Estimating Concrete Strength by the Maturity Method

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 Engineer 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 MnDOT Standard Specification 2461.

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

1) Developing the maturity-strength curve in the laboratory or in the field,
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.

$$TTF = \sum (T_a - T_0)\Delta t \qquad \text{Equation 1}$$

Where:
TTF = the time-temperature factor at age t, degree-days or degree-hours,
Δt = time interval, days or hours,
T_a = average concrete temperature during time interval, Δt, °C, and
T_0 = datum temperature, -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.

Apparatus

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.

Calibrate maturity meters yearly to ensure proper operation and temperature sensing.

Verify proper operation of maturity meters and temperature sensors every 30 days during normal plant production. Perform verification by comparing the temperature recorded by the maturity meter or temperature sensor to a known temperature, as provided by a calibrated thermometer. Use at least three temperature points (e.g. 40°F, 75°F, and 110°F [5°C, 25°C and 45°C]) in the sensor verification.

B. Beam Specimen Molds
Developing a maturity relationship with beams, a minimum of 15 beam specimen molds are required. Use beam molds 6 in x 6 in (150 mm x 150 mm) 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
Developing a maturity relationship with cylinders, a minimum of 17 cylinders specimen molds are required. Use cylinder molds 4 in x 8 in (100 x 200 mm). If the aggregate has a maximum size greater than 1¼ in (31.5 mm), use 6 in x 12 in (150 x 300 mm) 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.

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

Preparation of Specimens

A. Prepare specimens according as described in the MnDOT Concrete Manual. The preferred method is to cast, cure, store, and test specimens in the field at the beginning of the construction project. Ensure that concrete temperatures in the specimens do not drop below 50°F (10°C). If air temperatures are expected to drop below 40°F (4°C), place the specimens on foam board or plywood to insulate them from the cold ground. Place insulation on and around the specimens.

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.

B. Test and record air content, temperature, and slump 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.

C. For beams, prepare 15 specimens according to the appropriate standard listed in Section B.2 above. Use a minimum of 3 cubic yards of concrete. Embed temperature sensors in at least two of the specimens. Place all sensors so that they are approximately 3 in. (75 mm) from any surface and in one of the outside thirds (i.e. within 6 in. (150 mm) from the end of the beam). Save the specimens with the temperature sensors for testing last.

For cylinders, prepare 17 specimens according to the appropriate standard listed in Section B.3 above. Use a minimum of 1 cubic yard of concrete. Embed temperature sensors in the center of two of the specimens, record the data and do not test for strength.

D. Protect the concrete specimens as described in the MnDOT Concrete Manual.

Procedure

A. Develop Strength-Maturity Relationship

Perform strength tests as described in the MnDOT Concrete Manual for the type of concrete at the ages specified in the table below.

Chronological Testing Ages of Strength Specimens	
Type of Concrete	**Testing Ages ***
Concrete pavement as defined in 2301	Determined by the Contractor ‖
Normal Strength Concrete as defined in 2461	1, 2, 3, 7 and 28 days
High-Early (HE) Concrete as defined in 2461	12 hours, 1, 2, 7 and 28 days
Ultra High-Early (UHE) Concrete as defined in 2302	3, 4 and 8 hours, 1 and 14 days

* The Contractor may adjust the testing ages if approved by the Engineer, in conjunction with the Concrete Engineer.
‖ Test at least two (2) sets of strength specimens before the anticipated opening strength.

Test three specimens at each age and compute the average strength.

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.

At each test age, determine the average maturity index (TTF) at the time the specimens are tested, by averaging the values obtained from the two maturity meters or data loggers. 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, and Equation 1 in Section 1 of this procedure. 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.

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

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
τ, α = 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

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 a temperature sensor in the concrete at a rate specified in MnDOT Standard Specification 2461.

Record the identification number(s) of the maturity meters or data loggers on the *Maturity - Field Data* form. 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.

At regular intervals, check the recorded maturity index (or temperature history and compute the maturity index). Record the temperature readings and calculate the maturity values on the *Maturity - Field Data* form to estimate the strength of the in-place concrete.

C. Verify Strength-Maturity Relationship

At intervals specified in Standard Specification 2461, cast and cure three specimens and insert a temperature sensor in at least one of them. If using cylinders, cast an additional cylinder for inserting the temperature sensor only. Test all three specimens as described in this standard as close to the maturity index (TTF) for the opening, loading or form removal strength criteria as possible. 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 according to Standard Specification 2461.

Report the results of the validation testing on the *Concrete Maturity-Strength Verification* form and submit the form to the Engineer in the field.

Minnesota Department of Transportation

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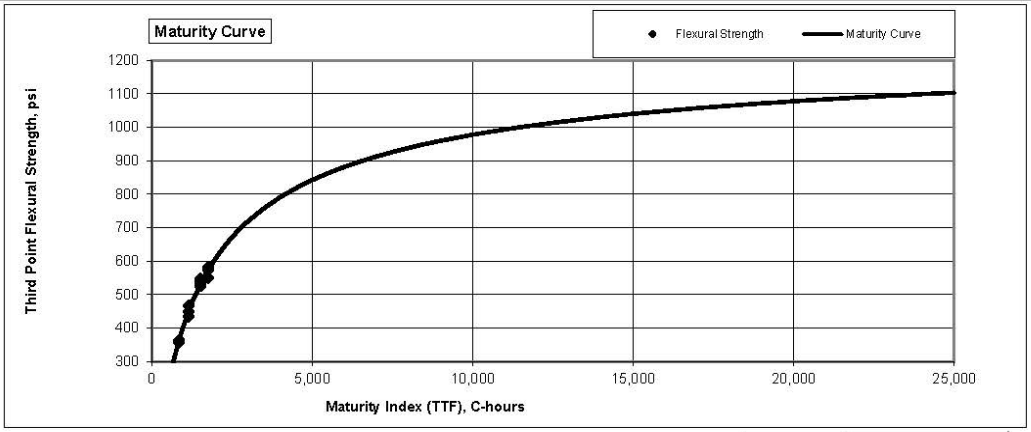
Concrete Maturity - Flexural Beam Strength Development

Report Date: 5/27/17

Project No.:	8901-23	Tester:	C.Calloway	Casting Date:	5/24/17
Location:	I-425	Contractor:	TUV Paving	Casting Time:	14:15
Curve #:	1	Engineer:	T.Sander	Slab Thickness:	7

Beam Breaker Type: Rainhart Beam Breaker

Beam No.	Age at Break (hours or days)	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 Sensor 1 (C-Hours)	TTF Sensor 2 (C-Hours)	Ave. TTF (C-Hours)
1	16.5	6.00	5.94	242	1.01	y	244	525	534	530
2		6.06	6.00	248	0.98	y	243			
3		6.00	6.00	225	1	y	225			
4	28.5	6.03	6.00	361	0.99	y	357	852	864	860
5		6.06	6.00	371	0.98	y	364			
6		6.12	6.00	380	0.96	y	365			
7	39.5	6.12	6.00	453	0.96	y	435	1148	1160	1155
8		6.09	5.94	477	0.98	y	467			
9		6.06	6.00	458	0.98	y	449			
10	53.5	6.06	5.94	543	0.99	y	538	1508	1534	1520
11		6.12	5.88	536	0.98	y	525			
12		6.00	5.97	543	1.01	y	548			
13	64.5	6.09	6.00	567	0.97	y	550	1752	1781	1765
14		6.06	5.97	588	0.99	y	582			
15		6.00	6.00	575	1	y	575			



Curve Coefficients:

Su=	1295.35
t=	1263.14
a=	0.61256372

Solve Maturity Curve

Required Strength for Opening 500 psi

Required TTF for Opening **1370** C-hours

Comments:

Mix Information	
Mix No.	3A21-1
Truck No.	5200791
Air, %	8.7
Slump, in.	2.5
W/C Ratio	0.37

Certified Contractor Representative: Bill Batcher

Maturity Curve Reviewed by: Leo Bean

Figure A

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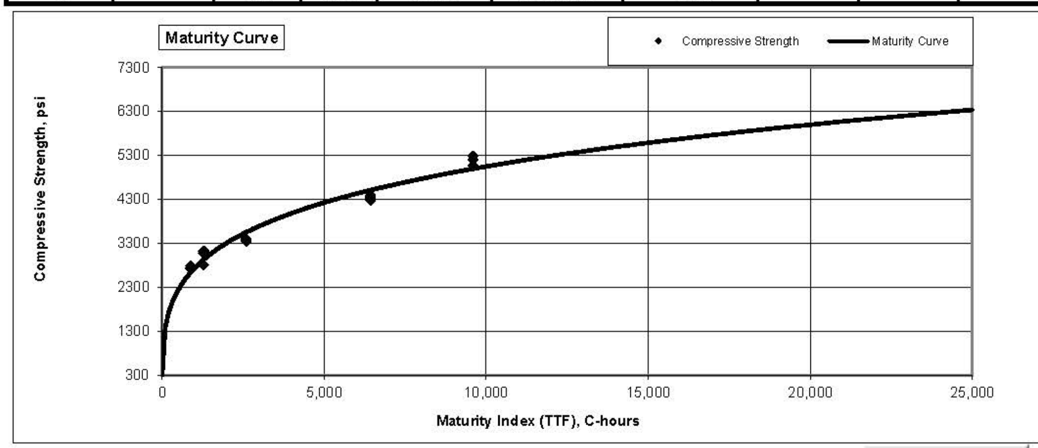
Concrete Maturity - Compressive Strength Development

				Report Date:	5/27/17
Project No.:	8901-23	Tester:	C.Calloway	Casting Date:	5/24/17
Location:	I-425	Contractor:	TUV Paving	Casting Time:	2:15 PM
Curve #:	1	Engineer:	T.Sanders	Opening Strength, psi	3000

Beam No.	Age at Break (hours or days)	Ave. Diameter "D" (in)	Ave. Length "L" (in)	Total Test Load (lbs)	Failure Type	Compressive Strength (psi)	TTF Sensor 1 (C-Hours)	TTF Sensor 2 (C-Hours)	Ave. TTF (C Hours)
1	16.5	6.01	12.02	79060	Cone	2785	881	887	885
2		6.00	12.00	77090	Cone/Split	2725			
3		5.98	11.99	76720	Cone	2730			
4	28.5	6.01	12.02	79860	Cone	2815	1235	1321	1280
5		6.00	12.00	87290	Cone	3085			
6		5.98	11.99	87830	Cone/Split	3125			
7	39.5	6.01	12.02	95400	Cone	3365	2547	2654	2600
8		6.00	12.00	95900	Cone	3390			
9		5.98	11.99	94230	Cone/Split	3355			
10	53.5	6.01	12.02	121740	Cone	4290	6521	6352	6435
11		6.00	12.00	124110	Cone	4390			
12		5.98	11.99	121800	Cone	4335			
13	64.5	6.01	12.02	149940	Cone	5285	9542	9654	9600
14		6.00	12.00	147070	Cone	5200			
15		5.98	11.99	142340	Cone/Split	5070			



Required TTF for Opening **1394** C-hours

Su= 1434248.44
t= 6.4269E+20
a= 0.04473928

Solve Maturity Curve

Comments:

Mix Information	
Mix No.	3A21-1
Truck No.	5200987
Air, %	7.7
Slump, in.	2.6
W/C Ratio	0.37

Certified Contractor Rep: Bill Batcher

Maturity Curve Reviewed by: Leo Bean

Figure B

Minnesota Department of Transportation 5/2017

Maturity - Field Data

Project No.: 8901-23 Tester: C.Calloway Mix No.: 3A21-1

Location: I-425 Contractor: Bill Batcher Probe No.: 1

Curve #: 1 Engineer: T.Sanders TTF Required: 1370

Site No.: I-425

Structural Unit Location: NB, Passing

Or Probe Location From STA: 34+45 To STA: 49+95

Apparatus Used: Maturity Meter

				Maturity Meter			
Date	Time	Age (hours)	Air Temp (deg F)	TTF (deg C-hr)			
5/27/17	10:30 AM	0.00	75	0			
5/27/17	5:30 PM	7.00	77	452			
5/28/17	7:30 AM	21.00	71	1102			
5/28/17	12:30 PM	26.00	75	1235			
5/28/17	4:45 AM	30.25	77	1398			

Comments:

Figure C

Minnesota Department of Transportation

5/2017

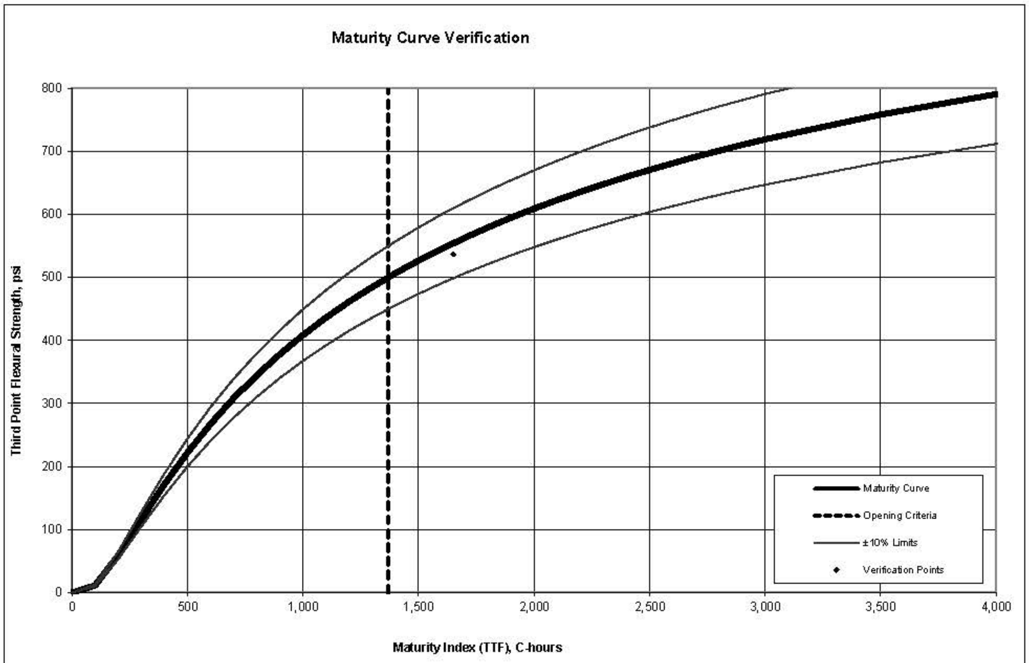
Concrete Maturity - Flexural Beam Strength Verification

Project No.:	8901-23	Tester:	C.Calloway	Mix No.:	3A21-1
Location:	I-425	Contractor:	TUV Paving	Air, %:	7.8
Curve #:	1	Engineer:	T.Sanders	Slump, in.:	2.4
				W/C Ratio	0.37

Curve Coefficients	**Su =** 1295.35	Slab Thickness:	7
(from Maturity-Strength	**t =** 1263.14	Required Strength for Opening:	500 psi
Development Report)	**a =** 0.6125637	Required TTF for Opening:	**1369** C-hours

Beam Breaker Type: **Rainhart Beam Breaker**

Test No.	Beam No.	Age at Break (hours /days)	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	45	5/27/17	1:35	6.03	6.00	543	0.99	Y	538	1652	PASS
	2				6.06	6.00	536	0.98	Y	525		
	3				6.12	6.00	543	1.01	Y	548		



Comments		
	Certified Contractor Representative:	Bill Batcher
	Verification Test Reviewed by:	Leo Bean

Figure D

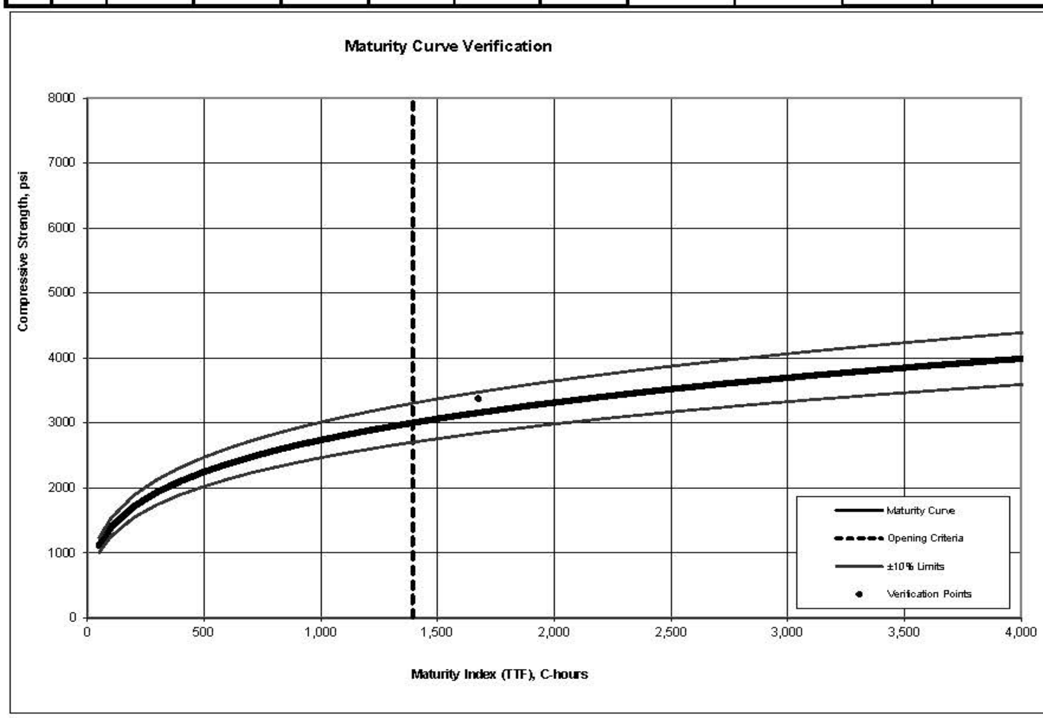
Minnesota Department of Transportation 5/2017

Concrete Maturity - Compressive Strength Verification

Project No.:	8901-23	Tester:	C.Calloway	Mix No.:	3A21-1
Location:	I-425	Contractor:	TUV Paving	Air, %:	7.7
Curve:	1	Engineer:	T.Sanders	Slump, in.:	2.6
				W/C Ratio	0.37

Curve Coefficients	**Su =** 1434248.4	Opening Strength, psi	3000
(from Maturity-Strength	**t =** 6.43E+20	Required TTF for Opening	**1394**
Development Report)	**a =** 0.0447393		

Test No.	Cylinder No.	Age at Break (hours/days)	Date	Time	Ave. Diameter "D" (in)	Ave. Length "L" (in)	Total Test Load (lbs)	Failure Type	Compressive Strength (psi)	TTF (C-Hours)	Verification Test Passes?
	1				6.01	12.02	95400	Cone	3365		
1	2	31	5/27/17	1:35	6.00	12.00	95900	Cone	3390	1675	**PASS**
	3				5.98	11.99	94230	Cone	3355		



Comments	
	Certified Contractor Representative: Bill Batcher
	Verification Test Reviewed by: Leo Bean

Figure E