Estimating Concrete Strength by the Maturity Method

General

The maturity method utilizes the principle that directly relates the strength of concrete to the cumulative temperature history of the concrete. Using this principle, the Department and Contractor can quickly and reliably estimate the field strength of concrete based on the maturity index (equivalent age or time-temperature factor) rather than by beam or cylinder tests in the field or the laboratory. The maturity as applied to a concrete mix is specific to that particular mix. When the mix design is changed, the Contractor may need to develop a new maturity relationship, or maturity curve in accordance with 2461.3G.6, “Estimating Concrete Strength by the Maturity Method.”

The development of a maturity-strength relationship requires three steps. These include:

1) Developing the maturity-strength curve (at the plant site is the desired location),
2) Estimating the in-place strength in the field, and
3) Verifying the strength-maturity relationship in the field.

This procedure utilizes the Nurse-Saul method for developing strength-maturity curves, as described in ASTM C 1074. The Nurse-Saul method uses a specific datum temperature (usually -10°C, but may be determined experimentally) to calculate the time-temperature factor (TTF) and to relate this to the measured concrete flexural or compressive strength at the particular TTF value. The general form of the Nurse-Saul method is shown in Equation 1.

\[
TTF = \sum (T_a - T_0) \Delta t
\]

Where:
- \( TTF \) = the time-temperature factor at age \( t \), degree-days or degree-hours,
- \( \Delta t \) = time interval, days or hours,
- \( T_a \) = average concrete temperature during time interval, \( \Delta t \), °C, and
- \( T_0 \) = datum temperature, which equals -10°C.

This test method describes the procedure for developing maturity-strength relationships to estimate concrete strength using the maturity method. This method uses either beams for flexural strength or cylinders for compressive strength. While the majority of this procedure uses dual units, measure and record all temperatures relating to the computation of maturity in degrees centigrade (°C).

Definitions

A. Temperature Sensor

The device on a maturity meter or data logger that is inserted into the concrete and provides a measure of temperature.

B. Data Logger

A commercially available device that records temperature measurements from a temperature sensor at various intervals.
C. Maturity Meter
   A commercially available device that includes a temperature sensor, data logger, and conducts maturity calculations automatically.

D. Maturity Index
   The cumulative area under the time-temperature curve developed as concrete cures. The units of maturity index are in degree-hours (C-hr). For the purposes of this procedure, the maturity index called the time-temperature factor (TTF).

E. Maturity Curve
   The relationship between the time-temperature factor and the strength of the concrete.

F. Verification Test
   At various intervals during construction, the maturity curve is verified by casting additional specimens and comparing the TTF-strength relationship with the original maturity curve for a particular mix.

Equipment

A. Maturity Meter or Temperature Sensor and Data Logger
   A maturity meter, for the sole purpose of recording concrete maturity, or a temperature sensor and data logger combination, accurate to ±1°C.

   Meters should be inspected prior to use to ensure the datum temperature is set to -10°C.

   Meters should be calibrated on an annual basis at a minimum to ensure proper temperature sensing. Perform calibration by comparing the temperature recorded by the maturity meter to a known temperature. This can be done by inserting the sensors into a controlled-temperature water bath. If deviations greater than 1°C is noticed, the device should be re-calibrated according to the manufacturer.

   Meters should be protected from moisture, extreme heat or cold, and theft when left in the field during testing. Each meter should be maintained in a manner consistent with manufacturer’s specifications.

   If a maturity meter that employs the use of thermocouples is used, the wire tips at the temperature-sensing end of each thermocouple must be soldered or spot welded together.

B. Beam Specimen Molds
   Use 6 in x 6 in beam molds in cross section, and with an overall length allowing for a span length in the testing apparatus of at least 3 times the depth.

C. Cylinder Specimen Molds
   Use 4 in x 8 in cylinder molds. If the aggregate has a maximum size greater than 1¼ in, use 6 in x 12 in cylinder molds.
D. Flexural Strength Test Apparatus
The apparatus for testing beam strength in flexure shall conform to the requirements as described in the MnDOT Concrete Manual or as approved by the Concrete Engineer.

E. Compressive Strength Test Apparatus
The apparatus for testing compressive strength shall conform to the requirements as described in the MnDOT Concrete Manual or as approved by the Concrete Engineer.

Preparation of Specimens
Cast beams or cylinders in accordance with 2461.3G.6, “Estimating Concrete Strength by the Maturity Method.” Embed temperature sensors in the two (2) additional beams approximately 3 in from any surface and in one of the outside thirds (i.e. within 6 in. from the end of the beam). Embed temperature sensors in the center of the two (2) additional cylinders. Record the data and do not test the additional beams or cylinders for strength.

The beams should be covered with plastic immediately after casting and prior to removal of the forms. If possible, place wet burlap over the surface of the beams under the plastic. Remove the forms the following day. Bury the beams in a pit of wet sand after form removal until they are tested. Beams may be cured in a water tank with the water temperature controlled at 60° to 80°F.

Ensure that concrete temperatures in the specimens do not drop below 50°F. Development of strength maturity relationship should be performed on concrete with temperature above 50°F.

If air temperatures are expected to drop below 40°F, place the specimens on foam board or plywood to insulate them from the cold ground. Place insulation on and around the specimens to retain heat.

If prepared in the laboratory, ensure that concrete used in making the specimens is identical in mixture proportions, quantities and material manufacturers to those specified on the approved mix design.

Use the Concrete Maturity-Strength Development form to determine maturity-strength relationship. In addition, test and record air content and temperature of the fresh concrete on the Concrete Maturity-Strength Development form. See Figure A for an example of a completed form using Flexural Beam Strength. See Figure B for an example of a completed form using Compressive Strength.

Procedure
A. Develop Strength-Maturity Relationship
Perform strength tests for the type of concrete at the ages in accordance with 2461.3G.6, “Estimating Concrete Strength by the Maturity Method.”
Test three specimens at each age and compute the average strength at each age. The maturity (TTF) value is calculated from the temperature reading at the time the specimen is tested for strength, by averaging the values obtained from the two maturity meters or data loggers. The tests should be spaced so they are performed at somewhat consistent intervals of time and span a range in strength that includes the opening strength desired. Ideally, there would be at least two sets of strength values below the anticipated opening strength. Test age may need to be increased when concrete temperature is below 50°F, when retarders are used, or when high early concrete is used. Test age may need to be decreased at higher temperatures above 80°F.

If a low test is the result of an obviously defective specimen, discard the result from the average but record its value and the reason for discarding it in the data entry form.

If using a maturity meter, read the maturity index directly from the meter. If using a temperature sensor and data logger, calculate the maturity index using the time-temperature history from the logger using Equation 1 above. Average the two maturity index values and report this in the appropriate location on the Concrete Maturity-Strength Development form.

The Concrete Maturity-Strength Development form is a Microsoft Excel® spreadsheet that plots the average flexural strength vs. the average maturity index for each test age, and determines the best-fit exponential curve using the form.

$$MR = S_u e^{-\left(\frac{\tau}{TTF}\right)^{\alpha}}$$ Equation 2

Where:
- $MR$ = flexural strength (modulus of rupture) or compressive strength, psi
- $TTF$ = the time-temperature factor at age $t$, degree-days or degree-hours,
- $S_u$ = ultimate expected flexural strength, psi
- $\tau, \alpha$ = time and shape coefficients.

Use the resulting fitted curve maturity-strength relationship for estimating the in-place strength of concrete cured under any conditions including those in the lab or in the field.

Obtain the Concrete Maturity-Strength Development form for these calculations from the Concrete Engineering website [http://www.dot.state.mn.us/materials/concretematurity.html](http://www.dot.state.mn.us/materials/concretematurity.html)

For pavements, determine the opening strength criteria for concrete pavements in accordance with 2301.3.O, “Opening Pavement to Traffic.”

For pavement repairs, determine the opening strength criteria for concrete pavements in accordance with 2302.3.B.4, “Opening to Construction Equipment and Traffic.”

For structures, determine the strength criteria for form removal or loading in accordance with 2401.3.G, “Concrete Curing and Protection.”

Enter all collected and recorded data in the Concrete Maturity-Strength Development form.
B. Estimate In-Place Concrete Strength
To estimate the in-place concrete strength in the field, place/insert a temperature sensor in the concrete at a location and frequency as specified in accordance with 2461.3G.6, “Estimating Concrete Strength by the Maturity Method.” On days when there is a large difference between daytime high temperatures and nighttime low temperatures, placing additional sensors near the beginning of the day’s paving and at a point near the midday location provides useful information. The concrete placed during the middle of the day can gain strength faster than the concrete placed at the beginning of the day because of daytime heating. Place sensors at side roads, or other locations, where opening to traffic is critical.

Record the identification number(s) of the maturity meters or data loggers on the *Maturity - Field Data* form or as approved by the Concrete Engineer. See Figure C for an example of a completed form.

Protect any protruding wires from construction equipment. Initiate data collection and recording according to the manufacturer’s instructions. **Use a datum temperature value of -10°C.**

Check the recorded maturity index (or temperature history and compute the maturity index). To estimate the strength of the in-place concrete, record the temperature readings and calculate the maturity values on the *Maturity - Field Data* form or as approved by the Concrete Engineer.

C. Verify Strength-Maturity Relationship
Cast beams or cylinders in accordance with 2461.3G.6, “Estimating Concrete Strength by the Maturity Method.” Test the beams or cylinders as close to the maturity index (TTF) for the opening, loading or form removal strength criteria as possible. Do not test the additional beam or cylinder containing the temperature sensor for strength. Compute the average strength using the *Concrete Maturity-Strength Verification* form. See Figure D for an example of a completed form using Flexural Beam Strength. See Figure E for an example of a completed form using Compressive Strength.

Plot the average strength and maturity index on the *Concrete Maturity-Strength Verification* form and check that it falls on or near the curve. Take appropriate actions in accordance with 2461.3G.6, “Estimating Concrete Strength by the Maturity Method.”

Report the results of the validation testing on the *Concrete Maturity-Strength Verification* form and submit the form to the Department.
Figure A
### Concrete Maturity - Compressive Strength Development

<table>
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<tr>
<th>Beam No.</th>
<th>Age at Break (hours or days)</th>
<th>Ave. Diameter &quot;D&quot; (in)</th>
<th>Ave. Length &quot;L&quot; (in)</th>
<th>Total Test Load (lbs)</th>
<th>Failure Type</th>
<th>Compressive Strength (psi)</th>
<th>TTF Sensor 1 (C-Hours)</th>
<th>TTF Sensor 2 (C-Hours)</th>
<th>Ave. TTF (C-Hours)</th>
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### Maturity Curve

- Compressive Strength
- Maturity Curve

**Comments:**

- **Mix Information**
  - Mix No.: 3A21-1
  - Truck No.: 5200987
  - Air %: 7.7
  - Sump. in.: 26
  - WC Ratio: 0.37
  - Certified Contractor Rep.: Bill Eatcher
  - Maturity Curve Reviewed by: Leo Bean

**Figure B**
### Maturity - Field Data

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Age (Hours)</th>
<th>Air Temp (deg F)</th>
<th>TTF (log C/hr)</th>
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<td>21:00</td>
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**Comments:**

Figure C
**Concrete Maturity - Flexural Beam Strength Verification**

- **Project No.:** 9881-23
- **Tester:** C. Callaway
- **Min. No.:** 3A21-1
- **Location:** 1425
- **Contractor:** TUV Paving
- **Air, %:** 7.8
- **Engineer:** T. Sanders
- **Slump, in.:** 2.6
- **W/C Ratio:** 0.37

**Beam Breaker Type:** Rainhart Beam Breaker

| Test No. | Beam No. | Age at Break (hours) | Date     | Time | Ave. Width "B" (in) | Ave. Depth "D" (in) | Total Test Load, psi | Area Correction Factor | Broken in Center Third? (Y/N) | Modulus of Rupture (psi) | TTF (C-Hours) | Verification Test Result |
|----------|----------|----------------------|----------|------|---------------------|---------------------|----------------------|--------------------------|--------------------------|-----------------|------------------------|
| 1        | 1        | 46                   | 5/07/17  | 1:35 | 6.00                 | 6.60                | 543                  | 0.98                     | Y                        | 536             | 1652                   | PASS             |

**Maturity Curve Verification**

- **Maturity Curve**
- **Opening Criteria**
- **Other Data**
- **Verification Point**

**Comments**

Certified Contractor Representative: Bill Batchelar

Verification Test Reviewed by: Leo Bean

*Figure D*
Figure E