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Table of Contents:

Introduction	4
About intelliRock	4
Most Innovative Product in the General Construction Equipment category at the World of Concrete 2003.	4
An Overview of the Concrete Maturity Method	5
Brief History of the Maturity Method	5
Concrete Maturity -- A Proven Technology For Estimating In-situ Strength of Concrete	5
Benefits of Using the Maturity Method	6
Concrete Maturity Method	8
Generating the Calibration Curve	8
Applying the Maturity Method in the Field with intelliRock	8
Early Age Strength of Concrete: A Comparison of Several Nondestructive Test Methods	9
State of Tennessee Department of Transportation Study	11
Maturity Specifications	13
Letter from the International Code Council	13
ASTM C 1074 – 98	14
ACI Committee 318-02, Chapter 6 par. 6.2: Building Code Requirements for Structural Concrete	25
ACI Nondestructive Committee 228, par. 2.7	27
ACI Cold Weather - Committee 306, par. 6.4	29
OSHA 1926.752 and 1926.703	32
FHWA –SA - 97-105	32
Guide for Implementing Concrete Maturity with <i>intelliRock</i>	33
Quick Reference: Implementing Concrete Maturity using intelliRock	33
Quick Reference: Implementing Concrete Maturity for Early Mix or Batch Validation	34
Concrete Maturity Method Background	35
How the Method Works	35
Why use the Concrete Maturity Method	36
How to Implement the Concrete Maturity Method	37
<i>intelliRock</i> Overview	41
Product Description	41
intelliRock I Logger Specifications	42
intelliRock II Logger Specifications	43
intelliRock System Benefits	44
Who Uses intelliRock	45
How To Use intelliRock	45
Operating Instructions for <i>intelliRock</i> I	46
About the intelliRock Maturity Meter	46
Selecting a logger	46
Starting a Logger	47
Display Current and Historical Readings	47
Stopping a Logger	48
Saving Data onto the Reader for Transfer to Computer	48
Erasing the Reader's Saved Data	48

Transferring Saved Loggers from Reader to Computer (PC)	48
Installing the IntelliRock Software	49
Frequently Asked Questions About IntelliRock I	50
Operating Instructions for IntelliRock II	51
Reader Overview	51
Reader Configuration	52
Entering alpha-numeric text using the IntelliRock II keypad	52
Setting the Time & Date	53
Setting Temperature Units	53
Adjusting the Display Contrast	53
Erasing Reader Data	53
Basic Logger Operations	53
Starting a logger	53
Reading data from the logger	54
Advanced Logger/Reader Operation	54
Adding Notes and Events	54
Graphing Data	54
Stopping a logger	54
Viewing logger model number	54
IntelliRock II Reader PC Interface Software	55
PC Hardware & Software Requirements	55
Installation Steps	55
Installing USB Drivers for IntelliRock II Reader	55
Trouble-Shooting "Reader Not Found" Problems	55
Frequently Asked Questions About IntelliRock II	59
Customers' Quotes and Case Studies	60
IntelliRock Customer Comments	60
IntelliRock Case Studies	66
Pavers, Inc. - City of Wichita, KS Project	66
McCarthy Building Companies – 4 th Avenue Jail Project, Phoenix, AZ	68
Gilbert Central Construction (Kiewit) – Interstate 40 Bridge Reconstruction Project	71
Flintco, Inc. - OU Memorial Stadium Construction Project, Norman, OK	74
Flintco, Inc. - Courtyard by Marriott Project, Oklahoma City, OK	78
Gohmann Asphalt & Construction, Inc. - Interstate 65 Paving Project, Indiana	81
Zachry Construction Corporation – Dallas High Five Construction Project	84
LGS Joint Venture - Washington Metropolitan Area Transit Authority (WMATA), Washington D.C	88
Duit Construction Company – Interstate 30 Cold Weather Concrete Paving Project, Little Rock, Arkansas	91
IntelliRock FAQ's and Contact Information	93
IntelliRock I FAQs	93
IntelliRock II FAQs	94
Contact Information:	95

Introduction

The *intelliRock* Resource Guide was created as a reference for Engineers, Inspectors, QA/QC professionals, Materials Managers and others who create and maintain construction policies, procedures, methods and specifications. This document exists to provide background, product information, specifications and application case studies to help specify the use of the concrete maturity method on concrete construction projects.

The maturity method, an American Society for Testing and Materials standard since 1987 (ASTM C 1074), enables contractors and engineers to determine early concrete strength in a structure at any time and as many times as necessary until the required strength is achieved.

As specified in ASTM C 1074-98, to implement maturity, “a device is required to monitor and record the concrete temperature as a function of time.” The *intelliRock* concrete strength and quality measurement system serves this purpose, and information about the system is contained in the product overview section of this document. Equipped with an understanding of the *intelliRock* system and its benefits, the remaining material in this guide will help the reader exploit the system by specifying the *intelliRock* system on projects.

About *intelliRock*

intelliRock, from Engius, LLC,, is a comprehensive concrete strength and quality measurement system allows contractors to conveniently utilize the maturity method to non-destructively determine in-place concrete strength. The *intelliRock* system was awarded:

Most Innovative Product in the General Construction Equipment category at the World of Concrete 2003.

Since the introduction of *intelliRock* in 2002, 24 Departments of Transportation, 31 states, and in 5 countries have used the *intelliRock* system on projects. Some of the more notable uses of *intelliRock* include construction of a nuclear waste disposal facility by the Department of Energy, the Dallas High Five project, the Woodrow Wilson Bridge project, the Washington DC Metro extension project, and on construction at Baltimore Washington International Airport.

The *intelliRock* concrete maturity system saves time and money by enhancing:

- **Contractor’s critical path** – extends the winter construction calendar.
- **Quality Control** – early validation of batching consistency.
- **Quality Assurance** – documents early strength & temperature information for: *form stripping, shoring and reshoring, post tension, loading structures, saw cutting, picking tilt-up panels, traffic opening, harvesting pre-cast members, concrete climate control (hot or cold weather), and mass concrete gradient.*

Numerous case studies document projects ranging from high-rise, sports complexes, bridges, mainline pavement as well as patching and restoration – projects where early concrete strength or temperature profiling are critical. Some of the more notable uses of *intelliRock* include construction of a nuclear waste disposal facility by the Department of Energy, the Dallas High Five project, the Woodrow Wilson Bridge project, the Washington DC Metro extension project, and on construction at Baltimore Washington International Airport.

For more information about the *intelliRock* system, please visit:

<http://www.intelliRock.com>

An Overview of the Concrete Maturity Method

Brief History of the Maturity Method

The maturity method for measuring concrete strength has been in use for over fifty years and became an ASTM (American Society for Testing and Materials) standard in 1987 (ASTM C 1074) and an AASHTO (American Association of State Highway and Transportation Officials) provisional standard in 1995 (TP 52). The heart of the method lies in the scientific relationship between chemical reaction rates and the energy (i.e. temperature) of the molecules involved in the reaction. Almost without exception, chemical reactions proceed more quickly at elevated temperatures. The application of this law to the complex chemical reactions in concrete has been demonstrated time and again both in the laboratory and the field over the past fifty years. A tragic display of this phenomenon occurred in 1973 in Fairfax County, Virginia when a multi-story building collapsed during construction, killing fourteen and injuring 34. The National Bureau of Standards (NBS) investigated the accident at the request of the Occupational Safety and Health Administration (OSHA). NBS investigators identified a four-day-old floor slab (which had been subjected to an average ambient temperature of only 7 °C) as the most likely cause of the accident ([Carino and Lew 2001](#)). This disastrous result of the temperature-dependence of concrete strength gain and a similar accident in 1978 sparked serious examination of available methods for estimating the in-place strength of concrete during construction. As a result, the NBS identified the maturity method as a viable means for estimating the strength of concrete subjected to different curing temperatures ([Carino and Lew 2001](#)). This, in turn, led to the establishment of the world's first standard (ASTM C 1074) for estimating concrete strength via the maturity method. As a part of the Strategic Highway Research Program (SHRP) in the mid-1990s, the Federal Highway Administration (FHWA) recommended maturity as an available technology for estimating in-place concrete strength development in highway structures ([Carino and Lew 2001](#)). The FHWA now routinely demonstrates the application of the concrete maturity method to interested federal, state and local transportation personnel via their [Mobile Concrete Laboratory](#)

Concrete Maturity -- A Proven Technology For Estimating In-situ Strength of Concrete

Concrete Maturity Timeline:

1950: Nurse & Saul first described the concrete maturity concept (time- temperature factor).

1987: Concrete Maturity became an **ASTM** standard (C 1074)

1991: Center for Transportation Research at Univ. of Texas at Austin (**See: 'Early Age Strength of Concrete Research Report 1198-1F later in this section**) concluded "Of all the test methods studied, the maturity method exhibited the lowest variability and most consistent agreement with the generally-accepted standards for concrete testing. Of all the test methods evaluated, the maturity method was found to be the only one that provided reliable data comparable in variability and consistency to those obtained from standard quality control. The primary goal of this study was to evaluate the currently available concrete testing practices, which may aid in evaluating and estimating the strength of concrete in the field, particularly at early ages before the standard 28-day cylinder strength or the 7-day beam strength is available."

1994: Guidelines for Timing Contraction, Joint Sawing, and Earliest Loading for Concrete Pavements. Okamoto, P.A. et al Turner-Fairbank Highway Research Center, FHWA

- 1995: AASHTO** (American Association of State Highway and Transportation Officials) standard
- 1996:** Maturity of Concrete: Field Implementation, MLR-96-1, Iowa Department of Transportation concluded, "The use of maturity may reduce project construction time. "
- 1997: FHWA-SA-97-105** (Crawford) Federal Highway Administration recommended maturity, stating, "The maturity method is a useful, easily-implemented, accurate means of estimating in-situ concrete strength. In a time when public agencies and contractors are concerned with escalating costs and shrinking budgets, this method provides a viable means of reducing costs through testing and scheduling. Also quality assurance cost can be reduced because the number of cylinders is reduced by using the maturity concept."
- 2001:** National Institute of Standards and Testing (**NIST**), Carino, N.J. and Lew, H.S. The Maturity Method: From Theory to Application.
- 2001:** Using Concrete Maturity for QA/QC, Tikalsky, P.J. et al University Park, PA: Pennsylvania State University.
- 2003:** International Code Council (**ICC**), David A. Bowman, P.E. Manager, Standards Codes and Standards Development - letter addressed to Nomadics Construction Labs, "...therefore, any provision contained in ACI 318 that are applicable to the issue are provisions that must be considered part of the code, regardless of whether provision have been place directly into the model building code."

American Concrete Institute (ACI):

Committee 318, Para 6.2—Building Code for Requirements for Structural Concrete
Committee 228, Para 2.7—Nondestructive Committee
Committee 306, Para 6.4—Cold Weather Committee

OSHA:

January 2002: Section 1926.752 & 1926.703 – Requires ASTM standard test method for determining compressive strength. Maturity is based on ASTM C 1074.

Benefits of Using the Maturity Method

The maturity method for measuring concrete strength delivers the following benefits:

- Provides a better representation of in situ concrete strength gain than laboratory- or field-cured specimens.
- Enables any-time in situ strength measurements.
- Provides better timing for strength-dependent construction activities.
- Saves time and money compared to conventional strength-testing procedures.
- Enables in situ strength measurements at "lowest strength" locations.
- Enables in situ strength measurements at "critical stress" locations.

Concerning the representation of in situ concrete strengths, the Federal Highway Administration (**FHWA 1988**) determined that even field-cured specimens do not accurately reflect the true rate of hydration experienced by the concrete in a structure. Hossain and Wojakowski (1994) also observed significant differences in hydration rates between in situ concrete and field-cured beam specimens. These inaccuracies are then amplified when laboratory-cured rather than field-cured specimens are used to estimate in situ concrete strength. In fact, even destructive testing of specimens cored directly from the structure may not accurately represent the strength of the concrete in the structure. The American Concrete Institute (ACI) indirectly acknowledges this fact in

their well-known building code for concrete construction (ACI 318). ACI 318 recommends strength acceptance of concrete if the average of three drilled cores meets or exceeds 85% of the specified strength as long as no single core falls below 75% of the required strength. In summary, when adequate process control measures are in place for the concrete production and placement operations, maturity represents the best available method for measuring the in situ strength gain for a concrete structure.

In addition, the maturity method enables the Contractor and/or Engineer to measure strength within a structure at any time and as many times as necessary until the desired strength is achieved. Conventional strength-estimation methods require the destructive testing of cylinder, beam or core specimens and, as such, are subject to a serious "Catch-22." If all the specimens are tested too early (i.e. the measured strength is still too low), no specimens will be available to measure strength at a later time. If the specimens are tested too late (i.e. the measured strength is much higher than required), valuable construction time has been lost. This problem can be alleviated by producing extra test specimens (e.g. two or three times as many) to make sure enough specimens are available at just the right time. Casting, curing and testing extra specimens is obviously expensive and time consuming. By far, the better solution involves the use of maturity to provide any-time measurements for in situ concrete strengths.

Because the maturity method provides a better representation of the in situ strength gain for a concrete structure and can be measured at any time, better timing can be applied to construction activities that are dependent upon the concrete having attained certain minimum strength values (e.g. post-tensioning, cutting pre-stress tendons, removing formwork/false-work, backfilling, etc.). This improved timing results in maximum timesavings without sacrificing safety or quality.

Given the high cost of user delays and contract overhead, the financial savings resulting from the improved timing of construction activities is sizeable. Furthermore, additional financial savings results from the reduced number of test specimens required when maturity methods are appropriately utilized. Concerning the potential savings from the use of maturity methods, the Federal Highway Administration (Crawford 1997) states,

"The maturity method is a useful, easily implemented, accurate means of estimating *in situ* concrete strength. ... In a time when public agencies and contractors are concerned with escalating costs and shrinking budgets, this method provides a viable means of reducing costs through testing and scheduling. Also, quality assurance costs can be reduced because the number ... of test cylinders is reduced by using the maturity concept."

Given the fact that concrete subjected to higher temperatures will gain strength faster than concrete cured at lower temperatures, the concrete within a structure will gain strength at different rates in different locations depending upon the different temperature conditions within the structure. For instance, thinner sections will tend to generate and retain less internal heat than will adjacent sections containing more mass and/or less surface area. Similarly, portions of a structure (particularly pavement structures) can gain strength at different rates due to the effects of shading and/or direct sunlight. The maturity method for measuring in situ concrete strength enables the interested parties to take measurements at locations where the strength gain is likely to be slowest, providing additional assurance that no subsequent work begins until adequate strength has been gained within the entire structure.

In addition, this "pinpoint" capability of measuring strength via maturity allows the engineer to specifically target strength measurements in those locations where critical stresses are expected for the anticipated loading conditions during subsequent construction activities.

Concrete Maturity Method

The concrete maturity method is a proven strength estimation technique (ASTM C 1074) that accounts for the effects of time and temperature on the strength development of in-place structures. This method gives a continuous estimate of concrete strength during the curing period thereby greatly reducing the need for destructive testing. This information can be used to greatly accelerate the construction process, and can also be used as a very powerful quality control tool.

Applying this method involves two steps: the generation of the calibration curve that depicts the strength-maturity relationship, then the actual application of the method in the field.

Generating the Calibration Curve

The strength-maturity relationship is generated in the lab by first preparing cylindrical specimens made from the same mix-design that will be used in the field. These specimens are instrumented by *intelliRock* maturity loggers, which process the time-temperature history and report the maturity of the cylinders during the curing process. Periodically, the strength of the calibration specimens is evaluated by compression testing. Finally, a graph of maturity versus strength is generated by drawing a curve through the calibration points. This process is depicted below:



Figure 1. Maturity calibration curve creation process

Applying the Maturity Method in the Field with *intelliRock*

Before or during concrete placement, *intelliRock* loggers are inserted in the concrete structure. The loggers process the time-temperature history of the structure and report the maturity of the concrete at the point of placement of the logger. The corresponding concrete strength is then easily determined at any time from the strength-maturity relationship described above.

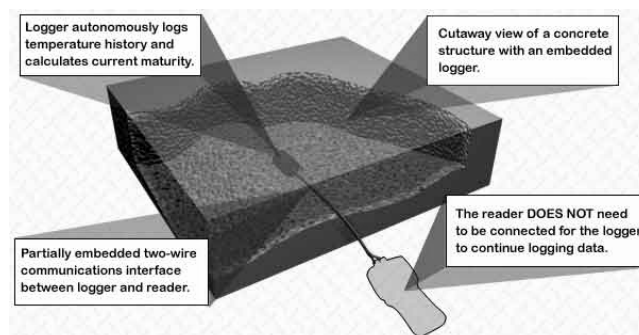


Figure 2. Placement of *intelliRock* logger in a structure

Early Age Strength of Concrete: A Comparison of Several Nondestructive Test Methods

NOTE: The following are excerpts from the document, "Early Age Strength of Concrete: A Comparison of Several Nondestructive Test Methods"

Theodore Telisak, Ramon L. Carrasquillo, and David W. Fowler

Research Report 1198-1F

Project 3-9-89/0-1198

Center for Transportation Research
Bureau of Engineering Research
The University of Texas at Austin
January 1991

Abstract:

The concrete tests currently in widespread use were developed decades ago, and although there have been continual updates and refinements; there are inherent limitations which cannot be overlooked. Most important, current test methods are often rendered unrepresentative of the concrete in the field, especially at early ages or under different curing conditions. The study described herein was conducted to evaluate the applicability and effectiveness of several nondestructive test methods for assessing concrete strength in the field.

The test methods used in this study included compressive cylinders, flexural beams, penetration resistance, rebound hammer, pullout, maturity, ultrasonic pulse velocity, and drilled cores. Test results from the different methods being evaluated were compared at concrete ages ranging from 1 to 28 days. Each test method was also evaluated for within-test variability among sets of companion specimens.

Three different concrete mix designs were used including cement plus fly ash contents ranging from 300 to 500 pounds per cubic yard, three maximum sizes of river gravels, and one maximum-size crushed limestone coarse aggregates. Specified design concrete strengths were 3,500, and 5,000-psi, resulting in measured 28-day cylinder compressive strengths ranging from 3,700 to 8,700-psi. Full-size test slabs were cast and cured outdoors under simulated field conditions during the period from August through May. Test specimens were cured both under laboratory-controlled conditions and under field conditions adjacent to the slabs.

Of all the test methods studied, the maturity method exhibited the lowest variability and most consistent agreement with the generally-accepted standards for concrete testing, including compression cylinder and flexural beams for test ages after 1 day. The maturity method can also be used to predict the strength of concrete at 1 day; however, special considerations and curve-fitting techniques can lead to the development of an accurate strength versus maturity relationship.

SUMMARY:

The primary goal of this study was to evaluate the currently available concrete testing practices, which may aid in evaluating and estimating the strength of concrete in the field, particularly at early ages before the standard 28-day cylinder strength or the 7-day beam strength is available. Special consideration was given to including both laboratory and field-cured specimens during hot and cold weather conditions.

The test methods used in this study included compressive cylinders, flexural beams, penetration resistance, rebound hammer, pullout, maturity, ultrasonic pulse velocity, and drilled cores.

Three different concrete mix designs were used including cement plus fly ash contents ranging from 300 to 500 pounds per cubic yard, three maximum sizes of river gravels, and one maximum-size crushed limestone coarse aggregates. Specified design concrete strengths were 3,500, and 5,000-psi, resulting in measured 28-day cylinder compressive strengths ranging from 3,700 to 8,700-psi. Full-size test slabs were cast and cured outdoors under simulated field conditions during the period from August through May. Test specimens were cured both under laboratory-controlled conditions and under field conditions adjacent to the slabs.

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IMPLEMENTATION STATEMENT

This report summarizes an experimental study aimed at developing sufficient information to allow highway engineers to evaluate the potential for using different nondestructive testing techniques for concrete strength determination in concrete highway construction.

Recommendations are made regarding the applicability and variability of the different testing methods considered. Implementation of the findings from this study will result in improved assessment of the quality of concrete in the field, especially at early ages. This allows for construction to proceed on an accelerated schedule and ensures that the quality of the concrete is adequately monitored.

CHAPTER 6. SUMMARY AND CONCLUSIONS

6.2 CONCLUSIONS

Based on the results from the research presented herein, the following conclusions can be drawn:

- 1.) Results from the rebound hammer were found to be the least reliable of those from all the test methods studied.
- 2.) Pullout test results were found to be significantly more variable than those from standard beam or cylinder tests. In addition, pullout tests require either preplanning when the Lok-Test is performed or a significant amount of labor at the time of testing when the CAPO test is used.
- 3.) Penetration resistance test such as the Windsor Probe provide useful information regarding the relative strength of concrete, but the test variability is considerably high, especially at early ages.
- 4.) Of all the test methods evaluated, the maturity method was found to be the only one that provided reliable data comparable in variability and consistency to those obtained from standard quality control specimens
- 5.) When the maturity method is used in conjunction with a hyperbolic curve-fitting procedure for developing the strength versus maturity curve, this method represents an excellent, reliable, and easy test procedure for evaluating the strength of concrete at early ages in the field.

State of Tennessee Department of Transportation Study

In a study commissioned by the Tennessee Department of Transportation (DOT), L.K. Crouch, Ph.D. professor of Civil Engineering at Tennessee Tech University reports that adoption of the *intelliRock* system will allow the Tennessee DOT to speed construction by allowing pavement to be opened at the optimum time (e.g. 300 PSI flexural and 1400 PSI compressive). In warmer weather this could occur within 24 hours and in cold weather with warming blankets the pavement may reach opening strength in 36 hours. The study also shows that *intelliRock* will reduce QC costs due to fewer cylinder breaks, while improving public relations and safety by reducing project time.

See the Strength versus Maturity graph from this study below.

The State of Tennessee from the study described above, including a comparison of:

- 6 X 12 field cured cores
- 6 X 12 lab cured cores
- 4 X 8 cores
- Rebound Hammer
- The *intelliRock* system

For a copy of the complete CD, contact Amy Biggerstaff at Engius, LLC.

Compressive Strength vs. Maturity for Various Curing Temperatures

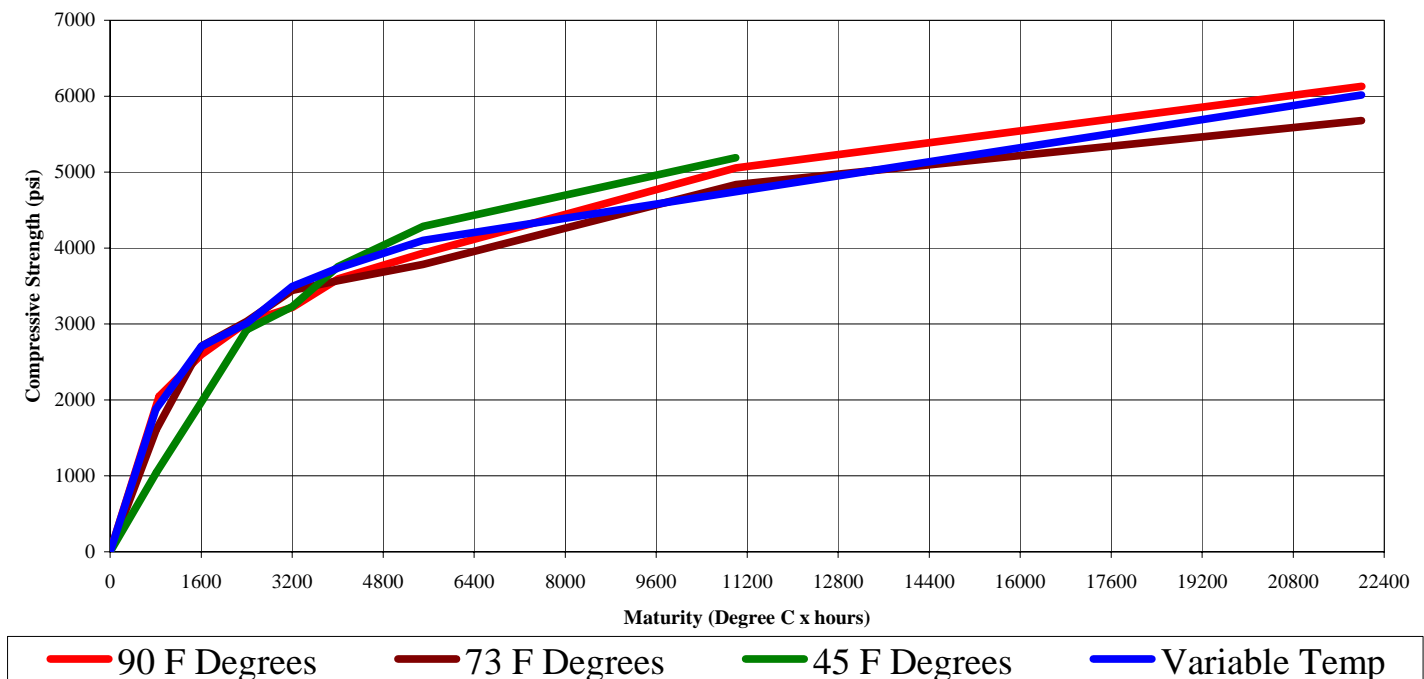


Figure 3: Slide Number 62 from the TN DOT/ Tennessee Tech. Maturity Update CD

Even though the concrete in Figure 3 was cured at different temperatures, the lines representing the strength vs. maturity relationship overlap. Once this relationship of strength vs. maturity has been characterized for a specific mix, real-time, in-place strength is easily determined simply by reading the maturity of the structure using *intelliRock*, and using a calibration curve to convert that maturity reading to a strength estimate. Details on creating a mix-specific calibration curve are presented later in this document

The graph below illustrates how strength gain varies based on different curing temperatures. Hotter specimens gain strength more quickly where as cooler specimens cure at a slower rate.

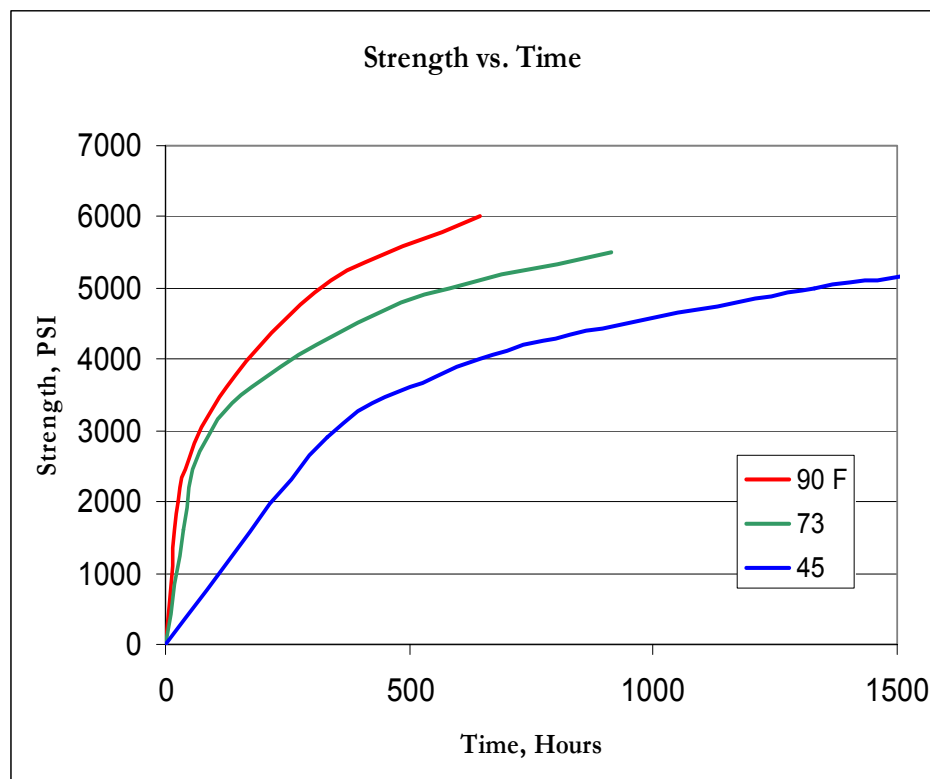


Figure 4: Graph of Concrete strength gain over time

Maturity Specifications

Letter from the International Code Council



Setting the Standard for Building Safety™

Chicago Regional Office

4051 W. Flossmoor Road ■ Country Club Hills, IL 60478-5795 U.S.A.
Tel: +1 (708) 799-2300 ■ Fax: +1 (708) 799-4981

www.iccsafe.org

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Hampton, Virginia

JIM TIDWELL
Executive Deputy Chief
Fire Department
Fort Worth, Texas

CHIEF EXECUTIVE OFFICER
JAMES LEE WITT

June 16, 2003

Mr. Richard D. Sallee
Normadics Construction Labs
1024 S. Innovation Way
Stillwater, OK 74074

Dear Mr. Sallee,

This letter is in response to your letter, dated 5 May 2003, regarding code requirements for concreting. In particular, you were concerned about the requirements for determination of adequate strength to allow removal of forms.

In your letter, you mention the "1997 UBC", which, in a later conversation, you were unclear as to what code that was, but you thought it was the Uniform Building Code for the State of Virginia. At any rate, I will give you a response based upon the *BOCA National Building Code/1996*, which is the base model code used for the State of Virginia and the *2000 International Building Code*.

Both of these codes require that the design and construction of concrete structures be in accordance with the requirements of ACI 318, *and* the provisions of the respective codes. Therefore, any provisions contained in ACI 318 that are applicable to the issue are provisions that must be considered part of the code, regardless of whether provisions have been placed directly into the model building code.

This opinion is based on the information which you have provided. We have made no independent effort to verify the accuracy of your submitted information nor have we conducted a review beyond the scope of your question. As this interpretation is only advisory, please consult with the authority having jurisdiction, the code official.

I hope this letter assists you. Please feel free to contact me if you have any further questions.

Regards,

David A. Bowman, P.E.
Manager, Standards
Codes and Standards Development

Headquarters: 5203 Leesburg Pike, Suite 600 ■ Falls Church, VA 22041-3405 U.S.A.
Tel: +1 (703) 931-4533 ■ Fax: +1 (703) 379-1546

ASTM C 1074 – 98

“Reprinted with permission, from the Annual Book of ASTM International,
100 Barr Harbor Drive, West Conshohocken, PA 19428”

Standard Practice for Estimating Concrete Strength by the Maturity Method¹

This standard is issued under the fixed designation C 1074; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (e) indicates an editorial change since the last revision or reapproval.

1. Scope

- 1.1 This practice provides a procedure for estimating concrete strength by means of the maturity method. The maturity index is expressed either in terms of the temperature-time factor or in terms of the equivalent age at a specified temperature.
- 1.2 This practice requires establishing the strength-maturity relationship of the concrete mixture in the laboratory and recording the temperature history of the concrete for which strength is to be estimated.
- 1.3 The values stated in SI units are to be regarded as the standard.
- 1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- C 39 Test Method for Compressive Strength of Cylindrical Concrete Specimens²
- C 109/C 109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)³
- C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory²
- C 403/C 403M Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance²
- C 511 Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes³
- C 684 Test Method for Making, Accelerated Curing, and Testing of Concrete Compression Test Specimens²
- C 803/C 803M Test Method for Penetration Resistance of Hardened Concrete²
- C 873 Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds²
- C 900 Test Method for Pullout Strength of Hardened Concrete²
- C 918 Test Method for Measuring Early-Age Compressive Strength and Projecting Later-Age Strength²
- C 1150 Test Method for the Break-Off Number of Concrete²

¹ This practice is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.64 on Nondestructive and In-Place Testing. Current edition approved Nov. 10, 1998. Published March 1999. Originally published as C 1074 – 87. Last previous edition C 1074 – 93e1.

² *Annual Book of ASTM Standards*, Vol 04.02.

³ *Annual Book of ASTM Standards*, Vol 04.01.

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

- 3.1.1 *datum temperature*—the temperature that is subtracted from the measured concrete temperature for calculating the temperature-time factor according to Eq 1.
- 3.1.2 *equivalent age*—the number of days or hours at a specified temperature required to produce a maturity equal to the maturity achieved by a curing period at temperatures different from the specified temperature.
- 3.1.3 *maturity*—the extent of the development of a property of a cementitious mixture.
 - 3.1.3.1 *Discussion*—While the term is used usually to describe the extent of relative strength development, it can also be applied to the evolution of other properties that are dependent on the chemical reactions that occur in a cementitious mixture. At any age, maturity is dependent on the curing history.
- 3.1.4 *maturity function*—a mathematical expression that uses the measured temperature history of a cementitious mixture during the curing period to calculate an index that is indicative of the maturity at the end of that period. Refer to Appendix X1 for additional discussion of this term.
- 3.1.5 *maturity index*—an indicator of maturity that is calculated from the temperature history of the cementitious mixture by using a maturity function.
 - 3.1.5.1 *Discussion*—The computed index is indicative of maturity provided there has been a sufficient supply of water for hydration or pozzolanic reaction of the cementitious materials during the time used in the calculation. Two widely used maturity indexes are the *temperature-time factor* and the *equivalent age*.
- 3.1.6 *maturity method*—a technique for estimating concrete strength that is based on the assumption that samples of a given concrete mixture attain equal strengths if they attain equal values of the maturity index (1, 2, 3).⁴
- 3.1.7 *strength-maturity relationship*—an empirical relationship between compressive strength and maturity index that is obtained by testing specimens whose temperature history up to the time of test has been recorded.
- 3.1.8 *temperature-time factor*—the maturity index computed according to Eq 1.

4. Summary of Practice

- 4.1 A strength-maturity relationship is developed by laboratory tests on the concrete mixture to be used.
- 4.2 The temperature history of the field concrete, for which strength is to be estimated, is recorded from the time of concrete placement to the time when the strength estimation is desired.
- 4.3 The recorded temperature history is used to calculate the maturity index of the field concrete.
- 4.4 Using the calculated maturity index and the strength-maturity relationship, the strength of the field concrete is estimated.

5. Significance and Use

- 5.1 This practice can be used to estimate the in-place strength of concrete to allow the start of critical construction activities such as: (1) removal of formwork and reshoring; (2) post-tensioning of tendons; (3) termination of cold weather protection; and (4) opening of the roadways to traffic.
- 5.2 This practice can be used to estimate strength of laboratory specimens cured under non-standard temperature conditions.
- 5.3 The major limitations of the maturity method are: (1) the concrete must be maintained in a condition that permits cement hydration; (2) the method does not take into account the effects of early-age concrete temperature on the long-term ultimate strength; and (3) the method needs to be supplemented by other indications of the potential strength of the concrete mixture.
- 5.4 The accuracy of the estimated strength depends on properly determining the maturity function for the particular concrete mixture.

6. Maturity Functions

6.1 There are two alternative functions for computing the maturity index from the measured temperature history of the concrete.

6.2 One maturity function is used to compute the *temperature-time factor* as follows:

$$M(t) = \sum (T_a - T_o) \Delta t \quad (1)$$

where:

$M(t)$ = the temperature-time factor at age t , degree-days or degree-hours,

Δt = a time interval, days or hours,

T_a = average concrete temperature during time interval, Δt , °C, and

T_o = datum temperature, °C.

6.3 The other maturity function is used to compute *equivalent age* at a specified temperature as follows **(4)**:

$$t_e = \sum \left[e^{-Q \left(\frac{1}{T_a} - \frac{1}{T_s} \right)} \cdot \Delta t \right] \quad (2)$$

where:

t_e = equivalent age at a specified temperature T_s , days or h,

Q = activation energy divided by the gas constant, K,

T_a = average temperature of concrete during time interval Δt , K,

T_s = specified temperature, K, and

Δt = time interval, days or h.

6.4 Approximate values of the datum temperature, T_o , and the activation energy divided by the gas constant, Q , are given in Appendix X1. Where maximum accuracy of strength estimation is desired, the appropriate values of T_o or Q for a specific concrete mixture can be determined according to the procedures given in Annex A1.

7. Apparatus

7.1 A device is required to monitor and record the concrete temperature as a function of time. Acceptable devices include thermocouples or thermistors connected to strip-chart recorders or digital data-loggers. The recording time interval shall be 1/2h or less for the first 48 h and 1 h or less thereafter. The temperature-recording device shall be accurate to within $\pm 1^\circ\text{C}$.

7.2 Alternative devices include commercial maturity instruments that automatically compute and display either temperature-time factor or equivalent age.

NOTE 1—Commercial maturity instruments use specific values of datum temperature or activation energy in evaluating the maturity index; thus the displayed maturity index may not be indicative of the true value for the concrete mixture being used. Refer to Appendix X1 for information on correcting the displayed values.

8. Procedure to Develop Strength-Maturity Relationship

8.1 Prepare at least 15 cylindrical specimens according to Practice C 192/C 192M. The mixture proportions and constituents of the concrete shall be similar to those of the concrete whose strength will be estimated using this practice.

8.2 Embed temperature sensors to within ± 15 mm of the centers of at least two specimens. Connect the sensors to maturity instruments or to temperature-recording devices such as data-loggers or strip-chart recorders.

⁴ The boldface numbers in parentheses refer to the list of references at the end of this practice.

NOTE 2—A method to assist in the proper positioning of the sensor is to insert a small diameter rigid rod into the center of the freshly made cylinder. The rod will push aside any interfering aggregate particles. The rod is removed and the sensor is inserted into the cylinder. The side of the cylinder mold should be tapped with a rubber mallet or the tamping rod to ensure that the concrete comes into contact with the sensor.

8.3 Moist cure the specimens in a water bath or in a moist room meeting the requirements of Specification C 511.

8.4 Perform compression tests at ages of 1, 3, 7, 14, and 28 days in accordance with Test Method C 39. Test two specimens at each age and compute the average strength. If the range of compressive strength of the two specimens exceeds 10 % of their average strength, test another cylinder and compute the average of the three tests. If a low-test result is due to an obviously defective specimen, discard the low-test result.

8.5 At each test age, record the average maturity index for the instrumented specimens.

8.5.1 If maturity instruments are used, record the average of the displayed values.

8.5.2 If temperature recorders are used, evaluate the maturity according to Eq 1 or Eq 2. Use a time interval (Δt) of 1/2 h or less for the first 48 h of the temperature record. Longer time intervals may be used for the relatively constant portion of the subsequent temperature record.

NOTE 3—Appendix X2 gives an example of how to evaluate the temperature-time factor or equivalent age from the recorded temperature history of the concrete.

8.6 On graph paper, plot the average compressive strength as a function of the average value of the maturity index. Draw a best-fit curve through the data. The resulting curve is the strength-maturity relationship to be used for estimating the strength of the concrete mixture cured under other temperature conditions. Fig. 1 is an example of a relationship between compressive strength and temperature-time factor, and Fig. 2 is an example of a relationship between compressive strength and equivalent age at 20°C.

NOTE 4—The strength-maturity relationship can also be established by using regression analysis to determine a best-fit equation to the data. Possible equations that have been found to be suitable for this purpose may be found in Ref. (3).

9. Procedure to Estimate In-Place Strength

9.1 As soon as is practicable after concrete placement, embed temperature sensors into the fresh concrete. When using this practice to allow critical construction operations to begin, install sensors at locations in the structure that are critical in terms of exposure conditions and structural requirements.

NOTE 5—In building construction, exposed portions of slabs and slab-column connections are typically critical locations. The advice of the Engineer should be sought for the critical locations in the particular structure under construction.

9.2 Connect the sensors to maturity instruments or temperature-recording devices and activate the recording devices as soon as is practicable.

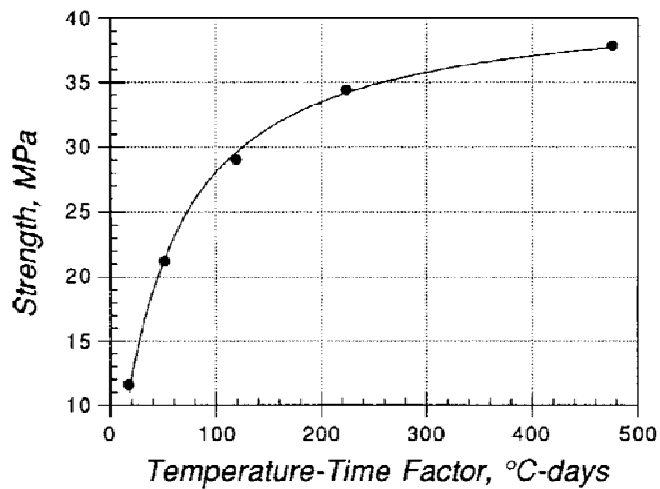


FIG. 1 Example of a Relationship Between Compressive Strength and Temperature-Time Factor

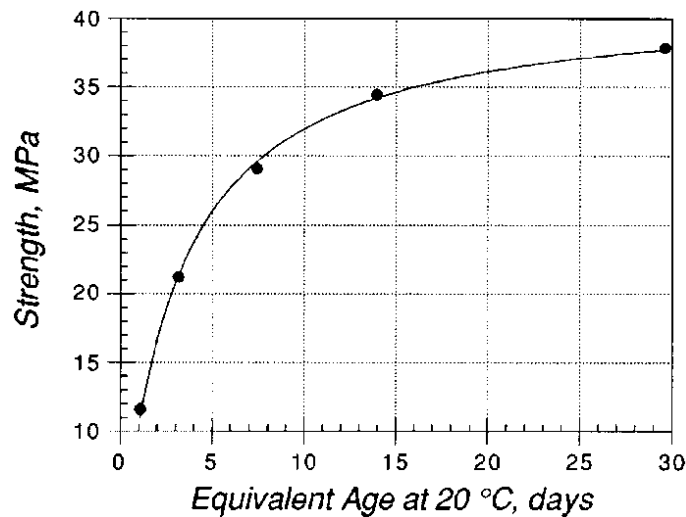


FIG. 2 Example of a Relationship Between Compressive Strength and Equivalent Age at 20°C

- 9.3 When the strength at the location of a sensor is to be estimated, read the value of the maturity index from the maturity instrument or evaluate the maturity index from the temperature record.
- 9.4 Using the strength-maturity relationship developed in Section 8, read off the value of compressive strength corresponding to the measured maturity index.
- 9.5 Prior to performing critical operations, such as formwork removal or post-tensioning, supplement determination of the concrete maturity with other tests to ensure that the concrete in the structure has a potential strength that is similar to that of the concrete used to develop the strength-maturity relationship. Appropriate techniques include:
 - 9.5.1 In-place tests that give indications of strength, such as Test Method C 803/C 803M, Test Method C 873, Test Method C 900, or Test Method C 1150.
 - 9.5.2 Early-age compressive strength tests in accordance with Test Method C 918 of standard-cured specimens molded from samples of the concrete as-delivered, or
 - 9.5.3 Compressive strength tests on specimens molded from samples of the concrete as-delivered and subjected to accelerated curing in accordance with Test Method C 684.

10. Precision and Bias

10.1 This practice is used to estimate the in-place strength of concrete based on the measured thermal history at a point in the structure and a previously established strength-maturity relationship. The accuracy of the estimated strength is dependent on several factors, such as the appropriateness of the maturity function for the specific mixture, the early-age temperature history, and the actual mixture proportions. For this reason, it is not possible to write statements about the precision and bias of the estimated strength.

11. Keywords

11.1 maturity method; nondestructive testing; strength; temperature

ANNEX

(Mandatory Information)

A1. DETERMINATION OF DATUM TEMPERATURE OR ACTIVATION ENERGY

A1.1 Procedure

A1.1.1 The testing required to experimentally determine the datum temperature or the activation energy can be performed using mortar specimens, and the results are applicable to the concrete under investigation (**5, 6, 7**). The basic approach is to establish the compressive strength versus age relationships for mortar specimens cured in water baths maintained at three different temperatures. Two baths should be at the maximum and minimum concrete temperatures expected for the in-place concrete during the period when strengths are to be estimated. The third bath temperature should be midway between the extremes. Depending on the data analysis procedure that is used, the final setting times of the mortar at the three temperatures may also have to be measured.

A1.1.2 Proportion a mortar mixture having a fine aggregate-to-cement ratio (by mass) that is the same as the coarse aggregate-to-cement ratio of the concrete mixture under investigation (**6**). The paste shall have the same water-to-cementitious materials ratio and the same amounts of admixtures that will be used in the concrete.

A1.1.3 If the strength data will be analyzed using the reciprocal plotting procedure in A1.1.7 final setting times must be measured. Prepare three mortar specimens using containers specified in Test Method C 403/C 403M. Carefully submerge each specimen into its corresponding temperature bath. Determine the time of final setting for each temperature in accordance with Test Method C 403/C 403M. The specimens are removed from the water baths and excess water is removed prior to making penetration measurements. If the data will be analyzed using the regression procedures in A1.1.8, it is not necessary to measure setting times.

A1.1.4 Prepare three sets of 50-mm mortar cubes, with 18 cubes per set. Mold the cubes in accordance with Test Method C 109/C 109M and carefully submerge each set into one of the temperature baths. For each set, remove the molds and return the specimens to their respective baths approximately 1 h before the first series of compression tests.

A1.1.5 For each set of cubes, determine the compressive strength of three cubes in accordance with Test Method C 109/C 109M at an age that is approximately twice the time of final setting. If final setting times were not measured, perform the first test when the compressive strength is approximately 4 MPa. Perform subsequent tests on three cubes from each set at ages that are approximately twice the age of the previous tests. For example, if the time of the first test was 12 h, successive compressive strength tests would be performed at 1, 2, 4, 8, 16, and 32 days.

A1.1.6 The strength versus age data obtained at the three curing temperatures are analyzed to determine the relationship between the rate constant for strength development (*K*-value) and the curing temperature. Different procedures can be used depending on the available computational tools. If the user has the capability to

perform only linear regression analysis, use the procedure in A1.1.7 or A1.1.8.2. If the user has a computer program that can perform regression analyses with a general function, use the procedure in A1.1.8.1.

A1.1.7 To use this procedure, the final setting times at the three temperatures must be known. Prepare a graph with the reciprocal of strength as the y-axis and the reciprocal of age as the x-axis. For each curing temperature, plot the reciprocal of the average cube strength along the y-axis and the reciprocal of the age beyond the time of final setting along the x-axis. An example of such a plot is shown in Fig. A1.1. Determine the slope and the intercept of the best-fitting straight line through the data for each curing temperature. For each straight-line, divide the value of the intercept by the value of the slope. These quotients are the K -values that are used to calculate the datum temperature or the activation energy.

A1.1.8 As an alternative to the procedure in A1.1.7, the K -values can be estimated by either of the following methods. In these cases, the final setting times do not have to be measured.

A1.1.8.1 If the user has access to a computer program that will permit the fitting of a general equation to a set of data, determine the K -values by fitting the following equation to the strength-age data for each curing temperature:

$$S = S_u \frac{K(t - t_0)}{1 + K(t - t_0)} \quad (\text{A1.1})$$

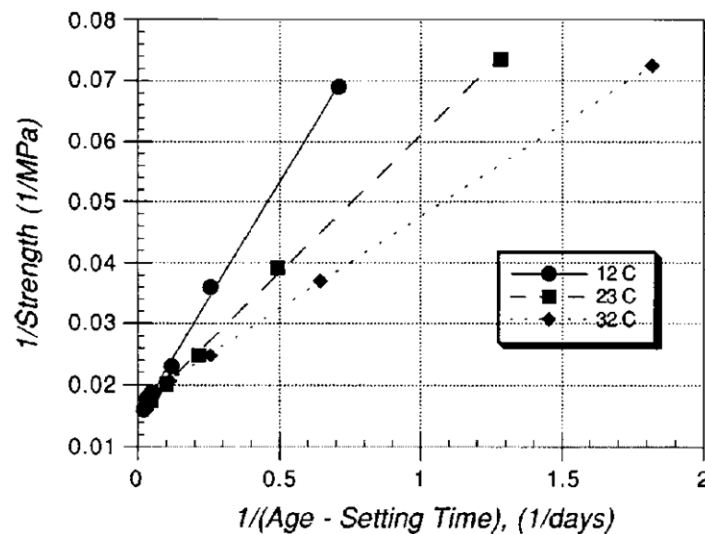


FIG. A1.1 Reciprocal of Strength Versus Reciprocal of Age Beyond Time of Final Setting

where:

S = average cube compressive strength at age t ,

T = test age,

S_u = limiting strength,

t_0 = age when strength development is assumed to begin, and

K = the rate constant.

The computer program will calculate the best-fit values of S_u , t_0 , and K .

A1.1.8.2 The K -values can also be estimated by the following method (5, 8).

- (1) Using the strength-age data for the last four test ages, plot the reciprocal of strength (y-axis) versus the reciprocal of age (x-axis). Determine the y-axis intercept. The inverse of the intercept is the limiting strength, S_u . Repeat this procedure for each curing temperature.
- (2) For each curing temperature, use the strength-age data at the four earliest test ages and the value of S_u to compute the values of A for each strength, where A is given by the following equation:

$$A = \frac{S}{S_u - S} \quad (\text{A1.2})$$

- (3) For each curing temperature, plot the values of A versus age. Determine the slopes of the best-fit straight lines for each curing temperature. These slopes are the K -values.

A1.2 Determination of Datum Temperature

- A1.2.1 Plot the K -values as a function of the water bath temperatures (Fig. A1.2). Determine the best-fitting straight line through the three points and determine the intercept of the line with the temperature axis. This intercept is the datum temperature, T_o , that is to be used in computing the temperature-time factor according to Eq 1.

A1.3 Determination of Activation Energy

- A1.3.1 Calculate the natural logarithms of the K -values, and determine the absolute temperatures (in Kelvin) of the water baths (Kelvin = Celsius + 273).
- A1.3.2 Plot the natural logarithm of the K -values as a function of the reciprocal absolute temperature (Fig. A1.3). Determine the best-fitting straight line through the three points. The negative of the slope of the line is the value of the activation energy divided by the gas constant, Q , that is to be used in computing equivalent age according to Eq 2.

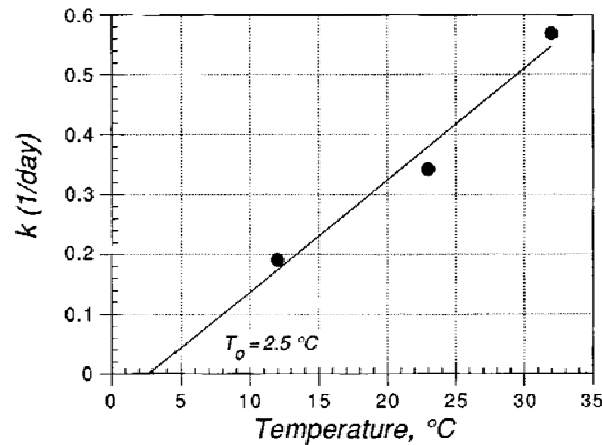


FIG. A1.2 Example of Plot of K-Values Versus Curing Temperature for Determining the Datum Temperature

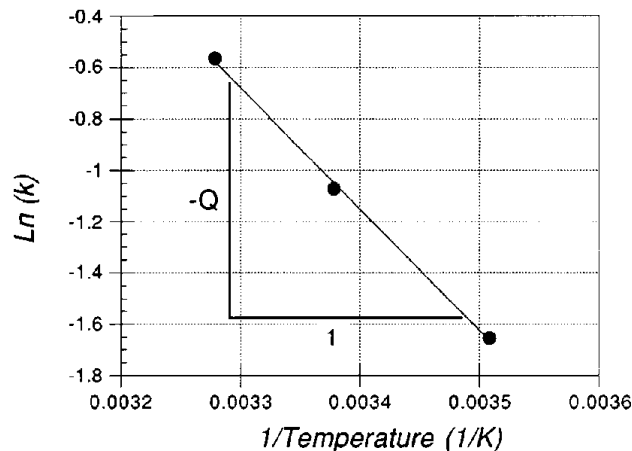


FIG. A1.3 Example of Plot of the Natural Logarithm of K-Values Versus the Inverse Absolute Temperature for Determining the Value of Q used in Calculating Equivalent Age

APPENDIXES

(Nonmandatory Information)

X1. MATURITY FUNCTIONS

X1.1 General

X1.1.1 A maturity function is a mathematical expression to account for the combined effects of time and temperature on the strength development of a cementitious mixture. The key feature of a maturity function is the representation of how temperature affects the rate of strength development. There are two widely-used approaches; one assumes that the rate of strength development is a linear function of temperature, and the other assumes that rate of strength development obeys the exponential Arrhenius equation (3, 4, 5).

X1.2 Temperature-Time Factor

X1.2.1 The assumption that the rate of strength development is a linear function of temperature leads to the maturity function given in Eq 1 that is used to compute the temperature-time factor. To compute the temperature-time factor, it is necessary to know the appropriate value of the datum temperature for the specific materials and conditions. The datum temperature may depend on the type of cement, on the type and the dosage of admixtures or other additives that affect hydration rate, and on the temperature range that the concrete will experience while hardening (5, 7). For Type I cement without admixtures and a curing temperature range from 0 to 40°C, the recommended datum temperature is 0°C (5). For other conditions and when maximum accuracy of strength estimation is desired, the appropriate datum temperature can be determined experimentally according to the procedures in Annex A1.

X1.2.2 Some types of maturity instruments that compute temperature-time factor may not employ the appropriate datum temperature, and therefore may not indicate the true value of the factor. The value of the temperature-time factor displayed by the instrument can be corrected for the datum temperature as follows:

$$M_c = M_d - (T_o - T_d)t \quad (X1.1)$$

where:

M_c = the corrected temperature-time factor, degree-days or degree-hours,

M_d = the temperature-time factor displayed by the instrument, degree-days or degree-hours,

T_o = the appropriate datum temperature for the concrete, °C,

T_d = the datum temperature incorporated into the instrument, °C, and

t = the elapsed time from when the instrument was turned on to when a reading was taken, days or h.

X1.3 Equivalent Age

X1.3.1 The assumption that the rate of strength development obeys the Arrhenius equation leads to the maturity function given in Eq 2 that is used to compute equivalent age at a specified temperature. Note that in using Eq 2, the temperature must be in Kelvin (Kelvin = Celsius + 273). To compute equivalent age it is necessary to know the activation energy for the specific materials and conditions. It has been shown that the activation energy depends on the type of cement, the type and the dosage of admixtures that affect the rate of strength development, and the water-to-cementitious materials ratio (7). In general, for Type I cement without admixtures or additions, values of activation energy in the range of 40 000 to 45 000 J/mol have been reported (6). Thus an approximate value of Q , the activation energy divided by the gas constant for use in Eq 2, is 5000 K. (The value of the gas constant is 8.31 J/(K-mol)). For other conditions and when maximum accuracy of strength estimation is desired, the appropriate value for Q can be determined experimentally according to the procedures in Annex A1.

- X1.3.2 The calculation of equivalent age also requires a specified temperature, T_s . Traditionally, a value of 20°C has been used (4), but any other convenient temperature, such as 23°C, is permissible provided that it is reported along with the value of the equivalent age.
- X1.3.3 Maturity instruments that compute equivalent age according to Eq 2, are based on specific values of activation energy. The displayed readings cannot be corrected for the appropriate activation energy value of the concrete being used. The user should recognize this limitation when the in-place concrete has an activation energy that is widely different from that incorporated into the instrument. Refer to (3) for information on the effect of the activation energy on the computed value of equivalent age.

X2. EXAMPLE MATURITY CALCULATIONS

X2.1 Temperature Record

- X2.1.1 Fig. X2.1 shows a hypothetical temperature history for concrete that will be used to illustrate the calculations of temperature-time factor and equivalent age. The temperature values at half-hour intervals are tabulated in column 2 of Table X2.1.

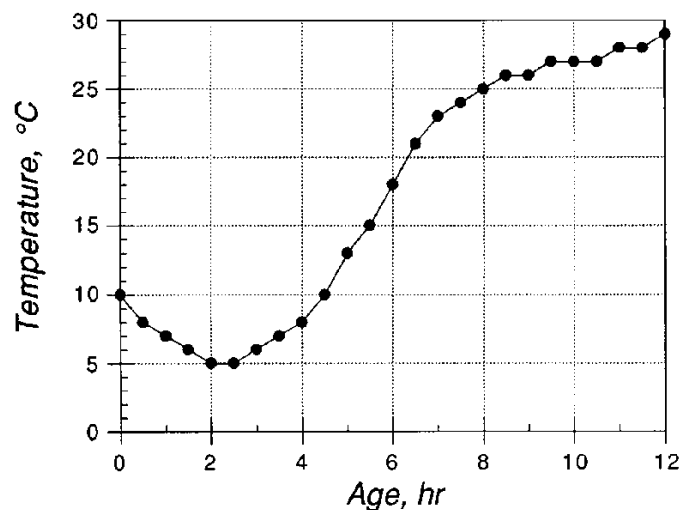


FIG. X2.1 Hypothetical Temperature History used to Illustrate Computations of Temperature-Time Factor and Equivalent Age

X2.2 Calculation of Temperature-time Factor

- X2.2.1 The value of the datum temperature, T_o , is required to compute the temperature-time factor according to Eq 1. For this example, a value of 2.5°C is assumed as indicated in Fig. A1.2.
- X2.2.2 The average temperature during each half-hour interval is computed and the results are given in column 4 of Table X2.1. The datum temperature is subtracted from the average temperature, and the difference is multiplied by the age interval, which in this example is 0.5 h. The product gives the incremental value of the temperature-time factor for that age interval. The incremental values are shown in column 5 of Table X2.1.
- X2.2.3 The summation of the incremental temperature-time factors gives the cumulative temperature-time factor at each age. For example, at an age of 12 h the temperature-time factor is 175° C-hours.

X2.3 Calculation of Equivalent Age

X2.3.1 The value of Q and the value of the specified temperature, T_s , are required to compute the equivalent age according to Eq 2. For this example, the value of Q is assumed to be 4700°K, and the specified temperature is assumed to be 20°C (293 K).

X2.3.2 Using the average temperature, in Kelvin, during each age interval, the values of the exponential function in Eq 2 are calculated. These values are given in column 7 of Table X2.1 under the heading Age Factor. The product of each of the age factors and the age interval (0.5 h) gives the incremental equivalent ages at 20°C; the incremental equivalent ages are shown in column 8 of Table X2.1.

X2.3.3 The summation of the incremental equivalent ages gives the cumulative equivalent age at 20°C (column 9 of Table X2.1). For example, at an age of 12 h the equivalent age at 20°C is 11.3 h.

Table X2.1 Example Maturity Calculations

(1) Age, h	(2) Temperature, °C	(3) Age Increment, h	(4) Average Temperature, °C	(5) Temp-Time Factor, Increment °C-h	(6) Temp-Time Factor Cumulative °C-h	(7) Age Factor	(8) Eq. Age at 20°C, Increment h	(9) Eq. Age at 20°C, Cumulative h
0	10	0	0.0
0.5	8	0.5	9	3.3	3	0.53	0.27	0.3
1.0	7	0.5	7.5	2.5	6	0.49	0.24	0.5
1.5	6	0.5	6.5	2.0	8	0.46	0.23	0.7
2.0	5	0.5	5.5	1.5	9	0.43	0.22	1.0
2.5	5	0.5	5	1.3	11	0.42	0.21	1.2
3.0	6	0.5	5.5	1.5	12	0.43	0.22	1.4
3.5	7	0.5	6.5	2.0	14	0.46	0.23	1.6
4.0	8	0.5	7.5	2.5	17	0.49	0.24	1.9
4.5	10	0.5	9	3.3	20	0.53	0.27	2.1
5.0	13	0.5	11.5	4.5	24	0.62	0.31	2.4
5.5	15	0.5	14	5.8	30	0.72	0.36	2.8
6.0	18	0.5	16.5	7.0	37	0.82	0.41	3.2
6.5	21	0.5	19.5	8.5	46	0.97	0.49	3.7
7.0	23	0.5	22	9.8	55	1.11	0.56	4.3
7.5	24	0.5	23.5	10.5	66	1.21	0.60	4.9
8.0	25	0.5	24.5	11.0	77	1.27	0.64	5.5
8.5	26	0.5	25.5	11.5	88	1.34	0.67	6.2
9.0	26	0.5	26	11.8	100	1.38	0.69	6.9
9.5	27	0.5	26.5	12.0	112	1.42	0.71	7.6
10.0	27	0.5	27	12.3	124	1.45	0.73	8.3
10.5	27	0.5	27	12.3	137	1.45	0.73	9.0
11.0	28	0.5	27.5	12.5	149	1.49	0.75	9.8
11.5	28	0.5	28	12.8	162	1.53	0.77	10.5
12.0	29	0.5	28.5	13.0	175	1.57	0.79	11.3

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ACI Committee 318-02, Chapter 6 par. 6.2: Building Code Requirements for Structural Concrete

6.2-Removal of forms, shores, and reshoring – Permission is granted to copy ACI 318R-02 Chapter 6 Paragraphs 6.2 & R6.2

6.2 – Removal of forms, shores, and reshoring

6.2.1 – Removal of forms

Forms shall be removed in such a manner as not to impair safety and serviceability of the structure. Concrete exposed by form removal shall have sufficient strength not to be damaged by removal operation.

6.2.2 – Removal of shores and reshoring

The provisions of 6.2.2.1 through 6.2.2.3 shall apply to slabs and beams except where cast on the ground

6.2.2.1 – Before starting construction, the contractor shall develop a procedure and schedule for removal of shores and installation of reshores and for calculating the loads transferred to the structure during the process.

(a.) The structural analysis and concrete strength data used in planning and implementing form removal and shoring shall be furnished by the contractor to the building official when so requested;

(b.) No construction loads shall be supported on, nor any shoring removed from, any part of the structure under construction except when that portion of the structure in combination with remaining forming and shoring system has sufficient strength to support safely its weight and loads placed thereon;

(c.) Sufficient strength shall be demonstrated by structural analysis considering proposed loads, strength of forming and shoring system, and concrete strength data. Concrete strength data shall be based on tests of field-cured cylinders or, when approved by the building official, on other procedures to evaluate concrete strength.

6.2.2.2 – No construction loads exceeding the combination of superimposed dead load plus specified live load shall be supported on any unshored portion of the structure under construction, unless analysis indicates adequate strength to support such additional loads.

6.2.2.3 – Form supports for prestressed concrete members shall not be removed until sufficient prestressing has been applied to enable prestressed members to carry their dead load and anticipated construction loads.

Commentary

R6.2 – Removal of forms, shores, and reshoring

In determining the time for removal of forms, consideration should be given to the construction loads and to the possibilities of deflections. ^{6.3} the construction loads are frequently at least as great as the specified live loads. At early ages, a structure may be adequate to support the applied loads but may deflect sufficiently to cause permanent damage.

Evaluation of concrete strength during construction may be demonstrated by field-cured test cylinders or other procedures approved by the building official such as:

- (a.) Tests of cast-in-place cylinders in accordance with “Standard Test Method for Compressive Strength of Concrete Cylinders Cast-in-Place in Cylindrical Molds” (ASTM C 873 ^{6.4}). (This method is limited to use in slabs where the depth of concrete is from 5 to 12 in.);
- (b.) Penetration resistance in accordance with “Standard Test Method for Penetration Resistance of Hardened Concrete: (ASTM C 803 ^{6.5});
- (c.) Pullout strength in accordance with “Standard Test Method for Pullout Strength of Hardened Concrete” (ASTM 900 ^{6.6});
- (d.) Maturity factor measurements and correlation in accordance with ASTM C 1074.^{6.7}

Procedures (b), (c), and (d) require sufficient data, using job materials, to demonstrate correlation of measurements on the structure with compressive strength of molded cylinders or drilled cores.

Where the structure is adequately supported on shores, the side forms of beams, girders, columns, walls, and similar vertical forms may generally be removed after 12 h of cumulative curing time, provided the side forms support no loads other than the lateral pressure of the plastic concrete. Cumulative curing time represents the sum of time intervals, not necessarily consecutive, during which the temperature of the air surrounding the concrete is above 50 F. the 12 h curing time is based on regular cements and ordinary conditions; the use of special cements or unusual conditions may require adjustment of the given limits. For example, concrete made with Type II or V (ASTM C 150 or ASTM C 595 cements, concrete containing retarding admixtures, and concrete to which ice was added during mixing (to lower the temperature of fresh concrete) may not have sufficient strength in 12 h and should be investigated before removal of formwork.

The removal of formwork for multistory construction should be a part of planned procedure considering the temporary support of the whole structure as well as that of each individual member. Such a procedure should be worked out prior to construction and should be based on a structural analysis taking into account the following items as a minimum:

- (a.) The structural system that exists at the various stages of construction and the construction loads correspond to those stages;
- (b.) The strength of the concrete at the various ages during construction;
- (c.) The influence of deformations of the structure and shoring system on the distribution of dead loads and construction loads during the various stages of construction;

(d.) The strength and spacing of shores or shoring systems used, as well as the method of shoring, bracing, shore removal, and reshoring including the minimum time intervals between the various operations;

(e.) Any other loading or condition that affects the safety or serviceability of the structure during construction.

For multistory construction, the strength of the concrete during the various stages of construction should be substantiated by field-cured test specimens or other approved methods.

ACI Nondestructive Committee 228, par. 2.7

2.7-Maturity method (ASTM C 1074) – Permission is granted to copy ACI 228.1 Section 2.7

Freshly placed concrete gains strength because of the exothermic chemical reactions between the water and cementitious materials in the mixture. Provided sufficient moisture is present, the rates of the hydration reactions are influenced by the concrete temperature; an increase in temperature causes an increase in the reaction rates. The extent of hydration and, therefore, strength at any age depends on the thermal history of the concrete.

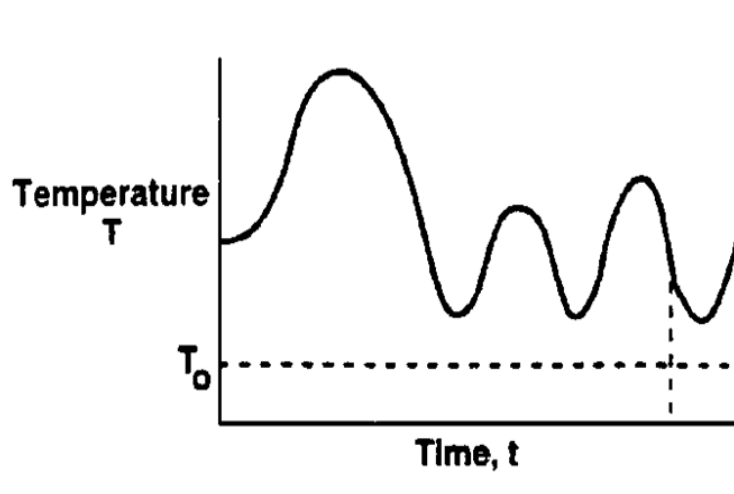


Fig. 2.10 - Maturity function based on assumption that rate of strength gain varies linearly with temperature

The maturity method is a technique to estimate in-place strength by accounting for the effects of temperature and time on strength development. The thermal history of the concrete and a *maturity function* are used to calculate a *maturity index* that quantifies the combined effects of time and temperature. The strength of a particular concrete mixture is expressed as a function of its maturity index by means of a *strength-maturity relationship*. If samples of the same concrete are subjected to different temperature conditions, the strength-maturity relationship for that concrete and the temperature histories of the samples can be used to predict their strengths.

The maturity function is a mathematical expression that converts the temperature history of the concrete to a maturity index. Several such functions have been proposed and are reviewed in Malhotra (1971), RILEM (1981), and Malhotra and Carino (1991). The key feature of a maturity function is the expression used to represent the influence of temperature on the rate of strength development. Two expressions have found widespread usage. In one expression it is assumed that the rate of strength development is a linear function of temperature, and this leads to the simple maturity function shown in Fig. 2.10. In this case, the maturity index at any age equals the area between a datum temperature T_0 and the temperature curve of the concrete. The term *temperature-time factor* is used for this area and is calculated as follows

$$M(t) = \sum (T_a - T_0) \Delta t \quad (2-1)$$

where

$M(t)$ = the temperature-time factor at age t , deg-days or deg-hr

Δt = a time interval, days or hr

T_a = average concrete temperature during time interval Δt

T_0 = datum temperature

Traditionally, the datum temperature used in Eq. (2-1) has been the temperature below which strength gain ceases, which has been assumed to be about 14 F (-10 C). However, it has been suggested that a single value for the datum temperature would not be the most appropriate approach and that the datum temperature should be evaluated for the specific materials in the concrete mixture (Carino 1984). ASTM C 1074 recommends a datum temperature of 32 F (0 C) for concrete made with Type I cement when the concrete temperature is expected to be between 32 and 104 F (0 and 40 C). A procedure is also provided to determine experimentally the datum temperature for other types of cement and for different ranges of curing temperature.

In the second expression, the maturity function assumes that the rate of strength gain varies exponentially with concrete temperature. This exponential function is used to compute an *equivalent age* of the concrete at some specified temperature as follows

$$t_e = \sum \left[e^{-Q \left(\frac{1}{T_a} - \frac{1}{T_s} \right)} \cdot \Delta t \right] \quad (2-2)$$

where

t_e = equivalent age at a specified temperature T_s , days or hr

Q = activation energy divided by the gas constant, K

T_a = average temperature of concrete during time interval Δt , K

T_s = specified temperature, K

Δt = time interval, days or hr

In Eq. (2-2), the exponential function converts a time interval, Δt , at the actual concrete temperature to an equivalent interval (in terms of strength gain) at the specified temperature. In the U.S., the specified temperature is 23 C (296 K), while in the Scandinavian countries 20 C (293 K) is used. The exponential function in Eq. (2-2) can be thought of as an *age conversion factor*. To calculate the equivalent age of a concrete mixture, one needs the value of a characteristic known as the *activation energy*, which depends on the type of cementitious materials (Carino and Tank 1992). The water-cement ratio may also influence the activation energy. The Q -value in Eq. (2-2) is the activation energy divided by the gas constant [≈ 8.31 joules/(mole-K)]. ASTM C 1074 recommends a Q -value of 5000 K for concrete made with Type I cement. Fig. 2.11 shows how the age conversion factor varies with concrete temperature for $Q=5000$ K and a specified temperature of 23 C.

To use the maturity method requires establishing the strength-maturity relationship for the concrete that will be used in the structure. The temperature history of the in-place concrete is continuously monitored and from this data the in-place maturity index (temperature-time factor or equivalent age) is computed. Knowing the in-place maturity index and strength-maturity relationship, the in-place strength can be estimated. Instruments are available that automatically compute the maturity index, but care should be exercised in their use because the value of T_0 or Q used by the instrument may not be applicable to the concrete in the structure. ASTM C 1074 gives the procedure for using the maturity method and provides examples of how to compute the temperature-time factor or equivalent age from the recorded temperature history of the concrete. ACI 306R illustrates the use of the maturity method to estimate in-place strength during cold weather concreting operations.

The maturity method is intended for estimating strength development of concrete. Strength estimates are based on two important assumptions: (1) there is sufficient water for continued hydration, and (2) the concrete in the structure is the same as that used to develop the strength-maturity relationship. Proper curing procedures (as provided in ACI 308) will ensure that the first condition is satisfied. The second condition requires additional confirmation that the concrete in the structure has the correct strength potential. This can be achieved by performing accelerated strength tests on concrete sampled from the structure or by performing other in-place tests that give positive indications of the strength level. Such verification is essential when estimates of in-place strength are used for timing critical operations such as formwork removal or application of post-tensioning.

ACI Cold Weather - Committee 306, par. 6.4

6.4 - Maturity method – Permission is granted to copy ACI 306R, section 6.4

Since strength gain of concrete is a function of time and temperature, estimation of strength development of concrete in a structure also can be made by relating the time-temperature history of field concrete to the strength of cylinders of the same concrete mixture cured under standard conditions in a laboratory. This relationship has been established (Bergstrom 1953) by use of a maturity factor M expressed as

$$M = \sum (T - T_0) \Delta t \quad (6-1)$$

where

M = maturity factor, deg-hr

T = temperature of concrete, deg F (C)

T_0 = datum temperature, deg F (C)

Δt = duration of curing period at temperature T , hr

When concrete temperature is constant, as in laboratory curing methods, the summation sign in Eq. (6-1) is not necessary. The appropriate value for the datum temperature T_0 depends on the type of cement, the type and quantity of admixture, and the range of the curing temperature. A value of 23 F (-5 C) is suggested (Carino 1984) for concrete made with Type I cement and cured within the range of 32 to 70 F (0 to 20 C). This value may not be applicable to other types of cements or to Type I cement in combination with liquid or mineral admixtures. A procedure for experimental determination of the datum temperature is given in ASTM C 1074.

6.4.1 - The principle of the maturity method is that the strength of a given concrete mixture can be related to the value of the maturity factor. To use this technique, a strength versus maturity factor curve is established by performing compressive strength tests at various ages on a series of cylinders made with concrete similar to that, which will be used in construction. The specimens are usually cured at room temperature and the temperature history of the concrete is recorded to compute the maturity factor at the time of testing. The average cylinder strengths and corresponding maturity factors at each test age are plotted, and a smooth curve is fitted to the data.

6.4.2 - The in-place strength of properly cured concrete at a particular location and at a particular time is predicted by determining the maturity factor at that time and reading the corresponding strength on the strength-maturity factor curve. The in-place maturity factor at a particular location is determined by measuring the temperature of the concrete at closely spaced time intervals and using Eq. (6-1) to sum the successive products of the time intervals and the corresponding average concrete temperature above the datum temperature. Temperatures can be measured with expendable thermister or thermocouples cast in the concrete. The temperature sensors should be embedded in the structure at critical locations in terms of severity of exposure and loading conditions. Electronic instruments known as maturity meters are available that permit direct and continuous determination of the maturity factor at a particular location in the structure. These instruments use a probe inserted into a tube embedded in the concrete to measure the temperature, and they automatically compute and display the maturity factor in degree-hours.

Table 6.4.4 Calculation of maturity factor and estimated in-place strength

1	2	3	4	5	6	7	8	9	10
Date	Elapsed time h, hr	Temperature in structure, F	Average temperature in structure		Col. 5 + 5 C, C	Time interval h, hr	Col. 6 x Col. 7 C hr	Maturity factor Σ Col. 8, C hr	Corresponding compressive strength psi
			F	C					
Sept. 1	0	50	50	10	15	12	180		
	12	50	50	10	15	12	180	180	-
2	24	50	48	8.9	13.9	6	83	360	-
	30	46	47	8.3	13.3	18	240	443	400
3	48	48	47	8.3	13.3	12	160	683	1080
	60	46	45	7.2	12.2	12	146	843	1400
4	72	44	43	6.1	11.1	96	1065	989	1600
8	168	42	42	5.6	10.6	72	763	2054	2600
11	240	42	42	5.6	10.6	72	763	2817	3100
14	312	42	42	5.6	10.6	72	763	3580	3400

6.4.3 -Strength prediction based on the maturity factor assumes that the in-place concrete has the same strength potential as the concrete used to develop the strength-maturity factor curve. Prior to removing forms or shores, it is necessary to determine whether the in-place concrete has the assumed strength potential. This may be done by additional testing of the concrete in question, such as by testing standard-cured cylinders at early ages, by using accelerated strength tests as described in ASTM C 684, by testing field-cured cylinders for which the maturity factor has been monitored, or by using one of the in-place tests listed in 6.3.

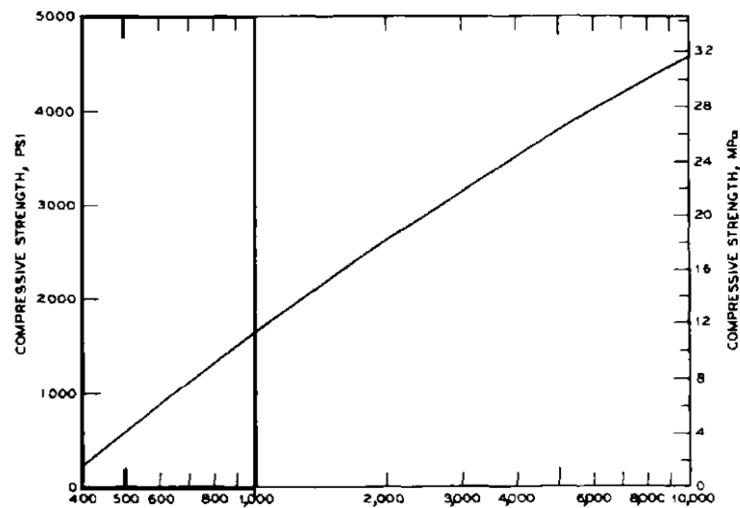


Fig. 6.4.4 - Example of a strength-maturity factor relationship for laboratory-cured cylinders (22.8 C)

6.4.4 Example - The following example illustrates the use of the maturity factor method: In anticipation of old weather, a contractor installed thermocouples at critical locations in a concrete wall placed at 9:00 A.M. on Sept. 1. A history of the strength gain for the particular concrete mixture to be used in the wall had been developed under laboratory conditions, and the strength-maturity factor curve, which is shown in Fig. 6.4.4, had been established. A record of the in-place concrete temperature was maintained as indicated in Columns 2 and 3 of Table 6.4.4. After 3 days (72 hr), the contractor needed to know the in-place strength of the concrete in the wall. Using the temperature record, the contractor calculated the average temperature (Column 5) during the various time intervals and the cumulative maturity factors at different ages (Column 9). Based on the strength-maturity factor curve (Fig. 6.4.4), the predicted in-place strength (Column 10) at 72 hr is 1600 PSI (11.0 MPa). By continuing the procedure, strength at later ages can be predicted.

OSHA 1926.752 and 1926.703

SECTION 1927.752-SITE LAYOUT, SITE-SPECIFIC ERECTION PLAN AND CONSTRUCTION SEQUENCE.

Question 12: Before any steel erection begins, who is responsible for performing the test to determine whether the concrete has cured to 75% of the intended minimum compressive design strength or cured enough so that it can support the loads imposed during steel erection?

Answer: The controlling contractor must ensure that written notification is given to the steel erector that the concrete has cured to the level required by the standard. The standard does not require any specific entity to perform the test. The choice of who will do the test is left to the controlling contractor. Since it is the controlling contractor's responsibility to ensure that the notification is given to the steel erector, the controlling contractor must select an entity that has the expertise to perform the test. The controlling contractor may do the test itself if it has the expertise to do so. In the preamble of the final rule (page 5206), OSHA stated:

In the proposed rule, the controlling contractor would have had to provide the ASTM test results to the steel erector. The final rule has been changed to reflect that the controlling contractor must ensure that the test results are provided to the steel erector. This rephrasing will allow the controlling contractor to have a contractor familiar with the ASTM test methods perform the test and provide the results to the steel erector.

SECTION 1927.703-Requirements for Cast-in-Place Concrete

1926.703(e)(1): Forms and shores for cast-in-place concrete were removed before a determination was made, based on either plans and specifications or proper tests, that the concrete had gained sufficient strength to support its weight and superimposed loads: (a) (LOCATION) (WHEN APPROPRIATE, IDENTIFY DEFICIENCIES IN THE TEST USED) NOTE: See exception - review 29 CFR 1926.703(e)(1)(i) and (e) (1) (ii) for determination of compliance.

1926.703(e)(1)(ii): The concrete has been properly tested with an appropriate ASTM standard test method designed to indicate the concrete compressive strength, and the test results indicate that the concrete has gained sufficient strength to support its weight and superimposed loads.

1926.703(e)(2): Re-shoring for cast-in-place concrete was removed before the concrete being supported had attained adequate strength to support its weight and all loads in place upon it:

FHWA –SA - 97-105

The Federal Highway Administration "Guide to nondestructive Testing" is available online at:
<http://www.intelliRock.com/library.html>

Guide for Implementing Concrete Maturity with *intelliRock*

Quick Reference: Implementing Concrete Maturity using *intelliRock*

1. Develop a calibration curve for the concrete mix:

- A. Develop a trial batch of specified concrete per ASTM 192
- B. Cast a minimum of 17 cylinders.
- C. Place *intelliRock* maturity loggers in two (2) of these 17 cylinders.
- D. Activate the *intelliRock* maturity loggers using the *intelliRock* reader.
- E. Cure cylinders per specifications.
- F. During the curing process break one set of three cylinders compressively at predetermined intervals:
 - The project engineer should determine intervals. Typically, intervals used to generate a calibration curve are: Day 1, Day 2, Day 4, Day 7 and Day 14. If additional data points are desired, cast extra cylinders.
 - Each time a set of three cylinders are broken, take a maturity (°CH) reading from both of the cylinders with embedded *intelliRock* maturity loggers.
 - Average the three strength (PSI) readings that result from compressive testing and then
 - Average the two maturity (°CH) readings from the embedded *intelliRock* maturity loggers.
 - Enter the resulting point in the Excel spreadsheet provided on the CD that came with the *intelliRock* Starter Kit. This Excel spreadsheet will then produce the calibration curve or graph for you.

2. Embed *intelliRock* maturity loggers

- A. Embed one or more *intelliRock* maturity loggers in the concrete placement.
- B. Embed loggers within the placement at those points where real-time strength estimates are desired.
- C. Avoid embedding loggers within 10 inches (25 centimeters) of the edge of the placement.
- D. Activate the *intelliRock* maturity loggers using the *intelliRock* reader as soon as concrete is poured.

3. Take maturity measurements

- A. Connect the wires from an embedded logger to the *intelliRock* reader to get maturity readings.

4. Consult Calibration Curve to get Strength Estimate

- A. After taking a maturity reading, refer to the calibration curve developed in step 1 to convert the maturity reading into a concrete strength estimate.

Quick Reference: Implementing Concrete Maturity for Early Mix or Batch Validation

A successful concrete maturity protocol must include the adoption of an early validation (quality control) process. The purpose of the early validation procedure is to provide an ongoing quality control (QC) process. This is similar to what is accomplished with early strength companion test cylinders. Although the validation process is not outlined in ASTM C 1074, it is a process that has been utilized for several years by the state highway departments, and is currently being used as a standard on projects across the country. Organizations that use the maturity method are strongly encouraged to implement a comprehensive early validation plan. To implement an early validation plan utilizing the *intelliRock* system, do the following:

1. Cast validation cylinders

Cast no fewer than four (4) early validation cylinders anytime a slump and air test is conducted.

2. Embed an *intelliRock* maturity logger

Embed an *intelliRock* maturity logger in one of these cylinders, and activate the logger.

3. Cure cylinders

Cure these cylinders as directed by the project engineer. For optimal results the validation cylinders should be cured in the same manner as the calibration cylinders.

4. Break cylinders

Break the three cylinders without the embedded *intelliRock* maturity logger in a traditional fashion and record the break data. Simultaneously read the maturity from the companion cylinder outfitted with the *intelliRock* logger. Compare this information (strength and maturity) to the same information on the original calibration curve. (The maturity reading from the companion cylinder will not be the same as the maturity reading in the actual concrete placement).

- A. If the strength and maturity from the early validation cylinders are within 10% of the predicated strength on the calibration curve this confirms that the batch being placed is comparable to the original batch used to generate the calibration curve.
- B. If these figures are outside the 10% limit, notify the project engineer, who should initiate an investigation to determine why the mix has changed.

DO NOT break the early validation cylinders until their maturity is at least that of the earliest break point on the calibration curve. For rapid assessment of mix consistency, this break should be as early as possible. For validation of accuracy for critical procedures, this break should be timed such that the expected strength is close to that of the strength required for the critical procedure.

Concrete Maturity Method Background

The concrete maturity method has existed since the mid-20th century. Only recently have maturity measuring systems, like *intelliRock*, enabled the widespread adoption of the method.

The maturity method is a proven, non-destructive technique that exhibits the lowest variability and most consistent agreement with the generally accepted standards for concrete testing. The maturity method is specified in both ACI and ASTM. It accounts for the effects of time and temperature on the strength development of the actual in-place concrete.

How the Method Works

Using a maturity measurement sensing system like *intelliRock*, the method accurately estimates the strength of an in-place concrete by combining strength data from lab or field-cured cylinders with the time- temperature profile of the actual placement. The resulting strength data is available in real-time, anytime during the curing process

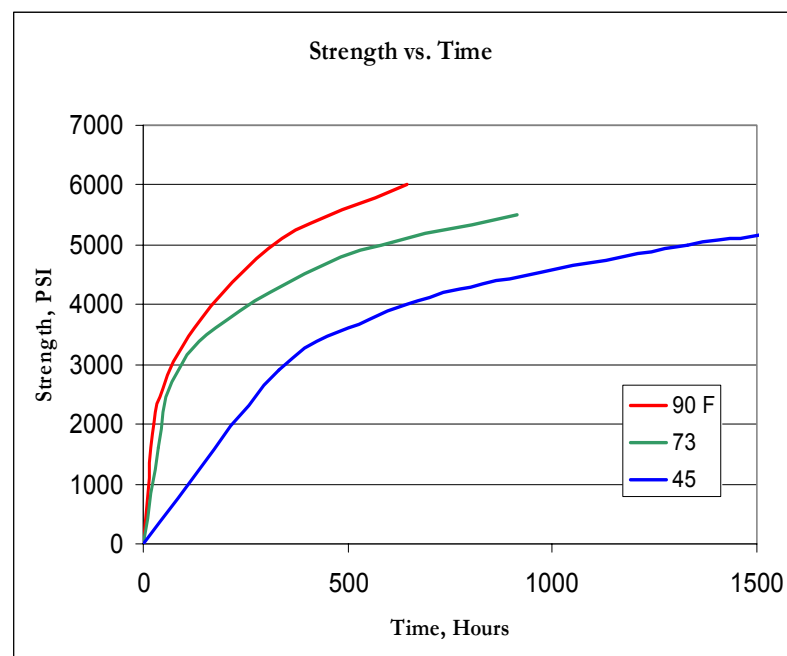


Figure 5: Concrete strength gain over time

As illustrated in Figure 5, concrete strength gain varies based on differing curing temperatures. Hotter specimens gain strength faster than cooler ones.

ASTM C 1074-98 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 strengths if they attain equal values of the maturity index. The strength-maturity relationship is an empirical relationship between compressive strength and maturity index that is obtained by testing specimens whose temperature history up to the time of the test has been recorded. Figure 6 illustrates this relationship for the same concrete mix and cure temperatures used in Figure 5:

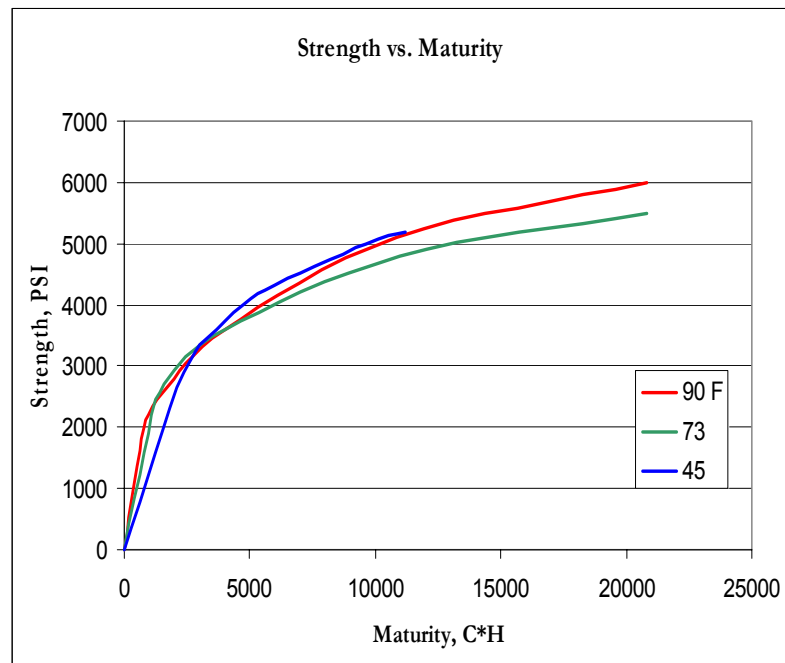


Figure 6: Concrete strength vs. maturity

Even though the concrete in Figure 6 was cured at different temperatures, the lines representing the strength vs. maturity relationship overlap. Once this relationship of strength vs. maturity has been characterized for a specific mix, real-time, in-place strength is easily determined simply by reading the maturity of the placement using *intelliRock*, and using a calibration curve to convert that maturity reading to a strength estimate. Details on creating a mix-specific calibration curve are presented later in this document.

Why use the Concrete Maturity Method

Accuracy is the reason to use the concrete maturity method to estimate early strength. The method provides a better representation of in-place concrete strength gain than lab or field-cured specimens, because specimens rarely have the same time-temperature profile as the concrete placement. Strength data is also available anytime, in real-time, often providing necessary strength estimates that allow acceleration of construction schedules. Other reasons to use the concrete maturity method include:

- Enabling earlier form removal
- Optimizing post-tensioning
- Performing mix validation
- Improving quality control
- Reducing cylinder break costs
- Documenting time/temperature history

In summary, contractors are experiencing savings of time and money through the use of the concrete maturity method.

How to Implement the Concrete Maturity Method

The concrete maturity method is implemented for several reasons:

1. To estimate and document early strength in concrete placements, in real-time during construction. This information can be used for timing critical construction activities such as form stripping, removing reshoring, post tensioning, loading structures, saw-cutting, picking tilt-up panels, traffic opening, and harvesting pre-cast members. The temperature information is also useful for concrete climate control (hot or cold weather), and mass concrete gradient determination.
2. To provide early validation of concrete batching. (QC)

The steps to implement the concrete maturity method with *intelliRock* will be presented.

Implementing the Concrete Maturity Method to Estimate Strength

Implementing the concrete maturity method involves three, simple steps:

1. Develop a mixture-specific calibration curve according to the ASTM C 1074
2. Place the *intelliRock* maturity sensors or loggers in the concrete placement prior to pouring the element, and then activate the loggers.

Take maturity readings while the placement is curing, then convert maturity to strength using the calibration curve developed from step 1.

Step 1: Developing a Calibration Curve

To develop a calibration curve, refer to ASTM C 1074. A suggested method is to cast a minimum of 17 cylinders (Fig. 7) from a specified trial batch prior to placing on site concrete:

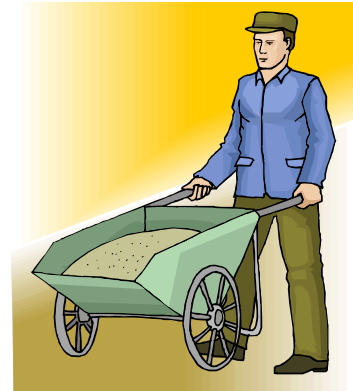
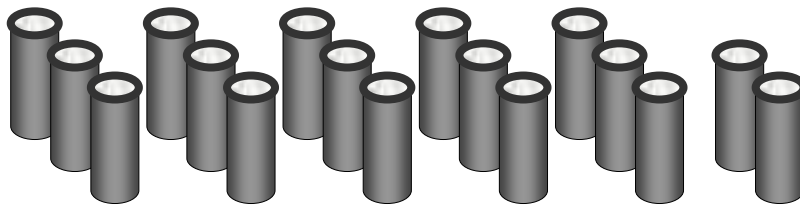


Figure 7: Casting cylinders to develop a calibration curve

These cylinders will be cast and cured in accordance with standard procedures for curing specimen cylinders. Two of these cylinders will have *intelliRock* maturity loggers placed in them and activated, depicted with sensor wires protruding from the tops of the cylinders in Figure 8:

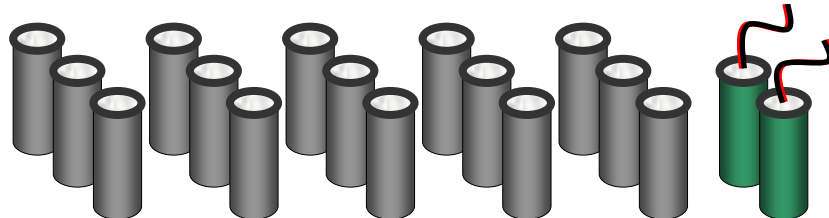


Figure 8: Cylinders with wire leads protruding from tops have embedded *intelliRock* loggers

Embed the *intelliRock* maturity logger directly in the **center of the cylinder**.
Cure the cylinders per specifications.

IMPORTANT NOTE: Be sure to activate the *intelliRock* maturity loggers when cylinders are cast!

To develop a calibration curve for this mix design, the 15 cylinders without *intelliRock* maturity loggers will be broken compressively, three each at five different intervals, or as the project engineer directs. Each time a set of three cylinders is broken, take a maturity reading from the two cylinders containing *intelliRock* maturity loggers. Record the resulting strength and maturity readings and average them.

To generate the calibration graph, plot the average maturity against the average strength measurement from each breakpoint. Finally, draw a curve that best fits the data. An alternative method for creating the curve is to simply “connect the dots.” The “connect the dots” method is the most conservative and therefore the safest method of fitting a curve to the data. The table in figure 9 contains example data from this process:

Day	Maturity Readings, °CH			Cylinder Break Strength, PSI			
	M1	M2	Average	B1	B2	B3	Average
1	503	497	500	1070	1099	1090	1086
2	1055	1045	1050	2300	2280	2160	2247
4	3791	3808	3800	3600	3720	3750	3690
7	10495	10513	10504	4320	4180	4180	4227
14	24041	23964	24003	4500	4590	4525	4538

Figure 9: Data collected to generate a maturity calibration curve

It is up to the engineer to decide when these five break points will occur.

For example:

- Standard 6 sack mix: 1, 3, 7, 14, 28 days (ASTM C 1074-98 recommended intervals)
- High early: 12 hour, 1, 2, 4, 7 days
- High early (faster): 4, 6, 8, 12, 24 hours (patching applications)
- Slow setting: 7, 14, 28, 42, 56 days

Generally, the maturity data that is of most interest comes from early in the maturity cycle. The expected strength development of the placed concrete, and the strength regions of interest influence the determination of cylinder break intervals. If extra data points are necessary, extra cylinders can be cast to create them.

When completed, this calibration curve (Figure 10 on the next page) represents the corresponding strength numbers for each maturity reading. For example, if it is determined that 4300 °CH corresponds to 3000 PSI, then during the curing process the engineer is looking for maturity of 4300°CH in order to proceed with construction activities, e.g. opening to construction, sawing, post-tensioning, stripping of forms and shoring and reshoring activities.

Once the necessary strength is attained and forms can be removed or pavement opened to construction traffic, it may be necessary to continue an active curing process by applying curing compound, covering or in cold climates, heating. Maturity is strictly a method for estimating the early strength in concrete. Concrete must be allowed to continue the curing process as specified by the project engineer. However in many cases concrete attains its necessary strength and can be accessed even while an active curing process continues.

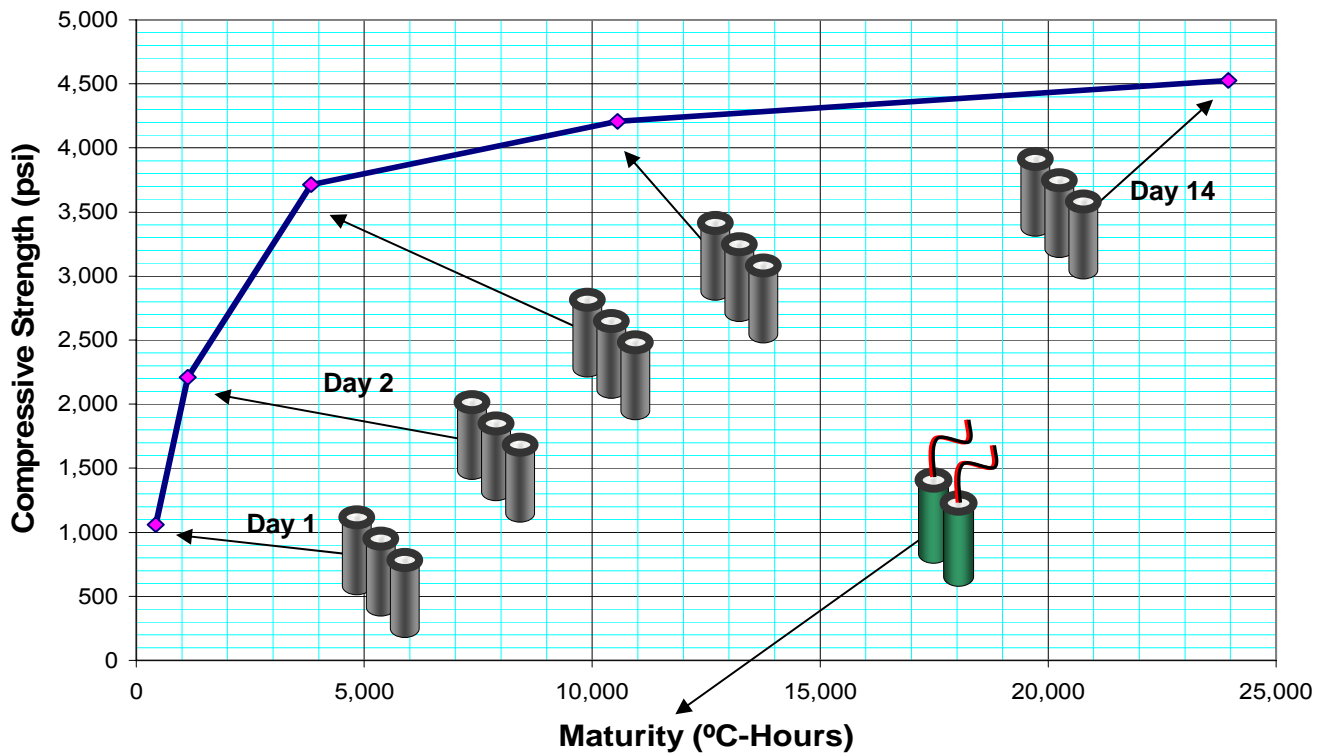


Figure 10: Developing a mix-specific calibration curve

Step 2: Embedding *intelliRock* Maturity Loggers

To use the concrete maturity method with a mix for which a calibration curve has been developed, simply embed one or more *intelliRock* maturity loggers (Figure 11) into the placed concrete.



Figure 11: *intelliRock* maturity logger

Actual size of an *intelliRock* maturity logger is approximately 1.4 inches in length (3.5 centimeters) with a diameter of one inch (2.54 centimeters). [Approximately the same size as a 35 mm film container.] Standard length of wire leads is 4 feet (1.2 meters).

Embed *intelliRock* maturity loggers at those points in the placement where real-time strength estimates are desired e.g. points where strength is expected to gain more slowly (shaded) or at critical stress points. General guidelines on a placement are to place the logger nominally 4 to 6 inches from a surface. On horizontal placements e.g. pavement or slabs at mid-depth at least 10 inches (25 centimeters) or more away from the edge. Consult with the project engineer or specifications to determine where to embed *intelliRock* maturity loggers. Figure 12 shows the placement of an *intelliRock* maturity logger into a freshly poured section of pavement:



Figure 12: Placing an IntelliRock maturity logger into pavement

Do not forget to activate the *IntelliRock* maturity loggers in the concrete placement.

Step 3: Take Maturity Measurements

After *IntelliRock* maturity loggers are embedded and activated, maturity measurements can occur immediately and as often as desired to estimate early concrete strength.

Step 4: Using the Calibration Curve to Estimate Strength from Maturity

After taking a maturity reading, refer to the calibration curve developed in step 1 to convert the maturity reading to a concrete strength estimate. Figure 13 depicts an example of this simple process, where a maturity reading of 4,000 corresponds to a strength estimate of 3,750 PSI:

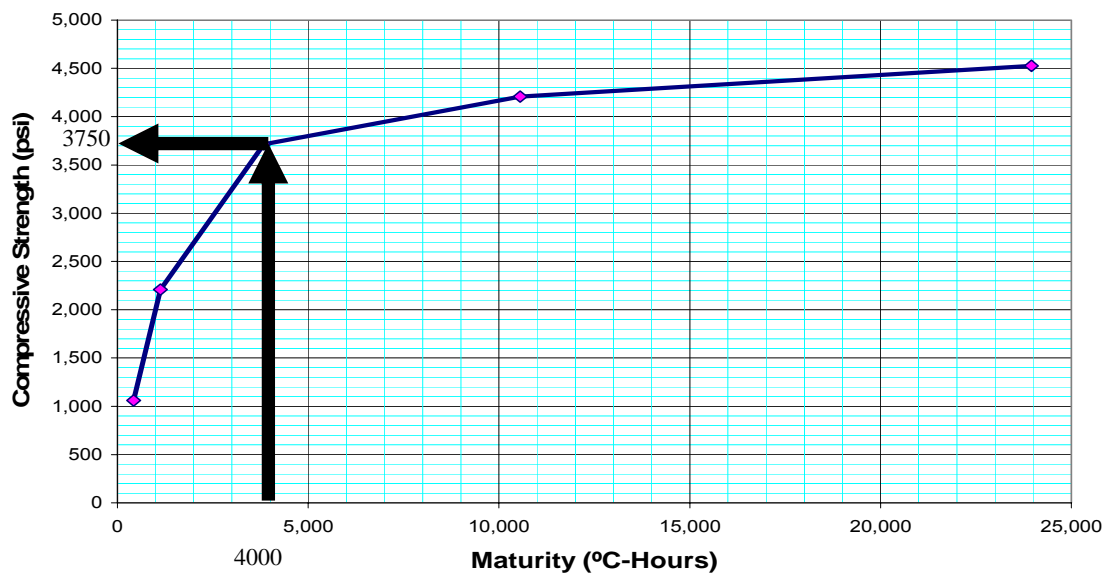


Figure 13: Converting maturity to strength using the calibration curve

intelliRock Overview

Product Description

intelliRock is a comprehensive concrete strength and quality measurement system that allows contractors to conveniently utilize the maturity method to non-destructively determine real-time, in-place concrete strength. The maturity method, an American Society for Testing and Materials standard since 1987 (ASTM C 1074), enables contractors and engineers to determine concrete strength in a structure at any time and as many times as necessary until the required strength is achieved.

The *intelliRock* system consists of three major components:

1. **A logger.** An intelligent sensor that calculates maturity within the structure where it is placed.
2. **A handheld reader.** The *intelliRock* reader is used to communicate with and download maturity and temperature data from the loggers.
3. **Software.** The *intelliRock* software facilitates the downloading of maturity and temperature data from the reader into secure, unalterable electronic files for subsequent distribution, documentation and/or analysis.

There are two versions of the *intelliRock* system: (Pictured below)

1. *intelliRock* I
2. *intelliRock* II



Figure 14. *intelliRock* I handheld reader and logger



Figure 15: *intelliRock* II handheld reader and Logger

intelliRock I Logger Specifications



LGR-01 – Concrete Maturity Logger

- Processes temperature data in real-time to calculate and store maturity data
- Use when real-time strength measurements are needed

TPL-01 – Temperature Logger

- Records concrete's internal temperature for 28 Days
- Use when temperature data is required but not strength measurement



The *intelliRock* loggers are self-contained, microprocessor based data loggers that can be embedded directly into a concrete structure. The loggers measure, process, and store temperature data within the concrete itself. As such, they are extremely rugged and operate continuously with no permanently affixed external devices, thereby virtually eliminating the risks of lost data and equipment due to theft, vandalism, weather, and other job-site hazards. Two different logger models are available depending upon the specific need and application. The LGR-01 concrete maturity logger processes temperature data in real-time to calculate and store concrete maturity data (i.e. concrete strength). The TPL-01 temperature logger records the concrete's internal temperature profile for up to 28 days. The LRG-01 and TPL-01 both store the maximum and minimum temperatures and time at which they occur. Typically, the LGR-01 maturity logger is used when real-time strength measurements are needed; the TPL-01 is useful when temperature data are required but strength measurements are not. Both loggers use precision thermister to provide highly accurate temperature measurements. The precision thermister eliminate any need for temperature calibration.

LGR-01 –Maturity Logger Specifications

Temperature Accuracy	+/- 1°C
Maturity Integration Period	15 Minutes
Maturity Technique	ASTM C 1074 Nurse Saul Method
Stored Historical Temp. & Maturity Points	Temp & Maturity at Start, 4 hrs. 12 hrs, 1 Day, 2 Days 3 Days, 4 Days, 5 Days, 6 Days, & 7 Days
Additional Data Stored	Time & Value of min./max. Temp. & Maturity
Logger Dimensions	1-½ in. X 1-1/8 in. Diameter
Standard Cable Length	4 Ft. (custom lengths offered up to 100 ft.)
Wire	18 Gauge
Operating Temperature	-18°C to 85°C (0°F to 185°F)
Logging Battery Life	3 Months
Battery shelf Life	5 Years

TPL-01 – Temperature Logger Specifications

Temperature Accuracy	Same as LGR-01
Maturity Integration Period	N/A
Maturity Technique	N/A
Stored Historical Temp. & Maturity Points	Temperature at Start, every 2 Hours on days 1-3, every 4 hours on days 4-6, every 12 hours on days 7-28
Additional Data Stored	Time & Value of min./max. Temperature
Logger Dimensions	Same as LGR-01
Standard Cable Length	Same as LGR-01
Wire	Same as LGR 01
Operating Temperature	Same as LGR-01
Logging Battery Life	Same as LGR-01
Battery shelf Life	Same as LGR-01

intelliRock II Logger Specifications

LGR-02: Concrete Maturity Loggers

- Processes temperature data in real-time to calculate maturity
- Stores temperature and maturity data
- Use when real-time strength measurements are needed



TMP-02: Temperature Loggers

- Record concrete's internal temperature
- Use when temperature data is required but not strength measurement
- Use for mass pours to monitor temperature gradients
- Use in cold weather to monitor concrete temperature and manage thermal protection

LGR-02 –Maturity Logger Specifications

Temperature Accuracy	+/- 1°C
Maturity Integration Period	1 Minute
Maturity Techniques Available	ASTM C 1074 Nurse Saul Method ASTM C 1074 Arrhenius Method Patent Pending Arrhenius + Method
Stored Historical Temp. & Maturity Points	Logger Dependent
Additional Data Stored	Time & Value of min./max. Temperature & Maturity Up to 8 Notes and 6 Events Job Site Name, Logger Location Notes
Logger Dimensions	1-½ in. X 1-1/8 in. Diameter
Standard Cable Length	4 Ft. (custom lengths offered.)
Wire	18 Gauge
Operating Temperature	-18°C to 85°C (0°F to 185°F) Tested (but not guaranteed) to 100 °C
Logging Battery Life	6 Months
Battery shelf Life	5 Years

Standard Logger Configurations (call for additional or custom configurations)

Model	Use	Data Logged	Logging Interval	Logging Time
MAT-02-1H28D	Standard Maturity	Temp & Maturity	1 Hour	28 Days
MAT-02-5M7D	High Early	Temp & Maturity	5 Minutes	7 Days
TMP-02-1H28D	Standard Temp	Temp	1 Hour	28 Days
TMP-02-1H180D	Tanks/Rooms	Temp	1 Hour	180 Days

***intelliRock* System Benefits**

The *intelliRock* system is a tool that provides contractors a simple, reliable, and inexpensive way to measure in-place, real-time concrete strength. The information provided by the *intelliRock* system helps accelerate the construction process, resulting in the savings of time and money in the following areas:

- Reduces the number of cylinder tests required
 - *intelliRock* can reduce the number of cylinder breaks by 50 – 60 % on some projects.
- Provides a powerful quality control tool
 - *intelliRock* removes most of the human factor from the preparation and handling of cylinders
 - *intelliRock* improves the project's quality control procedures. Concrete procedures are aware that mixture mistakes may be detected within hours versus days, and thus, more diligence occurs.
- Optimizes post-tension timing
 - PT can now be accomplished according to specifications by utilizing in-situ strength versus cylinder breaks.
- Allows for earlier form removal which reduces form rental
- Provides traceable documentation on the time/temperature history of a structure
 - Placed-concrete's maturity/strength and temperature data are provided in an encrypted electronic format (Windows™ compatible) complete with an electronic time stamp of maximum and minimum temperatures. In addition, the concrete's seven (7) day history is easily retrieved in electronic format for several months after placement. The concrete data can be electronically forwarded to owners, labs, engineers, etc. (OSHA 1926.752 / 703).



Who Uses *intelliRock*

The *intelliRock* system is in wide use by large construction companies, municipalities, contractors, paving companies and other organizations involved in the concrete construction industry. The *intelliRock* system is now being used around the world. Some of the more notable uses of *intelliRock* include construction of a nuclear waste disposal facility by the Department of Energy, The Dallas High Five project, the Woodrow Wilson Bridge project, the Washington DC Metro extension project, and on construction at Baltimore Washington International Airport.

How To Use *intelliRock*

At the same time concrete is placed in the formwork, one or more *intelliRock* maturity loggers are placed in the structure as well. The loggers process the time-temperature history of the structure and store the resulting maturity history of the concrete at the specific location of the logger. The corresponding strength of the structure is easily determined at any time from the maturity data provided by the logger in conjunction with previously determined strength-maturity relationship data (Figure 16). This timely information about concrete strength can accelerate the construction process and also functions as a powerful quality control tool.

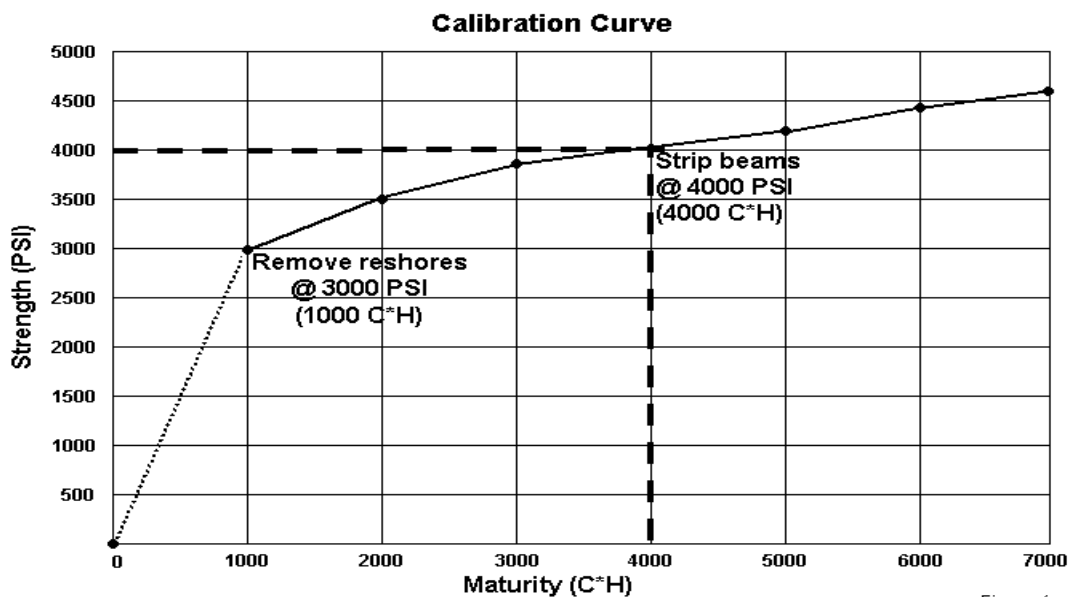


Figure 1

Figure 16. Sample maturity calibration curve

The *intelliRock* loggers function independently, without permanent connection to any external devices. This arrangement allows multiple loggers to be controlled and accessed by a single handheld reader, making the system ideal for use at multiple sites, and eliminating system damage and lost data from vandalism, theft, weather and other job site hazards.

Operating Instructions for *intelliRock I*

About the *intelliRock* Maturity Meter

Engius' *intelliRock* concrete maturity system uses state-of-the-art technology to overcome many of the problems associated with traditional concrete maturity meters (i.e. accidental damage, vandalism, theft, etc.). The *intelliRock* system uses an embedded microprocessor and high-precision temperature sensors in place of the external recording devices and thermocouple wires used by other systems, therefore the *intelliRock* system does not require temperature calibration and allows the temperature sensors to function independently, with no permanent connection to any external devices.

A typical system would consist of a Reader, multiple inexpensive Loggers, and (optionally) a PC to store, graph and print maturity and temperature data. Since the meter does not have to be connected while the logger calculates maturity and logs data, only a single reader is required to operate any number of loggers. (Although it is often convenient to have multiple readers on large job sites.)

Overview:

In typical usage, the logger is placed into the concrete structure just before, or immediately following the concrete pour. The wire leads should be left sticking out of the concrete. After the concrete is poured, the logger leads are attached to the *intelliRock* reader to place the logger into "Run" mode. After the logger is placed in Run mode, the reader can be disconnected from the logger and used to start or read additional loggers. When a logger is in Run mode, it continues to monitor and log the concrete maturity even when detached from the reader. At any time, the reader can be reconnected to the logger wires and the current concrete maturity, history, and temperature profile can be displayed. If a permanent record of the data is needed, data from the logger can be downloaded into the handheld reader. This saved data can later be downloaded from the reader to a Windows-based PC using the *intelliRock* software. When the data is downloaded to a PC, the data is saved in two file formats. One is a convenient ". csv" format that is compatible with Excel and other common applications. The other is a ". sec" format that is a proprietary, secure, tamper resistant file format, which can be provided to supervising agencies. The secure file can be converted to a readable format by using the *intelliRock* software. This process guarantees data integrity from the logger to the end-user.

Operation:

The following sections describe the general operation of the Engius *intelliRock I* system.

Selecting a logger

The *intelliRock* MTR-01S Reader is compatible with two versions of loggers, the LGR-01 and the TPL-01. The LGR-01 calculates and logs maturity as well as temperature information (10 historical data points), and the TPL-01 only logs temperature (99 historical data points). Both loggers record and time-stamp the maximum and minimum temperatures. For more information please refer to the respective data sheet.

Starting a Logger

1. Embed the sensor into the concrete structure or test specimen leaving the data wires extended out of the concrete at least 6 inches.
2. Connect the logger to the hand-held reader, matching the red wire to the red jack and the black wire to the black jack. (NOTE: Reversing the connections will NOT damage either unit; however the system will not operate with the wires reversed).
3. Turn the reader on by pressing the <POWER> button. The meter will then indicate, "Ready".
4. Press the <CURRENT READING> button. The meter will display the sensor serial number in the upper left corner of the display, the sensor mode in the upper right ("Stdby" or "RUN"), the current maturity reading in the lower left (in degree C Hours), and the current temperature reading in the lower right.
5. The reader should indicate that the sensor is in the Standby mode ("Stdby") mode. **If** the sensor is in "Run" mode, return the sensor to Standby mode by holding down the <ENTER> and <START/STOP> keys simultaneously (for several seconds) until the reader indicates "Stdby".
6. Check the datum temperature by pressing the <DATUM> key. By default the datum temperature is set at -10°C. Adjust the datum temperature by holding down the <UP> or <DOWN> keys until the desired datum temperature is shown. The datum is the reference from which maturity is calculated. **It is important that you use the SAME datum temperature in the field as used to generate the calibration curves for the mix.** Once the desired datum temperature is displayed, press the <ENTER> key to update the datum or press the <CANCEL> key to cancel the change. **Once entered, this datum temperature will be used when starting all future loggers unless it is changed to a different value.**
7. Start the sensor by pressing the <START> key. Once the sensor is running, "RUN" is displayed in the upper right of the "CURRENT READING" display.
8. You may now disconnect the sensor from the reader.
9. Turn off the reader by pressing the <POWER> key. NOTE: The reader will automatically power down after two minutes of inactivity.

Display Current and Historical Readings

1. Connect the sensor to the reader (see #2 from *Starting a Sensor* above).
2. The current reading screens can be displayed by pressing the <CURRENT READING> button. Three different screens will be displayed:
 - a. The first press of the <CURRENT READING> button will show the logger *serial number*, if the logger is *running* or in *standby*, current *maturity*, and current *temperature*.
 - b. If you then press <CURRENT READING> again, the display will change to show *elapsed time*, current *maturity*, and current *temperature*.
 - c. If you then press <CURRENT READING> again, the display will say "SAVE LOGGER DATA, ENTER TO CONFIRM." Now you may press <ENTER> to save the logger data into the reader, so that it can be transferred to a PC later (see "Saving Data onto Reader for Transfer to Computer" section below). If you press any key besides <ENTER> the data will not be stored.
 - d. Pressing <CURRENT READING> again will return you to the first screen in this list (a).

*NOTE: When *current maturity* is displayed above, the last calculated maturity value is shown. A new maturity value is calculated every 15 minutes. When *current temperature* is displayed, the temperature displayed is the temperature when the <CURRENT READING> button is pressed.

3. History readings can be displayed by pressing the <HISTORY> button. The first reading displayed is the initial temperature reading. The recorded historical values can then be displayed by successively pressing the <UP> and <DOWN> arrow keys. (For the LGR-01 readings are stored at time of start, 4 hours, 12 hours, 24 hours and each day for 7 days).

4. The maximum and minimum temperature and their times can be displayed with the **<Tmax/Tmin>** key.
5. You may now disconnect the sensor from the reader.
6. Turn off the reader by pressing the **<POWER>** key. NOTE: The reader will automatically power down after two minutes of inactivity to conserve battery power.

Stopping a Logger

Although it should not be necessary to stop the sensor, this can be done by holding down the **<ENTER>** key and the **<START/STOP>** key at the same time for several seconds. This can be used to reset a logger that is accidentally 'started' before you are ready to start calculating maturity. The sensor will maintain data from the run unless it is restarted with the **<START/STOP>** button. **If the sensor is restarted after being stopped as described above, the sensor readings will be reset and ALL DATA WILL BE LOST.**

Saving Data onto the Reader for Transfer to Computer

1. Connect the sensor to the reader (see #2 from *Starting a Sensor* above).
2. Press the **<CURRENT READING>** button. The Reader will display the first current status screen for the logger.
3. Press the **<CURRENT READING>** button again. The Reader will display the second current status screen for the logger.
4. Press the **<CURRENT READING>** button a third time. The Reader will display "Save Logger Data, ENTER To Confirm." At this point you may press **<ENTER>** to save the data from the logger onto the reader. Any other key will abort the save.

The Save operation will store all history values, Tmax/Tmin values, current reading values, elapsed time, datum, and serial number of the logger onto the reader for later transfer to a Computer. Up to 200 loggers may be saved onto the reader before it is full. If a logger is saved multiple times, it will take up multiple memory locations since all readings are saved. This allows data to be collected manually at critical times. Saving data from a Logger to the Reader does NOT erase the data from the logger or stop a logger if it is in RUN mode.

Erasing the Reader's Saved Data

When saved logger data is no longer needed on the reader, it may be cleared to allow new data to be saved. The reader can be cleared at any time by holding down the **<CANCEL>** button, and pressing the **<POWER>** button. Press **<ENTER>** to confirm when prompted. NOTE: This will clear ALL logger data from the Reader. Any logger data that has not been transferred to the Computer will be lost.

Transferring Saved Loggers from Reader to Computer (PC)

1. Connect the Reader to your Computer's COM Port using the included serial cable.
2. Start the *intelliRock* Software (See the following section for details on installing the software). Configure the software to use the correct COM Port for your Computer using the FILE menu followed by COMMUNICATIONS SETUP. If you don't know which Port to use, try COM1 first then try COM2 if it does not work correctly.
3. Press the **<POWER>** button on the Reader. The reader will show on the display "COMPUTER ONLINE"
4. Within a few seconds, the *intelliRock* Program should display the Reader model number and the number of saved loggers that the Reader is holding

5. Press the “Download Stored Logger Data” button on the *intelliRock* Program. You will be prompted to select a download directory. Select a directory where you would like the data placed and select “OK.”
6. The data will be now transferred to the computer. This can take up to 1 minute depending on how full the Reader’s memory is. Once completed a report will be shown listing all of the data files created.

For each Saved logger two files will be created, an Excel format file (.CSV) and a secure format file (.SEC). The filenames will be based on the serial number of each logger. Multiple copies of the same logger will generate multiple files. An example filename is: 1234567-000.CSV; this would be the first data file for serial number 1234567, and it is in Excel format. The equivalent secure file would be named 1234567-000.SEC.

NOTE: A secure file can be converted to an equivalent Excel format for use by the FILE menu, but an Excel file can **NEVER** be converted to secure format. This preserves the integrity of the original data in the secure file.

7. Once the data is saved to the computer you may wish to erase it from the logger. This is done by pressing the “Erase Reader Memory” button in the *intelliRock* Program.

Installing the *intelliRock* Software

1. Please close any open programs (saving your data as appropriate) before installing the *intelliRock* software. (The install program may request that you reboot your computer after installation.)
2. Insert the *intelliRock* CD into the CDROM drive of the computer. (The *intelliRock* software is compatible with Windows 95, Windows 98, Windows NT 4, Windows ME, Windows 2000, or Windows XP.)
3. The installation program should start automatically after a few seconds. If the install program does not start automatically, then use Windows File Explorer to browse to the CD and double-click the Setup.EXE program.
4. Once the install program has started. Follow the on-screen instructions to install the software.

Transmission Line Length

Loggers come standard with 4 ft long transmission lines. Custom loggers may be requested having transmission lines extending up to 100 ft in length.

Changing Reader Batteries

A set of fresh batteries should power the reader for several months of typical usage. As the batteries near the end of their useful life, the display will get noticeably dimmer. This indicates it is time to change the batteries. To change the batteries, remove the six screws on the back of the reader. The reader can then be opened for access to the batteries. The reader runs on four (4) standard AA-size alkaline batteries. (Note: The reader *will* retain any stored logger data while the batteries are being changed.)

Frequently Asked Questions About *intelliRock I*

Q: How many sensors can be used with each reader?

A: The sensors are completely stand-alone, independent units. Therefore a single reader can be used with an unlimited number of sensors.

Q: How long will the logger operate?

A: Once set to Run mode, the logger will continue to calculate maturity values until the battery dies. Under normal conditions, each logger can continue recording for several months. All loggers are shipped in Standby mode. In this state, the battery will last up to five years.

Q: Can additional wire be added to the loggers?

A: Yes. You may order extension wire from Engius. We do recommend that the connection be watertight, and no longer than 100 ft total length. Engius can also provide custom cable lengths on request. *Note that the maximum cable length is significantly decreased if there are long runs (more than 10 ft) in concrete or under water.* Please contact our technical support staff if you have questions regarding this issue.

Q: Does the reader need to be turned off while connecting and disconnecting loggers?

A: No. The electrical connection is quite robust. Remember, however, that the display information is not updated until you request a new reading from the reader.

Q: Sometimes I get a “Bad Connection” message when everything looks fine. What am I doing wrong?

A: Sometimes the connector on the reader gets dirty and causes these errors. Clean out any dirt or grime from the inside of the connector. A cotton swab or toothpick soaked in household cleaner works well.

Q: What is the sensors’ operating temperature range.

A: The sensors can operate and accurately measure temperatures from –18 C to 85 C.

Operating Instructions for *intelliRock II*

The *intelliRock II* system is a state-of-the-art concrete maturity and temperature profiling system. The system is comprised of three major components: Loggers, Readers, and Windows Software. The loggers are totally self-contained measurement and computing systems that contain a precision temperature measurement system, microprocessor, memory, and a battery. The reader is used to communicate with the logger (i.e. start loggers, download data) as well as “shuttle” data from loggers in the field to a PC. The windows software that is provided with the system is used to download logger data from the hand-held reader to a PC. Once on a PC, the data is stored in 2 formats: Text (.csv comma separated value), and Secure (.sec).

The text files are in a convenient format that is readable by most PC software including Microsoft Excel.

The secure file is encrypted but a decrypted text file may be generated from the data by anyone with the download software. The secure file is unalterable and ensures that the data is exactly what was downloaded from the logger.

intelliRock II loggers are available with a variety of functions including temperature logging and several maturity calculation methods. The model number of the logger describes the basic functionality.

For example:

MAT-02-1H28D: Maturity Logger, logs data every 1 hour for 28 days

TPL-02-5M7D: Temperature logger, Logs data every 5 minutes for 7 Days

Several configurations are available to meet most applications and custom configurations are available to satisfy any specification. For a complete list of available loggers, contact an *intelliRock* representative.

Reader Overview

The figure on the next page shows the general layout of the reader. The reader has two connectors.

- The connector on the top is the logger connector.
- The connector on the side of the reader is for interfacing to a PC and other devices.

The eight-line display area provides these indicators:

- The *intelliRock* system status line is on the top line of the display.
- The upper left text is the menu name, which differs depending on the status of the logger connected to the reader, if any.
- The number with the # symbol is the serial number of the connected logger. The logger icon is present if a logger is connected. The Logger Mode icon indicates the status of the connected logger (Hourglass: Standby, R: Run, S: Stopped). The locked/unlocked symbol indicated if the logger operation has been locked.
- The battery icon gradually turns from black to transparent to indicate the reader's battery level.

Navigation through the menu system is accomplished using the function keys, F1 thru F5. When a number needs to be entered the numeric keys on the keypad become active. When text is expected, the keypads alpha keys and numbers become active.

Reader Configuration

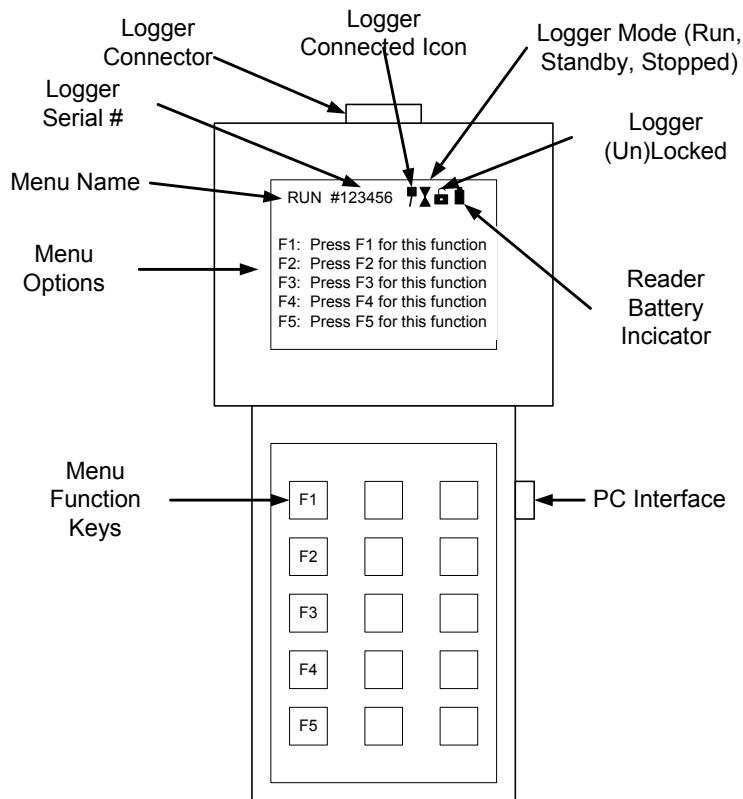


Figure 17: *intelliRock II Reader*

Entering alpha-numeric text using the *intelliRock II* keypad

intelliRock II has adopted the current industry standard for alpha-numeric text entry from a limited keyboard such as a cell phone.

When entering text information using the *intelliRock II* keypad

1. Find the key that has the letter or number that you want to enter
2. Press the key as many times as needed for the letter to appear on the screen.

For example, to enter INTELLIROCK 2 do the following at a text input prompt (such as entering a note):

Press 4 4 4	I	
Press 6 6	N	
Press 8	T	
Press 3 3	E	
Press 5 5 5	L	
Press 5 5 5	L	(See note 1)
Press 4 4 4	I	
Press 7 7 7	R	
Press 6 6 6	O	
Press 2 2 2	C	
Press 5 5	K	
Press 0	(space)	
Press 2 2 2 2	2	(See note 2)

Note 1: When entering a letter that is on the same key as the previous letter you must pause for one second to wait for the cursor to advance to the next letter.

Note 2: When text is expected, the keyboard automatically enters the alpha mode. In alpha mode letters are selected when pressing a key before the number is selected. For example, if there are three letters on the key along with the number that you would like to enter, then press the key four times. If a text entry box expects a number, then the keypad is automatically switched into numeric mode, where only the numbers on the keypad are active.

To backspace press the left arrow key (on the F5 button)

3. When finished press Enter

Setting the Time & Date

The *intelliRock* time and date needs to be set for your particular time zone. To set the time and date, turn the reader on and do NOT attach a logger. Select "Set time and date" by pressing F2 on the keypad. Follow the on-screen instructions to set the time and date. Use 2 digit numbers for all parameters (i.e. February is "02", 2003 is "03")

Setting Temperature Units

The *intelliRock* II system ships from the factory configured to display temperature in °C. If you would prefer to have temperature displayed in °F, then turn the system on without a logger attached and select "Set °C/°F Display" then follow the on-screen instructions. Note that maturity time-temperature factors will still read in units of °C*H. Data will also be downloaded to a PC in °C.

Adjusting the Display Contrast

To adjust the display contrast for best readability, turn the system on without a logger attached and press F1 repeatedly.

Erasing Reader Data

To erase the data in the reader, turn the reader on without a logger attached and select "Erase Reader Data" (what function key is this?). Typically this operation should be done via the Windows software. However, erasing the data from the reader keypad is also an option. This may take a couple of minutes if the reader contains a large amount of data.

Basic Logger Operations

The *intelliRock* II system is designed to be very simple to operate, yet have a variety of data management options available when needed. The only functionality for basic operation is 1) starting loggers and 2) reading loggers. The following paragraphs describe these operations.

Starting a logger

To start a logger, connect the logger to the red/black terminals on the top of the reader. The reader will automatically detect the logger. When the logger is detected the reader menu changes to the "Standby" logger menu. To start the logger, press F2 then follow the on-screen instructions to set the job site, logger location and other information required by the logger. Once complete, the logger will be in "Run" mode and will be logging data. (Note: a logger will be immediately started without an option to enter additional information by holding down the ENTER key while pressing F2)

The logger will continue to log data for a predetermined interval depending on the model number. Once complete, the logger will automatically enter "Stopped" mode. Data can be retrieved at any time for the remainder of the logger's battery life (typically over 1 year).

Reading data from the logger

Logger readings may be either viewed in the field or downloaded into the reader for post-processing on a PC. To simply view the current readings, connect to a logger and press F1 – “Current Reading”. To download the data into the reader for subsequent transfer to a PC, press F2 – “Download Logger”.

Advanced Logger/Reader Operation

Several additional data management features are available for large jobs, and jobs with critical operation timing. To get to the advanced logger configuration options, connect a logger and select the F5- “Advanced” menu item.

Adding Notes and Events

Notes and events can be added to the logger and viewed via the “Advanced” menu option. Notes and events are text messages that are permanently stored in the logger. The difference between a note and event is that an event is time and value stamped, and a note is only a line of text. For example, if a slab can be post-tensioned at 3000 °CH and an event is added, then the time, maturity, and temperature of the slab can be stored in the logger by adding an event named, for example, “Post Tension”.

Graphing Data

Data can be graphed by selecting the F3 - “View History Data” option. When this function is selected, all of the data is downloaded from the logger. The reader then gives you the option of graphing any of the properties that are being reported by the logger (i.e. temperature, maturity). After selecting the measurement to graph, select the display window time to view by pressing F1 and F2 to increase/decrease the time on the x-axis as indicated by the “Data per screen” value. Once the time is selected, press ENTER to graph the data. When the graph is displayed, scroll through the data, or press “Cancel” to return to the menu.

This function is very useful for monitoring concrete temperature swings in cold weather and extrapolating maturity values to target maturity levels to for scheduling operations.

Stopping a logger

Once a logger has been started, it may be stopped and reset only during the first hour of operation. To stop a logger select the “Stop Logger” option in the “Advanced” menu. Once a logger has been stopped it must be “Reset” from the “Advanced” menu before it can be restarted.

After 1 hour of logging the logger will “lock” itself. After that time data can be added to the logger and data can be retrieved, however the overall operation of the logger cannot be altered. Once the logger is locked, a lock icon appears in the status line.

Viewing logger model number

From the Notes menu, selecting “Logger Info” will display the logger model number, along with other useful logger information.

intelliRock II Reader PC Interface Software

intelliRock Software Windows Version 1.0 - Windows 2000 & Windows XP

For a complete Guide to installing the software, please contact an *intelliRock* Representative.

PC Hardware & Software Requirements

- Operating System: Windows 2000 or Windows XP
- Administrative Privileges Under Windows 2000 or Windows XP
- A CD-ROM drive
- Computer processor: Pentium 90 or better
- Memory: 96 megabytes RAM recommended (32MB minimum)
- Free disk space 4MB to 100MB depending on whether the supporting Microsoft software is already installed on your system
- Internet Explorer 5.01 or later (Internet Explorer 6 SP1 is included on CD)

Installation Steps

This software must be installed while logged on to Windows as a user with Administrative privileges.

Installing USB Drivers for *intelliRock II Reader*

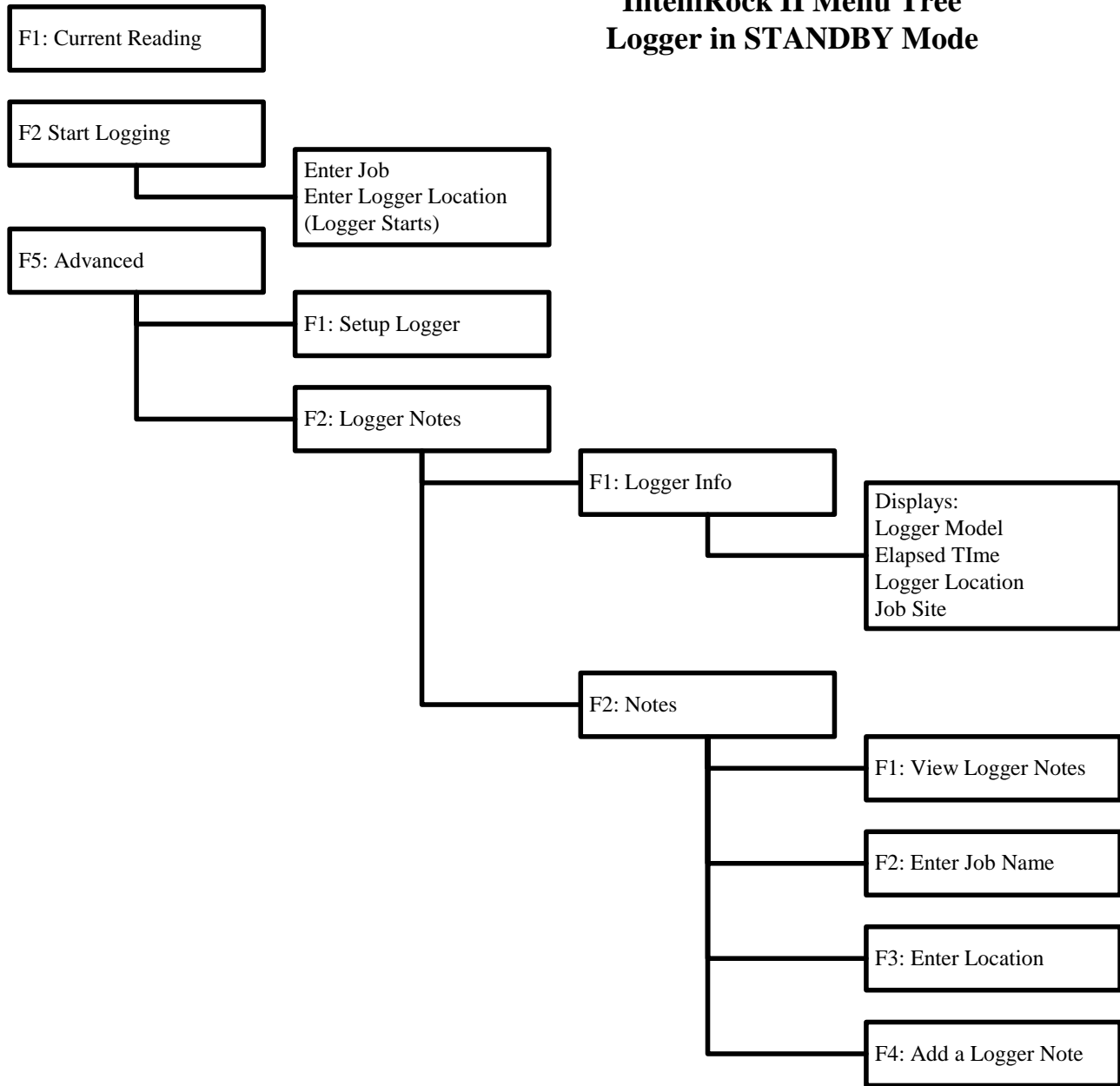
The installation of two USB driver files is required to communicate with the *intelliRock II Reader*. This may seem confusing because it will appear as if Windows is asking you for the same thing twice. The following screenshots illustrate the installation process.

Windows will automatically find the reader when it is connected and the “Found New Hardware Wizard” and will walk you through the installation steps. The driver software is located on the *intelliRock II* CD-ROM.

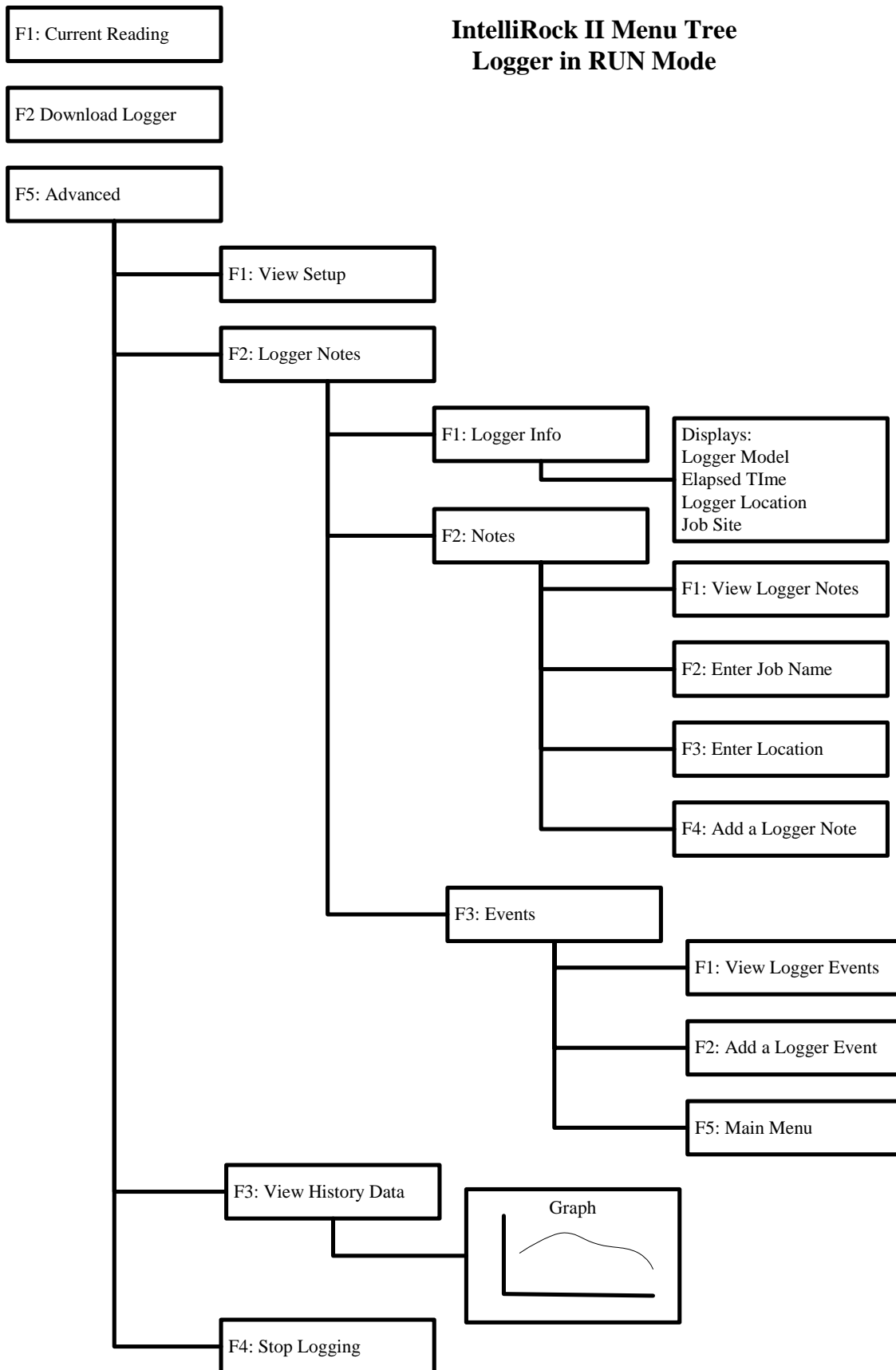
Trouble-Shooting “Reader Not Found” Problems

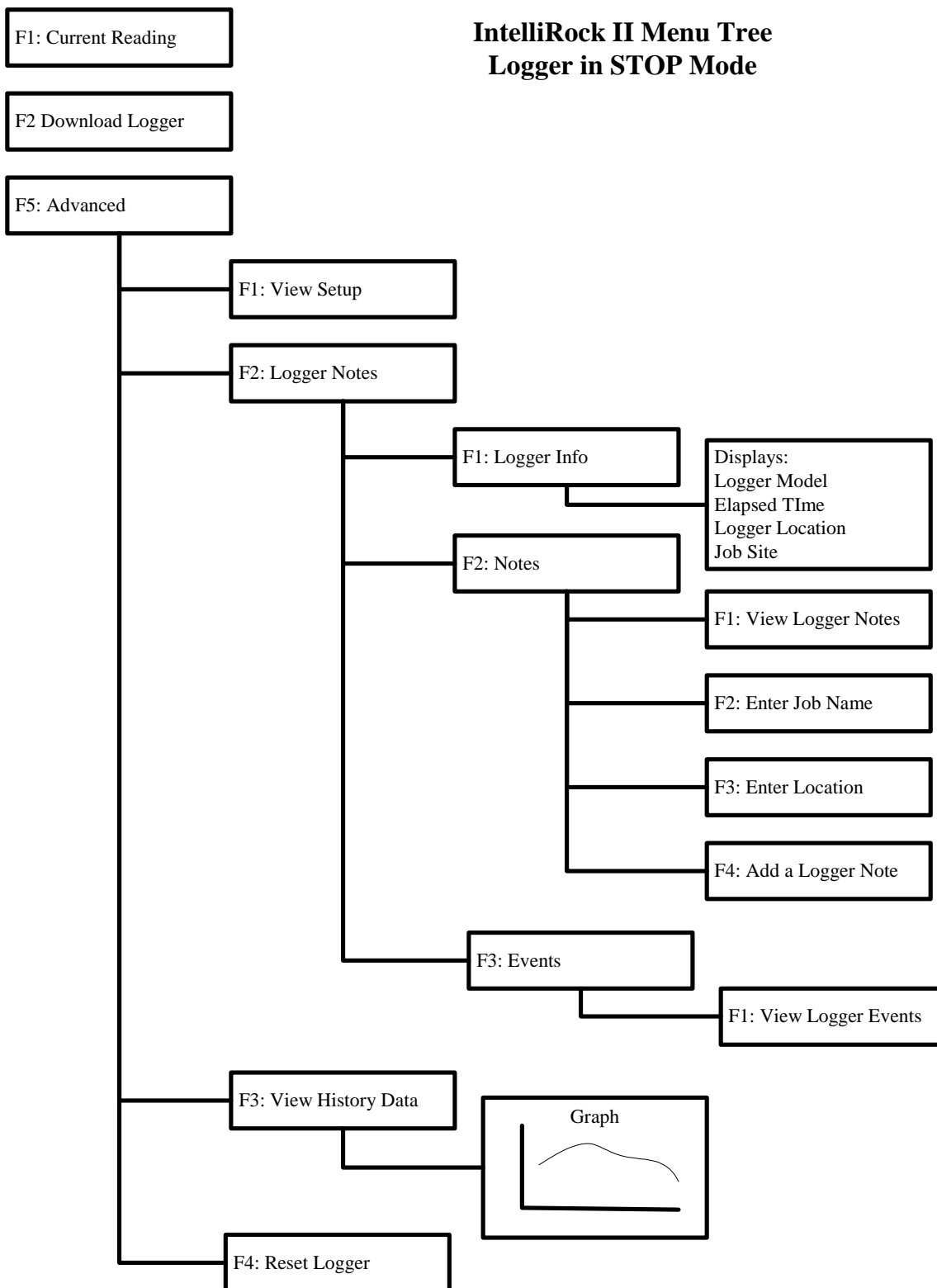
- Make sure reader is turned-on. Press any key on the handheld reader to turn it on.
- Check both connections of the USB cable. Try disconnecting the USB cable from the PC for 5 seconds before reconnecting.
- Make sure reader batteries are not empty. A reader icon at the upper right corner of the screen indicates battery life. If the battery icon is not black in the center it is empty. New batteries will need to be installed.
- Try running Scan Ports from the *intelliRock II*->Tools folder. When the reader is connected and turned on you should see a USB COM port appear.

IntelliRock II Menu Tree Logger in STANDBY Mode



IntelliRock II Menu Tree Logger in RUN Mode





Frequently Asked Questions About *intelliRock II*

Q: Are the loggers from the original *intelliRock* system (*intelliRock I*) compatible with the new *intelliRock II* system?

A: No they are not.

Q: Will the original *intelliRock* system be discontinued?

A: No, it will still be available for purchase.

Q: Do I need a PC to use the new *intelliRock II* system?

A: Not necessarily. You can read the data out of the reader, but if you want to transfer the data out of the reader, you will need a PC to do so.

Q: What are the system requirements if I have a PC?

A: The operating system supports Windows XP and Windows 2000. You will also need a USB port on the PC to transfer the data from the reader to the PC.

Q: Why would I use *intelliRock II* instead of the *intelliRock I* system?

A: There are many reasons.

1. The *intelliRock II* system supports the Nurse-Saul and Arrhenius methods of maturity.
2. The *intelliRock II* loggers can log many more points than the *intelliRock I* system.
3. The *intelliRock II* system provides more information on placement, like job number, logger location, job notes, etc.
4. The documented time of start is recorded with a real-time clock that can be programmed to your time zone. This provides an absolute reference point to associate sensor data with critical construction schedules.
5. The reader has an eight-line graphical display so you can graph curves right in the field.
6. The loggers are configurable to meet individual specifications and integrate maturity every minute instead of every 15 minutes in the *intelliRock I* system and logging intervals of down to every minute.
7. *intelliRock II* loggers have a much longer logging life (up to six months)
8. This system has unalterable, uninterruptible data logging feature that provides permanent and traceable data.
9. It provides more data in temperature so you can determine when and how much thermal protection is required in cold weather and documenting mass temperature gradients.

Customers' Quotes and Case Studies

***intelliRock* Customer Comments**

Users of the *intelliRock* system are validating the benefits of the system described above, as well as the rapid return-on-investment in the system:

Cost/Benefit Analysis



"*intelliRock* has helped us go **from being behind on the project to ahead of schedule**. Being able to measure strength in real time is a major benefit. In five months, **our cost [for *intelliRock*] has been around \$3,500 and our benefit is calculated at \$175,000**. In warmer weather we have been able to reduce the number of days we wait to remove reshores from 7 days to 2 days."

*Pam Culbertson
Project Engineer
Phoenix 4th Street Jail
McCarthy Construction*



"In the last six months the *intelliRock* maturity system has **saved us \$309,000 in man-hour costs**. Our expenditure has been less than \$5,000, and in cold weather it has kept us from stripping forms too early."

*Tom Heffernan
Director of Field Operations
FLINTCO Construction Co*



"Our *intelliRock* system paid for itself in less than 1 week..."

*Todd Freeman, P.E.
D.F. Freemann Construction
Kansas City, KS*

Large Construction Companies



"Bechtel National Inc. began using the *intelliRock* sensor system last year to record temperatures of mass concrete placements at the Department of Energy's Waste Treatment Plant at Hanford in southeast Washington. This system has proved **reliable and rugged**, and it provides digital documentation of key information. Bechtel has invited them to demonstrate the *intelliRock* system at our upcoming international conference of construction engineers."

*Rich Marl, Manager,
Construction Engineering
and Technologies,
Bechtel Inc.*



"Kiewit first used the *intelliRock* maturity sensor system on the I-40 Oklahoma Bridge project. Since then we have implemented the system on several other projects around the county, e.g. Woodrow Wilson Bridge, T-Rex, Atlanta Water Project, several projects in Texas and recently on a Kiewit-owned project. The *intelliRock* system brings **the age of information technology to the concrete construction world**. We have found the *intelliRock* system to be **a superior technology in measuring the in-situ real-time strength of placed concrete.**"

*Mr. Joe Deihl
Corporate QA Manager,
Peter Kiewit & Sons*



"I will not do another cast-in-place concrete job of any size without using *intelliRock*, because it speeds the project up, saves money and because of the quality assurance data it provides. It lets me know where I am with my strength and temperature. If you are ever going to get into an argument with a testing lab or a structural engineer, you need some data to verify your position, and the *intelliRock* system provides that."

*Randy Holland,
Flintco Project Superintendent
Courtyard by Marriott Project*

Large Construction Projects



"...[*intelliRock*] has significantly **improved the flow of work and the timing of critical activities** for the project. The *intelliRock* maturity system is an easy-to-use, end-to-end, reliable construction-friendly alternative to conventional maturity meters..."

*Brian Salerno, PE, Zachry,
High-Five Project Director*



"The *intelliRock* sensors allow us to precisely determine the **earliest safe stripping time**, whether the ambient temperature is warm or cold. We have used them to demonstrate the necessity and the amount of heating and protection needed during the recent cold weather and to demonstrate the value of different approaches to protecting and heating. This has resulted in **real savings in time and in money** to the project."

*Robert G. Bolduc,
PE QC/ QA manager
LGS JV Washington D.C.
Metro Extension
(Lane Construction. Co.)*

Municipal Projects



Pavers, Inc.

"Pavers, Inc. purchased an *intelliRock* Maturity Meter at the ACPA Kansas/Missouri paving conference in March of 2002. We instantly put it to work on a \$2.5 million urban concrete paving project in Wichita, Kansas, and a \$2 million urban concrete paving project in Manhattan, Kansas. We immediately found that we were **obtaining design in-place field strength estimated by the maturity method in 2 days, even in cold weather!** That is 2 to 5 days of savings of time when compared to the traditional 4 to 7-day laboratory test requirements. We were able to **open driveways to businesses in 30 to 48 hours** after placement, without using high early mixes. Instant test results, when you want the results. A very simple and easy method to estimate concrete strength. **Accurate, quick, and cost effective.**"

*Neal Saskowski
Project Manager
Pavers, Inc.*



"Can it be that easy?' That was the question asked when I spoke at a conference on the *intelliRock* Maturity Meter. The answer is YES. It is easy to calibrate and easy to use. Not only is it easy to use, it is the **most accurate** way to determine 'In Place - Real Time' concrete strength. I feel that the *intelliRock* Maturity Meter is one of the **most important and useful tools to hit the testing industry in 25 years!**"

*Randy Roths E.T.
Senior Lab Technician
City of Wichita*

Concrete Producer



"The *intelliRock* Maturity Probe is one of the **best tools for the concrete market**. Its ability to record maximum and minimum temperature is a plus. Recently we installed a maturity probe in a post-tensioned slab of concrete in a housing project on December 16, 2002. That week and the next it snowed and was real cold - minus 10 F. When we took the probe readings the maximum temperature was 21 C or 70 F, when we got started. The minimum temperature was -1C or 30F at about 16 days after placement. The probe indicated approximately 2500 psi in the slab at 7 days based on maturity. The quality control engineer was glad we had placed it in the concrete as a demonstration as to what it could accomplish. I have learned a lot about concrete and in-place temperatures since we have been using the *intelliRock* maturity probe."



*Frank A. Kozeliski, PE F.A.C.I., President and
Material Engineer Gallup Sand & Gravel Co.,
Chairman ACI International Committee 211,
Proportioning Concrete Mixes*

Departments of Transportation

"The *intelliRock* Maturity System **takes maturity testing to another level** as to the acceptance and convenience of use."

Jim Hunt, PE
Director of Construction,
TxDOT Dallas District



"We've been using maturity with great success for the past seven years. TxDOT has been using the *intelliRock* system exclusively on their SH-66 project since early 2002 and has found it to **be reliable, rugged and easy to use.**"

James Hill
Lead Inspector,
TxDOT Dallas District

"...by using maturity, we **reduced the field production of cylinders by at least 75%.** That led to our inspectors having that much more time to inspect the work and verify the quality of the concrete placement. It also probably led to fewer back injuries **and more accurate results overall for strengths.**"

Tracey Friggle, PE,
Assistant Director of Construction,
TxDOT Dallas District



"... *intelliRock* resulted in significant overall time savings and **enabled considerable acceleration of form removal operations.**"

Pete Byers, PE,
Resident Engineer,
OK Dept. of Transportation, I-40 OK Bridge Project
(Gilbert Central a Kiewit subsidiary earned a \$1.5 million bonus for completing this project in 47 days.)

June 25, 2002



July 20, 2002



July 29, 2002



Geoscience



intelliRock's evolution in strength estimating technology is comparable to when the nuclear gauge replaced the sand-cone density test method. **Having real-time in-situ information of the concrete hydration at one's fingertips is a definite improvement over the current concrete testing methods".**

*David A Belcher, P.E.
Senior Project Engineer,
Fugro South, Inc.*

Highway Paving Project



"Gohmann Asphalt & Construction, Inc. has found the December weather in Indiana to be unpredictable, but with the *intelliRock* system we could **predict opening strength and time**. This was generally 60 hours with ambient temperatures ranging from lows in the 20's to highs in the lower 40's. The *intelliRock* system and ingenuity allowed

Gohmann to continue concrete paving operations throughout the month of December **without having to waste time waiting for field cured beam test results**. This was the second performance-based specification contract in Indiana DOT history. The *intelliRock* system proved to be the **right product, at the right time and at the right price.**"

*Michael E. Kaelin,
Concrete Laboratory Supervisor,
Gohmann Asphalt & Construction, Inc.*

Railroad Bridge Project

"The superstructure construction was completed in 35 days. Without discussion of confidential production measures, costs and statistics, it is fair to say that a minimum of 30 days (additional) critical contract time could have been lost if this system had not been utilized. Yes, the overall savings by implementation of the *intelliRock* system (which subsequently allowed for element construction efficiencies) was **nearly 50%**"

*Todd Saxton
MJ Lee Construction Company
A division of Manhattan Construction*

Engineer of Record: University of Oklahoma football stadium expansion project



"The *intelliRock* maturity system has been an asset to the project. During warmer weather, it has benefited the construction schedule by allowing **earlier form removal** than would have been allowed per destructive testing of laboratory-cured cylinders. In cooler weather, it has provided the **assurance that concrete has achieved proper strength** prior to form removal."

*Larry E. Curtis, PE
Kirkpatrick, Forest, & Curtis PC*

University & DOT Study



**Tennessee
Technological
University**

We'll take you there

In a four-month study comparing a rebound hammer, field cured 6 x 12 cylinders, laboratory cured 6 x 12 cylinders, 4 x 8 cores and the *intelliRock*™ maturity system Tennessee Tech concluded:

*"...by adopting the intelliRock maturity system it will allow the Tennessee DOT to speed construction by allowing pavement to be opened at lower strength, e.g. 300 psi flexural and 1400 psi compressive. In warmer weather this could be within **24 hours** and in cold weather with warming blankets the pavement may reach opening strength in **36 hours**. In addition it will **reduce QC costs** with less cylinder breaks, **improve public relations** and **improve safety** by reducing project time."*



L.K. Crouch, Ph.D.
Professor of Civil Engineering,
Tennessee Tech University
and presented to TDOT Jan 03

Study commissioned by Tennessee Department of Transportation



intelliRock Case Studies

Pavers, Inc. - City of Wichita, KS Project



Using intelliRock™, Pavers Inc. learned that it was obtaining strength for concrete it placed faster than destructive testing methods indicated. As a result, it was able to open pavement sooner for businesses and residents, and recover time lost to weather delays.

Project Background

Over the past three years, Pavers Inc. Project Manager Neal Saskowski had read about how contractors in other states were utilizing the maturity method to estimate the strength of concrete placements. “I was intrigued with how quickly they were achieving concrete strengths, in two or three days.” In March 2002, Saskowski attended the Kansas/Missouri ACPA annual conference and encountered *intelliRock*, a system using proprietary sensors to measure concrete strength in real-time by utilizing the maturity method, based on ACI¹ and ASTM² standards. At the time, Pavers Inc. had already begun an urban paving job for the City of Wichita. With Saskowski at the conference were two of the city’s engineers. Together, they reviewed the *intelliRock* system and made the decision to try it on this project, reconstructing a section of Seneca Street that is a main thoroughfare through the city.

The Seneca Street project required reconstructing 3,300 feet of a busy thoroughfare with a traffic count of 15,000 cars per day. The existing pavement was a combination of decades-old concrete, brick and asphalt paving that Pavers Inc. would replace with eight inches of concrete pavement. This section of Seneca street is a venue for a variety of businesses – fast-food restaurants, Convenience stores, attorney and dentist’s offices, auto-repair shops – as well as a middle school and residences.

Expectations for intelliRock

Saskowski’s objective for using *intelliRock* was to know more quickly when concrete

placements achieved strength, in less time than destructive testing methods indicated. “When doing jobs, you have businesses and residents

“... the ability to use intelliRock and obtain a strength reading anytime, on the spot, was a great convenience.”

to consider. You can’t let traffic on concrete until you know its strength. Traditionally, we cast and break cylinders to determine concrete’s strength, but this method doesn’t let you take a strength reading at anytime. Since we don’t own a lab, the ability to use *intelliRock* and obtain a strength reading anytime, on the spot, was a great convenience.”



Steve Diaz taking a maturity reading obtaining real-time strength on the job site

Project Data

The City of Wichita’s specification is 550-psi flexural strength within seven days before pavement is reopened. The project used the Kansas Department of Transportation (KDOT) Optimized Mix, a fairly standard mix consisting

ACI, Non-destructive- Committee 228, par. 2.6 & ACI, Cold Weather- Committee 306, par 6.4
ATSM C1074-98 Standard Practice for Estimating Concrete Strength by the Maturity Method

of: 580 lbs. of cement per cubic yard, 60% coarse MA2 sand and 40% rock with a mid-range water reducer. The mix did not contain any fly ash. The water: cement ratio for the mix varied between .43 and .45, the slump was between 1.25 and 2 inches, and the air content was 5.5 to 6.5%. Overall, the project required 8,000 cubic yards of concrete.

The City of Wichita has its own testing lab, so Saskowski involved the lab's testing personnel to develop a maturity calibration curve for use with the *intelliRock* system. In compliance with ASTM C 1074, the city made 12 cylinder specimens, two were tested at Day 1, two at Day 3, two at Day 7, two at Day 14 and two at Day 28. In addition, two maturity curves were developed for the project, one for a hot water mix for use in colder weather, and another for a standard mix for use in warmer weather. The specifications for both mixes were the same, but the mix using 160-°F water was used when air temperatures were below 35 °F, to get the minimum concrete temperature up to 50 °F. During the course of placing concrete, the ambient temperatures ranged from 25 °F to 110 °F. Blankets were used to protect the placements in cooler weather.

intelliRock Results

At the project's next concrete placement, intelliRock sensors were placed at a depth of 4 inches. The data provided by intelliRock revealed that strength was being achieved within two or three days, even in cooler weather. Data from cylinder breaks confirmed the strength indicated by intelliRock. Using the intelliRock sensors, Pavers Inc. was able to open one section of

Pavers Inc. was able to open one section of pavement, a driveway to a convenience store, 30 hours after concrete placement.

pavement, a driveway to a Convenience store, 30 hours after concrete placement. Many other sections were opened in the 36-40 hour range based on maturity readings provided by the intelliRock system. "Prior to using intelliRock, we would have expected to open pavement in approximately four to seven days, because KDOT begins testing at four days, and the City of Wichita standards call for testing in seven days," adds Saskowski.

On June 1, 2002, there were 45 days remaining to finish the project, which was about 60% completed. The owner of a car wash, whose business was directly affected by the repaving project, told Pavers Inc. representatives that he did not expect them to finish the project by the July 15th deadline. "I bet him that if we completed the project within plus or minus five days of July 15th that he would have to thank us by putting a sign on his marquee. We did complete the project, and the business owner kept his word by putting up a sign publicly thanking us. The *intelliRock* system helped by allowing us to complete our work more quickly." Pavers Inc. used the *intelliRock* system throughout the job, and has made it a standard part of subsequent paving projects. After completion of the Wichita project, the *intelliRock* system was employed on two paving projects in Manhattan, Kansas, a different part of the state, with different concrete materials and a slightly modified concrete mix – but with the same strength gain results.

"Utilizing this method saved us time on all of our projects in 2003, and allowed us to complete those projects within the times anticipated by the owners, despite losing working days to the weather," Saskowski concluded. "Before we began using *intelliRock* to test concrete strength, we had to cast extra cylinders so we could test them more frequently. With *intelliRock*, we don't have to do this. We still do some traditional cylinder testing, but *intelliRock* lets us measure strength anytime we want to. It's quick, easy and accurate."

"...intelliRock lets us measure strength anytime we want to. It's quick, easy and accurate."

Randy Roths, the City of Wichita's Senior Lab Technician, commented on his experience with *intelliRock*: "It is easy to calibrate and easy to use. Not only is it easy to use, it is the most accurate way to determine 'in-place – real-time' concrete strength. I feel that this maturity meter [*intelliRock*] is one of the most important and useful tools to hit the testing industry in 25 years!

McCarthy Building Companies – 4th Avenue Jail Project, Phoenix, AZ



On the Maricopa County 4th Avenue Jail project, McCarthy Building Companies Inc. did not have to wait for seven-day lab results to strip forms and re-shores. Thanks to real-time, in-place concrete strength data from the IntelliRock™ system, McCarthy saved man-hours and money by renting less formwork and cycling it faster.

Project Background

Construction is completing on Maricopa County's 4th Avenue Jail facility in Phoenix. McCarthy Building Companies, Inc. is managing this \$91 million project, scheduled for completion in 2003. The new facility will contain 1,360 cells, including 144 special management cells for close custody inmates. It will also house the new Central Intake facility, capable of handling 600 bookings every 12 hours.

The job consists of 600,000 square feet in eight levels of structural cast-in-place (CIP) elevated concrete decks. It also has structural CIP interior shear walls, CIP exterior shear walls, six CIP stair shafts, and four CIP elevator shafts. The decks account for approximately 24,500 cubic yards of concrete. McCarthy is using IntelliRock, a system using proprietary sensors to estimate in-place concrete strength in real-time by utilizing the maturity method, based on ACI and ASTM standards. As these decks are cast, it is critical that McCarthy is able to strip its forming systems and remove re-shores as soon as possible.



Maricopa County 4th Avenue Jail project site – August 2002.



IntelliRock Real-Time Data

At the beginning of the project, McCarthy was utilizing the traditional destructive compressive testing to estimate seven-day concrete strength. "At the beginning of the project, I learned about IntelliRock from Robert Barkley, the QC guy at Hanson, our concrete supplier," said Pamela Culbertson, Project Engineer with McCarthy Building Companies, Inc. "We had run into some test result problems from the contract testing lab. He proposed that we and the structural engineer of record use the IntelliRock system instead of relying solely on the testing lab for seven-day strength results."

To begin using IntelliRock, Culbertson developed a maturity calibration curve (Below) for the mix used on the project by testing

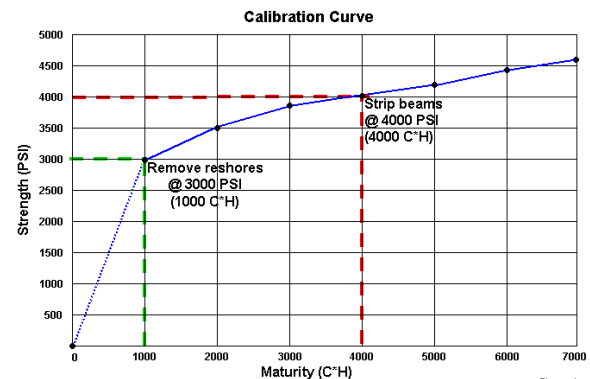


Figure 1

cylinder specimens at specific intervals. Using this curve, Culbertson was able to determine real-time, in-place concrete strength by taking readings from the IntelliRock system at will.

ACI, Non-destructive- Committee 228, par. 2.6; ACI, Cold Weather- Committee 306, par 6.4 & ACI Committee 318, par. 6.2(d)

The *intelliRock* system provided Culbertson in-place, real-time data about the deck pours, including details about the structure's temperature history (Graph 1), maturity vs. time (Graph 2) and strength vs. time (Graph 3).

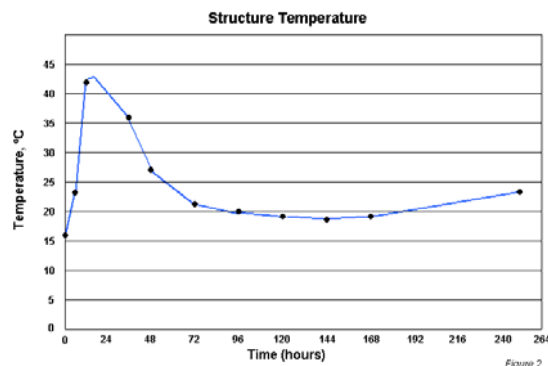


Figure 2

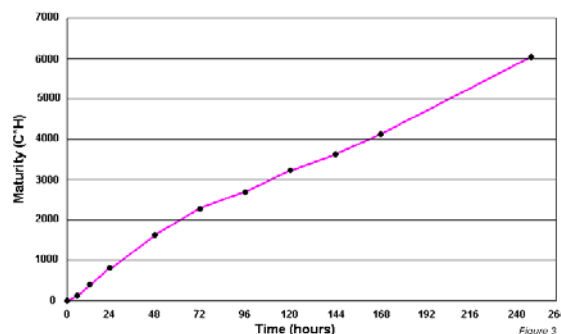


Figure 3

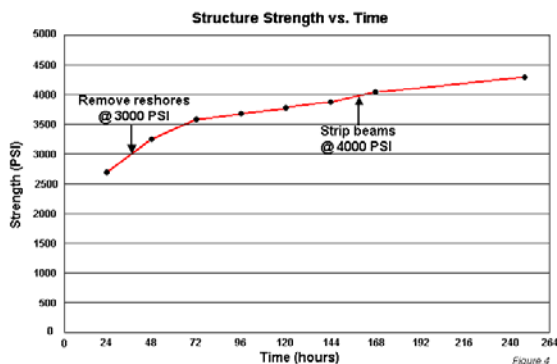


Figure 4

Project specifications allowed for stripping forms when 4,000-PSI strength was achieved, so 5,000-PSI concrete was used to ensure that the strength objective was achieved within seven days. “The *intelliRock* system is a proactive approach to concrete placement, and it gave us more control over when we could strip our forms and remove re-shores in areas,” continued Culbertson. “We were only getting seven-day reports from the testing lab, so the strength data from *intelliRock* allowed us to prove we were at design strength for re-shoring and form removal before the seven days.” During the project, Culbertson placed five

intelliRock sensors per deck pour. Each pour ranged from 400 cubic yards to 550 cubic yards. The sensors were typically placed in the center of the cross-section. One was placed in

“The *intelliRock* system is a proactive approach to concrete placement, and it gave us more control over when we could strip our forms and remove re-shores in areas.... the reliable strength data from *intelliRock* allowed us to prove we were at design strength for re-shore and form removal before the seven days.”

the exterior spandrel beam, which had an overall depth of 18 inches and was 30 inches wide. Two sensors were placed in the slab area, which has a depth of 12 inches. Two more sensors were placed in beams that had depths of 24 inches and were 36 to 48 inches wide. To obtain a strength reading, Culbertson simply connected the handheld *intelliRock* reader to the *intelliRock* sensor wires protruding from the deck, took a reading, then disconnected and moved to another sensor location.

Project Mix Specifications

The 4th Avenue Jail project used a 5,000-PSI mix:

- Performance: 5,000 PSI @ 28 days
- Slump Range: 3 inches to 5 inches
- Weight per Cubic Yard: 4,002
- Water/(Cement + Pozzolan): 0.44
- Fly Ash: ASTM C-618 Type F
- Entrapped Air: 1.0%

When pouring occurred, temperatures ranged from up to 100°F (37.7°C) during the summer, to a low of about 40°F (4.4°C) during the winter. McCarthy accomplished its deck placements at night with operations typically beginning between 9:00 PM and 10:00 PM, and completing around 6:00 AM the next morning. McCarthy used tower cranes and three to four yard buckets for these deck placements.

intelliRock Advantages

The impact of *intelliRock* on the 4th Avenue Jail project was a savings of time and money. "Using *intelliRock* allows us to cycle our forms faster, by being sure we could remove re-shores and strip beams," Culbertson added. "This allows us to rent a smaller amount of form-work and cycle it faster."



McCarthy Project Engineer Pamela Culbertson uses intelliRock to take a strength reading at the 4th Avenue Jail project site.

intelliRock Benefits & ROI

"*intelliRock* has helped us go from being behind on the project to back on schedule," concluded Culbertson. "Being able to measure strength in real time is a major benefit. In five months, our cost [for *intelliRock*] has been around \$3,500, and our benefit is calculated at \$175,000. It gave us reassurance that the concrete was at a safe strength and we weren't putting our people in danger, while at the same time allowing us to gain time on our schedule."

About McCarthy

Founded in 1864, McCarthy is one of the oldest privately held construction firms in the nation. The employee-owned firm provides construction management, design/build and general contracting services. More than 60 percent of McCarthy's work is from repeat clients, contributing to the firm's ranking as the 19th largest domestic general contractor (Engineering News-Record, May 2002) and fifth in healthcare construction. McCarthy currently has more than \$2 billion in healthcare projects underway. With national headquarters in St. Louis, the company has additional offices in Phoenix, Las Vegas, Dallas, Newport Beach, San Francisco and Sacramento.

"intelliRock has helped us go from being behind on the project to back on schedule. Being able to measure strength in real time is a major benefit. In five months, our cost [for intelliRock] has been around \$3,500, and our benefit is calculated at \$175,000."



Gilbert Central Construction (Kiewit) – Interstate 40 Bridge Reconstruction Project

On May 26th, 2002, a barge collided with the Interstate 40 Bridge near Webbers Falls, Oklahoma, collapsing multiple spans and killing 14 people. The flow of traffic in both directions of this major east-west national transportation corridor was abruptly severed. State transportation officials predicted a six-month reconstruction schedule, however, the bridge was reopened to traffic after just 47 days of construction. The IntelliRock™ concrete strength measurement system played a major role in the effort, helping the contractor earn a \$1.5 million early completion bonus.

Project Background

The Interstate 40-bridge near Webbers Falls, Oklahoma is a heavily traveled trans-continental interstate route – an average of 22,000 vehicles traverse the bridge each day. Estimated user costs of rerouting this traffic around the bridge were \$475,000 per day, negatively impacting the economies of the surrounding communities as well as the commuters. The two-lane detour routes began deteriorating quickly under the increased traffic loads and were simply not able to adequately accommodate the increased traffic flow.

The Oklahoma Department of Transportation (ODOT) awarded a \$10.9 million bid for reconstruction of the bridge to Gilbert Central Corporation, a unit of Peter Kiewit Sons' Inc. At any given time, contractors and sub-contractors had between 60 and 130 people on the site working two extended shifts, resulting in around the clock activity. It was literally a race against the clock, as the ODOT contract specified a \$6,000 per hour bonus for early completion, or a \$6,000 penalty for late completion, with no limit set on the amount either way.

The urgency of the project led ODOT to allow contractors to utilize the maturity method to non-destructively determine in-place concrete strength. The maturity method, an American Society for Testing and Materials standard since 1987 (ASTM C 1074), enables



contractors and engineers to measure concrete strength in a structure at any time and as many times as necessary until the required strength is achieved.

Measuring Strength with Maturity Meters

ODOT realized that use of the maturity method on this project would save time by allowing the contractor to expedite strength-dependent construction activities such as removing forms, setting beams, and opening to traffic. Because the maturity method has only recently found its way into mainstream use in the United States, ODOT had not used it on a project.

A barrier to more widespread adoption of the maturity method had been the reliability of conventional maturity meters, which have a history of failures for the following reasons:

- Moisture in the maturity meter.
- Theft of the maturity meter.
- Damage to the maturity meter.
- Battery failure of the maturity meter.
- Sensor wires being severed or otherwise disconnected from the maturity meter.
- Maturity meter malfunction due to electrical and/or magnetic interference.
- Chemical discoloration of the maturity meter display cover.
- Inability to read the maturity meter's LCD display due to exposure to sunlight.

Furthermore, conventional maturity meters must remain physically connected to the embedded temperature probes for the entire duration over which maturity readings are desired, exposing them to theft or damage.

By contrast, the *intelliRock* system uses an embedded microprocessor with a high-precision temperature sensor to measure temperature and calculate maturity in real time with *no permanently affixed external devices*. The embedded microprocessor and sensor (called a “logger”) is placed into the concrete structure and then activated using a handheld reader. The reader is then disconnected, leaving only two lead wires protruding from the concrete. Whenever a strength measurement is desired, the handheld reader is simply reattached to the two wires and the current temperature and maturity is displayed. In addition, a history of temperature and maturity values and time-stamped minimum and maximum temperatures can be viewed and then downloaded to a personal computer in a secure, unalterable format.



The IntelliRock system reader pictured with a logger.

The Texas Experience

ODOT took advantage of experience the Texas Department of Transportation (TxDOT) had as a pioneer in the use of the maturity method for construction projects, and with the *intelliRock* system. ODOT opened a dialogue with TxDOT, who sent a representative to the I-40 bridge construction site.

“We’ve been using maturity with great success for the past seven years,” states James Hill, TxDOT lead inspector, Dallas District. TxDOT had been using the *intelliRock* system exclusively on its SH-66 project since early 2002 and had found it to be reliable, rugged and easy to use. The TxDOT experience with maturity and *intelliRock* has resulted in a 60% to 70% reduction in the number of test specimens required for each project as well as savings of 3- to 5-days for each concrete placement.

“The Texas Department of Transportation experience with maturity and IntelliRock has resulted in a 60% to 70% reduction in the number of test specimens required for each project as well as savings of 3 to 5-days for each concrete placement.”

Pete Byers, ODOT Resident Engineer for the I-40 bridge project, was influenced by the success TxDOT experienced with concrete maturity methods and the *intelliRock* system. “We developed confidence in the *intelliRock* system when we learned about the success they were having with it in Texas,” says Byers. The expectation was that the use of *intelliRock* would let the contractor better plan the timing of subsequent construction activities without sacrificing quality or safety.

In addition to scheduling advantages, the *intelliRock* system added a new dimension of quality control to the project. Based on methods pioneered by TxDOT, periodic destructive testing results were compared to the strengths predicted by the maturity method. Any discrepancy could indicate an unintentional change in the concrete mix provided to the job site. However, engineers on site were impressed with the across-the-board agreement between the cylinder break strength and the strength predicted by the *intelliRock* system.

Project Details

The reconstruction of the bridge required replacing three piers and four spans – just over 500 feet of bridge. Gilbert Central Corporation used ODOT spec AA high early concrete with super plasticizer for pouring abutments, piers, drill shafts, curbs, walls and the deck. The project consumed about 5,000 cubic yards of concrete, and as it was placed in the formwork, one or more *intelliRock* maturity loggers were placed in each structural element. The loggers process the time-temperature history of the structure and store the resulting maturity history of the concrete at the specific location of the logger. Project engineers using a handheld reader, were able to connect to these embedded loggers and easily determine the corresponding strength of the structure at any time from the maturity data provided by the logger. The *intelliRock* system provided data to project engineers that allowed stripping of forms from the crash wall and pier caps in record time. In fact, forms were stripped just 12 ½ hours after pouring pier cap #3!



*An engineer takes a strength reading at the I-40 bridge construction site using *intelliRock*.*

***intelliRock* Helps Land \$1.5 Million Bonus**

On July 29, 2002, Mary Peters, administrator for the U.S. Department of Transportation's Federal Highway Administration, presided over the ribbon cutting for the completed Interstate 40 bridge, just 47 days after the reconstruction project began, a full ten days ahead of schedule. This remarkable feat earned the contractor a \$1.5 million dollar bonus. The maturity method and the *intelliRock* system played a role in this success. "When coupled with the high-early concrete used on the project, *intelliRock* resulted in significant overall time savings, and enabled considerable acceleration of form removal operations," concludes Byers.



I-40 Bridge, July 26, 2002.

"When coupled with the high-early concrete used on the project, *intelliRock* resulted in significant overall time savings, and enabled considerable acceleration of form removal operations."



Flintco, Inc. - OU Memorial Stadium Construction Project, Norman, OK

Flintco Inc. is adding 8,000 seats and 27 suites to the University of Oklahoma Memorial Stadium as part of a \$52 million, 18-month project. At a cost of less than \$5,000, the intelliRock concrete strength measurement system has saved Flintco \$309,000 in man-hour costs.

Project Background

In January 2002, an 18-month project began to add seating capacity to Memorial Stadium on the University of Oklahoma campus. This \$52 million project was awarded to Flintco Inc., a top 50 commercial contractors in the United States. The project, scheduled for completion by the end of August 2003, will add an upper deck supported by 168' columns. This new deck extends over the existing seating, and will add 8,000 seats and 27 skyboxes to the 75,000-seat stadium. By the time the project is complete, it will consume about 18,000 cubic yards of concrete. Flintco used a 5,000-PSI concrete mix containing fly ash, which was placed using pumps and buckets:

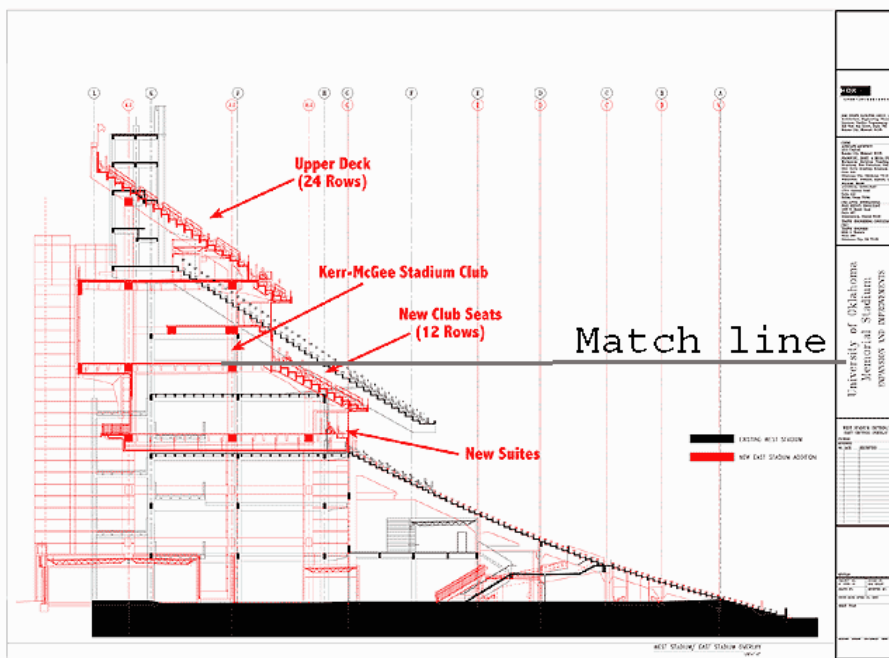


- Performance: 5,000 PSI @ 28 days
- Slump Range: 2 inches to 4 inches
- ASTM Stone Size: #67
- Water/Cement Ratio: 0.36

The University of Oklahoma's first home football game for the 2003 season is scheduled for August 30, presenting Flintco with a challenging construction schedule. Flintco will incur heavy penalties per seat and per skybox – as much as \$2.5 million per game – if the new stadium facilities are unavailable in time. Project superintendent Rick Cole, no stranger to difficult construction projects, was previously the superintendent on the \$88 million, 20,000-seat Ford Arena project in downtown Oklahoma City. He is currently running two shifts full-time

and a part-time graveyard shift, six days per week. From the beginning of the project, the concrete work was in the critical path, and Cole looked for ways to expedite it. Innovative means and methods to keep the project on schedule were of interest.

The *intelliRock* concrete strength and quality control system came to the attention of Tom Heffernan, Flintco Director of Field Operations, because of its use on the highly publicized I-40 Bridge reconstruction project in Oklahoma. The use of



intelliRock on the I-40 project helped earn the contractor a \$1.5 million early completion bonus. (For detail on this and other projects, please visit <http://www.intelliRock.com> and follow the link to "Case Studies.")



University of Oklahoma Memorial Stadium – Oct.7, 2002.

Heffernan realized that the *intelliRock* system could provide him with a method to estimate the strength of a concrete structure at any time, indicating when a placement had reached the strength necessary for subsequent operations, such as stripping forms and reshoring activities.

Based on ACI and ASTM standards for using the maturity method of estimating concrete strength, *intelliRock* estimates the strength within the structure, not a specimen. This is critical because the temperature of test specimens is typically different than the temperature of the structure. Therefore the structure and the test specimens gain strength at different rates. The original project specification allowed for the stripping of forms when the concrete reached 75% of the design strength, as determined by traditional destructive cylinder testing, AND when seven days had passed. By using *intelliRock* sensors to estimate the strength of the structure itself, the construction process could be accelerated considerably.

Prior to utilizing *intelliRock* on the project, Heffernan and Cole had to get the approval of the structural engineer. Initially, project engineer Larry E. Curtis, PE of Kirkpatrick, Forest & Curtis PC, needed some evidence of the *intelliRock* system's reliability before permitting its use. Cole ran a series of tests, comparing *intelliRock* strength data to cylinder testing data. Based on these results Curtis

decided to allow the use of the *intelliRock* system on the project as long as strict quality control plan was implemented.



University of Oklahoma Memorial Stadium – Dec.16, 2002

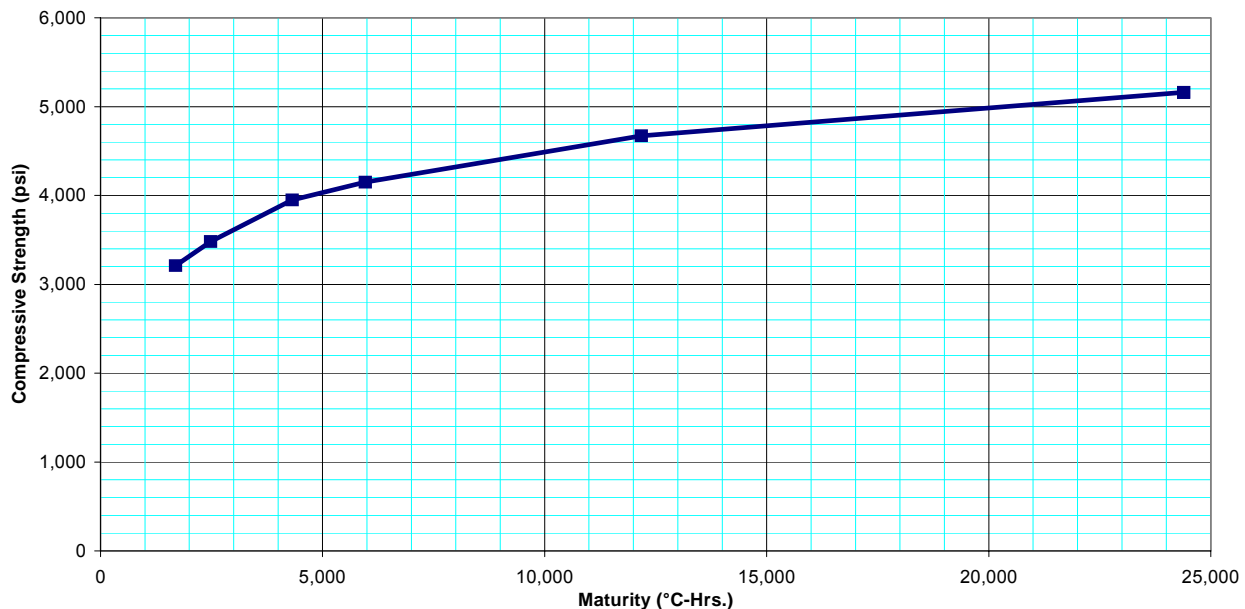
Prior to implementing the *intelliRock* system on the project, Heffernan met with the key project

team members to educate them on the capabilities of the *intelliRock* system. This meeting included the concrete producer's quality control engineer, the testing lab's engineer and all project superintendents. During the meeting, the critical path applications as well as the quality control/quality assurance aspects of the *intelliRock* system were explained.

Flintco began using the *intelliRock* system on the stadium project during July 2002. It began by developing a calibration curve (see Strength – Maturity graph) which correlates the maturity data from the *intelliRock* system with the strength gain of the concrete mix being used. Cole placed *intelliRock* sensors in each of the horizontal beams, cross members and cast-in-place floor sections. During the project, a variety of people from concrete superintendents, to labor and carpenter foremen, and Quality Control managers would periodically take in-situ readings to estimate the concrete's strength.

In warm weather, the *intelliRock* system indicated that 75% strength was often achieved in as little as two and one half to three days. This information allowed Cole to cycle the limited number of specialty forms and re-shore faster, often in half the time expected based on traditional cylinder testing called for by the

Strength - Maturity Relationship



original project specification. The advantages of this approach were significant: faster forms cycling would shave weeks off the construction schedule – up to four days per placement, save man-hours, lower form rental costs, and reduce the number of cylinder breaks required in the quality control process.

In cold weather, concrete gains strength more slowly, and the *intelliRock* system would allow Cole to monitor a structure's temperature to know how much heat was necessary to apply in order to accelerate its strength gain. The *intelliRock* system provided a more accurate estimate of the actual structure's strength than did cylinder specimens, ensuring that forms were not stripped or the structure loaded

“In the last six months, the *intelliRock* maturity system has saved us \$309,000 in man-hour costs. Our expenditure has been less than \$5,000, and in cold weather it has kept us from stripping forms too early.”

prematurely. “The quality assurance data *intelliRock* provided throughout the winter was a big benefit to the project,” stated Cole. “It provided in-situ information on which to base critical construction decisions.”

“In the last six months the *intelliRock* maturity system has saved us \$309,000 in man-hour costs,” stated Tom Heffernan. “Our expenditure has been less than \$5,000, and in cold weather it has kept us from stripping forms too early”.

“The *intelliRock* maturity system has been an asset to the project. During warmer weather, it has benefited the construction schedule by allowing earlier form removal than would have been allowed per destructive testing of laboratory-cured cylinders. In cooler weather, it has provided the assurance that concrete has achieved proper strength prior to form removal.”

“The *intelliRock* maturity system has been an asset to the project,” said Curtis. “During warmer weather, it has benefited the construction schedule by allowing earlier form removal than would have been allowed per destructive testing of laboratory-cured cylinders. In cooler weather, it has provided the assurance that concrete has achieved proper strength prior to form removal.”



University of Oklahoma Memorial Stadium – Jan. 13, 2003.

“The intelliRock system has changed the way we will approach concrete intensive jobs, and I will continue to use intelliRock on future projects.”

Cole found the *intelliRock* system easy to implement and use. “I’ve had experience using thermocouple devices to measure temperature on another project. The *intelliRock* system is much more advanced than a thermocouple device. It was also simple for my people to use, at times I have utilized carpenter and labor foreman to download strength data. The beneficial aspects of the system extend beyond the obvious critical path advantages, into the realm of quality control and quality assurance. It provides a new perspective for driving project concrete operations. The *intelliRock* system has changed the way we will approach concrete intensive jobs, and I will continue to use *intelliRock* on future projects.”



Flintco, Inc. - Courtyard by Marriott Project, Oklahoma City, OK

Flintco Inc. is completing an eight-story, 225-room Marriott Courtyard hotel in downtown Oklahoma City. Using the intelliRock system to optimize post-tensioning and provide reliable temperature profiling during cold-weather concrete operations saved one day per pour during the project.

Project Background

Flintco Inc. is nearing completion on a 225-room Marriott Courtyard hotel being built in downtown Oklahoma City. The \$20-million project will place about 7,400 cubic yards of concrete for cast-in-place piers and 16 elevated decks. The 7.5 inch elevated decks are post-tensioned. For this project, Flintco used a 5,000-PSI concrete mix with high-range plasticizer and water reducing agent:

- Performance: 5,000 PSI @ 28 days
- ASTM Stone Size: #57
- Water/Cement Ratio: 0.39

The project began in late fall during the time of year that would require Flintco Project Superintendent, Randy Holland, to do much of the cast-in-place concrete work during cooler weather, when concrete gains strength more slowly. Holland gained experience with the *intelliRock* system while using it on the \$52 million University of Oklahoma football stadium expansion project. With *intelliRock*, Holland could check real-time, in-situ concrete temperature and strength at any time, a great advantage on this post-tensioned, elevated deck job. The *intelliRock* system's ability to provide traceable documentation on a structure's temperature also made *intelliRock* a valuable quality assurance tool.

Estimating Concrete Strength

The *intelliRock* system streamlined and accelerated concrete operations on the project based on ACI and ASTM standards for using the maturity method of estimating concrete strength. The *intelliRock* system estimates the strength gain within the structure, not within a companion specimen, a critical difference because the hydration rate of test specimens is typically different than the hydration rate of the placed element. Utilizing a system that measures and records in-situ strength and

temperature is an improvement over using traditional test specimens, since they gain strength at different rates.

Normally a testing lab, through destructive testing of cylinder specimens, provides estimates of concrete strength on a project like this. Even though this project's contract called for pulling six to eight extra early break cylinders, Holland implemented the *intelliRock* system in order to know the strength of a placement at any given time, without having to call the lab and have a set of cylinders tested which would not represent the true strength of the placement.



Flintco Project Superintendent Randy Holland.

Optimizing Post-tensioning with *intelliRock*

Since this job involved placing post-tensioned elevated decks, Holland knew that the ability to check in-place strength in real-time with the *intelliRock* system would significantly enhance his critical path as well as his QA efforts – it allowed Holland to know when to stress the post-tension cables. “We would pour concrete and plan on stressing at a minimum of 60% of design strength,” stated Holland. “But you shouldn’t wait until it reaches 100%. There is a window where you can stress per specifications. I like to do it as soon as I know and can document that we have reached the required 60% strength.”



Job site in downtown Oklahoma City, April 2003.

As concrete cures, it shrinks, building up internal tensile stresses. When those internal stresses exceed the tensile strength, a crack develops. If post-tensioning is done too early, there is risk of compressive-strength failure. If post-tensioning is done at the right time, it reduces overall crack formation by counteracting the tensile stresses before they exceed the tensile strength. If done too late, the post-tensioning will still hold the cracks together and be structurally sound, but with arguably increased exposure to water- and salt-intrusion, corrosion, etc. By using the *intelliRock* system, Holland had timely information and thus, confidence about when the optimal time had arrived to stress the cables.

Concrete Operations

The strength estimates provided by the *intelliRock* system allowed Holland to accelerate the project workflow. “On a cast-in-place job, the quicker you can cycle the forms, the faster the job is going to go,” said Holland. “The key to cycling the forms is knowing when you reach the required strength. On this job, I was able to cycle forms in 2 to 3 days even in colder weather because we had the in-situ information necessary to know how much the element needed protection or how much supplementary heat was needed. Had I waited for cylinder results from the lab, it would have taken five to seven days.” On this project, cycling forms faster based on *intelliRock* strength estimates saved Holland on the average one 8-hour day per pour. The total number of man-hours saved for the 16 pours on the project totaled 128 hours.

During a deck pour, which was either 6,500 square feet or 11,000 square feet deck, Holland would place an *intelliRock* logger in each deck, toward the end of the pour but away from the edge. When these loggers indicated strength was reached, Holland knew the rest of the deck had achieved strength as well. “Having used the *intelliRock* system before, I know the loggers are giving me a true strength reading,” continued Holland. “I also used *intelliRock* to validate data from cylinder breaks. There is a lot of human error in the cylinder testing process – how they get taken, stored, handled, and cured, etc. On this particular job, we continued to break validation cylinders for the purpose of confirming the QC batching process. In addition, the cylinder breaks provided a level of comfort to some professionals on the project who weren’t familiar with *intelliRock*. Based on the *intelliRock* information, I would make sure to get cylinder breaks as quickly as possible, but it was the sensors I relied on to know that structurally the concrete was okay.”

“Having used the *intelliRock* system before, I know the loggers are giving me a true strength reading...There is a lot of human error in the cylinder testing process – how they get taken, stored, handled, and cured, etc.”

Cold Weather Quality Assurance

The *intelliRock* system also proved its QA worth by providing Holland a way to check concrete temperatures and strengths in cold weather. “We began pouring piers in September, and poured elevated decks during December, January, and February, during what turned out to be an unusually cold winter,” Holland said. “I had to make to make sure the concrete didn’t freeze. Keeping it warmer would let it gain strength faster.”

Project specifications required that concrete temperature on placements be at least 50 °F (10 °C) or above. After a pour is completed, concrete begins to generate its own heat, however, in cold weather it is sometimes necessary to heat from underneath as well as with blankets. Holland would routinely connect the *intelliRock* reader to the embedded sensors within the first 24 hours just to check the temperature of a placement. “This was

important, because I was spending money wrapping decks, tenting them underneath and heating them. At one point during the project, I had 3 million BTUs of heat running. As long as I had at least 50 °F (10 °C) concrete temperatures and it didn't freeze, it was okay. At 25 °F (-3.9 °C) ambient temperature, I was having 70 °F (21.1 °C) concrete."



Taking a reading using the *intelliRock* system reader.

War Stories

Holland recalls one concrete pour that, because of the weather forecast, he decided to use a hot-water mix. The pour was completed in mid-afternoon. That night, temperatures in the teens with a north wind were predicted. "The next morning, as I drove up to the site, I could see that during the night the wind had blown many of the blankets off the deck, and sometime after midnight, power to about half the heaters had been lost as well. The outside temperature was 19 °F (-7.2 °C). I was worried about having frozen concrete. I quickly took a few sensor readings from the deck placement – the concrete temperature was 60 °F (15.5 °C). This information allowed me to simply put the blankets back on the slab without any concerns."

Knowing he would need supporting documentation from cylinder breaks, Holland called the testing lab and asked for some cylinders breaks from the pour. The *intelliRock* system was already indicating 65% strength on

this deck, but the testing lab cylinder break data showed only 40-45%. Suspecting a problem with the way the tested cylinders were handled, Holland called the concrete producer, who had also cast some cylinders, and had those cylinders tested. These test results confirmed the *intelliRock* data. Upon investigation, Holland learned that the first set of cylinders tested by the lab had not been stored properly. They had been left out unprotected overnight and had frozen, accounting for the low breaks.

Without the in-situ, real-time strength estimates provided by the *intelliRock* system, Holland would have been faced with coring the placement to verify its strength. Besides slowing down the critical path, coring a post-tensioned slab can create another problem - the risk of cutting a cable during the process. Without *intelliRock* to provide quality assurance information to resolve this incident, it would have set the project back significantly in terms of time and money.

"intelliRock was a quality assurance and quality control tool that let me know when to stress and continually cycle forms to keep the job moving."

Summary

"*intelliRock* was a quality assurance and quality control tool that let me know when to stress tendons and continually cycle forms to keep the job moving," concludes Holland. "Pouring through the winter, just being able to know the concrete's temperature was a big help. This is my second job using *intelliRock* – I will not do another cast-in-place concrete job of any size without using *intelliRock*, because it speeds the project up, saves money and because of the quality assurance data it provides. It lets me know where I am with my strength and temperature. If you are ever going to get into an argument with a testing lab or a structural engineer, you need some data to verify your position, and the *intelliRock* system provides that."

"I will not do another cast-in-place concrete job of any size without using intelliRock, because it speeds the project up, saves money and because of the quality assurance data it provides."



Gohmann Asphalt & Construction, Inc. - Interstate 65 Paving Project, Indiana

The IntelliRock system provided Gohmann Asphalt & Construction with a powerful QC/QA tool for a performance-based paving contract. Not only did it provide documentation of compliance with strength criteria, it helped ensure that cold weather concrete placements were within temperature specifications, helping earn the company a significant bonus.

Project Background

In 2002, Gohmann Asphalt & Construction Inc. was awarded a performance contract by the Indiana Department of Transportation (INDOT) to pave a section of Interstate 65 between mile marker 4.5 and 7 with concrete. This was only the second performance contract awarded at that time by INDOT. The bid specifications for the pavement called for a thickness of 375 millimeters (14.8 inches) and a width of 7.2 meters (7.87 yards).

The performance specifications associated with this job were based on the degree of deviation from key specifications, one of which was 7-day strength. Staying within the acceptable range of deviation from these specifications could earn Gohmann a bonus, but if the deviation were too great, penalties would result. For this project, INDOT specifications required 550-flexural strength to open pavement to construction traffic. To receive 100 percent payment, Gohmann had to achieve 570-flexural strength within seven days, and eligibility for a bonus required that concrete attain 650-flexural strength within 28 days.



Thermocouple-based System Woes

On previous projects with performance specifications, Gohmann had used thermocouple-based systems to estimate concrete placement strength. These systems employ an external unit to process and log time and temperature information. These units or boxes connect to thermocouples threaded in concrete structures. Gohmann's experience with thermocouple-based systems had not been trouble-free. It experienced many of the problems related to the use of such systems, such as thermocouple wires breaking during and after concrete placement and damage to the external units from accidents, vandalism or weather.

In 2002, Gohmann Bridge Division Manager Roy Zimmerman learned about the *intelliRock* system, a comprehensive concrete strength and quality measurement system that allows contractors to conveniently utilize the maturity method to non-destructively determine in-place concrete strength. Based on ACI⁵ and ASTM⁶ standards for using the maturity method of estimating concrete strength, the *intelliRock* system estimates the strength within the structure, not a specimen. Zimmerman introduced others in the division to *intelliRock*, including Mike Kaelin, Concrete Lab and QC/QA Supervisor at Gohmann.

The *intelliRock* System

The *intelliRock* maturity system consists of three components:

- A logger: An intelligent sensor that calculates maturity within the concrete element where it is placed.
- A handheld reader: The *intelliRock* reader is used to communicate with and download maturity and temperature data from the loggers.
- Software: The *intelliRock* software facilitates the downloading of maturity and temperature data from the reader into secure, unalterable electronic files for subsequent distribution, documentation and/or analysis.

At the same time concrete is placed in the formwork, one or more *intelliRock* maturity loggers are placed in the concrete as well. The loggers compute the time-temperature history of the concrete and store the resulting maturity history of the concrete at the specific location of the logger. The corresponding strength of the structure is easily determined at any time from the maturity data provided by the logger in conjunction with previously determined strength-maturity relationship data. This timely information about concrete strength can accelerate the construction process and also functions as a powerful QC/QA tool.

The *intelliRock* loggers function independently for up to three months, without permanent connection to any external devices. This arrangement allows multiple loggers to be controlled and accessed by a single handheld reader, making the system ideal for use at multiple sites, and eliminating system damage and lost data from vandalism, theft, weather and other job site hazards.

Because of the problems Gohmann experienced with thermocouple-based systems, it purchased an *intelliRock* system and started using it on this job. But Joel Field, Paving Division Manager, concerned about whether maturity would work or be implemented successfully, was initially skeptical about the introduction of *intelliRock*. His concerns had to do with whether the QC department was ready to make the commitment necessary, and had the ability to fully utilize the maturity method.

Also, Field was concerned that the *intelliRock* system might just be another \$1,500 gadget being hyped. Kaelin and Field struck a bargain – Kaelin would try the *intelliRock* system. If it worked, Field agreed to absorb the cost, but if it didn't Kaelin would pay the expense out of his budget. "There was some perceived risk," Kaelin noted. "We have a saying here, 'all change is not good, and all progress is not forward!'"

Project Time Constraints

The specifications for this project required Gohmann to complete 50 percent of the paving by December 31, 2002, and the remaining 50 percent during 2003. Work was begun on the northbound lanes, but by October 15, 2002, only 15 percent of the paving had been complete. To complete the work on time, without sacrificing any bonuses, or incurring penalties, Gohmann would have to place a lot of concrete during colder weather.



"We ended up doing a lot of concrete placement in November and December [2002]," stated Kaelin. "December is not my favorite month to place concrete. Only two months are worse – February and July."

INDOT specifications state that concrete placement could only occur when the ambient air temperature was 35 °F (1.67 °C) and rising, and concrete operations had to cease when the ambient air temperature was 37 °F (2.78 °C) and falling.

To ensure that concrete placements were within temperature range specifications, Kaelin used the *intelliRock* system to do temperature

profiling. Using a hot water mix during November and December, concrete was leaving Gohmann's plant at 75 °F (23.9 °C). An *intelliRock* logger was placed 100 feet from the end of each day's production run, a minimum of 18 inches from the edge. Kaelin and the INDOT inspectors were able to use the *intelliRock* handheld reader to connect to the logger and get a real-time, in-place strength reading as well as temperature history.

"The INDOT inspectors were very happy with this arrangement, because they could use the *intelliRock* reader and take measurements on their own," continued Kaelin. "The easier it is for the inspector to get the information they need, the happier they are."



In-house, *intelliRock* was gaining supporters as well. Once a skeptic, Paving Division Manager Joel Field has become an advocate of the *intelliRock* system, and is now pushing to get it accepted for use on projects in Indiana with early-opening strength payment criteria. Currently, INDOT still relies on seven-day beam flexural strength breaks to determine strength payments to contractors.

Bonus Time

Using the *intelliRock* system as part of the quality control/quality assurance process for this job, Gohmann averaged placing about 1200-1300 feet of pavement per day. 23,000 cubic yards of concrete were placed in the month of December 2002 alone. "We averaged 66 hours on turnaround – the time from placing the concrete with the *intelliRock* logger embedded, to putting traffic back on it," Kaelin commented. "We had traffic running on this pavement by January 15th [2003]. Without a system like *intelliRock*, we would have been sitting around waiting on field-cured beams that do not retain heat and gain strength like the pavement will. It would have slowed the project down. Without *intelliRock*, we most likely would still have been paving on January 15th, instead of traffic driving on it."

The *intelliRock* system helped Gohmann successfully complete the first 50 percent of this project by December 31, 2003, earning Gohmann a significant bonus.

Since then, Joel Field, Concrete Paving Division Manager for Gohmann, won't bid a job without including the *intelliRock* system as part of the bid. "Jobs where maturity are NOT part of the specification carry more risk." Field's enthusiasm for *intelliRock* is a reflection of the paving division's attitude, which now pushes Kaelin's organization to quickly develop the maturity calibration curves it needs to implement *intelliRock* on projects. "The skepticism turned around when we went from opening pavement in three to four days from field-cured breaks, to opening pavement in 27 hours in some cases, thanks to *intelliRock*," concluded Kaelin.



Zachry Construction Corporation – Dallas High Five Construction Project

Zachry Construction Corporation is on track to earn a large portion of \$11 million in bonus for early completion of the Dallas High Five interchange. Use of the IntelliRock system for measuring concrete maturity is one of the reasons why the project is 38 percent completed after only 18 months.

Project Background

The Dallas High Five is a \$261 million project by the Texas Department of Transportation (TxDOT) to build a five-level interchange where I-635 and US 75 meet in Dallas. It is the largest single contract in TxDOT's history. Zachry Construction Corporation is the contractor. The project began on January 2, 2002 and is scheduled for completion in April 2007.

Zachry is a privately held construction company, headquartered in San Antonio, Texas. The company provides a wide array of services including construction, project development, construction management, and industrial maintenance to both domestic and international customers. Zachry constructs and maintains power plants, steel mills, pulp and paper mills, chemical plants and refineries. Dams, reservoirs, airfields, runways, highways, wastewater treatment plants, and commercial construction are also included in Zachry's portfolio.



Dallas High Five Interchange Model.

The existing interchange was a bottleneck for rush hour traffic. The traffic count is 500,000 vehicles per day, making it one of the busiest interchanges in the country. US 75 narrowed from four lanes to two lanes before and after the interchange, frontage roads ended and forced

local traffic onto the highway, and existing cloverleaf loops slowed traffic. The resulting stop-and-go problem could back up traffic for one to two hours. TxDOT expects the project to result in improved driver safety, improved air quality, better local access, increased traffic capacity, and flexibility to meet future growth.

The project will use 500,000 cubic yards of concrete for structures, drill shafts, walls, and paving. Terms of the contract include incentives to meet or beat the completion date. TxDOT will pay Zachry a \$32,000 per day bonus for every day that Zachry completes the project earlier than 1,800 days. However, Zachry must pay TxDOT \$82,000 per day for each day later than 1,800 days. The maximum bonus is \$11 million should Zachry complete the project in four years or less. To accelerate workflow, TxDOT specified the use of the concrete maturity method on this project. The maturity method is an ACI and ASTM standard for estimating concrete strength based on variables such as temperature.

TxDOT and the Maturity Method

In January 1991, the Center for Transportation Research at the University of Texas published research report 1198-1F, concluding that "of all the test methods evaluated, the maturity method was found to be the only one that provided reliable data comparable in variability and consistency to those obtained from standard quality control specimens." Over the past decade, TxDOT has completed two large field studies utilizing concrete maturity on projects totaling over \$200 million and involving several hundred thousand cubic yards of concrete. The earlier use of the maturity method on these TxDOT projects was successful. Since the implementation of maturity ten years ago, TxDOT has now completed or let concrete maturity projects totaling over \$1.6 billion.

The initial use of the maturity method on a large TxDOT project came on a project that was let in 1993, when it was used on the Dallas Central Expressway, where Granite Construction was the contractor. This project involved a lot of sequence work, including a bridge with 18 construction phases. At that time, best practices recommended a 27-day wait between phases. The use of the maturity method reduced to as few as four days the time needed between phases. The success of maturity on that project led to the development of a statewide maturity specification. Now, other large TxDOT districts have begun to specify the maturity method in their projects as well, including pavement patching and restoration jobs with 6-hour opening and closing schedules

The Dallas High Five is the first project where TxDOT contractually required the use of the maturity method to check concrete strength. For Zachry, this was their first time to use maturity on a job. “We were somewhat hesitant at the beginning of the project, because of our lack of experience with the maturity process,” admitted Brian Salerno P.E., Dallas High Five Project Director for Zachry. “But, once the requirement was there, we started looking for the best way to implement it.”



Brian Salerno, P.E., Dallas High Five Project Director,
Zachry Construction Corporation.

Implementing the concrete maturity method on a project requires the use of a system for measuring maturity. Prior to selecting the *intelliRock* system, Zachry tried two other products that utilized external boxes for measuring maturity with which TxDOT had previous experience. These systems were powered with standard nine-volt batteries. Those designs were unusable because the batteries did not last through a complete maturity cycle, resulting in lost data. The manufacturer reconfigured the system to use less power, and ultimately switched to rechargeable batteries in an effort to solve this problem. But problems with the system's reliability continued. Zachry learned about the *intelliRock* system through TxDOT personnel who had recently used it successfully on another Dallas-area project. The decision was made to use the *intelliRock* system on this project as well.

The *intelliRock* System

The *intelliRock* maturity system consists of three components:

- A logger: An intelligent sensor that calculates maturity within the concrete element where it is placed.
- A handheld reader: The *intelliRock* reader is used to conveniently download maturity and temperature data from the loggers.
- Software: The *intelliRock* software facilitates the downloading of maturity and temperature data from the reader into secure, unalterable electronic files for subsequent distribution, documentation and/or analysis.

At the same time concrete is placed in the formwork, one or more *intelliRock* maturity loggers are placed in the concrete. The loggers calculate the time-temperature profile, record the maximum and minimum temperature and the seven-day strength history of the concrete. The resulting information is stored for downloading at the contractor's convenience. The corresponding strength of the structure is easily determined at any time from the maturity data provided by the logger in conjunction with previously determined strength-maturity relationship data. This timely information about the concrete's strength can accelerate the construction process and it also functions as a powerful QC/QA tool.



Dallas High Five Construction Site.

The *intelliRock* loggers function independently for three months or more without a permanent connection to any external devices. This design allows access to an unlimited number of loggers for information downloading by a single handheld reader, making the system ideal for use at multiple sites. In addition, this design eliminates potential system damage and lost data from vandalism, theft, weather and other job site hazards.

Measuring Maturity with *intelliRock*

Zachry schedules a pour and TxDOT inspectors install the *intelliRock* loggers and collect the data. By specification, *intelliRock* loggers are placed every 60 yards in structures, and every 2,500 square yards in pavement. It is estimated that over the life of the project, TxDOT will install approximately 8,000 *intelliRock* loggers. TxDOT uses the data to determine maturity and whether a structure meets strength specifications. (So far, all Zachry pours have met specifications.) This has allowed Zachry and TxDOT to substantially reduce the number of cylinders needed for the concrete strength testing process. There are many steps in the traditional cylinder testing process that introduce potential errors that can result in low cylinder breaks. Should this happen, TxDOT must core the structure to determine if the placed concrete meets design strength. By using the *intelliRock* system's real-time data, the strength of the placed element is easily determined and documented. Because the Dallas High Five site is so large, traditional cylinder tests are still used in some parts of the project where data collection is a problem, but the use of the *intelliRock* system has reduced the number of cylinder breaks by approximately 70 percent.



Dallas High Five Construction Site.

According to Jim Hunt, P.E., Director of Construction, Dallas District, TxDOT, "The structural segmental work on the project is where some of the most dramatic benefits of maturity occur. The original plans called for cast-in-place segments where it would take an average of 21 days for each segment to be completed." By changing to pre-cast segments using maturity, the *intelliRock* system indicates the specified 2,500-psi is achieved in 10-12 hours. "It is phenomenal the rate at which they are able to complete work by pre-casting and using *intelliRock* to tell when we really have strength."



Jim Hunt, P.E., Director of Construction, Dallas District, TxDOT

TxDOT has a recent history of using incentives to help get projects to completion on schedule. "We used lane rental, windowed milestones, and other incentives," says Hunt. "Something like maturity really helps the contractor to make these incentives." Zachry is a believer. After just 18 months of work or 30 percent of the contract time, the Dallas High Five construction is 38 percent complete. At this rate, Zachry is on track to collect a large portion of the \$11 million early completion incentives.

"It is phenomenal the rate at which they are able to complete work by pre-casting and using IntelliRock to tell when we really have strength. "

IntelliRock Advantages

Compared to other products evaluated for use with TxDOT jobs, the IntelliRock system offered several advantages. First, the IntelliRock loggers provide anytime, current data, while some products used inadequate power sources that failed before completion of the maturity cycle. Second, some products include only the loggers but not the software to calculate maturity based on the logger data. IntelliRock is a complete, end-to-end solution that measures, gathers, and reports maturity data to estimate early concrete strength in real time. Third, unlike companies that make systems with external components,

IntelliRock loggers are placed inside the element itself where they can't be damaged or stolen. Says Hunt, "IntelliRock is the technology leader. We are really satisfied with it."

IntelliRock Benefits and ROI

The use of the IntelliRock system is helping the Dallas High Five project stay ahead of schedule. "We put maturity into the project because we knew it had the capability of streamlining the work," says Hunt. For the TxDOT and the 500,000 vehicles per day that pass through the interchange, the IntelliRock system will help bring relief from traffic congestion years faster than could have been done otherwise. For Zachry, the use of maturity and IntelliRock has them on track to collect a large portion of \$11 million in early completion incentives.



Dallas High Five Construction Site.

"IntelliRock is the technology leader. We are really satisfied with it. "

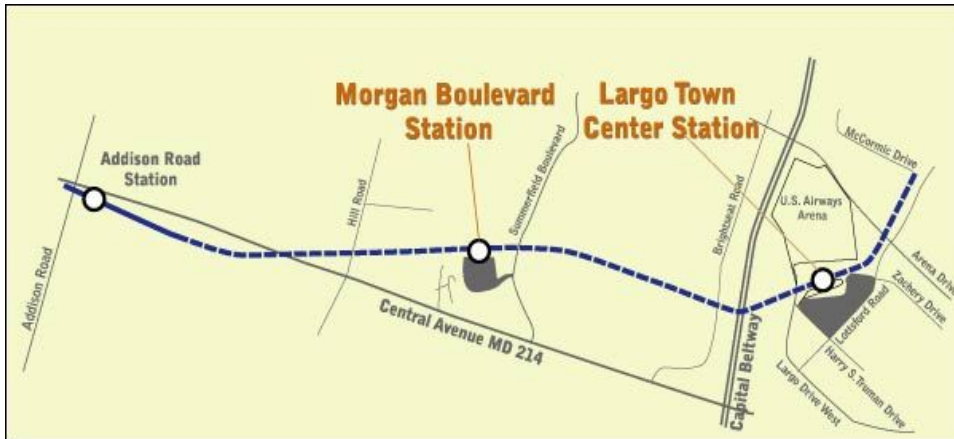


LGS Joint Venture - Washington Metropolitan Area Transit Authority (WMATA), Washington D.C

Using the intelliRock system on the Washington Metropolitan Area Transit Authority Blue Line Extension project to optimize concrete workflow operations has been an effective, economical alternative to purchasing additional traveling forms. Furthermore, intelliRock provides the concrete maturity data and QC/QA information needed to keep the project moving on schedule, even during the cold weather months.

Project Background

A joint venture between the Lane Construction Corporation, Granite Construction and Slattery Skanska, known as LGS, is constructing a \$217 million major mass transportation project in suburban Washington, D.C. for the Washington Metropolitan Area Transit Authority (WMATA). Jacobs Engineering is the lead design firm, and the Lane Construction Corporation serves as the lead contractor performing the work.



Map depicting WMATA extension project

This contract involves 3.1 miles of concrete cut-and-cover double box units with a concrete wall separating the inbound and outbound track. Several multi-span aerial structures on concrete piers will be constructed along with retained cut reinforced concrete walls. Over 150,000 cubic yards of concrete will be placed. Extensive mechanical and electrical systems including tunnel ventilation systems as well as track electrification are also included in the design-build contract. All track work and automated control systems including train protection, train operation, and automatic train supervision will provide WMATA with a complete system ready for use by winter of 2004.

Maturity Method is Project Accelerator

For the WMATA project, construction of the double-box concrete tunnel is in the critical path. In order to meet the aggressive construction schedule, LGS is utilizing the concrete maturity method to determine how soon it is safe to strip forms. The maturity method is an ACI and ASTM standard for non-destructive testing and early estimation of concrete strength. LGS has implemented the method using the *intelliRock* system to estimate the concrete's in-situ strength in real time. The *intelliRock* system uses the Nurse-Saul maturity method to estimate concrete strength within the placement itself, as opposed to a companion test specimen. This is a critical difference, since the placed concrete and associated companion test specimens typically gain strength at different rates.

LGS Selects Maturity Measurement Device

The *intelliRock* system uses an embedded sensor that contains a microprocessor, a precision temperature sensor and battery to measure temperature and calculate concrete maturity in real time with *no permanently affixed external devices*. The sensor (or "logger") is placed into the concrete structure at the time of placement and then activated using a handheld reader. The reader is then disconnected, leaving only 18-gauge lead wires protruding from the concrete. Whenever a strength measurement is desired, the handheld reader is easily connected to the leads and the current maturity and associated temperature is displayed. In addition, a seven-day history of temperature and maturity values, and

the time-stamped minimum and maximum temperatures are displayed and then full documentation is downloadable to a personal computer in a secure, unalterable format.

Before selecting *intelliRock*, LGS considered a type of concrete measurement device that was labor intensive, large and unwieldy, and required connection to an external device for the duration of the strength cycle, exposing it to damage or theft. Greg Johannes, Project Manager, learned about the *intelliRock* system in August 2002 and decided to try it on this project.

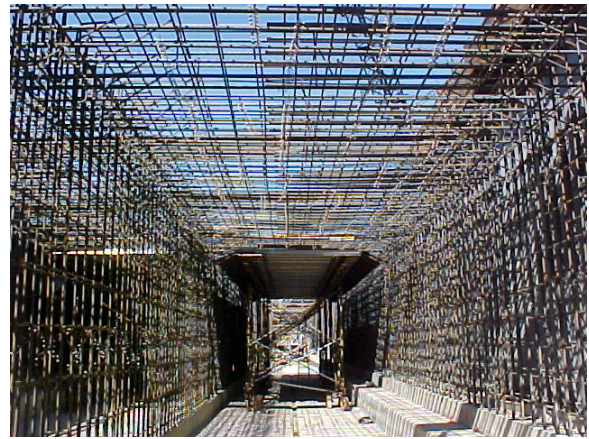
Maturity & *intelliRock* Create Immediate Savings

For the Washington Metro extension project, construction crews place concrete on one day, and are able to strip forms the following day based on maturity data provided by the *intelliRock* system. LGS submitted an aggressive bid, knowing it would need to expedite the critical path by stripping forms early. If LGS could do this, it would avoid purchasing additional expensive moving formworks, or travelers, (see figure below). Using the *intelliRock* maturity system has allowed the project to progress without increasing the number of traveling form units estimated at bid time.



Moving formworks, or traveler system.

Mike Branson, C.E.T., the field Quality Control Inspector, places the *intelliRock* sensors toward the end of a concrete placement, using three sensors in each 50-foot segment of the box tunnel roofs. Each pour contains about 270 cubic yards of concrete with roofs and walls about two feet thick. Before concrete is placed, the *intelliRock* sensors are wired to rebar about six inches deep in the structure, and six inches from the outer edge of the pour. Immediately after the pour, he activates the *intelliRock* sensors and can begin checking the structure's maturity and strength at any time.



Tunnel structure prior to setting forms and pouring

In a typical placement, the *intelliRock* system indicates 1600 PSI, or 40% strength, within 18 hours, which is the strength threshold for stripping forms. At this strength, specifications permit crews to retract the forms and move the traveler to the next location to start the process over. The *intelliRock* system documents the strength data that allows crews to strip the forms as soon as the necessary strength is attained. The critical path enhancements have been significant, allowing completion of three double-box placements per week.

“The *intelliRock* system has been easy to use and allows us to pour and strip forms like clockwork. It is very straightforward – either you have maturity and strength, or you don’t, and the system tells you this.”

***intelliRock* Benefits**

intelliRock has allowed LGS to maintain the aggressive schedule for the WMATA project. “The *intelliRock* system has been easy to use and allows us to pour and strip forms like clockwork. It is very straightforward – either you have maturity and strength or you don’t, and the system tells you this,” says Bob Bolduc, QA/QC Manager for Lane Construction Corporation. The *intelliRock* concrete maturity system is more precise than breaking cylinder specimens, although the project still performs 28-day cylinder breaks as required by contract. “If we didn’t have this system, we’d have to have more cylinders,” adds Bolduc. “As it is, we don’t pull early break cylinders, but have implemented an early mix verification [QC] plan.”

A significant advantage of the *intelliRock* system is the result of its design: all the intelligence of the system is contained in the sensor, which is protected by the concrete in which it is embedded. This approach ensures that the data for documenting strength and critical construction activities in unalterable, and uninterrupted.

intelliRock allowed LGS to continue working through the harsh winter of 2002, extending the construction calendar and allowing the project to stay on the aggressive schedule throughout the winter. The winter of 2002 was one of the harshest on record in the DC area, with snow beginning in December and occurring regularly through mid-March. An exceptionally heavy snow occurred on Valentines Day, blanketing the area with two feet of snow.

“If we didn’t have this system, we’d have to have more cylinders. As it is, we don’t pull early break cylinders, but have implemented an early mix verification [QC] plan.”

Test cylinders rarely gain strength at the same rate the concrete placement does. In colder weather, test cylinders typically gain strength more rapidly; therefore protection (visqueen or blankets) and warmers are utilized on the structure to accelerate strength gain. The use of the *intelliRock* system provided the project team with data that simplified the determination of how much protection and heat the placement required to keep construction on pace.

In warmer weather, companion test cylinders often do not gain strength as rapidly, since placed concrete generates more internal heat than companion test cylinders. For this reason, relying on traditional cylinder testing during cold weather can provide unreliable data from which to make construction decisions, leading to premature forms removal and safety issues. According to Bolduc, “Loggers documented and defined all the parameters and variables, so we have the confidence and documentation to strip in cold weather and keep work moving.” In addition to the time saved, the *intelliRock* system eliminated the expense of purchasing additional specialty moving forms systems (travelers).



Traveling forms pictured just prior to rebar placement

Mr. Ed Shepperson, WMATA Construction Project Engineer, states: “having the strength data taken directly from the structure being placed assured WMATA’s Management and QA staff that the Design-Builder’s early stripping procedure was safe and ultimately resulted in enhanced concrete quality and production.”

The irony of using maturity in the DC area is this: cold weather concreting accidents in this area during the 1970s led to ASTM approval of maturity for early concrete strength estimation.



Duit Construction Company – Interstate 30 Cold Weather Concrete Paving Project, Little Rock, Arkansas

Cold weather threatened to set an Interstate Highway paving job back between six to eight weeks at the outset of the project. Using the IntelliRock system, the paving contractor was able to monitor the in-situ temperature of the pavement in real-time, providing the owner with necessary quality assurance data to allow the contractor to proceed as scheduled.

Project Background

When Duit Construction Company won the bid to pave a section of Interstate 30 southwest of Little Rock, Arkansas; it ran into a weather problem almost from the start.

The first step in this job involved pouring temporary concrete pavement in order to divert traffic from the lanes of the Interstate highway for construction of new, permanent pavement. Unseasonably cold weather during the winter of 2002-2003 threatened to delay the pouring of temporary pavement from between six to eight weeks. Instead, Duit would face the very real possibility of paying a penalty for late completion at the end of the project unless innovative methods were utilized.

Temperature Profiling System Introduced

The Arkansas Highway & Transportation Department (AHTD) specifications for paving in cold weather do not allow for concrete paving to occur when the ambient temperature is 40° F (4.4° C) and falling. Furthermore, paving cannot begin again until ambient temperatures are 35° F (1.7° C) and rising.

John Privrat, Quality Control Engineer for Duit, began to investigate what other states were doing with respect to cold weather concrete paving. He looked very closely at the specification developed by the Colorado Department of Transportation to address this concern. The result of this research revealed that the primary consideration when paving in cold weather is to protect the slab from freezing during the first 72 hours by monitoring the temperature of the slab and using the appropriate thermal protection.

Privrat approached the resident engineer and PBS&J, the consultant on the project, and proposed a change: if Duit could monitor and document that the pavement temperature did not freeze during the initial 72 hours after placement, could Duit continue placing temporary pavement during cold weather? The resident engineer agreed to the change, with the stipulation that Duit would be responsible for performing a petrographic analysis of any slab whose monitored temperature fell below freezing during the initial 72-hour period, and removed and replaced damaged slabs.



Duit crew places temporary pavement for the I-30 job.

Temperature Profiling with IntelliRock

To prove that it could safely place concrete during cooler weather, Duit required an in-situ monitoring system that logs and documents temperature data that is unalterable and un-interruptible. Privrat chose the *IntelliRock* system, which uses an embedded sensor to measure, log and document temperature in real time with no permanently affixed external devices.

The sensor (or “logger”) is placed into the concrete structure at the time of placement and activated using a handheld reader. The reader is then disconnected, leaving only 18-gauge lead wires protruding from the concrete. Whenever a temperature measurement is desired, the handheld reader is simply connected to the leads and the current temperature is displayed. In addition, a history of temperature values, and the time-stamped minimum and maximum temperatures are displayed and full documentation is downloadable to a personal computer in a secure, unalterable format.

Cold Weather Paving Proceeds

Duit began using the *intelliRock* system to continue paving when specifications would normally require a halt to operations. As a slab was being poured, the Project Engineer chose three locations in the slab where an *intelliRock* sensor was embedded: one near the top of the pavement, one in the middle of the pavement thickness, and one near the bottom of the pavement. These sensors were monitored to help determine how much thermal protection to apply to the slab, and to provide documentation on the temperature of the slab during the initial 72-hour window.

The *intelliRock* data from Duit’s experience documented that the entire pavement stayed close to 40° F (4.4° C) – none of the slabs froze.



Placing temporary concrete pavement for I-30 project.

Had Duit not been able to use *intelliRock* for temperature profiling on this project, delays of six to eight weeks would have resulted. “More than half the days we actually paved using the *intelliRock* system to monitor slab temperatures, would have been non-permitted placement days,” states Privrat. “Right now, the project is very tight, so the ability to pave in cold weather was critical to keeping Duit on schedule.”

“More than half the days we actually paved using the *intelliRock* system to monitor slab temperatures, would have been non-permitted placement days. Right now, the project is very tight, so the ability to pave in cold weather was critical to keeping Duit on schedule.”

***intelliRock* FAQ's and Contact Information**

***intelliRock I* FAQs**

Q: How many sensors can be used with each reader?

A: The sensors are completely stand-alone, independent units. Therefore a single reader can be used with an unlimited number of sensors.

Q: How long will the logger operate?

A: Once set to Run mode, the logger will continue to calculate maturity values until the battery dies. Under normal conditions, each logger can continue recording for several months. All loggers are shipped in Standby mode. In this state, the battery will last up to five years.

Q: Can additional wire be added to the loggers?

A: Yes. You may order extension wire from Engius. We do recommend that the connection be watertight. Engius can also provide custom cable lengths on request. *Note that the maximum cable length is significantly decreased if there are long runs (more than 10 ft) in concrete or under water.* Please contact our technical support staff if you have questions regarding this issue.

Q: Does the reader need to be turned off while connecting and disconnecting loggers?

A: No. The electrical connection is quite robust. Remember, however, that the display information is not updated until you request a new reading from the reader.

Q: Sometimes I get a "Bad Connection" message when everything looks fine. What am I doing wrong?

A: Sometimes the connector on the reader gets dirty and causes these errors. Clean out any dirt or grime from the inside of the connector. A cotton swab or toothpick soaked in household cleaner works well.

Q: What is the sensors' operating temperature range.

A: The sensors can operate and accurately measure temperatures from -18 C to 85 C.

intelliRock II FAQs

Q: Are the loggers from the original *intelliRock* system (*intelliRock* I) compatible with the new *intelliRock* II system?

A: No they are not.

Q: Will the original *intelliRock* system be discontinued?

A: No, it will still be available for purchase.

Q: Do I need a PC to use the new *intelliRock* II system?

A: Not necessarily. You can view the data in the reader, but if you want to transfer the data out of the reader, you will need a PC to do so.

Q: What are the system requirements if I have a PC?

A: The operating systems supports Windows XP and Windows 2000. You will also need a USB port on the PC to transfer the data from the reader to the PC.

Q: Why would I use *intelliRock* II instead of the *intelliRock* I system?

A: There are many reasons.

1. The *intelliRock* II system supports the Nurse-Saul and Arrhenius methods of maturity.
2. The *intelliRock* II loggers can log many more points than the *intelliRock* I system.
3. The *intelliRock* II system provides more information on placement, like job number, logger location, job notes, etc.
4. The documented time of start is recorded with a real-time clock that can be programmed to your time zone. This provides an absolute reference point to associate sensor data with critical construction schedules.
5. The reader has an eight-line graphical display so you can graph curves right in the field.
6. The loggers are configurable to meet individual specifications and integrate maturity every minute instead of every 15 minutes in the *intelliRock* I system and logging intervals of down to every minute.
7. *intelliRock* II loggers have a much longer logging life (up to six months)
8. This system has unalterable, uninterruptible data logging feature that provides permanent and traceable data.
9. It provides more data in temperature so you can determine when and how much thermal protection is required in cold weather and documenting mass temperature gradients.

Contact Information:

1414 South Sangre Road
IDC Building
Stillwater, OK 74074
Phone: (405) 533.3770
Fax: (405) 533.3146
www.Engius.com

Christian Grill
President & CEO
cgrill@engius.com

Michael Fox
COO & VP of Technology
mfox@engius.com

Amy Biggerstaff
Account Manager
abiggerstaff@engius.com

Richard Sallee
Regional Sales Manager
South Central US
rsallee@engius.com

Rick Rohrer
VP of Commercial Sales
rrohrer@engius.com

Jim Mikulanec
VP of Highway Sales
jmikulanec@engius.com

Craig Aker
Engineer/Technical Support
(405) 372-9535
caker@nomadics.com

Tom Luby
Regional Sales Manager
North East US
(216) 272.5801 Cell
tluby@engius.com

Robert Barkley
Senior Sales Executive
Southwest US
(909) 772-5879 Cell
rbarkley@engius.com

Jerry Rackley
Media Relations
(405) 707.0514
jrackley@brightok.net

Jim O'Daniel
Representative
(405) 533.3055
jodaniel@engius.com

Todd Johnson
Representative
(405) 533-3050
tjohnson@engius.com

