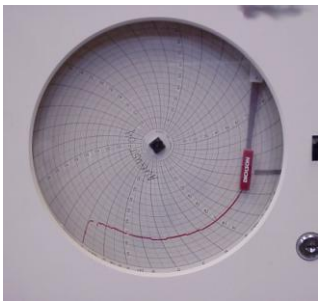
- For initial curing of cylinders, the curing place must be firm, within ¼ in. of a level surface, and free from vibrations or other disturbances.



**Recording Thermometer**

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- Maintain initial curing temperature of 60º to 80°F or 68º to 78°F for concrete with strength of 6000 psi or more.
- Prevent loss of moisture.

**Specimen identification**

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**Initial cure in a temperature controlled chest-type curing box**

1. Finish the cylinder using the tamping rod, straightedge, float or trowel. The finished surface shall be flat with no projections or depressions greater than 6.3 mm (1/8 in.).
2. Place the lid on the mold to prevent moisture loss.
3. Mark the necessary identification data on the cylinder mold and lid.
4. Place the mold in the curing box. When lifting light-gauge molds be careful to avoid distortion (support the bottom, avoid squeezing the sides).
5. Remember, caps keep cylinders round and prevent moisture loss.

**Thermostatically Controlled Cure Box**

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28 **Procedure – Transporting Specimens**

After 24 to 48 hours of initial curing, the specimens will be transported to the laboratory for storing under standard conditions. Specimen identity will be noted along with the date / time the specimen was made and the maximum and minimum temperatures registered during the initial cure.

- While in transport, specimens shall be protected from jarring, extreme changes in temperature, freezing, or moisture loss.
- Cylinders shall be secured so that the axis is vertical.
- Transportation time shall not exceed 4 hours

29 **Final Curing**

- For all specimens (cylinders or beams) final curing must be started within 30 minutes of mold removal. Temperature shall be maintained at 23° ±2° C (73º ±3° F) Free moisture must be present on the surfaces of the specimens during the entire curing period. Curing may be accomplished in a moist room or water tank conforming to M 201.
- For cylinders, during the final 3 hours prior to testing the temperature requirement may be waived, but free moisture must be maintained on specimen surfaces at all times until tested.
- Final curing of beams must include immersing in lime-saturated water for at least 20 hours prior to testing.

30

## Report

- Report on standard agency forms.
- Placement information for identification of project, element(s) represented, etc.
- Date molded & Time molded.
- Test ages.
- Slump, Air Content & density.
- Temperature (concrete, initial cure max. & min., and ambient).
- Method of initial curing.
- Other information as required by agency such as concrete supplier, truck number, invoice number, water added, etc.

## Tips!

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- Start within 15 minutes of obtaining sample.
- Use hand, for tapping single-use, light-gauge molds.
- Consolidation technique depends on the slump. Rodding and/or vibration may be appropriate for different slumps.
- Protect specimens from damage during transport and keep cylinders vertical.

## REVIEW QUESTIONS

1. AASHTO T 23 gives standardized procedures for _____, _____, and _____ of test specimens.

2. Describe two methods for initially curing test specimens.

3. When consolidating a flexural strength test specimen by rodding, rod one stroke for each _____ of top surface area.

4. Describe the process for making flexural beam specimens using internal vibration. What precautions must be taken?

5. During transportation, what must be done to protect test specimens?

# COMPRESSIVE STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS FOP FOR AASHTO T 22

02

## Scope

This test method covers the determination of compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores. It is limited to concrete having a unit weight in excess of 50 lb/ft$^3$.

This method consists of applying a compressive axial load to molded cylinders or cores at a rate that is within a prescribed range until failure occurs. The compressive strength of the specimens is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen.

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## Significance

Compressive strength is not a fundamental or intrinsic property of concrete; therefore, care must be exercised in the interpretation of the significance of compressive strength determinations. Strength values obtained will depend on the size and shape of the specimen, batching and mixing procedures, methods of sampling and molding, and the age, temperature, and moisture conditions during curing.

This test method may be used to determine compressive strength of cylindrical specimens prepared and cured in accordance with AASHTO R 39, T 23, T 24, T 231 and ASTM C 873.

The results of this test may be used as a basis for quality control of concrete proportioning, mixing, and placing operations; determination of compliance with specification; and control for evaluating effectiveness of admixtures and similar uses.

04 **Apparatus**

- **Testing Machine:** Capacity sufficient to cause specimen failure at prescribed loading rates. The machine shall be power operated and must apply the load continuously without shock. The machine shall be accurate such that the percentage of error shall not exceed ±1.0 percent of the indicated load. See AASHTO T 22 for a detailed listing of the provisions under which the accuracy of a testing machine is to be determined.

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- **Bearing Blocks:** The machine shall be equipped with two bearing blocks. Bearing faces of both blocks shall have a least horizontal dimension at least 3 percent greater than the diameter of the specimen to be tested. The top bearing block shall be spherically seated. The top and bottom surfaces of the bottom bearing block shall be parallel to each other. See AASHTO T 22 for a more detailed listing of requirements for bearing blocks.

07

- **Load Indication:** If the load of a compression machine is registered on a dial, the dial shall be graduated to at least the nearest 0.1 percent of the full-scale load. Each dial shall be equipped with a suitable device that at all times, until reset, will indicate to within 1 percent accuracy the maximum load applied to the specimen. If the load of the compression machine is indicated in digital form, the numerical increment must be equal to or less than 0.1 percent of the full-scale load of a given loading range.

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- **Safety:** A means to contain fragments in the case of an explosive rupture.
- **Neoprene Caps and Controllers:** Meeting the requirements of ASTM C 1231.

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*Note 1*: 0.5° is approximately equivalent to a difference of 0.12 in. in 12 inches.

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**Table 1**
**Permissible Time Tolerances**

| *Specified Age* | *Tolerance* |
|---|---|
| 12 hrs | 15 min (2.1%) |
| 24 hrs | 30 min (2.1%) |
| 3 days | 2 hrs (2.8%) |
| 7 days | 6 hrs (3.6%) |
| 28 days | 20 hrs (3.0%) |
| 56 days | 40 hrs (3.0%) |
| 90 days | 2 days (2.2%) |

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15

## Specimens

Specimens may be prepared for testing either by AASHTO T 231 "Capping Cylindrical Concrete Specimens" or by use of neoprene caps. When density of the test specimens is required, determine as described in AASHTO T 22, prior to capping.

- For either method, specimens shall not be tested if any individual diameter of a cylinder differs from any other diameter of the same cylinder by more than 2 percent.
- Neither end of compressive test specimen when tested shall depart from perpendicularity to the longitudinal axis by more than 0.5°.
- If the ends of the specimen are not plane within 0.002 in. the specimen shall be capped, sawed or ground according to AASHTO T 231, or prepared in accordance with ASTM C 1231.

## Procedure

1. All test specimens for a given test age shall be broken within the permissible time tolerances prescribed in Table 1.
2. Compression tests of moisture-cured specimens shall be made as soon as practicable after removal from moist storage. Specimens shall be kept moist by any convenient method until tested.
3. Determine specimen diameter to the nearest 0.01 inch as the average of two measurements made at right angles to each other at mid-height of the specimen. If the specimens are known to have been made using reusable or single use molds from the same lot that consistently result in specimen diameters within a range of 0.02 inches, then diameter measurement for each days testing may be reduced to 1 for each 10 specimens or three specimens per day, whichever is greater. In this case, the average diameter of the specimens measured shall be used for calculation of the cross-sectional area.

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4. Place the plain bearing block, with its hardened face up, on the table or platen of the testing machine directly under the spherically seated upper bearing block. Wipe clean the bearing faces of the upper and lower bearing blocks and the test specimen. Carefully align the axis of the specimen with the center of thrust of the spherically seated block.

5. Rotate the spherically seated block immediately prior to testing, to assure free movement.

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6. The speed of crosshead travel shall be controlled to result in a rate of loading within the range of 35 ±7 psi/second.

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7. The designated rate of movement shall be maintained at least during the latter half of the anticipated loading phase of the test cycle. During the application of the first half of the anticipated loading phase a higher rate of movement shall be permitted.

8. Make no adjustment in the rate of movement while the specimen is yielding rapidly immediately before failure.

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9. At specimen failure record the maximum load carried by the specimen during the test. Note the type of fracture and appearance of the concrete.

**Types of Fracture**

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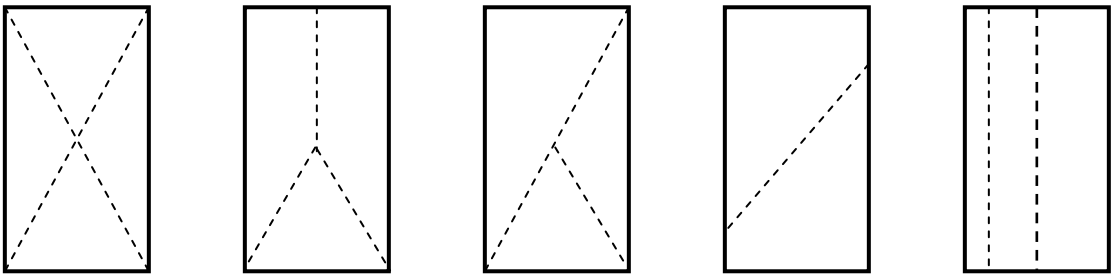

**Cone (a)** **Cone and Split (b)** **Cone and Shear (c)** **Shear (d)** **Columnar (e)**

23 **Calculation**

1. Calculate the compressive strength of the specimen by dividing the maximum load by the cross-sectional area.

| Table 2 | | | | |
|---|---|---|---|---|
| Length/Diameter Correction | | | | |
| L/D | 1.75 | 1.50 | 1.25 | 1.00 |
| Factor | 0.98 | 0.96 | 0.93 | 0.87 |

24 2. If the specimen length-to-diameter is 1.75 or less, correct the result just obtained by multiplying that result by the appropriate correction factor shown in Table 2. Values not given shall be determined by interpolation. When correction is required, specimen length must be determined to the nearest 0.1 inch.

25 The correction factors apply to:

- Concrete with compressive strength ranging from 2000 to 6000 psi.
- Concrete in a dry or soaked state at time of testing.
- Normal weight concrete.
- Lightweight concrete weighing between 100 and 120 lb/ft$^3$.

26 **Report**

- Results shall be reported on standard forms approved for use by the agency.
- Identification number
- Diameter (and length if outside the range of 1.8D to 2.2D)
- Cross-sectional area
- Maximum load
- Compressive strength calculated to the nearest 10 psi.
- Type of fracture.
- Defects in specimen or caps.
- Age of specimen.

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**Tips!**

- Remember to rotate the spherically seated upper bearing block just prior to load application.
- Check agency specifications to determine if use of neoprene caps is allowed.
- Compressive strength is calculated and reported to the nearest 10 psi.

## Calculation Examples

**Calculate compressive strength according to the following formulas**: 28

Cross-sectional Area ($in^2$): $\pi r^2$

where:

$\pi$ = a transcendental number approximating 3.1416, representing the ratio of the circumference to the diameter of a circle (Used here as a constant).

r = radius of the specimen (1/2 the diameter)

Compressive Strength (psi): $\dfrac{\text{Total Load (lbs)}}{\text{Cross-sectional Area (in}^2\text{)}} \times \text{Correction Factor}$

**Example #1 (No correction for L/D required)** 29

Specimen Diameter: 4.02”
Specimen Length: 7.9”
Maximum Load: 58,510 lbs.
L/D: 1.97 (No Correction Required)

Cross-sectional area = $3.1416 \times 2.01^2 = 12.692,\ \text{say } 12.69 \text{in}^2$

Compressive Strength = $\dfrac{58{,}510 \text{ lbs}}{12.69 \text{ in}^2} = 4611,\ \text{say } 4610 \text{ psi}$

**Example #2 (Correction for L/D required)** 30

Specimen Diameter: 3.78”
Specimen Length: 6.1”
Maximum Load: 63,460 lbs.
L/D: 1.61 (Correction Factor = 0.97)

Cross-sectional area = $3.1416 \times 1.89^2 = 11.222,\ \text{say } 11.22 \text{in}^2$

Compressive Strength = $\dfrac{63{,}460 \text{ lbs}}{11.22 \text{ in}^2} = 5656 \times 0.97 = 5486,\ \text{say } 5490 \text{ psi}$

## REVIEW QUESTIONS

1. Why is this test performed?

2. How many cylinders must be measured for determination of specimen diameter?

3. Describe the method of load application.

4. After specimen failure, what must be recorded?

5. Given the following, calculate the compressive strength:
   Maximum sustained load: 46,240 lbs.
   Average specimen diameter: 3.73 inches.
   Specimen length: 6.15 inches.

# PERFORMANCE EXAM CHECKLIST

## DETERMINATION OF COMPRESSIVE STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS

## FOP FOR AASHTO T 22

**Record the symbols "P" for passing or "F" for failing on each step of the checklist.**

Participant Name:_____ Exam Date:_____

| Specimens | Trial 1 | Trial 2 |
|---|---|---|
| 1. Specimen verified that any diameter does not differ from any other diameter of the same cylinder by more than 2 percent? | _____ | _____ |
| 2. Verified that neither end of the specimen when tested departs from perpendicularity to the axis by more than 0.5°? | _____ | _____ |
| 3. Ends of the specimen capped, sawed or ground according to AASHTO T 231, or neoprene caps used according to ASTM C 1231? | _____ | _____ |

| Procedure | | |
|---|---|---|
| 1. Test specimens kept moist between removal from storage and testing? | _____ | _____ |
| 2. Test conducted within the specified time limits for the test age? | _____ | _____ |
| 3. Test specimen properly centered with thrust of spherically seated block? | _____ | _____ |
| 4. Spherically seated block rotated immediately prior to testing? | _____ | _____ |
| 5. Compression load applied continuously and without shock? | _____ | _____ |
| 6. The designated rate of movement maintained during the latter half of the anticipated loading phase? | _____ | _____ |
| 7. At specimen failure the maximum load carried by the specimen was recorded along with the type of failure? | _____ | _____ |

| Calculations | | |
|---|---|---|
| 1. Compressive strength properly determined? | _____ | _____ |
| 2. Correction factor applied if length-to-diameter ratio is less than 1.8? | _____ | _____ |

Comments: First attempt: Pass ☐ Fail ☐ Second attempt: Pass ☐ Fail ☐

_____
_____
_____
_____
_____
_____
_____
_____

Signature of Examiner_____

# FLEXURAL STRENGTH OF CONCRETE (USING SIMPLE BEAM WITH THIRD-POINT LOADING)
# FOP FOR AASHTO T 97

02

## Scope

This test method covers the determination of flexural strength of concrete using a simple beam with third-point loading.

The most commonly tested beam size is one having a nominal width and depth of 6 inches and a length of at least 20 inches.

## Apparatus

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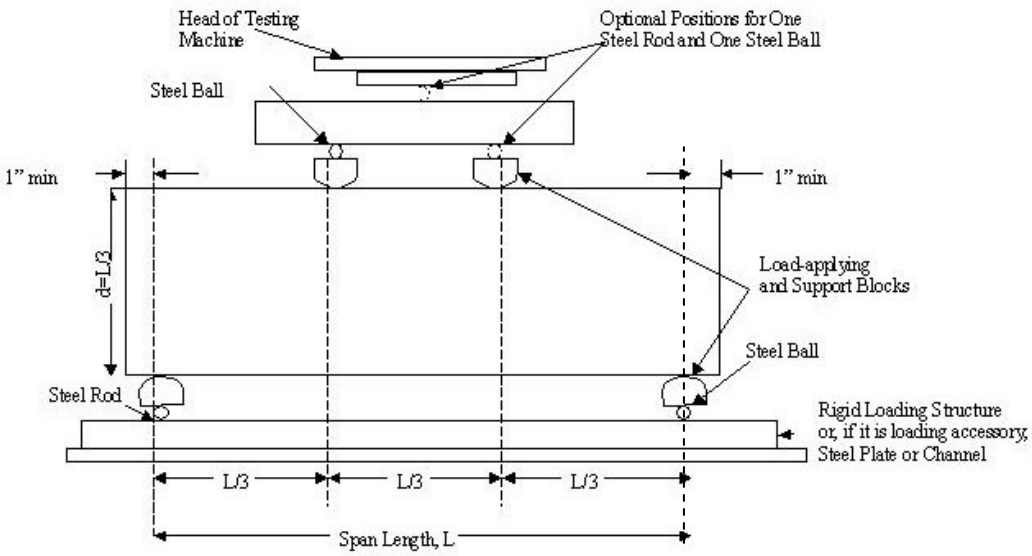
04

- **Testing Machine:** Capacity sufficient to cause specimen failure at prescribed loading rates. The machine shall be either power operated or of the hand operated pump variety such that a single stroke of the pump is sufficient to apply the entire load to specimen failure at the prescribed rate. The apparatus must apply the load continuously and without shock. The machine shall be accurate such that the percentage of error shall not exceed ±1.0 percent of the indicated load.
- **Loading Apparatus:** Suitable to insure that applied loads will be perpendicular to the face of the specimen and applied without eccentricity. See FIGURE 1 for a typical acceptable apparatus. The apparatus must be capable of maintaining the specified span length and loading points within 0.05” of that specified.

  Load-applying and support blocks must extend across at least the full width of the specimen. The shape of each block shall be a portion of a cylinder, the axis of which is coincident with either the axis of the steel rod or ball on which it pivots. The bearing surfaces shall not depart from a plane by more than 0.002” and shall be case hardened. The load-applying and support blocks must be maintained in a vertical position and in contact with the steel rod or ball with spring-loaded screws.

Figure 1

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***Note 1*:** The support blocks and loading blocks must bear on a steel rod at one location and one steel ball at the opposite location.

- **Feeler Gages:** Of 0.004" and 0.015" thickness, used for measuring gap between test specimen and load-applying or support blocks.
- **Leather Shims:** Uniform thickness of ¼ inch, 1 to 2 inches in width, of sufficient length to extend across the entire bearing width of the specimens.

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## Specimens

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Specimens shall comply with all applicable provisions of AASHTO T 23, T 24, or R 39.

The test span may not depart by more than 2% of being three times the specimen depth as tested.

The sides of the specimens must be at right angles to the top and bottom. The bearing surfaces must be smooth, free of scars, holes, and indentations.

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$$\frac{3d - S}{S} \leq 2\%$$

where:

d = specimen depth as tested
S = test span, distance between supports

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## Procedure

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**Table 1**
**Permissible Time Tolerances**

| *Specified Age* | *Tolerance* |
|---|---|
| 12 hrs | 15 min (2.1%) |
| 24 hrs | 30 min (2.1%) |
| 3 days | 2 hrs (2.8%) |
| 7 days | 6 hrs (3.6%) |
| 28 days | 20 hrs (3.0%) |
| 90 days | 2 days (2.2%) |

1. All test specimens for a given test age shall be broken within the permissible time tolerances prescribed in Table 1.
2. Flexure tests of moisture-cured specimens shall be made as soon as practicable after removal from moist storage. Specimens shall be kept moist by any convenient method until tested.
3. Place the test specimen in the apparatus by turning the specimen on its side so that the sides as molded become the top and bottom against which the loading and support blocks will bear.
4. Apply a load between 3 and 6% of the anticipated ultimate load.
5. Determine that full bearing is achieved between all four blocks and the specimen. If full bearing is achieved, the specimen may be tested as is without the use of leather shims or capping.

   If there is any gap 1 inch or more in length exceeding 0.004 inch but not greater than 0.015 inch, leather shims may be used to achieve proper specimen bearing.

   If there is a gap 1 inch or more in length exceeding 0.015 inches, the specimen must be ground or capped such that the bearing surfaces meet the required specifications.

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6. No loose particles may be trapped between the test specimen and any bearing point, or between shims and bearing points during application of the test load.

*Note 2:* For a 6-inch nominal beam cross-section, the prescribed loading rate of 125 to 175 psi per minute equates to a range of approximately 1500 to 2100 load pounds per minute.

7. Apply Load (Ref. AASHTO T 97 Part 6.5): Load the specimen continuously and without shock. The load shall be applied at a constant rate to the breaking point. Apply a load at a rate that constantly increases the maximum stress on the tension face between 0.9 and 1.2 MPa/min (125 and 175 psi), until rupture occurs. The loading rate is calculated using the following equation:

   $r = Sbd^2/L$

   Where:

   r = loading rate, N/min (lb/min);
   S = rate of increase in extreme fiber stress, MPa/min (psi/min);
   b = average width of specimen mm (in.);
   d = average depth of specimen mm (in.); and
   L = span length, mm (in.).

16

## Measurement of Test Specimens After Test

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Take three measurements across each dimension (one at each edge and one at the center) to the nearest 0.05 inches to determine specimen width, depth, and location of the fracture. Fracture location is to be measured along the bottom (tension) face as oriented for testing.

If the fracture occurs in a capped section, include the cap thickness in the measurement.

18

## Calculation

- If the fracture occurs within the middle third of the span length, calculate the modulus of rupture according to the following formula:

$$R = \frac{P\,l}{b\,d^2}$$

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where:

R = modulus of rupture, psi
P = maximum applied load, lbf
l = span length, in.
b = average specimen width, in.
d = average specimen depth, in.

20

- If the fracture occurs outside of the middle third of span length by not more than 5%, calculate the modulus of rupture as follows:

$$R = \frac{3\,P\,a}{b\,d^2}$$

where:

a = average distance between line of fracture and the nearest support, in.

- If the fracture occurs outside of the middle third of span length by more than 5% of span length, discard the results of the test.

## Calculation Examples

### Calculate modulus of rupture according to one of the following formulas:

**1. When fracture is within the middle third of span:**

$$R = \frac{P\,l}{b\,d^2}$$

where:

R = modulus of rupture, psi.
P = maximum applied load, lbf
l = span length, in.
b = specimen width, in.
d = specimen depth, in.

**2. When fracture is outside the middle third of span by not more than 5%:**

$$R = \frac{3\,P\,a}{b\,d^2}$$

where:

a = distance between line of fracture and nearest support, in.

**Example #1 (Fracture within the middle third of span)** 21

Maximum Load (P): 8,520 lbs.
Span Length (l): 18.00”
Specimen Width (b): 6.10”
Specimen Depth (d): 6.05”

$$R = \frac{8520 \times 18}{6.10 \times 6.05^2}$$

$$R = \frac{153360}{223.28} = 687, \text{say } 685 \text{ psi}$$

**Example #2 (Fracture not more than 5% outside of middle third of span)** 22

Maximum Load (P): 8,520 lbs.
Span Length: 18.00”
Distance of Fracture From Nearest Support (a): 5.75” (1.4%)
Specimen Width (b): 6.10”
Specimen Depth (d): 6.05”

$$R = \frac{3 \times 8520 \times 5.75}{6.10 \times 6.05^2}$$

$$R = \frac{146970}{223.28} = 658, \text{say } 660 \text{ psi}$$

23

24

## Report

- Results shall be reported on standard forms approved for use by the agency
- Identification number
- Specimen age
- Average width to the nearest 0.05”
- Average depth to the nearest 0.05”
- Span length, in.
- Maximum load
- Modulus of rupture to the nearest 5 psi
- Curing history and apparent moisture condition at time of test
- If specimen was capped, ground, or if leather shims were used
- Observed defects in specimens
- Age of specimen.

25

## Tips!

- Support blocks must bear on a steel rod at one span support and on a steel ball at the other. Loading blocks may also be required to conform to this configuration (see Figure 1 and explanatory notes in T 97)

26

- Remember to check for gaps between beam and apparatus bearing surfaces using feeler gages. Use leather shims or cap specimens as required.
- Measure location of failure along the bottom side of the beam as tested.
- Modulus of rupture is calculated and reported to the nearest 5 psi.

## REVIEW QUESTIONS

1. Why is this test performed?

2. The support and loading blocks must be positioned in the apparatus within _____ of that specified.

3. Describe the method of load application.

4. After specimen failure, what must be recorded? Describe.

5. Given the following, calculate the modulus of rupture:

| | |
|---|---|
| Maximum sustained load: | 6,240 lbs. |
| Span length: | 18.00” |
| Distance of fracture from nearest support: | 5.80” |
| Average specimen width: | 6.05” |
| Average specimen depth | 6.15” |

6. What is wrong with the test conducted as described in question number 5?

# PERFORMANCE EXAM CHECKLIST

## FLEXURAL STRENGTH OF CONCRETE (USING SIMPLE BEAM WITH THIRD-POINT LOADING)

## FOP FOR AASHTO T 97

**Record the symbols "P" for passing or "F" for failing on each step of the checklist.**

Participant Name:_____ Exam Date:_____

| Apparatus | Trial 1 | Trial 2 |
|---|---|---|
| 1. Testing machine capable of applying load continuously, without shock, accurate to ±1.0% of indicated test load? | _____ | _____ |
| 2. Supports and loading blocks within 0.05" of required location and have steel rod at one end, steel ball at the other with spring loaded screws to maintain alignment? | _____ | _____ |
| 3. Feeler gages of 0.004" and 0.015" present to check for gaps? | _____ | _____ |
| 4. Leather shims available if needed of 1/4" uniform thickness, 1 to 2 inches wide and long enough to span across full bearing distance? | _____ | _____ |
| **Specimens** | | |
| 1. Test span does not depart by more than 2% from being three times specimen depth? | _____ | _____ |
| 2. Specimen sides at right angles to top and bottom; bearing surfaces smooth and free from scars, holes, and indentations? | | _____ |
| 3. Specimen sides at right angles to top and bottom; bearing surfaces smooth and free from scars, holes, and indentations? | _____ | _____ |
| **Procedure** | | |
| 1. Test specimens kept moist between removal from storage and testing? | _____ | _____ |
| 2. Test conducted within the specified time limits for the test age? | _____ | _____ |
| 3. Test specimen positioned in apparatus so that the sides as cast become the top and bottom; 3 to 6% of anticipated load applied prior to checking bearing surfaces for gaps? | _____ | _____ |
| 4. Feeler gages used to check for gaps greater than 1" in length; leather shims or capping as required; no loose particles trapped? | _____ | _____ |
| 5. Load applied continuously and without shock; designated rate of load application maintained over last half of anticipated load; load recorded? | _____ | _____ |
| 6. Specimen measured in three locations each for width, depth, and fracture; fracture measurements along bottom of beam as tested? | _____ | _____ |
| 7. Fracture not more than 5% outside middle third of span? | _____ | _____ |
| **Calculations** | | |
| 4. Appropriate formula selected based on fracture location and modulus of rupture calculated to nearest 5 psi? | _____ | _____ |
| 5. Result discarded if fracture more than 5% outside of middle portion of span? | _____ | _____ |

**a. When fracture is within the middle third of span:**

$$R = \frac{P\,l}{b\,d^2}$$

where:

R = modulus of rupture, psi.
P = maximum applied load, lbf
l = span length, in.
b = specimen width, in.
d = specimen depth, in.

- **When fracture is outside the middle third of span by not more than 5%:**

$$R = \frac{3\,P\,a}{b\,d^2}$$

where:

a = distance between line of fracture and nearest support, in.

**Problem #1**

Maximum Load (P): 7,710 lbs.
Span Length: 18.00”
Distance of Fracture From Nearest Support (a): 5.80”
Specimen Width (b): 6.00”
Specimen Depth (d): 6.05”

**R = _____**

**Problem #2**

Maximum Load (P): 9,310 lbs.
Span Length (l): 18.00”
Distance of Fracture From Nearest Support (a): 8.75”
Specimen Width (b): 6.05”
Specimen Depth (d): 6.10”

**R = _____**

Comments: First attempt: Pass ☐ Fail ☐ Second attempt: Pass ☐ Fail ☐

_____
_____
_____
_____
_____
_____

Signature of Examiner_____

# CAPPING CONCRETE TEST SPECIMENS FOP FOR AASHTO T 231

02

## Scope

This FOP covers the apparatus, materials, and procedures for capping hardened concrete specimens using either high-strength gypsum plaster or sulfur mortar.

Capping of freshly molded specimens with neat cement paste is not covered. (Refer to AASHTO T 231 for a discussion of this procedure)

03

## Significance

Procedures are described for preparing surfaces of hardened concrete cylinders, drilled cores, or beams in preparation for strength testing when the surfaces do not conform to the requirements of the applicable testing procedures.

04

## Apparatus

- **Capping Plates:** Capable of providing surfaces plane to within 0.002 in. across any dimension.

  In all cases, plates shall be at least 1 in. larger than the specimen being prepared.

  Glass plates at least 0.25 in. thick, metal plates at least 0.45 in. thick, or polished granite or diabase plates at least 3 in. thick shall be used for high-strength gypsum plaster capping.

  Sulfur mortar capping plates shall consist of metal or stone plates as described for gypsum plaster.

  When new, metal plates shall be free of gouges, grooves, or indentations beyond those caused by the finishing operation. When in use, they shall be free of gouges, grooves, or indentations having surface area greater than 0.05 in.$^2$ or depth greater than 0.010 in.

**Note:** It is advisable to case-harden the capping surface of metal plates to a Rockwell hardness of HRC 48 to help maintain the capping surface free of objectionable defects.

05

- **Alignment Devices:** Guide bars or bulls-eye levels must be used to ensure that no cap departs from perpendicularity to the axis by more than 0.125 in. in 12 in. When guide bars are used for cylinders, they must be positioned such that no cap is more than 0.06 in. off center.

**Caution:** Sulfur mortar reacts with organic compounds such as oil to release hydrogen sulfide gas. In high concentrations it is lethal. It is advisable that the melting pot and capping area be within a vent hood with fumes exhausted out of doors to prevent buildup of the gas.

06

07

- **Melting Pot for Sulfur Mortar:** Melting pots equipped with peripheral heating suitable to prevent accidents when reheating cooled capping material. In lieu of peripheral heating elements, a steel rod may be used to transfer heat and provide a "halo" of melted material in the crust during reheating.

  Melting pots should be thermostatically controlled to prevent sulfur fires. Pots should only be used under a vent hood exhausting the fumes out of doors.

- **Cube Molds:** Molds capable of forming cubes of 2-inch size (50mm molds are also permitted), consisting of two pieces and a base plate. Molds shall have a maximum of three compartments, meeting the requirements of Table 1.

- **Cover Plate (for cube molds):** Conforming to Figure 1 of AASHTO T 231, providing a means of overfilling the molds when pouring sulfur mortar strength specimens.

- **Testing Machine:** Complying with AASHTO T 106 for testing compressive strength of capping materials.

**Table 1 – Permissible Variations of Cube Molds** 08

| Parameter | 2-inch Cube Molds | |
|---|---|---|
| | New | In Use |
| Deviation from planeness of sides | < 0.001 inch | < 0.002 inch |
| Distance between opposite sides | 2 inches ± 0.005 | 2 inches ± 0.02 |
| Height of each compartment | 2 inches + 0.01 to –0.005 inches | 2 inches + 0.01 to –0.015 inches |
| Angle between adjacent faces | 90 ± 0.5° | 90 ± 0.5° |

09

## Capping Materials

**Strength Requirements and Cap Thickness:** Sulfur mortar or high-strength gypsum plaster may be used provided they meet the requirements shown in Table 2 (including note).

**Table 2 – Compressive Strength and Maximum Thickness of Capping Materials** 10-13

| Cylinder Compressive Strength (psi) | Minimum Strength of Capping Material | Maximum Average Thickness of Cap | Maximum Thickness (Any Part of Cap) |
|---|---|---|---|
| 500 to 7000 psi | 5000 psi or cylinder strength, whichever is greater | 0.25 inch | 0.31 inch |
| Greater than 7000 psi | Not less than cylinder strength [1] | 0.125 inch | 0.20 inch |

Note 1 – The manufacturer or user must provide the following documentation:

- That the average strength of 15 cylinders capped with the material is not less than 98 percent of the average strength of 15 companion cylinders capped with neat cement paste or 15 cylinders ground plane to within 0.002 in.,
- That the standard deviation of the strengths of the capped cylinders is not greater than 1.57 times that of the standard deviation of the reference cylinders,
- That the cap thickness requirements were met in the qualification tests, and
- Of the hardening time of the caps used in the qualification tests.

The qualification test report must include the compressive strength of 2-in. cubes of the material qualified and of neat cement paste cubes, if used. Capping materials conforming to these requirements are permitted to be used for cylinders with strengths up to 20 percent greater than the concrete tested in these qualification tests. The manufacturer must requalify lots of material manufactured on an annual basis, or whenever there is a change in the formulation of the raw materials. The user of the material must retain a copy of the qualification results, and the dates of manufacture of material qualified and of the material currently being used.

14
- Strength verification of capping materials must be made for each lot of material and at intervals not exceeding three months.
- Prior to testing cube strength for verification of capping materials, allow the cubes to cure in the same environment for the same length of time as the materials used to cap specimens.

15
- If a given lot fails the strength test, it shall not be used and replacement material must be obtained. The replacement material will be tested weekly until four consecutive tests indicate compliance with strength requirements.
- The proportion of water used for mixing gypsum plaster capping material should be between 26 and 30 percent by mass of the high-strength gypsum cement.

16 **Determining compressive strength**:

- For high-strength gypsum plaster, mold specimens as required by AASHTO T 106. Conduct strength tests according to steps 7 through 9 for sulfur mortar (see sulfur mortar procedure below).

17 - For sulfur mortar, mold cubes and conduct strength testing as follows:

    1. Apply a light coat of mineral oil to the cube mold and cover plate. Assemble the mold and attach the cover plate.
    2. Bring the assembled apparatus to a temperature of 68 to 86ºF. Place the apparatus near the capping area.
    3. Bring the temperature of the molten sulfur mortar in the pot to a range of 265 to 290ºF, stir thoroughly, and begin casting cubes.

18 4. Using a ladle, pour the molten sulfur mortar into the filling holes of the cover plate until level with the top of the filling holes.

5. Allow the material to cool such that maximum shrinkage occurs (usually about 15 minutes), then refill with molten sulfur mortar to the top of the filling holes.

6. After cubes have solidified, remove the mold without breaking off knobs formed by filling holes and remove oil, sharp edges, and fins.

19 7. After the required curing period at room temperature (not less than 2 hours), check planeness of bearing surfaces, and measure dimensions. Calculate cross-sectional area.

8. Test for compressive strength according to AASHTO T 106, applying the test load at a rate of 200 to 400 pounds/second.

9. Calculate compressive strength by dividing the total load by the cross-sectional area.

20 **Capping Procedure – General**

- During each day's capping operation check planeness of the caps at least three times (at the beginning, middle, and end of the run).
- Ensure that caps do not depart from a plane by more than 0.002 in. Check across at least 3 diameters or dimensions using a straightedge and feeler gauge.

21
- Cap thickness should comply with the requirements of Table 2. Caps should be as thin as possible, normally about 0.125 in. Thickness of any portion of a cap may not exceed 0.20 in. or 0.31 in., depending on cylinder strength.

22
- If specimens have any material adhering to them that would interfere with bonding to the cap, this material should be removed prior to capping. Light scoring of smooth surfaces is permissible to improve bond with the capping material.
- A thin coating of mineral oil or grease may be used on capping plates to prevent bonding of the capping material to these surfaces. In no case may the specimen surfaces be oiled.

23
- After capping, at least two hours of hardening must be allowed prior to testing of specimens having compressive strength less than 5000 psi (at least sixteen hours of hardening for specimens 5000 psi or greater), unless a shorter time has been shown to be suitable during qualification testing.

24 **Capping Procedure**

**High-Strength Gypsum Plaster:**

1. Mix the material at the same percent of mixing water as used for qualification tests.
2. Rapidly spread the capping material on the capping plate.
3. Immediately place the specimen on the capping material, using guide plates or a bulls-eye level to assure perpendicularity of the axis to the capped surface.

25

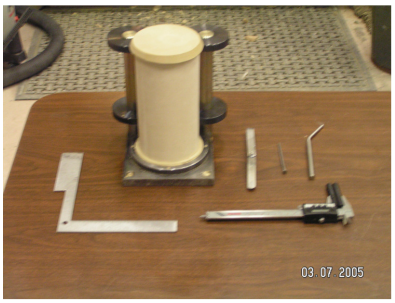
4. Carefully isolate each specimen from the surrounding gypsum plaster without disturbing the material coating the end of the specimen (scribing around the perimeter with the finger is effective).
5. Allow material to harden sufficiently to avoid damage during removal from the capping plate.

26 **Sulfur Mortar:**

1. Empty the pot and refill with fresh material with sufficient frequency to assure that material is not being used more than five times. Capping material must be kept dry to prevent foaming.
2. Preheat sulfur mortar to about 265ºF.
3. Warm the capping plate to slow hardening, thus permitting production of thin caps.
4. Oil capping plate lightly and stir capping compound prior to pouring each cap.
5. Dry off specimen surfaces to prevent foaming and air bubbles between the specimen and capping compound.
6. Pour capping material into the mold and immediately place the specimen in the compound, using alignment devices to assure perpendicularity of the capped surface to the axis.
7. Allow sufficient time for the cap to harden prior to removal from mold.

27

28




29

## Protection of Specimens After Capping

- Moist cured specimens must be maintained in a moist surface condition between capping and testing by returning them to moist storage or wrapping with at least two layers of wet burlap.
- Specimens with gypsum plaster caps should not be stored in moist rooms longer than four hours after capping and capped surfaces must be protected from water dripping on them.

**Tips!** 30

- Check capping plate condition frequently for planeness and surface defects.
- Check strength of capping material at required intervals.
- Check capped surfaces for conformance with planeness requirements.
- Use guide bars or bulls-eye level to assure conformance with perpendicularity requirements.
- Make sure that sulfur mortar is dry to prevent foaming.
- When using sulfur mortar, dry the surfaces of specimens to prevent inclusion of gas bubbles in the caps. 31
- When capping with gypsum plaster, mix material at the same water percentage as used for qualification tests.
- Take precautions to prevent buildup of hydrogen sulfide gas in lab facility by having capping pot and capping area under a vent hood that exhausts gas out of doors.

## REVIEW QUESTIONS

1. Describe the requirements for capping plates.

2. Describe the requirements for high-strength gypsum capping material.

3. Describe how caps are checked for dimensional tolerances.

4. Describe the process for conducting strength tests of sulfur mortar for compliance testing.

5. Describe the capping process using high-strength gypsum plaster.

6. Describe the capping process using sulfur mortar.

7. Discuss safety precautions for using sulfur mortar.

# USE OF UNBONDED CAPS IN DETERMINATION OF COMPRESSIVE STRENGTH OF HARDENED CONCRETE CYLINDERS FOP FOR ASTM C 1231

02

## Scope

This practice covers requirements for a capping system using unbonded caps for testing molded concrete cylinders. This practice may require the user to conduct tests to qualify the unbonded capping system for certain strength levels.

03

Unbonded caps may not be used for acceptance testing of concrete with compressive strength below 1500 or above 12000 psi.

The qualification tests require testing companion cylinders, one prepared according to AASHTO T 231 and one with unbonded caps. Statistical procedures are used to ensure that unbonded caps do not reduce strengths more than 2%.

04

## Significance

This practice may be used in lieu of capping as described in AASHTO T 231.

05

## Apparatus

**Note:** This FOP requires using pads made of neoprene having Shore A durometer hardness of 50 to 70. Materials other than neoprene must be specifically qualified according to the section on qualification of unbonded capping systems.

This practice requires the materials and equipment necessary to produce ends of hardened concrete cylinders that conform to the plane requirements of AASHTO T 22 and the capping requirements of AASHTO T 231. This may include grinding equipment or capping materials and equipment to produce neat cement paste, high strength gypsum plaster, or sulfur mortar caps.

06

- **Pads:** Pads shall be 1/2 ±1/16 in. thick with a diameter not more than 1/16 in. less than the inside diameter of the controller. Pads shall be made from neoprene of Shore A durometer of 50, 60, or 70. The following information shall accompany the pads: Name of manufacturer or supplier; Shore A hardness; applicable strength range (see Table 1).

**Table 1 – Requirements for Use of Neoprene Pads** 07

| Cylinder Compressive Strength, psi | Shore A Durometer Hardness | Qualification Tests Required | Maximum Reuses |
|---|---|---|---|
| Less than 1500 | Not Permitted | | |
| 1500 to 6000 | 50 | None | 100 |
| 2500 to 7000 | 60 | None | 100 |
| 4000 to 7000 | 70 | None | 100 |
| 7000 to 12000 | 70 | Required | 50 |
| Greater than 12000 | Not Permitted | | |

**Note:** Maximum reuses may be less than shown in this table based on wear or cracking noted in the pads.

08

09

**Pads and Retainers**

10

**Note:** 0.5° is approximately equivalent to 1/8" in 12 inches.

The user must maintain records to track the number of uses of the pads, when the pads were put into service, and the pad durometer. Qualification tests must be performed if strength testing above 7000 psi is conducted using pads.

- **Retainers:** Made of metal durable in repeated use. The cavity of the metal retainers shall have an inside height of 1.0 ± 0.1-in. The inside diameter of the retainer shall be not less than 102% or greater than 107% of the cylinder. The surface of the metal retainer that contacts the bearing blocks of the compression machine shall be plane to within 0.002 in. and shall be free of gouges, grooves, or indentations more than 0.010 in. deep or 0.05 in$^2$ surface area.

## Specimens

Specimens shall be either 6 by 12 or 4 by 8 inch cylinders made according to AASHTO T 23 or R 39.

Specimens shall not be tested if any individual diameter of a cylinder differs from any other diameter of the same cylinder by more than 2 percent. Neither end of compressive test specimen shall depart from perpendicularity to the axis by more than 0.5° (see note).

If the ends of the specimen are not plane within 0.20 in. the specimen shall be corrected by sawing or grinding

11

**Caution:** Concrete cylinders tested with unbonded caps rupture more violently than comparable cylinders tested with bonded caps.

## Procedure

Record the date in service and track the number of pad uses.

Unbonded caps may be used on one or both ends of a cylinder in lieu of a cap or caps meeting the practice of AASHTO T 231, provided they have been properly qualified.

Examine the pads for excessive wear or damage. Replace pads that have cracks or splits exceeding 3/8 in. in length regardless of depth.

12 Center the unbonded cap on the cylinder and place the cylinder on the lower bearing block of the testing machine directly under the spherically seated (upper) bearing block. Carefully align the axis of the specimen with the center of thrust of the spherically seated block. The spherically seated block is to be rotated immediately prior to testing, to assure free movement. Apply the load continuously and without shock.

13 After application of load, but before reaching 10% of the anticipated specimen strength, check to see that the axis of the cylinder is within vertical tolerance of 1/8” in 12” and that the ends are centered within the retaining rings. A pause in load
14 application to check cylinder alignment is permissible.

15 Complete the load application, testing, calculation and reporting in accordance with AASHTO T 22.

16

## Qualification of Unbonded Capping Systems and Verification of Reuse of Pads

The compressive strength of molded cylinders tested with unbonded caps shall be compared with that of companion cylinders tested with ends ground or capped to meet requirements of AASHTO T 22 and the capping requirements of AASHTO T 231.

To be acceptable, tests must demonstrate that at a
17 95% confidence level ($\alpha = 0.05$), the average strength obtained using unbonded caps is not less than 98% of the average strength of companion cylinders capped or ground.

- 18 When required, qualification tests shall be conducted either by the supplier or user of the neoprene caps. The qualification testing shall be

**Note:** Pad life may depend on the hardness and type of pad material, the strength of the concrete, the difference between the outside diameter of the cylinder and the inside diameter of the retaining ring, the unevenness and roughness of the ends of the cylinder, and other factors.

conducted as described below on initial use of an unbonded cap at both the highest and lowest strength levels anticipated to establish an acceptable range of cylinder strength for use. Initial qualification tests shall include that after 100 uses the pads meet the confidence levels described above.

- The maximum number of reuses of a pad is 100 (50 for strength above 7000 psi). When conducting qualification tests for strengths above 7000 psi, make such verification tests at the highest strength levels for which the pads are to be used.

19 - Only those tests or reuses, which are within 2000 psi of the highest strength level to be qualified, will be included in the reuse count.

## Specimen Preparation for Qualification and Pad Reuse Testing

20 - Pairs of individual cylinders shall be made from a sample of concrete and cured as nearly alike as possible.

**Note:** The range of strengths permitted in qualification testing to define strength level is 1000 psi; but, in counting number of reuses only cylinders within 2000 psi of the highest strength level being qualified are included in the reuse count.

- A minimum of 10 pairs of cylinders shall be made at each strength level (many more pairs may actually be required). The “strength level” is the average of the strengths of the 20 or more cylinders whose strengths are within a range of 1000 psi.

21 - More than one pair of cylinders can be made from a single concrete sample but the cylinders must come from a minimum of 2 samples made on different days for each concrete strength level.

22 **Calculation**

For each strength level, compute the difference in strength for each pair of cylinders, and compute the average strength of the cylinders with the reference caps and the average strength of the cylinders with unbonded caps as follows:

23
$$d_i = x_{pi} - x_{si}$$

$$\bar{x}_s = (x_{s1} + x_{s2} + x_{s3} \ldots + x_{sn})/n$$

$$\bar{x}_p = (x_{p1} + x_{p2} + x_{p3} \ldots + x_{pn})/n$$

24 where:

$d_i$ = difference in strength of a pair of cylinders computed as the strength of the unbonded capped cylinder minus the strength of the cylinder prepared by T 231,

$x_{pi}$ = cylinder strength using unbonded cap,

$x_{si}$ = cylinder strength using practice T 231,

$n$ = number of pairs of cylinders tested for the strength level,

$\bar{x}_s$ = average strength of T 231 capped cylinders for a strength level, and

$\bar{x}_p$ = average strength of unbonded capped cylinders for a strength level.

25 Compute the average difference ($\bar{d}$) and standard deviation of the difference (**$s_d$**), for each strength level, as follows:

$$\bar{d} = (d_1 + d_2 \ldots + d_n)/n$$

$$s_d = \left[\sum (d_i - \bar{d})^2 / (n-1)\right]^{1/2}$$

26 To comply with this practice the following relationship must be satisfied:

27
$$\bar{x}_p \geq 0.98\ \bar{x}_s + (ts_d)/(n)^{1/2}$$

where **t** is the value of "students t" for (n-1) pairs at $\alpha$= 0.05 from table 2.

**Table 2 – Values of "t"**

| (n-1) | t($\alpha$=0.05)[A] |
|---|---|
| 9 | 1.833 |
| 14 | 1.761 |
| 19 | 1.729 |
| 100 | 1.662 |

[A] Use linear interpolation for other values of (n-1) or refer to appropriate statistical tables.

28

## Report

A sample report for pad qualification, including calculations, is shown below.

## Sample Report and Calculation

29

| Cylinder Pair | Compressive Strength, psi | | |
|---|---|---|---|
| | Neoprene Pad | Sulfur Cap | Difference, d |
| 1 | 3605 | 3580 | 25 |
| 2 | 3605 | 3690 | -85 |
| 3 | 3585 | 3595 | -10 |
| 4 | 3570 | 3625 | -55 |
| 5 | 3625 | 3640 | -15 |
| 6 | 3660 | 3740 | -80 |
| 7 | 3750 | 3720 | 30 |
| 8 | 3725 | 3720 | 5 |
| 9 | 3700 | 3725 | -25 |
| 10 | 3805 | 3755 | 50 |
| | | | |
| Averages | $\bar{x}_p$ 3663 | $\bar{x}_s$ 3679 | $\bar{d}$ -16 |
| Std. Dev. | | | sd 46.06 |

**Pad Material:** Lot 3742, Shore A = 52, Thickness = 0.51”
**Retaining Ring:** Set A manufactured 1-87.
**Concrete Cylinders:** Job 1207, Nos. 1–10, January 2 to 5, 1987.
**Sulfur Mortar:** Lot 3420. Compressive Strength of 6985 psi.
**Test Age:** All Tests 28 days age.

## Summary and Calculation

30

**Summary:**

$\bar{x}_s$ = 3679 psi
$\bar{x}_p$ = 3663 psi
$s_d$ = 46.06 psi
n = 10
t = 1.833

**Calculation:**

$$3663 \geq (0.98)(3679) + (1.833)(46.06)/(10)^{1/2}$$

3663 > 3632 (system qualifies at 3670 psi)

**Tips!** 31

- Check durometer of pads against requirements for the strength of cylinders being tested.
- Record date pads were placed in service and the number of reuses (100 maximum up to 7000 psi; 50 maximum from 7000 to 12000 psi).
- Examine pads carefully for cracks or splits (3/8" maximum length regardless of depth).
- Check perpendicularity and alignment of cylinder after application of up to 10% of load.
- For strength levels above 7000 psi, qualification of the neoprene caps is required. 32
- Evaluate qualification data to assure 95% confidence that strengths using unbonded caps are at least 98% of those prepared according to T 231.

## REVIEW QUESTIONS

1. What range of compressive strength does this FOP cover?

2. Describe required pad dimensions.

3. For a compressive strength of 9000 psi, the Shore A durometer pad hardness must be _____ and the maximum number of reuses may not exceed _____.

4. Describe the requirements for specimens (cylinders) tested under this FOP.

5. Describe the condition of an acceptable neoprene pad.

6. Describe the parameters defining an acceptable cap qualification. (Confidence level, minimum strength, definition of strength levels, etc.)