Alabama Dept. of Transportation
Bureau of Materials and Tests
Testing Manual

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APPROVED
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Procedure for Determination of In-Place Compressive Strength of Concrete

1. **Scope**

   This procedure establishes requirements & methods for extracting concrete cores from a structure and determining the average equivalent 28-day compressive strengths of said cores as in-place compressive strength.

2. **References**

   2.1. AASHTO T 24, "Standard Method of Test for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete"

   2.2. ASTM E178, "Standard Practice for Dealing with Outlying Observations"

   2.3. ALDOT-405, "Certification and Qualification Program for Concrete Technicians and Concrete Laboratories"

3. **Core Testing Requirements**

   3.1. The Department or a laboratory qualified by the Department, per ALDOT-405, shall extract the cores. Cores shall be shipped to the Bureau of Materials and Tests with all pertinent information.

   3.2. 24-hours notice should be given to the project manager and concrete producer prior to coring any structure.

   3.3. All cores shall be obtained, sealed, prepared, transported, and tested in accordance with AASHTO T 24, except that the length-to-diameter strength correction factor as defined in Section 4.2 will be used instead of the correction factors defined in AASHTO T 24.

   3.4. Recover a minimum of four (4) cores from the concrete placement in question. A minimum of four (4) cores are required, because if one is damaged or found to be an outlier, then an average of the remaining three cores can be used to determine the structural adequacy of the in-place concrete.

   3.5. Cores shall be obtained as soon as possible after testing cylinders at 28 days.

   3.6. Unless prior written approval is obtained from the Materials & Tests Engineer, cores with a diameter less than 3.70 in. shall only be used if they have a length-to-diameter ratio of 1.75 or greater at the time of testing.

   3.7. The presence of steel reinforcement, other than fibers, or other embedded metal in a core can affect its measured strength. Therefore, no core that contains reinforcing bars shall be tested unless absolutely necessary and its results shall only be used after receiving written approval from the Materials & Tests Engineer.

   3.8. AASHTO T 24 requires that after the cores have been drilled, the surface drill

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water should be wiped off, and the remaining surface moisture allowed to evaporate. When surfaces appear dry, but not later than 1 hour after drilling, the cores shall be placed in separate plastic bags that are sealed to prevent moisture loss. Cores are to be kept in the sealed plastic bags at all times except during end preparation and for a maximum time of 2 hours to permit capping before testing.

3.8.1. When coring drilled shafts or other deep elements, portions of a core may be stored to access the concrete quality, while other portions of a core may be tested to determine the in-place concrete strength. All portions of a core that will be tested to determine the in-place concrete strength shall be sealed in plastic bags to prevent moisture loss as outlined in Section 3.7.

4. Conversion of Core Strengths to Equivalent 28-Day Core Strengths

4.1. Determine the equivalent 28-day compressive strength of each individual core with Equation 1 to the nearest 10 psi. The core strength correction factors are defined in Sections 4.2 through 4.5. An example problem is presented in Appendix A. Each core strength correction factor shall be rounded to two decimal places.

$$f_c(28) = (F_{L/D} * F_{dia} * F_{age} * F_{dir}) * f_{core}(t) \qquad \text{(Equation 1)}$$

where $f_c(28)$ = the equivalent 28-day core compressive strength (psi)
              $F_{L/D}$ = length-to-diameter strength correction factor
              F_{dia} = diameter strength correction factor
              F_{age} = age strength correction factor
              F_{dir} = casting direction strength correction factor
              $f_{core}(t)$ = core compressive strength at any age, t (psi, measured in accordance with AASHTO T 24)

4.2. The core <u>length-to-diameter strength correction factor</u> ($F_{L/D}$) shall be determined with Equation 2.

$$F_{L/D} = 1 - \left[0.13 - \left(\frac{3}{1,000,000}\right) f_{core}(t)\right] (2 - L/D)^2 \qquad \text{(Equation 2)}$$

where $F_{L/D}$ = length-to-diameter strength correction factor
              L = core length (in., measured in accordance with AASHTO T 24)
              D = core diameter (in., measured in accordance with AASHTO T 24)
              $f_{core}(t)$ = core compressive strength at any age, t (psi, measured in accordance with AASHTO T 24)

4.3. The core <u>diameter strength correction factor (F_{dia})</u> shall be selected from Table 1. Values in between those listed shall be determined by linear interpolation.

Table 1: Core Diameter Correction Factor

Core Diameter	F_{dia}
2 inch	1.06
3 inch	1.03
4 inch	1.00
6 inch	0.98

4.4.   The <u>concrete age strength correction factor (F_{age})</u> for all cores shall be determined with Equation 3.

$$F_{age} = \left(\frac{4.1 + 0.85t}{t} \right)$$ (Equation 3)

where F_{age} = age strength correction factor
         t = concrete age at time of strength testing (days).

4.5.   The <u>concrete casting direction factor (F_{dir})</u> shall be selected from the values in Table 2. Unusual directions neither parallel nor perpendicular to the casting direction shall be measured and rounded to the nearest 90° to determine the case that is closest to the directions listed in Table 2.

Table 2: Casting Direction Strength Correction Factor

Casting Direction*	F_{dir}
Cores drilled **parallel** to casting direction	1.00
Cores drilled **perpendicular** to casting direction	1.04

*Note: Examples of where cores are drilled **parallel** to the concrete casting direction include drilling into bridge decks, footings, or drilled shafts from the top down. Examples of where cores are drilled **perpendicular** to the concrete casting direction include drilling into the vertical faces of columns or walls.

5. Designation of Outliers

5.1.   Due to the imperfect nature of drilling, handling, capping, and testing concrete cores, the reported range of strengths of a core set may vary significantly. In order to determine the most accurate value for in-place compressive strength, it is important to identify and discard any outliers from a given test set.

5.2.   After the equivalent 28-day compressive strengths of the cores have been determined from Equation 1, the dataset shall be checked for outliers, in accordance with ASTM E178. Outliers shall be determined using an upper 5% significance level.

5.3.   If one of the strength values from the dataset is determined to be an outlier,

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then this core strength shall be discarded and not used in the calculation of the average equivalent 28-day compressive strength. After an outlier has been discarded, the remaining dataset shall again be checked for outliers using the procedure outlined herein.

6. **Average Equivalent 28-Day Compressive Strength of Cores**

   6.1.   The average of the equivalent 28-day compressive strength from a minimum of 3 cores, after any outliers are discarded, will then be determined. The average will be rounded to the nearest 10 psi, and will be reported as the average equivalent 28-day compressive strength of the in-place concrete.

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APPENDIX A – EXAMPLE CALCULATIONS

1. Sample Core Test Results

   1.1. Six cores were recovered from the vertical faces of columns and tested at an age of 46 days in accordance with AASHTO T 24. The properties and strengths of the cores are listed in Table A-1.

Table A-1: Properties and compressive failure loads of cores

Core No.	Diameter (in.)	Length (in.)	Failure Load (pounds)
1	3.78	6.9	79,000
2	3.79	6.5	73,600
3	3.78	5.6	67,500
4	3.79	6.2	70,600
5	3.80	3.9	52,300
6	3.78	5.9	69,900

2. Calculation of Summary Core Data and Measured Core Strength

Table A-2: Calculation of the L/D, area, and measured strength of each core

Core No.	L/D (-)	Area (in.^{2})	Measured Strength, $f_{core}(t)$ (psi)
1	1.83	11.22	7,040
2	1.72	11.28	6,520
3	1.48	11.22	6,010
4	1.64	11.28	6,260
5	1.03	11.34	4,610
6	1.56	11.22	6,230

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3. Conversion of Core Strengths to Equivalent Strengths

3.1 Since the cores were recovered from the vertical faces of columns, they were drilled **perpendicular** to the concrete casting direction.

Table A-3: Calculation of strength correction factors and the equivalent core strength

Core No.	$F_{L/D}$	F_{dia}	F_{age}	F_{dir}	Equivalent 28-day Strength, $f_c(28)$ (psi)
1	1.00	1.01	0.94	1.04	6,950
2	0.99	1.01	0.94	1.04	6,370
3	0.97	1.01	0.94	1.04	5,760
4	0.98	1.01	0.94	1.04	6,060
5	0.89	1.01	0.94	1.04	4,050
6	0.98	1.01	0.94	1.04	6,030

4. Check for Potential Outliers

4.1. Consider all **six (6)** equivalent 28-day core strengths:

$f_{c,average}$ = (6,950 + 6,370 + 5,760 + 6,060 + 4,050 + 6,030) / 6 = 5,870 psi

$f_{c,low}$ = 4,050 psi

$f_{c,high}$ = 6,950 psi

σ = 980 psi

$T_{critical}$ = 1.822 (from ASTM E178 for n = 6 and using a 5% significance level)

From Equation 4: $\dfrac{f_{c,average} - f_{c,low}}{\sigma} = \dfrac{5,870\,\text{psi} - 4,050\,\text{psi}}{980\,\text{psi}} = 1.86 > T_{crittcal}$

Therefore, **Core No. 5** (lowest result) is an outlier and shall be discarded.

From Equation 5: $\dfrac{f_{c,high} - f_{c,average}}{\sigma} = \dfrac{6,950\,\text{psi} - 5,870\,\text{psi}}{980\,\text{psi}} = 1.10 < T_{crittcal}$

Therefore, the highest core result is not an outlier.

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4.2. Consider **five (5)** remaining equivalent 28-day core strengths:

$f_{c,average}$ = (6,950 + 6,370 + 5,760 + 6,060 + 6,030) / 5 = 6,234 psi

$f_{c,low}$ = 5,760 psi

$f_{c,high}$ = 6,950 psi

σ = 455 psi

$T_{critical}$ = 1.672 (from Table 3 for n = 5)

From Equation 4: $\dfrac{f_{c,average} - f_{c,low}}{\sigma} = \dfrac{6{,}234\,\text{psi} - 5{,}760\,\text{psi}}{455\,\text{psi}} = 1.04 < T_{crittcal}$

Therefore, the lowest core result is not an outlier.

From Equation 5: $\dfrac{f_{c,high} - f_{c,average}}{\sigma} = \dfrac{6{,}950\,\text{psi} - 6{,}234\,\text{psi}}{455\,\text{psi}} = 1.57 < T_{crittcal}$

Therefore, the highest core result is not an outlier.

5. Average Equivalent 28-Day Core Strengths

Based on the **five (5)** cores that remain in the dataset, the **average** equivalent 28-day compressive strength of the cores is **6,230 psi**.