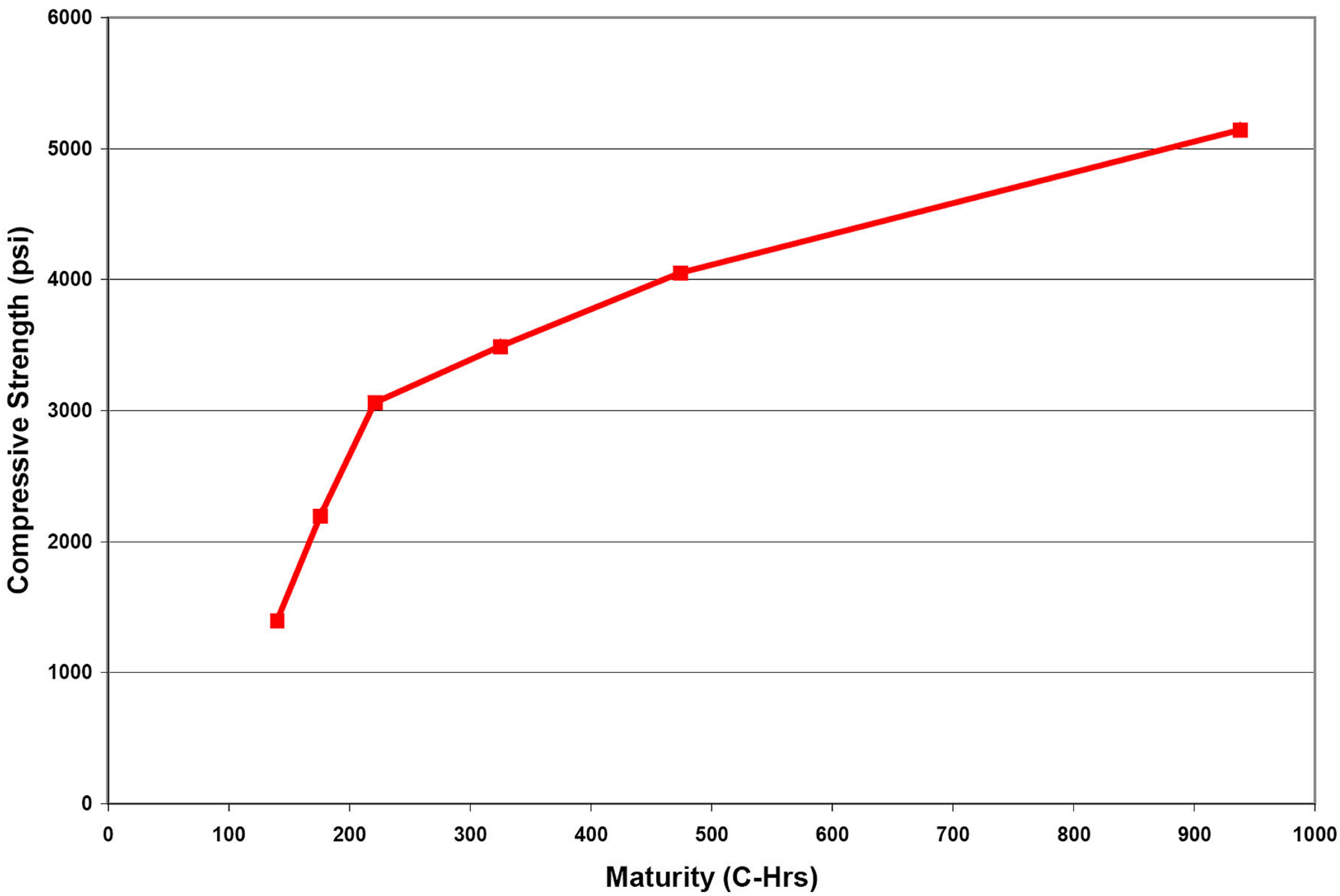
Use of the Maturity Method In Accelerated PCCP Construction

WA-RD 698.1 Keith W. Anderson, Jeff S. Uhlmeyer, Chuck Kinne, Linda M. Pierce and Steve Muench April 2009



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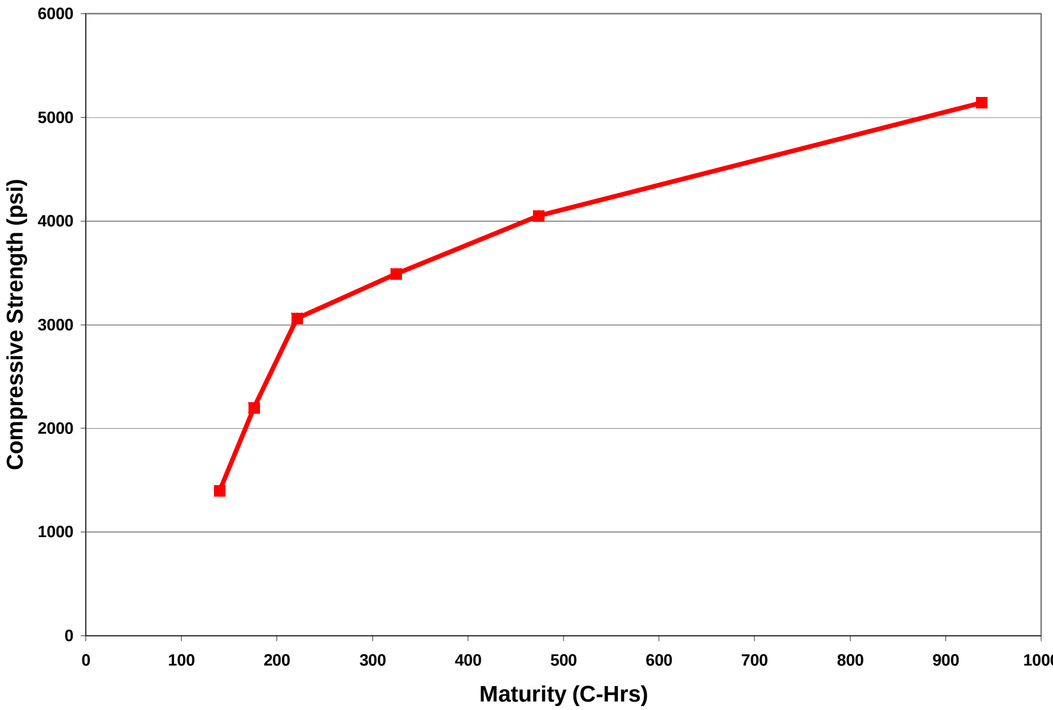
Use of the Maturity Method In Accelerated PCCP Construction

Contract 6473, I-5, 36th St. Vic. to SR-542 PCCP Rehab.
Contract 6886, I-5, James Street Vicinity to Olive Way
Contract 6916, I-205, SR-500 to I-5 PCCP Rehab. and Dowel Bar Retrofit



Washington State Department of Transportation

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 698.1		
4. TITLE AND SUBTITLE		5. REPORT DATE
Use of the Maturity Method In Accelerated PCCP Construction		April 2009
		6. PERFORMING ORGANIZATION CODE
		WA 04-02
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
Keith W. Anderson, Jeff S. Uhlmeyer, Chuck Kinne, Linda M. Pierce* and Steve Muench**		
. PERFORMING ORGANIZATION NAME AND ADDRESS		10. WORK UNIT NO.
Washington State Department of Transportation Materials Laboratory, MS-47365 Olympia, WA 98504-7365		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS		13. TYPE OF REPORT AND PERIOD COVERED
Washington State Department of Transportation Transportation Building, MS 47372 Olympia, Washington 98504-7372 Project Manager: Kim Willoughby, 360-705-7978		Final Report
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

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16. ABSTRACT

This report describes the maturity concept and its application on three case studies on actual construction projects. The three were all paving projects in the state of Washington, one a complete rebuild of a section of I-5 in downtown Seattle, and the other two panel replacements, one on I-5 in Bellingham and the other on I-205 in Vancouver.

The study found that maturity is a useful tool for determining the strength of the pavement and allowing early opening of the roadway to traffic. The use of all of the principles of the maturity concept such as the development of the calibration curve, the use of the verification method to assure compliance of the mix with the original mix, and systematic recording keeping and reporting were not evenly applied on each case study. As a result of the uneven application, additional case studies with strict compliance to all principles of the maturity concept are recommended prior to the full implementation of this tool on future accelerated paving projects.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Portland cement concrete, PCCP, concrete maturity method, accelerated construction	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	102	

DISCLAIMER

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Introduction

This study is the result of a continued effort by the Washington State Department of Transportation (WSDOT) to pursue and implement new technologies into the construction process to better serve the public. One of these new technologies is concrete maturity. Maturity is an approach to quality control that predicts the strength of the in-place concrete based on its internal temperature. It is a quality control technique for concrete that is firmly grounded in basic concrete fundamentals such as cement hydration and concrete's response to field conditions such as temperature and moisture. These basic fundamentals include the knowledge that concrete will gain strength faster when cured at higher temperatures and will gain little or no strength when exposed to very cold temperatures. Maturity takes these varying curing conditions in the field into account by measuring and recording the internal temperature of the concrete with special sensors or loggers embedded in the concrete at the time of placement.

WSDOT's current quality control procedures are based primarily on determining the strength at 28 days for samples cured in the laboratory under very controlled conditions. It does not take into account the environmental conditions experienced by the concrete placed on the job site. A concrete cylinder being cured under moist room conditions at 73°F will perform the same way during winter and summer construction months. Concrete placed in a structure or on a roadway at varying conditions of temperature and moisture will develop strength very differently than the cylinders in the laboratory.

Knowing the actual strength of the in-place concrete is especially important for projects where the stripping of forms on structures or opening to traffic for pavements is a critical factor in maintaining accelerated construction schedules. This report provides information on the maturity concept and describes the experience of using this technology on three pavement construction projects built between 2003 and 2005.

Current Concrete Acceptance Practices

Current practices for the acceptance of concrete involve the sampling of the concrete as it is delivered to the job site. The sampled concrete is cast into cylinders that are cured at the job site for 24 hours before being transported to a laboratory facility where they are cured under controlled temperature and humidity for the prescribed length of time. The cylinders are then tested at various intervals of time to determine their compressive strength and thus their compliance with specification requirements. On occasion, accelerated construction practices require that concrete pavement be opened to traffic 12 hours or less after concrete placement. For these projects, concrete cylinders are cast and cured at the side of the roadway. Prior to opening the roadway to traffic the cylinders are tested for compressive strength requirements.

These current quality control practices as they relate to predicting the strength of the concrete result in an un-conservative prediction of the in-place concrete strength during cold weather months when the temperature of the concrete in the field may be lower than that at which the quality control cylinders have been cured in the laboratory. In contrast, they represent an overly conservative approach when predicting the strength of the in-place concrete during the hot summer months when the concrete has experienced higher temperatures as compared to those experienced by the quality control cylinders in the laboratory.

When the prediction is un-conservative, as is the case when lower temperatures result in less strength gain, there is a chance that pavements could be open to traffic before they reach necessary strength or forms could be stripped from structures before adequate strength is attained resulting in the possible collapse of the structure. If the predictions are overly conservative, as is the case when field conditions result in a more rapid strength gain due to higher temperatures, the contractor may be unnecessarily delayed in opening pavements to traffic or stripping forms from structures resulting in lost time and money.

Maturity

Maturity is an approach to quality control that predicts the strength of the in-place concrete under any temperature conditions. ASTM defines the maturity method as “a technique for estimating concrete strength that is based on the assumption that samples of a given concrete mixture attain equal strength if they attain equal values of maturity index” (ASTM C 1074). A.G. Saul, one of the pioneers of the maturity concept, defined maturity as “concrete of the same mix at the same maturity has approximately the same strength whatever combination of temperature and time go to make up that maturity”. In his book entitled The Maturity Method, Carino states “as is well known, the strength of a given concrete mixture, which has been properly placed, consolidated, and cured, is a function of its age and temperature history."(Carino, 1991) Before describing the maturity method, some basic fundamentals concerning concrete must be understood.

Concrete Fundamentals

Concrete strength gain is a function of time and temperature as shown in the following examples. Figure 1 shows a typical concrete mix with a strength gain and time plot when cured at 100 percent relative humidity at 70°F. Under these curing conditions the concrete will achieve a compressive strength (**S**) of approximately 3,500 psi at four days (**4**) of age.

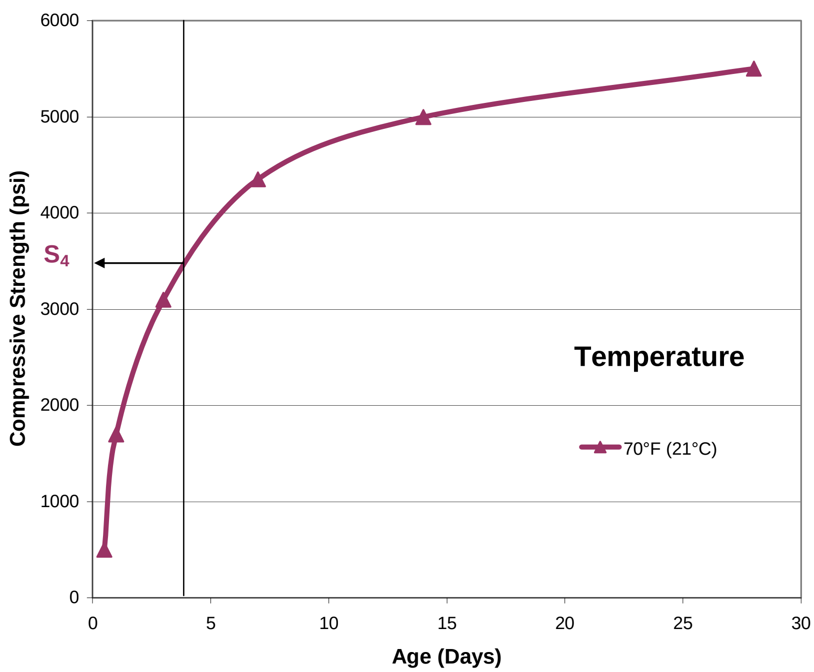

Figure 1. Concrete strength gain with time at curing temperature of 70°F.

If the same concrete is cured at 90°F and 100 percent humidity, it will exhibit a different strength gain with time behavior as shown in Figure 2. At the same age of four days, the concrete will have a higher compressive strength, S_4 (approximately 3,900 psi).

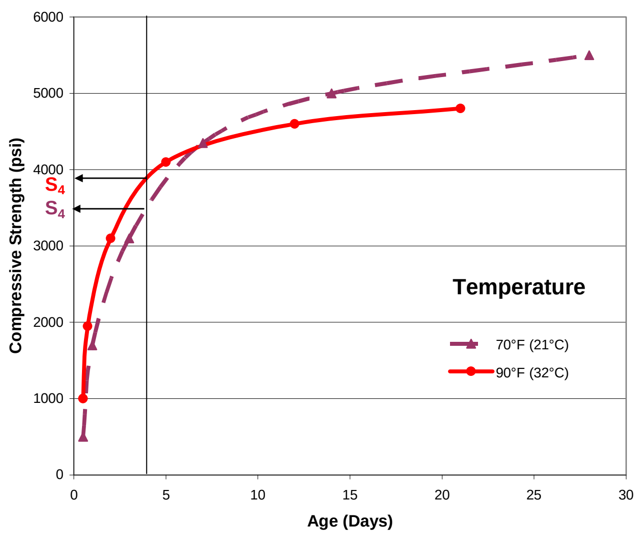

Figure 2. Concrete strength gain with time at curing temperature of 90°F versus 70°F.

Going in the other direction, if the concrete is cured at a lower temperature, say 54°F, the concrete will have a lower compressive strength at an age of four days, S_4 (approximately 3,250 psi) as shown in Figure 3.

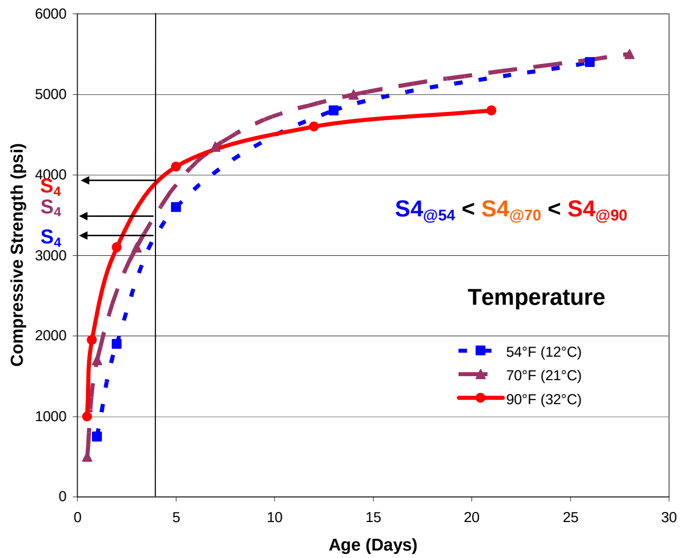

Figure 3. Concrete strength gain of concrete cured at 54°F versus 70°F and 90°F.

It should be noted that the concrete cured at higher temperatures will most likely exhibit a lower ultimate strength than the concrete cured at the lower temperature as shown in Figure 3.

The following are the basic concrete fundamentals on which the maturity concept is based.

- Strength gain is the result of cement reactions with water, also referred to as cement hydration
- Cement hydration results in the generation of heat
- Generation of heat results in a temperature rise in the concrete
- Maturity is related to the strength gain in the concrete as a function of time and temperature

Maturity Principles

In order to use the maturity concept, a mathematical function that can accurately relate time and temperature to strength must be used. The one most commonly used is called the Nurse-Saul maturity function. It assumes that the chemical reaction rate in concrete increases linearly with temperature. The equation that describes this relationship is commonly referred to as the Nurse-Saul maturity function, shown as Equation 1.

Equation 1

$$M = \sum_{0}^{t} \left(T - T_o\right) \cdot \Delta t$$

M = Maturity (a.k.a. Temperature-Time Factor) at age t

T = Average Temperature of the concrete during time interval Δt

T_o = Datum Temperature

The index computed by the equation is known by many different terms, such as the maturity index value; the temperature-time factor (TTF), or simply the "maturity" of the concrete (Trost, 2006). The Nurse-Saul function is a mathematical means of calculating the area under the temperature-time curve for a given concrete above a datum temperature. Various datum temperatures have been used, but the most common are between -10° C and -20° C with -10° C being the typical one used. The most common way of expressing the maturity index is in metric units of °C-hours (usually shown by the shorthand notation "C-Hrs").

The Arrhenius equation is the most commonly used alternative to the Nurse-Saul equation (Carino, 1991). It was derived empirically from observations of homogeneous chemical systems undergoing a single reaction. Roy and Idorn (1982) note that researchers "… cautioned that since cement is a multiphase material and also the process of cement hydration is not a simple reaction, homogeneous reaction kinetics cannot be applied." The Nurse-Saul equation assumes that the chemical reaction rate of concrete increases linearly with temperature whereas the Arrhenius equation assumes that the relationship is an exponential function. Trost, (2006) states that, "Whereas real-world chemical reactions do in fact follow an exponential rate law, the Arrhenius method is considered theoretically more "correct" than Nurse-Saul.

However, the exponential nature of the Arrhenius equation can cause extreme over prediction of concrete strength under certain unpredictable and uncontrollable conditions." It thus is not as widely used as the Nurse-Saul equation.

The datum temperature is the temperature for a given concrete mix below which all hydration reactions cease. When the temperature of the concrete falls below this temperature no additional strength gain occurs and no net gain in maturity is recorded. ASTM C 1074 recommends that 0°C (32°F) be used as the datum temperature for Type I cement used without admixtures when the expected curing temperature is within 0°C and 40°C (32°F and 104°F).

Calibration Curve Development

In order to use maturity the relationship between time, temperature and strength must be determined for each of the mix designs to be used on a given project. This involves making cylinders from a test batch of each mix design and breaking them at prescribed intervals. Additional cylinders are cast into which devices that measure maturity are placed and these devices are read and recorded as the other cylinders are broken at the prescribed intervals. The prescribed intervals are chosen so that maturity readings bracket the strength needed to open the roadway to traffic or strip the forms on a structure. A minimum of two cylinders are broken and averaged to arrive at the compressive strength for each time interval. The cylinders with the maturity devices imbedded in them can be broken for compressive strength measurement, but they should be the last in the series. It is desirable that enough points are established for the curve to break over, that is, change from the steep initial phase to the leveling off phase of strength gain. This can be attained in as little as three points, however, five points is more ideal.

For example, a panel replacement project on I-5 in the Bellingham developed a mix that was designed to reach 2,500 psi in 12 to 24 hours. The interval for taking readings and breaking cylinders began at hour five and progressed hourly until the 2,500 psi target had been exceeded. The readings where then spaced out to 9 hours, 12 hours and 24 hours as shown in Table 1. This provided a maturity curve that broke over and provided a very good relationship between maturity index and compressive strength as shown in Figure 4. For this example a maturity reading of 191 was obtained at the required opening to traffic strength of 2,500 psi (see WSDOT Standard Specifications, Section 5-05.3(17) Opening to Traffic).

Table 1. Example calibration data for a 12 hour mix design.			
Time (Hours)	Temperature (°C)	Maturity Reading (C-Hrs)	Compressive Strength (psi)
0	22	0	0
5	38	140	1,400
6	43	176	2,200
7	47	221	3,060
9	50	325	3,490
12	45	474	4,050
24	33	938	5,140

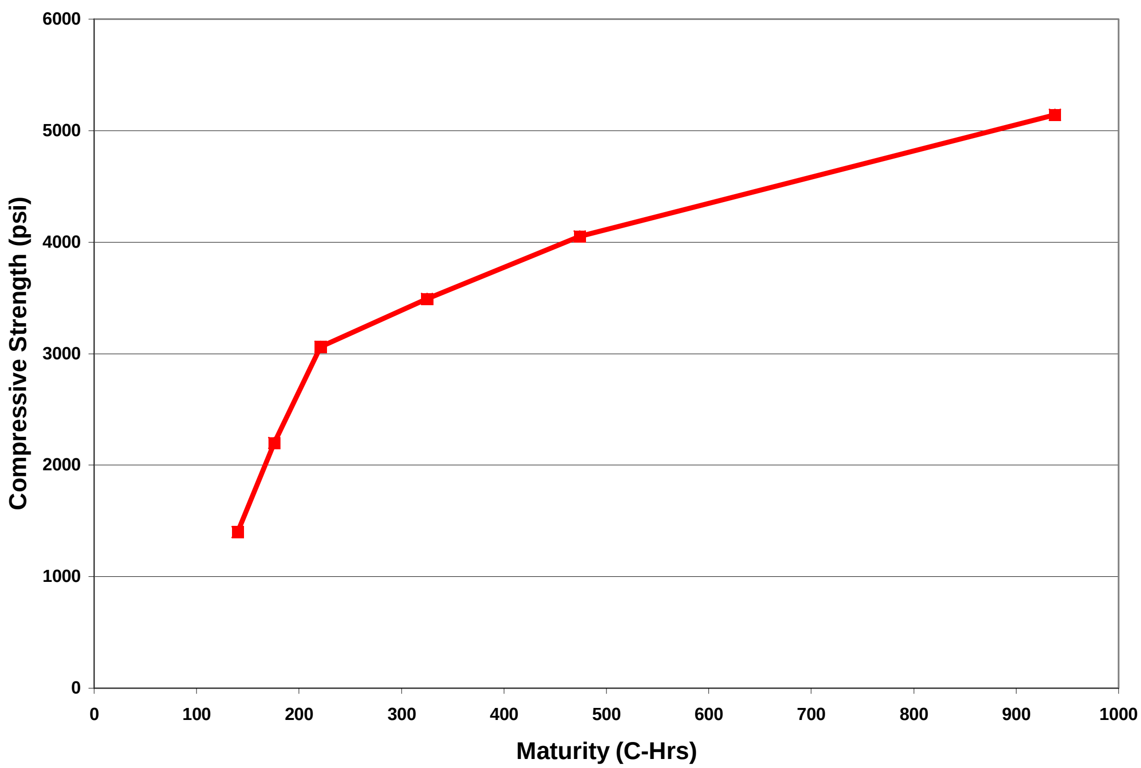

Figure 4. Maturity versus compressive strength curve.
Note: The desired 2,500 psi compressive strength is reached at a maturity reading of 191.

Once the strength versus maturity calibration curve has been established in the laboratory, the monitoring of the concrete placed in the field can begin. This involves the placement of maturity loggers in the pavement, panels, or structures that are being built. The maturity loggers are read at the appropriate time intervals to determine if the in-place concrete has reached the maturity value required for opening to traffic or form stripping.

The major caveat to the use of the maturity method is that the concrete mixing proportions and materials being monitored must not deviate from the ones used to develop the strength-maturity relationship. This would include changes in the brand of cement, the source and type of fly ash, the sources of aggregates and the water to cement ratio, or the use of accelerators or other admixtures that would affect the set time of the concrete. If any of these items change a new strength-maturity curve must be developed.

Verification

In order to assure that the concrete being placed in the field has not deviated from the original mix design, a process called verification is employed. Sets of two or three cylinders are cast from the concrete being placed in the field. A maturity logger is cast into one of the cylinders. The cylinders are cured in the laboratory under the same controlled conditions used to develop the original calibration curve. Maturity readings are taken periodically until the cylinders reach the target maturity value. Two or all three of the cylinders are broken and the average compressive strength is compared with the predicted compressive strength corresponding to the target maturity value. If the compressive strengths of the verification cylinders are within ±10 percent of the predicted strength, verification is confirmed. Figure 5 is an example of the required limits for a set of verification cylinder compressive strengths when the target maturity value was 191 for a required opening to traffic compressive strength of 2,500 psi. If the average is not within the ±10 percent the verification criteria is not met and verification is not confirmed. When this condition occurs, the contractor is normally directed to switch to traditional inspection testing techniques until a new strength-maturity relationship can be developed for the changed conditions of the mix design.

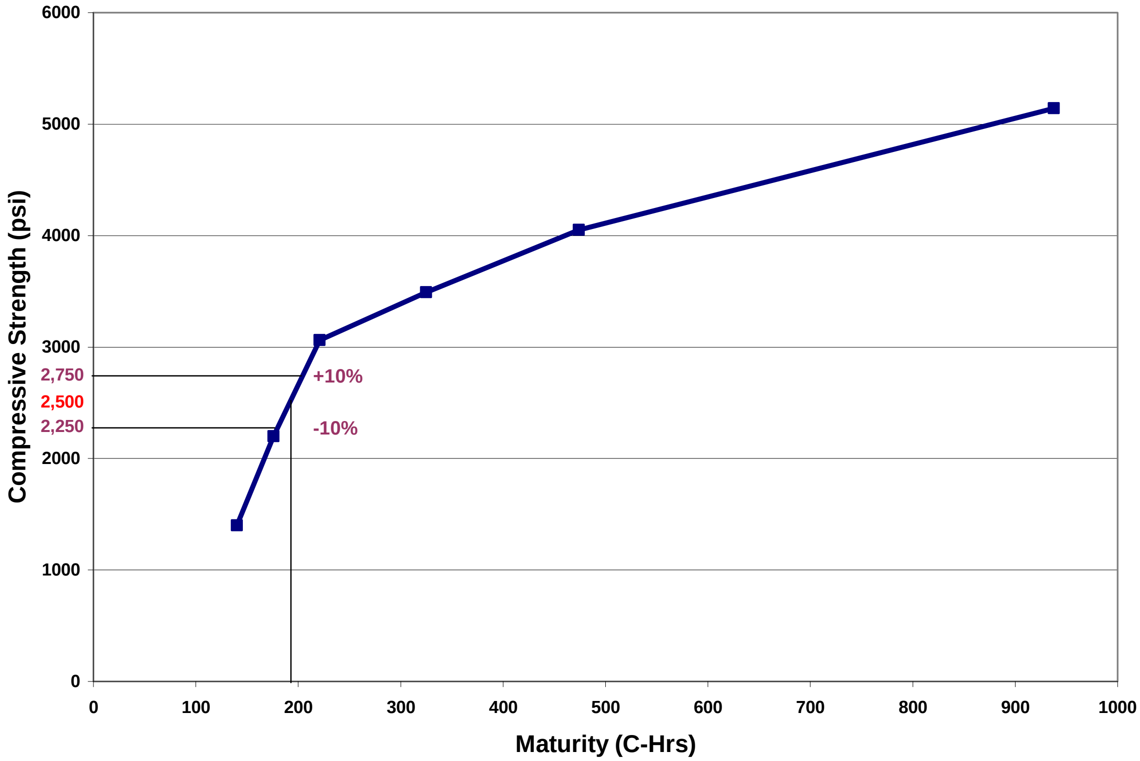

Figure 5. Limits of compressive strength required to verify a maturity value of 191 and compressive strength of 2,500 psi.

Field Procedures

In summary, a calibration curve is developed to establish at what level of maturity the desired strength is reached. For WSDOT paving projects, this desired strength is the 2,500 psi required before the pavement can be opened to traffic. After the calibration curve is developed it is desirable that the contractor have an estimate of the time necessary to achieve that maturity level for concrete used on the job site. For this reason test panels are often poured with embedded loggers. The time to reach maturity is often quicker for the test panels than the cylinders that are cured in the laboratory because there is more mass of concrete in the panel. This increases the heat in the concrete which accelerates the hydration process.

During the production of the concrete on the project, the loggers embedded in the panels for any particular pour are monitored until the maturity value reaches the target for opening to traffic. This time to reach the target maturity value should be fairly consistent throughout the course of the project unless the ambient temperatures are fluctuating wildly. If consistency is not observed then it should be suspected that the concrete being delivered to the job site has changed. If it is suspected that the concrete mix has changed, then verification cylinders should be cast and checked against the original strength-maturity curve. If the original calibration curve cannot be verified a new calibration curve should be developed.

Maturity Equipment

The equipment used to measure maturity has evolved over time from manual methods using temperature probes and hand held calculators to the current systems that, at the high end, use a wireless identification tag placed in the concrete that can be read remotely from a vehicle parked next to the structure or roadway. The type used by WSDOT and many contractors uses a wired sensor (comprising of a temperature sensor, microprocessor, and data logger) that is embedded in the concrete. The sensor continuously records the temperature of the concrete and converts it to a maturity reading. A handheld reader is temporarily connected to the logger to download the continuously measured temperature and maturity values. This information can then be downloaded from the reader to a PC.

A 2003 Innovative Pavement Research Foundation report on using maturity for airfield pavement construction compares the performance of a number of devices used to measure maturity (Rasmussen and Cable 2003). The devices compared in this report were:

1. T-Type Thermocouples
2. Dallas Semiconductor Thermocron iButton®
3. Engius intelliRock™ Maturity, Temperature and prototype Strength Loggers
4. Identec Solutions i-Q Tags

The report concluded that current maturity technology can be used to successfully assess the strength of a concrete airfield pavement in real-time. It further concluded that maturity technology can expedite airfield repair and construction and provide an improved knowledge of the concrete pavement in place as it is placed. Figure 6 shows a typical maturity reader and logger and Figure 7 shows an inspector taking maturity readings on the job site. The logger is approximately the same size as a 35 mm film container.

Figure 6. IntelliRock™ maturity reader and logger.

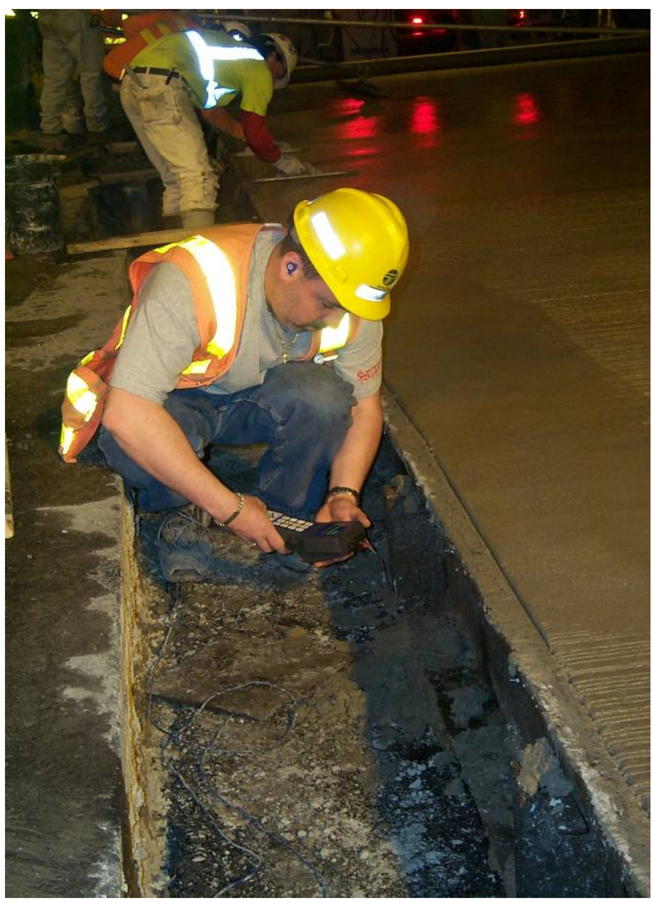

Figure 7. Reading maturity on the job site.

Benefits of Maturity

The benefits of using maturity as contrasted with traditional quality control procedures are:

- It provides a real-time, in-place indication of the strength of the concrete.
- It is a non-destructive testing method as contrasted to breaking cylinders in the laboratory.
- It provides early quality verification of the in-place concrete, often within hours of its placement.
- It accelerates the construction process by allowing the pavement to be opened to traffic or formwork stripped from structures.
- It reduces the quantity and cost of sampling and testing by reducing the number of cylinders that need to be cast and broken to determine strength.
- The maturity method is readily assessable to most materials laboratories because it is based on traditional cylinder compressive strength tests for its development.

Weaknesses of Maturity

The maturity method also has its weaknesses. Changes in the brand of cement, the source and type of fly ash, the source of the aggregate or the water to cement ratio can result in a change in the strength-maturity relationship and require a new calibration curve. The method also cannot account for humidity conditions during curing, that is, if there is not enough moisture present for hydration to occur the strength gain will not be realized as predicted by the maturity curve. It is not accurate when there are large temperature swings during the curing process. The method also cannot account for concreting practices that result in inadequate consolidation, poor placement techniques, inadequate curing, lack of protection during early ages, or fluctuations in air content.

Use of the Maturity Concept

WSDOT has allowed the use of maturity on its projects since the early 1990’s. The first use was documented in a report by Goller and Bharil on a project that built the Albro and Spokane Street exit ramps from I-5 into downtown Seattle (Goller and Bharil 1992). Maturity was used to provide assurance that the opening to traffic flexural strength was achieved prior to the opening of these two major structures. Maturity has also been used on a number of fast track concrete intersection construction projects in the state. A report by Nemati, et. al. documented the use of maturity in the construction of three intersections in the Kennewick, Washington urban area (Nemati, et. al. 2003). Maturity has also been employed on a number of other state projects by Contractors, independent of WSDOT specification requirements.

Case Studies

WSDOT has used the maturity concept on three major projects beginning in 2003. Two of the projects involved panel replacements, one on I-5 in Bellingham and the other on I-205 in Vancouver. The third project involved the replacement of a short section of I-5 in downtown Seattle. On each of these projects the work was done under an accelerated schedule with respect to opening the finished pavement to traffic. As with any new process, there is a learning curve for both State and Contractor personnel on how the maturity process works in real situations.

The questions that should be asked for each case study are as follows:

- Were valid calibration curves developed for each mix design used on the project?
- Were verification procedures used to make sure the mix design used on the project matched the original mix design used for calibration?
- Were the times to the target maturity value consistent throughout the project, indicating that the concrete delivered to the job site was consistent?
- Were target maturity values used to open the pavement to traffic?
- Was the maturity data collected and reported in a clear and understandable format?

It should be noted that not all of these questions can be answered for each case study because of variations in the requirements contained in the contract Special Provisions, which were different for each project.

The information from each case study is organized to look first at the development of the calibration curves for each mix design followed by data from the loggers installed on the project. Next, any verification testing is described, followed by a discussion of the Special Provisions contained in the project's contract plans and how the Contractor did or did not comply with them. This is followed by a discussion of any special problems that were encountered with the use of maturity on the project. Finally, the questions presented above are discussed to determine how well the maturity concept was implemented.

Bellingham

Introduction

Contract 6473, 36th St Vicinity to SR 542 Vicinity PCCP Rehabilitation and Seismic, included the replacement of approximately 500 concrete panels between Milepost 252.14 and 255.44 on both north and southbound I-5 through Bellingham. The contract plans called for six Monday morning to Friday morning closures to accomplish the work. The Contractor, however, used only four of the six planned closures and thereby earned nearly $100,000 in incentives. All of the panel replacement work took place in August and September of 2003.

Calibration

The Contractor developed a calibration curve for his single mix design using cylinders and beams as directed in the Special Provisions (Appendix A) for the contract. The calibration curve was developed from the cylinder compressive strength data (Table 2) and the data from the beams, as it turns out, was not used. The curve developed from the cylinder information was excellent with two points on the curve before the target strength and four points after that strength was achieved. This provided a curve that broke over, indicating that the hydration of the concrete had reached its peak and was slowing down (Figure 8). For this mix the 2,500 psi compressive strength was achieved at a maturity reading of 191 in approximately 6.2 hours. According to the Inspector's Daily Report (IDR) of August 19, 2003, the concrete supplier had intended the mix would cure to the opening to traffic strength in approximately seven hours.

Table 2. Data for Bellingham calibration curve developed from cylinders.

Age (Hours)	Maturity (C-Hrs)	Compressive Strength (psi)
5	140	1,400
6	176	2,200
7	221	3,060
9	325	3,490
12	474	4,050
24	938	5,140

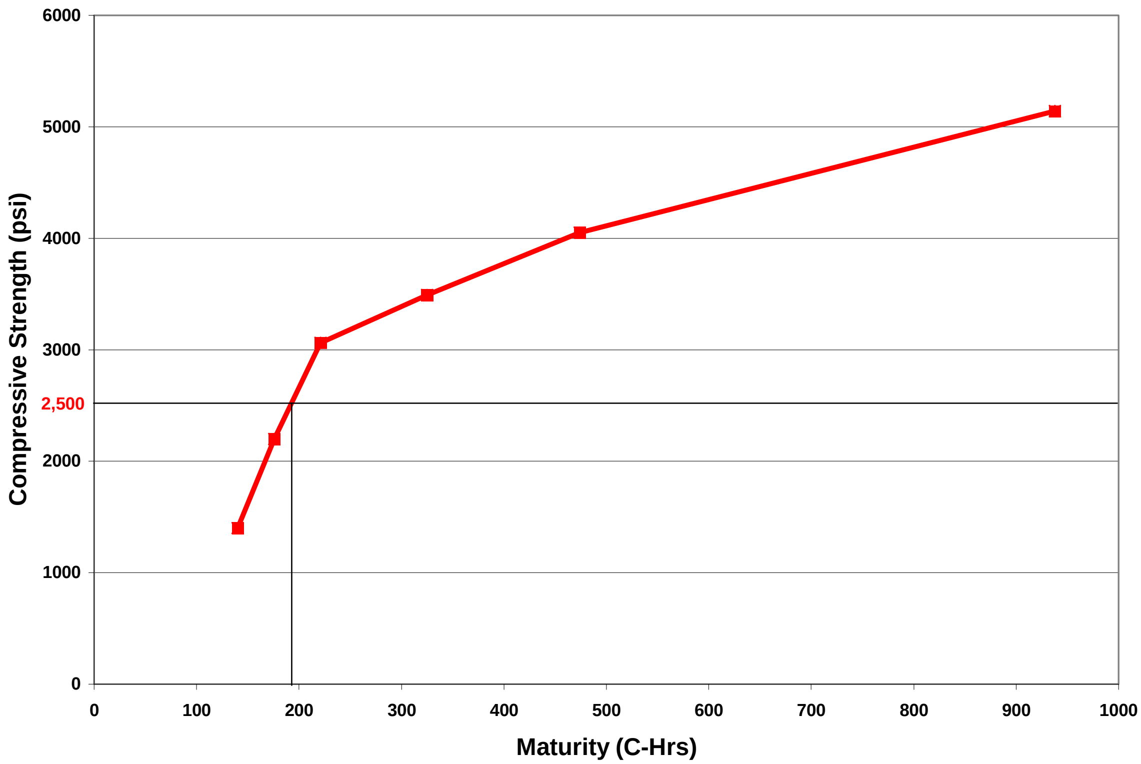

Figure 8. Maturity curve for Bellingham panel replacement project.

The Contractor also cast a test panel to see how long a larger mass of concrete would take to reach the target maturity value determined by the calibration curve. The maturity readings from the loggers installed in the test panel showed a slower rate of strength gain than the cylinders cured in the laboratory, reaching the target maturity value in approximately 6.6 hours (see Figure 9). This is contrary to what is expected given that the test panel has a greater mass of concrete than the cylinders and should reach the target maturity more rapidly due to the larger amount of heat generated by the cement hydration process. The project office reported that the difference was likely the result of allowing the cylinders used to develop the calibration curve to be exposed to direct sunlight during the initial curing prior to being placed in the moist room. This extra heating accelerated the curing of the concrete in the cylinders more than the mass of concrete accelerated the curing of the panels.

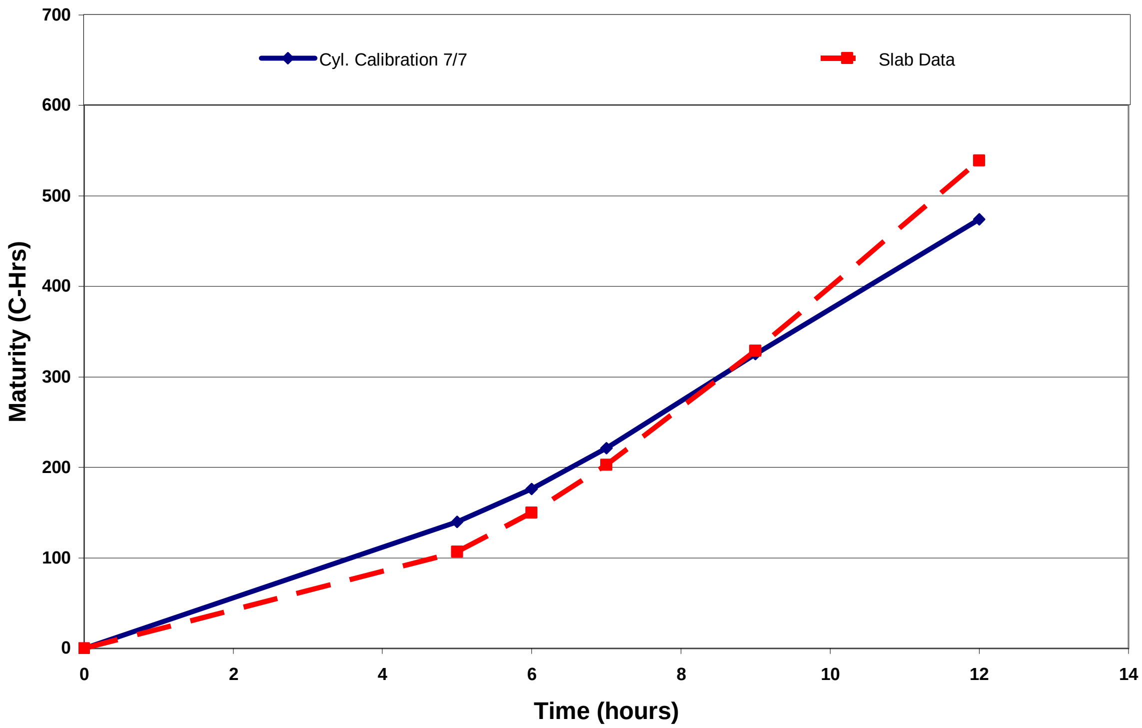

Figure 9. Time versus maturity for the cylinders used for calibration and the test panel.

Field Measurements

Week One

The Region and Headquarters' Materials Laboratory personnel visited the project during the first three of the four weeks of the project to make sets of cylinders which were cured in the laboratory to verify the calibration curve developed by the Contractor. Two such sets were cast on the first day with a logger embedded in one of the cylinders to monitor the maturity value. The first logger was read at 5, 6 and 24 hours and the second logger was read at 4, 5, 7, 8 and 23 hours. Cylinders were broken at 6 hours and 24 hours for the first set and 6 hours and 23 hours for the second set. Figure 10 shows one of the sets of five cylinders, one with a logger, placed on the shoulder where they remained for 24 hour prior to being transported to the laboratory for moist curing and testing.

Figure 10. Verification cylinders at the job site.

The logger embedded in the first set of cylinders indicated that the target maturity value of 191 was reached at 5.3 hours. The logger embedded in the second set of cylinders indicated a more reasonable time of 7.5 hours to the target maturity value of 191. The cylinders broken for the first set had compressive strengths of 2,040 psi at 6 hours and 4,650 psi at 24 hours. The cylinders broken for the second set had compressive strengths of 1,010 at 6 hours and 5,300 psi at 23 hours. The results from the two sets of cylinders are compared to the calibration curve in Figure 11.

The four data points from the two sets of cylinders were checked to see if they verify that the mix used to make the cylinders matched the mix used to make the calibration curve. Simple linear equations were derived to describe the straight line portions of the calibration curve in the vicinity of the four points. These equations were used to calculate the compressive strength of the calibration curve at the maturity value from the sets of points. Only one of the points was found to verify the calibration curve, and it was, as expected, the one that actually fell on the calibration curve at a maturity value of 760 and compressive strength of 4,650 for the first set of cylinders.

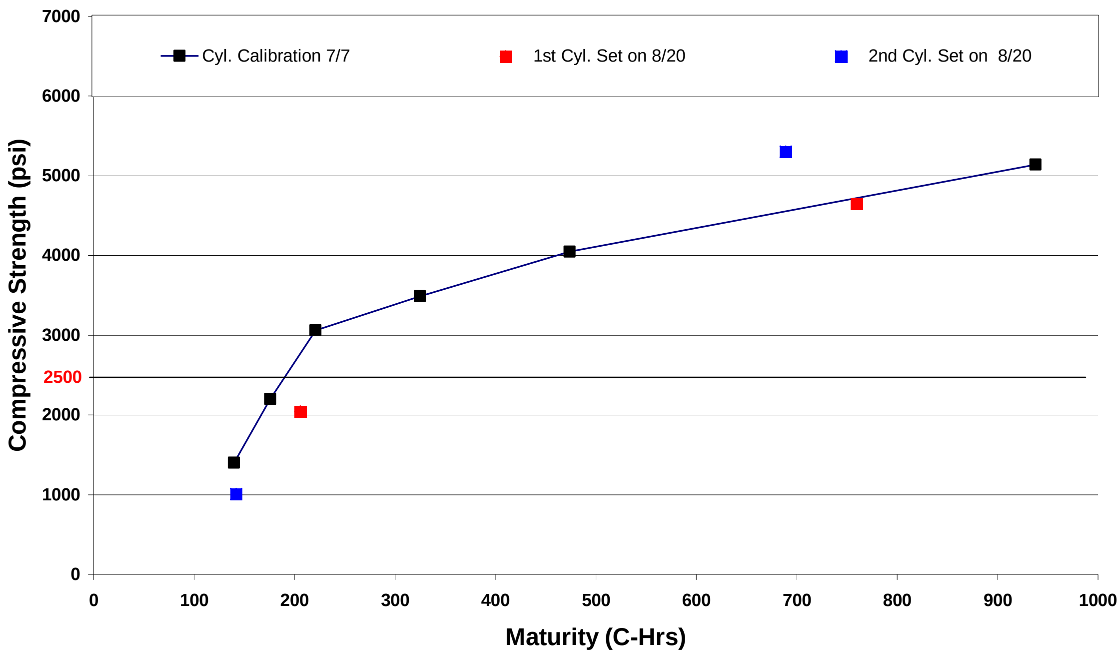

Figure 11. Maturity data from the first week of the project.

During the first week of the project the maturity meter broke and the Contractor was forced to use cylinder breaks to determine when the roadway could be opened to traffic. A cylinder tested at seven hours from the last pour on August 21 reached only 500 psi. Another cylinder tested at 15 hours broke at 3,000 psi allowing the opening to traffic to begin at 15 hours from the last pour. The IDR's have a note that a panel poured with the mix that had only reached 500 psi in seven hours could easily be chipped with a fingernail.

Week Two

The second week of the project a third set of cylinders was cast to see if the mix in the field matched the calibration curve. A sufficient number of cylinders were cast so that compressive strength data could be collected at five, six, seven, eight, and 12 hours. The curve developed from these cylinders is shown in Figure 12 along with the original calibration curve. The second curve predicted that 2,500 psi would be reached at a maturity value of 319, which is well beyond the 191 target value from the original calibration curve. Once again the data from the third set of cylinders does not match the original calibration curve. Figure 13 shows the cylinders on the grade, one with a logger, waiting for transport to the laboratory.

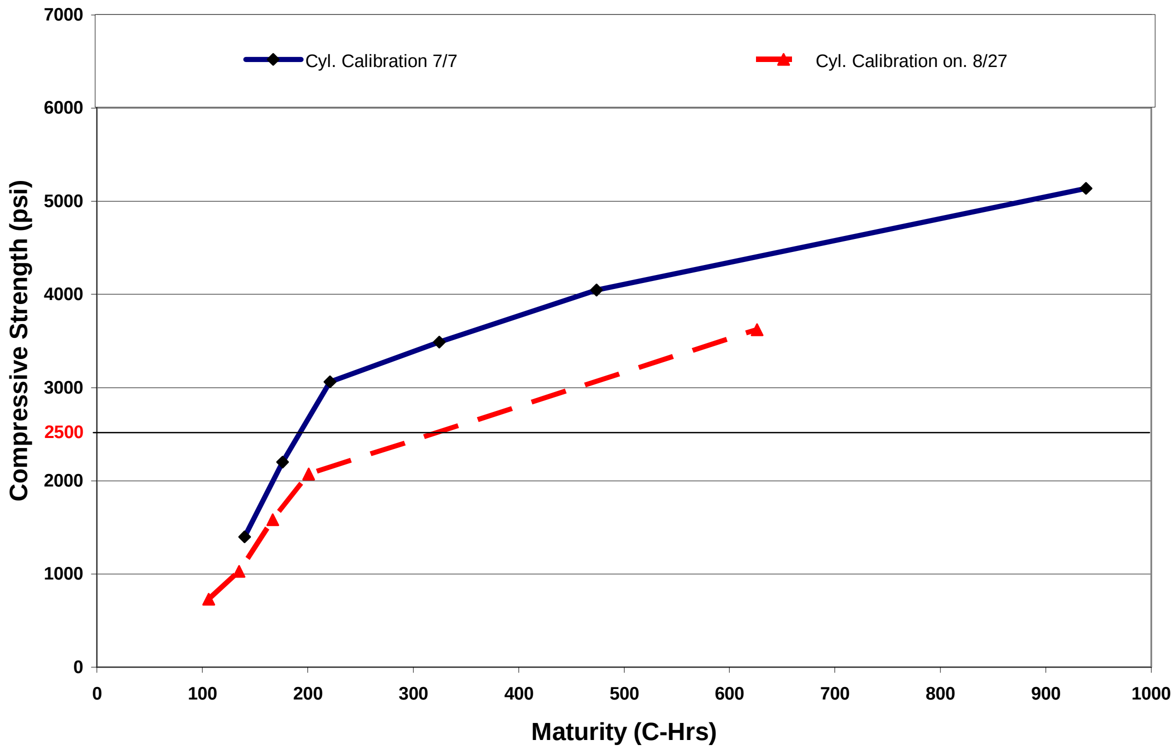

Figure 12. Maturity data from the second week of the project.

Figure 13. Set of 11 verification cylinders, one with a logger.

Week Three

On the third week of the project a fourth set of cylinders was cast to check on the mix placed in the field. Sufficient cylinders were cast to develop a calibration curve and it is shown in Figure 14 along with the original calibration curve. The data from the third week's maturity versus compressive strength almost exactly match the original calibration curve with a maturity value of 192 at 2,500 psi compressive strength.

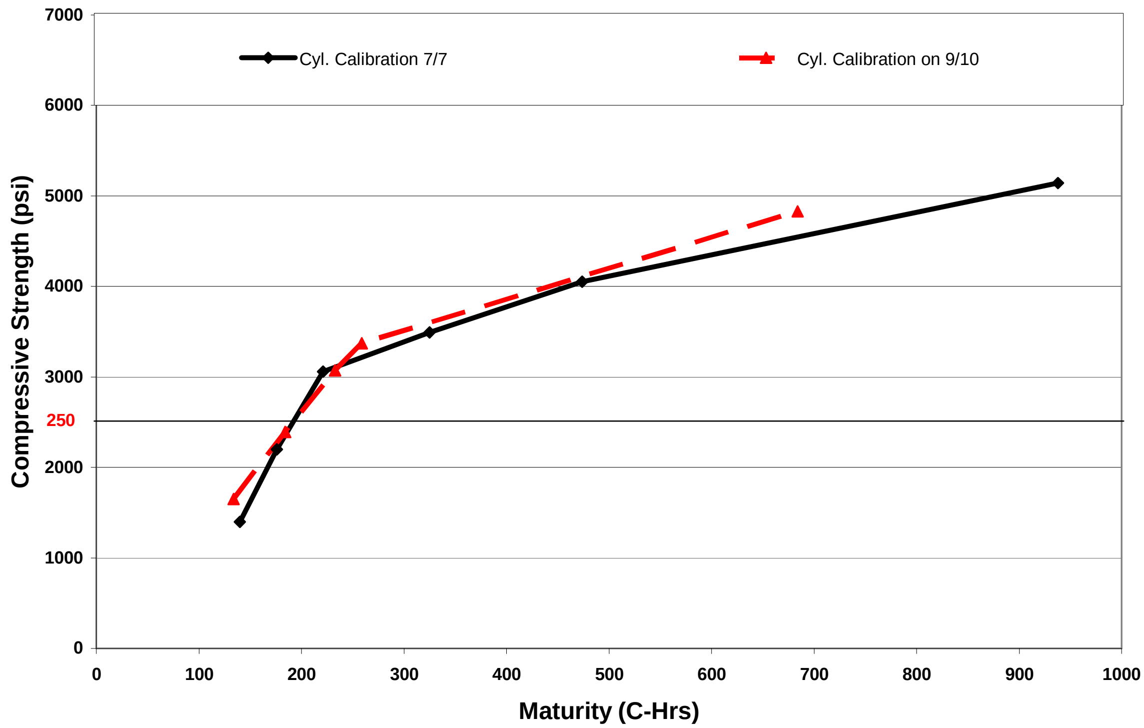

Figure 14. Maturity data from the third week of the project.

Week Four

There was no data collected for the fourth and final week of closure.

Verification

The calibration curve developed by the Contractor was checked on three of the four weeks that construction took place. The typical verification procedures described at the beginning of this report were not followed, but the process that was followed did point out some problems with the mix on the first two weeks of concrete placement. As standard procedure for all WSDOT projects, cylinders were cast on each day's pour and broken at 28 days to provide additional assurance that the concert used on the project met strength requirements. The results from these cylinders (Table 3) show that the project's average compressive strength from each set of two cylinders broken for each day was 7,365 psi with a range of 6,580 to 8,570 and a standard deviation of 520 psi. The almost 2,000 psi range and high standard deviation confirm the absence of consistency in the mix being delivered to the project. This inconsistency was also confirmed by the results from the cylinders cast for verification purposes.

Table 3. Average 28 day compressive strength data for Contract 6473.		
Date	**Week**	**28 Day Compressive Strength (psi)**
8/19/2003	1	7,480
8/20/2003	1	7,430
8/21/2003	1	7,320
8/26/2003	2	7,190
8/26/2003	2	6,580
9/09/2003	3	6,960
9/10/2003	3	8,570
9/11/2003	3	7,190
9/16/2003	4	7,240
9/17/2003	4	7,690
Average		**7,365**
Standard Deviation		**520**

Special Provisions

The Contract Special Provisions contained specific instruction concerning the use of the maturity concept as noted in Appendix A. The primary requirements of these Special Provisions are summarized below:

- Test panel are required along with test beams and cylinders for calibration.
- Test panels are to receive curing compound, plastic wrap and insulation blankets for curing.
- Twenty five test beams are to be cast and cured identical to the test panel.
- Thirteen cylinders are to be cast and cured identical to the test panel.
- Sensors are to be placed in the panel, one cylinder and one test beam and all monitored continuously for maturity.
- Test beams are to be broken every hour beginning at the fifth hour.
- Cylinders are to be broken every hour beginning at the seventh hour.
- Test beam and test cylinder with embedded sensors are not to be broken.
- Maturity data is to be recorded in writing and copies submitted to Engineer.
- Maturity value is to be plotted against the flexural strength.

- Minimum maturity value for opening pavement to traffic is the maturity value at 2.8 Mpa (2,500 psi)

Special Provisions Compliance

The Special Provisions concerning maturity were very minimal for this project. They did not specify the frequency that loggers should be placed in panels and or that verification testing was to be performed. They did specify the casting of test beams which apparently were not used to develop the strength-maturity value. No standard data collection sheets were specified, however, one data sheet developed by WSDOT was used throughout the project to record data from the maturity meters (see Appendix B). The number of cylinders required at 13 was an absolute minimum given the six points that were established on the strength-maturity curve. The validation of the strength-maturity relationships throughout the course of the project was done by the Region and HQ Materials Laboratory for information purposes as it was not a requirement of the Special Provisions.

Primary Questions Addressed

A review of the primary questions will provide an idea of how the maturity concept was implemented on the Bellingham panel replacement project.

Were valid calibration curves developed for each mix design used on the project?

The calibration curve for this project was excellent with two points on the curve before and four points after the break over point in the curve.

Were verification procedures used to make sure the mix designs used on the project matching the original mix design used for calibration?

No validation testing was required in the Special Provision; however, the Region and Headquarters Materials Laboratory staff sampled the job mix and did testing to verify that the mix being used matched the original mix design. The results indicated that the mix used during the first two weeks of the project did not match the original maturity curve. The samples tested the third week of the project duplicated the original maturity curve.

Were the times to the target maturity value consistent throughout the project indicating that the concrete delivered to the job site was consistent?

The record keeping on the project did not capture the maturity data in a manner that could be analyzed to determine if there was any consistency in the time to reach the target maturity value. Listed below are the three values recorded in the IDR's:

1. August 28, 2003 entry "We read the Maturity Meter on the NB Lt Lane. Reading was 356."
2. September 11, 2003 entry "Bill Lingenfelder of Landel Construction read the Maturity Meter at 6.5 hours the reading was 243 CH. Wilder was told that they could reopen the NB Rt. Lane to traffic at 9:45 p.m."
3. September 18, 2003 entry "Bill Lingenfelder read Maturity Meter on panels placed yesterday. Reading was 710 degrees at 9:10 am."

Did the use of the maturity method have any affect on opening the pavement to traffic in a timely manner?

It was impossible to determine if the maturity values were being relied upon to determine the opening to traffic time due to the lack of documentation for the project as noted above. That does not mean that they were not used, just that there is no record indicating this happened.

Were the forms for recording and reporting data used throughout the project?

The Special Provisions did not provide any standard forms for reporting. The Region Materials Laboratory did use one form for collecting maturity meter readings throughout the project. The data from the loggers installed in the field was erratically reported in the IDR's as noted previously.

Problems

The sets of cylinders tested during the first two weeks of closure indicated that the mix being delivered to the job site was different than the mix used to develop the calibration curve. This irregularity combined with the fact that the maturity meter broke the first week of the project eliminated the use of the maturity concept until the third week of closure. An overall lack of familiarity with the maturity concept by both Contractor and State personnel, the lack of direction provided by the Special Provisions, and the newness of the methodology worked against this being a successful implementation of the maturity method. However, the project office was generally supportive of the using maturity as evidences in the comments found in the debriefing following the conclusion of the project, see Appendix C

James to Olive

Introduction

The second case study was also located on I-5. Contract 6886, James Street Vicinity to Olive Way Vicinity Pavement Rehabilitation – PCCP, replaced 1,800 lineal feet of damaged PCCP pavement with approximately 6,000 cubic yards of new PCCP between Milepost 164.41 and 166.36. Although the project was only 0.34 miles in length it was complicated by having to pave under the Washington State Convention Center that spans I-5 at this location. The construction took place on four 55-hour non-consecutive weekend closures between April and July of 2005. This project had a very high risk factor because of the high traffic volumes, the short construction windows, the confined spaces, and the high impact to the public, making it an ideal project for the use of maturity.

Calibration

Two types of concrete paving were used, slip formed and hand placed. Two mix designs and two strength-maturity calibration curves were developed, one for each placement process. Figure 15 shows the two maturity curves developed by the concrete supplier. The curve for the mix to use with the slip form placement method was excellent with one point before the break over in the curve and three after the break. Although the curve for the hand placed mix design had only three data points the break in the curve was well defined and its similarity to the curve for the slip form mix provided assurance of its applicability. The target maturity values at the 2,500 psi compressive strength opening to traffic requirement were 292 for the mix used for the slip form placement method and 322 for the mix used for the hand placed mix.

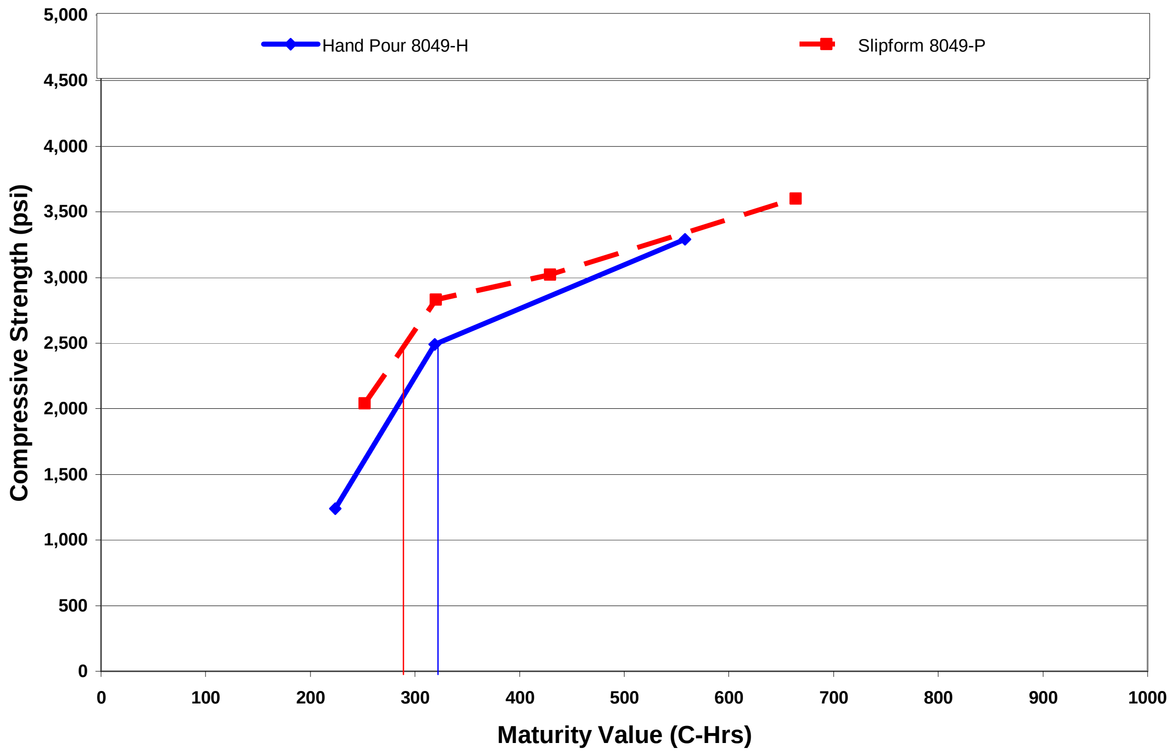

Figure 15. Strength-maturity curves for slip form and hand poured mix designs

Field Measurements

Stage 1

The four weekend construction periods were designated Stages 1-4. In Stage 1, that took place on the weekend of April 23 and 24, there were 16 loggers embedded for the mix used in the slip form pavement method. Ten of the sensors survived to provide maturity data. Table 4 summarizes the time to reach the target maturity value of 292 for the 10 loggers. The results were very consistent with a range between seven hours and nine hours and an average of 7.9 hours. There was one logger placed in the mix designed for the hand placed method and it had a time to maturity of seven hours as shown in Table 5.

Table 4. Time to target maturity value slip form mix, Stage 1, April 23-24.	
Sensor Number	**Time to Maturity Value of 292 (Hours)**
1	8.0
2	8.0
3	8.7
4	8.0
5	7.8
6	7.5
7	7.7
8	7.6
9	7.4
10	8.8
Average	**8.0**

Table 5. Time to target maturity value for hand poured mix, Stage 1, April 23-24.	
Sensor Number	**Time to Maturity Value of 322**
1	7.0

Stage 2

The maturity information for Stage 1 was provided by the Contractor using the monitoring equipment and loggers installed by his personnel. The results from Stages 2-4 were from loggers installed by the WSDOT and read with a WSDOT maturity meter. A Maturity Worksheet was provided to the Project Engineer by the Headquarters Pavement Division to record the information. Appendix D contains a blank maturity worksheet and completed sample worksheet. Both slip form and hand placed mixes were used on this second weekend closure on June 18th and 19th. The times to reach the target maturity value for the two loggers embedded in the slip form mix are shown in Table 6. The time to reach maturity for the logger in the one hand poured mix is shown in Table 7. The slip form mix was slower in reaching maturity than the mix used for the Stage 1 pours with target maturity values being reached in the 9.3 to 10.4. The hand placed mix was also slower to reach the target value than the first Stage hand pour mix.

Table 6. Time to target maturity value for slip form mix, Stage 2, June 18-19.	
Sensor Number	**Time to Maturity Value of 292**
1	10.4
2	9.3
Average	**9.9**

Table 7. Time to target maturity value for hand poured mix, Stage 2, June 18-19.	
Sensor Number	**Time to Maturity Value of 322**
1	9.6

Stage 3

All of the concrete placed on June 25 and 26 in Stage 3 of the project was slip formed. Four loggers were embedded and the time to the target maturity values are listed in Table 8. Three of the four loggers reached the target maturity value at a time between 9.2 and 10.1 hours. The fourth was much faster at 7.8 hours which may indicate a possible mix variation.

Table 8. Time to target maturity value for slip form mix, Stage 3, June 25-26.	
Sensor Number	**Time to Maturity Value of 292**
1	7.8
2	10.1
3	9.2
4	9.5
Average	**9.2**

Stage 4

Two hand placed mixes and two slip form mixes were placed on July 17-18. The time to maturity readings are summarized in Table 9 and 10. The time to reach the target maturity value ranged from 7.5 to 11.6 hours for the hand formed mix and from 7.2 to 9.9 for the slip form mix, indicating some inconsistency for both mixes.

Table 9. Time to target maturity value for hand formed, Stage 4, July 16-17.

Sensor Number	Time to Maturity Value of 322
1	7.5
2	11.6
Average	**9.6**

Table 10. Time to target maturity value for slip form mix, Stage 4, July 16-17.

Sensor Number	Time to Maturity Value of 292
1	9.9
2	7.2
Average	**8.6**

Summary of Maturity Data

The only data available from this project was the time to the target maturity values for the loggers embedded in the various pours. The average time to the target maturity value for the slip form pavement for all stages of the project was 8.5 hours with a range of from 7.1 to 10.4 hours with a standard deviation of 1.05 hours (Table 11). The average for the hand placed mix was 8.9 hours with a range of 7.0 to 11.6 hours and a standard deviation of 2.11 hours (Table 12). In the absence of verification tests, there is no proof that the mix delivered to the job site was the same as the mix used to develop the calibration curve. The consistency of the maturity values are an indirect measure of the consistency of the mix but not its quality. For this project, the slip form mix was more consistent than the hand placed mix.

Table 11. Time to target maturity value for slip form mix for all pours.

Stage	Sensor Number	Time to Maturity Value of 292	Cut Off Maturity Value*	Time Beyond Cut Off (Hours)	Cut Off Maturity Value minus Target Value
1	1	8.0	423	**2.0**	131
1	2	8.0	391	**1.5**	99
1	3	8.7	361	**1.0**	69
1	4	8.0	373	**1.5**	81
1	5	7.8	413	**2.0**	121
1	6	7.5	436	**3.5**	144
1	7	7.7	370	**1.0**	78
1	8	7.6	393	**1.5**	101
1	9	7.4	382	**1.5**	90
1	10	8.8	311	**0.0**	19
2	1	10.4	244	**0.0**	-48
2	2	9.3	1049	15.0	757
3	1	7.8	491	13.0	199
3	2	10.1	661	9.0	369
3	3	9.2	1057	17.0	765
3	4	9.5	302	**0.0**	10
4	1	9.9	1062	9.0	770
4	2	7.2	765	10.0	473
Average		**8.5**	**527**	**4.9**	**235**
Standard Deviation		**1.01**	**272.1**	**5.6**	**272.1**

***** The cut off value is the maturity last reading recorded before the wires were cut or readings were discontinued.

Table 12. Time to target maturity value for hand placed mix for all pours.					
Stage	Sensor Number	Time to Maturity Value of 322	Cut Off Maturity Value	Time Beyond Cut Off (Hours)	Cut Off Maturity Value minus Target Value
1	1	7.0	1030	10.0	708
2	1	9.6	226	0.0	-96
4	1	7.5	1001	13.0	679
4	2	11.6	352	0.0	30
Average		**8.9**	**652**	**5.8**	**330**
Standard Deviation		**2.11**	**422.8**	**6.8**	**422.8**

Verification

No verification tests were performed on this project.

Special Provisions

The complete Contract Special Provisions are shown in Appendix E. The highlights of the special provisions are summarized below:

- Maturity loggers are to be installed at the frequency of one every 500 cubic yards or fraction thereof.
- Verification testing is required on days 1 and 2 of concrete placement.
- A Quality Control Plan based on the strength-maturity relationship is required to monitor and provide remedial action to ensure the concrete meets design strengths.
- Twenty cylinders are required for each mix design and must be cured in accordance with FOP for AASHTO T 23. Three cylinders are to be tested at each age to develop the strength-maturity relationship.
- Individual and average values are to be recorded at each age for the strength and maturity value.
- Average maturities are to be plotted against average strengths for each age. The plot is to produce a curve which is the strength-maturity relationship
- Loggers/sensors are to be installed in the field a minimum of 2 feet from a panel edge and 4-5 inches from any panel surface
- The Contractor is to supply to the Engineer encrypted data files of the maturity data from the loggers/sensors prior to opening the pavement to traffic.
- Verification procedure is to make a minimum of two cylinders with a logger/sensor embedded in one of the cylinders with cylinders cured in accordance with FOP for

AASHTO T 23. Compression strength tests are to be performed to verify the strength and time to reach 2,500 psi for opening to traffic. The average strength of the cylinders at each test age (average of 2 cylinders at a time, not the average of additional cylinders) is to be used. Maturity values at the time of compression testing and individual and average strengths of the cylinders are to be recorded on a data sheet. The predicted strength based on the strength-maturity relationship and the percent difference between the predicted strength and the average strength from the cylinder breaks is to be recorded. The strength maturity relationship is verified when the predicted strength established from the strength maturity relationship and the average strength from the cylinder breaks are within 10%.

- A copy of WSDOT Table 3 and an encrypted file for the maturity data shall be provided to the Engineer on a daily basis.

Special Provisions Compliance

It appears that the Contractor complied with the number of logger/sensors and the testing interval requirements, but either did not do the required verification testing, or did not report the results to the Engineer. If a Quality Control Plan was developed using maturity, it was not apparent from the records examined for this contract. The maturity data provided by the Contractor consisted of printouts from the maturity meters which were required, but the data was not summarized on the forms provided in the Special Provisions.

Primary Questions Addressed

Were valid calibration curves developed for each mix design used on the project?

The calibration curves were just adequate to define the break over point in the curve for both mix designs used on the project. The curve for the hand poured mix had only three points with one before and two after the break over point. The curve for the slip formed mix has four points, one before and three after the break. It is desirable to have more than three or four points defining the strength-maturity curve. A third mix design was used at the end of the project for hand pours and the calibration data provided was not in a format suitable for the determination of the target maturity value.

Were verification procedures used to make sure the mix designs used on the project matched the original mix design used for calibration?

There were no verification tests performed during the course of the project.

Were the times to the target maturity value consistent throughout the project indicating that the concrete delivered to the job site was consistent?

The times to the target maturity value were fairly consistent for the slip form mix with a standard deviation of 1.05. The hand placed mix had a standard deviation of 2.11, however, there were only four loggers in this group as contrasted with the slip form mix group that had 18 loggers.

Were target maturity values used to open the pavements to traffic?

There was no information available that indicated if the Contactor relied upon the maturity data for his opening to traffic requests to the State. The maturity value at which the loggers were disconnected may be a secondary source of information on whether maturity was used to allow the pavement to be open to traffic. If the logger was read well beyond the target maturity value it might be assumed that opening the pavement to traffic was not a critical issue. If, however, the logger was turned off immediately after the target maturity value was reached, then it might be assumed that there was an urgency to get the pavement open to traffic. This assumes, however, that the loggers were placed in the mix that was poured at the end of the pours done for that particular weekend, as per the instructions from WSDOT. Tables 11 and 12, which summarize the maturity reading data for both slip form and hand placed pours includes the maturity value when the logger was disconnected and compares that to the target maturity value. The data indicates that for the slip form pours all of the Stage 1 loggers were disconnected within 3.5 hours of the target maturity value. For the slip form pours there was one logger in Stage 2 and one in Stage 3 that were disconnected when at or before the target maturity was reached indicating that opening to traffic was critical. For the hand poured areas, two out of the four were disconnected at or before the target maturity value was reached. In summary, 14 our of the total of 22 (64 percent) of the loggers were disconnected at or before the target maturity value was reached indicating that for the majority of the concrete placed the maturity value may have played a critical role in allowing the Contractor to open the pavement to traffic.

The maturity value at the time the loggers were disconnected may also be a secondary indication of the possible urgency to open the pavement to traffic. If the cut off maturity value exceeds the target maturity value by a large margin, then it probably was not critical to open that particular portion of the pavement to traffic. The cut off maturity value and the extent to which it exceeded the target maturity value are also listed in Tables 11 and 12. The data mimics the previous data on cut off time with most of the maturity values did not exceed the target value by a large margin.

Were the forms provided in the Special Provisions used for recording and reporting maturity data on the project?

The Contractor used one of the forms to develop calibration curves. The Stage 1 maturity data was provided as required in the Special Provisions. A form provided by the Headquarters Pavements Division was used to collect maturity data from loggers installed by WSDOT for Stages 2-4.

Vancouver Vicinity

Introduction

The final case study is another panel replacement project. Contract 6916, SR-500 to I-5 PCCP Rehabilitation and Dowel Bar Retrofit, was located on I-205 in the vicinity of Vancouver. The work entailed the replacement of approximately 110 full and 60 half panels over a distance of approximately 6.5 miles between Mileposts 31.36 and 37.73. Construction took place on six weekend closures from May to July of 2005. The Contractor developed both a 12-hour and a 24-hour mix that was used depending upon the constraints of time. The Contractor also obtained the services of a consultant to do the maturity calibration curve development and logger monitoring on the project.

Calibration

12-Hour Mix Design

Two calibration runs were made for the 12-hour mix, one in May and another in June. The raw data from these two runs is shown in Tables 13 and 14. In both cases the first cylinder breaks came after the target 2,500 psi compressive strength had been exceeded. On the first calibration run the initial cylinder break was made at a little over 10 hours and the maturity value was 323 and the compressive strength 2,637 psi, 137 psi over the 2,500 target. On the second calibration run the first break was made at seven hours. Even though the break was made three hours earlier then the first run, the maturity value was 350 and the compressive strength 2,981, 481 psi over the target. The maturity curves developed from both calibrations are shown in Figure 16.

Table 13. First calibration of the 12-hour mix design run in May 2005.

Time (Hrs)	Day	Temperature (°C)	Maturity ([0 C] °C-Hrs)	Compressive Strength
10:13	0.43	29	323	2,637
12:00	0.50	27	365	3,170
18:00	0.75	23	513	4,363
48:00:00	2.00	21	1147	5,327
72:00:00	3.00	20	1627	6,037
168:00:00	7.00	26	3728	7,533

Table 14. Second calibration of the 12-hour mix design run in June 2005.				
Time (Hrs)	**Day**	**Temperature (°C)**	**Maturity ([0 C] °C-Hrs)**	**Compressive Strength**
5:00	0.21	63	222	0
6:00	0.25	65	286	0
7:00	0.29	64	350	2,981
8:00	0.33	63	413	3.557
9:00	0.38	61	476	4.065
10:00	0.42	58	535	4.397
12:00	0.50	53	648	4.564

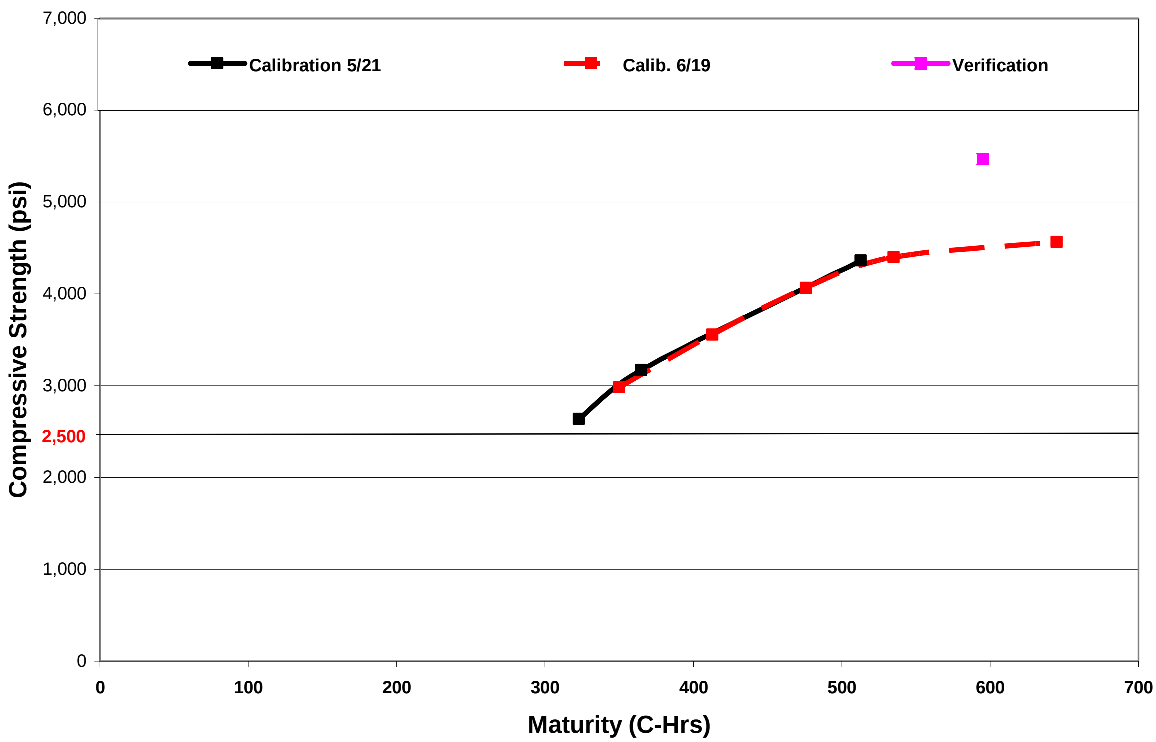

Figure 16. Maturity curves for the 12-hour mix design with point plotted from verification cylinders.

Missing the 2,500 psi target on the first calibration attempt is probably understandable if the mix was supposed to reach that strength in 12 hours, although, the conservative approach would have been to start breaking cylinders even sooner than 10 hours. The second calibration run could have been prompted by that very reason, that is, the failure to have readings before the target compressive strength of 2,500 psi. On the second run the maturity meter readings start at hour five and progressed hourly through 12 hours. The hour five maturity reading at 222 should have prompted those running the calibration to begin testing cylinders based on the fact that the first calibration resulted in a target maturity value around 300. However, no cylinders were tested until hour seven when the compressive strength reached 2,981 psi, 481 psi over the 2,500 psi target. The second calibration thus also failed to produce a curve that intersected the 2,500 psi compressive strength line.

An explanation for what happened on the second calibration run can be found in an examination of the temperatures recorded for the cylinders used on the second run, Tables 13 and 14. The temperatures on the second run are more than double those of the first run. Knowing that maturity is a function of time **and** temperature, the consultant doing the testing should have realized that the cylinders for the second calibration run were going to reach the target maturity value much faster than the first run, and should have begun breaking cylinders much earlier. The time versus maturity relationship for each of the calibration runs is shown in Figure 17.

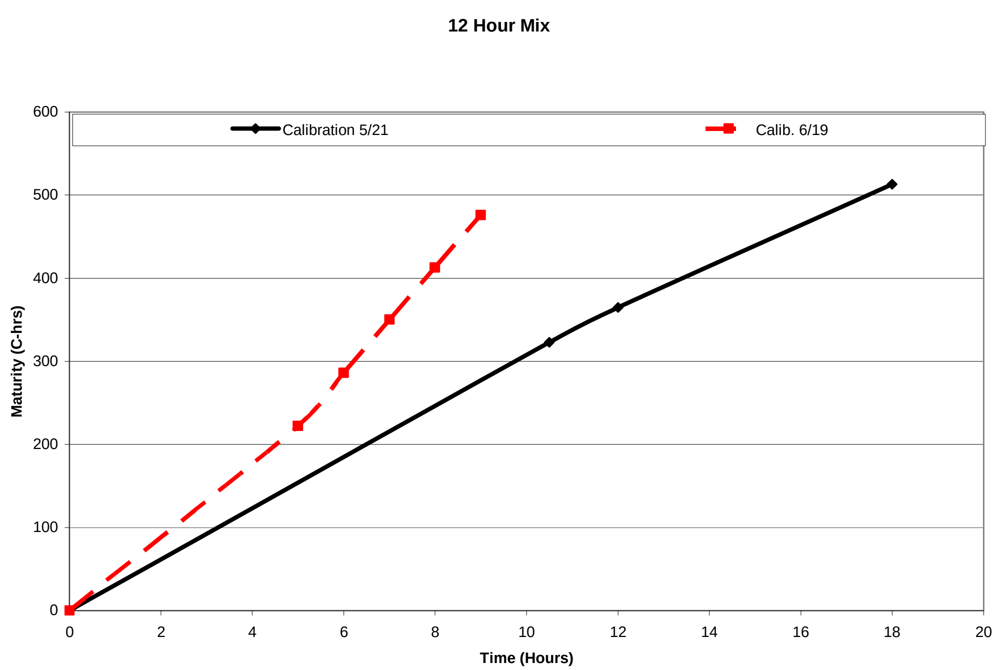

Figure 17. Time versus maturity for the 12-hour mix calibration and test panels.

The elevated temperatures noted in the cylinders for the second calibration run raises two questions; (1) was the mix design used for the second calibration run identical to the mix design used for the first calibration run, and (2) if the mix designs were identical, then what curing conditions existed for the cylinders from the second calibration run that would greatly increase the internal temperature of the cylinders and thus accelerate the maturing of the concrete. Cylinders are normally cured in the laboratory either in a moist room or in a water bath kept at a constant temperature of 73° F. It is difficult to understand how the breakdown of either type of curing method could result in internal temperatures of between 53 and 64 °C (127 and 148°F for those metrically challenged). The evidence points to a change in the mix design for the second calibration run.

The Consultant chose 323 as the target maturity value which probably errs on the conservative side. This conservatism provided additional assurance that the opening strength was reached prior to opening to traffic.

24-Hour Mix Design

The calibration curve for the 24-hour mix design is shown in Figure 18. Only three points define the curve with maturity readings at 12, 18 and 24 hours. The curve does not break over and form a knee as desired, but there is one point prior to the 2,500 psi compressive strength level and two after, therefore it is a valid maturity curve. The target maturity value of 433 was determined from this maturity/compressive strength plot.

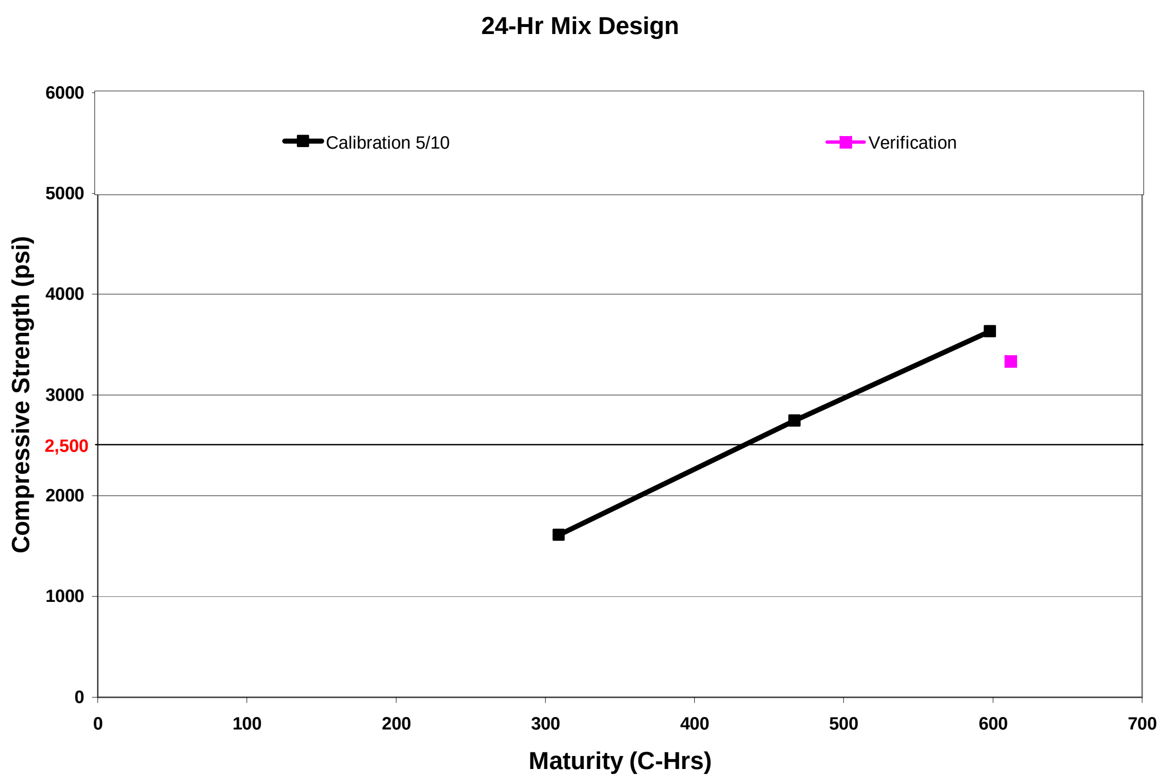

Figure 18. Calibration curve for the 24-hour mix design with point plotted for verification cylinders.

Test panels were also cast with loggers to get an idea of how a larger mass of the mix would mature as contrasted with the cylinders. One panel was insulated with plastic and the other was left open to the elements. The time versus maturity data for both of the panels is plotted against the time versus maturity data for the 12-hour calibration curve in Figure 19. As expected the greater mass of concrete resulted in curves that achieved maturity at a faster rate then the cylinders, with the insulated panel being quicker than the non-insulated panel.

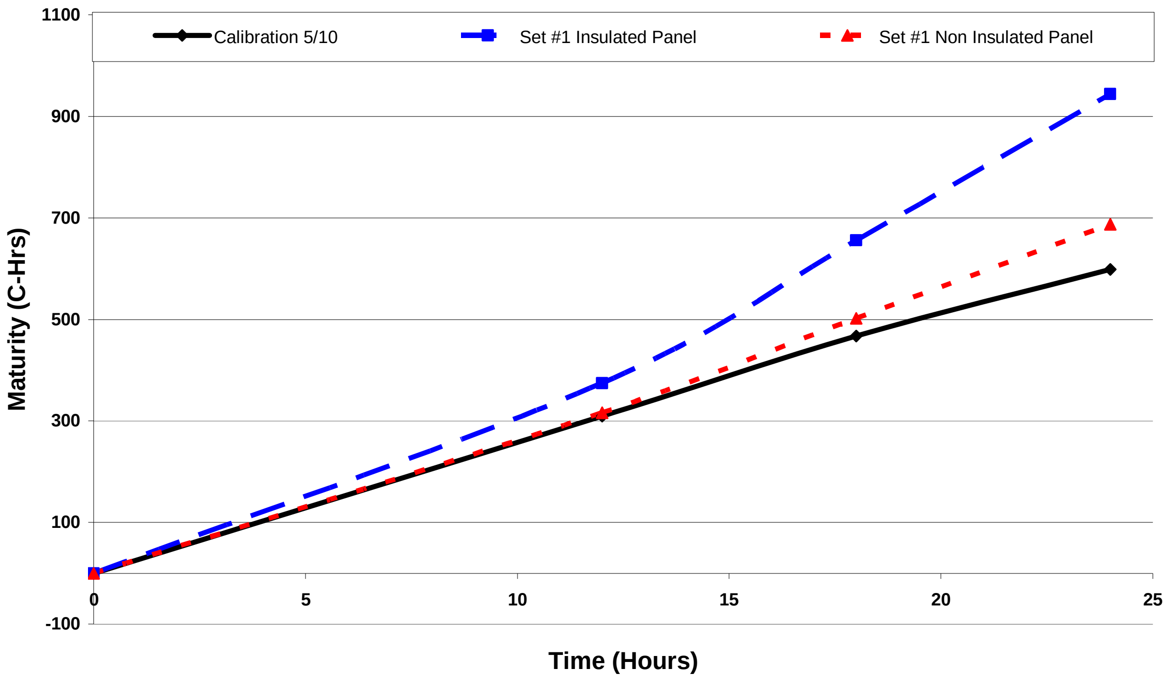

Figure 19. Time versus maturity for the 24-hour mix and test panels.

Field Measurements

12-Hour Mix Design

The 12-hour mix design was only used twice during the course of the project, once on the second weekend and once on the third weekend. The results from both uses are summarized in Table 15. The information on the project indicated that the 12-hour mix design was the same as the 24-hour mix design with double the amount of accelerator.

Table 15. Time to target maturity value for 12-hour mix installations.					
Logger Number	**Date of Installation**	**Time to Maturity Value of 323 (Hours)**	**Cut Off Maturity Value**	**Time Beyond Cut Off (Hours)**	**Cut Off Maturity Value minus Target Value**
4034635	6/5	8.2	583	10.5	260
4034634	6/19	6.4	705	7.0	382
Average		**7.3**	**644**	**8.8**	**321**
Standard Deviation		**1.27**	**86.3**	**2.47**	**86.3**

24-Hour Mix Design

The majority of the project was built using the 24-hour mix design. The time to target maturity data is shown in Table 16. It is interesting to note that the time to the target maturity value for the first weekend is significantly longer than times to maturity for the loggers used on the weekends that followed. It could have been suspected that something had changed in the concrete being delivered to the job based on this marked change in the time to maturity, however; apparently no red flags were raised by the consulting firm monitoring the results.

Table 16. Time to target maturity value for 24-hour mix installations.					
Logger Number	**Date of Installation**	**Time to Maturity Value of 433 (Hours)**	**Cut Off Maturity Value**	**Time Beyond Cut Off (Hours)**	**Cut Off Maturity Value minus Target Value**
4034658	5/21	16.9	785	12.0	352
4034641	5/21	17.5	615	3.5	182
4034643	6/4	13.5	572	19.5	139
4034545	6/5	13.2	564	14.0	131
4034642	6/19	12.2	715	6.0	282
4041452	6/26	13.5	574	3.5	141
4042193	7/10	12.5	593	3.5	160
Average		**14.2**	**631**	**8.9**	**198**
Standard Deviation		**2.12**	**85.3**	**6.37**	**85.3**

Verification

12-Hour Mix Design

Verification of the mix design maturity versus compressive strength curve was not conducted during the course of the project as per the instruction in the Special Provisions. However, the Consultant did on two occasions cast two test cylinders, one of which had an embedded logger, for both the 12-hour and 24-hour mixes. The cylinders were not placed in curing boxes, but cured in the open air. The logger for the 12-hour mix design was monitored for 19 hours at which time both cylinders were broken. The average compressive strength was 5,470 psi. The maturity value at this time was 595. This point is plotted on Figure 16. Although the recommended method for verification was not followed, it is interesting to see if the average compressive strength of the two cylinders falls within ±10 percent of the compressive strength at the same maturity value as the calibration curve. The compressive strength from the calibration curve at a maturity value of 595 is 5,105 psi. The average compressive strength of the two verification cylinders was 5470. This falls within ±10 percent of the value from the calibration curve (±10 percent is 4595 to 5616 psi). The special cylinders did verify that they were made from the 12-hour mix design used to develop the calibration curve.

24-Hour Mix Design

The maturity of the two test cylinders of the 24-hour mix were monitored for 38 hours at which time both cylinders were broken resulting in an average compressive strength of 3,335 psi. The maturity value at this point was 612. The single point from the two test cylinders is plotted in Figure 18. The average compressive strength of the verification cylinders, 3,335 psi does not fall within ±10 percent of the value from the calibration curve (±10 percent equals 3364 to 4112 psi) and thus the mix was not verified.

Special Provisions

The complete Contract Special Provisions are shown in Appendix F. The highlights of the special provisions are summarized below:

- The same Special Provisions used for the James to Olive project were used on this project except that the number of cylinders for the calibration testing was increased from 20 to 23 for each mix design.

Special Provisions Compliance

A lack of written data from the project makes it difficult to assess whether the Special Provisions were followed. Data from nine loggers for a project that extended over four weekend closures would seem to indicate that one logger per 500 cubic yards or fraction thereof was not followed. Project correspondence indicates that the testing firm hired to do the maturity testing was running out of money at the end of the project which may be the reason why there is no data from the pours on the last weekend. Verification testing was attempted, but not on the first and second days of concrete placement as specified in the Special Provisions and the testing was not performed according to these guidelines. One of the two tests did fall within the ±10 percent requirement at the maturity value that it was tested at and one failed. The verification tests, because they were not performed at the target maturity value, did not provide any assurance that the target maturity value established by the calibration curves was valid for the mix used on the project. Maturity data was reported on forms produced by the maturity meter as required, but the forms provided in the Special Provisions were not used as required. The reports from the consultant doing the maturity testing were in letter format and were not consistent in the information reported, did not always identify the mix design used for each logger installation, and were, in general, very difficult to decipher.

Primary Questions Addressed

Were valid calibration curves developed for each mix design used on the project?

Neither of the two trial runs for the 12-hour mix design produced a valid calibration curve. The curve for the 24-hour mix design was straight line with no break over point, and is therefore also somewhat suspect although it did bracket the target compressive strength.

Were verification procedures used to make sure the mix designs used on the project matched the original mix design used for calibration?

A form of verification was performed that used only two cylinders. The breaks did not occur at the target maturity value as required. The maturity/compressive strength point was within the ±10 percent requirement for the 12-hour mix design, but was not for the cylinders cast for the 24-hour mix.

Were the times to the target maturity value consistent throughout the project indicating that the concrete delivered to the job site was consistent?

The standard deviation for the 24-hour mix design was 2.12 as contrasted with the 1.27 for the 12-hour mix design. The large change in the time to maturity from the pours in the first week as compared to the shorter times to maturity for the following weeks pours accounts for the larger standard deviation for the 24-hour mix design.

Were target maturity values used to open the pavement to traffic?

Tables 15 and 16 shown that the maturity value reported to the Contractor by the consultant doing the maturity testing were always in excess of the target maturity value. The maturity value recorded minus the target maturity value average for the 12-hour mix was 321 and for the 24-hour mix was 198. The time that the loggers were read beyond the target maturity value is noted in Tables 15 and 16. The two loggers for the 12-hour mix averaged 8.8 hours beyond the target maturity value which does not seem to indicate any urgency to discontinue the readings because of opening to traffic issues. Three out of seven of the 24-hour mix loggers were cut off at 3.5 hours after the target maturity value was reached indicating some urgency and may therefore indicate that opening to traffic was an issue. The bottom line is that it is difficult to tell without other evidence that the maturity readings were used to permit the Contractor to open the pavement to traffic.

Were the forms provided in the Special Provisions used for recording and reporting maturity data on the project?

None of the forms included in the Special Provisions were used by the testing consultant. The encrypted maturity data from the loggers was transmitted to the state for most of the loggers.

Case Study Summary

Calibration Curves

The first two projects, Bellingham and James to Olive, had valid calibration curves developed for all of the mix designs used on the project. The Vancouver Vicinity project had one barely adequate calibration curve with only three points and no break over point and one invalid curve that did not bracket the target compressive strength for opening to traffic. The curve developed for the Bellingham project was the only one that had more than two points defining the curve before the break point. This raises a concern that the Special Provisions do not adequately define the need to bracket the target compressive strength. It may also point to a lack of understanding of the maturity concept when, in the case of the Vancouver Vicinity project, the curve developed for one of the mix designs was not valid.

Verification

There were no verification tests run on the James to Olive project. Attempts at verification were performed on the Bellingham and Vancouver projects, but they provided no definitive proof that the mix being used on the projects matched the mix design used to develop the strength/maturity curve. It is apparent that there is a lack of understanding of the need to verify the mix designs used on the project by either the Contractor or the Project Engineer.

Opening to Traffic

The only project that appeared to use the target maturity value as a means to open the pavement to traffic was James to Olive. The record keeping on the Bellingham project did not provide information on the issue of opening to traffic. The same can be said for the Vancouver project, that is, maturity may or may not have been used as the trigger to allow opening to traffic, but the records do not provide any evidence of either case. Perhaps the newness of the technology or a lack of understanding of how it can be used did not enable Contractors to adjust their schedules to take advantage of knowing the in-place strength.

Record Keeping

None of the three case studies had adequate recording keeping. Forms provided for the last two case studies were not, for the most part, used. The result is the records from a project do not adequately document what happened on the project. For example, on all three case studies there is no easy way to find out if the loggers were installed in the first or last concrete poured of the day or closure period, which is vital piece of information if that logger is being used for the target maturity value for opening to traffic. Perhaps this is known by the Contractor or even the street inspectors, but it has not been recorded in any of the contract documentation, at least on these three case studies.

Discussion

Maturity is a very good tool for predicting the in-place strength of concrete. Proper understanding and use of maturity can allow contractors to increase their productivity on projects with accelerated schedules. In only one of the three cast studies, James to Olive, was it clear that the contractor understood maturity and was able to use it to his advantage. On all of the case studies there was a lack of compliance with the Special Provision, no verification testing, inadequate recording keeping, and in one case a calibration curve that was not valid. This indicates an overall lack of understanding of maturity perhaps on both the Contractor side and the Project Engineer side of the process. Training, therefore, seems to be one of the key components missing, or inadequate in its present format.

Survey

In late 2007 a survey on the use of the maturity concept was conducted by the West Virginia Division of Highways in which 34 states, one Canadian province and Washington D.C. responded. The questions and a summary of the responses are provided below. The agencies responding were: Alabama, Arizona, Arkansas, California, Colorado, Connecticut, Florida, Georgia, Idaho, Illinois, Iowa, Kansas, Kentucky, Louisiana, Maine, Michigan, Minnesota, Mississippi, Missouri, New Hampshire, New Jersey, New Mexico, North Carolina, Ohio, Oklahoma, Ontario, South Carolina, South Dakota, Tennessee, Texas, Virginia, Washington D.C., Washington, West Virginia, Wisconsin, and Wyoming. The complete survey can be found in Appendix E.

Question #1. Are you familiar with the concrete maturity concept (strength gain based on time and temperature)? One hundred percent answered in the affirmative.

Question #2. Do you allow the use of concrete maturity curves (equations) as a substitution for compressive strength cylinders?

Table 17. Are maturity curves allowed as a substitution for compressive strength cylinders?

Category	Number of Responses
Yes	15
No	10
Allowed On An Experimental Basis	5
Allowed On A Conditional Basis	6
Total	**36**

Question #3. If so, do you allow this substitution for early break cylinders (field control specimens for form removal, etc.), 28-day acceptance cylinders (standard cured cylinders), or both?

Table 18. Is maturity allowed as a substitute for early breaks, 28-day acceptance, or both?	
Category	**Number of Responses**
Allowed	24
Not Allowed	10
Both Early and 28-Day	2
Total	**36**

Question #4. If you allow the use of maturity concept as a substitute for cylinders, do you still require some cylinders be fabricated and tested during the course of the construction to verify the accuracy of the maturity curves? If so, how often do you require cylinders to be tested in order to verity the curve?

Table 19. Requirement are in place for verification of the maturity-strength calibration curve.	
Category of Use	**Number of Responses**
Yes	19
No	2
Not Applicable	15
Totals	36

Question #5. If you permit the use of the maturity concept, would you please attach a copy of or a link to, your specifications regarding its use?

Table 20. Are specifications available for the use of maturity?	
Yes	15
No	15
In Draft Form	6
Total	**36**

Seventy-two percent of the responders (25) used the maturity concept either on a regular, experimental or conditional basis while the remaining 28 percent (11) were not currently using maturity. Of the 72 percent using maturity, 92 percent were using it as a substitute for early strength cylinder breaks to allow forms to be stripped or pavements to be opened to traffic. The other eight percent indicated they also allowed maturity to be substituted for both early cylinder breaks and or 28-day acceptance testing. A majority of the states that used maturity required some form of verification testing usually in the early stages of the project and then periodically throughout its course. A little over one half of the responders (58 percent) had specifications either in place or in draft form. In summary, a high percentage of the agencies are using the maturity concept, most as an early strength indicator to allow forms to be stripped or pavements to be opened to traffic, and most require some type of verification to assure that the mix being placed in the field matches the mix used to develop the strength-maturity calibration curve. Specification for maturity are currently in place in many agencies (15) and in draft form in several others (6).

Recommendations

The following recommendations are made on the future use of the maturity concept for determining early opening of concrete pavements.

- A training course should be developed that covers all aspects of the maturity concept from its theory to its day-to-day application on a project. The Texas Department of Transportation has such a course and it would provide a good model.
- A consistent method of reporting information should be developed an implemented.
- Maturity calibration curves should be developed with a minimum of five points defining the curve with at least one point before the target compressive strength is attained.
- Future implementation of the maturity concept should include additional trial projects that are closely monitored to assure that the processes and record keeping are functioning as designed.

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Appendix A

Bellingham Special Provisions

Concrete Maturity Value

The Contractor shall establish a Maturity Value on the approved concrete mix through the use of a testing program. The testing program shall establish the Maturity Value through test specimen correlation.

The procedure of the test specimen correlation is as follows: construct a test panel comprised of the approved concrete mix design and sufficient standard size test beams and cylinders to adequately determine the maturity/flexural strength relationship. The test panel shall measure 4m x 4m x0.3m and shall be at a site provided by the Contractor. The test panel placement methods shall match those that the Contractor intends to use on this contract. One test panel shall be constructed for each mix design proposed. The test panel shall receive an application of curing compound, then covered with a moisture retention covering (plastic wrap) and an insulating curing blanket (R-value=3). The Contractor hall make a minimum of 25 standard size beams and a minimum of 13 standard concrete cylinders at the same time that the concrete is being placed in the test panel and shall cure them in a manner identical to the test panel. Temperature probes shall be placed in the test panel, in a single test beam, and in a single concrete cylinder. The temperature of the test panel, test beam, and test cylinder shall be monitored by the maturity meter and by recording thermometers continuously during the testing period and the temperatures recorded.

In the presence of the Engineer, the Contractor shall begin breaking test beams every hour starting at the 5th hour after beginning concrete placement. The Contractor shall break the concrete cylinders every hour starting at the 7th hour after beginning concrete placement. The test beam and test cylinder that have the temperature probes shall not be broken. Add data shall be recorded in writing and copies submitted to the Engineer.

Calculation of the Maturity Value is as follows:

Maturity Value (MV)	=	(Temperature Avg. – Temperature datum) X (Time interval)
Temperature	=	Degrees centigrade
Temperature Avg	=	Temperature at the beginning of the interval +Temperature at the end of the interval divided by two.
Temperature datum	=	Datum temperature which is a function of the meter used
Time interval	=	Time between temperature readings.

The Maturity Value is the sum of all the incremental maturity value readings with the temperature recorded at the time of the test beam and cylinder breaks.

MV 1-x = MV1+…+MV x

The Maturity Value is plotted against the corresponding flexural strength (Mpa) obtained when the test beam is broken. The Maturity Value that corresponds to 2.8 Mpa using WSDOT test Method 802 shall be the minimum Maturity value used for opening the replacement panels to traffic. For calculation of the Maturity Value the Contractor shall follow ASTM C 1074 test procedures.

Appendix B

Bellingham Maturity Worksheet and Sample

Maturity Worksheet

JOB NAME: ______________________ **DATE:** ____________

SAMPLE TYPE: ______________________ **START TIME:** ____________

SERIAL #: ______________________ **TECHNICIAN:** ____________

#	TIME	HR	MIN	CH	C	COMP. STR.

Sample Worksheet

JOB NAME:	**BELLINGHAM MATURITY**	**DATE:**	**7/7/2003**
SAMPLE TYPE:	**CYLINDER**	**START TIME:**	**8:19AM**
SERIAL #:	**3503**	**TECHNICIAN:**	**CHRIS JOHNS**

#	TIME	HR	MIN	CH	C	COMP. STR.
1	8:38	0	0	0	23	-
2	1:38	5	0	145	38	1400 psi
3	2:38	5	57	176	43	2200 psi
4	3:38	6	59	221	47	3060 psi
5	4:38	8	1	281	50	-
6	5:38	9	0	331	50	3490 psi
7	6:38	9	59	369	49	-
8	7:38	10	59	417	47	-
9	8:38	12	2	474	45	4050 psi
10	9:38	13	1	518	43	-
11	10:38	13	59	550	42	-
12	11:38	15	0	602	41	-
13	12:44	16	7	643	40	-
14	1:46	17	8	683	39	-
15	2:39	18	2	721	38	-
16	3:39	18	59	750	37	-
17	4:39	19	58	787	36	-
18	5:40	21	0	831	35	-
19	6:40	22	0	866	34	-
20	7:40	22	58	892	34	-
21	8:53	24	12	933	32	5140 psi
22	9:40	24	59	957	32	-
23	8:40	48	0			7450 psi

Appendix C

Bellingham Debriefing Report

Washington State Department of Transportation

Memorandum

December 17, 2003

TO: Tom Baker, 47365

FROM: Jeff Uhlmeyer, 47365

SUBJECT: I-5, 36^{th} St. Vic. To SR 542 PCCP Rehab
Concrete Maturity Debrief - December 10, 2003

Attendees:

Jeff Uhlmeyer – HQ Material Lab
Chris Johns – HQ Materials Lab
Jack Turner – NW Region Lab
Larry Worchester – NW Region Lab
Jeff Peterson – Project Office
Beth Warfield – Project Office
Brian West – Project Office

Background

Concrete maturity was chosen for this project as a means to facilitate the early opening to traffic of approximately 500 panel replacements for this 3-mile project. The contract allowed six closure periods, Monday morning to Friday morning, to perform the work. Contract incentives were offered if the contractor could reduce the number of closures. The contractor chose to complete the work with only four closure periods thus obtaining nearly $100,000 in incentives.

Project Office Comments

Mark Russell's Project Engineering Office administered the contract. The Bellingham staff had not previously worked with concrete maturity. Overall, their experience was positive and they liked the idea of opening the pavement to traffic while not depending on early break cylinders. The actual opening to traffic occurred before or after work hours therefore obtaining early cylinder break information (4:30 am) would have been difficult. Specific comments from the project office addressing maturity and panel replacement work are noted in the following comments:

Since the project office had no experience with maturity, training prior to the contract would serve to reduced questions and concerns.

The maturity specification must clarify that maturity does not replace 28-day cylinder breaks.

The project office questioned the use of only one maturity logger placed during the last pour prior to opening to traffic. The project office recommended placing two loggers to avoid problems if one malfunctions.

A procedure needs to be in place, should a maturity reader fail. On the first lane closure, the contractor's maturity reader broke leaving the project office in a scramble to determine a way to open the roadway to traffic.

The project office recommended a contractor verification procedure to ensure the mix placed is the same as was used for the maturity calibration. This recommendation came as a result of observed differences in the consistency of the contractor's mix.

Variations in mix consistency were observed in the concrete delivered to the project. Some loads were soupy and some loads were very stiff. Since the whole premise with maturity is that mix proportions do not change, project inspectors sometimes questioned the proportions of aggregates, water, or admixtures being added to the mix. Some of the consistency problems could be explained based on the amount of water added at the plant, however, the project inspector noted that the contractor did not appear to exceed the maximum water content. Consistency in the concrete was observed towards the end of the contract work.

The mix used on the project appeared to be very temperature sensitive. Often, the concrete became unworkable after 45 minutes. With delivery delays and an unworkable mix, cold joints became an issue. The inspectors feel our specifications are not strong enough to stop cold joints. Standard Specification 5-05.3(8)C only says, "that when placing concrete is discontinued for more than 45 minutes, a transverse construction joint shall be installed." The project office recommends stronger language within our specifications to eliminate cold joints when working with panel replacements and fast setting mixes.

The project office had difficulty convincing the contractor that panel replacements need to be saw cut as soon as possible rather than waiting up to 24 hours. After the first pour mid-panel cracks appeared. The contractor began sawing as soon as possible on the remaining pours to avoid cracks.

The panel replacement contractor chose to pour panel replacements up to ½ inch high. The diamond-grinding contractor had to provide bump grinding prior to the final profile grinding. While on this contract this was a problem for the two subs to work out, specifying to what grade (flush with the existing panels or a maximum of ¼ inch high?) may provide some clarification.

Note: Under the Special Provision "Replace Cement Concrete Panel" - There is a line that says, "Grade control shall be the responsibility of the contractor". The next paragraph says, "Surface smoothness shall be measured by the Engineer…in accordance with Section 5-05.3(12)." Since PCCP grinding is performed after panel replacement – This should be modified to say, <u>"Grade control and surface smoothness shall be the responsibility of the contractor. The contractor shall</u>

measure surface smoothness with a 3 meter straight edge in accordance with Section 5-05.3(12)". Make the contractor totally responsible for this since it is not the final product.

Headquarters Comments

The Headquarters Materials Lab worked closely with the contractor to develop the calibration curve for the mix. The cylinder and beams for the calibration curve and test slab were poured at the contractor's yard in Bellingham. After 4 hours of cure, the cylinders and beams were hauled to a private test lab in Everett. The cylinder and beams were monitored for maturity and broken for compression strength for a 24-hour period. The contractor monitored the test slab for maturity values for a 15-hour period. Fortunately, the contractor purchased the same Intellirock™ Maturity Meter as WSDOT. The availability of two meters allowed the monitoring of cylinders and the test slab, each at different locations.

The purpose of monitoring the test slab for maturity values in addition to the cylinders was to determine a shift in strength from the cylinder specimens to the slab. Typically, the slab will gain strength at a faster rate due to the mass pour/heat of hydration effects. WSDOT's analysis showed that the maturity of the slab did not catch up to the maturity of the cylinders until the 10th hour. Both the cylinders and slab were covered with plastic and blankets. After considering all factors, it was reasoned that the cylinders may have "cooked" more than the slab. In future calibration scenarios when a test slab is used, care should be given to cure the calibration cylinders as close as possible to the same manner used for the slab. This will give a more "accurate" shift in strength gain when comparing cylinders and slabs.

The maturity value needed to open the panel replacements to traffic at 2,500-psi compression was 191 Celsius-Hours (°CH). The calibration curve obtained the desired maturity in 6.5 hours. The assumption used by the project office was that the mix proportions used during construction would be identical to the proportions used to develop the calibration curve. For maturity to be valid, this assumption must be true. A verification procedure will ensure that the calibration curve and the contract mix is the same.

The Headquarters Materials Lab was able to visit the Bellingham project for three of the four lane closures in order to perform verification testing of the calibration curve. On each visit, cylinders were cast and broken and maturity was monitored. The maturity results measured, when the compressive strength reached 2,500 psi, was similar to the calibration curve for two of the three closures. At this time, it is not clear why the one test failed to match the calibration curve. The project inspector or the Headquarters material tester did not report anything unusual about the concrete used for this test. The maturity number of 191 °CH for the verification testing was obtained within 7.5 hours. For all closures, the time of the last pour to the opening to traffic was 9 to 10 hours, leading to actual maturity values of about 360 °CH.

The maturity meter purchased by WSDOT and used on this project has limited use. The primary dissatisfaction is that previous readings, recorded during maturity monitoring, cannot be saved without generating a new file. Therefore, numerous files are needed to capture the history of a specific maturity logger. Managing the many files stored in the Intellirock Maturity Meter can be time consuming. A newer model is now available for about $3,000. WSDOT's meter cost $1,000.

The Headquarters Material Lab will be providing a more complete summary of the Bellingham Maturity Experience via a Technote.

Appendix D

James to Olive Maturity Worksheet and Sample

James to Olive Maturity Worksheet

Contract

Closure Period: ______________________

Panel Replacement Location:

Mix Design Used: ______________________

Lane: (INSIDE / OUTSIDE)

Direction: (NB / SB)

ºC-Hrs Required to Open to Traffic:

Station: ______________

Offset: ______________

Technician: ______________________

Logger Start Date/Time:

		Elapsed Time		Logger Readings	
Logger #	Real Time	Elapsed Hour	Elapsed Minutes	Temperature	ºC-Hrs

Instructions: **For IntelliRock™ maturity readers.**

1) For initial startup of logger, connect colored wires to corresponding color terminal.
   Push "3" to turn on READER. Record logger #. Then either quick-start logger:
      Press and hold "ENTER" and "F2" at the same time.
   OR: Start the logger with Job Name & Location:
      Press "ENTER"
      Press "F2" ; Press "F1" ; Enter Job Name; Press "ENTER"
      Press "F1" ; Enter Location; Press "ENTER"
      Leave Data Temperature at 0; Press "ENTER"
   Push "3" and "6" at the same time to turnoff READER. Logger will continue recording.

2) Fill Form with startup data. Check that **"ºC-Hrs Needed to Open"** is from the same mix design.

3) Read hourly. Connect logger, then turn on.Confirm logger # and record real time.
   Push "F1" and record elapsed time, Temperature, & ºC-Hrs.
   Turnoff.

(NOTE) Logger should be placed in the last pour to represent ºC-Hrs needed to open to traffic. Activate the logger ASAP following concrete placement. Additional loggers should be placed throughout the pour for informational purposes.

James to Olive Sample Worksheet

Contract 6886

Closure Period: July 16, 2005 - July 17, 2005

Panel Replacement Location:

Mix Design Used: 8049-H

Lane: (INSIDE / **OUTSIDE**)

Direction: (NB / **SB**)

ºC-Hrs Required to Open to Traffic: 275

Station: CD 2158+82.6*

Offset:

Technician: Janette Carciller

Logger Start Date/Time: July 16, 2005 - 3:02 PM

		Elapsed Time		Logger Readings	
Logger #	Real Time	Elapsed Hour	Elapsed Minutes	Temperature	ºC-Hrs
2068297	3:02pm	0	0	28	0
2068297	4:22pm	1	20	29	35
2068297	5:17pm	2	15	31	65
2068297	6:21pm	3	19	34	97
2068297	8:16pm	5	17	50	177
2068297	10:20pm	7	21	60	291

Instructions: **For IntelliRock™ maturity readers.**

1) For initial startup of logger, connect colored wires to corresponding color terminal.
   Push "3" to turn on READER. Record logger #. Then either quick-start logger:
      Press and hold "ENTER" and "F2" at the same time.
   OR: Start the logger with Job Name & Location:
      Press "ENTER"
      Press "F2" ; Press "F1" ; Enter Job Name; Press "ENTER"
      Press "F1" ; Enter Location; Press "ENTER"
      Leave Data Temperature at 0; Press "ENTER"
   Push "3" and "6" at the same time to turnoff READER. Logger will continue recording.

2) Fill Form with startup data. Check that **"ºC-Hrs Needed to Open"** is from the same mix design.

3) Read hourly. Connect logger, then turn on.Confirm logger # and record real time.
   Push "F1" and record elapsed time, Temperature, & ºC-Hrs.
   Turnoff.

(NOTE) Logger should be placed in the last pour to represent ºC-Hrs needed to open to traffic. Activate the logger ASAP following concrete placement. Additional loggers should be placed throughout the pour for informational purposes.

Appendix E

James to Olive Special Provisions

Opening to Traffic

Section 5-05.3(17) is supplemented with the following:

Maturity Testing for Concrete Pavement

The Contractor shall establish a Maturity Value on the approved concrete mix through the use of a testing program following the WSDOT test procedure for estimating concrete strength.

The Contractor shall establish the strength maturity relationship at least 14 days prior to the production pours.

The Contractor shall be responsible for the installation of the maturity logger/sensor within the concrete pavement pour area. Place two loggers/sensors within the concrete pour area at a frequency of 500 cubic yards or fraction thereof. The Contractor shall maintain the integrity of the logger/sensor and wires during concrete pouring, finishing and curing operations or until the maturity information is no longer needed.

The Contractor shall perform the Quality Control Procedure to Verify the Strength-Maturity Relationship on days 1 and 2 of concrete placement as indicated in the test procedure.

The Contractor shall develop a Quality Control Plan based on the Strength-Maturity Relationship to monitor and provide remedial action to ensure the concrete meets design strengths.

Any alteration in mix proportions or source or type of any material, in excess of those tolerable by batching variability, requires the development of a new strength-maturity relationship prior to its use at the Contractors time and expense. This includes a change in type, source, or proportion of cement, fly ash, coarse aggregate, fine aggregate, or admixtures. A change in water-to-cementitious material ratio greater than 0.05 requires the development of a new strength-maturity relationship.

Maturity Method Test Procedure

This test method provides a procedure for estimating concrete strength by means of the maturity method. The maturity method is based on strength gain as a function of temperature and time. This method is a modification of ASTM C1074 covering the procedures for estimating concrete strength by means of the maturity method.

The maturity method consists of three steps:

- Develop strength-maturity relationship
- Estimate in-place strength
- Verify strength-maturity relationship.

The Nurse-Saul “temperature-time factor (TTF)” maturity index shall be used in this test method, with a datum temperature of 0 ^{o}C (32 ^{o}F).

Apparatus

- If the maturity meter has input capability for datum temperature, verify that the proper value of the datum temperature has been selected prior to each use.
- Intellirock maturity system (or approved equivalent). This system shall include the logger/sensor, handheld reader, and software.
- The data obtained from the maturity meter shall be unalterable and un-interruptible.
- The same brand and type of maturity meters shall be used in the field as those used to develop and verify the strength-maturity relationship.
- Logger/sensor wire grade shall be larger than or equal to 20 awg.

Contractors Procedure to Develop Strength-Maturity Relationship

Step Action

1. For every concrete design that will be evaluated by the maturity method, prepare a minimum of 20 cylinders in accordance with FOP for ASSHTO T 23. Additional cylinders should be cast to avoid having to repeat the procedure. The mixture proportions and constituents of the concrete shall be the same as those of the job concrete whose strength will be estimated using this practice. The minimum size of each batch shall be approximately 3 m^3 (4 yd^3).

2. Fresh concrete testing for each batch shall include concrete placement temperature, slump, air content in accordance with FOP for AASHTO T 309, FOP for AASHTO T 119, and FOP for AASHTO T 152.

3. Embed loggers/sensors in at least two cylinders. Loggers/sensors shall be placed 2-4 inches from any surface. Activate the loggers/sensors.

4. Cure the cylinders in accordance with FOP for AASHTO T 23.

5. Perform compression strength tests in accordance with FOP for AASHTO T 22 to target 2,500 psi for opening to traffic. Additional cylinders and test ages may be evaluated at the discretion of the Contractor. Test three cylinders at each age and compute the average strength. The cylinders with logger/sensors may be tested if additional cylinders are needed.

6. At each test age, record the individual and average values of maturity and strength for each batch on a permanent data sheet (see Appendix A – Table 1 for sample record log).

7. Plot the average strengths as a function of the average maturity values, with data points shown. Using a computer spreadsheet program such as Microsoft Excel, calculate a point-to-point interpolation through the data. The resulting curve is the strength-maturity relationship to be used for estimating the strength of the concrete mixture placed in the field.

When developing the strength-maturity relationship, the spreadsheet software allows the Engineer to develop the corresponding maturity equation, which defines the strength-maturity relationship. The Engineer should carefully examine the data for "outliners", faulty cylinder breaks, or faulty maturity readings. The Engineer should use judgment to determine if certain points should be discarded, or retested, or whether the entire strength-maturity relationship should be regenerated.

Contractors Procedure to Estimate In-Place Strength

Step	Action
1.	Prior to or at the time of concrete placement, install logger/sensors at the frequency specified. Loggers/sensors shall be placed a minimum of 2 ft. from a panel edge and 4 to 5 inches from the panel surface. Loggers/sensors may be tied to reinforcing steel, but should not be in direct contact with the reinforcing steel or formwork.
2.	As soon as practical after concrete placement, connect and activate the maturity meter(s).
3.	The Contractor shall provide to the Engineer, prior to the opening the pavement to traffic, encrypted data files (with software to read the files) of the maturity data from the logger/sensors. Data shall be provided until the maturity is at a value that is equal to or greater than the required strength for that concrete mixture, as determined by the strength-maturity relationship. Additionally, data shall be provided on a record log (See Appendix B – Table 2 for sample record log).

Contractors Quality Control Procedure to Verity Strength-Maturity Relationship

Step	Action
1.	At the specified verification interval make a minimum of two cylinders in accordance with FOP for AASHTO T 23.
2.	Embed a logger/sensor in one cylinder. Loggers/sensors shall be placed 2-4 inches from any surface. Activate the logger/sensor as soon as possible.
3.	Cure the cylinders in accordance with FOP for AASHTO T 23
4.	Perform compression strength tests on two cylinders in accordance with FOP for AASHTO T 22 to verity strength and time to reach 2,500 psi for opening to traffic. Compute the average strength of the cylinders at each test age (average of 2 cylinders at a time, not the average of additional cylinders).
5.	Record on a permanent data sheet the maturity value at the time of compression testing and individual and average strengths established from the cylinder breaks. Also record the predicted strength based on the strength-maturity relationship established for that particular concrete design, and the percent

difference between average and predicted values. The strength maturity relationship is verified when the predicted strength established from the strength maturity relationship and the cylinder breaks are within 10 percent. A copy of WSDOT Table 3 (See Appendix C) and an encrypted file for the maturity data shall be provided to the Engineer on a daily basis.

(Special Provisions were copied verbatim from the Contract with no correction made to the contents regardless of any obvious errors.)

Table 1. Record Log to Develop Strength-Maturity Relationship[1]

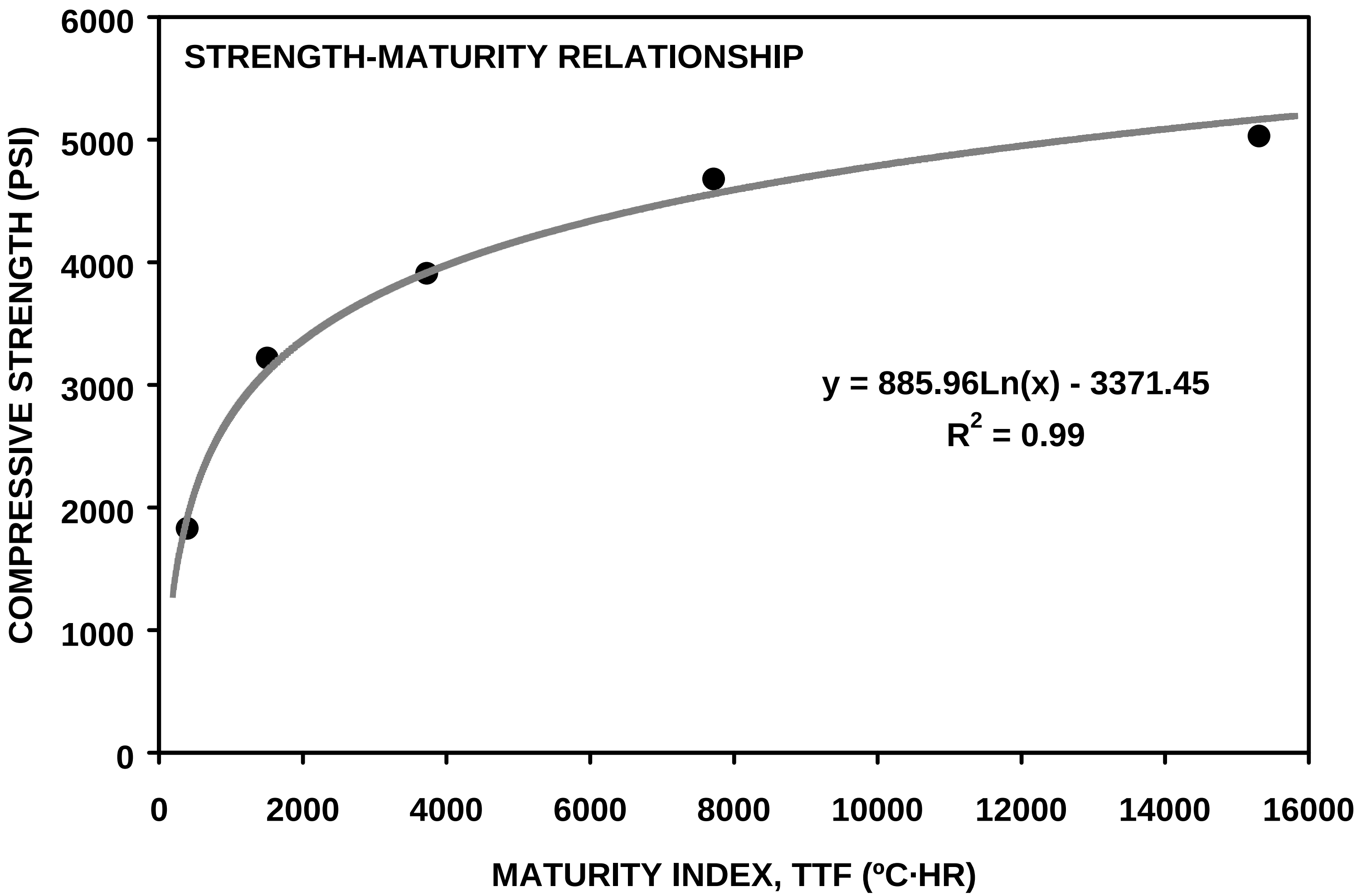
Control:		Lab Technician:	
Project:		Member:	
Highway:		Item No.:	
Structure:		Conc. Class / Mix No.:	
Engineer:	.	Date / Time Batch:	
Producer:		Required TTF / Action:	

Meter No.:	**Specimen 1:**		**Specimen 2:**
Batch No.:			
Air Temp. at Placement:		**°F**	**°C**
Slump:		**inches**	**mm**
Air Content:		**%**	

Date	**Time (hr:min)**	**Tank Temp (°C)**	**Instrumented Specimens for Monitoring Maturity**						**Strength Test Results (psi)**			
			Specimen 1		**Specimen 2**		**Average Value**					
			Conc. Temp (°C)	**TTF (°C·hr)**	**Conc. Temp (°C)**	**TTF (°C·hr)**	**Conc. Temp (°C)**	**TTF (°C·hr)**	**1**	**2**	**3**	**Average**

Comments:

Note (1): Attach copy of batch ticket


STRENGTH-MATURITY RELATIONSHIP
y = 885.96Ln(x) - 3371.45
R2 = 0.99
COMPRESSIVE STRENGTH (PSI)
0
1000
2000
3000
4000
5000
6000
0
2000
4000
6000
8000
10000
12000
14000
16000
MATURITY INDEX, TTF (ºC·HR)

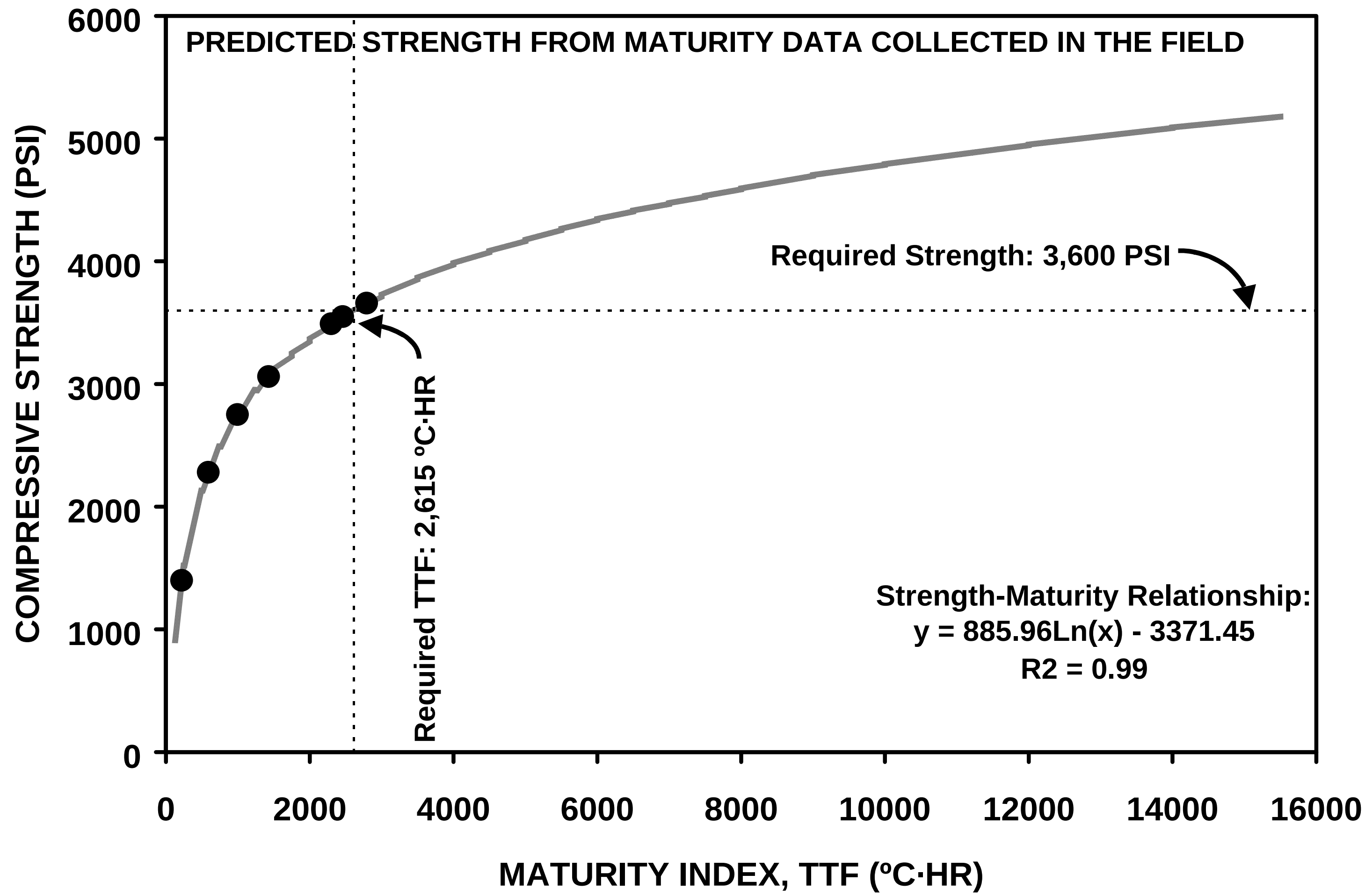

PREDICTED STRENGTH FROM MATURITY DATA COLLECTED IN THE FIELD
COMPRESSIVE STRENGTH (PSI)
6000
5000
4000
3000
2000
1000
0
Required Strength: 3,600 PSI
Required TTF: 2,615 ºC·HR
Strength-Maturity Relationship:
y = 885.96Ln(x) - 3371.45
R2 = 0.99
0
2000
4000
6000
8000
10000
12000
14000
16000
MATURITY INDEX, TTF (ºC·HR)

Table 3. Record Log to Verify Strength-Maturity Relationship(1)

Control:	______________________	Technician:	______________________
Project:	______________________	Member:	______________________
Highway:	______________________	Item No.:	______________________
Structure:	______________________	Conc. Class / Mix No.:	______________________
Engineer:	______________________	Date / Time Batch:	______________________
Contractor	______________________	Location of Sampling:	______________________
Producer:	______________________		

7

Meter No.	**Specimen 1:**	**Specimen 2:**
Batch No. (internal laboratory control number):		
Air Tem. at Placement	ºF	ºC
Concrete Temp. at Placement	ºF	ºC
Slump	inches	mm
Air Content	%	%
Required Strength of the Member:	psi	
Required TTF of the Member:	ºC-hr	
Operation:		

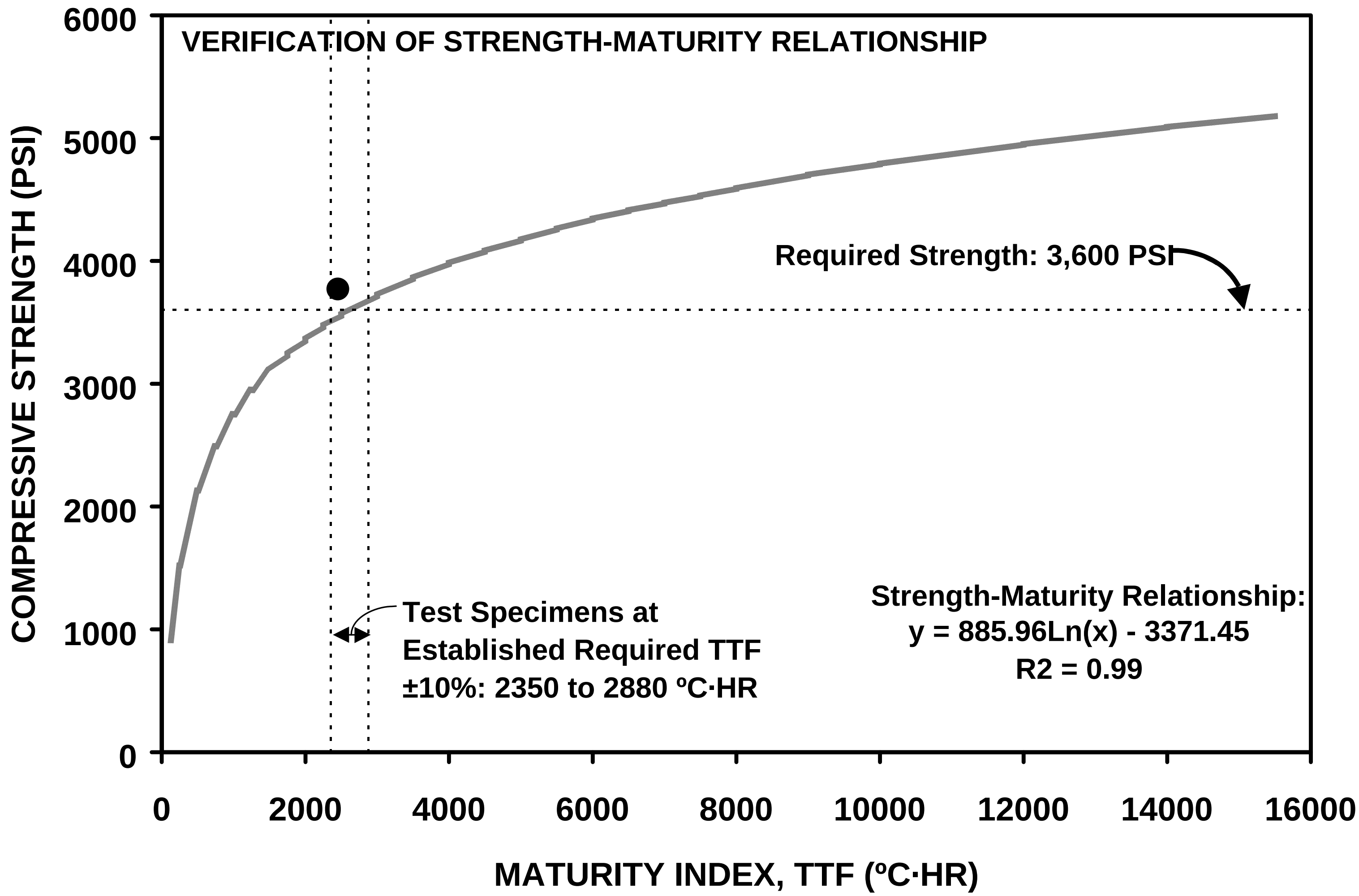
Date	**Time(2) (hr:min)**	**Verification Test**											
		Instrumented Specimens for Monitoring Maturity							**Strength Test Results (psi)**				**Percent Difference (3)**
		Specimen 1		**Specimen 2**		**Average Value**							
		Conc. Temp (ºC)	**TTF (ºC·hr)**	**Conc. Temp (ºC)**	**TTF (ºC·hr)**	**Conc. Temp (ºC)**	**TTF (ºC·hr)**	**Predicted Strength (psi)**	**1**	**2**	**3**	**Avg.**	

Comments:

Note (1): Attach copy of batch ticket

Note (2): Perform compression or flexural strength tests, as appropriate, when (a) the specimen achieves the TTF corresponding to the design strength, or (b) the required TTF of the member is achieved in the field if verifying for structurally-critical formwork or falsework or steel stressing or other safety-related operations.

Note (3): % Difference = ((Average Strength – Predicted Strength) / Predicted Strength) x 100



VERIFICATION OF STRENGTH-MATURITY RELATIONSHIP
6000
5000
4000
3000
2000
1000
0
COMPRESSIVE STRENGTH (PSI)
Required Strength: 3,600 PSI
Test Specimens at
Established Required TTF
±10%: 2350 to 2880 ºC·HR
Strength-Maturity Relationship:
y = 885.96Ln(x) - 3371.45
R2 = 0.99
0
2000
4000
6000
8000
10000
12000
14000
16000
MATURITY INDEX, TTF (ºC·HR)

Appendix F

Vancouver Vicinity Special Provisions

Opening to Traffic

Section 5-05.3(17) is supplemented with the following:

Maturity Testing for Concrete Pavement

The Contractor shall establish a Maturity Value on the approved concrete mix through the use of a testing program following the WSDOT test procedure for estimating concrete strength.

The Contractor shall establish the strength maturity relationship at least 14 days prior to the production pours.

The Contractor shall be responsible for the installation of the maturity logger/sensor within the concrete pavement pour area. Place two loggers/sensors within the concrete pour area at a frequency of 500 cubic yards or fraction thereof. The Contractor shall maintain the integrity of the logger/sensor and wires during concrete pouring, finishing and curing operations or until the maturity information is no longer needed.

The Contractor shall perform the Quality Control Procedure to Verify the Strength-Maturity Relationship on days 1 and 2 of concrete placement as indicated in the test procedure.

The Contractor shall develop a Quality Control Plan based on the Strength-Maturity Relationship to monitor and provide remedial action to ensure the concrete meets design strengths.

Any alteration in mix proportions or source or type of any material, in excess of those tolerable by batching variability, requires the development of a new strength-maturity relationship prior to its use at the Contractors time and expense. This includes a change in type, source, or proportion of cement, fly ash, coarse aggregate, fine aggregate, or admixtures. A change in water-to-cementitious material ratio greater than 0.05 requires the development of a new strength-maturity relationship.

Maturity Method Test Procedure

This test method provides a procedure for estimating concrete strength by means of the maturity method. The maturity method is based on strength gain as a function of temperature and time. This method is a modification of ASTM C1074 covering the procedures for estimating concrete strength by means of the maturity method.

The maturity method consists of three steps:

- Develop strength-maturity relationship
- Estimate in-place strength
- Verify strength-maturity relationship.

The Nurse-Saul “temperature-time factor (TTF)” maturity index shall be used in this test method, with a datum temperature of 0 ^{o}C (32 ^{o}F).

Apparatus

- Intellirock maturity system (meter, maturity loggers and software) available through Engius, Stillwater OK (1-866-636-4487)

Contractors Procedure to Develop Strength-Maturity Relationship

Step Action

1. For every concrete design that will be evaluated by the maturity method, prepare a minimum of 23 cylinders in accordance with FOP for ASSHTO T 23. Additional cylinders should be cast to avoid having to repeat the procedure. The mixture proportions and constituents of the concrete shall be the same as those of the job concrete whose strength will be estimated using this practice. The minimum size of each batch shall be approximately 3 m^3 (4 yd^3).

2. Fresh concrete testing for each batch shall include concrete placement temperature, slump, air content in accordance with FOP for AASHTO T 309, FOP for AASHTO T 119, and FOP for AASHTO T 152.

3. Embed loggers/sensors in at least two cylinders. Loggers/sensors shall be placed 2-4 inches from any surface. Activate the loggers/sensors.

4. Cure the cylinders in accordance with FOP for AASHTO T 23.

5. Perform compression strength tests in accordance with FOP for AASHTO T 22 to target 2,500 psi for opening to traffic. Compression tests shall also provide the maturity history up to 28 days. Additional cylinders and test ages may be evaluated at the discretion of the Contractor. Test three cylinders at each age and compute the average strength. The cylinders with logger/sensors may be tested if additional cylinders are needed.

6. At each test age, record the individual and average values of maturity and strength for each batch on a permanent data sheet (see WSDOT Table 1 for sample record log).

7. Plot the average strengths as a function of the average maturity values, with data points shown. Using a computer spreadsheet program such as Microsoft Excel, calculate a point-to-point interpolation through the data. The resulting curve is the strength-maturity relationship to be used for estimating the strength of the concrete mixture placed in the field.

   When developing the strength-maturity relationship, the spreadsheet software allows the Engineer to develop the corresponding maturity equation, which defines the strength-maturity relationship. The Engineer should carefully examine the data for "outliners", faulty cylinder breaks, or faulty maturity readings. The Engineer should use judgment to determine if certain points should be discarded, or retested, or whether the entire strength-maturity relationship should be regenerated.

Contractors Procedure to Estimate In-Place Strength

Step Action

1. Prior to or at the time of concrete placement, install logger/sensors at the frequency specified. Loggers/sensors shall be placed a minimum of 2 ft. from a panel edge and 4 to 5 inches from the panel surface. Loggers/sensors may be tied to reinforcing steel, but should not be in direct contact with the reinforcing steel or formwork.

2. As soon as practical after concrete placement, connect and activate the maturity meter(s).

3. The Contractor shall provide to the Engineer, prior to the opening the pavement to traffic, encrypted data files (with software to read the files) of the maturity data from the logger/sensors. Data shall be provided until the maturity is at a value that is equal to or greater than the required strength for that concrete mixture, as determined by the strength-maturity relationship. Additionally, data shall be provided on a record log (See WSDOT Table 2 for sample record log).

Contractors Quality Control Procedure to Verity Strength-Maturity Relationship

Step Action

1. At the specified verification interval make a minimum of two cylinders in accordance with FOP for AASHTO T 23.

2. Embed a logger/sensor in one cylinder. Loggers/sensors shall be placed 2-4 inches from any surface. Activate the logger/sensor as soon as possible.

3. Cure the cylinders in accordance with FOP for AASHTO T 23

4. Perform compression strength tests on two cylinders in accordance with FOP for AASHTO T 22 to verity strength and time to reach 2,500 psi for opening to traffic. Compute the average strength of the cylinders at each test age (average of 2 cylinders at a time, not the average of additional cylinders).

5. Record on a permanent data sheet the maturity value at the time of compression testing and individual and average strengths established from the cylinder breaks. Also record the predicted strength based on the strength-maturity relationship established for that particular concrete design, and the percent difference between average and predicted values. The strength maturity relationship is verified when the predicted strength established from the strength maturity relationship and the cylinder breaks are within 10 percent. A copy of WSDOT Table 3 and an encrypted file for the maturity data shall be provided to the Engineer on a daily basis.

(Special Provisions were copied verbatim from the Contract with no correction made to the contents regardless of any obvious errors. Red indicates changes from the James to Olive project.)

Table 1. Record Log to Develop Strength-Maturity Relationship[1]

Control:		Lab Technician:	
Project:		Member:	
Highway:		Item No.:	
Structure:		Conc. Class / Mix No.:	
Engineer:	.	Date / Time Batch:	
Producer:		Required TTF / Action:	

Meter No.:	Specimen 1:		Specimen 2:	
Batch No.:				
Air Temp. at Placement:		°F	°C	
Slump:		inches	mm	
Air Content:		%		

Date	Time (hr:min)	Tank Temp (°C)	Instrumented Specimens for Monitoring Maturity						Strength Test Results (psi)			
			Specimen 1		Specimen 2		Average Value					
			Conc. Temp (°C)	TTF (°C·hr)	Conc. Temp (°C)	TTF (°C·hr)	Conc. Temp (°C)	TTF (°C·hr)	1	2	3	Average
Comments:												

Note (1): Attach copy of batch ticket

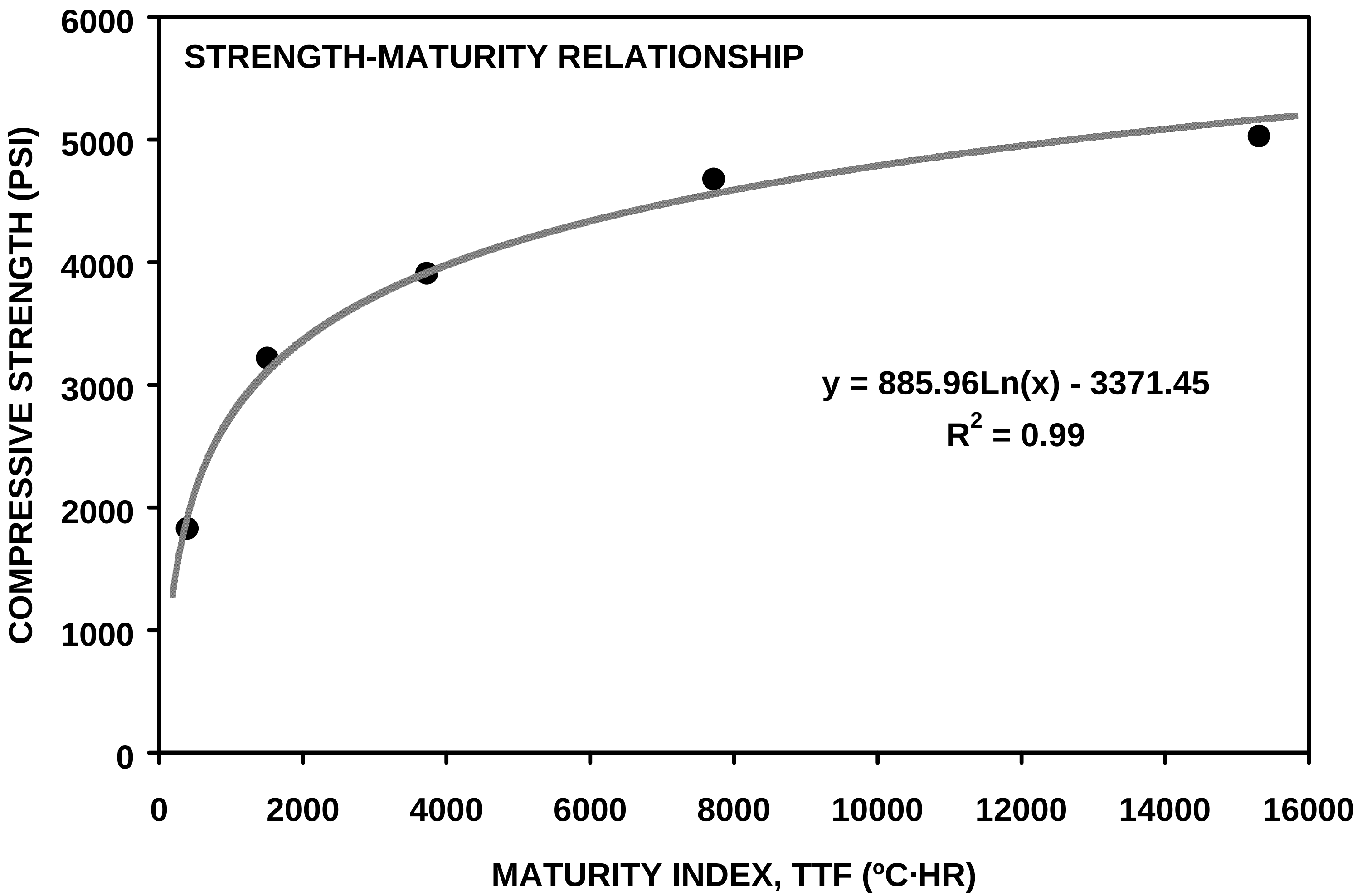

STRENGTH-MATURITY RELATIONSHIP
y = 885.96Ln(x) - 3371.45
R2 = 0.99
COMPRESSIVE STRENGTH (PSI)
0
1000
2000
3000
4000
5000
6000
0
2000
4000
6000
8000
10000
12000
14000
16000
MATURITY INDEX, TTF (ºC·HR)

Table 2. Record Log for Field Maturity Data[1] with Sample Data

Structure			
Member			
Meter No.			
Meter Location			
Spec. Item No.			
Conc. Class & Mix No.			
Date/Time Batch			
Air. Temp. Placed	ºF ºC	ºF ºC	ºF ºC
Conc. Temp. Placed	ºF ºC	ºF ºC	ºF ºC
Slump	inches mm	inches mm	inches mm
Air Content	%	%	%
Required Strength	psi	psi	psi
Required TTF	ºC·hr	ºC·hr	ºC·hr
Operation			

Inspector	Reading No.[2]	Date	Time (hh:min)	Air Temp. (°C)	Conc. Temp. (°C)	TTF (°C·hr)	Date	Time (hh:min)	Air Temp. (°C)	Conc. Temp. (°C)	TTF (°C·hr)	Date	Time (hh:min)	Air Temp. (°C)	Conc. Temp. (°C)	TTF (°C·hr)
Comments																

Note (1): Attach copy of batch ticket(s)
Note (2): When each reading is taken, verify that the specified curing procedures are being followed.

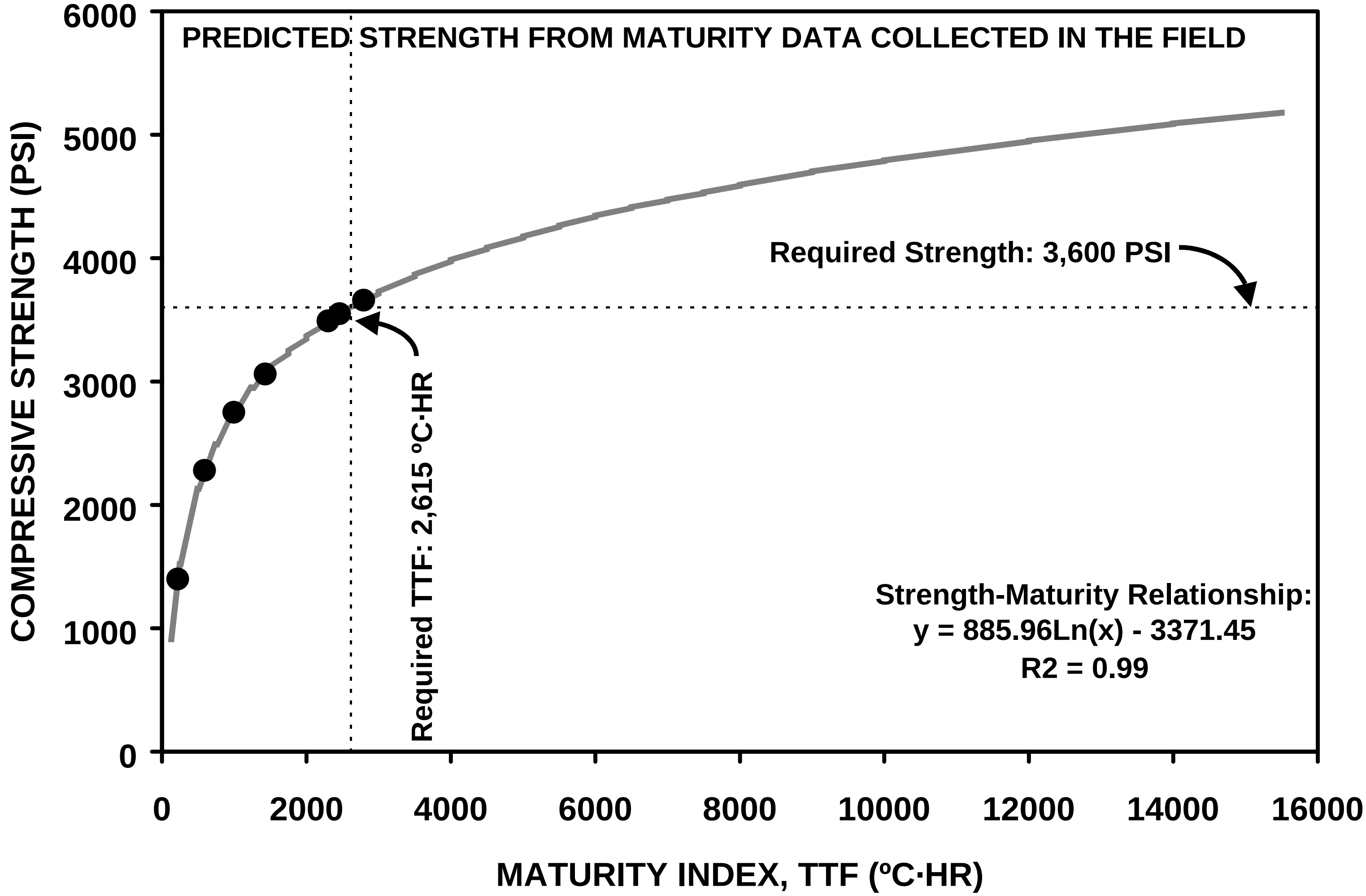

PREDICTED STRENGTH FROM MATURITY DATA COLLECTED IN THE FIELD
6000
5000
4000
3000
2000
1000
0
COMPRESSIVE STRENGTH (PSI)
Required Strength: 3,600 PSI
Required TTF: 2,615 ºC·HR
Strength-Maturity Relationship:
y = 885.96Ln(x) - 3371.45
R2 = 0.99
0
2000
4000
6000
8000
10000
12000
14000
16000
MATURITY INDEX, TTF (ºC·HR)

Table 3. Record Log to Verify Strength-Maturity Relationship[1]

Control:	______________	Technician:	______________
Project:	______________	Member:	______________
Highway:	______________	Item No.:	______________
Structure:	______________	Conc. Class / Mix No.:	______________
Engineer:	______________	Date / Time Batch:	______________
Contractor	______________	Location of Sampling:	______________
Producer:	______________		

7

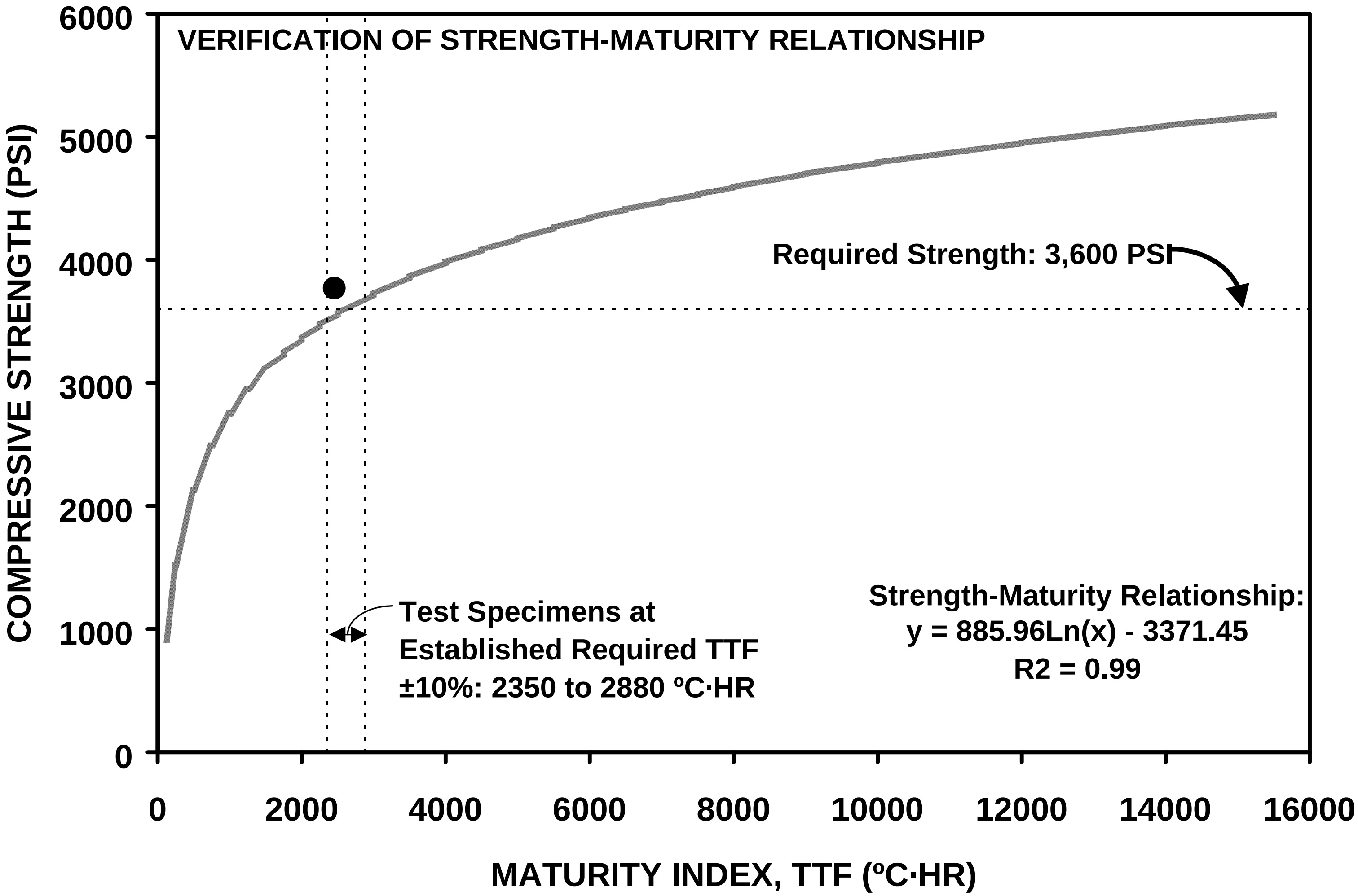
Meter No.	**Specimen 1:**	**Specimen 2:**
Batch No. (internal laboratory control number):		
Air Temp. at Placement	ºF	ºC
Concrete Temp. at Placement	ºF	ºC
Slump	inches	mm
Air Content	%	%
Required Strength of the Member:	psi	
Required TTF of the Member:	ºC-hr	
Operation:		

Date	**Time[2] (hr:min)**	**Verification Test**											
		Instrumented Specimens for Monitoring Maturity							**Strength Test Results (psi)**				**Percent Difference[3]**
		Specimen 1		**Specimen 2**		**Average Value**							
		Conc. Temp (ºC)	**TTF (ºC·hr)**	**Conc. Temp (ºC)**	**TTF (ºC·hr)**	**Conc. Temp (ºC)**	**TTF (ºC·hr)**	**Predicted Strength (psi)**	**1**	**2**	**3**	**Avg.**	
Comments:													

Note (1): Attach copy of batch ticket

Note (2): Perform compression or flexural strength tests, as appropriate, when (a) the specimen achieves the TTF corresponding to the design strength, or (b) the required TTF of the member is achieved in the field if verifying for structurally-critical formwork or falsework or steel stressing or other safety-related operations.

Note (3): % Difference = ((Average Strength – Predicted Strength) / Predicted Strength) x 100


VERIFICATION OF STRENGTH-MATURITY RELATIONSHIP
Required Strength: 3,600 PSI
Test Specimens at
Established Required TTF
±10%: 2350 to 2880 ºC·HR
Strength-Maturity Relationship:
y = 885.96Ln(x) - 3371.45
R2 = 0.99
COMPRESSIVE STRENGTH (PSI)
6000
5000
4000
3000
2000
1000
0
0
2000
4000
6000
8000
10000
12000
14000
16000
MATURITY INDEX, TTF (ºC·HR)

Appendix G

2007 West Virginia Division of Highways Maturity Survey

State	Are you familiar with the concrete maturity concept (strength gain based on time and temperature)?	Do you allow the use of concrete maturity curves (equations) as a substitution for compressive strength cylinders?	If so, do you allow this substitution for early break cylinders (field cured specimens for form removal, etc.), 28-day acceptance cylinders (standard cured cylinders), or both?	If you allow the use of the maturity concept as a substitution for cylinders, do you still require that some cylinders be fabricated and tested during the course of construction to verify the accuracy of the maturity curve? If so, how often do you require cylinders to be tested in order to verify the curve?	If you permit the use of the maturity concept, would you please attach a copy of, or a link to, your specifications regarding its use?
Alabama	Yes	Yes	Early break cylinders only (form removal, early opening to traffic, etc.)	Verification cylinders are required to verify the strength estimated by the maturity method. Perform compression testing on a set of cylinders (3 cylinders tested at the same age) when the maturity of the cylinder is more than 90% of the required maturity, or when the maturity of the structure is more than 90% of the required maturity, whichever occurs first.	Our maturity procedure is in the final review process. I am attaching a draft copy for your reference.
Arizona	Yes. I have used the technology in two projects. The first was at Little Colorado River Bridge on I-40 (around 2001 / 2002). We utilized the maturity meter to check if the bridge deck that was replaced was ready for opening to the traffic. The other time it was at Super Red Tan Interchange Phase II (2005), where it was with a different brand name called 'IntelliRock'. We were trying to use it for checking if the Reinforced Concrete Box Culvert, where a traveler forming system was used was ready for partially removing the forms.	We have tried maturity meter use on a couple projects but as a general statement we do not allow it. I do not think we allowed the maturity meter as a complete substitution for the compressive strength of the cylinders. I do not think we have that level of confidence yet on the maturity meters. On I-40, ADOT used the maturity meter for its own information (the contractor was not involved) to make decision on the opening of the deck to the traffic. Whereas on Super Red Tan, the contractor and ADOT both prepared the correlation curves for the IntelliRock.	We tired it for both. The feedback from the projects was that sometimes it seemed to be correlating well with actual compressive strengths and other times not so well. I do not think we allowed the maturity meter as a complete substitution for the compressive strength of the cylinders. I do not think we have that level of confidence yet on the maturity meters. On I-40, ADOT used the maturity meter for its own information (the contractor was not involved) to make decision on the opening of the deck to the traffic. Whereas on Super Red Tan, the contractor and ADOT both prepared the correlation curves for the IntelliRock.	Not that far along yet. One issue we had with the maturity meter was while using the admixtures. As I remember correctly, our mix had accelerator in the design. When breaking the cylinders, the strength from the cylinders was not matching with the value obtained from the maturity curve. I was told afterwards that mistakenly retarder was put in the mix during production instead of the accelerator, and the curve was not designed for it.	N/A
Arkansas	Yes, we are familiar with the maturity concept	No, we do not allow it as a substitution	N/A	N/A	N/A
California	Yes.	Not as a standard practice. It was used on a couple of projects (Bay Bridge, Carquinez Bridge) for form removal and early strength development determination. I understand that an ASTM method was used for these projects.	Only in a few projects and only for form removal and early strength development determination.	The use of maturity meters as substitution for compressive or flexural strength determination is always based on a correlation curve between the cylinders and/or beams and the meters. As this is not a standard practice we do not have a standard specification. We do not have a procedure for the time of testing of cylinders for the correlation.	We have attached a draft California Test Method for you. This was never approved for use.

Colorado	Yes	Yes	We do not accept maturity meter data for removing forms on structural concrete. We do allow maturity meter data to open fast track PCCP. Acceptance is still based on 28/56-day cylinder breaks. We also use maturity meter to monitor strength gain for cold weather placement & removal of curing.	No.	www.dot.state.co.us/DesignSupport/Construction/2005SpecsBook/2005Book/2005SpecBookWhole.pdf Section 412.15 (page 274) Cold weather PCCP. Section 601.13 (page 408) Cold weather for structural concrete & removal of curing.
Connecticut	Yes	No, not at his time, however the Department is in the process of developing language to allow the use of this method as an alternative to cylinders. We do not anticipate that all concrete producers or contractors will be willing to commit themselves exclusively to the maturity method.	That would come with our own experience and that of the producer and contractor.	In general, the curve will have to be well established for that producer/mix design for the method to be effective. The curve will also have to be verified on a regular basis, what that is right now, I don't know. I can see instances where the Dept. would absolutely require verification cylinders based on the application and/or the producer.	The development of a specification is in the early stages. Nothing to share at the present time.
Florida	Yes we have allowed its use with supporting data.	Yes. We do allow for opening traffic onto new pavement and for stripping forms.	We allow for stripping forms and early opening to traffic on pavement. We do not allow for acceptance of concrete. We require that cylinders be broken to determine the acceptance compressive strength.	In the acceptance letter we tell the contractor that the maturity data is only good for the specific mix used to develop the maturity data. If any component of the mix changes the maturity data is re-run to establish the new curves based on the changes made to the mix. So we do not require the contractor to make cylinders other than those used to accept the lot of concrete. This provides a good check on the mix consistency and the original approval with the maturity data.	It has been attached to this response.
Georgia	Yes	Not at this time, we are in the process of including the use of maturity for concrete pavements to determine early opening to traffic.	The use of maturity for 28 day acceptance has not been considered at this time.	Will require cylinders for QA, but have not determined the frequency.	
Idaho	Yes	Yes, for field cure.	Allowed for field cure used for form release, release to traffic, etc. If there is a minimum time requirement for curing (deck concrete) maturity does not replace that.	We currently do not have a verification requirement but we are looking at adding one to our maturity specifications. I would highly recommend including verification starting with the initial placement and following a minimum frequency	http://www.itd.idaho.gov/manuals/Online_Manuals/spec_03/index.htm pages 827, 828 and 832
Illinois	Yes.	Yes, for pavement patching and bridge deck patching.	Both.	The engineer has the option to verify the curve, but there is no set frequency.	Our specifications state "With the approval of the Engineer, concrete strength may be determined according to Illinois Modified T 325". A scan of the Illinois Modified test method is above, and the maturity concept can be used only for pavement patching and bridge deck patching.
Iowa	Yes.	We use flexural beams, but could be used for cylinders.	Early breaks. It has been used since 1997 in Iowa for opening strength or form removal.	Flexural specimens to verify curve monthly.	www.erl.dot.state.ia.us Article 2301.31 2403.19 and Materials IM 383

Kansas	Yes	No, flexural strength only	N/A	N/A	KsDOT Spec (see page 11/19, (3) (a)): www.ksdot.org/burConsMain/specprov/2007/501.pdf
Kentucky	Yes, Kentucky has used the maturity meter on a limited number of projects. We have a note posted on our Division of Construction website that covers paving concrete and we also, have a draft note for structural concrete. We have had good luck and not so good luck with this technology.	When we have used this method, we have only utilized the meter for early opening to traffic or form removal. Kentucky still required cylinders for 28 day acceptance tests.	See previous answer.	Yes, please see the following link http://transportation.ky.gov/materials/download/KYMethods/KM32202.pdf	See previous answer.
Louisiana	Yes.	We allowed on high performance pre-stressed concrete girders for one project to indicate strength development for form removal, but not as a substitution for cylinders.	We allow for contractor information only, but still require cylinders for early breaks. We are not aware of any contractor in Louisiana who is presently using the maturity meters.		
Maine	Yes (used experimentally on one project in 2007).	No	N/A	N/A	N/A---No specs at this time.
Michigan	Yes	Sort of. The current spec is for flexural strength, but I have no problems with using maturity testing for compressive strengths. We have to change the tolerances for the fingerprint validation in order to apply it to compressive strengths.	Exclusively early break (open-to-traffic, etc)	Destructive testing is required at the beginning of a project to create, or verify the accuracy of, a strength-maturity correlation. It's also required once every month, or whenever there's a change in the mix constituents or a substantial change in the weather.	Please see attached.
Minnesota	Yes	Yes, we have done it on specific projects	We don't have penalties for strength unless their is a requirement in the contract, so in most cases our 28 day cylinders are for information only. In some cases I believe people are considering maturity for removing forms. It has also been used for concrete pavement rehabilitation projects. The biggest thing it is being used for is just to monitor the temperature.	Not applicable	We are in the process of developing a specification for use of maturity.
Mississippi	Yes	Yes.	For use in lieu of field cured test cylinders.	Validation of the maturity curves shall be made every 500 cubic yards produced for each concrete mix used. Validation strength tests shall be within 10% of the predicted value determined by the maturity curve. If the 10% requirement is not met, a new maturity curve shall be developed.	

Missouri	MoDOT is familiar with the concrete maturity concept.	MoDOT does allow the use of concrete maturity curves.	For structures, MoDOT allows the maturity method to be used for determining early age strength and 28-day acceptance strength. For PCCP, the maturity method is used to determine when the pavement can be opened to traffic, when cores can be extracted and when the pavement can be exposed to freezing weather without protection. Pavement acceptance is based on cores extracted from the pavement. Compressive strength and thickness are determined from the cores. A pay factor is determined based an these test results using Percent Within Limits.	MoDOT does require that the maturity curve be verified. The maturity curve is to be verified every 7 days of production. The maturity curve is also to be verified whenever the following changes are made to the mix design or to the concrete production: Mix constitutes changed by more than 5% Water/cement ratio changed by more than 0.02 Mixing operation changed	MoDOT requirements pertaining with the use of the maturity method are outlined in Section 507 of the Standard Specifications. A link to the online specification is shown below: www.modot.mo.gov/business/standards_and_specs/Sec0507.pdf
New Hampshire	Yes	NH uses only cylinder strength testing for both early strength and 28 day acceptance. No one has proposed doing anything else at this time.	N/A	N/A	N/A
New Jersey	Yes	We would allow it to be used in some cases but no Contractor has used it to date.	We would allow it to be used for early breaks - for form removal, detensioning, early loading, etc.; but not for 28-day acceptance. We would want cylinders for the acceptance testing.	This would be established on a case by case basis.	We do not have a specification. Following is a link to our research webpage. If you select in "Maturity Method" from the keywords list and submit. There are two reports on research done for NJDOT on the maturity method. http://www.state.nj.us/transportation/refdata/research/ReportsDB.shtm
New Mexico	Yes.	Yes, if properly calibrated to the specific mix.	Yes. In fact, field cured cylinders are prohibited for use in early strength measurements for structurally significant applications. However, they are not acceptable for compliance documentation at the specified age.	Yes. Although at this time, our specifications do not include specific detail, they do require participation from the State Materials Bureau. As such, early strength corroborations are required before the maturity method can be accepted without cylinders.	Our specifications can be accessed in Section 509 of the Standard Specifications. It can be reached at our website or nmshtd.state.nm.us
North Carolina	Yes	Not for acceptance cylinders. We allow the use for early strength events such as opening item up to construction traffic, stripping forms, etc.	See previous answer.	The start and randomly after that. The department also establishes a curve, and we verify what the Contractor gets along with our results.	We have two uses. We also allow them to be used for concrete pavement. It is attached. We have a draft of it for case by case on ready mix concrete. I do not have an electronic version, so I will have to e-mail it to you.
Ohio	Yes	We haven't used it directly for cylinders but have used for flexural strength early opening of concrete pavement	We have proposed this in some of our concrete strength specifications and would support it but have yet to see a Contractor take advantage.	Yes	See attachment
Oklahoma	Yes.	Not formally, but it has happened.	When we have it was for early entry.	Yes. All 28-day cylinders and enough early cylinders to establish the curves.	We do not have a specification that I am aware of as it has only been used on a couple of projects at the contractor’s request.

Ontario	Yes	Ontario Ministry of Transportation (MTO) uses the maturity method for fast track concrete pavement repairs, for determination of compressive strength prior to opening to traffic.	Autogenous cylinder method and maturity method are used for determination of early age strength in fast track concrete repairs. MTO does not allow maturity method to replace standard 28-day compressive strength cylinder testing in fast track concrete repairs or in any other application.	For fast track concrete repairs, MTO verifies early age strength by testing cylinders cured by autogenous method. This is done prior to opening to traffic.	See attachment
South Carolina	Yes	No	N/A	N/A	N/A
South Dakota	Yes	Maturity Method does not replace the need for the 28 day cylinders. Maturity Method sometimes is used to replace one or two of the early age informational cylinders.	Early Break Cylinder only.	Yes - We check the curve calibration regularly depending on construction type and variability seen from supplier.	http://www.sddot.com/pe/materials/materials_manual_400.asp - SD 407 is the Procedure. The SDDOT has Maturity Meters and this procedure in place but does not use it very often, we have the older maturity system that isn't very user friendly. The last time it was used for maturity was about 2 years ago. I would recommend you also get a sampling of what Maturity Systems states are using. The SDDOT has Standard Scientific Inc. - Model 4101 (Humboldt Model H-2680).
Tennessee	Yes	At the present time we do not allow concrete maturity on a blanket basis. We have used it on one project as research. It was placed in that project by special provision, but cylinder breaks were the acceptance procedure.			
Texas	Yes	Yes, but with limitations. Maturity testing is only used for early opening to traffic situations and for early form removal situation. We require verification testing using actual strength specimens.	As of 2004, we no longer allow maturity for anything except early opening and form removal. It is NOT used for 28-day acceptance strength testing.	We require a verification break every time a safety sensitive operation is performed. As most form removal and early opening is safety sensitive, verification breaks are basically required for every activity. Note: the verification testing is just to confirm the validity of the maturity-strength relationship.	The use of maturity testing is referenced in Items 360, 361, 420 and 421. ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2004/standard/s360.pdf ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2004/standard/s361.pdf ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2004/standard/s420.pdf ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2004/standard/s421.pdf
Virginia	Yes.	Not for acceptance.	Virginia DOT will consider the maturity method to determine adequate concrete strength gain for form release, but does not allow concrete acceptance based upon the maturity method.	We allow the maturity method only for form release. The number of cylinders required to verify accuracy of the maturity curve is project dependent; taking into account risk.	Virginia DOT has a draft specification that uses the maturity method to allow opening concrete pavement to traffic. The draft specification is: The Contractor may use the Maturity Test Method in accordance with ASTM C1074 to confirm the development of satisfactory strength gain to open to traffic provided the maturity test results are based upon the same concrete mix design as used in the pavement as approved by the Engineer. We anticipate this specification becoming available for contracts later this year. Also, the maturity

					concept has been used with drilled shafts. It is important that concrete reached a minimum strength in a drilled shaft before work on an adjacent shaft is begun; thereby, preventing damage to the newly placed drilled shaft concrete. VDOT and Contractors like using the maturity method for this application.
Washington DC	Yes	No	N/A	N/A	N/A
Washington	Yes	Yes - for opening to traffic, typically on panel replacement projects.	Early break cylinders only	Yes - We require some cylinders to be fabricated and tested during the course of construction. We require the contractor to verify the calibration curve on days 1 and 2 of the project.	See attached. WSDOT has allowed maturity under the requirements of ASTM 1074 since the mid 1990's. Within the past 5 years we have required maturity on 4 projects. This allowed WSDOT to collect sufficient data to evaluate its use. We are currently summarizing our experience and hope to have a report out in a few months. A sample special provision from these projects is attached.
West Virginia	Yes	We are going to allow it for form removal on a current project.	This will be for form removal only. 28-day acceptance cylinders will still be required.	We will require cylinders to verify the maturity curve. Several sets of validation cylinders will be made initially until everyone agrees that the maturity curve correlates well enough to reduce the frequency down to 10%. If, during the work, the curve tends to differ from these validation cylinders, a new curve will be required.	N/A
Wisconsin	Yes	We allow use of maturity on PCC pavement and bridge projects as a substitute for concrete cylinders for job control functions such as opening to traffic or stripping formwork. We do NOT allow use of maturity as a substitute for 28-day acceptance (pay) cylinders.	See previous response.	We require that a set of verification cylinders be cast and broken once weekly during construction when the mix is in use.	See attachments. Section 415.3.17 contains maturity specs for pavement. Section 502.3.10 contains maturity specs for structures. Section 4-25-70 of the Construction & Materials Manual contains general guidance for use of maturity.
Wyoming	Yes	No	N/A	N/A	N/A