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) Validating 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 (14°F or -10°C) 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, which equals 14°F or -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. Measure and record all temperatures relating to the computation of maturity in conjunction with the datum temperature, degrees Fahrenheit (°F) or Celsius (°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 (F-hrs or C-hrs). For the purposes of this procedure, the maturity index is called the time-temperature factor (TTF).

E. Maturity Curve
The relationship between the TTF and the strength of the concrete.

F. Validation Test
At various intervals during construction, the maturity curve is validated 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°.

Maturity meters should be inspected prior to use to ensure the datum temperature is set to **14°F or -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° 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.

When using beams, cover with plastic immediately and if possible, place wet burlap over the surface of the beams under the plastic. When using cylinders, immediately place a cap on the molds. Remove the forms or molds the following day and cure the beams or cylinders in a temperature-controlled environment (moist room or water tank) at 60° to 80°F until they are tested. Another option at the field plant is to bury the beams or cylinders in a pit of wet sand after form removal until they are tested.

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.

Procedure

A. Develop Maturity-Strength 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.

If using a maturity meter, read the TTF directly from the meter. If using a temperature sensor and data logger, calculate the TTF using the time-temperature history from the logger using Equation 1 above. Average the two TTF values at each break age 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 strength vs. the average TTF for each test age and determines the best-fit exponential curve using the form.

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.

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."

Use the *Concrete Maturity-Strength Development* form to determine maturity-strength relationship or as approved by the Concrete Engineer. Submit the determined maturity-strength relationship to the Department. Figure A is an example of a completed form using Flexural Beam Strength and Figure B is an example of a completed form using Compressive Strength.

The concrete maturity forms can be found on the Concrete Engineering website: http://www.dot.state.mn.us/materials/concretematurity.html.

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.

Protect any protruding wires from construction equipment. Initiate data collection and recording according to the manufacturer's instructions. **Use a datum temperature value of 14°F or -10°C.**

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

The concrete maturity forms can be found on the Concrete Engineering website: http://www.dot.state.mn.us/materials/concretematurity.html.

C. Validate Strength-Maturity Relationship

Cast beams or cylinders in accordance with 2461.3G.6, "Estimating Concrete Strength by the Maturity Method." **Test the validation 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 Validation* 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 Validation* 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 Validation* form and submit the form to the Department.

The concrete maturity forms can be found on the Concrete Engineering website: http://www.dot.state.mn.us/materials/concretematurity.html.

Minnesota Department of Transportation

24-Nov-21

Concrete Maturity - Flexural Strength Development

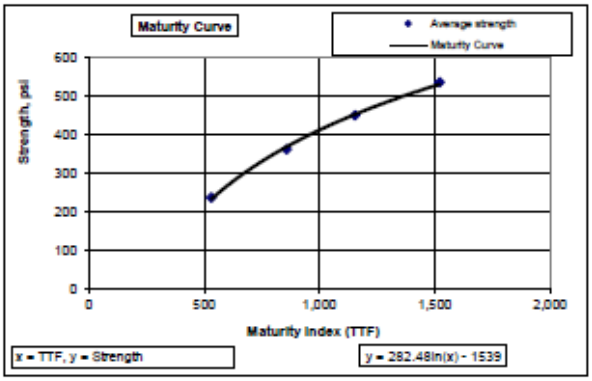
Mix #:	3A21-1	Performed by:	C. Calloway	Project #:	8901-23
Curve #:	1	Contractor:	TUV Paving	Casting Date:	5/3/22
Plant #:	123	Inspector:	T. Sander	Casting Time:	6:45am
Plant Location:	Concreteville	Datum used:	14 °F	Opening Strength, psi:	500
				Required TTF for Opening:	1364

Beam No.	Age at Break (hours)					Flexural Strength (psi)	TTF at Break (Sensor 1)	TTF at Break (Sensor 2)	Average TTF
1						244			
2	16.5					243	525	534	530
3						225			
4						357			
5	28.5					364	852	864	858
6						365			
7						435			
8	39.5					467	1148	1160	1154
9						449			
10						536			
11	53.5					525	1508	1534	1521
12						546			

Mix Information	
Mix #:	3A21-1
Cement:	Cement 1
Fly Ash:	Ash 1
Fine Aggregate:	Sand 1
Coarse Aggregate:	Rock 1
Coarse Aggregate:	Rock 2
Air, %:	6.6
Concrete Temp:	69

Comments

Beams made from the first load of concrete at the batch plant.



Curve Coefficients: m = 282.48 (Slope (m)); b = -1539.04 (Intercept (b))

Figure A

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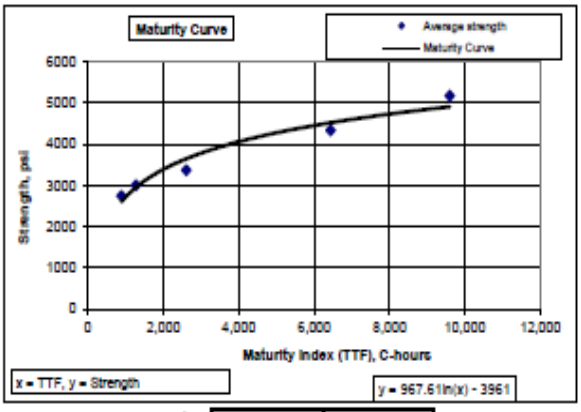
Concrete Maturity - Compressive Strength Development

Mix #:	3A21-1	Performed by:	C. Calloway	Project #:	8901-23
Curve #:	1	Contractor:	TUV Paving	Casting Date:	5/3/22
Plant #:	123	Inspector:	T. Sander	Casting Time:	6:45am
Plant Location:	Concreteville	Datum used:	14 °F	Opening Strength, psi:	3000
				Required TTF for Opening:	1331

Cylinder No.	Age at Break (hours)					Compressive Strength (psi)	TTF at Break (Sensor 1)	TTF at Break (Sensor 2)	Average TTF
1	12					2785	881	887	884
2						2725			
3						2730			
4	24					2815	1235	1321	1278
5						3085			
6						3125			
7	48					3365	2547	2654	2601
8						3390			
9						3355			
10	52					4290	6521	6352	6437
11						4390			
12						4335			
13	60					5285	9542	9654	9598
14						5200			
15						5070			

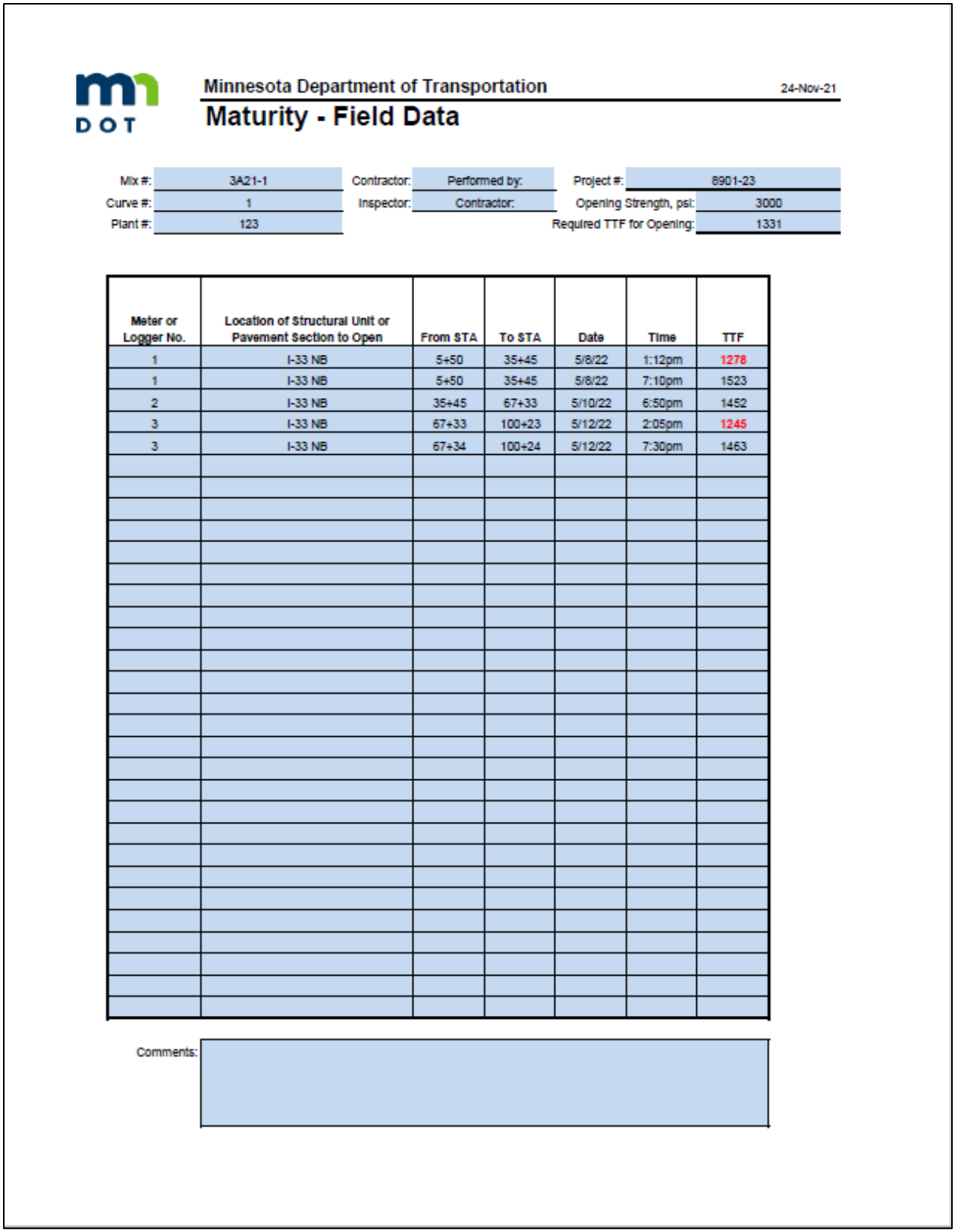
Mix Information	
Mix #:	3A21-1
Cement:	Cement1
Fly Ash:	Ash1
Fine Aggregate:	Sand1
Aggregate:	Rock1
Aggregate:	Rock2
Air, %:	6.7
Concrete Temp:	72

Comments



Curve Coefficients: m = 967.61 (Slope (m)); b = -3960.98 (Intercept (b))

Figure B



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Maturity - Field Data

Mix #:	3A21-1	Contractor:	Performed by:	Project #:	8901-23
Curve #:	1	Inspector:	Contractor:	Opening Strength, psi:	3000
Plant #:	123			Required TTF for Opening:	1331

Meter or Logger No.	Location of Structural Unit or Pavement Section to Open	From STA	To STA	Date	Time	TTF
1	I-33 NB	5+50	35+45	5/8/22	1:12pm	1278
1	I-33 NB	5+50	35+45	5/8/22	7:10pm	1523
2	I-33 NB	35+45	67+33	5/10/22	6:50pm	1452
3	I-33 NB	67+33	100+23	5/12/22	2:05pm	1245
3	I-33 NB	67+34	100+24	5/12/22	7:30pm	1463

Comments:

Figure C

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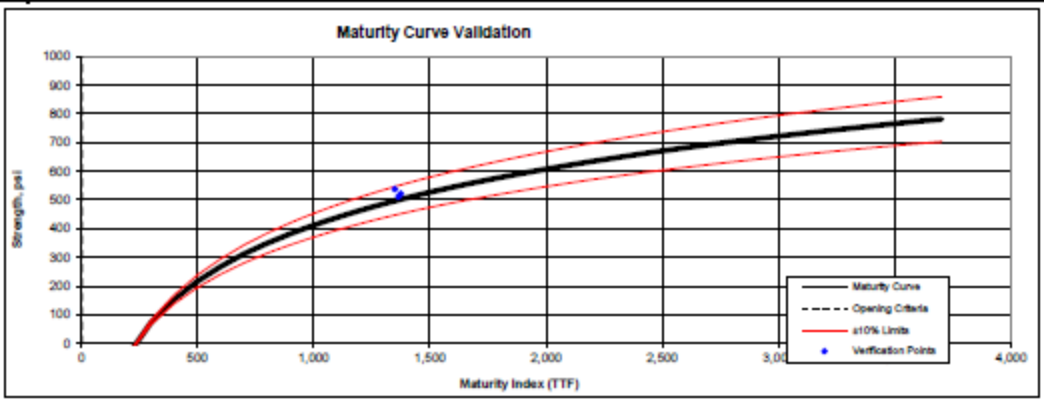
Concrete Maturity – Flexural Beam Strength Validation

Mix #:	3A21-1	Performed by:	C.Calloway	Project #:	8901-23
Curve #:	1	Contractor:	TUV Paving		
Plant #:	123	Inspector:	T.Sanders		
Plant Location:	Concreteville	Datum Used:	14 °F		

Enter From the Maturity Curve	Slope (m) =	282.48	Required Opening Strength, psi:	500
	Interoept (b) =	-1539.04	Required TTF for Opening:	1384

*Note:
The validation specimens should be broke as close to the required TTF as possible.

Validation Test No.	Beam No.	Age at Break (hours)	Casting Date	Casting Time			Flexural Strength (psi)	TTF at Break *	Average Strength (psi)	Lower Limit	Upper Limit	Validation Test Result
1	1	45	5/27/22	1:35PM			538	1350	537.00	447.33	546.74	PASS
	2						525					
	3						548					
2	1	44	6/15/22	2:34pm			523	1375	521.67	452.00	552.44	PASS
	2						512					
	3						530					
3	1	43	7/1/22	3:00pm			502	1365	512.00	450.14	550.17	PASS
	2						512					
	3						522					
4	1											
	2											
	3											
5	1											
	2											
	3											
6	1											
	2											
	3											



Comments:

Figure D

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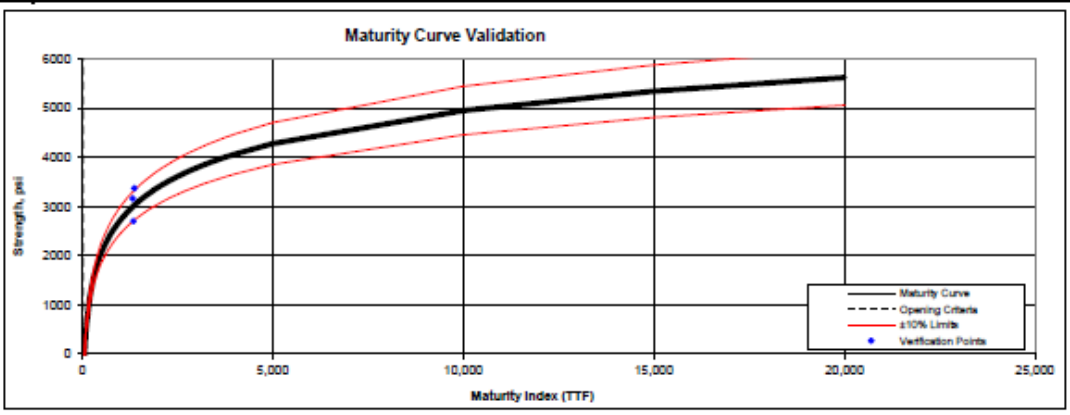
Concrete Maturity – Compressive Strength Validation

Mix #:	3A21-1	Performed by:	C. Calloway	Project #:	8901-23
Curve #:	1	Contractor:	TUV Paving		
Plant #:	123	Inspector:	T. Sander		
Plant Location:	Concreteville	Datum Used:	14 °F		

Enter from the Maturity Curve.	Slope (m) =	967.61	Opening Strength, psi:	3000
	Intercept (b) =	-3960.98	Required TTF for Opening:	1331

*Note:
The validation specimens should be broke as close to the required TTF as possible.

Validation Test No.	Cylinder No.	Age at Break (hours)	Casting Date	Casting Time			Strength (psi)	TTF at Break *	Average Strength (psi)	Lower Limit	Upper Limit	Validation Test Result
1	1	31	5/8/22	1:35pm			3365	1365	3370.00	2721.70	3326.52	ACCEPTABLE
	2						3390					
	3						3355					
2	1	30	5/21/22	1:22pm			3125	1325	3163.00	2695.80	3294.86	PASS
	2						3154					
	3						3210					
3	1	32	6/8/22	12:35pm			2695	1340	2703.00	2705.60	3306.85	FAIL
	2						2712					
	3						2702					
4	1											
	2											
	3											
5	1											
	2											
	3											
6	1											
	2											
	3											



Comments:

Figure E