EARLY OPENING OF PORTLAND CEMENT PAVEMENT USING MATURITY

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INTRODUCTION

In 1986, the Iowa Department of Transportation constructed the first Fast Track portland cement concrete (PCC) pavement. The goal of this project was to demonstrate that concrete pavement can be opened to traffic in the time frame of hours, instead of days or weeks. Opening strength was achieved in twelve hours on this project and established Fast Track concrete pavement as a viable construction practice.

The ability to achieve opening strength in less than a day was a major breakthrough for concrete paving. But, as important as this was from the standpoint of physically being able to achieve those early strengths, another equally, if not more important aspect of this project may have been its greatest accomplishment. The old paradigm of requiring opening to be based on both a minimum age and minimum strength requirement had been broken.

Once people accept the idea that strength is really the only necessary criteria for opening pavement to traffic, the possibilities for early opening of concrete pavement become nearly endless. As this new process has developed over the past ten years, many variations of the original elements of Fast Track have come about. The many needs for early opening pavement have brought about many new and unique approaches to the construction process.

When strength becomes the only criteria for opening, how that strength is measured takes on new importance. For projects where a Fast Track mixture could achieve opening strength in six hours, a quick and easy method of determining that strength level was needed. Test specimens were often cured on site, placed on top of the pavement to best simulate pavement curing conditions. But, transporting them to a laboratory for testing caused delays and detracted from the early opening process. Better methods of measuring strength were needed.

Non-destructive testing (NDT) methods were used on a number of Fast Track projects in Iowa. After gaining experience with pulse velocity and maturity methods, its was found that for field applications involving early age concrete, the maturity method gave more consistent and acceptable results.

The use of maturity has now moved beyond Fast Track. With the old standard requirement of a minimum age and minimum strength reduced to only strength for some pavements, logic led to the realization that maturity could be used to measure the pavement strength in any pavement, whether Fast Track processes are used or not.

Iowa has specified the maturity method may be utilized to determine opening time for most primary paving projects constructed in 1997. It will be a contractor's option. The intention is to make this a standard practice beginning in 1998. The benefits of time have already been proven to be significant. Those savings translate into both a savings of money and an increase in motorist safety due to more rapid completion of the work.

This report describes the evolving use of the maturity method in Iowa.

BEAMS VS. MATURITY

One hurdle that had to be overcome with maturity was an old mindset. Most people intuitively think test beams or cylinders actually measure the concrete pavement strength but a maturity reading was somehow an approximation. A close scrutiny of both methods was needed to help alleviate the reservations that existed.

The test beam or cylinder is not the same as the actual concrete in the pavement. It does not have the mass of the pavement, the same moisture conditions as pavement, or the same temperature during the curing process as the pavement. It can be tested and a strength determined, but that is only the strength of the specimen, not the strength of the pavement. There is no easy way to know how large the difference may be.

Maturity is based on tests of concrete specimens. From those tests, a determination of the maturity of the test specimen is made. Maturity is then measured in the pavement, in situ. The strength measurement is not a test of a specimen representing the pavement, but an actual measurement of the concrete in the pavement.

Both systems, direct strength measurements using test specimens and maturity, have short-comings. But maturity offers a reliable method to continuously monitor concrete strength, on site, very easily.

EVOLUTION OF THE MATURITY METHOD

A number of research projects in Iowa utilized NDT testing as a part of the strength monitoring process. Each provided a greater understanding of the processes and limitations of each method. Four projects utilized both pulse velocity and maturity. Each are described below. The past two construction seasons have seen maturity move beyond research and into use on conventional paving projects.

1988: U.S. 20, Dubuque County, Iowa

This research was conducted to evaluate an enhanced Fast Track mixture. An enhanced Fast Track concrete mixture which achieved opening strength in six hours was the goal. Both pulse velocity and maturity were used, along with test flexural beams, to monitor strength. This work demonstrated the significant advantage of NDT for measuring strength in early opening of pavements. The Federal Highway Administration (FHWA) included this project as a part of Demonstration Project No. 75 and performed the NDT testing.(*1*)

1989: Iowa 100, Collins Road, Cedar Rapids, Iowa

This project involved reconstructing 3 km (1.8 mi.) of the westbound lanes of an urban arterial street. The entire project was specified to use Fast Track concrete and the intersections only could be closed for reconstruction from 6 P.M. until 6 A.M. Again, the FHWA assisted the Iowa DOT in testing for strength using NDT, although flexural beams were used for project control.(*2*)

1994: Iowa 3, West of Hampton, Iowa

Maturity and pulse velocity were used to determine bonded concrete overlay strength and traffic opening times. With opening time targets of 6-8 hours and single lane paving requirements, maturity was used to indicate both minimum strength for the initiation of joint sawing and traffic control needs. Maturity measurements identified critical curing relationships between slab, air, and concrete temperatures.(*3*)

1995: Great River Road, Lee County, Iowa

This project required a 48 hour access to homes along the road by cars for 150 residents abutting an 11 km (7 mi.) project. A full depth 175 mm x 6.7 m (7 in. x 22 ft.) pavement was placed and strength monitored by maturity means. Using conventional concrete, a minimum strength for car traffic of 2.41 MPa MOR (350 psi, center point loading) was achieved in 18-20 hours after paving.(*4*) Local traffic was then allowed to use the center portion of the pavement for access. Maturity measurements in the slab and paved shoulders reduced construction time by 1-2 weeks and allowed for safe shoulder construction prior to inclement winter weather.

1995: Field Trials

Experience with the maturity method of monitoring strength gain in the field was needed to establish its applicability to normal construction projects. In 1995, fourteen projects were selected and maturity data collected. They represented a range of project types: primary highway paving, county highway paving, and patching. They utilized three different Iowa standard concrete mixtures and maturity-strength curves from three of those project are shown in Figures 1, 2, and 3.

Figure 1 represents a primary highway mixture (C-3WR-C20) containing, per cubic meter, 321 kg of cement, 68 kg of fly ash, aggregate at a 55% coarse/45% sand ratio, and a standard water reducer. Figure 2 is from a county paving project using a typical county mixture (B-5-C10 containing, per cubic meter, 241 kg of cement, 60 kg of fly ash, and aggregate at a 45% coarse/55% sand ratio. The third concrete mixture (M-4 with calcium chloride) is shown in Figure 3 and is used for patching. It contains, per cubic meter, 490 kg of cement, aggregate at a 50% coarse/50% sand ratio, and 13.6 L of calcium chloride at a 32% solution as an accelerator. All modulus of rupture (MOR) values are based on flexural tests using center point loading.

The small number of projects using the same standard mixture did not allow for a reasonable correlation between projects. After the 1997 work is completed, enough project results may be available to evaluate similarities and establish trends corresponding to strength gain and maturity values as they relate to such variables as weather conditions and slab thickness.

The results of these 14 projects were very positive and from them field techniques were developed and tested. Ouyang reported the results of these tests.(*5*) Most of those results have been incorporated into current procedures and are described latter in this report.

1996: Designated Maturity Projects

With the success of the work performed with maturity in 1995, six projects were selected for the 1996 construction season. These were let specifying maturity as the basis for opening to traffic. The Iowa Department of Transportation performed the testing. The results were very positive.

On two of the projects, opening strength was achieved in approximately 18 hours during hot, summer weather. These projects were conventional paving projects, with no Fast Track aspects. One was an interstate reconstruction where minimizing construction time is very important. The other was an urban highway reconstruction involving significant staging. The early opening greatly expedited each stage. Other projects and weather conditions found opening to traffic strength, that is, 3.45 MPa MOR (500 psi, center point loading), was achieved in about a day and a half to two days, 30 to 50 hours was common.

1997: First Projects Constructed

The spring weather in Iowa in May of this year was very cool. Daily high temperatures were barely above 15 °C. Therefore when construction began, aggregates were cool, the ambient air temperature was cool, and the cement was cool. It is likely that these conditions would result in concrete pavement strength gain being as slow as would normally be encountered throughout the year. The pavement open strength was reached in about three days on one of the first projects constructed.

MATURITY PROCESS

The maturity method for determining concrete strength is not complicated. It is based on the premise that every concrete mixture has unique characteristics, that the hydration process can be measured in terms of temperature, and a correlation can be established between the heat generated by the cementitious material and the strength of the concrete. The hydration process can vary over different time periods depending on temperature. Therefore, the amount of heat generated over a certain time period directly relates to concrete strength.

The use of the maturity process can be thought of as involving three steps. First, a maturity curve must be developed which relates the time-temperature measurement to strength. With that curve, time-temperature measurements of the pavement slab can be converted to strength values. Finally, a validation of the curve may be performed for projects lasting several months. The maturity procedure is described in ASTM C1074.(*6*) Even though Fast Track spurred the interest in this process, it is certainly applicable to any pavement. Each of the three steps is described in more detail below.

Step 1: Development of the Maturity Curve

The maturity curve is the basis for this process. The general procedure involves a number of beams or cylinders being cast and cured. A temperature measuring sensor is placed in at least one specimen and the temperature is recorded, either at certain intervals or continuously, over the period of the testing. At various ages, a certain number of specimens are tested to determine strength. At those same ages, a maturity value is determined. The maturity value is the integral product of the temperature plus the datum temperature multiplied by the elapsed time in hours. The maturity values can be determined from individual readings using a formula or a maturity meter can be used which will give the value directly. The maturity values are then plotted against the strength values and a curve is fitted through the resulting points.

The following describes the procedure the Iowa Department of Transportation has developed and will be using in 1997. The process continues to evolve and may be modified as more experience is gained during this coming construction season.

The Equipment Required

The process is relatively simple and except for a maturity meter, only a small amount of commonly available equipment is needed.

1. Beam molds. If the strength desired is compressive or split tensile, cylinders can be cast. Any method of measuring strength can be used with maturity testing. The specifying agency's strength specification will determine the type of strength tested, as well as the test methods required.
2. Maturity meter/thermometer. A maturity meter is recommended for use in the development of the maturity curve. This provides a continuous monitor of the temperature and also computes the maturity value. A thermometer is recommended for use in the field to monitor the pavement. It can then be attached to the thermocouple wires, a reading taken and recorded, and then re-attached to the wire at the next measurement site.
3. Thermocouple wire. The thermocouple wire is used to measure the temperature. It is inserted into the test beam in the initial curve development step and later thermocouple wire is used for pavement slab measurements. Numerous locations along the roadway may be monitored as the construction progresses.
4. Testing Machine. A testing device to test the strength of the beams (or cylinders), as per agency standards.
5. Computer/calculator. A computation of the maturity value will be needed when a thermometer is used. A spreadsheet program to develop a smooth curve for the strength-maturity relationship is very helpful. But, this curve can be developed by simply graphing the points and determining a best fit curve.

Where To Develop The Curve

The curve can be developed in a laboratory, using project materials, prior to construction. This allows the curve to be ready for use when construction begins. Unfortunately, it requires some work to gather project materials and transport them to a lab. It also will result in concrete made in small quantities, under lab conditions. There could be some concern as to how closely this will match actual project produced concrete.

The approach Iowa has adopted is to make the test specimens, that is, flexural beams, during the first day of production. This eliminates lab work ahead of time. This procedure results in field produced concrete being used for the development of the curve. As the project begins, strength is actually measured destructively, as the curve is being developed. After about 2 days, generally enough of the curve is developed so it can begin to be used.

If beams are cast on the project, they can be cured adjacent to the lab trailer by being covered with moist sand. The thermocouple wires can then be connected to a maturity meter stored in the lab trailer. This protects the maturity meter from theft and rain.

How Many Test Specimens To Cast

A statistically valid curve needs to be developed over a range of strengths that will include the opening strength. Lower strengths may be desirable if the procedure is to be used to determine the limits of the window for sawing joints. Long term strength (28 day) is normally not determined using this method. After a week's time, the temperature gain often will become negligible and for practical purposes, only time becomes a factor in developing the maturity. Maturity is the most useful in measuring strength in the first few days after paving.

For the trial work done in 1995, seventeen beams were cast. Many felt testing 17 beams was excessive and for the 1996 projects, the number was cut to nine. Two beams were tested at four ages, with the extra one being used for instrumentation.

After statistically analyzing the results of one project constructed in 1996, it was found that the 95% confidence interval resulted in the possibility that actual strength could vary as much as 1.38 MPa (200 psi) above or below the 3.45 MPa (500 psi) specified for opening. One other mixture varied 0.73 MPa (106 psi), but normally the variation was near 0.41 MPa (60 psi).

It was decided that the large standard deviations were not desirable so the number of beams has been increased to twelve for 1997. This will allow three beams to be tested at four ages. One of the test beams will be instrumented as described below, but will also be tested for strength.

Where The Probes Are Placed In The Test Specimen

Two probes are placed in the beam that is being instrumented, one near each end. The end of the probe should be approximately an equal distance from each side, top, and bottom, and the same distance in from the end of the beam. Two probes in the instrumented beam are used as a redundancy. It has happened that someone inadvertently tripped on the wire and pulled it out. Two probes allow for averaging the readings as well as a back-up reading. Since opening strength requirements in Iowa are based on flexural strength, only a specific procedure for flexural beams has been established at this time.

When The Strength Tests Should Be Performed

The age of the concrete for the first test is not easy to estimate. Different concrete mixtures will gain strength at different rates. Weather conditions can change the rate of strength gain for a given mixture. Ensuring that the first test is well below the opening strength is important. The remaining three tests (average of three beam tests for each test) should be spaced at somewhat regular maturity value intervals so the four tests define as smooth a curve as practical. The first test, in some cases, can be performed after four hours, depending on the mixture and conditions. Normally the first test should be performed before leaving the project the evening the specimens are cast. It is advisable to cast the beams in the morning. The last set of beams normally will be tested at approximately 48 hours of age during summer weather conditions.

Developing The Maturity Curve

The average of the three beam (cylinder) tests at four ages can be used in the development of the maturity curve. These flexural (compressive) strength values are then plotted against the maturity values determined at those ages when the specimens were tested. A simple regression equation was developed to determine the curve based on each beam test and to calculate the maturity number which corresponds to the required project opening strength.
Figure 4 is an example of the output of a spreadsheet program developed to perform these calculations. The maturity number at the opening strength is actually all that's needed for the field application of this process.

Step 2: Concrete Pavement Temperature Measurements

The field procedure needed to measure strength in the concrete slab is not difficult. A probe, i.e. the end of the thermocouple wire, is placed into the slab at approximately mid-depth. This removed as much effect as possible from the edge condition but still is close enough to the edge for a worker to reach out and place the probe. Iowa has chosen to place the probe 0.5 m (1.6 ft.) from the edge of the pavement. The insertion of the probe can be accomplished by

attaching the wire to a small wooden dowel and inserting the dowel in the pavement. Once testing is completed, the dowel can be broken off flush with the surface. Probes can be placed at any location or depth where a strength determination is desired. Iowa has called for a minimum of two locations for each day's paving. This provides for a back-up in case one probe becomes inoperative.

The temperature measurement can be taken as often as practical. Taking these measurements once at the beginning of the day and once at the end of the day seems sufficient for conventional paving. For Fast Track paving, a maturity meter may be advisable although frequent readings with the thermometer can provide adequate monitoring.

Step 3: Validation

Even though concrete mixtures are made from the same materials, they can change over time without being obvious. Some have felt that a method to validate the maturity curve is needed for projects that last many weeks or even months. Therefore, the work for 1997 will include a requirement for validation of the curve once per month. This will be done by casting three beams and then testing them at the maturity level which corresponds to the opening strength. If the average of three tests are within 0.34 MPa (50 psi), the test will be considered as validating the curve. If the average is not within these limits, a new curve must be developed. Again, because pavement opening strength is based on flexural strength requirements, limits for compression have not been established. Figure 5 is an example of the output of a spread sheet program used to record these tests.

Another change that can take place is that of temperature if the project spans both a cooler or cold season as well as the hot summer. Research by Ouyang (*7*) suggests that changes in temperature from 44 °C to 22.8 °C (40 °F to 73 °F) do not significantly affect the validity of the maturity curve for a given concrete mixture.

EXPERIENCE GAINED

The use of maturity as an NDT method has given insight not only into the rate of strength gain for concrete pavement but how it can be used, numerous variables that affect the process, and the advantages it offers. A few of the insights gained and questions which still remain are listed below:

- Transverse Joint Sawing
  The maturity method can be used to determine the limits of the window for joint sawing. This has not as yet been done definitively in Iowa.
- Mixture Materials
  All mixtures can be tested with maturity measures to determine opening times. Each mixture is unique and requires a unique maturity curve. The limits of how much change in materials or proportions can be made to the mixture before a new curve is needed has not been definitely defined.
- Traffic requirements
  The maturity method will monitor strength gain but concrete mixtures and curing methods must be used to affect the rate of strength gain.
- Location of probes
  The number of probes and their location within a day's paving may vary depending on the use of the information and the variables that may affect strength gain in different locations of the day's run.
- Field vs. Lab Curve Development
  Tests have shown that maturity curves developed on the project site are not dissimilar to curves developed in the lab. Development in the field is easier because materials don't have to be gathered prior to construction and has the advantage of being the same concrete produced for the pavement construction.
- Pavement Age at Time of Opening
  The 1996 and early 1997 work would indicate that weather conditions are the greatest factor affecting opening strength of conventional pavement. The same standard mixture reached opening strength in three days under cool, early spring conditions and approximately 18 hours under hot, summer conditions. Pavement thickness and other factors have very little effect compared to ambient temperature.
- Reduced Construction Time
  The maturity can be used very effectively to reduce total construction time by advancing all operations after concrete placement.

CONCLUSION

The maturity process was first used in Iowa almost ten years ago. Through research and field applications, it is now being applied to most major paving projects. The maturity process consists of three steps: development of the maturity curve, concrete pavement temperature measurements, and validation. Details of the practical application of this process to measuring the strength of concrete pavement have been gained through experience of research and actual project use.

Maturity can be applied to all PCC paving applications (maintenance patching, pavements, and overlays) to reduce construction time and traffic delays. It serves a major purpose in improving public relations during construction. The public's needs are met through enhanced NDT methods.

Maturity relationships aid engineers in understanding pavement strength development through project specific measures under field conditions. It moves concrete construction into a new era.

FIGURE CAPTIONS

1. Maturity-Strength Relationship: Jasper County, IM-80-5(184)160--13-50, Mix C-3WR-C26
2. Maturity-Strength Relationship: Monona County, FM-67(25)--55-67, Mix B-5-C10
3. Maturity-Strength Relationship: Greene County, FM-37(22)--55-37, Mix M-4 with Calcium Chloride
4. Typical Maturity Curve Calculation Documentation
5. Typical Validation Calculation Documentation

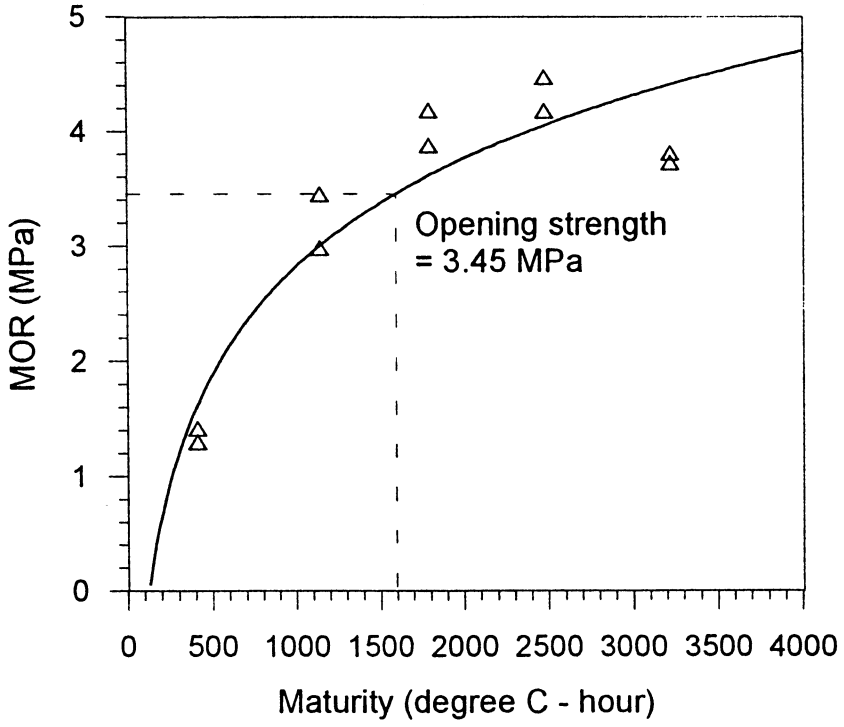


Fig. 1 Maturity-strength relationship: Jasper County, IM-80-5(184)160--13-50, Mix C-3WR-C26.

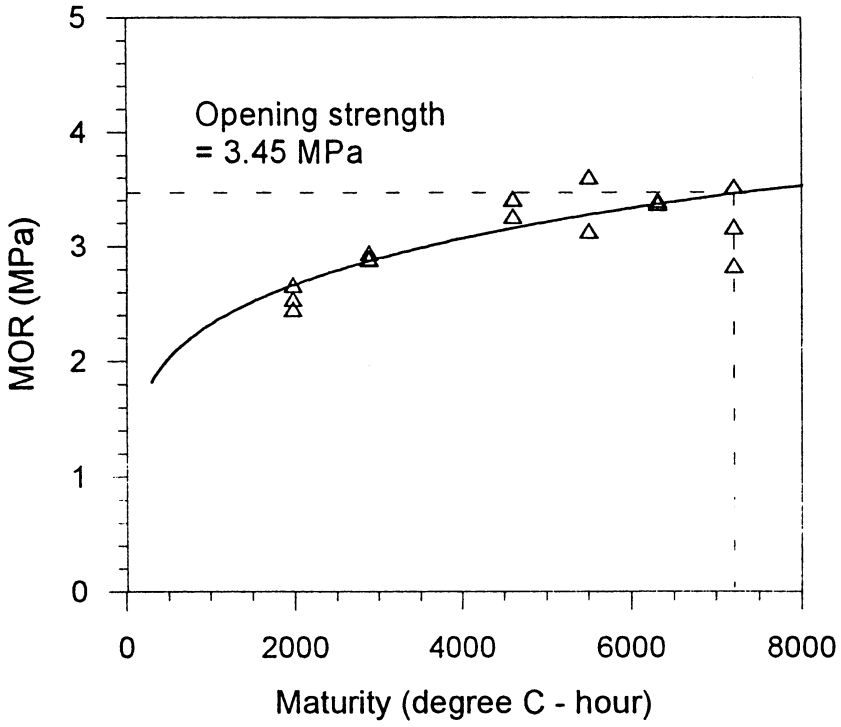


Fig. 2 Maturity-strength relationship: Monona County, FM-67(25)--55-67, Mix B-5-C10

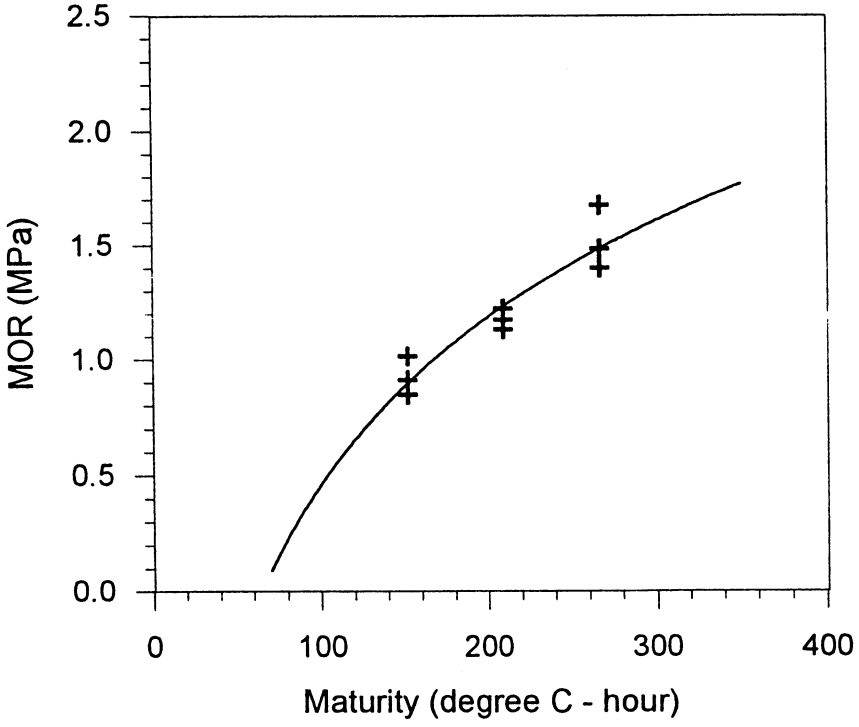


Fig. 3 Maturity-strength relationship: Greene County, FM-37(22)--55-37, Mix M-4 with calcium chloride.

MATURITY - STRENGTH DEVELOPMENT

CURVE #: 1
PROJ. #: NHS-500-1(6)--19-77

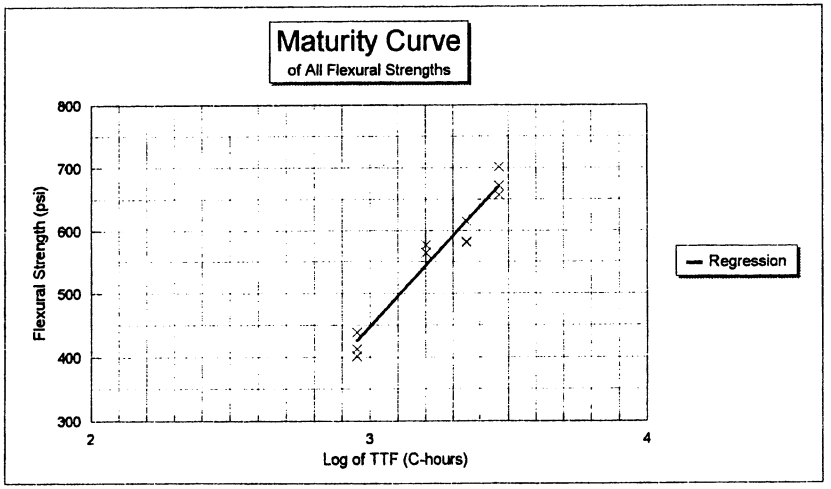
MONITOR: Mike Jenkins
REP/CONTRACTOR: GNA, Altoona Larry Wishon

INSPECTOR:
DATE: May 12, 1997

BEAM #	INDICATED LOAD (lbs)	ACTUAL LOAD (lbs)	BREAK LOCATION (in)	DEPTH (in)	WIDTH (in)	FLEXURAL COEFFICIENT	FLEXURAL STRENGTH (psi)	AGE AT BREAK (hours)	TTF CH 1	TTF CH 2	AVERAGE TTF
	Enter	*Enter*	*Enter*	*Enter*	*Enter*			*Enter*	*Enter*	*Enter*	
1	3100	3300	1/4	5.98	6.04	0.125004	413	24	921	877	899
2	3000	3210	1/2	5.98	6.04	0.125004	401	24	921	877	899
3	3400	3580	1/4	6.02	6.08	0.122537	439	24	921	877	899
4	4400	4530	1/2	6.00	6.02	0.124585	564	48	1635	1554	1595
5	4400	4530	3/4	6.00	6.02	0.124585	564	48	1635	1554	1595
6	4500	4630	1	6.00	6.02	0.124585	577	48	1635	1554	1595
7	4600	4720	0	6.00	6.08	0.123355	582	74	2306	2177	2242
8	4800	4920	1/2	6.00	6.00	0.125000	615	74	2306	2177	2242
9	4500	4630	3/4	5.96	6.06	0.125429	581	74	2306	2177	2242
10	5500	5610	1/2	6.00	6.00	0.125000	701	101	3011	2842	2927
11	5200	5310	1/2	6.02	6.02	0.123758	657	101	3011	2842	2927
12	5300	5410	3/4	6.02	6.00	0.124171	672	101	3011	2842	2927

MIX INFORMATION	*Enter*
AIR:	7.3 %
SLUMP:	2 3/4
W/C:	0.376
INITIAL TEMPERATURE OF BEAMS:	22 C
MIX NUMBER:	C-4WR-C20
FLY ASH SOURCE:	Pleasant Prairie
CEMENT SOURCE:	Lafarge
COARSE AGGREGATE SOURCE:	Martin Marietta, A85006
FINE AGGREGATE SOURCE:	Hallet Materials, A77504
WATER REDUCER BRAND:	Master Pave
ADD. RATE:	11 oz / yd^3
AIR ADMIXTURE BRAND:	MBAE 90
ADD. RATE:	4 oz/ yd^3
METHOD OF DEVELOPMENT:	Maturity Meter
Required Flexural Strength (MOR):	500 psi

REQUIRED TTF: **1289**



Certified Maturity Contractor Representative - _____
Signature

Maturity Curve Reviewed - _____
T.C. Materials Engineer

Comments:

cc: RCE, TCME, Central Materials, Pavement Materials Engineer, Contractor

Fig. 4 Typical Maturity Curve Calculation Documentation

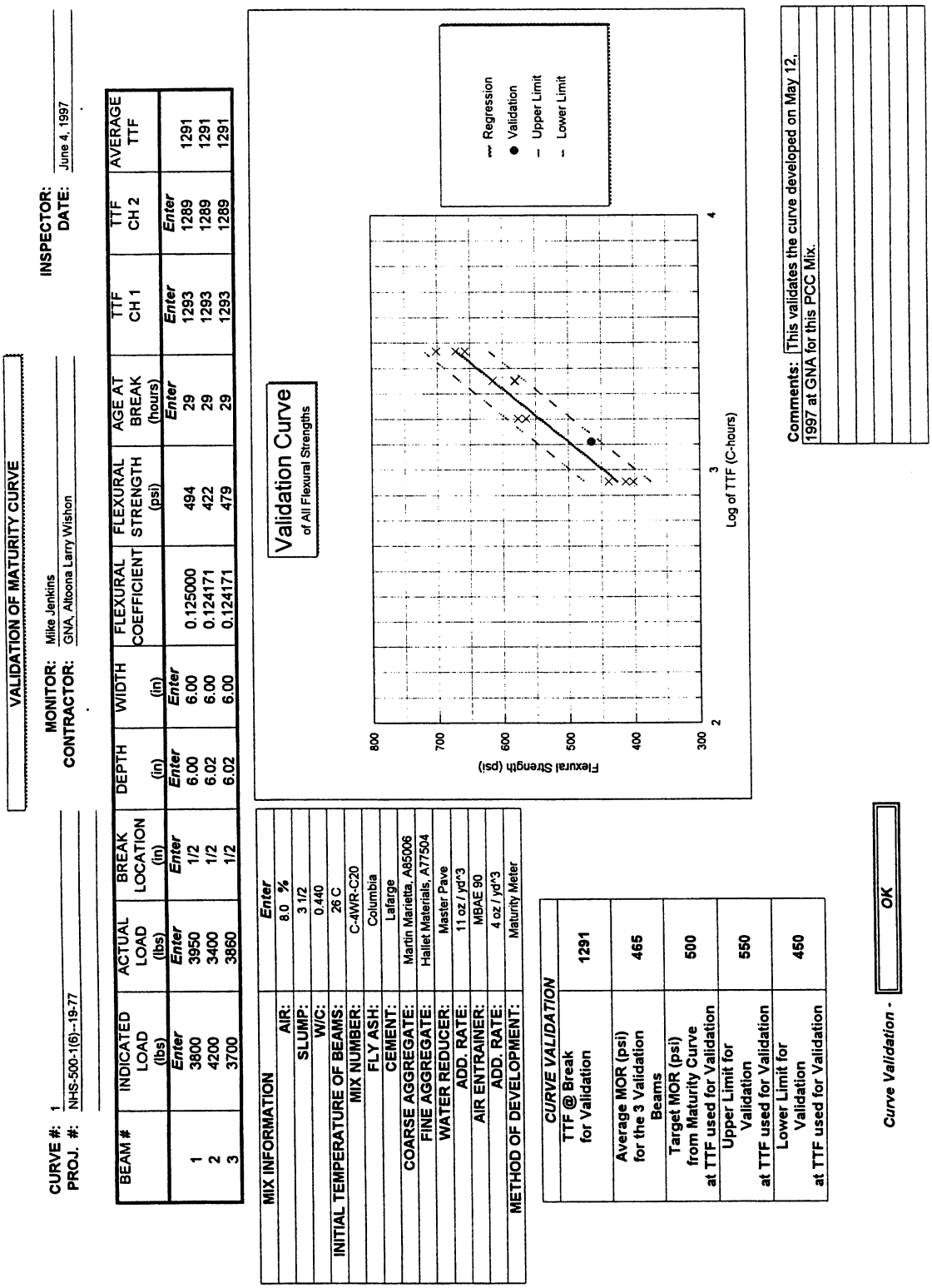


Fig. 5 Typical Valication Calculation Documentation

REFERENCES

1. *Early Strength Gain and Concrete Maturity*. Demonstration Project No. 75, Field Management of Concrete Mixes, FHWA, U.S. Department of Transportation, Washington, D.C., 1988.

2. Grove, J. D., K. B. Jones, Bharil, K. S., Agdulshafi, A., and Calderwood, W. Fast Track and Fast Track II. Cedar Rapids, Iowa. *Transportation Research Record* 1282, TRB, National Research Council, Washington, D.C., 1990.

3. Cable, J. K. *Bond Development in Concrete Overlays*. HR-561. Iowa Highway Research Board, Iowa Department of Transportation, 1995.

4. Cable, J. K. *Evaluation of Maturity and Pulse Velocity Measurements for PCC Traffic Opening Decisions*. HR-380. Iowa Highway Research Board, Iowa Department of Transportation, 1997.

5. Ouyang, C. *Maturity of Concrete: Field Implementation*. MLR-96-1. Iowa Department of Transportation, 1996.

6. American Society for Testing Materials (ASTM). Standard C 1074, Vol 4.02, 1996, Page 529.

7. Ouyang, C. *Strength Development of Concrete Based on Maturity and Pulse Velocity*. MLR-95-3. Iowa Department of Transportation, 1995.