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Strength Measurements Using Maturity for Portland Cement Concrete Pavement Construction at Airfields

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EXECUTIVE SUMMARY

The objective of this project is to demonstrate a non-complex solution for monitoring concrete strengths in real time using concrete maturity technology. The project team evaluated a number of commercially available maturity measurement devices coupled with an innovative strength assessment and prediction system, termed *Total Environmental Management for Paving (TEMP).*

This project included a field evaluation of a concrete pavement placement at Des Moines International Airport (DSM). The research team evaluated the following maturity measuring devices:

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

As a result of this field evaluation, it has been concluded that current maturity technology can be used to successfully assess the strength of a concrete airfield pavement in real-time. Furthermore, it is believed that the adoption of maturity-based technologies can result in expedited airfield repair and construction, and an improvement knowledge of the concrete pavement in place, as it is placed.

1. INTRODUCTION.

1.1 PURPOSE.

The primary objective for this research effort is as follows:

> *Demonstrate a non-complex solution for measuring the strength of airfield pavements in real time using concrete maturity theory.*

Through this demonstration, we have addressed two additional objectives including:

1. *Evaluation of several commercially available maturity measurement devices* – this includes the Dallas Semiconductor iButton®, Nomadics intelliRock™, Identec Solutions i-Q Tags, and "conventional" thermocouple sensors. Each of the devices has been used in a common test section, and was evaluated based on a number of criteria including accuracy, simplicity, ruggedness, and features (including flexibility).

2. *Evaluation of a strength assessment and prediction system* – software was demonstrated that provided a common interface with the collected temperature/maturity data. Referred to as the Total Environmental Management for Paving (TEMP) System, the outputs of the software provide the user with both a real-time assessment of the current concrete strength as well as a prediction of the future concrete strength as a function of time.

1.2 BACKGROUND.

Accelerated construction techniques are quickly becoming an essential element to the success of many pavement construction projects *(1)*. The ability to assess concrete strength in the field, both quickly and accurately, is essential for concrete pavements to remain a viable alternative in the high-speed airfield paving market.

The traditional method of measuring concrete strength in the field requires the careful sampling, casting, and destructive testing of laboratory specimens. For airfield pavements, flexural beams are most commonly used, however compressive cylinders have also been employed in the past for this purpose. Destructive testing is currently an element of almost all concrete paving projects. However, there are a number of disadvantages to the use of traditional destructive methods. These include:

1. *Need for Curing Facilities* – If the project is in a remote area, or if very rapid testing is required, special facilities may be required for sample curing.
2. *Test Variability* – In destructive testing, variability is always an issue due to differences in the sampled material as well as operator differences due to sampling, casting, handling, and curing. In short, the more you have to manipulate the concrete, the greater the overall variability will be.
3. *Sample Preparation* – Rapid-set concrete mixtures make the sample preparation process difficult due to the speed at which samples must be cast prior to the setting of the concrete.

4. *Inadequate Representation* – The strength of concrete delivered on site is most often estimated by measuring the strength of the concrete in a cylinder or beam. However, cylinders or beams do not always accurately represent the actual strength of the in-place concrete, since the in-place concrete has been consolidated, finished, and cured differently.

One alternative to the use of traditional destructive testing is the prediction of strength via maturity methods. Developed in the 1950's, maturity concepts have been used for years by the highway industry in predicting the strength development in maturing concrete *(2,3,4)*. The principle behind maturity is the relationship between strength, time, and temperature in young concrete. Maturity is a powerful and accurate means to predict early strength gain, which can assist in identifying critical elements such as the time of opening to traffic. Maturity has been around in some form for over 50 years, but has received unprecedented interest in the last few years due in most part to high-speed inspection required for high-speed construction.

2. DESCRIPTION OF MATURITY-BASED TECHNOLOGY.

Traditional maturity methods have been used effectively on concrete paving projects for a number of years. However, it is in this age of technology that new and improved methods can be realized. Because of its usefulness in evaluating maturity, a TEMP System approach was demonstrated in this project. This approach was chosen in order to facilitate evaluation of a number of commercially available maturity sensors. This system provides a common platform to interpret temperature and maturity data from a number of sources.

Sensing and recording technologies for use in concrete maturity have also made significant advancements in recent years. In its most basic form, maturity requires the collection of time and temperature data. Although the technology for measuring concrete temperature has been in existence for some time (e.g. thermocouples), new sensor technology is now available to more fully automate this process. Sensors recently developed and implemented by other industries (such as the food industry) are now being used for the monitoring of concrete temperatures. During this effort, several of these new systems were evaluated.

2.1 TEMP SYSTEM.

The mathematical modeling required to accurately estimate the strength in the field as a function of the time/temperature data can be rather involved. Standards such as American Society for Testing and Materials (ASTM) Specification C 1074 *(5)*, can assist the end-user to some degree. From a practical perspective, a chart or lookup table is commonly used to convert maturity readings measured in the field to estimate strength. Employing an automated approach facilitates this often mundane and potentially error-prone task. The TEMP System, demonstrated in this project, is one example of a system that performs these calculations in real time.

Whether performed manually or automatically, the process of converting maturity readings to strengths in the field is only an indication of the current strength of the concrete. The TEMP System further advances this technology by providing a means to predict the future strength as a function of the in-situ conditions employing the same maturity concepts that have been tried and accepted by the industry.

The specific components of the TEMP System are illustrated in figure 1. At a minimum, the system is comprised of concrete temperature sensors, similar to those used by modern maturity systems, as well as an inexpensive laptop or handheld computer, loaded with the TEMP System software. One type of sensor, the iButton® manufactured by Dallas Semiconductor, is currently fully integrated with the TEMP System. The iButtons® may either be interfaced to the computer via a direct connection, or alternatively queried by way of a wireless radio transceiver (manufactured by Point Six, Inc.). Figure 1 illustrates an optional portable weather station that can be included as an add-on to the system in order to further enhance the predictive ability of the TEMP System software.

Based on the same temperature-predictive abilities of the existing Federal Highway Administration (FHWA) High Performance Concrete Paving (HIPERPAV®) software *(6)*, the TEMP System advances one step further by providing real-time predictions of concrete temperature, maturity, and strength. This concept is illustrated in figure 2. The measured concrete temperature is shown as the solid line, with the HIPERPAV® prediction shown as the dashed line. Corrections to the HIPERPAV® predictions are made in real time using logical methods. Future concrete temperatures (shown as the dotted line) are then made reliably by entering the anticipated weather conditions. These weather conditions include the high and low temperatures expected for the following days and nights. The optional weather station add-on can minimize the need to manually enter the ambient weather conditions for the hours since construction.

One of the key uses of the TEMP System is the ability to predict the critical time of opening. The opening time can be predicted based on the past (known) and future (predicted) concrete temperatures, and thus strength. Figure 3 illustrates this estimating procedure, with the strength criteria shown as a horizontal dashed line. The minimum strength criterion to open to traffic is used to convert from strength to time, and this predicted time to open to traffic can be interpreted from the software.

In short, capabilities such as this highlight the TEMP System as an advancement over current practice. Using it, the industry can overcome several shortcomings inherent in the use of maturity methods for concrete paving today, namely automation and prediction. When coupled with the state-of-the-art in sensing technology, the objective of achieving a simple real-time strength assessment of concrete strength is realized.

2.2 MATURITY MEASURING DEVICES.

Measuring maturity in the field requires the monitoring of two parameters: temperature of the concrete, and elapsed time since placement. In principle, each of the devices that were evaluated in this project provide these two values. Transforming temperature and time data into an estimated concrete strength value requires some straightforward mathematical functions. For brevity, the background of this conversion can be found in appendix A.

2.2.1 Thermocouples.

The use of thermocouple wire represents the simplest and most commonly used maturity measuring device. Thermocouple leads include dissimilar metals that are in contact with each other at the location of interest. Calibrated according to wire type, a small potential is generated in the wires, and the temperature can be electronically backcalculated. Common calibration standards from the American National Standards Institute (ANSI) are Type-E, Type-J, Type-K, and Type-T – each of these standards includes contact of a unique pair of standardized metals. Type-T thermocouples (including copper and constantan) were used in this project, and were measured manually using a handheld reader manufactured by Omega. It should be noted that automated datalogging equipment is also commonly used to read and store thermocouple information in the field.

2.2.2 Dallas Semiconductor iButton®.

iButtons®, shown in figure 4, are self-powered and self-contained devices that record temperature measurements at user-defined intervals between 1 and 255 minutes. Up to 2048 measurements can be stored at one time, resulting in maximum observation ranges of between 34 hours (at one reading per minute) to approximately one year (at one reading every 255 minutes). An option in the iButton® allows more current readings to replace earlier readings. Alternatively, the iButton® can stop reading once the memory is filled. The "rollover" capability of the iButton® allows it to be used without having to be initialized during concrete placement. In addition to time and temperature, a histogram of temperature values is also stored in protected memory. A user-defined temperature range can be programmed, and a record automatically made of when temperatures leave that specified range. These records also include for how long the violation occurred. Finally, each iButton® contains a unique identifying code that is guaranteed by the vendor never to be used more than once.

A stainless steel casing protects the components of the iButton® from the concrete and construction operations. However, prior to installation, modifications are made to the iButtons® to allow for communication and protection while embedded in concrete. First, two wires are soldered to the terminals of an iButton®. Multiple layers of synthetic coating are then applied to the soldered iButtons® to provide electrical protection. An RJ-11 (telephone) adapter is then attached to the loose ends of the wire. When the user wishes to query the data, the RJ-11 adapter can be plugged into a Universal Serial Port Adapter (DS9097U-S09) provided by Dallas Semiconductor. This allows for connection to a 9-pin serial connection of either a handheld or laptop computer. As previously mentioned, the iButton® can be used with either a wireless or manual connection. In the wireless case, a Point Six radio transceiver is used in lieu of the DS9097U-S09 adapter. Additional specifications and manufacturer information are given in appendix C.

2.2.3 Nomadics Construction Labs intelliRock™.

The commercially available intelliRock™ system, shown in figure 4, consists of a handheld reader and one of two commercially available intelliRock™ sensing and logging devices (LGR-01 Maturity Logger or TPL-01 Temperature Logger). A prototype logger for strength (LGR-01-RTS Real-Time Strength Logger) was also evaluated in this study. All three loggers contain a battery, microprocessor, memory, and thermistor-based temperature sensor. Similar to the iButton®, these devices are encased in a protective coating. However, unlike the iButton®, they must be connected to a proprietary handheld reader (MTR-01S) for data recovery. Again, like the iButton®, each logger is unique and will continue to operate without a connection to the reader. Data from up to 200 loggers may be stored on a single handheld reader at any one time. The reader will download the data to a PC in two formats: an encrypted tamperproof version for project records and a format for use in common spreadsheet applications such as Microsoft Excel®.

The intelliRock™ Loggers must be initialized at the time of concrete placement in order to work properly. The Temperature Logger records temperature at fixed intervals: every 2 hours for the first three days, every four hours for days 4 through 6, and twice a day for days 7 through 28.

The Maturity Loggers perform internal maturity calculations every 15 minutes, but only record the maturity after 0, 4, and 12 hours, then again at the end of each day for the first 7 days. The current maturity reading can also be found when downloading the data. In addition to logging data at fixed times, the Temperature and Maturity Loggers also record maximum and minimum temperatures and the corresponding elapsed time since construction. The prototype intelliRock™ Strength Logger calculates maturity every 15 minutes like the Maturity Logger. However, an additional step of converting the maturity to strength is also made by the logger itself. A linear interpolation method (between known points on the established maturity curve) is used to estimate strength. At the time of this study, the Strength Logger was not able to store data, only display the current reading. However, the vendor reports that once in production mode, the data storage capabilities will be similar to the other available logger types. Additional specifications and manufacturer information on the intelliRock™ loggers are given in appendix C.

2.2.4 Identec Solutions i-Q Tag.

The Identec i-Q Tag is a wireless temperature-logging device that is embedded in the concrete. Utilizing ultra-high frequency (UHF) technology, it can transmit stored temperature data (theoretically) up to 100 m (300 ft) with no obstructions. However, during this project, it was found that since the i-Q Tag is embedded in concrete, the effective range is limited to only a few meters depending upon the density of the concrete and presence of metallic reinforcement. The tag is designed to interface with a proprietary interface card attached to a Pocket PC (Compaq iPaq). Accompanying software performs automated maturity and strength calculations. Each i-Q tag must be initialized at the time of placement in order to start recording temperatures. The device can record 1,024 temperatures at a user-defined interval between 1 and 255 minutes. The i-Q Tag, shown in figure 4, is the only device that operates only through a wireless connection. Additional specifications and manufacturer information are given in appendix C.

3. FIELD EVALUATION.

3.1 OVERVIEW OF ACTIVITIES.

The project selected for instrumentation included the paving of Runway 5-23 and Taxiways P and R at Des Moines International Airport (DSM). Concrete paving on this project was performed by the Flynn Company, Inc. of Dubuque, Iowa. The runway and taxiway paving included 76,000 square yards of 15-inch P-501 concrete pavement. An additional 31,000 square yards of 8-inch P-501 concrete pavement was used on shoulders. Figure 5 shows the airport layout and project location. A total of ten locations on Taxiways P and R were instrumented with the aforementioned maturity measuring devices. These locations are given in figures 6 through 8. As shown in figure 9, the taxiways are constructed with a nominal 15-inch thick jointed concrete pavement, constructed per the FAA P-501 (AC 150/5370-10A) specification. The underlying support layers include a 6-inch thick P-307 (cement stabilized drainable base), and 4 inches of P-208 (aggregate base).

The primary paving operation on this project included mechanical placement using a spreader and slipform paver in 18.75 to 25-foot widths, as shown in figure 10. Alternatively, placement operations employed hand placement techniques using a spreader, spud vibrator, and vibratory screed. This was commonly used on odd-shaped panels and panels with small radii.

A batch plant located immediately south of the airport supplied the concrete for the project. During our evaluation period, a number of unique concrete mixtures were used. Two of the mixtures had known maturity curves: one mix designated for the slipform operations, and another for the hand placements. Since construction was taking place in late November, close to the end of the construction season in Iowa, both mixes were designed for colder weather, and do not include mineral admixtures (e.g. fly ash), only Type I/II cement.

Referring to figures 6 through 8, location 1 was placed using the "hand placement" mixture. Locations 2, 3, and 5 through 10 were placed using the "slipform" mixture. Location 4 employed a third mixture that did not have a maturity curve, but was reported to be the "slipform mixture" with an additional 200 lbs. of cement per 9-cubic yard load (22.2 lb./cy). The project team felt that the third mix provided an opportunity to evaluate some unique thermal characteristics, and thus it was instrumented to observe the temperature development.

Table 1 and figure 11 contain mixture proportioning and laboratory maturity curve data, respectively, for the two standard concrete mixtures *(5,7)*.

3.2 INSTRUMENTATION PROCEDURE.

Prior to installation of the maturity gages, pieces of "L-shaped" rebar were driven into the subbase layer to serve as supports. The various maturity measurement devices were then mounted and secured on the rebar using twisted bailing wire and plastic "zip" ties. The wires from the thermocouple, iButton® and the intelliRock™ devices were then secured to the subbase, and adjacent concrete placement using duct tape. During slipform operations, if possible, the wires were then fed into adjacent joint cuts to protect them from the paver tracks. Figures 12 through 15 illustrate typical instrumentation details prior to concrete placement. After mounting the sensors, the depth and lateral location of the instruments were measured, as shown in figure 16. Immediately before the paving operation reached the location, fresh concrete was placed by hand (using a shovel) over the instruments to prevent potential damage from moving concrete. This is illustrated in figure 17.

Table 2 includes the experiment factorial of devices and corresponding instrumentation locations. Appendix B contains detailed information regarding each instrumentation location, such as pavement cross-section and charts of the measured pavement temperature, calculated maturity, and maturity-estimated strengths. Except for the intelliRock™ prototype Strength Logger, the reported maturity-estimated strengths are those determined by the sigmoidal curve-fitting procedure outlined in appendix A. The Strength Logger estimates strength using a linear-spline interpolation method between known maturity points, and does not extrapolate beyond the maturity range measured in the laboratory. As a result, the maximum strength that the Strength Logger is capable of reporting is the maximum value measured in the laboratory. Furthermore, the Strength Logger will report a zero strength until the maturity level of the first laboratory "point" is reached. It should be noted that this characteristic can be beneficial in some instances, since extrapolating strengths beyond the established limits of the maturity-strength curve should only be done by an experienced individual.

In general, the differences in temperature, maturity, and strength between the various devices in appendix B is due to the sensor location within the slab (depth), maturity intervals used by the sensor, accuracy and precision of the sensor, and the method used to determine strength from known maturity data. The difference in the predicted strength by any given sensor is small, and it is believed that each of the evaluated devices would be suitable for airfield pavement applications.

3.3 STRENGTH TESTING.

As is common on airfield projects, the concrete strength evaluation specified for this construction project included destructive tests of beams cast during construction, applying third-point loading to determine the modulus of rupture *(7)*. Contractor (Flynn Company) personnel and the representatives of the owner (City of Des Moines) cast the specimens for subsequent testing in the laboratory. During our field visit, two additional beams were cast with iButton® sensors to measure the temperature and to estimate the maturity of beams undergoing destructive tests. These beams were cast with concrete corresponding to locations 1 and 6. Both specimens exceeded the 28-day strength specification for this project (650 psi using third-point loading). The results of these tests are shown in table 3 and figures 18 and 19. These figures show both the maturity-estimated strength curves and the measured 7- and 28-day strengths from destructive testing.

However, the standard practice in the state of Iowa is to establish the maturity-strength curve using center-point loading *(8,9)*. Since third-point loading was used to test the beams, a correlation function was required to compare the strength values. Correlations between these strength types can vary considerably, but for this project, a conversion factor of 0.71 was selected. This factor is multiplied by the center-point strengths to estimate the strengths measured using third-point loading *(10)*. Although this coefficient is on the lower range of coefficients typically used for this purpose, it was selected based on engineering judgment in order to compare the estimated strengths using maturity to the test results from the beam specimens cast in the field. It is believed that a lower value may be warranted based on the fact that the verification beams were cured in tank conditions as opposed to an environmental chamber *(11)*. Plots of the temperatures and strength calculations for the beam tests are shown in figures 18 and 19. It should be noted that although both 7-day and 28-day beam testing was performed, the 28-day test results are not shown in this figure. It has been demonstrated that maturity-strength concepts, especially when using Nurse-Saul theory, can "break down" after several days of curing due to influences on strength gain other than temperature *(11,12)*.

It should be stressed that on P-501 projects, the maturity-strength curve should be developed using third-point flexural testing. This will allow for a much easier comparison to strengths measured using conventional breaks. The fact that the Iowa standard was to use center-point testing, as was done in this project, should not detract from the benefits of maturity that this study highlight. It has been shown by others that the differences between maturity-predicted and tested beam strengths are within the range of the strength variability of the beam breaks themselves *(11,13)*.

4. ANALYSIS AND FINDINGS.

4.1 SENSOR EVALUATION.

Although all of the maturity measurement devices that were evaluated perform basically the same task, some variations in functionality and performance were observed. Differences between the various devices were evident with respect to the ease of data retrieval, ruggedness, and the level of accuracy. A summary of the observations from the field evaluation are given in the following sections. In addition, appendix B contains more detailed information including ambient conditions (temperature, wind speed and relative humidity) during construction, identifications for each maturity-measuring device, and corresponding charts of pavement temperature, maturity, and maturity-estimated strengths.

Except for the intelliRock™ prototype Strength Logger, the reported maturity-estimated strengths are determined using the sigmoidal maturity-strength function described in appendix A. The Strength Logger estimates strength internally within the device, employing a linear "spline" interpolation between a finite number of maturity-strength points. It should be noted that the Strength Logger does not operate beyond the maturity range measured in the laboratory. Therefore, the maximum strength reported is the maximum value from the laboratory determination of the maturity-strength curve. However, this feature can be beneficial in those cases where uncertainty exists in extrapolating the strengths from the strength-maturity relationship. From this perspective, the Strength Logger is a more conservative device.

Other differences in the temperature, maturity, and strength data can be found between the devices. Most of these differences are due to variations in the sensor location within the slab (depth), temperature or maturity intervals used by the sensor, physical characteristics of the sensor, and the accuracy and precision of each sensor. Appendix C contains additional information about the various sensors, as reported by the manufacturers.

4.1.1 Thermocouple.

The "state of the practice" in maturity today is to embed thermocouple wire within the concrete, and to either take periodic manual readings, or else connect a datalogger to the exposed wire for more continuous readings. The main benefit of using thermocouple wire is the simplicity of installation, and the inexpensive replacement of lost "sensors". Data can also be recorded as long as the lead wires are protected.

However, unless a datalogger is used, this technology is limited to the number of manual measurements, which for practical reasons commonly do not include overnight monitoring. Manual readings are also subject to human error upon reading and recording. Furthermore, maturity and strength calculations must also be made manually, further allowing human error to be a source of concern.

If a datalogging system is used, this technology is less error-prone, but becomes more expensive. In order to function properly, the datalogger must remain connected for the duration of monitoring. Even on a controlled airfield paving project, datalogging equipment is subject to being stolen or destroyed during the monitoring process. This will not only result in permanent loss of data, but poses an additional cost consideration (i.e. the probability of replacement cost).

In this study, thermocouple wire was used at a number of locations. Measurements were manually taken periodically by the project team during the duration of the field visit. These results are plotted along with the results of the more automated techniques in the plots in appendix B. In general, there is good agreement with the other measures. One exception is at location 3, where there appears to be a "drift" in the measured temperature, as compared to the iButton®. The source of this deviation could be due to the accumulation of moisture near the ends of wire within the concrete. The moisture, coupled with the high-alkaline environment, can lead to variations in the measured potential from the thermocouple. This variation can translate to a false temperature reading. It should be noted that during the subsequent field visit, the temperature appears to fall back in-line with the other sensor. This may be due to reestablishment of an equilibrium condition within the concrete – at least in the vicinity of the wire.

Due to the nature of the mathematics used in predicting strength from time and temperature, the recorded deviations in the temperature between sensors resulted in minimal differences in the predicted strengths. As can be observed in the various strength plots in appendix B, there is very little difference in the predicted concrete strength between any two sensors. In fact, no case was found where the predicted concrete strength varied by more than five percent between two sensors at the same location.

4.1.2 iButton®.

For this sensor type, two interface protocols were used: manual readings and wireless interfacing. In both cases, data was routinely downloaded from the sensors. During the field evaluation, Point Six transceivers were installed at the various sensor locations in order to communicate with the iButtons®. The project team was able to successfully read data from the sensors from their hotel room, approximately ½ mile from the project site, outside of the airport property (see figure 20).

The iButton® sensor provides the ability to customize the measurement interval. This is particularly advantageous where the user may wish to select a more frequent interval during maturity monitoring. The user can then later change to a longer interval to allow for hourly, daily, and/or seasonal monitoring of pavement temperatures. If the project were constructed using a "fast track" patching-type mix for example, there is a significant advantage to having a short time interval. However, for this study, the interval used was 20 minutes. This allowed up to 28 days of data to be stored at one time.

Another advantage to the iButton® is the ability to initialize prior to construction. This was a particular convenience given the sometimes hectic nature of the sensor placement, where the additional task of sensor initialization was not always convenient. The additional benefits of being fully compatible with the TEMP System software meant that maturity and strength calculations could be instantly derived. Furthermore, this automation allowed for an easy comparison to the strength predictions made by the TEMP System using the HIPERPAV® analysis. More on this feature will be provided in section 4.2.

One issue that arose with the iButton® included the ruggedness of the connector (the plug used to connect to the computer). The standard protocols for iButtons® include the use of a RJ-11 “telephone jack” style connector. This connector was found to be unsatisfactory for the harsh environment of the construction site. As a result, a more rugged connector has been subsequently identified that minimizes this inherent weakness. A second issue that was found was with respect to the Point Six transceivers. Due to the longer-than-normal transmit times of the iButton® data over long distances, the transceivers were found to automatically power-down in some cases. According to the manufacturer, this problem has since been identified and corrected. It was found that too small of a heat sink was being used, leading to an overheating of the internal electronics. The power-down was a result of a self defense mechanism.

The iButton® sensor was used at some locations at various depths. As the plots in appendix B indicate, differences in temperature were noted throughout the depth of the pavement. These differences are one contributor to stresses that can lead to premature cracking in concrete airfield pavements. Using these sensors, and the models inherent in the HIPERPAV® analysis *(6)*, the measured temperature gradients in the slab may soon be able to not only predict strength, but also the risk of cracking in the field.

Overall, the iButton® sensors proved to be a simple, rugged, accurate, and practical means to measure temperatures in the field. Coupled with the TEMP System, maturity and strength can quickly be derived and reported in real-time. Coupled with the wireless option, the capabilities also exist to read the iButton® sensors from a central location on the project (e.g. the job trailer).

4.1.3 intelliRock™ Maturity Logger.

The intelliRock™ Maturity Logger was also found to be simple and easy to use. Maturity calculations are automated within the logger, and are based on temperature readings taken every 15 minutes. The time and value of the maximum and minimum temperatures is also recorded. The Nomadics handheld reader was periodically used to download the data, placing it into two separate files. One of these files is in comma delimited format, which allows for subsequent data analysis using a spreadsheet or other software (including the TEMP System). The other file is a proprietary encrypted file for project records. Overall, the loggers and handheld reader were found to be rugged and required minimal training.

One issue for this and the other intelliRock™ devices (identified below) is the requirement that each logger be initialized immediately before or shortly after construction. As a result, this sometimes resulted in disruption of construction operations or alternatively, required premature initialization of the device. At the very least, it added “another task” to the sometimes hectic schedule of the project team. In addition, although maturity calculations are automated, they are based on temperatures sampled at a fixed 15-minute interval. Furthermore, the maturity data is only recorded at fixed intervals that range between 4 hours and 1 day. Finally, upon the completion of maturity monitoring, the Maturity Logger continues to sample, but ceases to record data. For subsequent ages, the current maturity reading can be manually read on demand.

Although the majority of airfield paving projects will not be adversely impacted by this, it may limit the application of this technology on concrete mixtures with accelerated hydration characteristics (i.e. fast-track mixes).

In short, the readings from each of the Maturity Loggers that were used on this project coincided with the reading from the other sensors. As a result, it is believed that these sensors show real promise as a rugged and accurate means to collect and record maturity data in the field.

4.1.4 intelliRock™ Temperature Logger.

The intelliRock™ Temperature Logger operates in a similar manner as the Maturity Logger described previously. Like the Maturity Logger, it requires initialization on the site immediately before or after concrete placement. The time and value of the minimum and maximum temperatures are similarly recorded, as well as the current reading during downloading. Data storage within the Temperature Logger includes points at fixed intervals: every 2 hours for the first three days; every 4 hours for days 4 through 6; and every 12 hours (twice daily) for days 7 through 28. It is believed that these intervals provide adequate coverage during the period of interest for many projects that employ maturity. However, like the other Nomadics devices, the Temperate Logger cannot perform long-term monitoring of pavement temperatures, but this is typically not of interest to the contractor. Unlike the Maturity or Strength Loggers, maturity and strength calculations are not automated, and must therefore be determined through hand calculations, a spreadsheet, or other computer software.

4.1.5 intelliRock™ Strength Logger.

A prototype intelliRock™ device, a real-time Strength Logger, was installed at two locations on the project. In general, installation and use of this type of sensor follows the same basic operations described for the other intelliRock™ devices. Within the hardware, maturity and strength calculations are automated and performed every 15 minutes. However, at the time of this project, this data is not stored in the Logger, and must instead be manually read using a special handheld reader. The vendor has reported that once in production, this logger will store data in a similar fashion to the others described herein. Another limitation of this logger includes the need to preset the logger with maturity-strength data. Although the typical user would not need to routinely update this data, the added flexibility could prove beneficial in those cases where there are a number of different mixes being used, or where changes in the mix are occurring frequently. Estimation of strength is conducted using a linear spline interpolation between known maturity points. If the maturity-strength relationship is not generated with care (as per the vendors recommendations), variability in the maturity-strength data could lead to misleading results. It is therefore recommended that this interpolation technique be further reviewed to determine its adequacy as compared to curve-fit techniques commonly used today.

Since this sensor employed a unique maturity-strength algorithm, unlike that used for the remaining sensors, there are some differences noted in the strengths plotted in appendix B. However, the concept behind this logger shows promise, since it further simplifies the sometimes tedious nature of calculating strength in the field.

4.1.6 i-Q Tag.

The i-Q Tag is a unique type of sensor that communicates data to the user exclusively through a low-power wireless connection. The sensor has the capability to sample and store temperature data at a user-defined interval. For this project, an interval of 30 minutes was selected. Once the temperature data is downloaded to a Pocket PC through a proprietary wireless protocol, maturity and strength calculations are automated using customized software. The result is a complete system that can readily report strength data of the concrete on demand, without the need to connect leads to the computer.

One issue with the i-Q Tag is the need for initialization at the time of placement. Furthermore, it was found that the wireless communication with a given i-Q Tag was sometimes affected by other nearby i-Q Tags, although this has not been confirmed with the manufacturer. A second issue is the limited range of communications with the i-Q Tag. In some cases, the transmission range was limited to ten feet or less.

Furthermore, due to complications with the Pocket PC software, the devices installed on the first day of construction could not be initialized until the second day. Therefore, the maturity and strength calculations for the first two locations in appendix B were estimated for day 1 due to a lack of readings.

The i-Q Tag represents a unique type of device capable of measuring temperatures of concrete in the field. Its wireless communication capabilities, although limited in range, eliminate the need for external leads that can sometimes complicate the paving process. Its benefits should be recognized for those wishing a simple solution for maturity on concrete paving applications. However, these benefits should be weighed against the cost of each sensor, which is significantly higher than other sensors. Furthermore, this cost is “lost” when the sensor is embedded in the concrete, as opposed to reusable wireless solutions, such as the Point Six transceivers used with the iButton® sensors.

4.1.7 Sensor Comparison.

Each of the various sensor types used on this project possess unique benefits and costs. No one sensor demonstrated a clear advantage over the others. There appears to be a number of tradeoffs to be made when selecting the most appropriate device for the job. A list of some considerations that should be made, in no particular order, include:

1. Cost.
    a. Individual sensors (disposable cost).
    b. Readout equipment (capital cost).
2. Ruggedness.
    a. Sensors.
    b. Connectors (between the sensors and the readout).
    c. Readout equipment (e.g. computer).

3. Automation.
    a. Real-time temperature.
    b. Real-time maturity.
    c. Real-time strength.
4. Wireless.
    a. Capability.
    b. Range.
5. Flexibility.
    a. User-programmable sampling increment
    b. Number of total stored samples.
    c. Duration of storage (e.g. long-term monitoring).
    d. Longevity (battery life).
    e. Interface with third-party applications.
6. Labor Requirements.
    a. Need for initialization during placement
    b. Installation time.
    c. Monitoring time.
7. Training and Support.
    a. Availability of training courses or tutorials.
    b. Vendor knowledge.
    c. Vendor experience.
    d. Vendor availability.
8. Security
    a. Data security (to ensure validity of measurements).
    b. Theft susceptibility of hardware.
    c. Uniqueness (identification coding) of sensors.

The cost of the sensors and other equipment is not listed or compared in this report. The embedded microprocessor technology is evolving rapidly, and prices and options are changing frequently. These changes are expected to continue as implementation of the technology grows. Similarly, including specific time estimates for use of the variety of equipment tested herein is at best difficult. From our assessment in testing the equipment, each of the sensors requires about the same amount of time to place in the concrete. Although there are noted differences in initializing and reading the sensors, these are considered minimal in relation to the overall efficiency that maturity testing provides in relation to traditional destructive strength testing regimes.

Finally, no attempt is made herein to rank these various devices based on the above criteria. This is largely due to the fact that many of these are subjective in nature or difficult to quantify. The interested user is encouraged to gather the most current information possible from each of the vendors, and make their own decision based on their specific project requirements. Information on the various devices used on this project can be found in appendix C.

4.2 MONITORING AND FORECASTING USING THE TEMP SYSTEM.

In addition to evaluating a number of commercially available maturity sensors, a second task of this project included the evaluation of the TEMP System. Introduced in section 2.1, the TEMP System software is capable of efficiently and accurately calculating and reporting temperature, maturity, and strength data. Although the software has the capability to directly control the iButton® sensor, the software also possesses the ability to utilize maturity data from the other available devices in order to estimate the in-place strength.

Figures 21 through 24 include screen captures of the latest version of the software encompassing the TEMP System concept. Termed COMMAND Center (COMMAND = Concrete Materials Management, Analysis, and Design), the software proved successful in assisting the project team in both monitoring and forecasting the concrete strength.

During the field site, the TEMP System forecasting capabilities were evaluated. Entering the pertinent design, materials, climatic, and construction inputs was required for this purpose. This information was derived from the various records and observations made during the field visit. After 24 hours after placement, the TEMP System predictions of the concrete strength were evaluated. Differences between the maturity-estimated strength and the forecasted strength were typically no more than five percent. In some cases, the TEMP System estimates were within one percent of the strength estimated from the maturity sensors.

The successful prediction of the concrete temperature using TEMP System is a result of the significant investment of the FHWA in developing the HIPERPAV® software. The core of that software is a sophisticated pavement temperature prediction model that accounts for environmental effects as well as the heat of hydration.

Based on this field evaluation, it is believed that the TEMP System concept has proven not only feasible, but appears to produce accurate and practical results. By utilizing concrete strength predictions made through the TEMP System forecasting, the user is able to assess when critical events will occur. For example, the TEMP System can predict when a strength of 500 psi is expected (which may be the strength of opening to loading). It may also be used to better define windows for sawcutting, assuming a strength criterion is defined for this purpose.

5. SUMMARY AND CONCLUSIONS.

This project has successfully demonstrated the ability to evaluate and monitor the strength of concrete airfield pavements using simple and reliable technology. Meeting this basic objective is critical if maturity methods are to be considered more often in concrete airfield paving. This research has shown that both the private and public sectors have advanced a number of solutions. These include a variety of commercially available maturity devices, as well as predictive tools for better understanding concrete temperature and strength development. The TEMP System concept evaluated in conjunction with the maturity devices illustrates how this technology can be integrated together.

The key to the success of the project really lies beyond this research. With a number of commercial vendors currently available, it is now possible for any interested party to quickly adopt concrete maturity technology. The commercial (building), structural (bridge), and highway pavements communities are currently at various levels of integration of concrete maturity into practice. It is believed that the airfield pavement community can similarly benefit by adopting these same maturity technologies.

5.1 ADDITIONAL RESEARCH AND IMPLEMENTATION.

Although this project resulted in a successful demonstration of maturity-based technology for airfield concrete pavements, a number of additional avenues could be explored in order to better understand how this type of technology can benefit the airfield construction industry. The following items are ideas that could be considered in future research efforts:

- Demonstration of a maturity system (such as TEMP) along with various maturity monitoring devices on accelerated airfield concrete paving projects. In contrast, the project selected for demonstration under this effort utilized conventional paving processes. Rapid strength concrete mixtures present a number of unique challenges including a shorter paving window, and a higher-than-normal heat of hydration which requires a greater sampling frequency for maturity sensors.

- Development and evaluation of a special provision to utilize maturity for strength control. Although maturity should never be used exclusively for strength evaluation, it can be used to significantly reduce the amount of destructive testing that is currently done. In this proposed effort, language for a construction special provision can be developed, followed by a "shadow" trial of the specification to determine the potential for success in replacing some conventional testing with maturity-driven strength assessment. If successful, this special provision could then be tried on a subsequent project as a replacement of the conventional means of concrete strength control.

- Evaluation of maturity for predicting sawcut timing. By “calibrating” the sawcut window in the field using strength-driven threshold values, a system such as TEMP can be evaluated for its ability to predict and identify sawcut windows during construction. If used along with proper judgment, this technology can be used to further improve the reliability of the sawcutting process. Furthermore, used in combination with other techniques, it may be possible to compress construction schedules on fast-track concrete paving projects.

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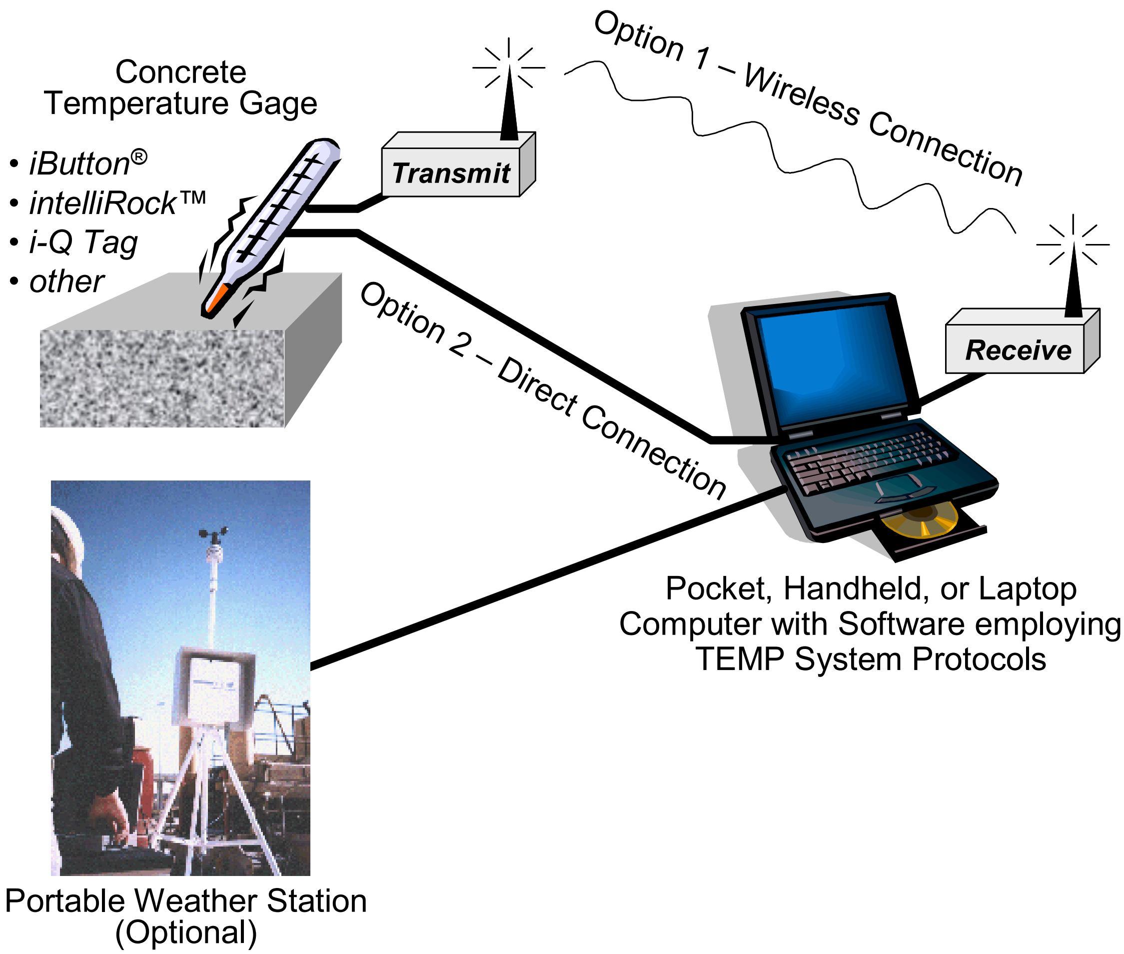


FIGURE 1. HARDWARE COMPONENTS OF THE TEMP SYSTEM

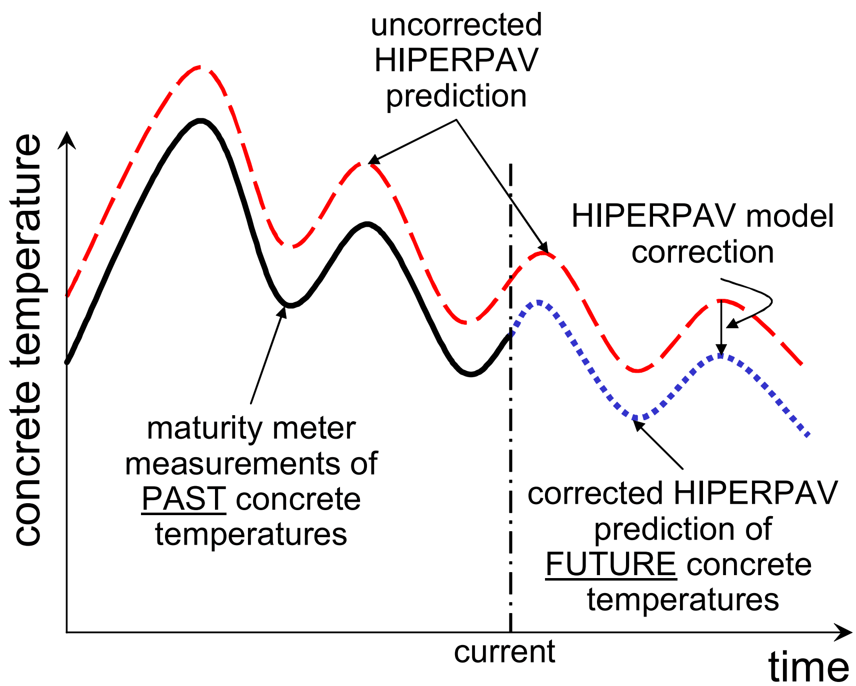


FIGURE 2. REAL-TIME HIPERPAV® PREDICTION OF FUTURE CONCRETE TEMPERATURES

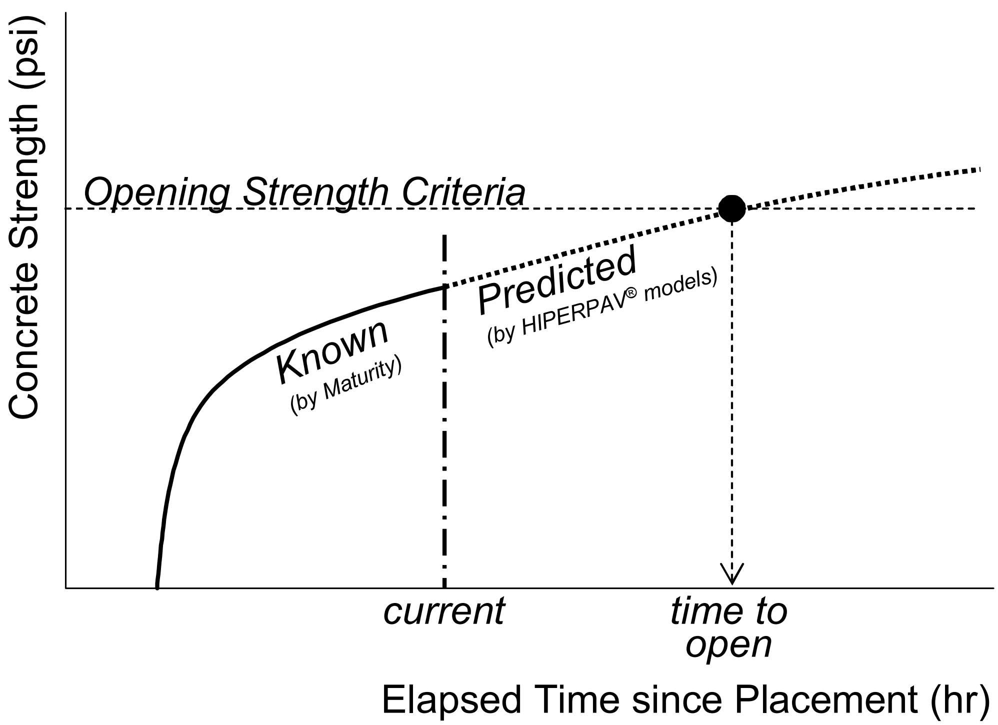
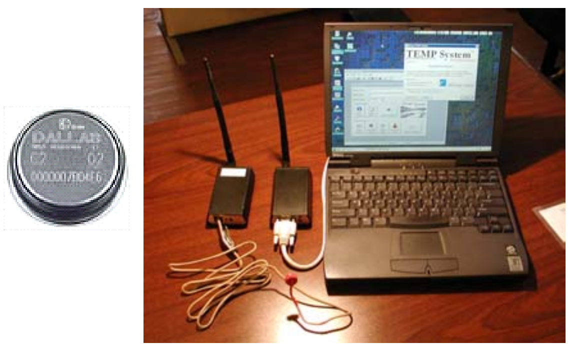


FIGURE 3. PREDICTION OF TIME OF OPENING TO TRAFFIC

Nomadics intelliRock™
(strength logger not shown)

Identec Solutions i-Q Tag
(Pocket PC not shown)



Dallas Semiconductor
Thermocron iButton® with
Point Six Transceivers and
TEMP System Software

FIGURE 4. MATURITY DEVICES EVALUATED AT THE
DES MOINES INTERNATIONAL AIRPORT

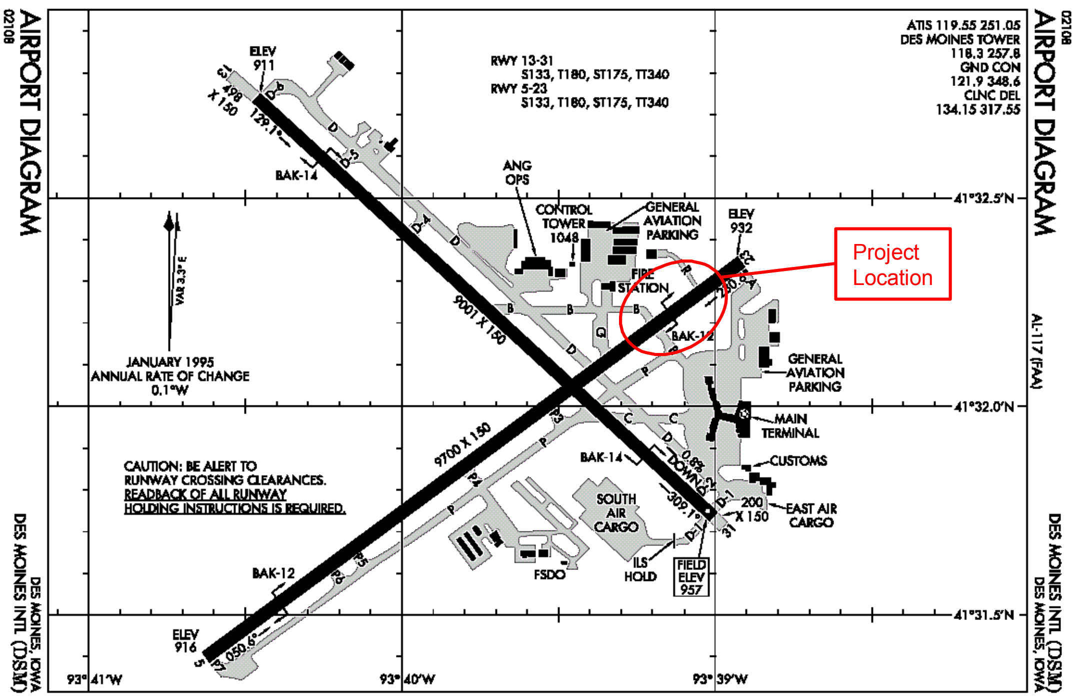


FIGURE 5. DES MOINES INTERNATIONAL AIRPORT LAYOUT

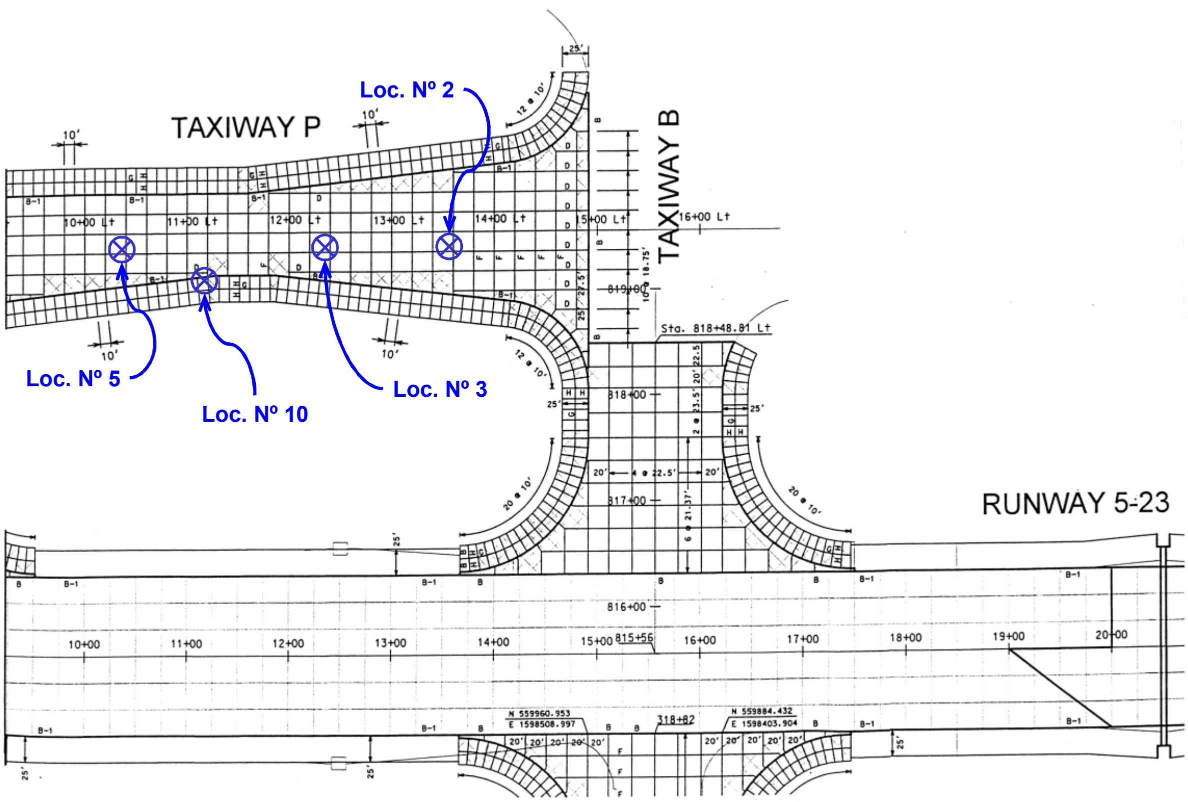


FIGURE 6. SENSOR LOCATION LAYOUT – 1 OF 3

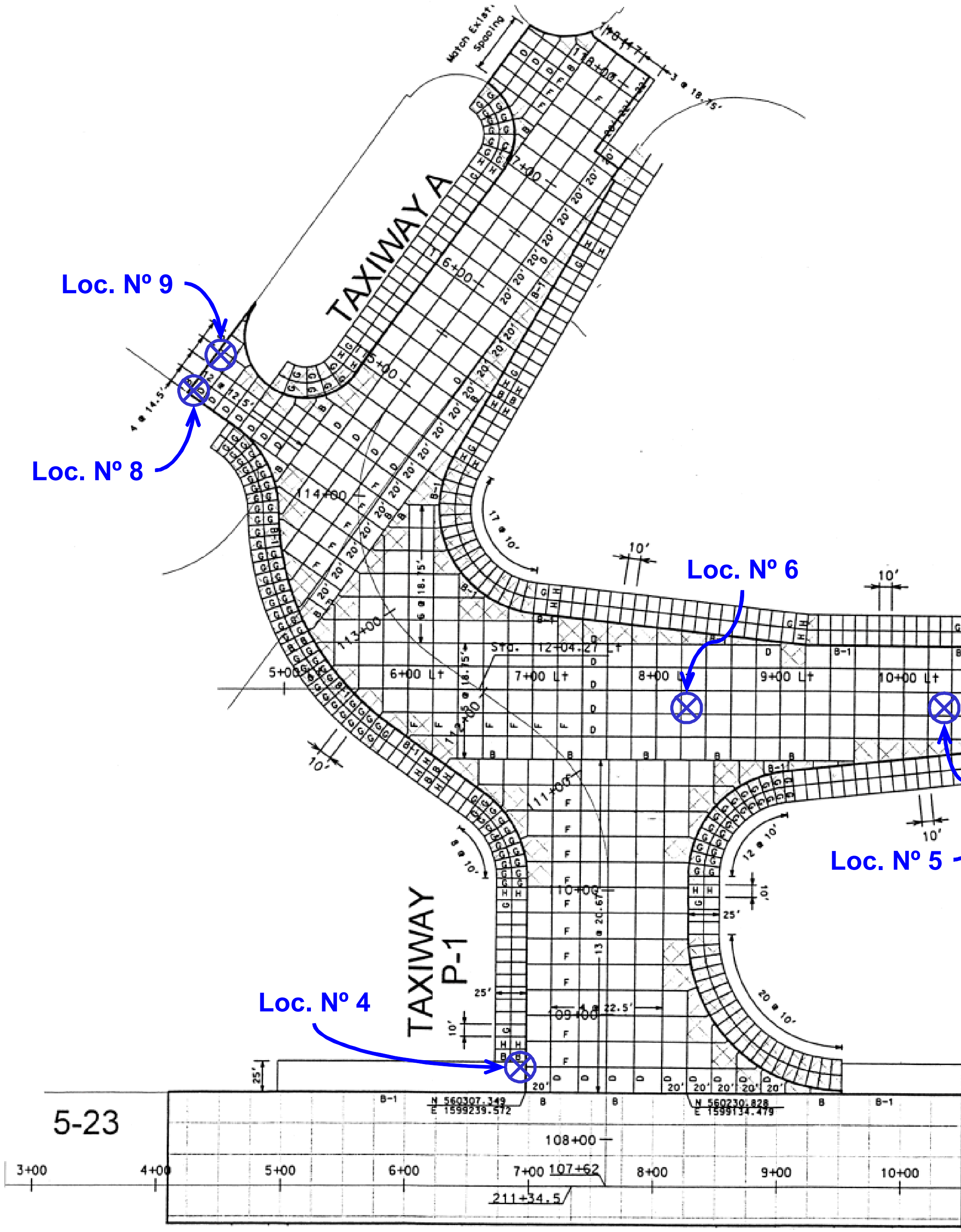


FIGURE 7. SENSOR LOCATION LAYOUT – 2 OF 3

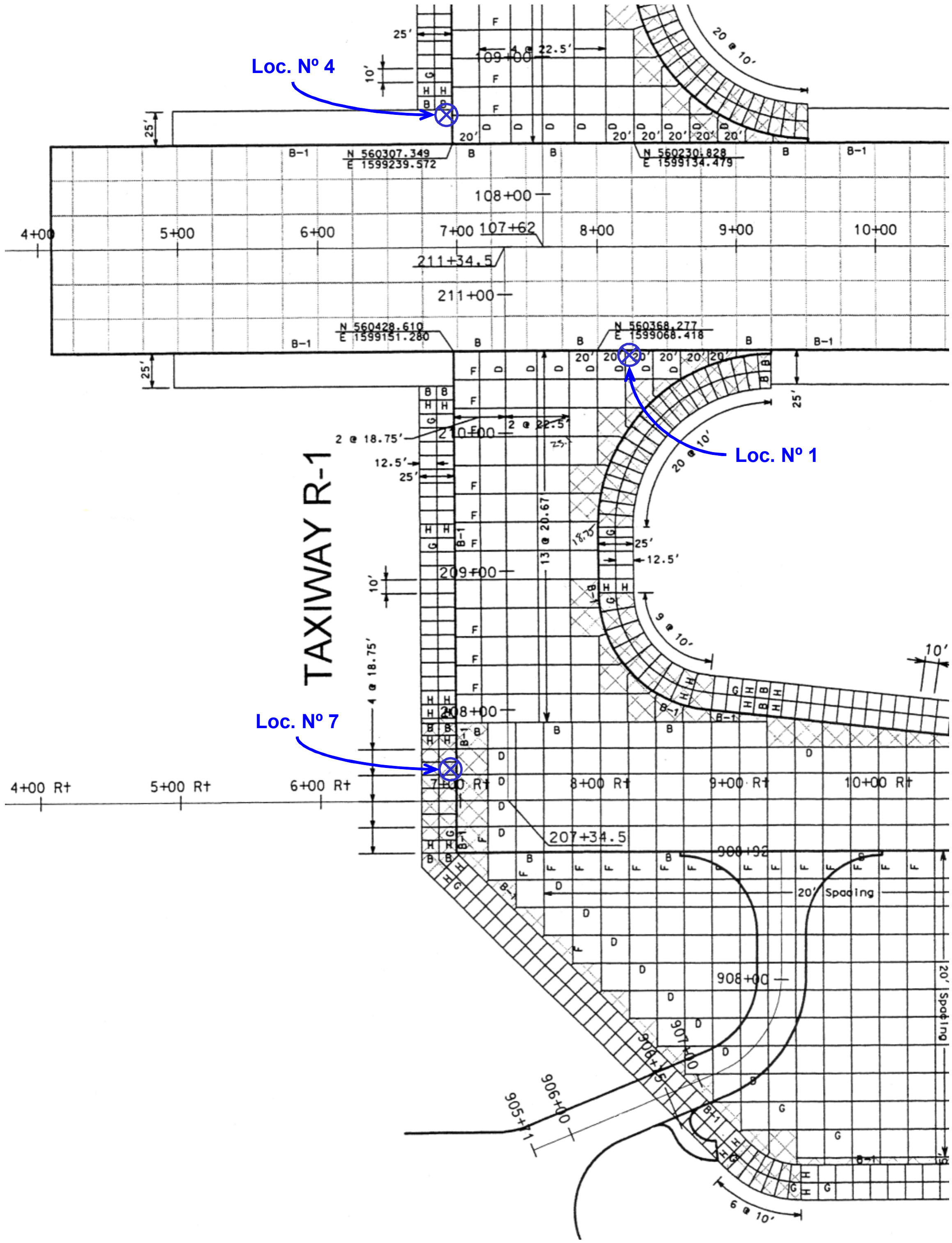


FIGURE 8. SENSOR LOCATION LAYOUT – 3 OF 3

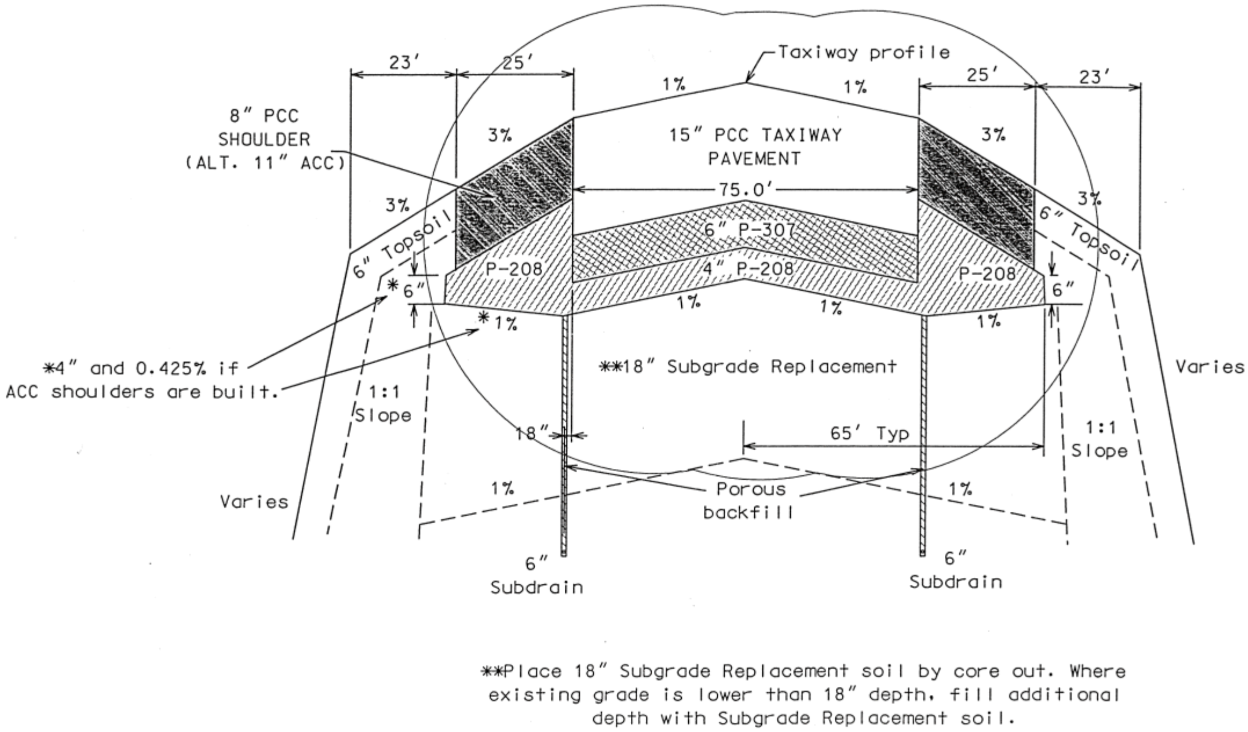


FIGURE 9. TYPICAL PAVEMENT CROSS-SECTION OF TAXIWAYS P AND R

FIGURE 10. TYPICAL PAVING OPERATIONS

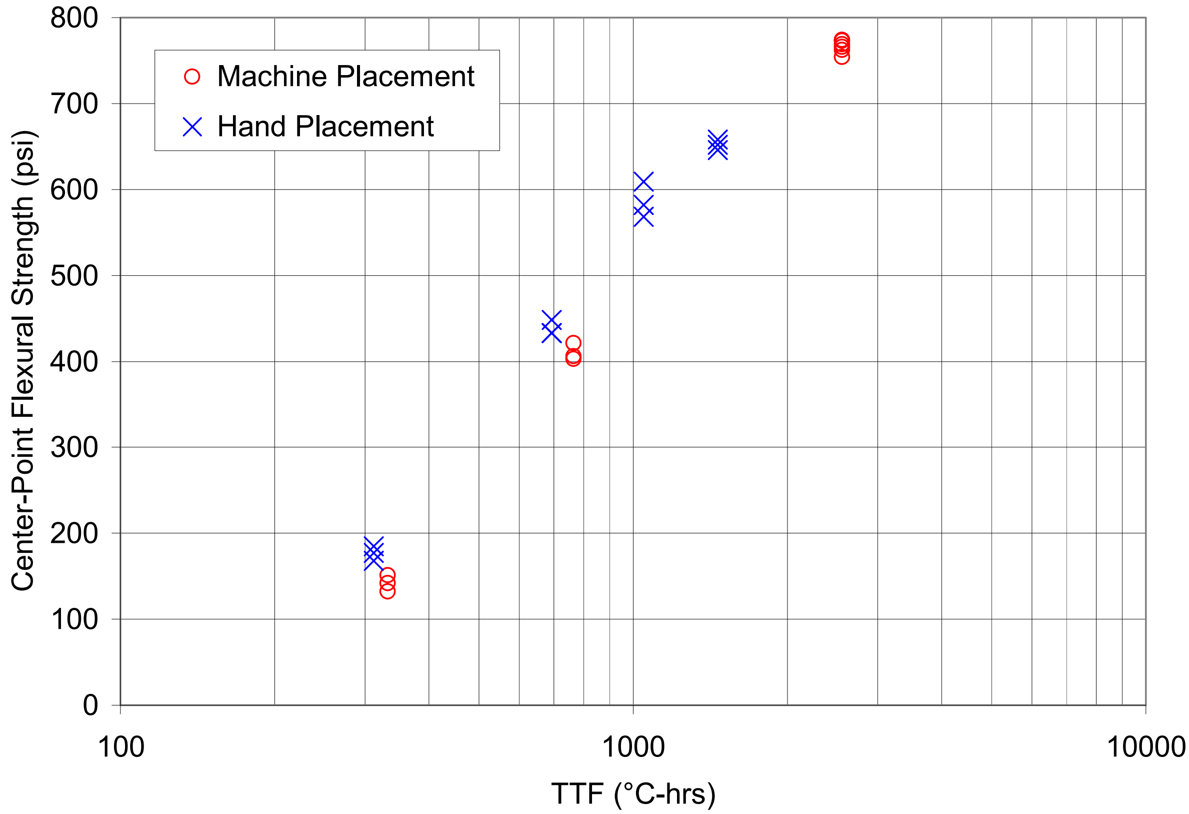


FIGURE 11. RESULTS OF LABORATORY MATURITY MEASUREMENTS PRIOR TO CONSTRUCTION

FIGURE 12. MATURITY DEVICES SECURED PRIOR TO PAVING

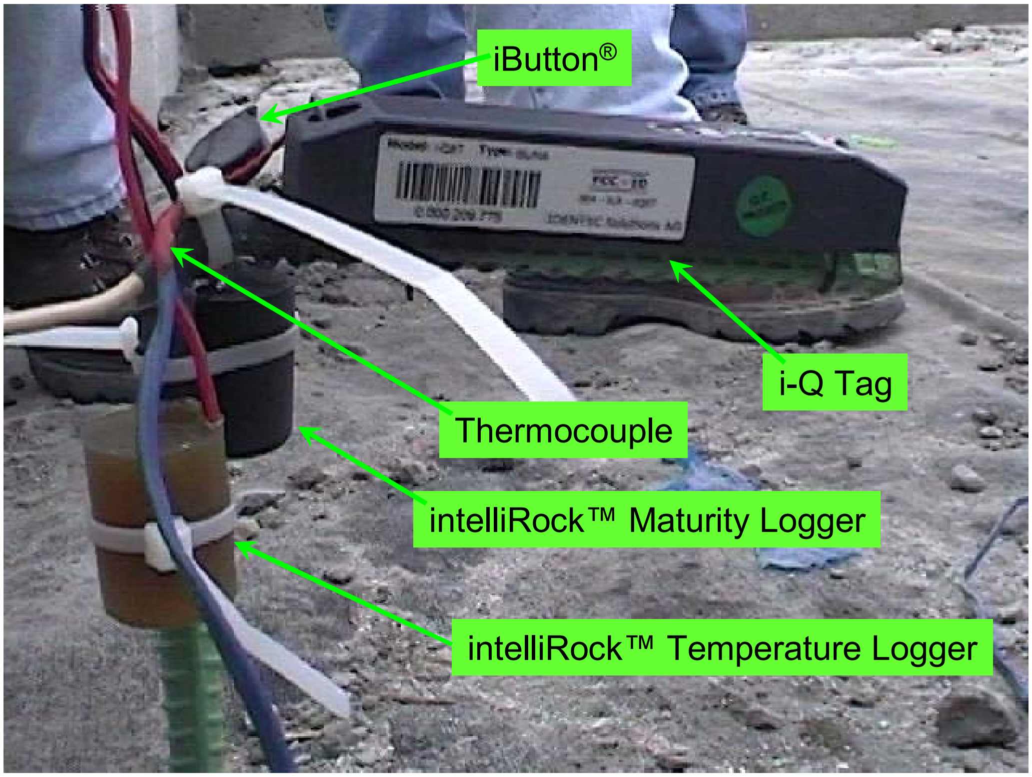


FIGURE 13. IDENTIFICATION OF MATURITY DEVICES

FIGURE 14. INSERTING SENSOR LEADS INTO ADJACENT JOINT CUT

FIGURE 15. SENSOR LEADS SECURED PRIOR TO PLACEMENT

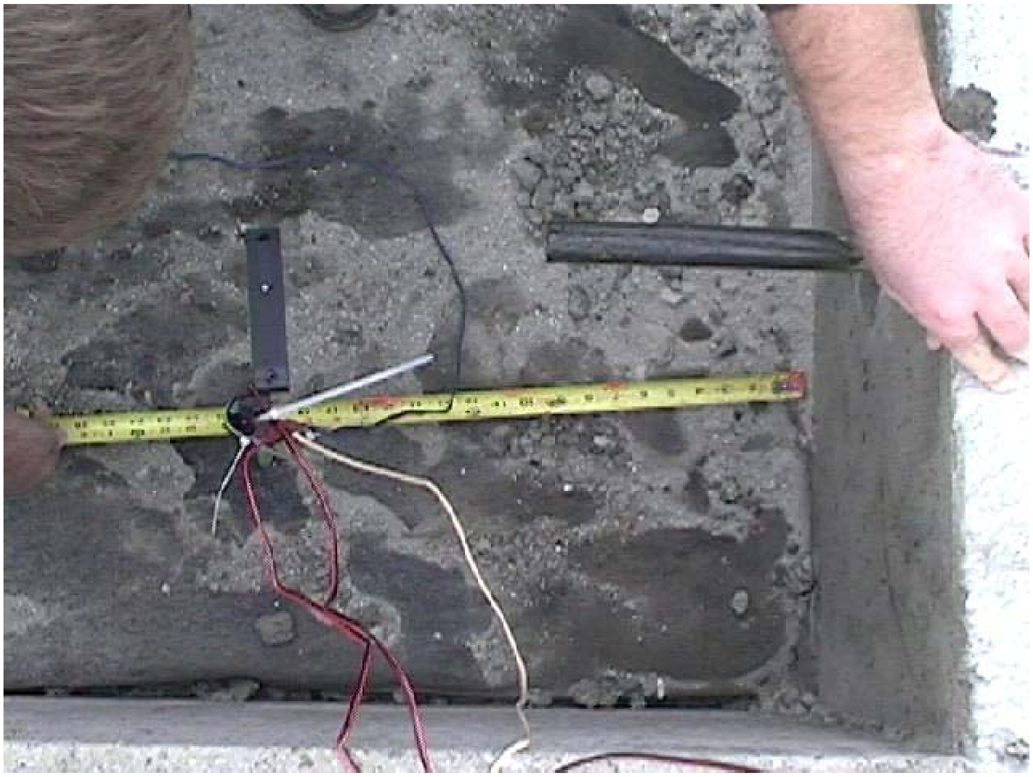
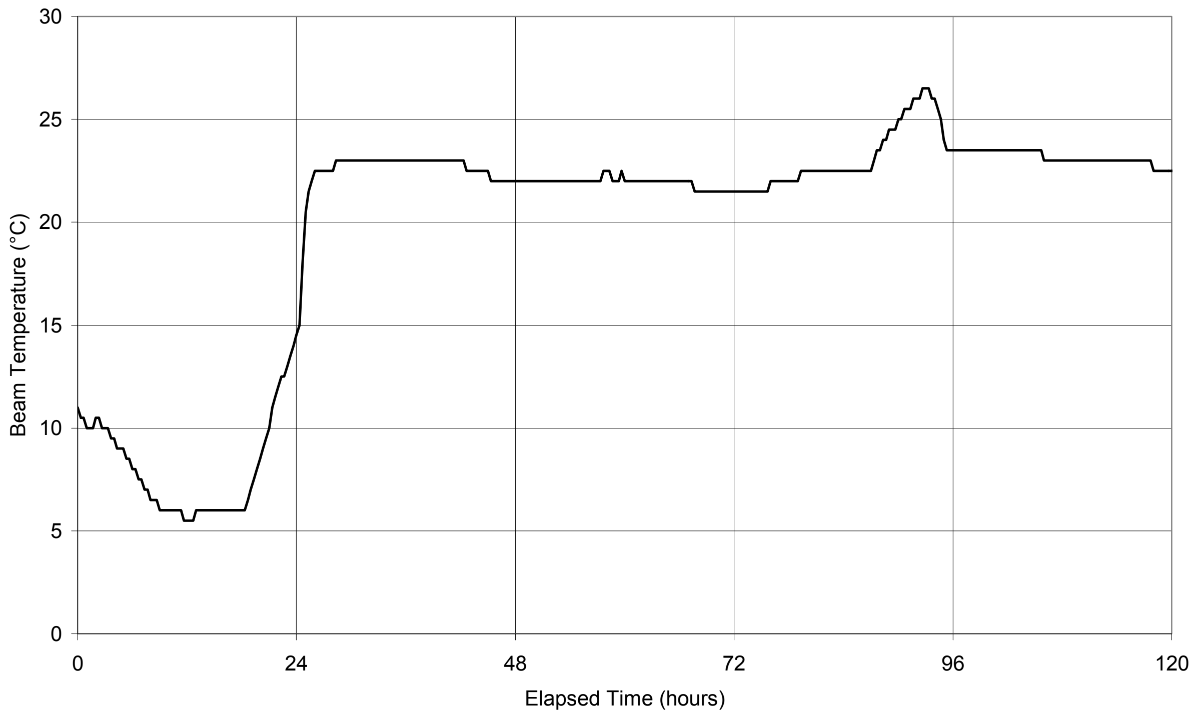


FIGURE 16. MEASUREMENT OF SENSOR POSITION

FIGURE 17. CONCRETE SHOVELED AROUND SENSORS TO PROTECT FROM PAVER



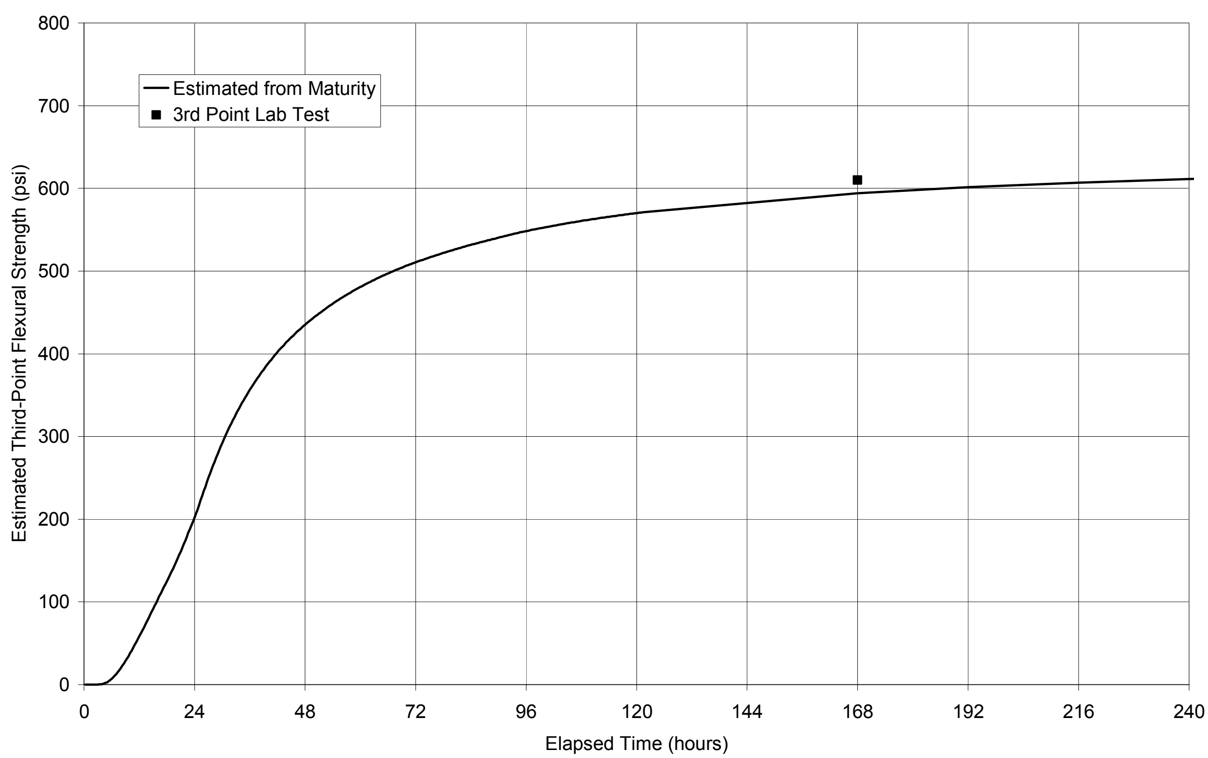
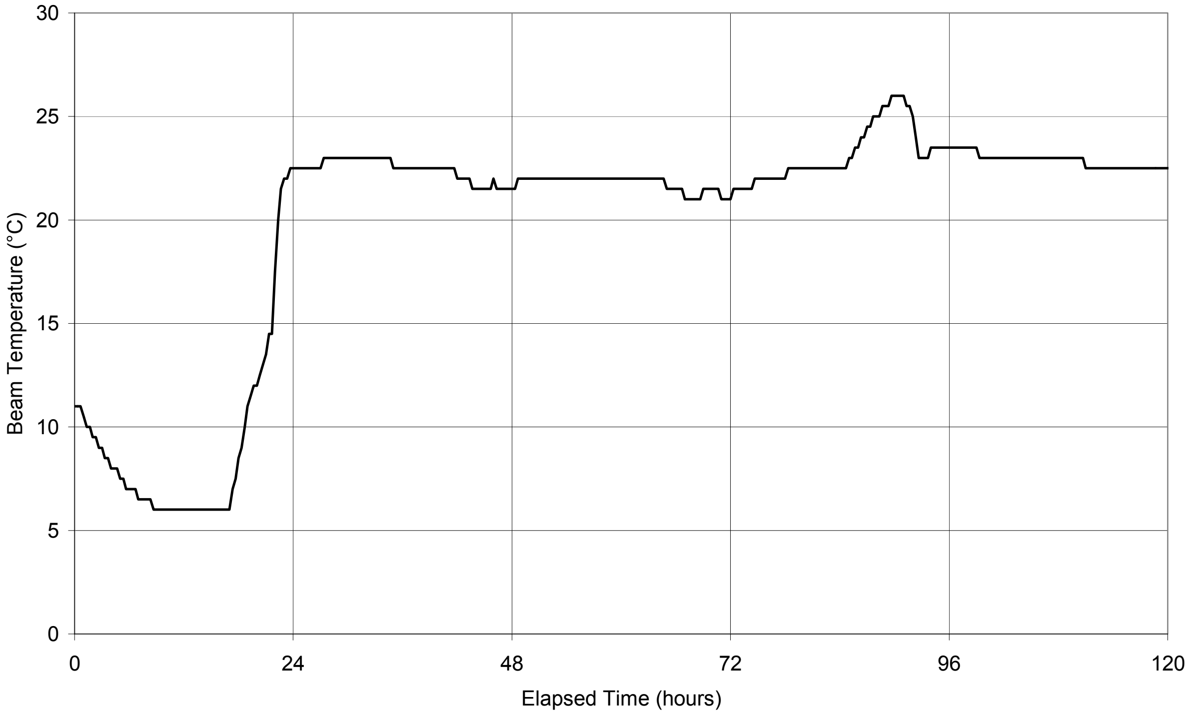


FIGURE 18. MEASURED AND ESTIMATED TEMPERATURES AND STRENGTHS FOR LOCATION 1 – HAND PLACEMENT



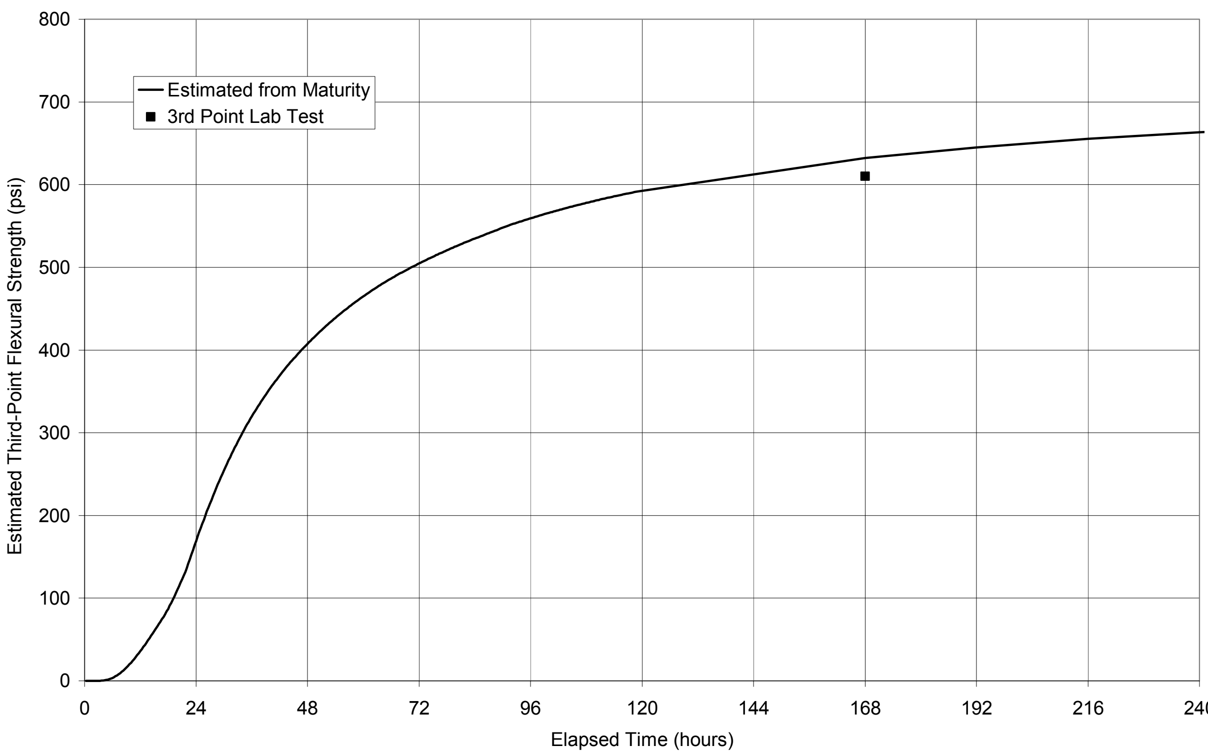


FIGURE 19. MEASURED AND ESTIMATED TEMPERATURES AND STRENGTHS FOR LOCATION 6 – MECHANICAL PLACEMENT

FIGURE 20. PROXIMITY OF FIELD SITE TO HOTEL ROOM AS IT RELATES TO ACQUIRING WIRELESS MATURITY READINGS FROM THE IBUTTONS®

FIGURE 21. SCREEN CAPTURE OF COMMAND CENTER SOFTWARE

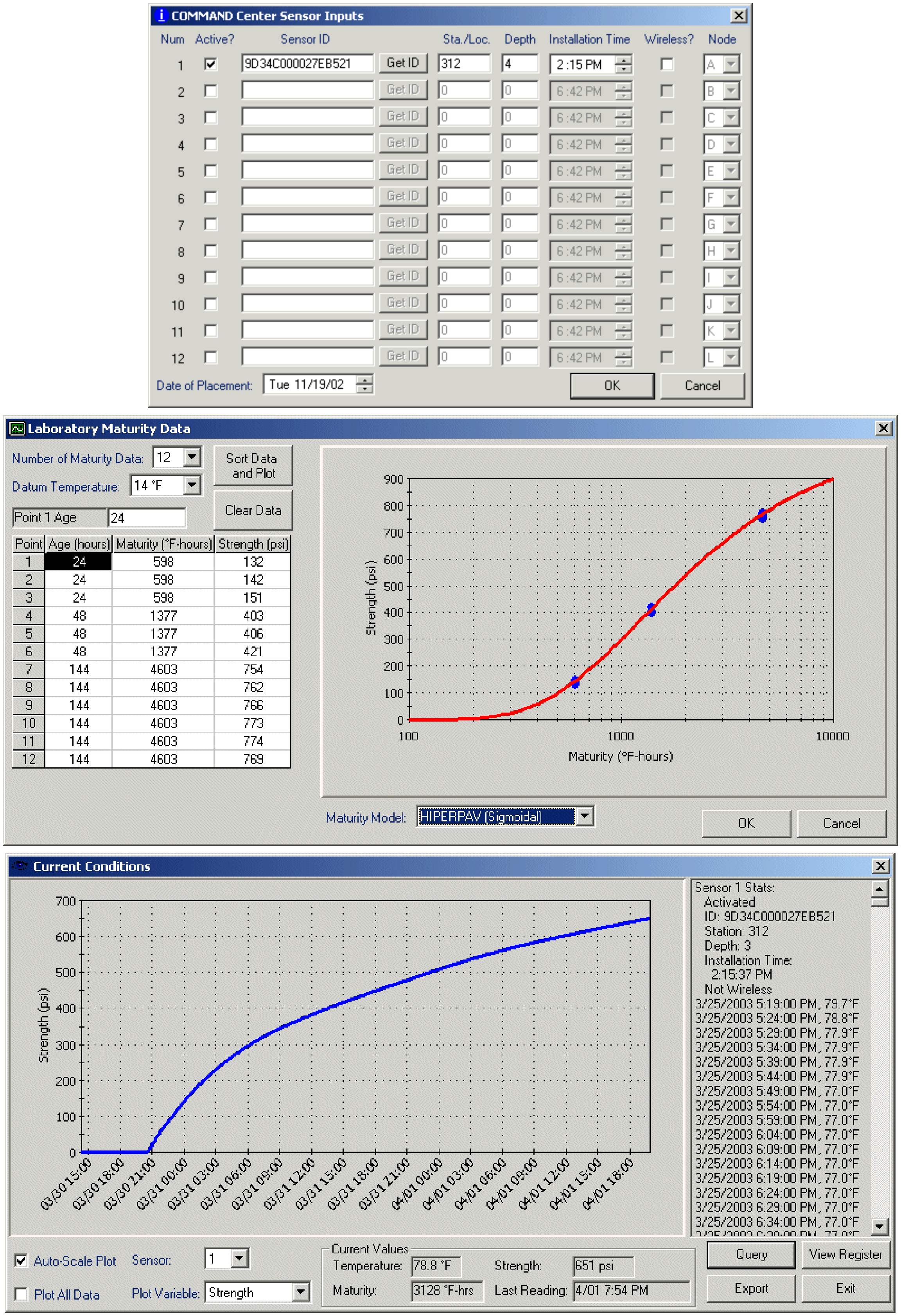


FIGURE 22. SCREEN CAPTURES OF COMMAND CENTER SOFTWARE

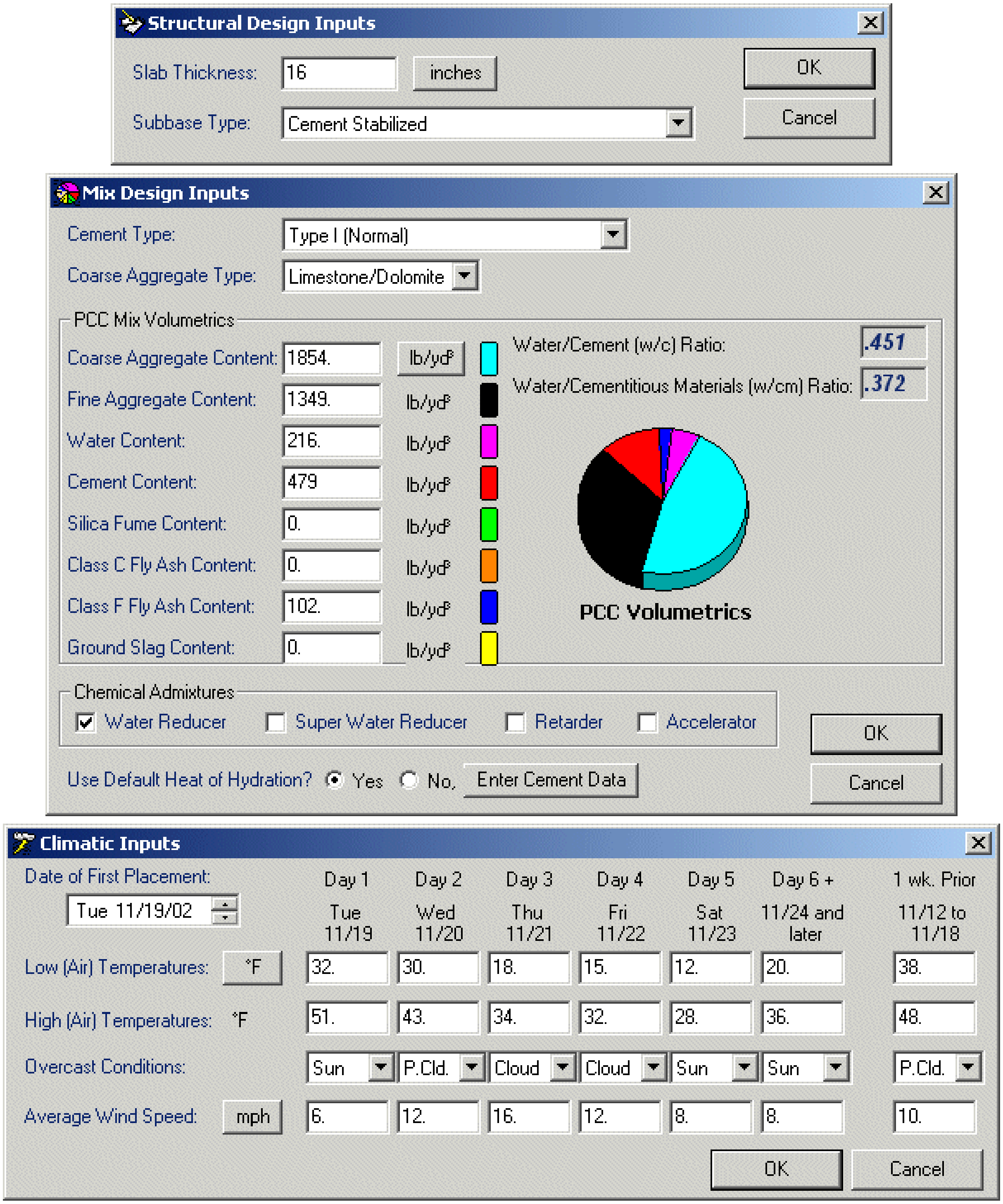


FIGURE 23. SCREEN CAPTURES OF COMMAND CENTER SOFTWARE

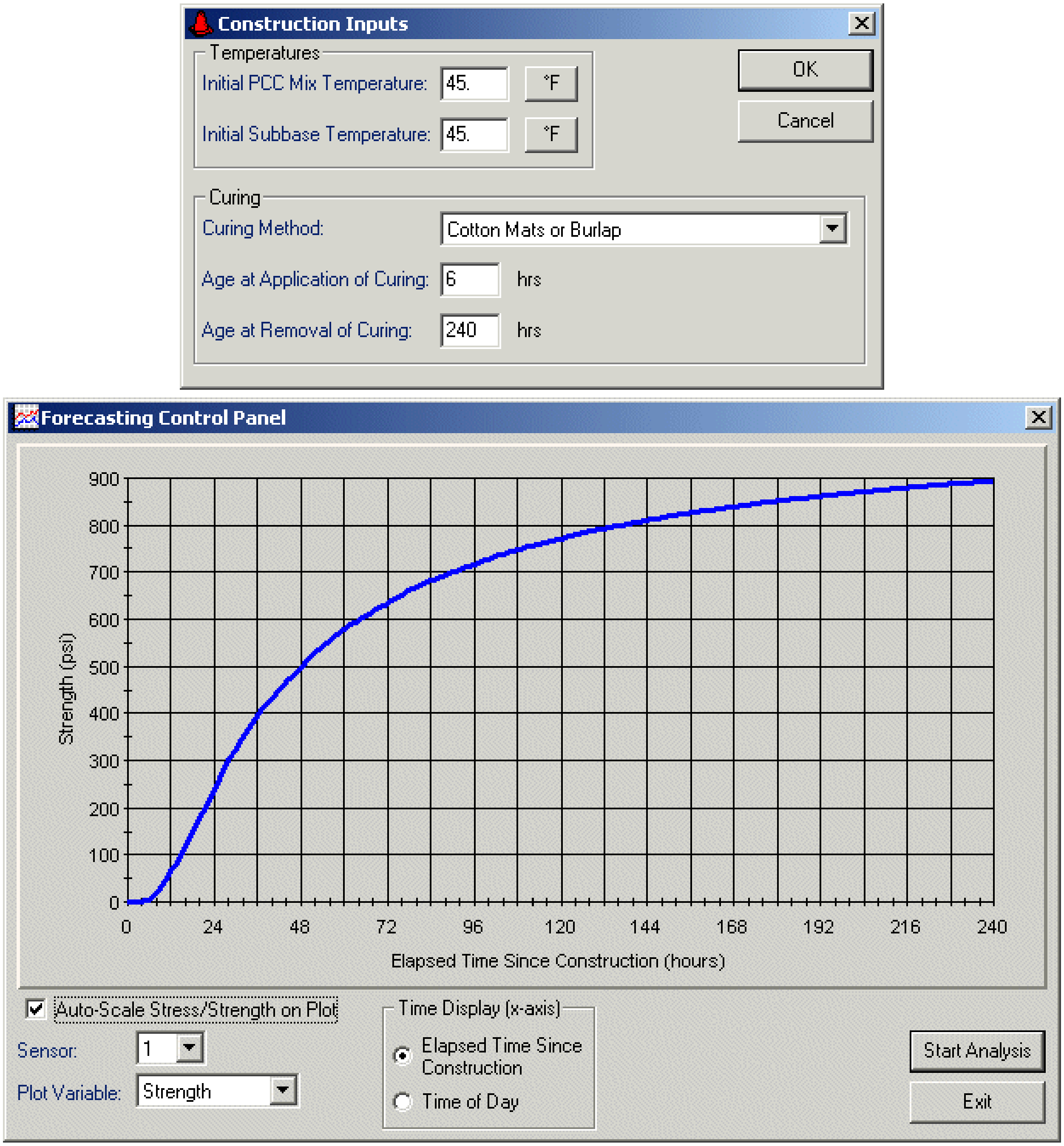


FIGURE 24. SCREEN CAPTURES OF COMMAND CENTER SOFTWARE

TABLE 1. CONCRETE MIXTURE PROPORTIONS

Material	Characteristics	Slipform Placement (#2) (per cubic yard)	Hand Placement (#6) (per cubic yard)
Cement (lbs.)	Type I/II – Ash Grove	566	614
Coarse Aggregate (lbs.)	1 1/2 in. Limestone - Sully	1404	1350
Coarse Aggregate (lbs.)	1/4 in. Limestone - M.M. Sully	468	450
Fine Aggregate (lbs.)	Concrete Sand - M.M. Johnston	1201	1155
Air Entraining Agent (oz.)	AEA-92	5.0	5.0
Water Reducing Agent (oz.)	EUCON WR	22.6	24.5
Water (gal.)		25.8	29.4
	Water-to-Cement Ratio	0.38	0.40
	Percent Air	6.3%	6.2%
	Slump (in.)	2	3

TABLE 2. EXPERIMENT FACTORIAL FOR MATURITY DEVICE INSTRUMENTATION

Location	Mix Type	Thermocouple	iButton®	intelliRock™ Maturity	intelliRock™ Temperature	intelliRock™ Strength	i-Q Tag
1	Hand	×	×	×	×		×
2	Slipform	×	×	×		×	×
3	Slipform	×	×				
4	Other		×	×			
5	Slipform	×	×	×	×		
6	Slipform		2 ×	×		×	
7	Slipform	×	3 ×	×			
8	Slipform		2 ×	×	×		×
9	Slipform		2 ×	×			×
10	Slipform		2 ×				×

TABLE 3. MEASURED STRENGTHS FROM VALIDATION BEAM TESTS

Location	Hours (Days)	Specimen ID	Test Date	Third-Point Flexural Strength (psi)	% Design Strength (650 psi)
Location 1 Hand Placement	168 (7)	R50-21	11/26/02	610	94%
	672 (28)	R50-17	12/17/02	680	105%
	672 (28)	R50-18	12/17/02	760	117%
Location 6 Slipform Placement	168 (7)	R49-11	11/26/02	610	94%
	672 (28)	R49-7	12/17/02	725	112%
	672 (28)	R49-8	12/17/02	675	104%

APPENDIX A – SUMMARY OF MATURITY THEORY

The theoretical premise of maturity is rather straightforward. Heat is released as a result of the various chemical reactions in the hydration of the cementitious materials. As time progresses, these reactions at first increase, and then begin to decrease. Figure A.1 illustrates this process. As can be seen in this figure, the rate of heat generation is a function of the cement type. Cement fineness, presence of admixtures (chemical and mineral), and the temperature of the concrete itself, also influence the rate and quantity of heat generated.

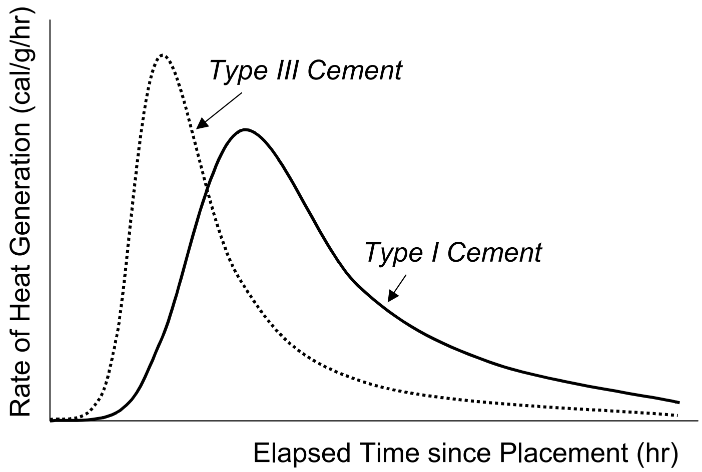


FIGURE A.1 TYPICAL HEAT GENERATION IN CEMENTS

Under normal circumstances, strength in the concrete develops throughout this heat evolution process. The chemical reactions that release this heat also result in hydration products that give concrete its strength. Maturity concepts were born as a result of the understanding of this phenomenon. As figure A.2 illustrates, it has been shown experimentally that a mathematical relationship exists between the quantity of heat liberated by the young concrete, and the associated strength. However, directly measuring the heat of hydration in the field is difficult and impractical due to the complexity of the required instrumentation.

A.1 HEAT AND TEMPERATURE.

Unlike direct heat measurements, concrete temperature is much easier to measure. A mathematical relationship can be derived between the temperature of concrete and the heat of hydration.

Temperature development in a concrete slab is a function of a number of factors. Some of these include:

1. The heat-of-hydration (HOH) characteristics of the cementitious materials,
2. The quantity of cementitious materials in the concrete,
3. Thermodynamic properties of the concrete (e.g. specific heat, thermal conductivity),
4. Boundary conditions (e.g. air and base temperatures), and
5. Time.

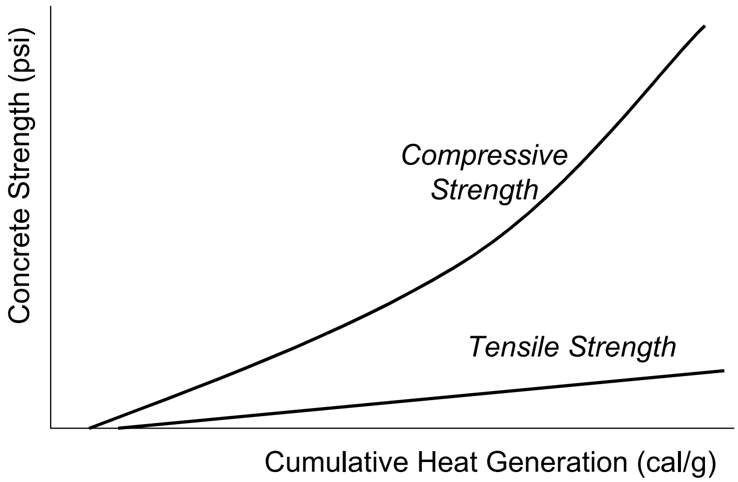


FIGURE A.2 RELATIONSHIP BETWEEN HEAT OF HYDRATION AND CONCRETE STRENGTH

Figure A.3 illustrates the interaction of these factors. Heat loss, and thus a temperature drop, is affected by the geometry of the concrete structure. Mass concrete applications, without provisions for internal cooling, can generate significant heat due to their inherent insulatory nature. Slabs, however, experience heat loss at the surfaces (top, bottom, and edges). This heat loss translates into a temperature decrease. Airfield pavements are generally rather thicker than highway pavements, making them a case "in between" a mass concrete and a thin slab, as illustrated in figure A.3.

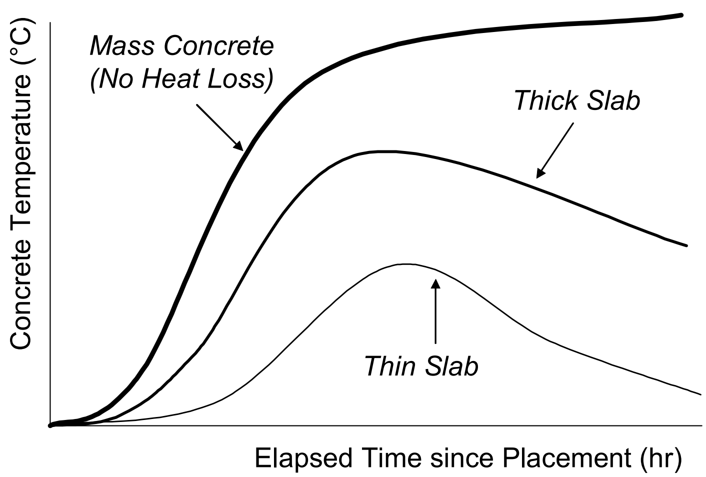


FIGURE A.3 RELATIONSHIP BETWEEN CONCRETE TEMPERATURE AND TIME FOR DIFFERENT STRUCTURES

To accurately predict the relationship between heat and temperature, all of the factors listed above must be taken into consideration simultaneously. To accomplish this efficiently, computer simulation is required. Programs such as the HIPERPAV® software, developed by Transtec for the Federal Highway Administration (FHWA), can be used to accomplish this task. The TEMP

System software evaluated in this effort is another example of a program that can make these calculations quickly and reliably.

A.2 STRENGTH PREDICTION.

The final step in the process of using maturity to predict concrete strength is to define this theoretical relationship. Currently, a number of mathematical functions are being employed to accomplish this task. The Nurse-Saul maturity method for strength prediction is the most commonly used method in the United States today for concrete pavement construction. In order to predict strength, a maturity value is first calculated as follows:

$$M_{current} = \sum_{i=0}^{t_{current}} \Delta t \left(T_i - T_{datum}\right)$$

where,

$M_{current}$ = maturity (time-temperature factor – TTF) (°C-hr),
$t_{current}$ = current time (hrs),
Δt = time increment (hrs),
T_i = temperature at increment *i* (°C),
T_{datum} = datum temperature, commonly equal to -10°C.

This equation is shown graphically in Figure A.4.

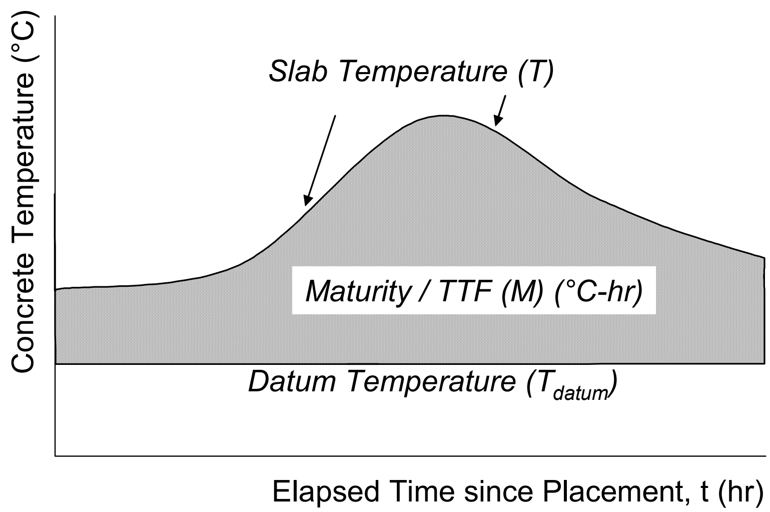


FIGURE A.4 MATURITY CALCULATION BASED ON NURSE-SAUL THEOREM

The final step is to estimate strength from maturity. The relationship between strength and maturity can be found from calibration in the laboratory. Figure A.5 illustrates a typical relationship.

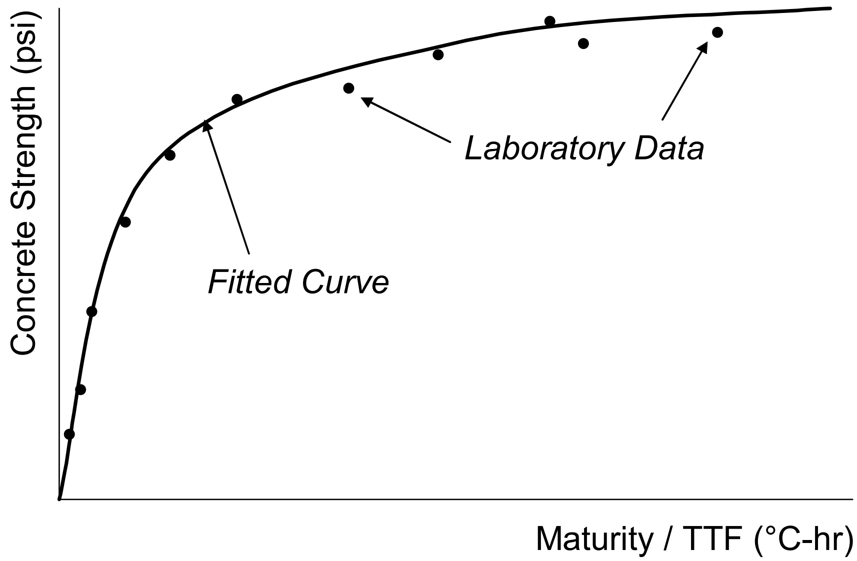


FIGURE A.5 RELATIONSHIP BETWEEN NURSE-SAUL MATURITY AND CONCRETE STRENGTH

In order to more efficiently use the relationship in figure A.5, a mathematical function is commonly fit through the measured points. Two common functions include (log) linear and (log) sigmoidal curves. These curves are defined mathematically as:

$$S_t = \max\{0, a + b \times \log_{10}(M_t)\} \qquad \text{(linear)}$$

$$S_t = S_\infty \times e^{-\left(\frac{\tau}{M_t}\right)^\alpha} \qquad \text{(sigmoidal)}$$

where,

S_t = strength at time t (psi),
M_t = maturity at time t (°C-hr),
a, b = log-linear curve fit parameters, and
S_∞, τ, α = log-sigmodial curve fit parameters.

Parameters for both of these functions were found fitting the Des Moines project concrete maturity data. These fits can be observed in figures A.6 and A.7 for the slipform and hand pour mixes, respectively. The fit parameters are summarized in table A.1. As can be seen in the figures, the sigmoidal curve is generally more reliable when interpolating and extrapolating strengths from the known maturity data. Although mathematically more complex, the user is not aware of this complexity when employing the TEMP System.

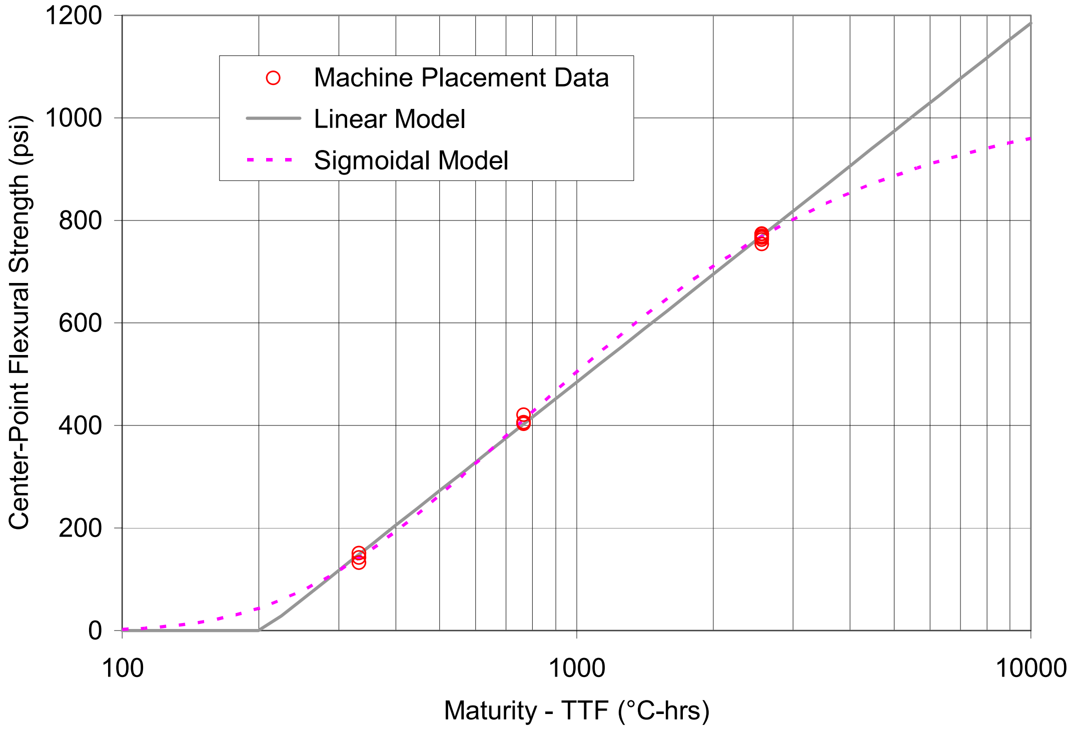


FIGURE A.6 MATURITY-STRENGTH RELATIONSHIP FOR DSM SLIPFORM MIX

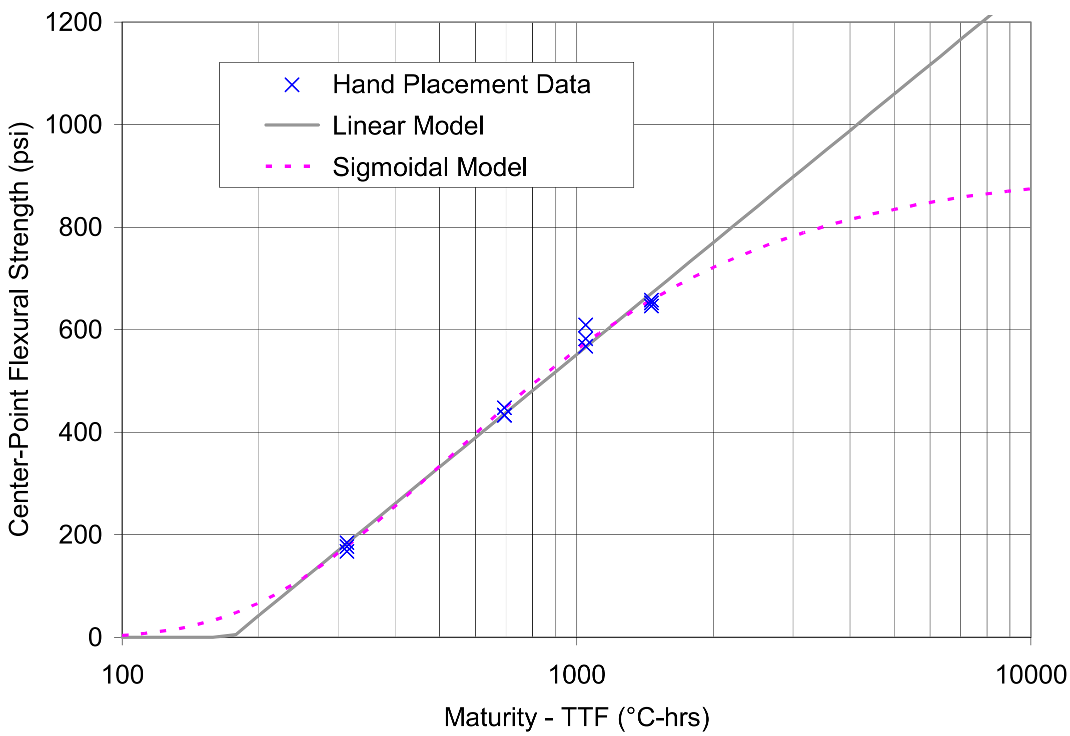


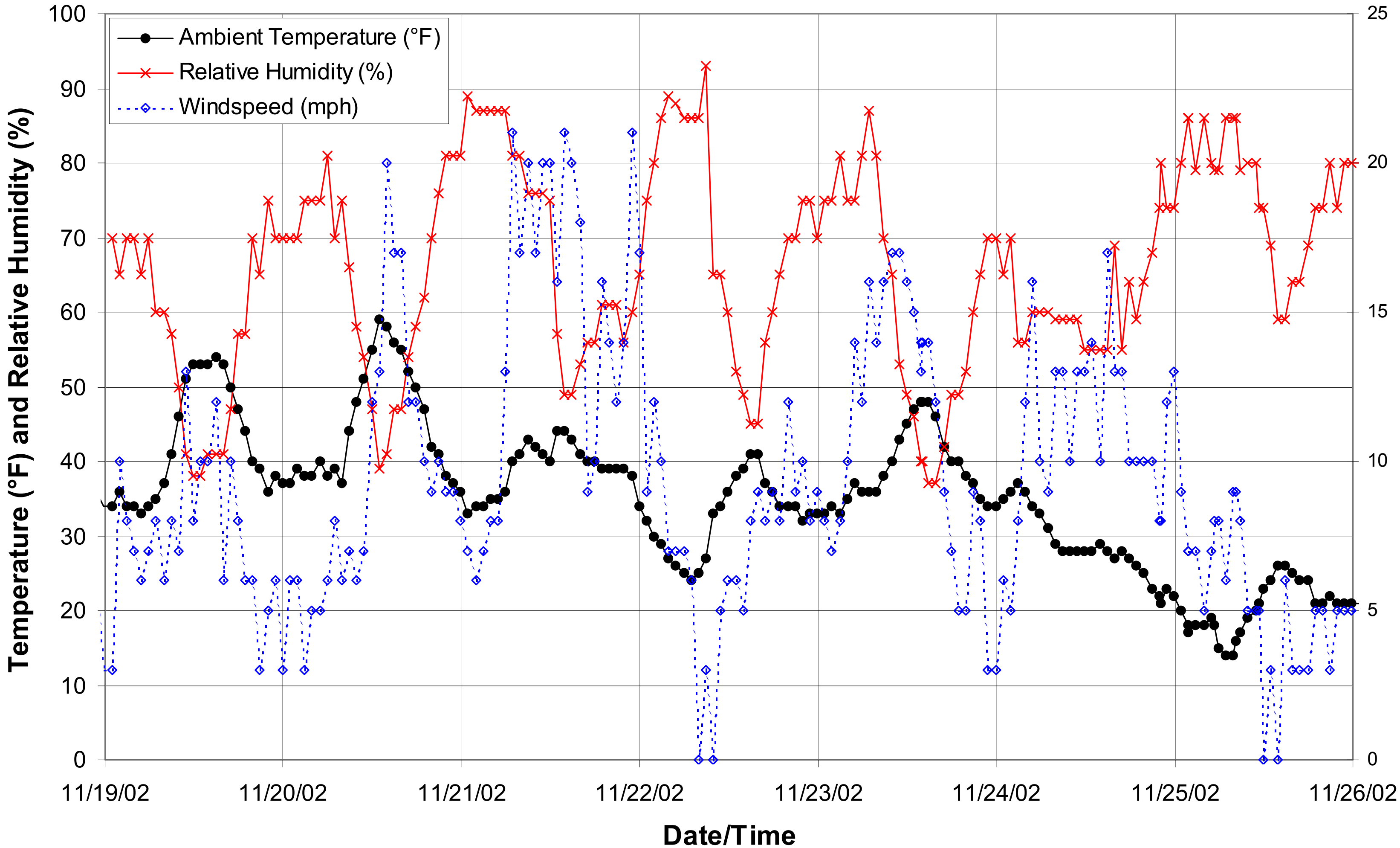
FIGURE A.7 MATURITY-STRENGTH RELATIONSHIP FOR DSM HAND PLACED MIX

TABLE A.1. MATURITY-STRENGTH FIT PARAMETERS FOR DSM MIXES

Mix	Model	Parameter	Value
Slipform (Machine)	Linear	a	-1619
		b	701
	Sigmoidal	S_∞	1051
		τ	714
		α	0.91
Hand Placement	Linear	a	-1630
		b	727
	Sigmoidal	S_∞	915
		τ	504
		α	1.04

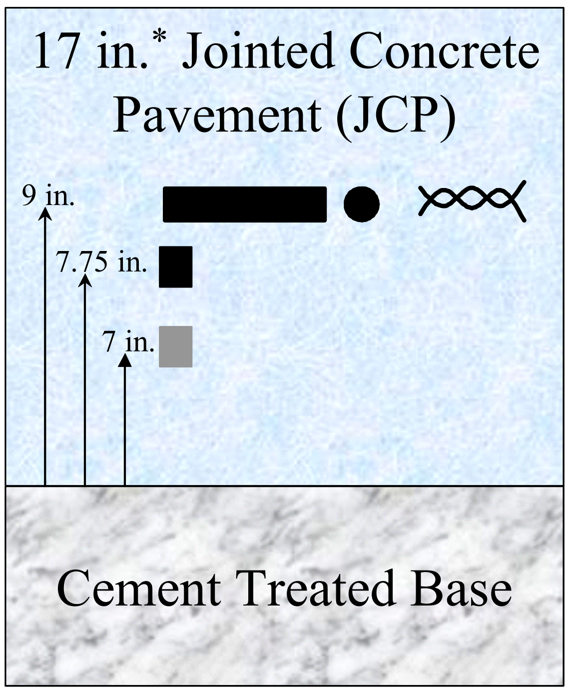
APPENDIX B – FIELD MEASUREMENTS AND RESULTS.

B.1 AMBIENT CONDITIONS.



B.2 LOCATION 1 – HAND PLACEMENT.

Concrete Placement	11/19/02 12:55 PM
Fresh Concrete Temperature	11.5°C (52.7°F)
Air Temperature	12°C (53°F)
Relative Humidity	38%
Windspeed	16 kph (10 mph)
Mix Design	Hand Placement



*Note: Design thickness is 15 in.

i-Q Tag (0.000.209.775)

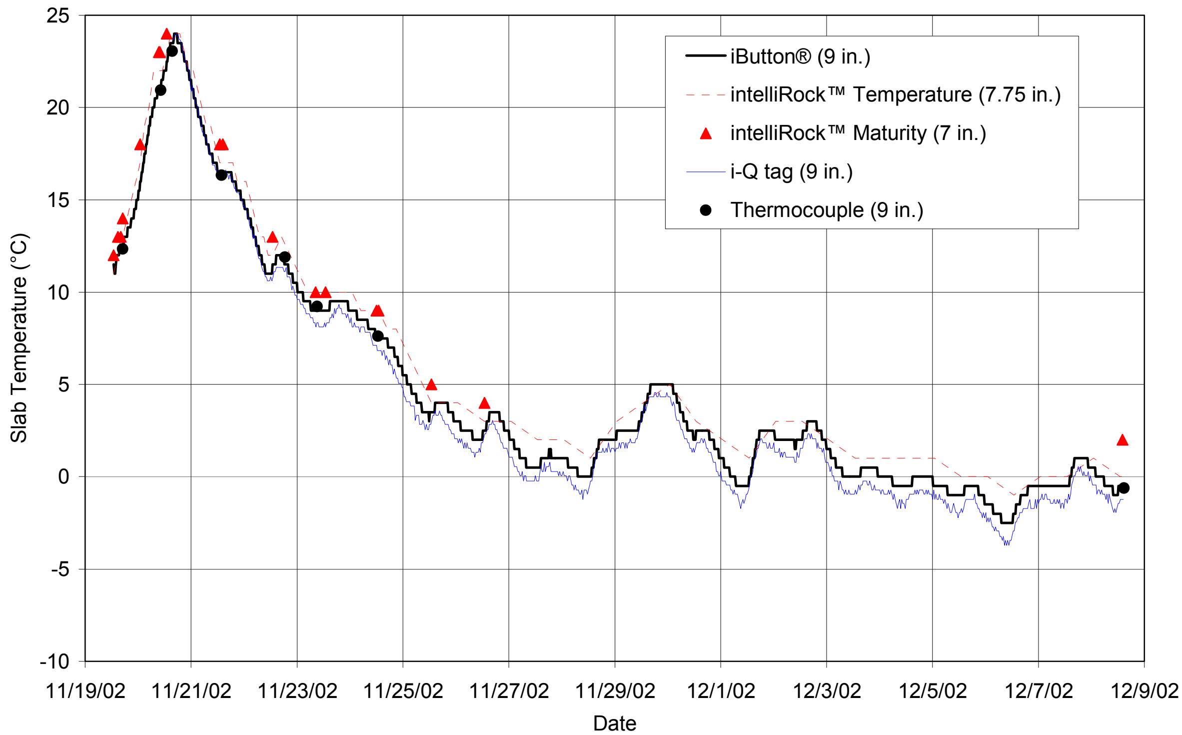
iButton® (0225400002C7BF21)

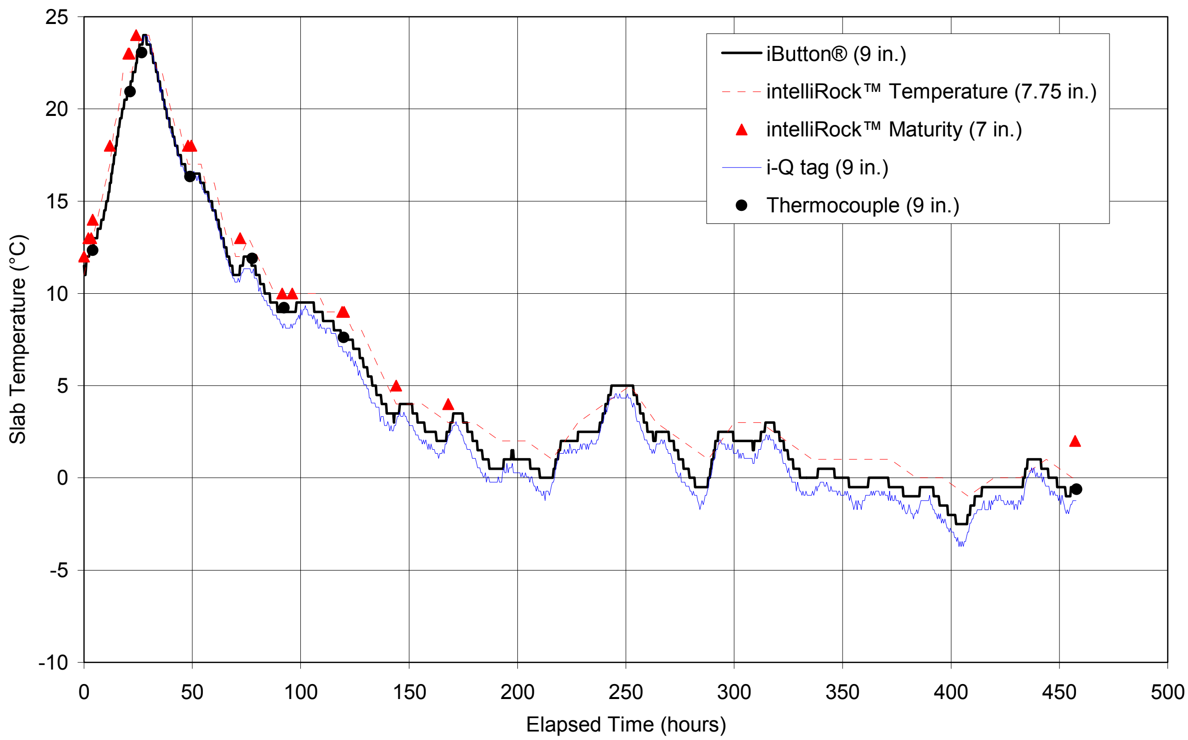
intelliRock™ Maturity (1830)

intelliRock™ Temperature (1002650)

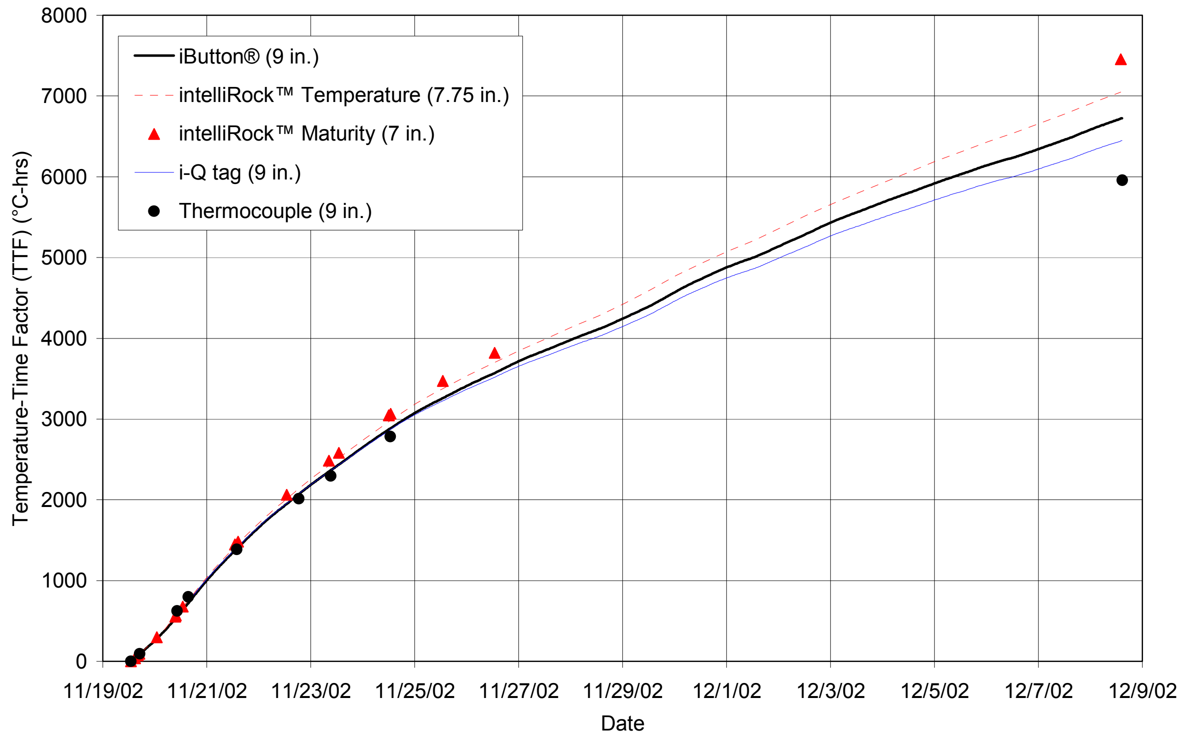
T-type Thermocouple

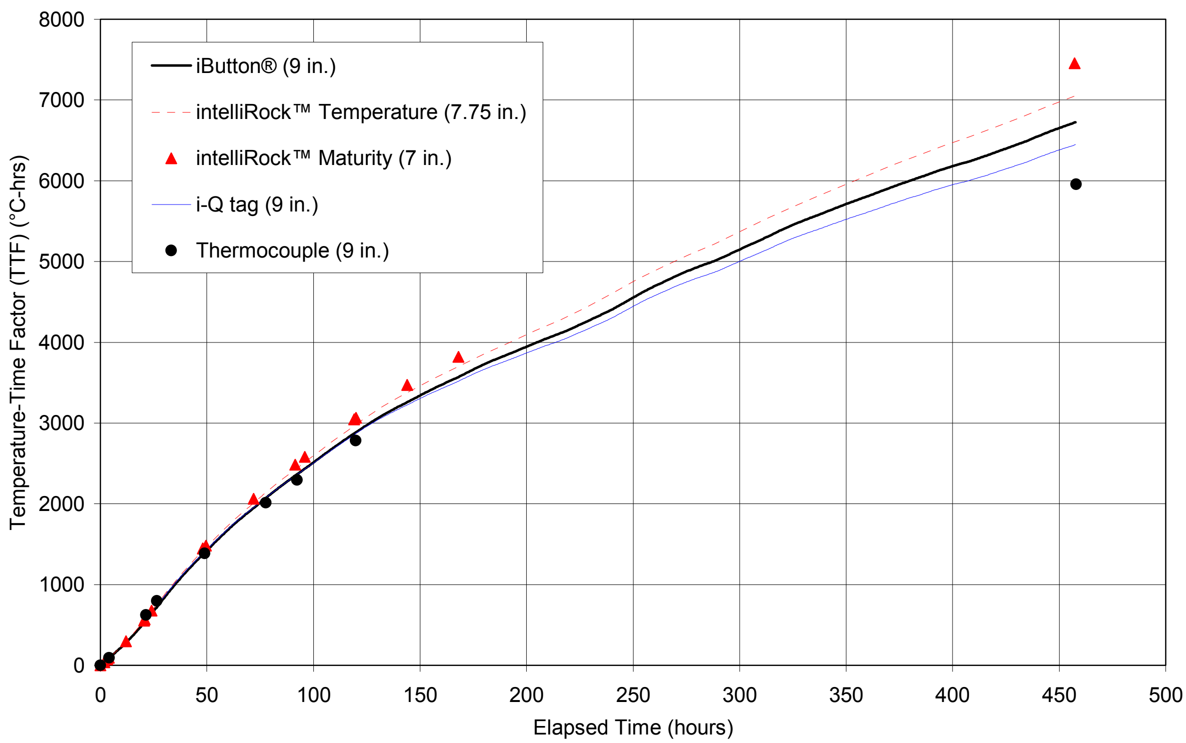
B.3 LOCATION 1 – SLAB TEMPERATURE.



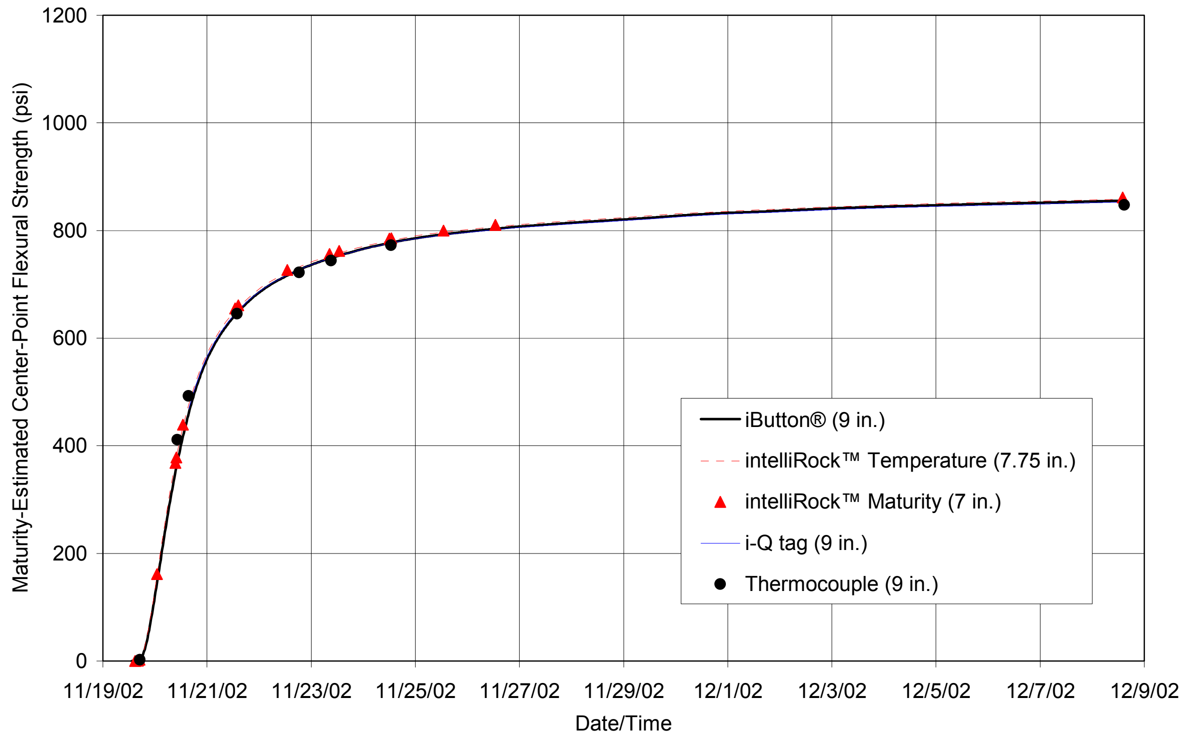


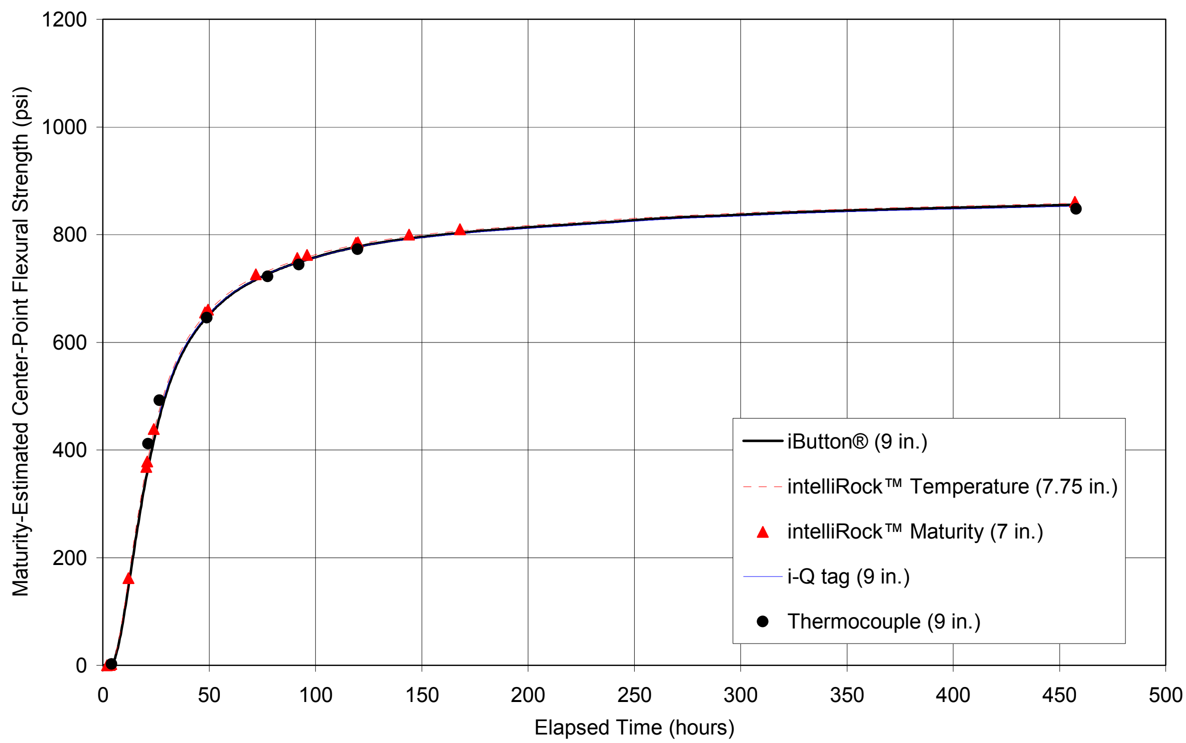
B.4 LOCATION 1 – MATURITY.





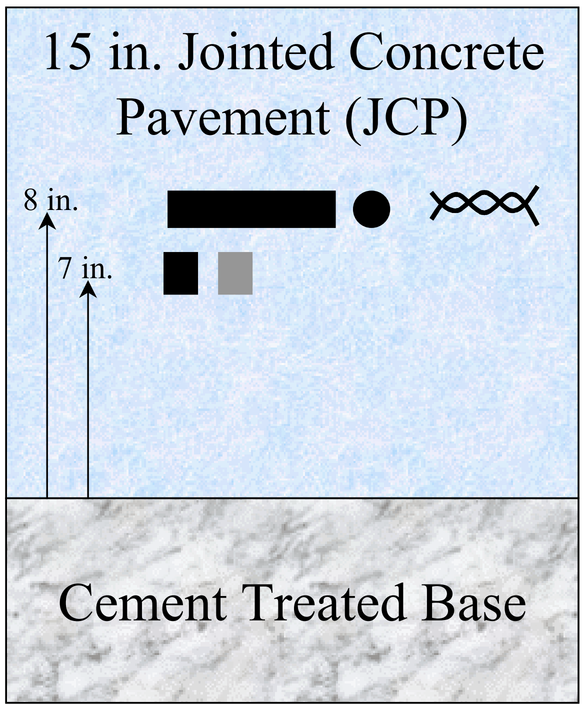
B.5 LOCATION 1 – MATURITY-ESTIMATED STRENGTH.

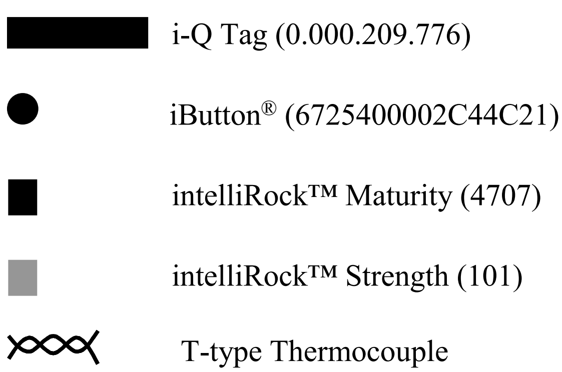




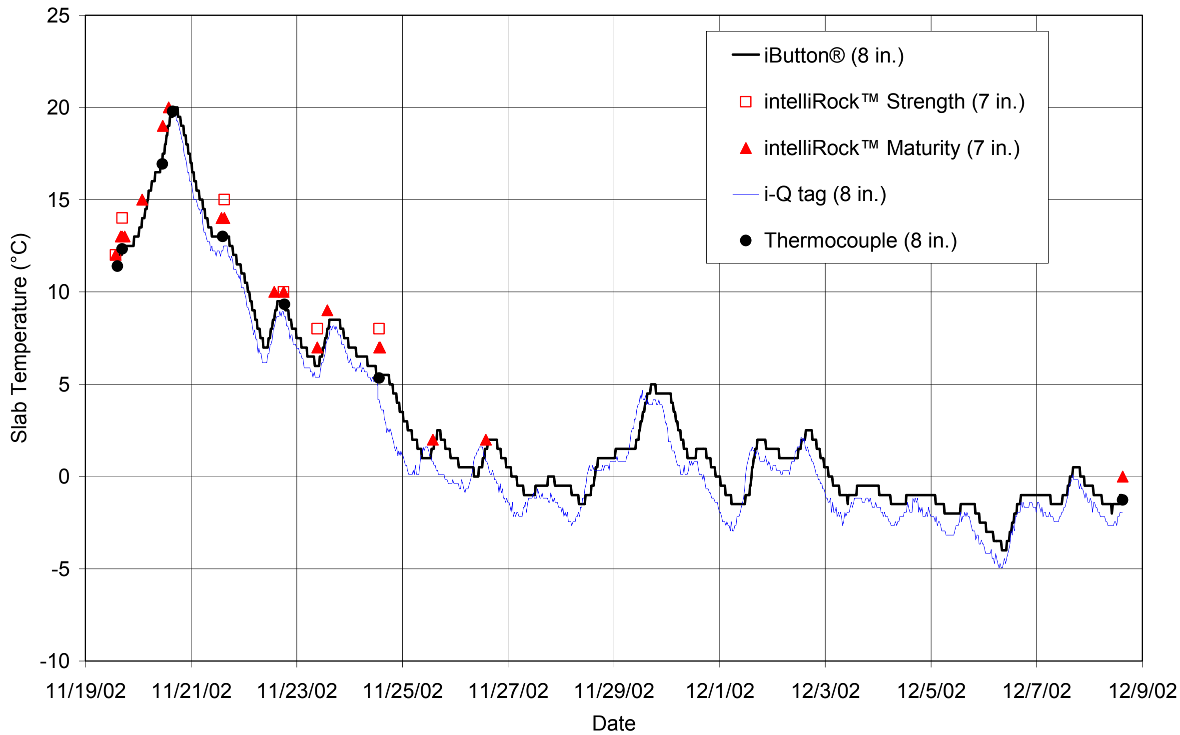
B.6 LOCATION 2 – MECHANICAL PLACEMENT.

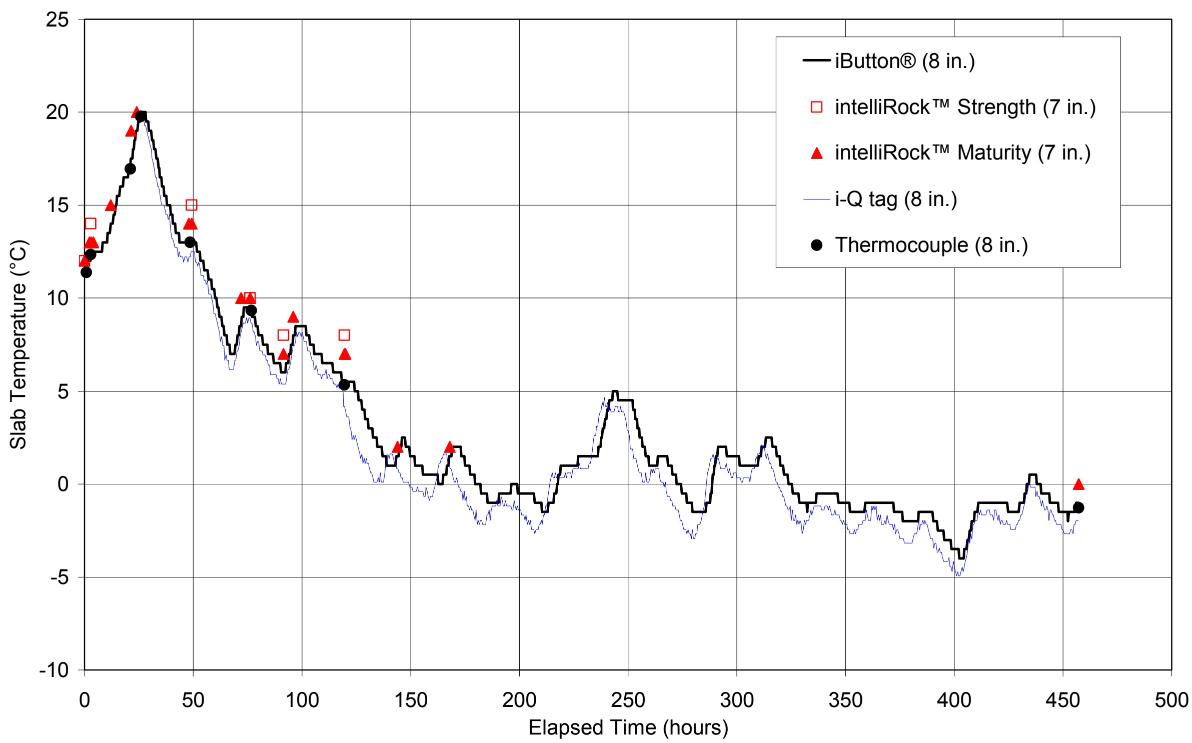
Concrete Placement	11/19/02 1:49 PM
Fresh Concrete Temperature	11.5°C (52.7°F)
Air Temperature	12°C (53°F)
Relative Humidity	41%
Windspeed	16 kph (10 mph)
Mix Design	Slipform



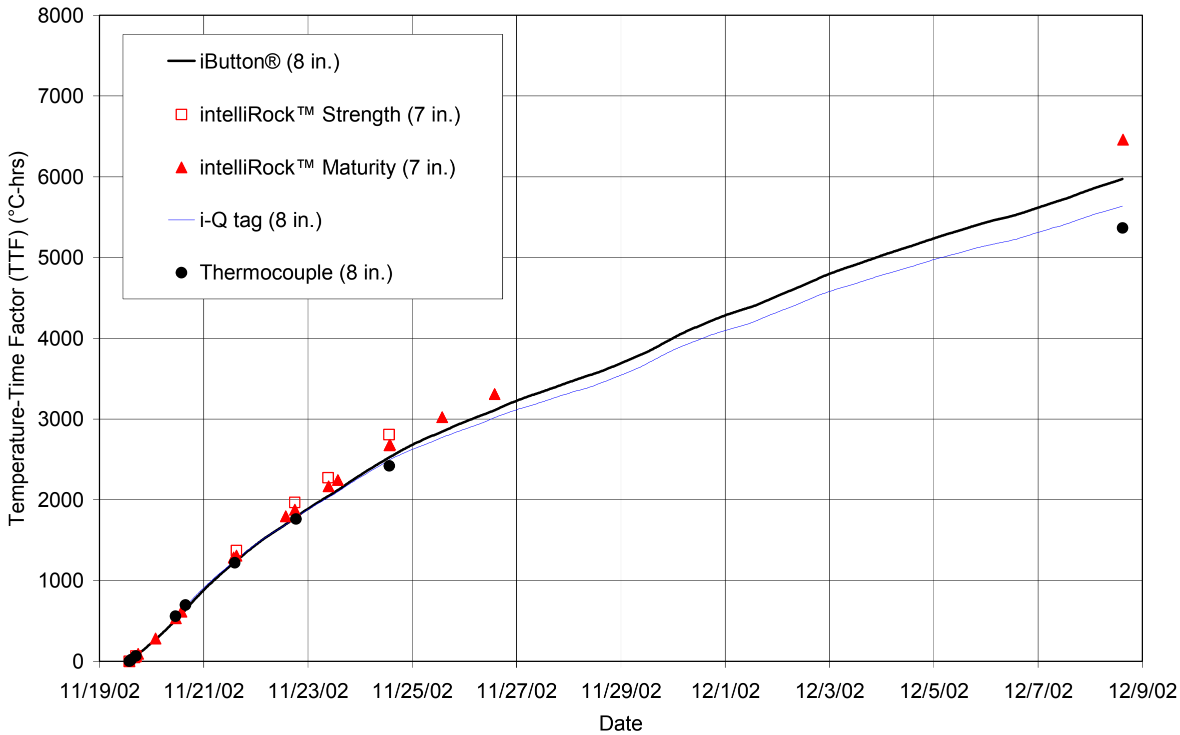


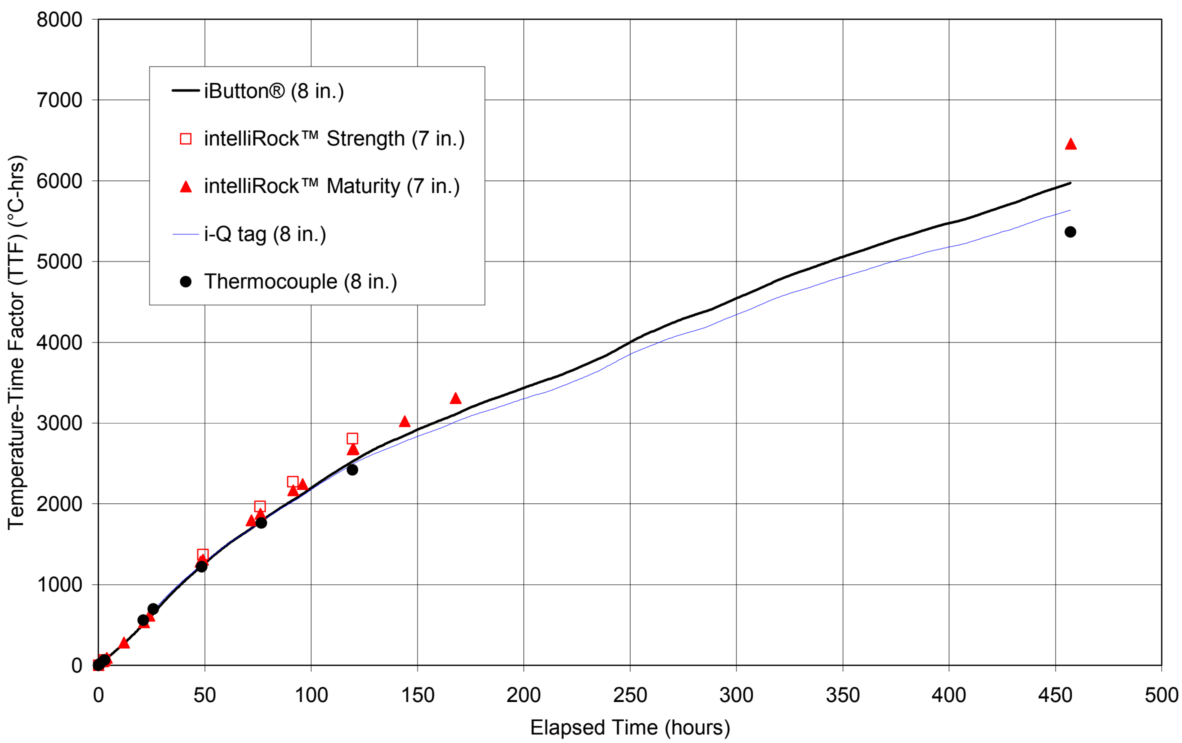
B.7 LOCATION 2 – SLAB TEMPERATURE.



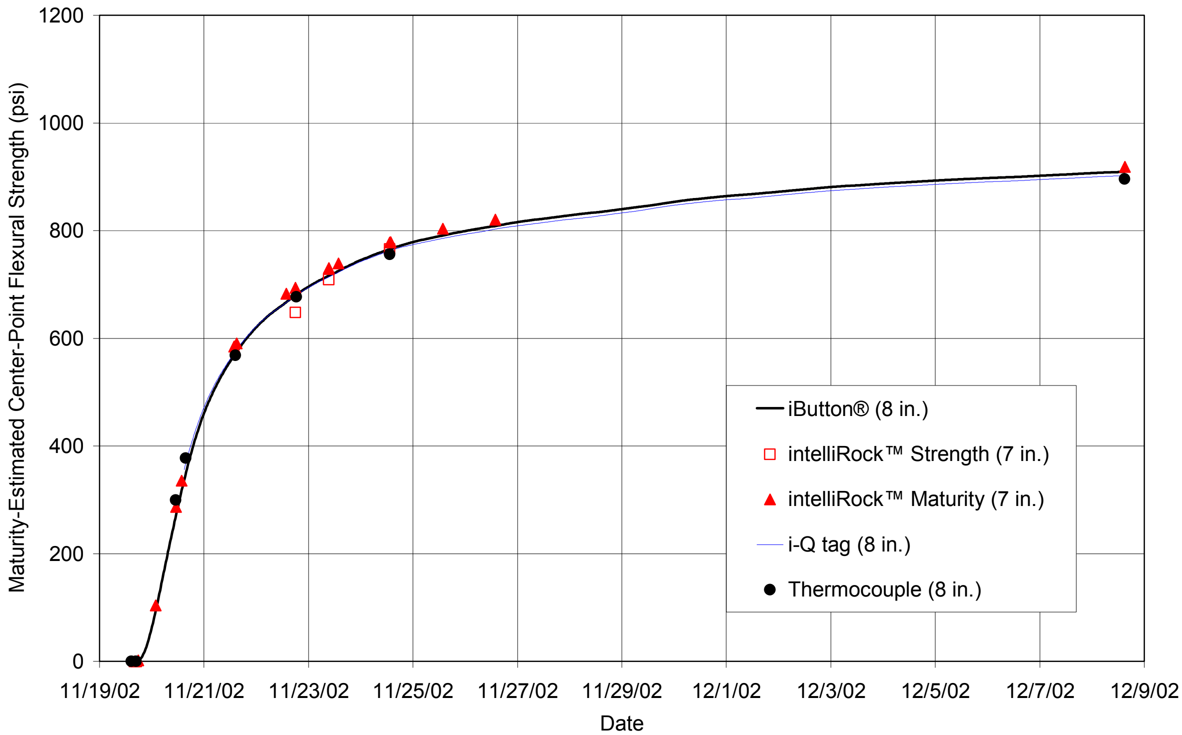


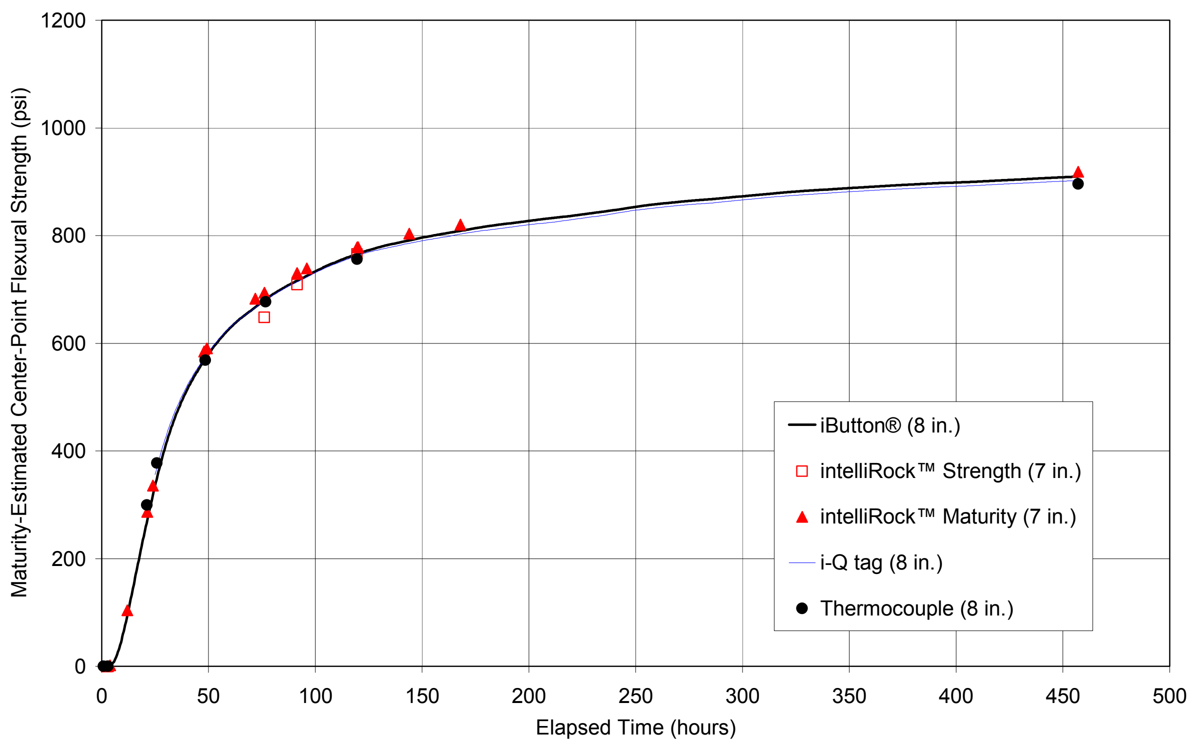
B.8 LOCATION 2 – MATURITY.





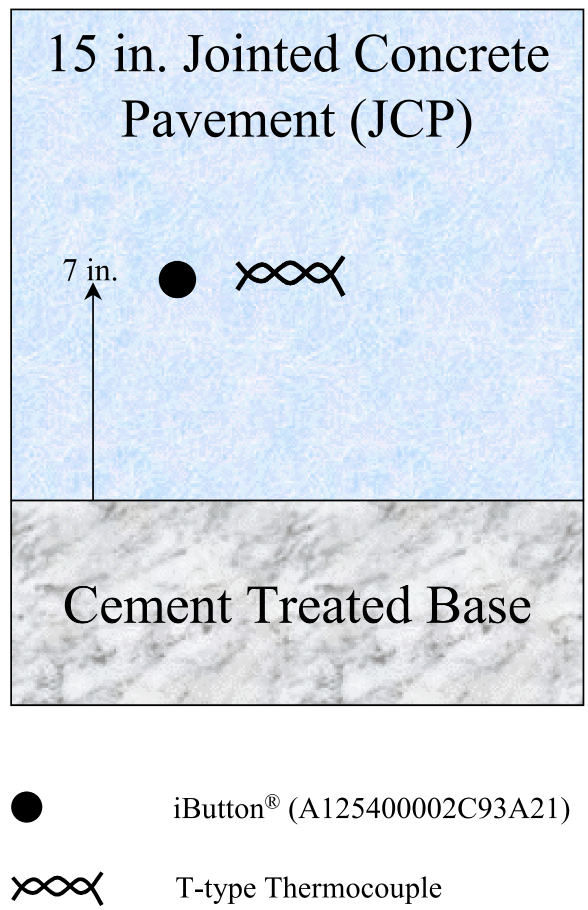
B.9 LOCATION 2 – MATURITY-ESTIMATED STRENGTH.



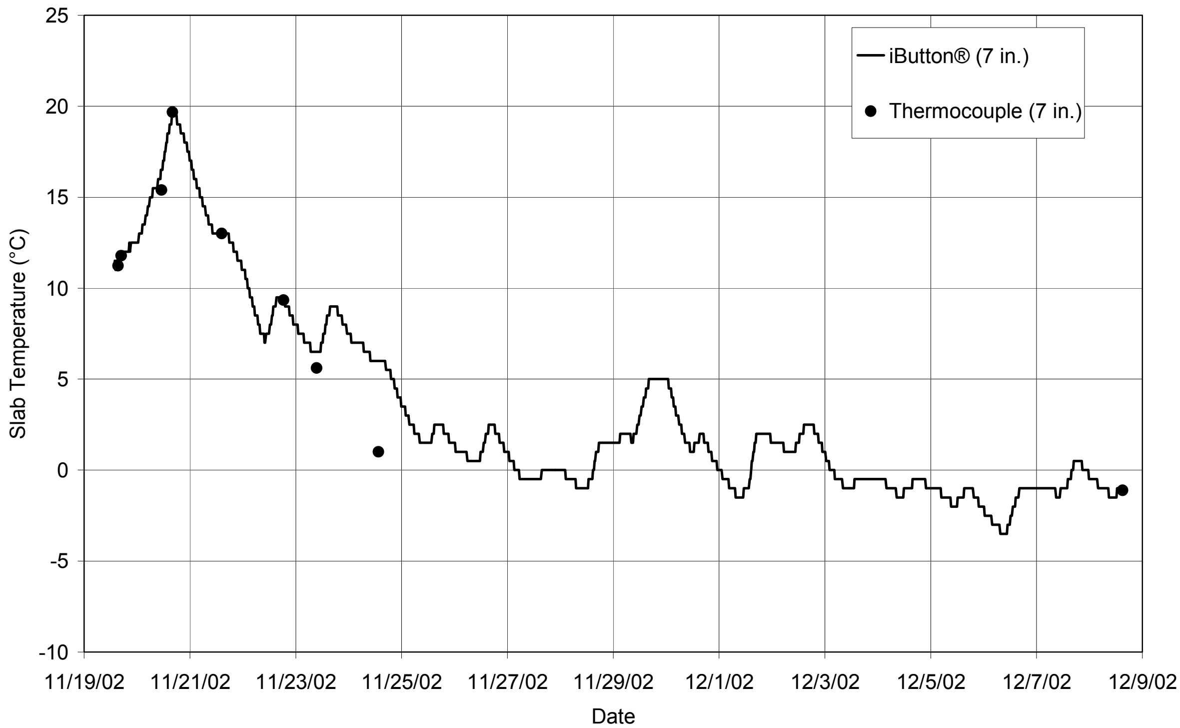


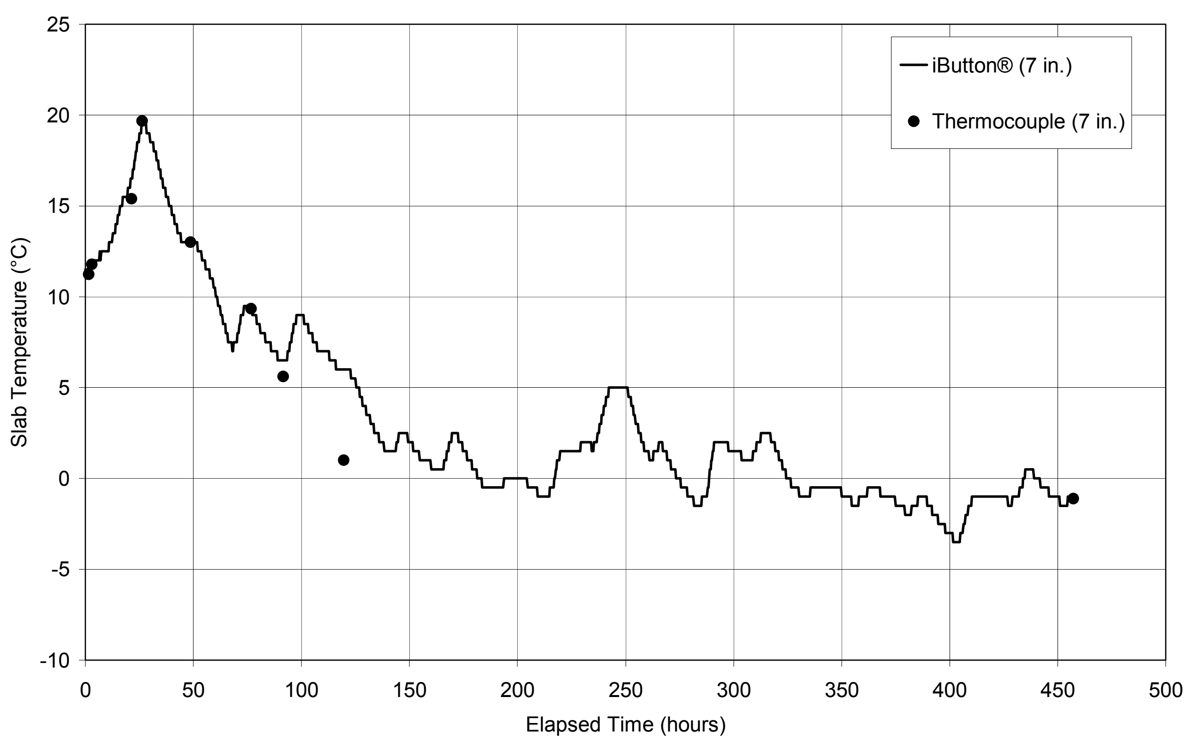
B.10 LOCATION 3 – MACHINE MIX.

Concrete Placement	11/19/02 1:51 PM
Fresh Concrete Temperature	11.5°C (52.7°F)
Air Temperature	12°C (53°F)
Relative Humidity	41%
Windspeed	16 kph (10 mph)
Mix Design	Slipform

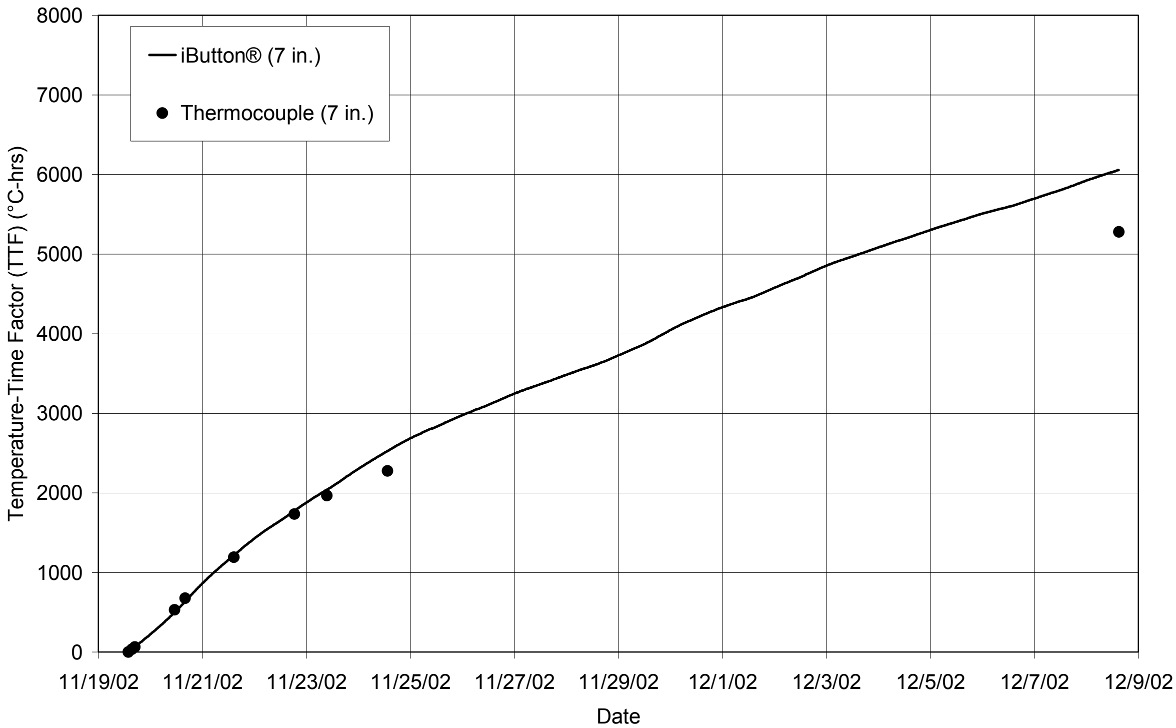


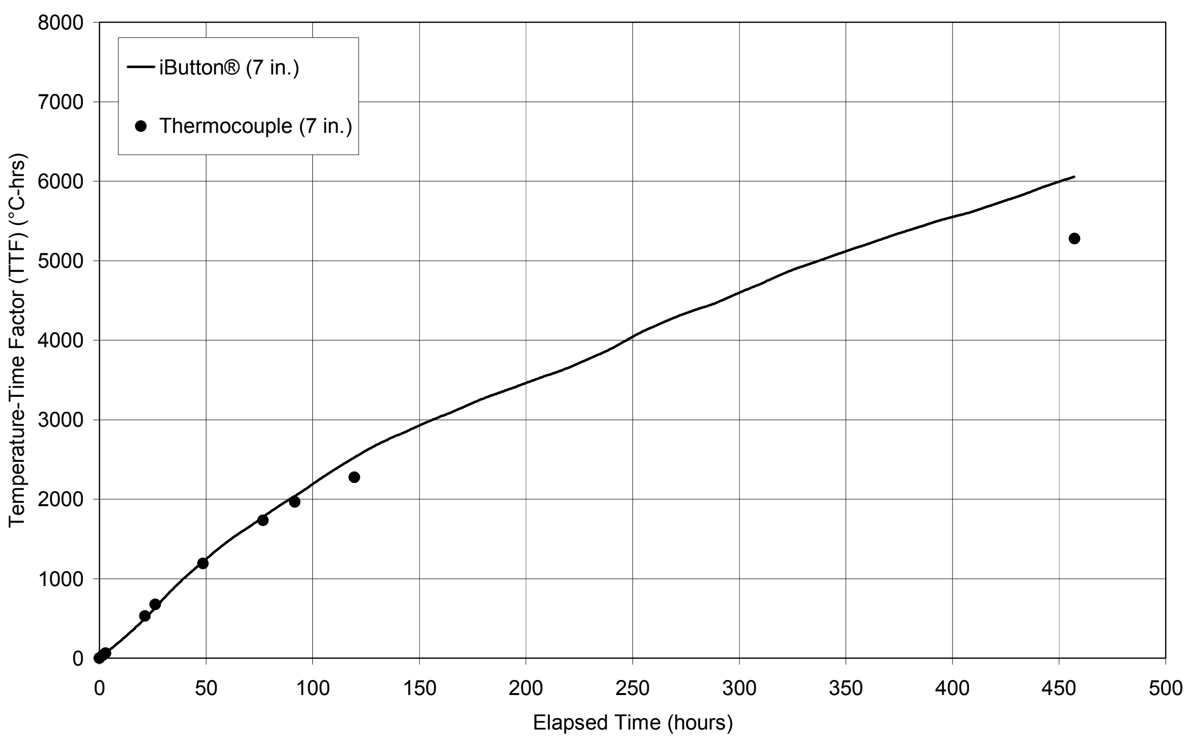
B.11 LOCATION 3 – SLAB TEMPERATURE.



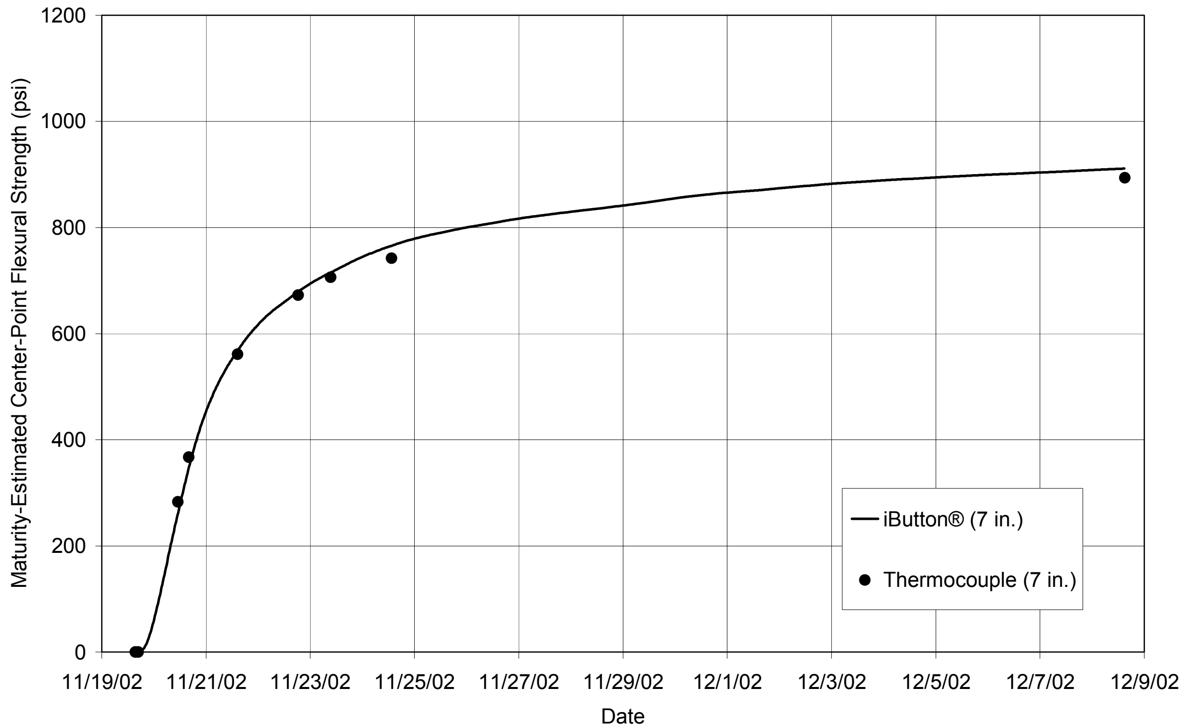


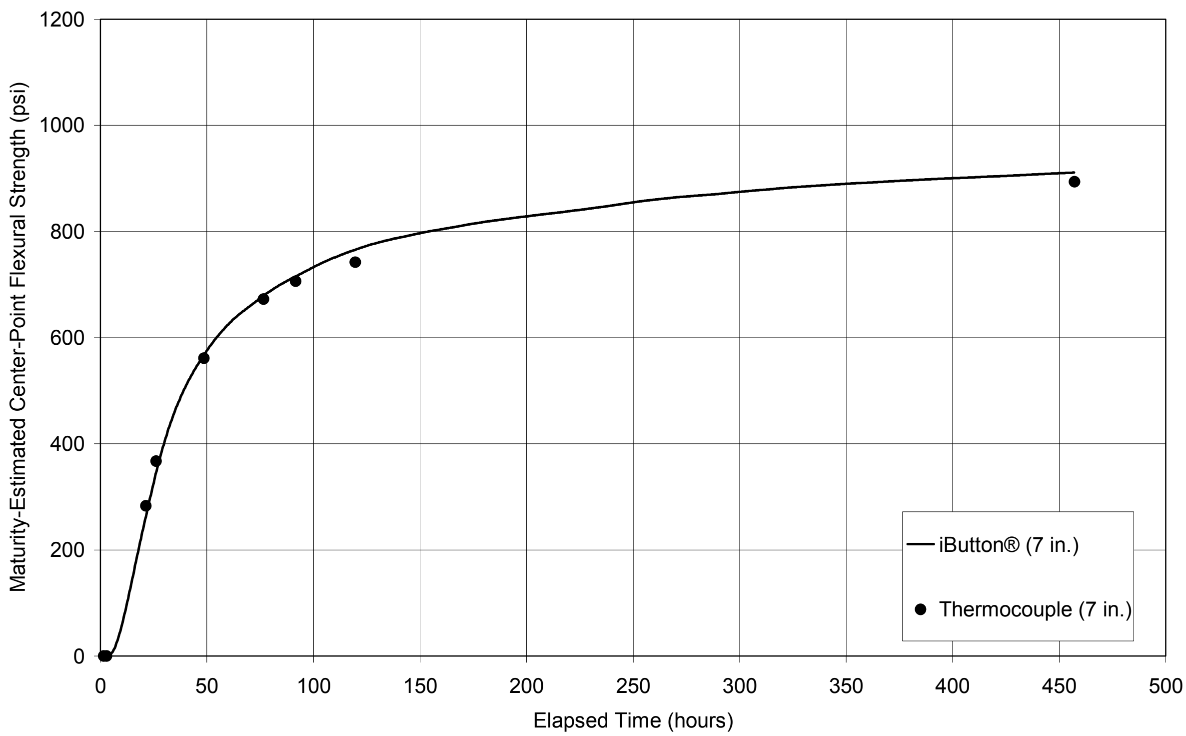
B.12 LOCATION 3 – MATURITY.





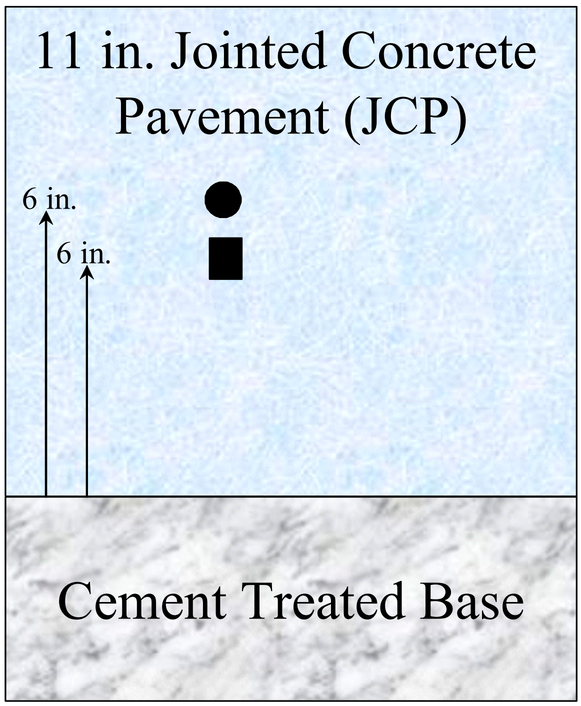
B.13 LOCATION 3 – MATURITY-ESTIMATED STRENGTH.





B.14 LOCATION 4 – HAND PLACEMENT (NO MATURITY-STRENGTH CURVE).

Concrete Placement	11/19/02 2:16 PM
Fresh Concrete Temperature	11.5°C (52.7°F)
Air Temperature	12°C (53°F)
Relative Humidity	41%
Windspeed	16 kph (10 mph)
Mix Design	Slipform + addl. Cement



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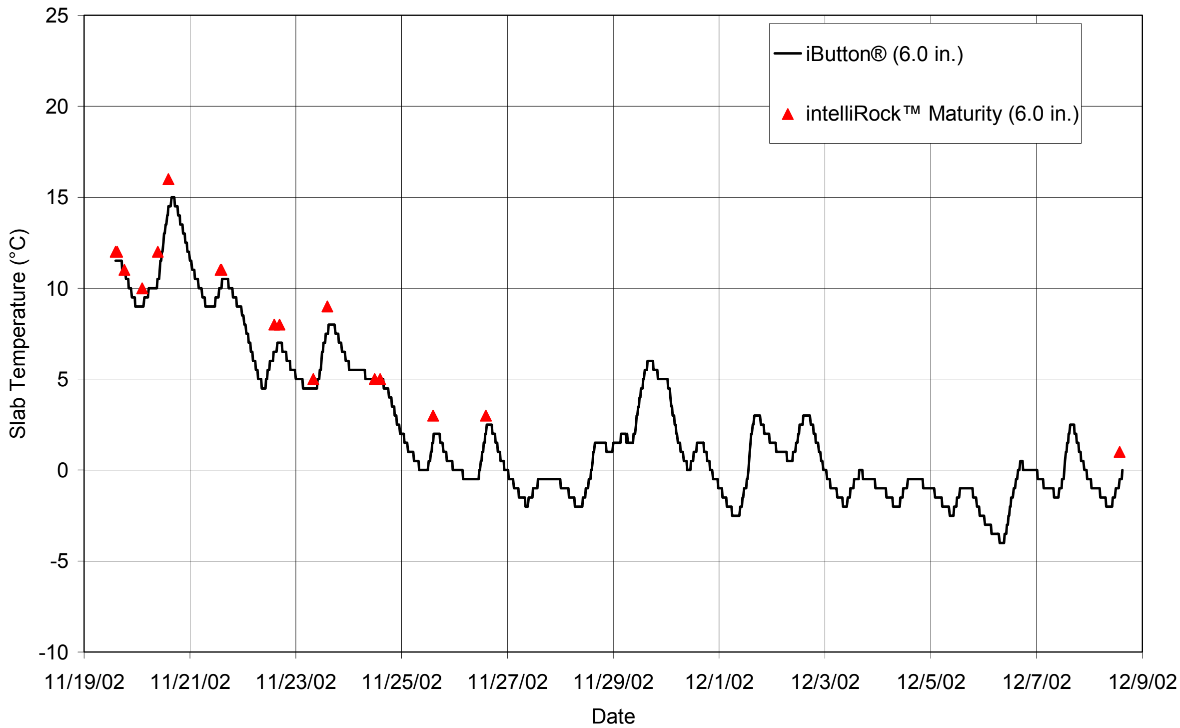
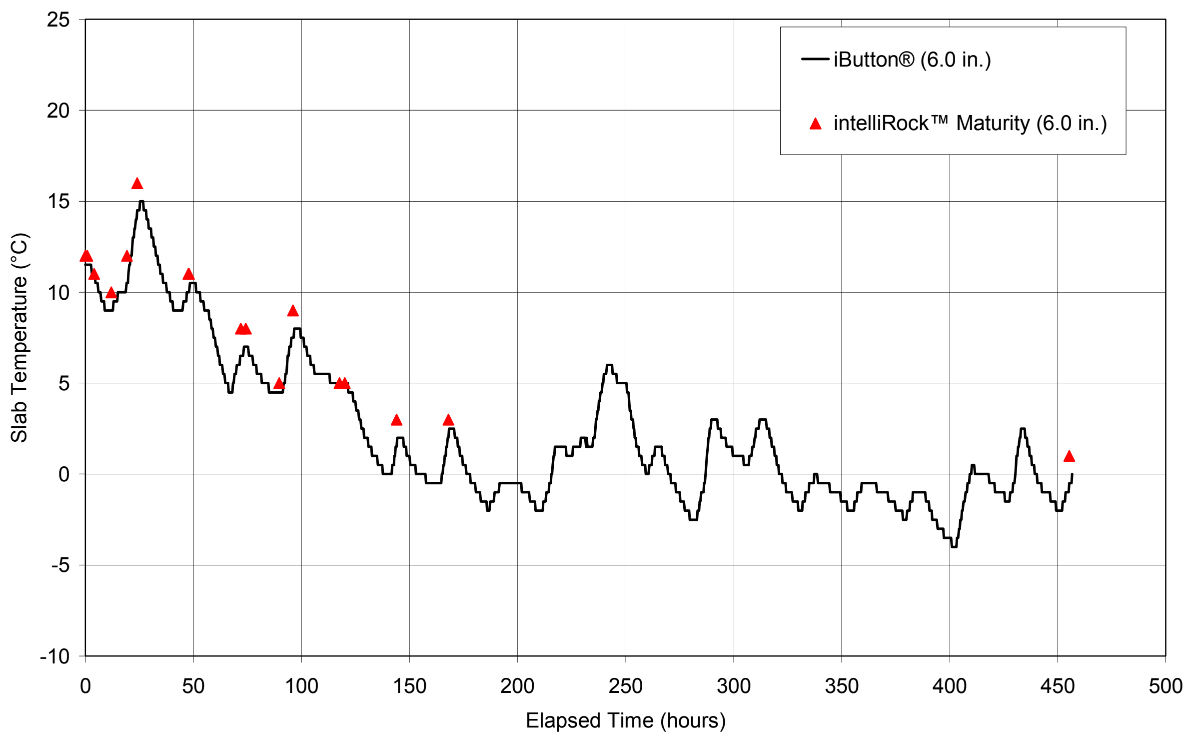
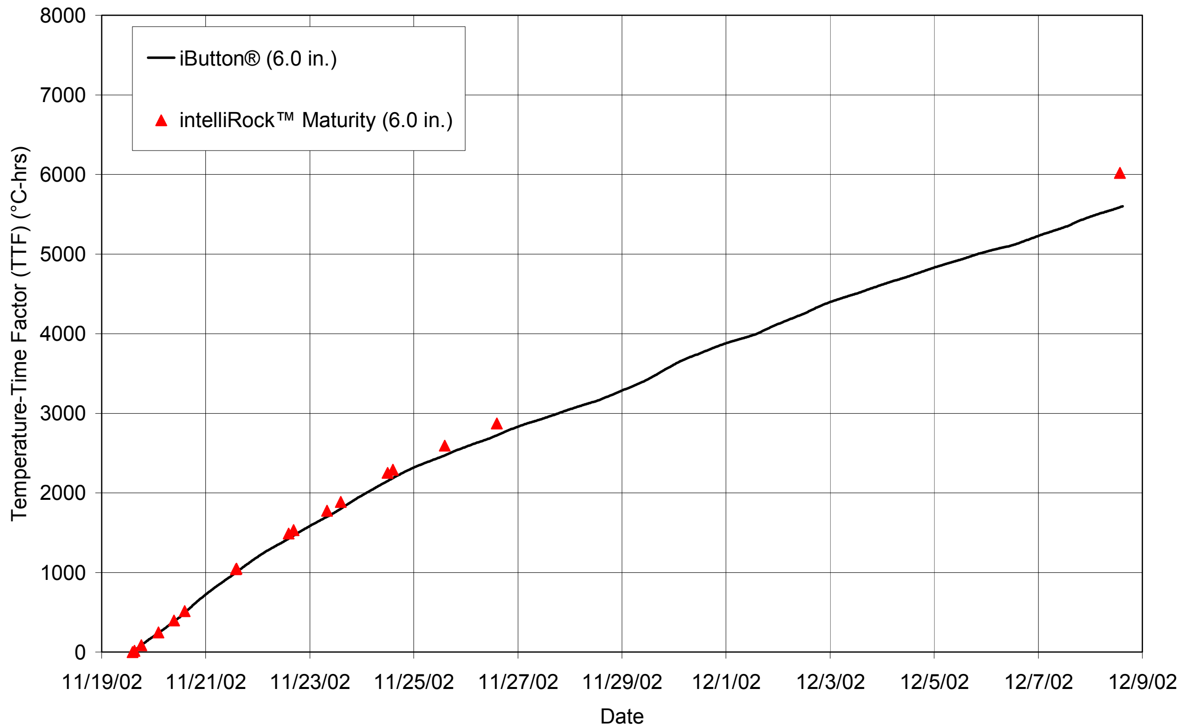
■ intelliRock™ Maturity (1821)

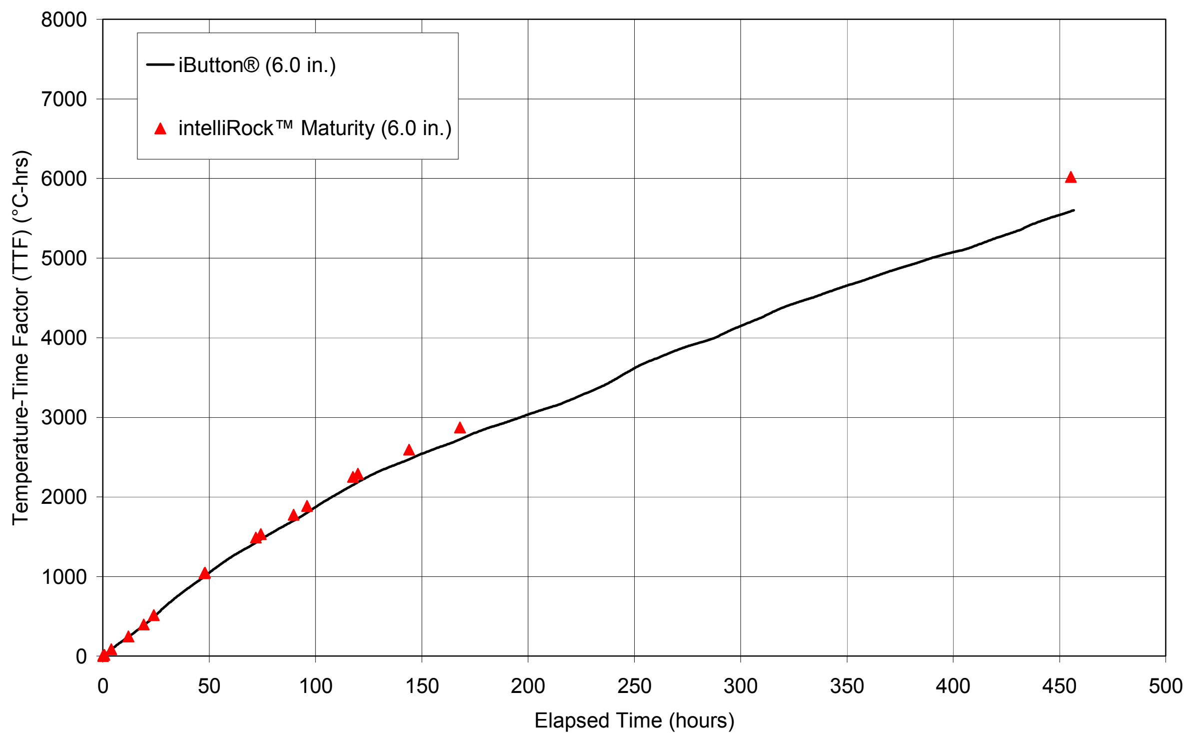
B.15 LOCATION 4 – SLAB TEMPERATURE.





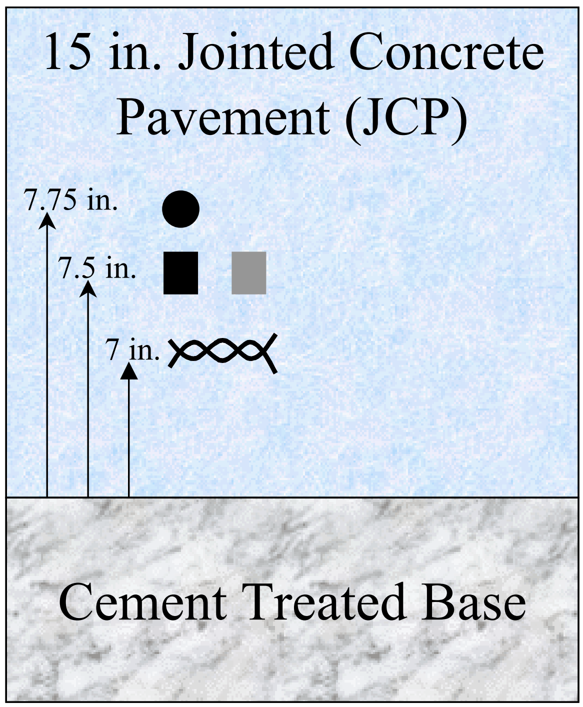
B.16 LOCATION 4 – MATURITY.

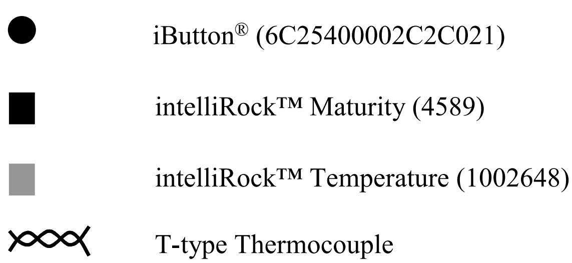




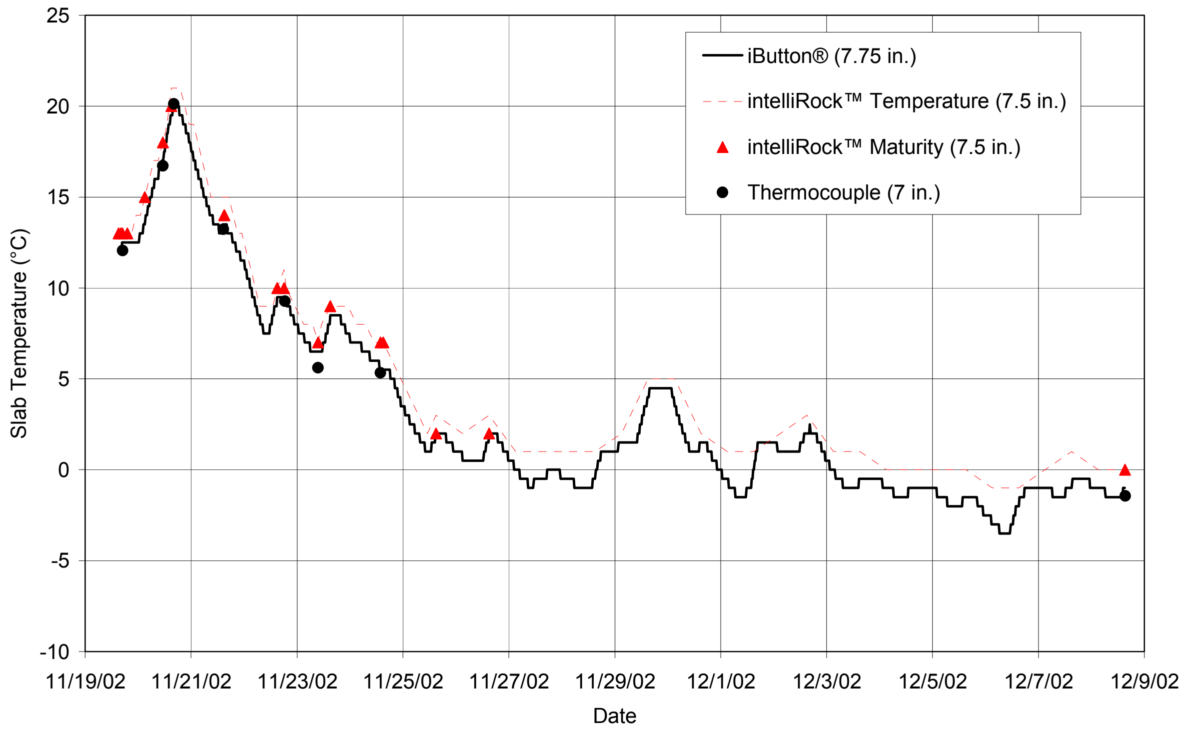
B.17 LOCATION 5 – MECHANICAL PLACEMENT.

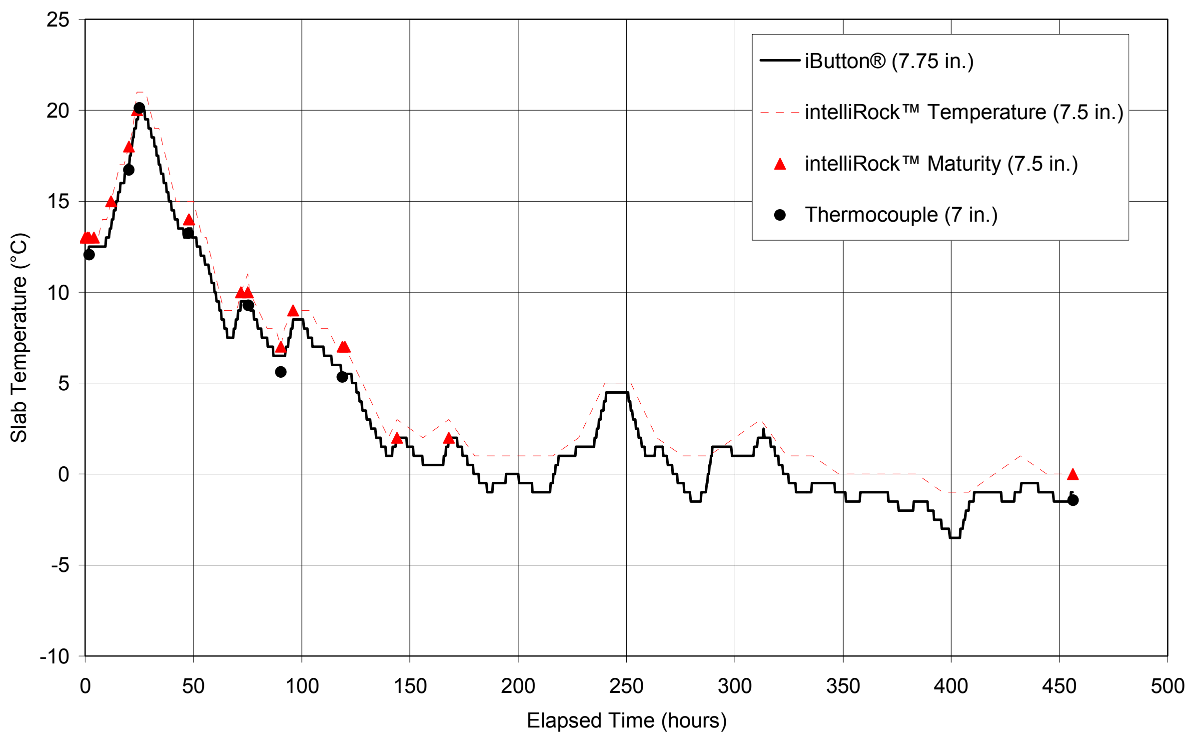
Concrete Placement	11/19/02 3:04 PM
Fresh Concrete Temperature	12.0°C (53.6°F)
Air Temperature	12°C (54°F)
Relative Humidity	41%
Windspeed	19 kph (12 mph)
Mix Design	Slipform



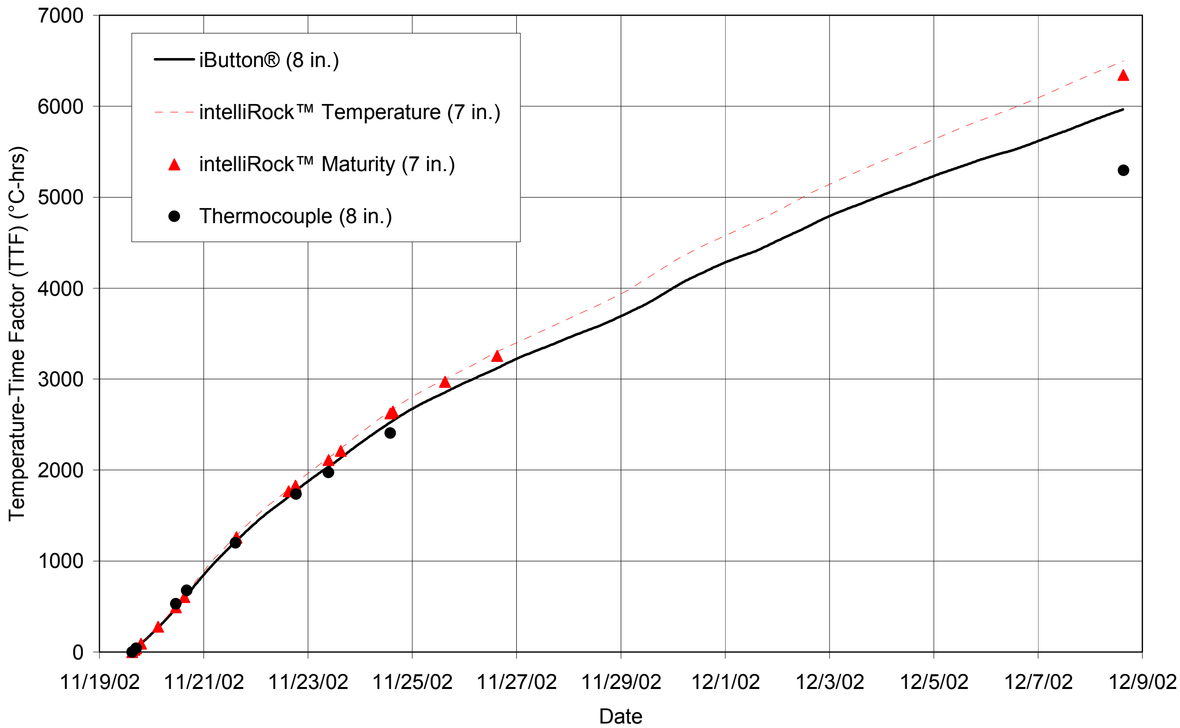


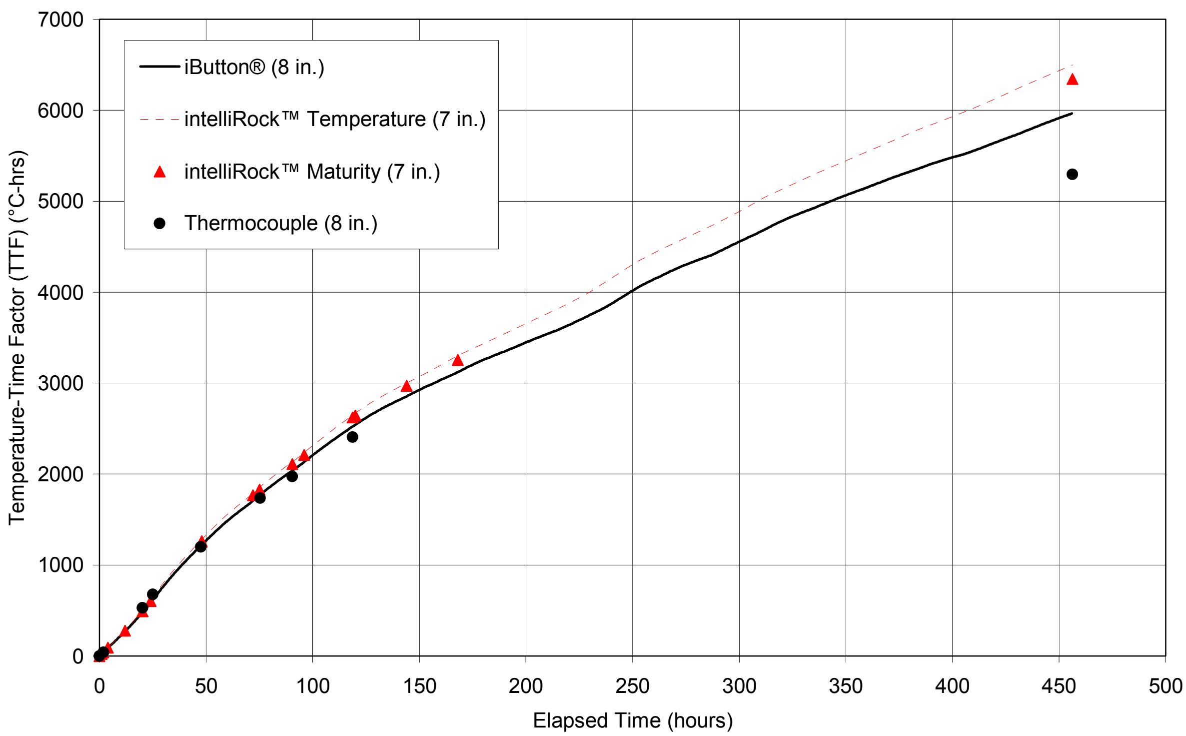
B.18 LOCATION 5 – SLAB TEMPERATURE.



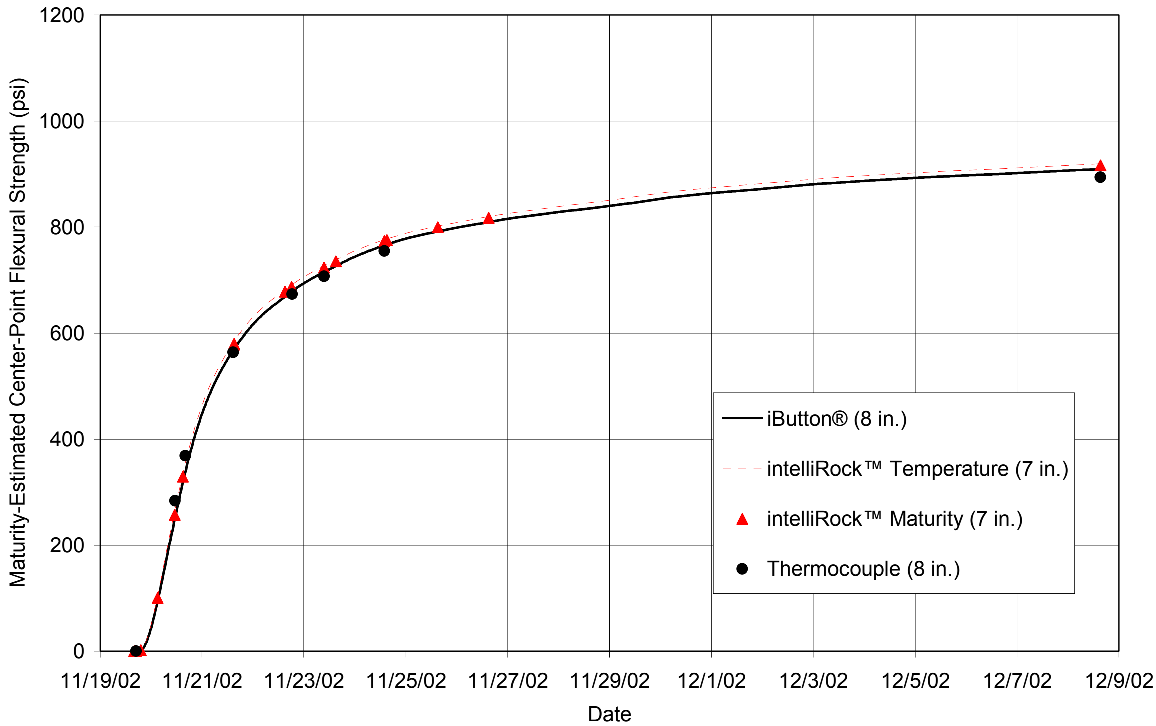


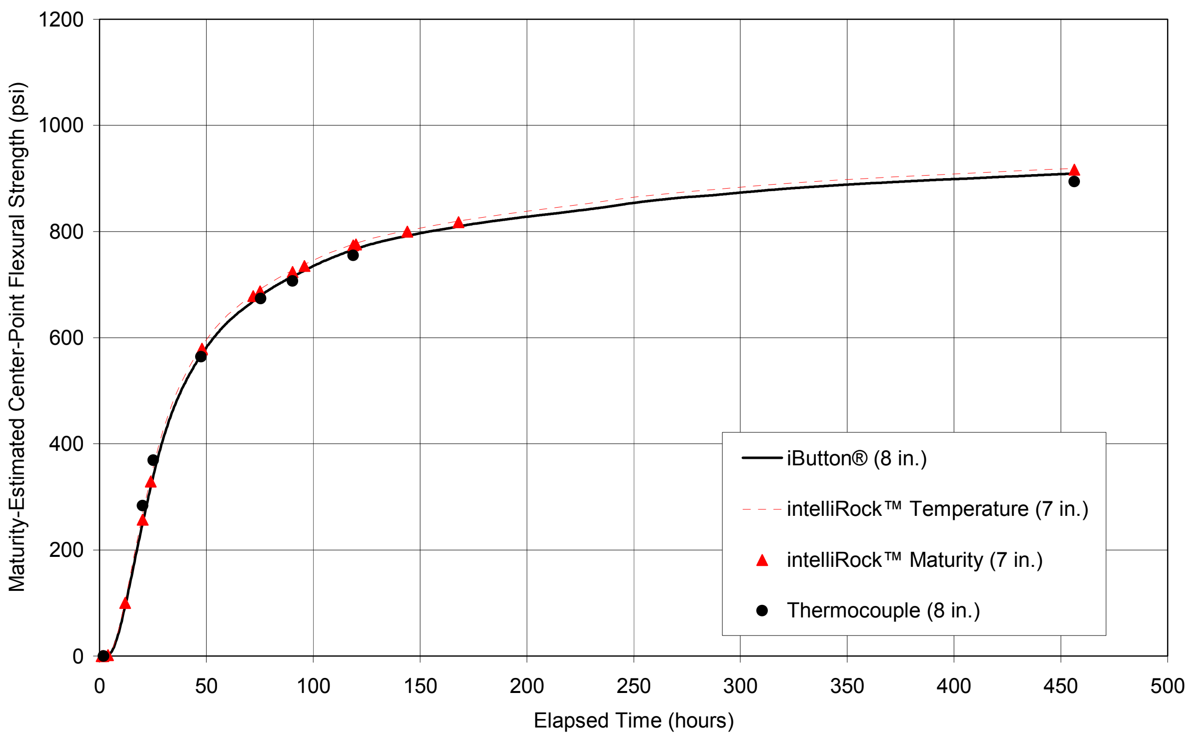
B.19 LOCATION 5 – MATURITY.





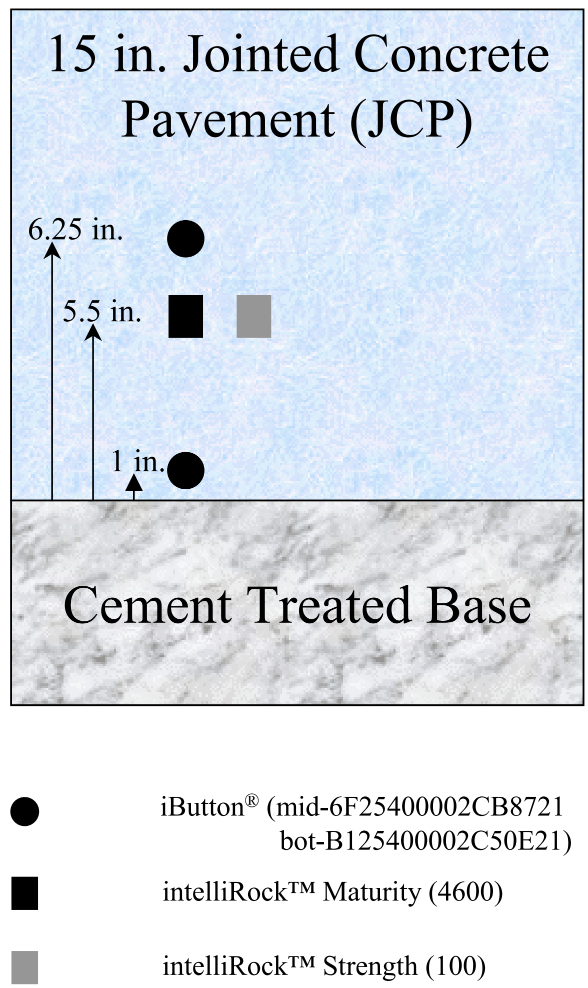
B.20 LOCATION 5 – MATURITY-ESTIMATED STRENGTH.



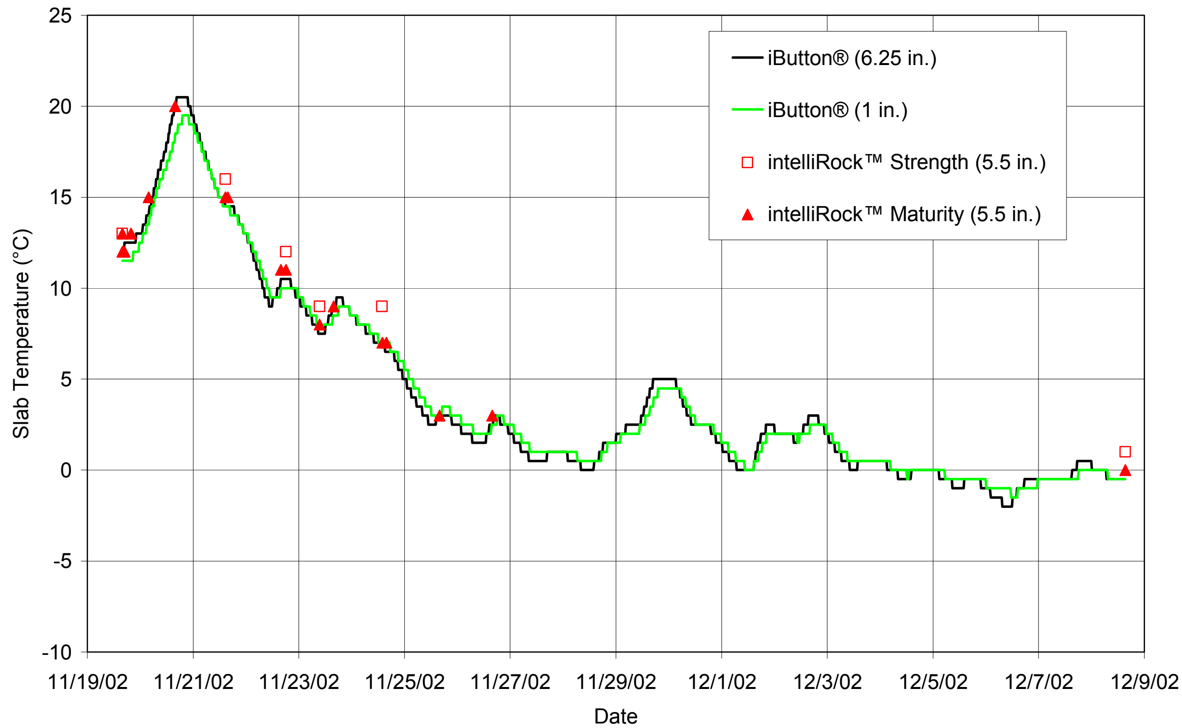


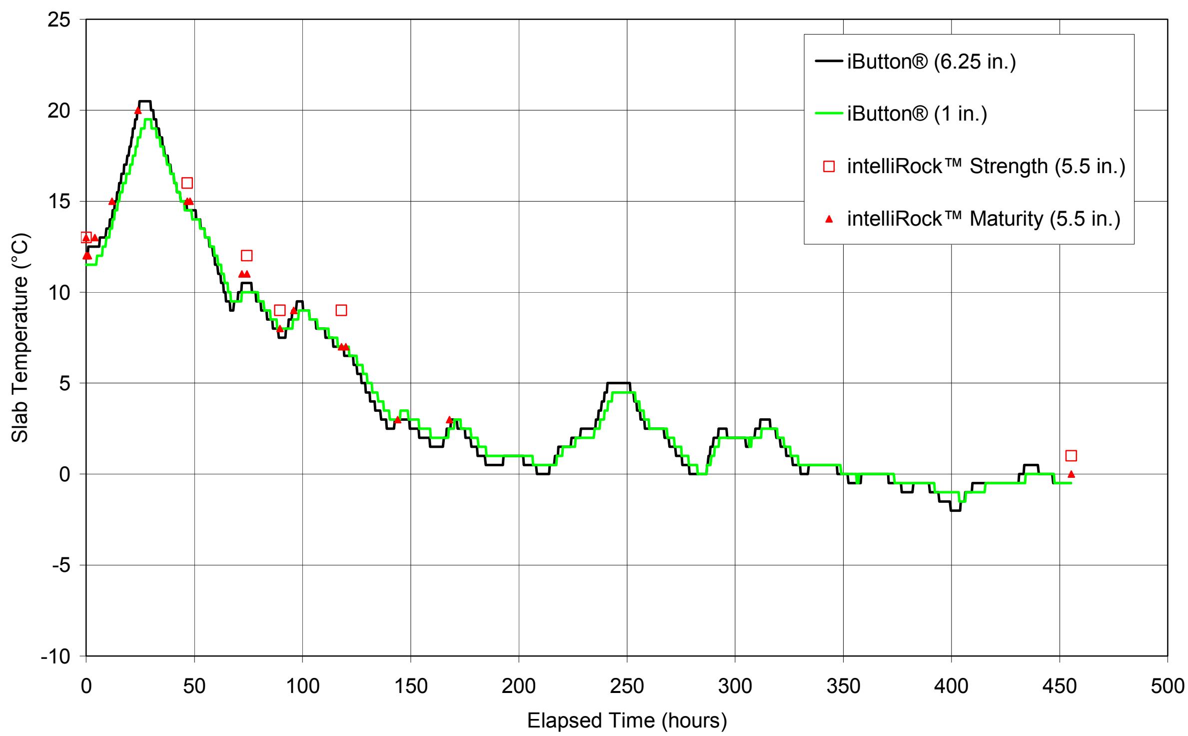
B.21 LOCATION 6 – MECHANICAL PLACEMENT.

Concrete Placement	11/19/02 3:51 PM
Fresh Concrete Temperature	12.0°C (53.6°F)
Air Temperature	12°C (53°F)
Relative Humidity	41%
Windspeed	10 kph (6 mph)
Mix Design	Slipform

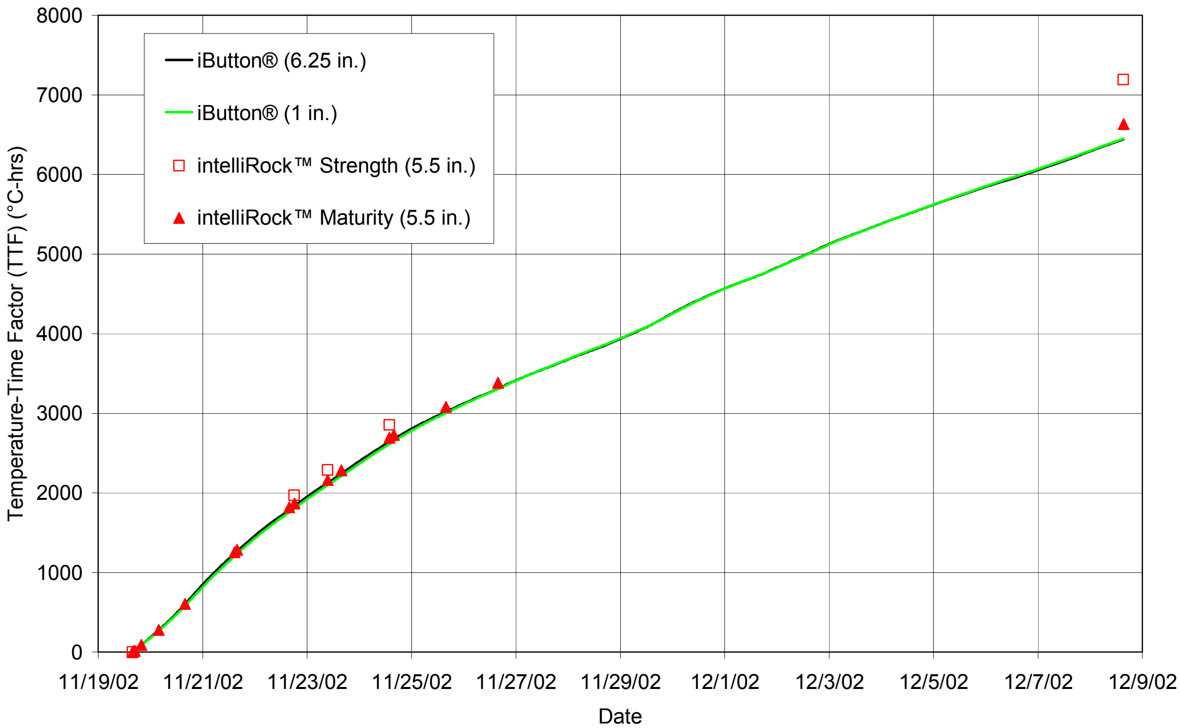


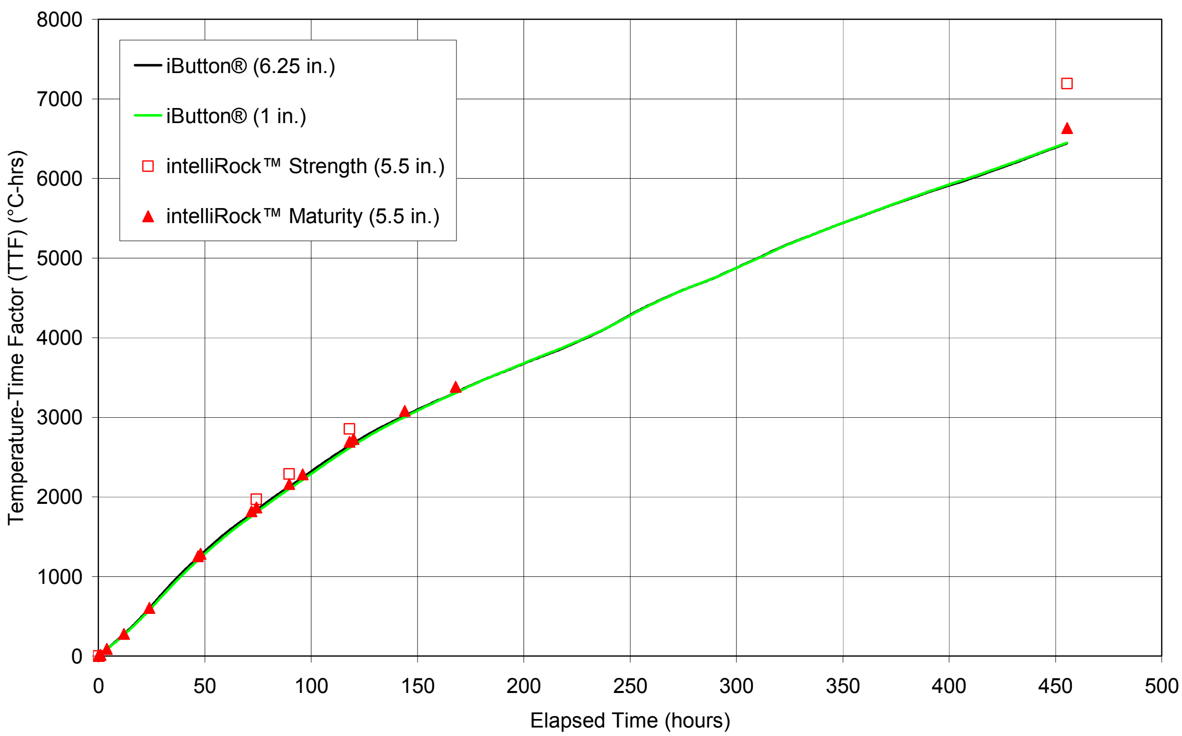
B.22 LOCATION 6 – SLAB TEMPERATURE.



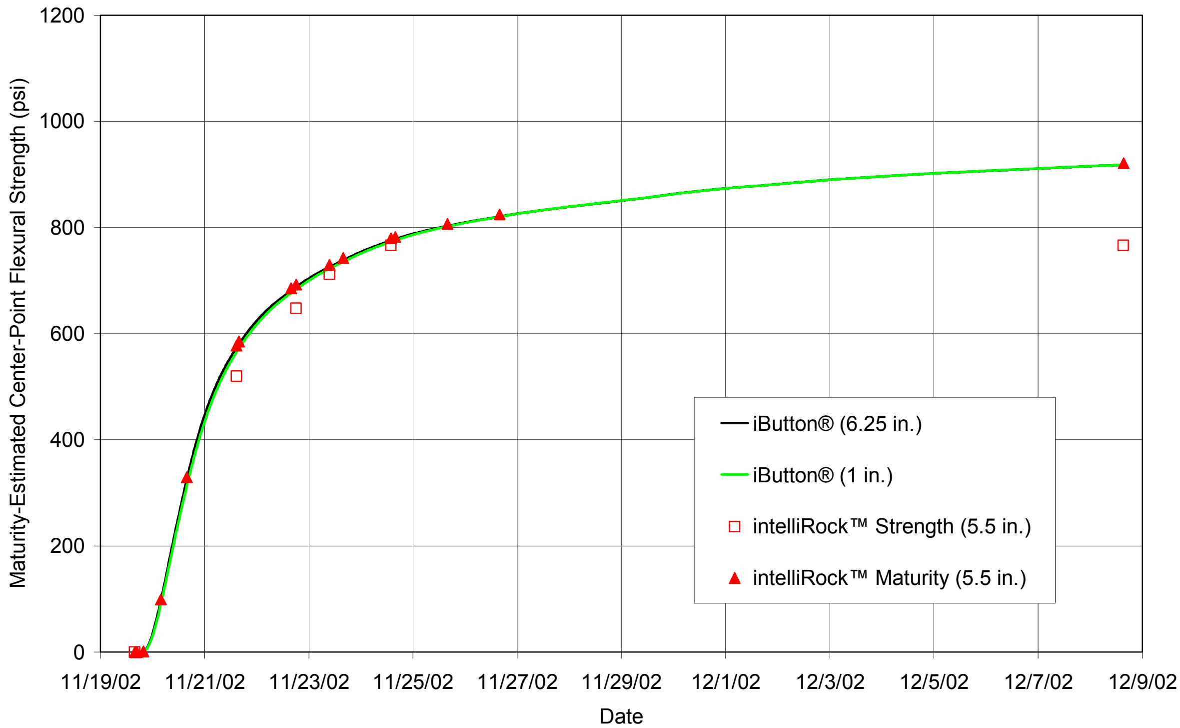


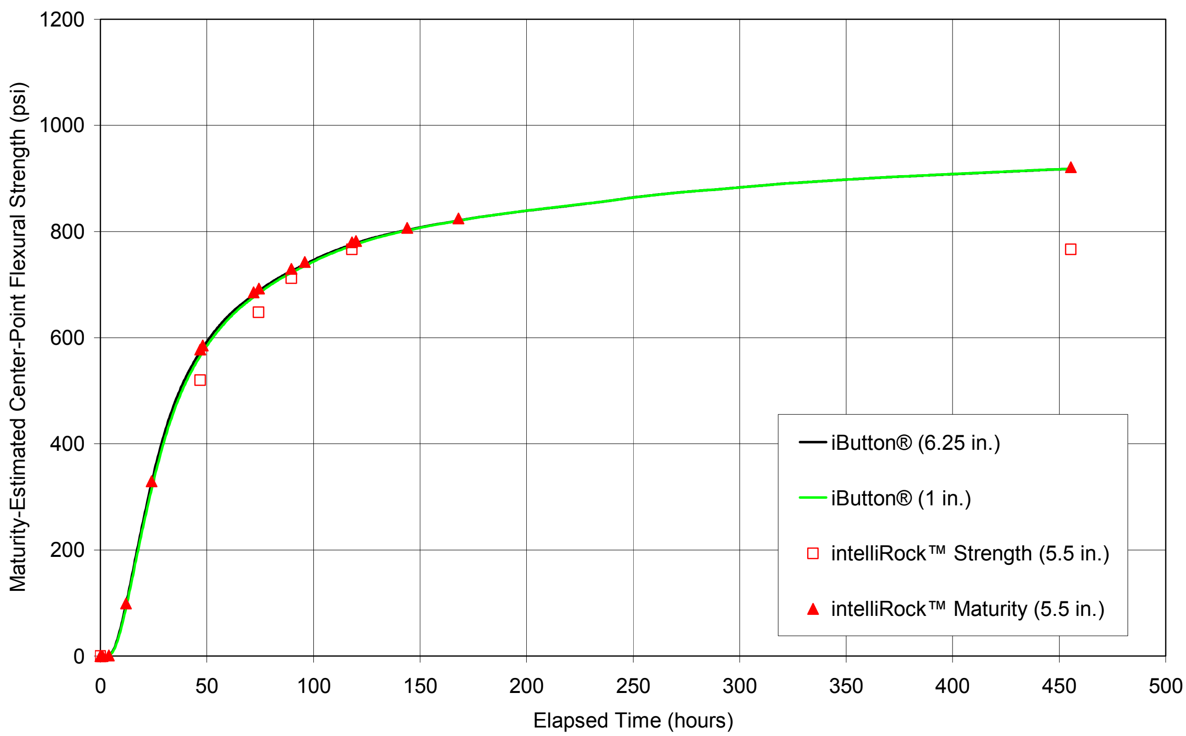
B.23 LOCATION 6 – MATURITY.





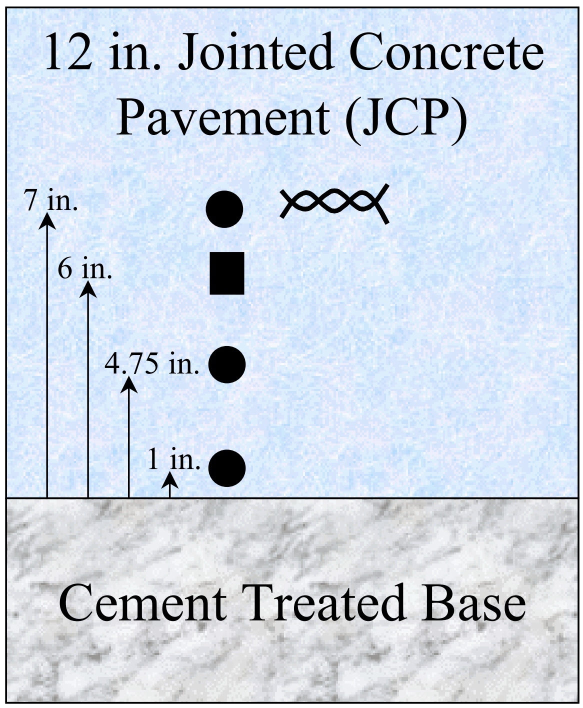
B.24 LOCATION 6 – MATURITY-ESTIMATED STRENGTH.





B.25 LOCATION 7 – MECHANICAL PLACEMENT.

Concrete Placement	11/20/02 9:42 AM
Fresh Concrete Temperature	10.5°C (50.9°F)
Air Temperature	9°C (48°F)
Relative Humidity	58%
Windspeed	10 kph (6 mph)
Mix Design	Slipform

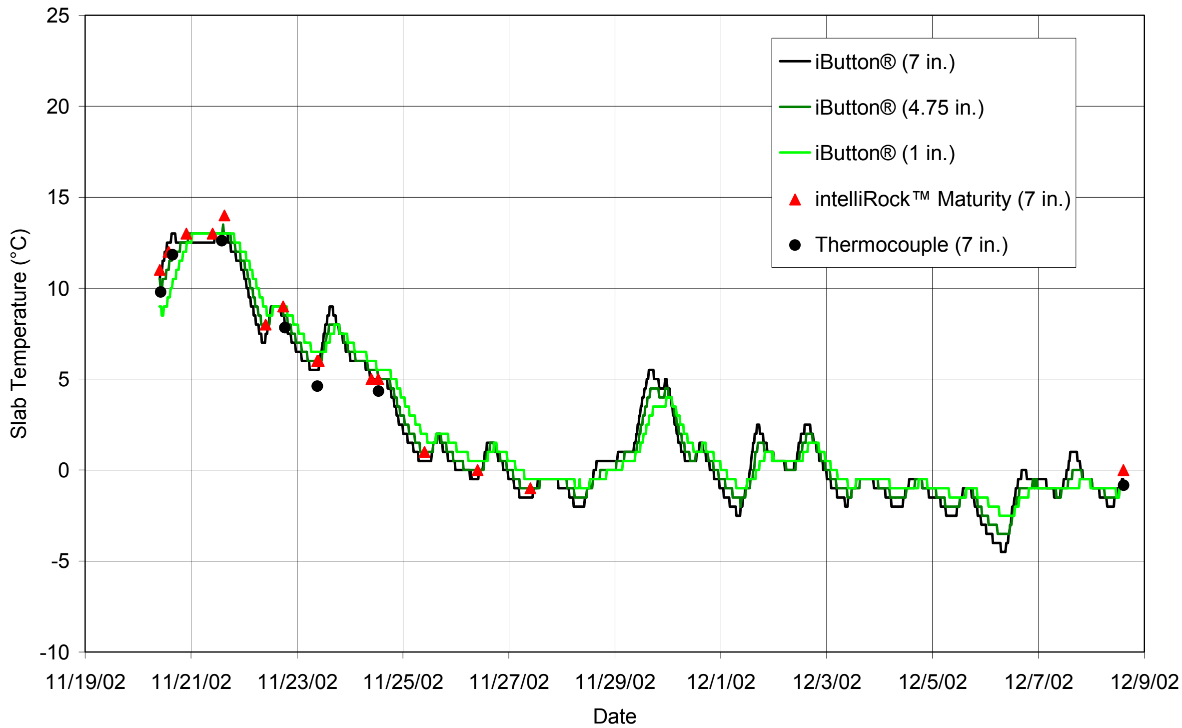


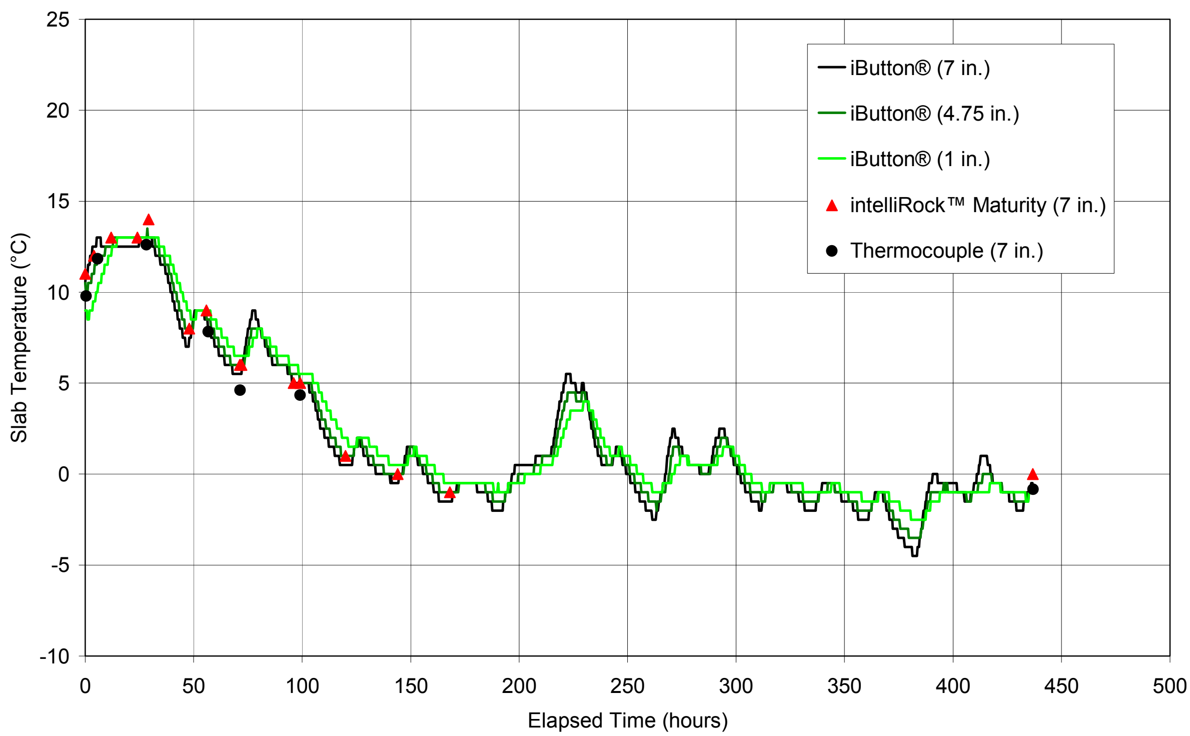
iButton® (top-6025400002C7D721
mid-AF25400002CD2721
bot-5C25400002CCEF21)

intelliRock™ Maturity (4593)

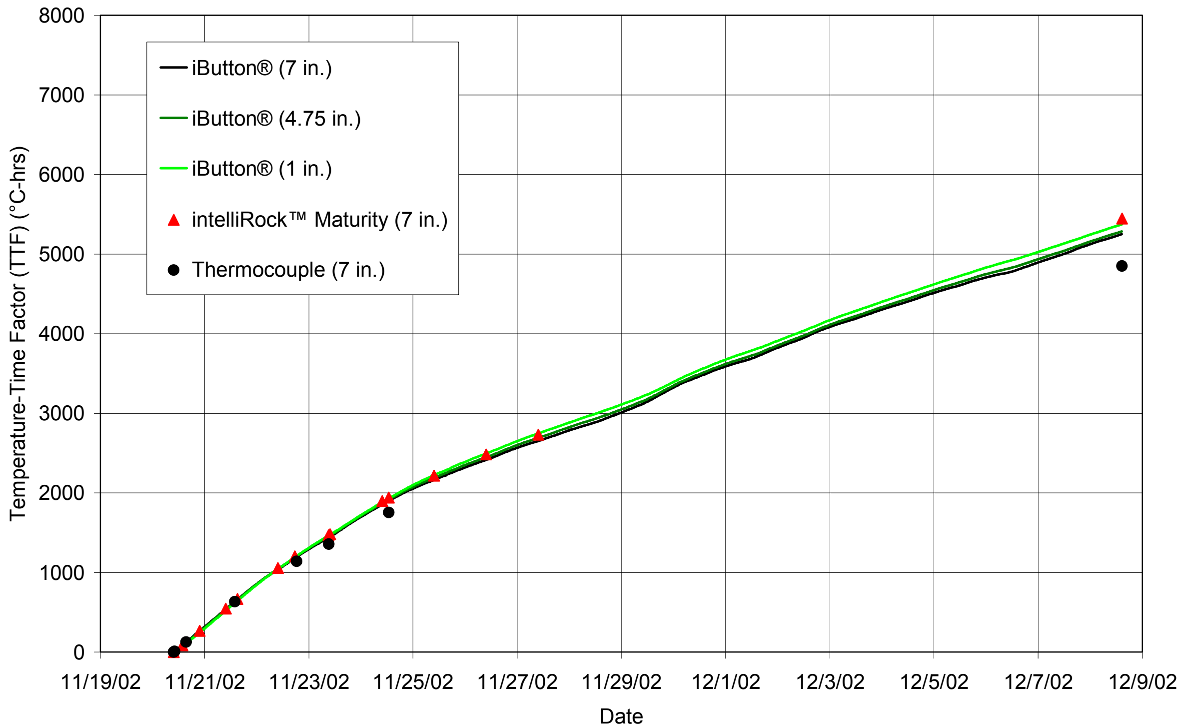
T-type Thermocouple

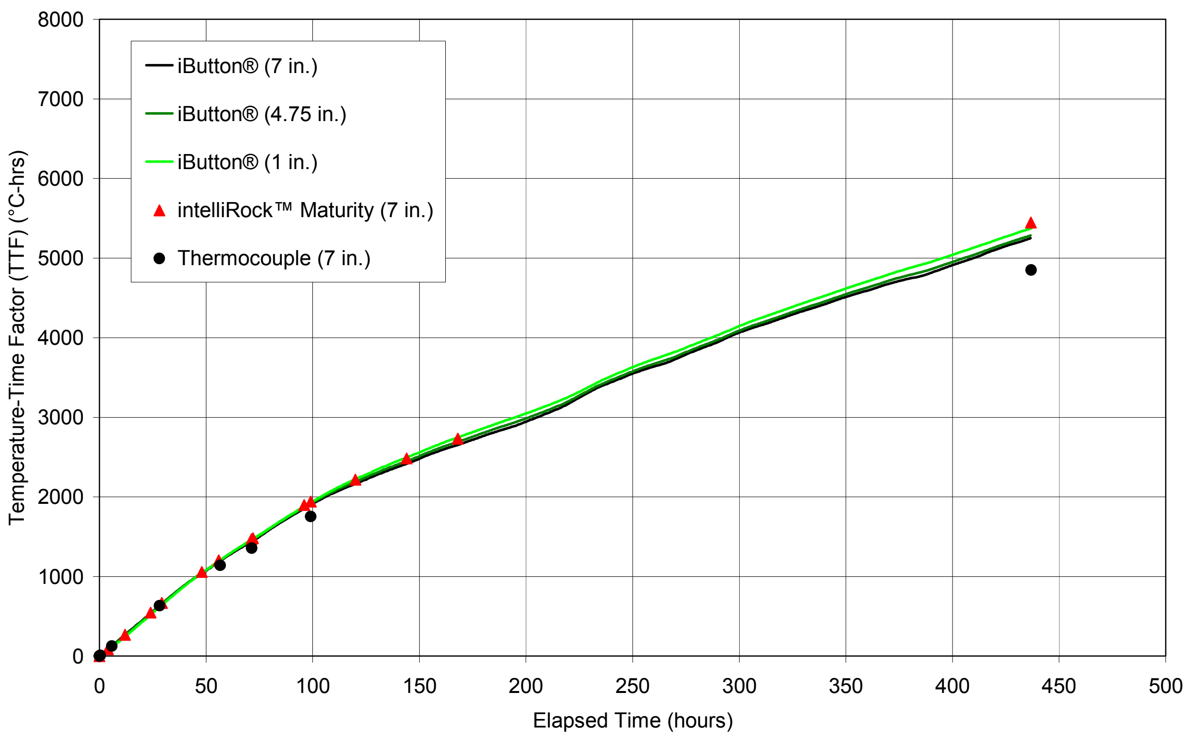
B.26 LOCATION 7 – SLAB TEMPERATURE.



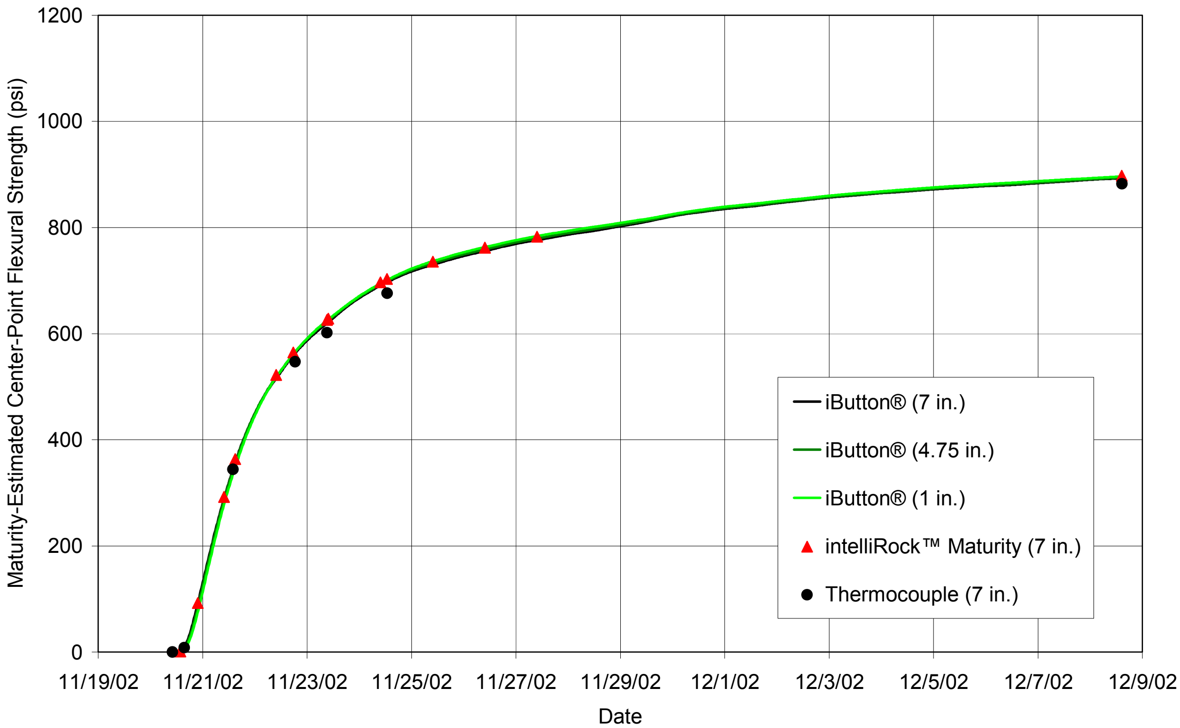


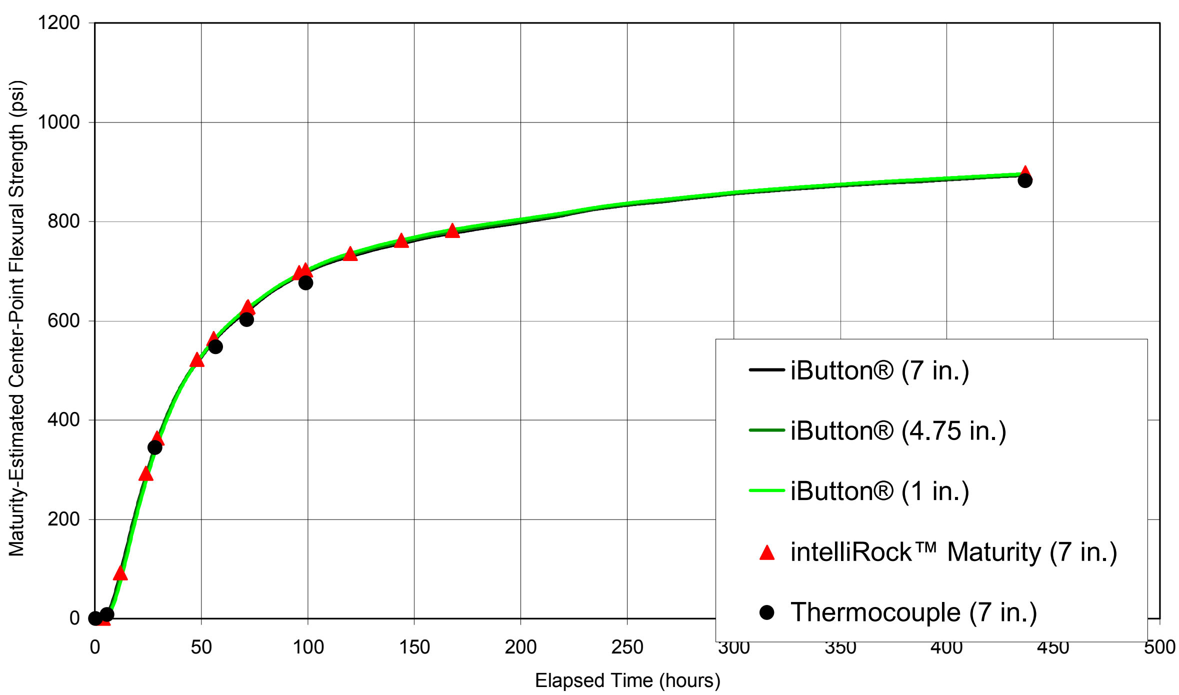
B.27 LOCATION 7 – MATURITY.





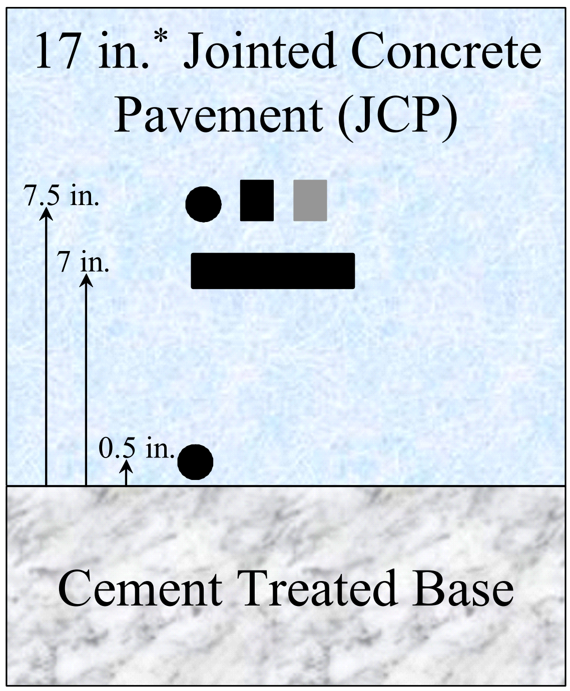
B.28 LOCATION 7 – MATURITY-ESTIMATED STRENGTH.





B.29 LOCATION 8 – MECHANICAL PLACEMENT.

Concrete Placement	11/20/02 11:36 AM
Fresh Concrete Temperature	13.0°C (55.4°F)
Air Temperature	13°C (55°F)
Relative Humidity	47%
Windspeed	19 kph (12 mph)
Mix Design	Slipform



*Note: Design thickness is 15 in.

i-Q Tag (0.000.209.783)

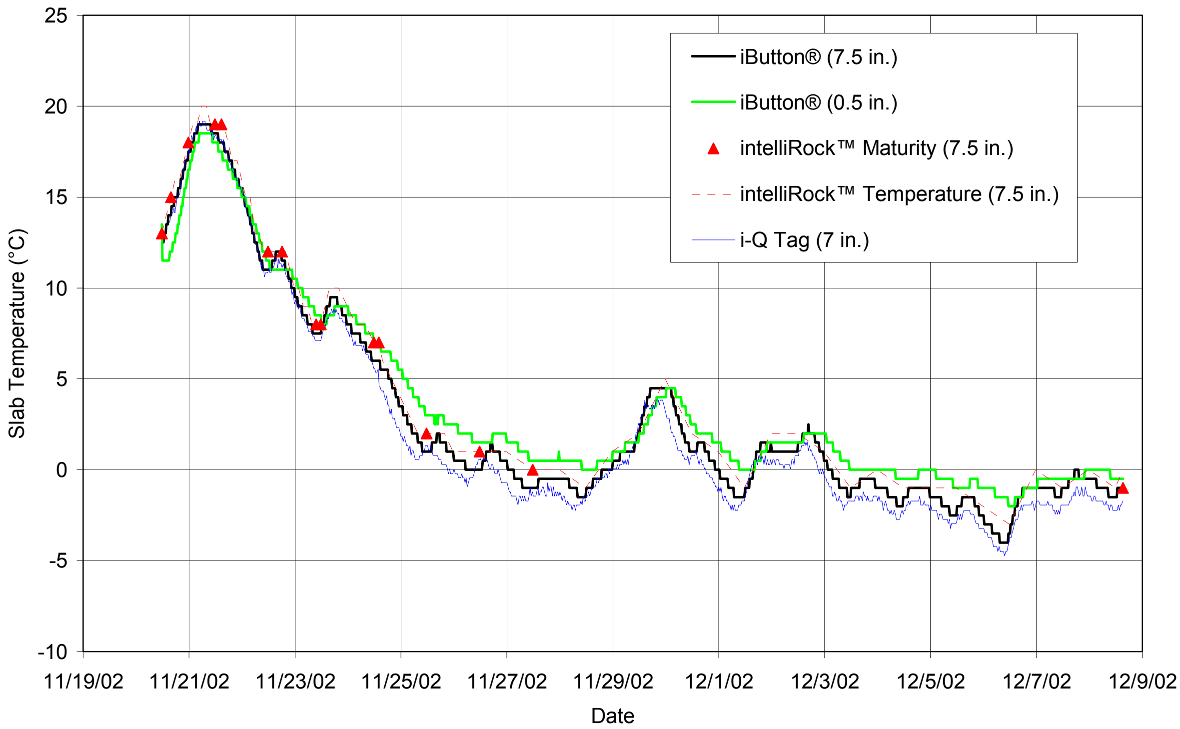
iButton® (mid-5C25400002C36821
bot-7925400002C4AD21)

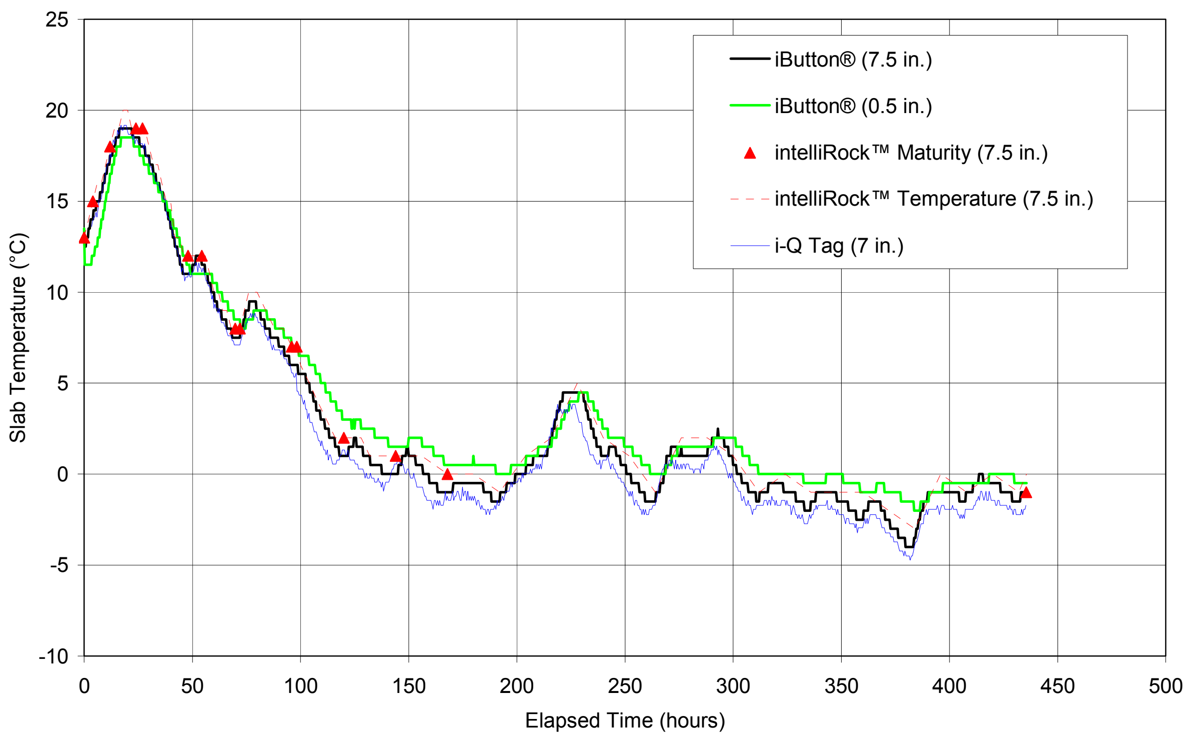
intelliRock™ Maturity (4713)

intelliRock™ Temperature (1002746)

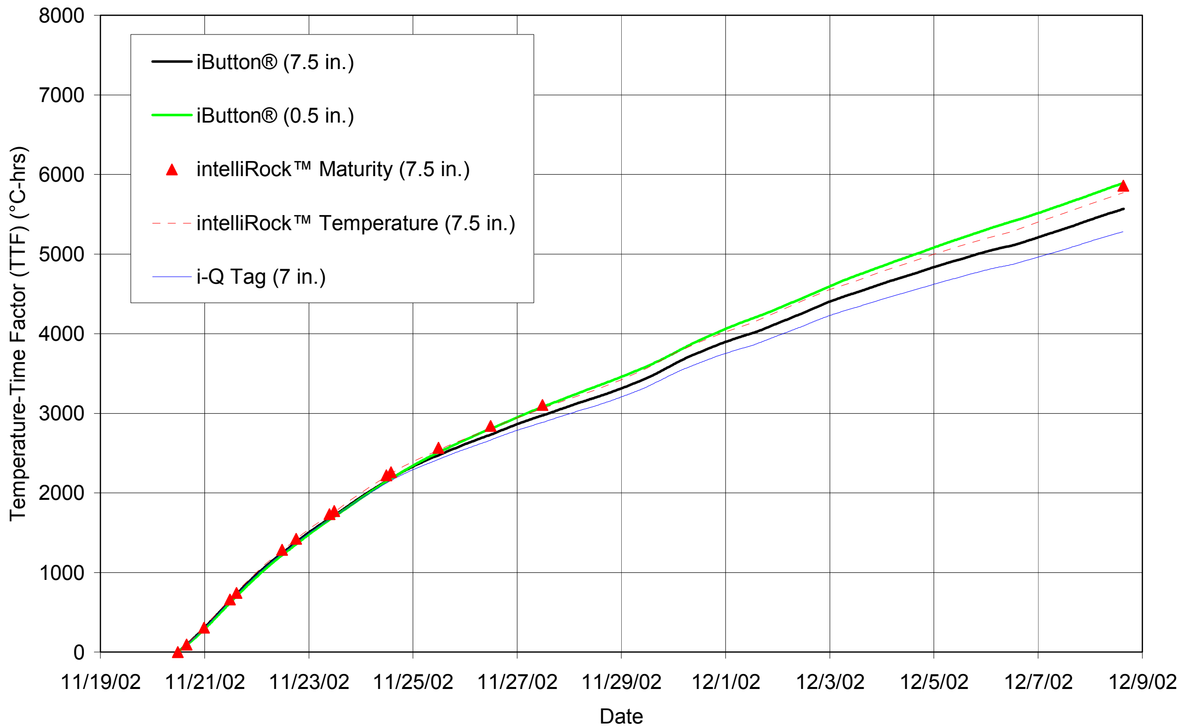
T-type Thermocouple

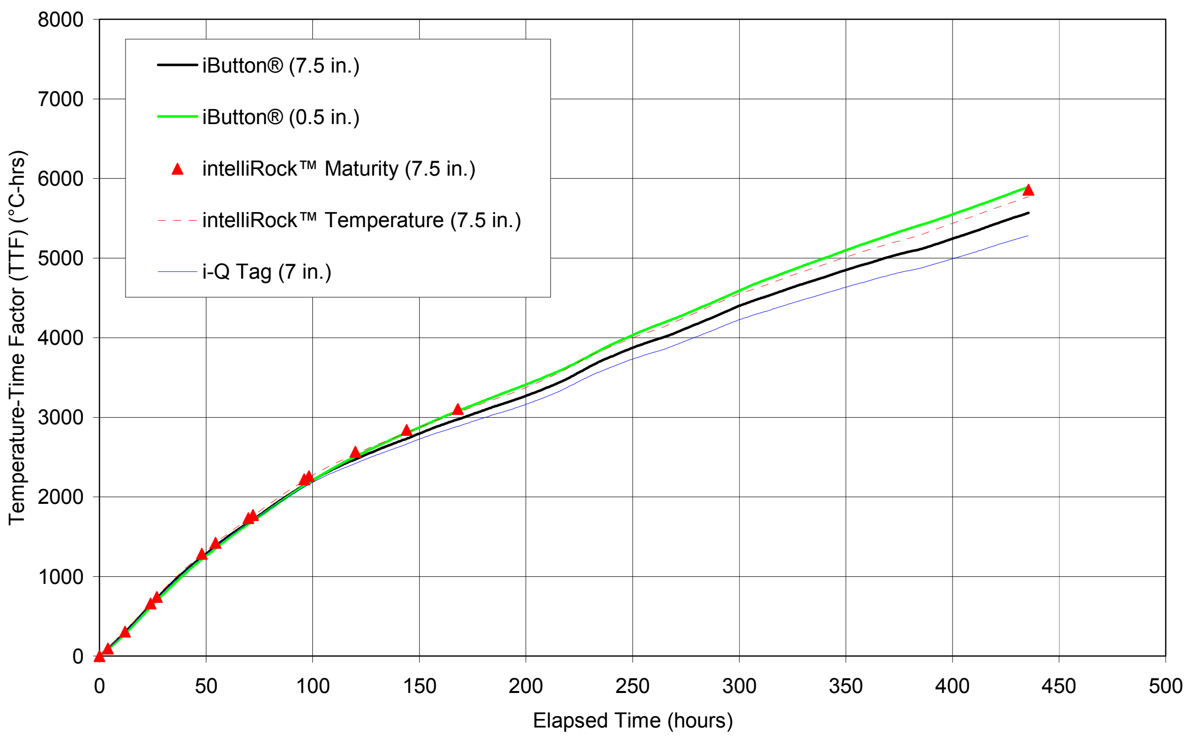
B.30 LOCATION 8 – SLAB TEMPERATURE.



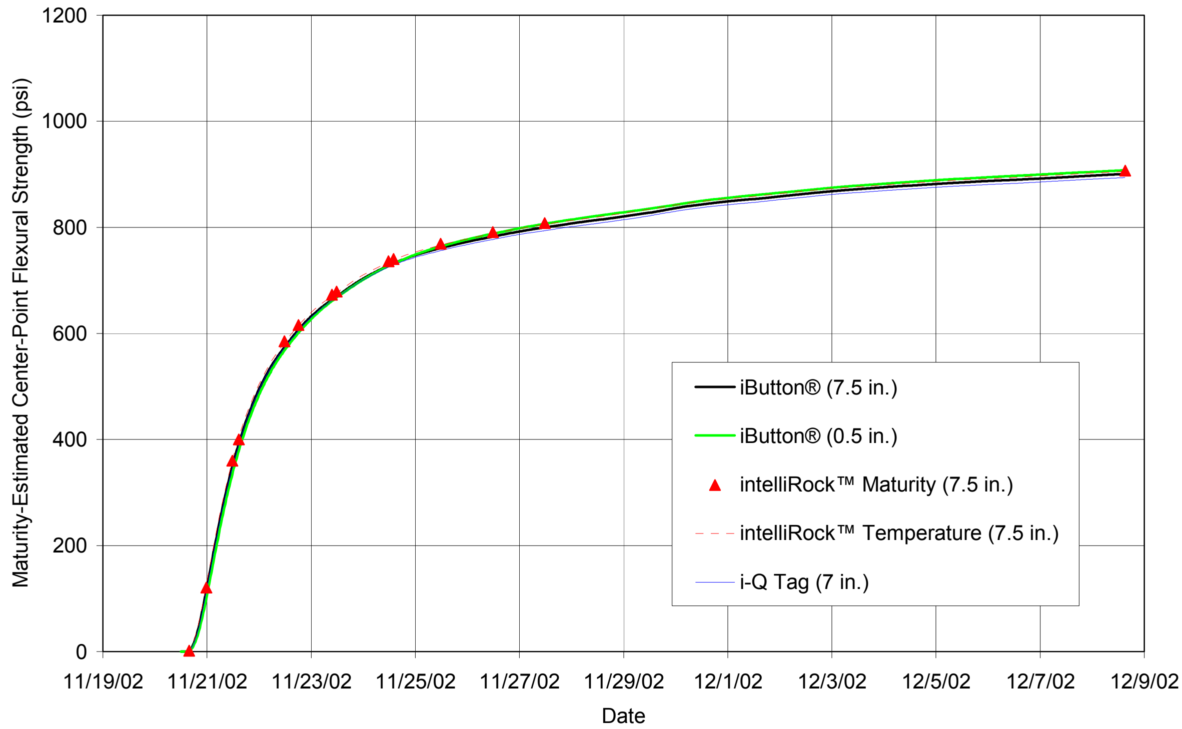


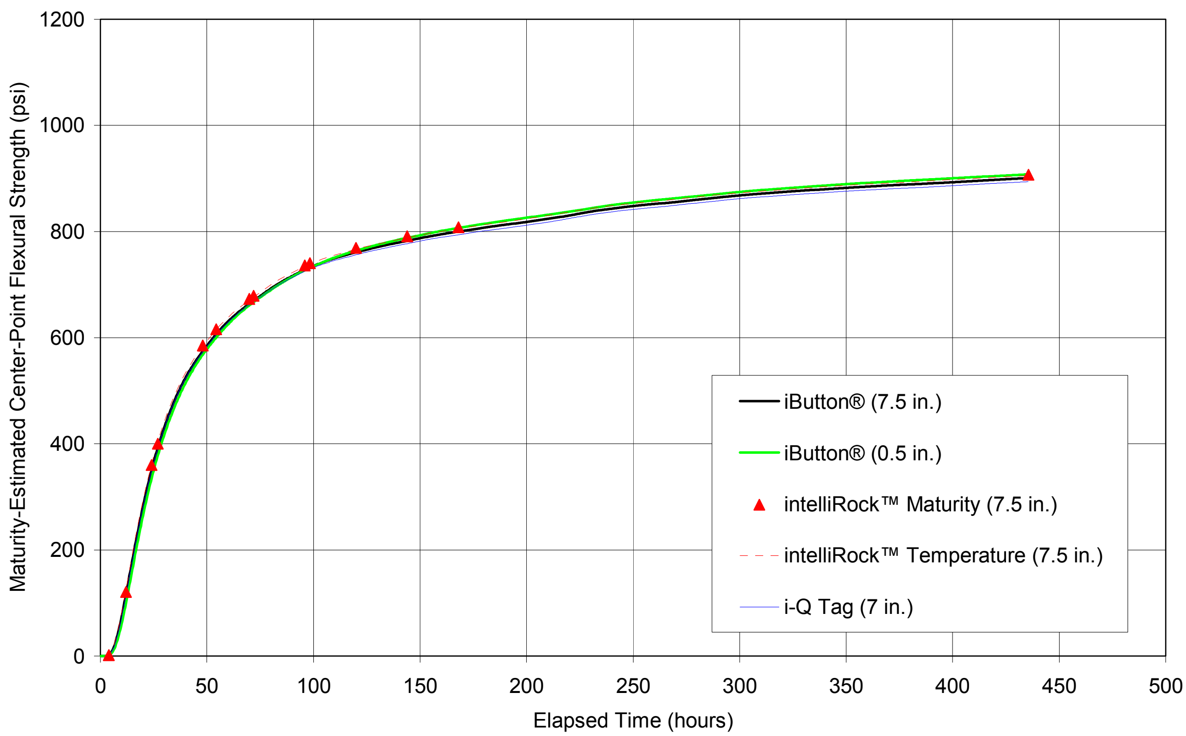
B.31 LOCATION 8 – MATURITY.





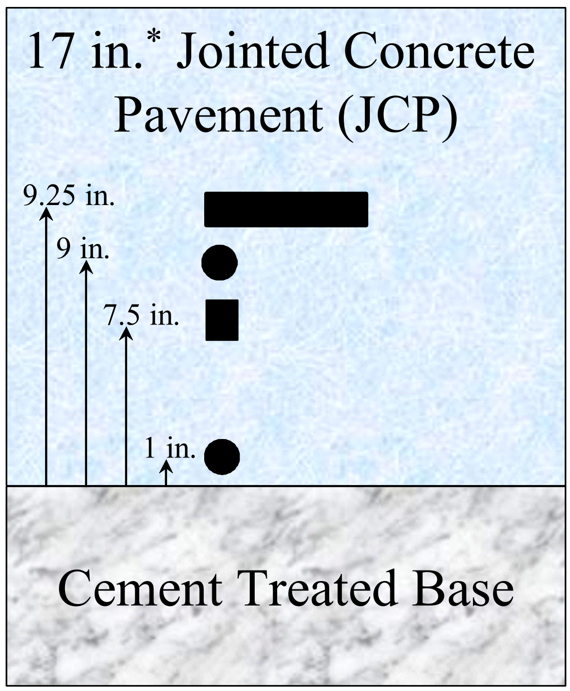
B.32 LOCATION 8 – MATURITY-ESTIMATED STRENGTH.





B.33 LOCATION 9 – MECHANICAL PLACEMENT.

Concrete Placement	11/20/02 12:45 PM
Fresh Concrete Temperature	12.5°C (54.5°F)
Air Temperature	15°C (59°F)
Relative Humidity	39%
Windspeed	21 kph (13 mph)
Mix Design	Slipform



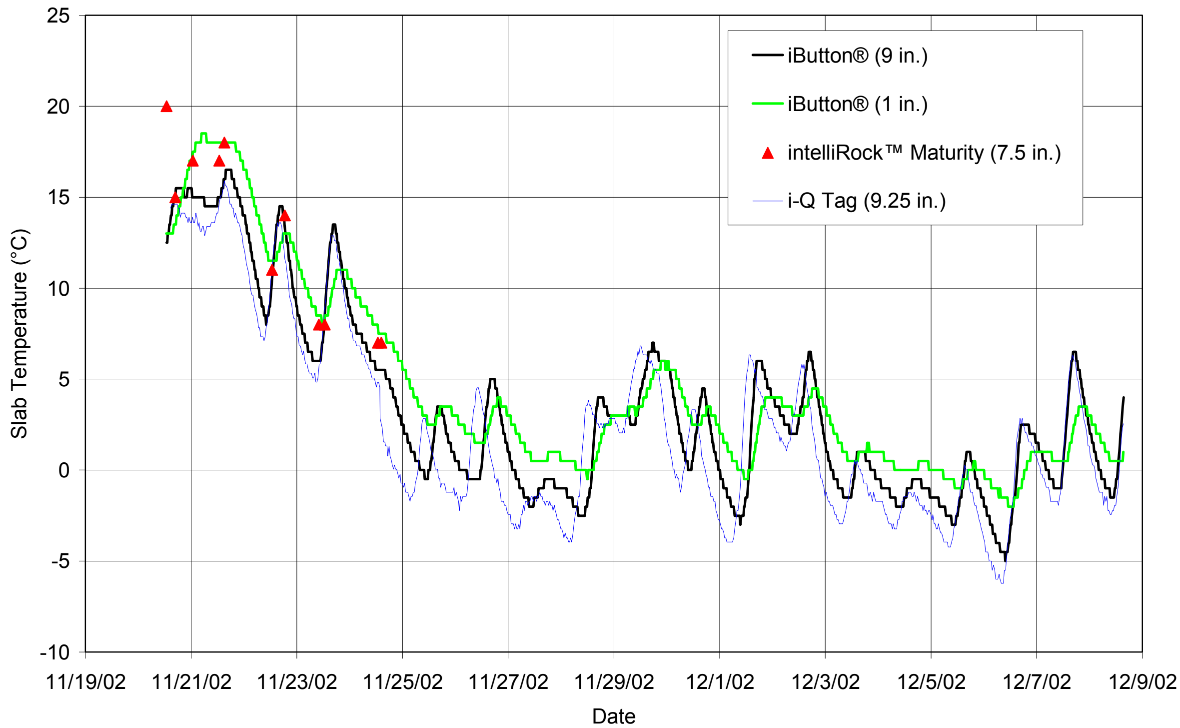
*Note: Design thickness is 15 in.

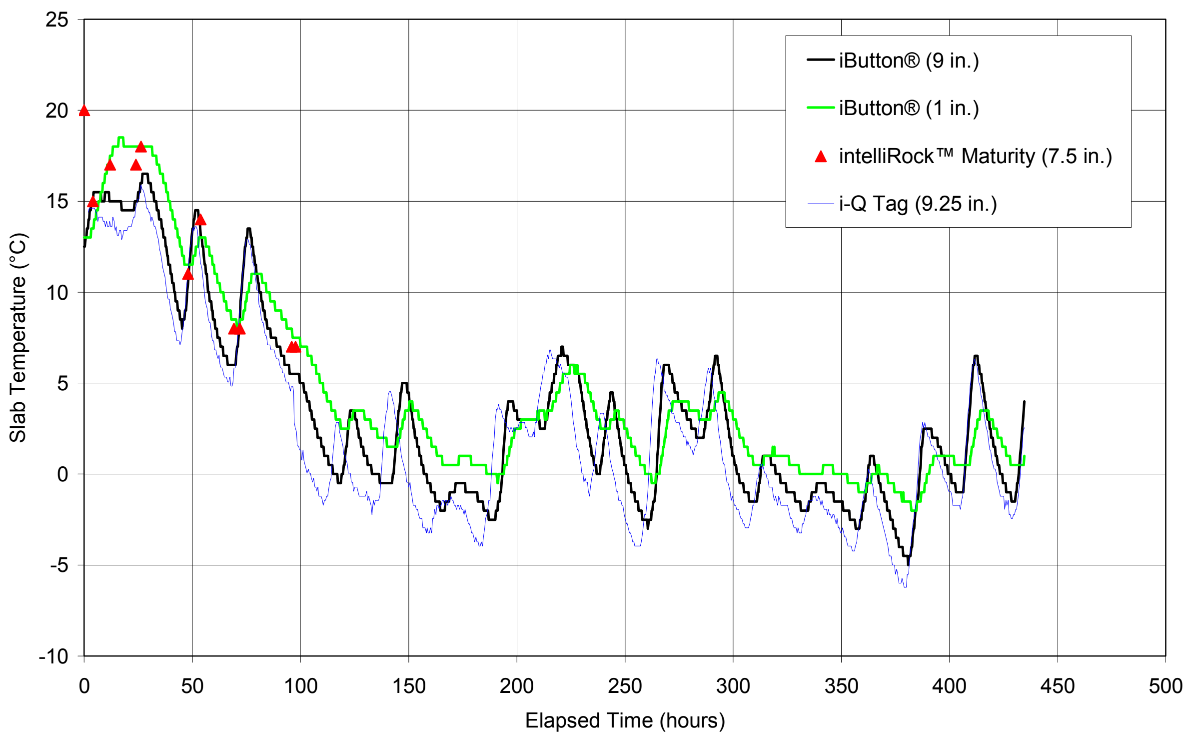
i-Q Tag (0.000.209.784)

iButton® (mid-8625400002CCDE21
bot-5E25400002C89821)

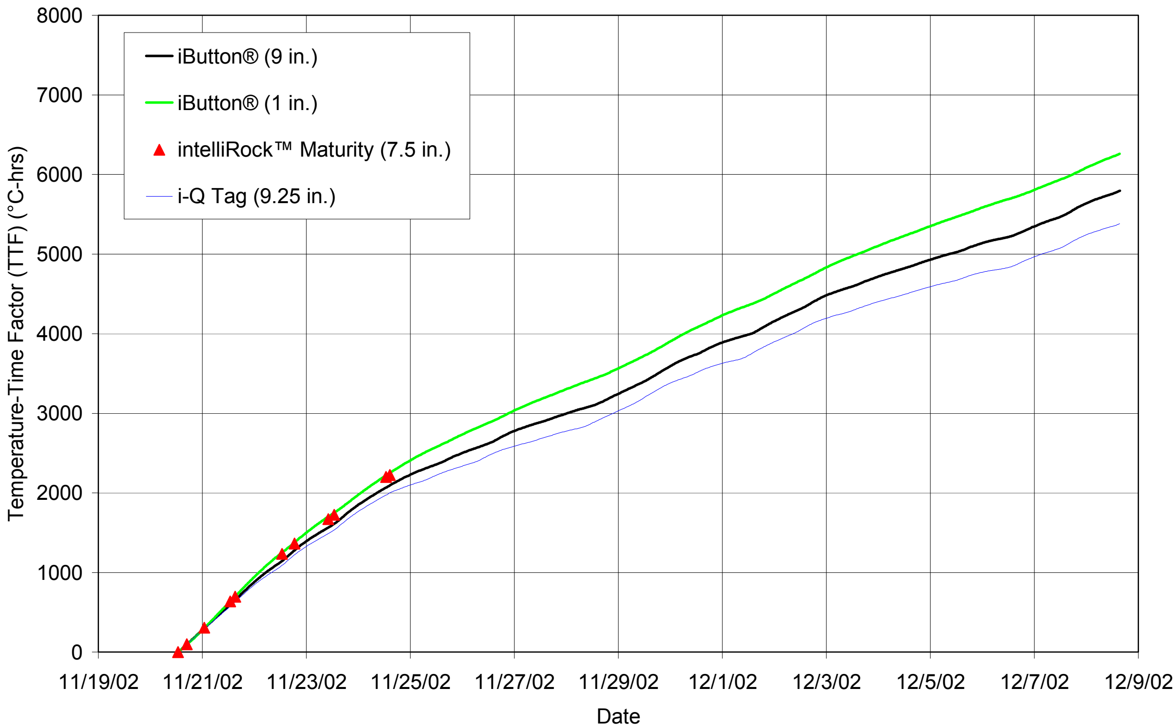
intelliRock™ Maturity (4573)

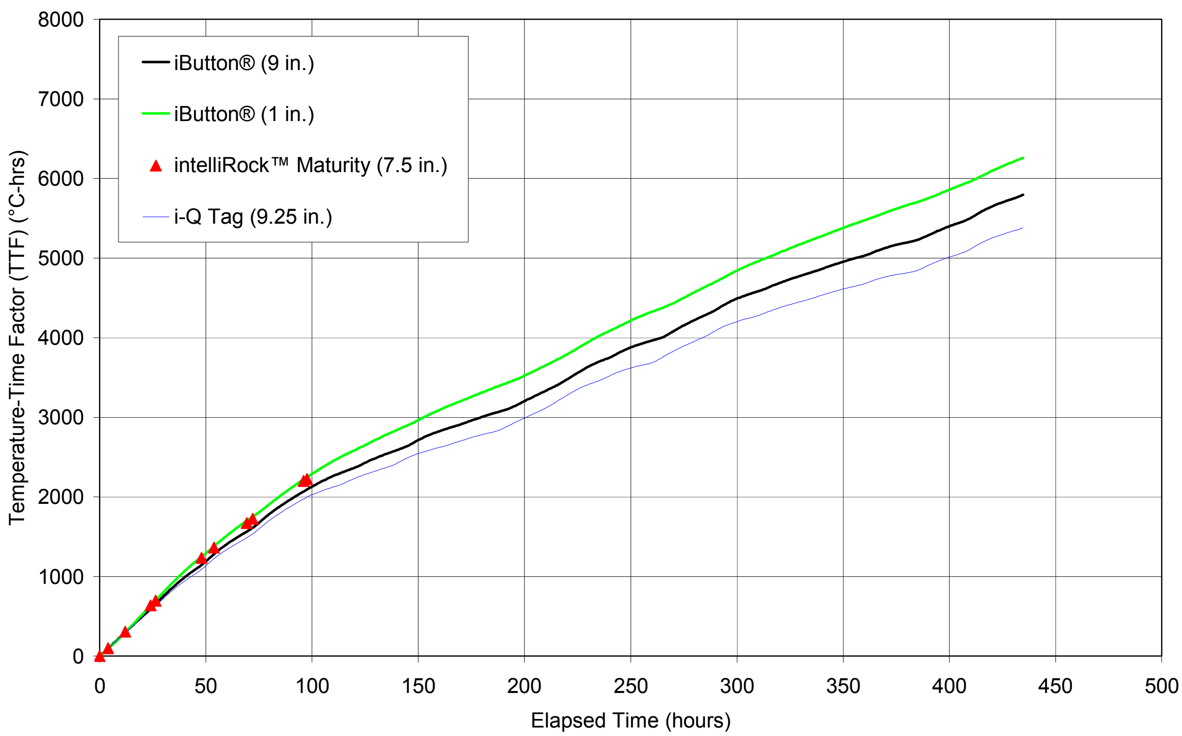
B.34 LOCATION 9 – SLAB TEMPERATURE.



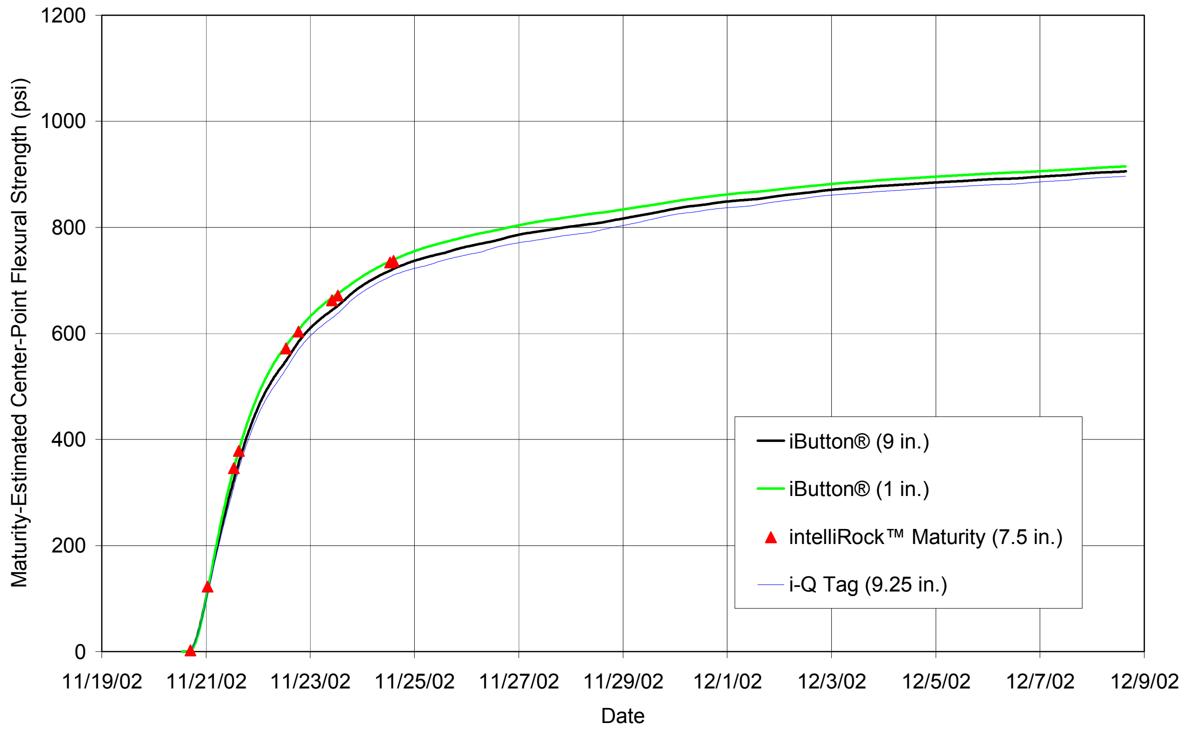


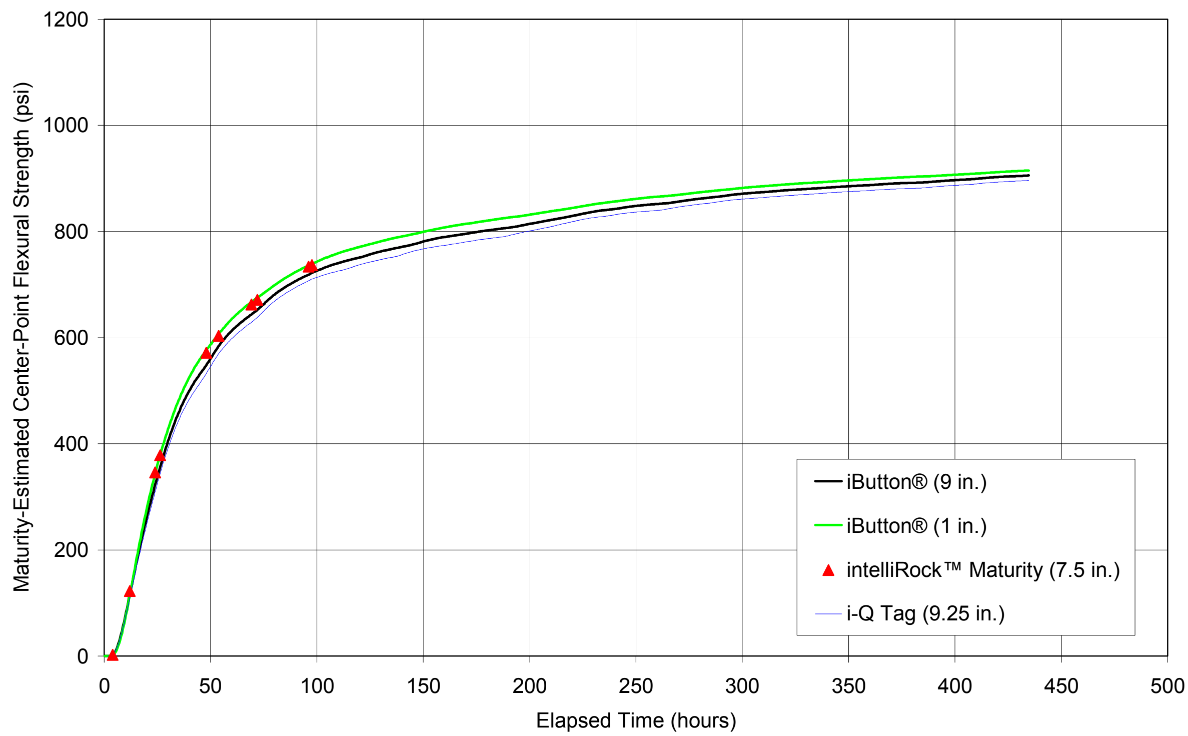
B.35 LOCATION 9 – MATURITY.





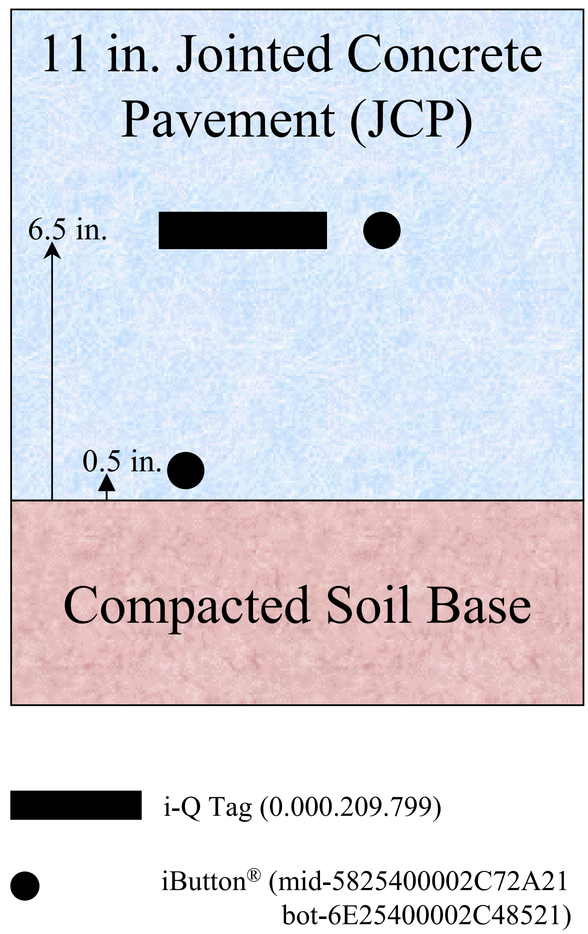
B.36 LOCATION 9 – MATURITY-ESTIMATED STRENGTH.



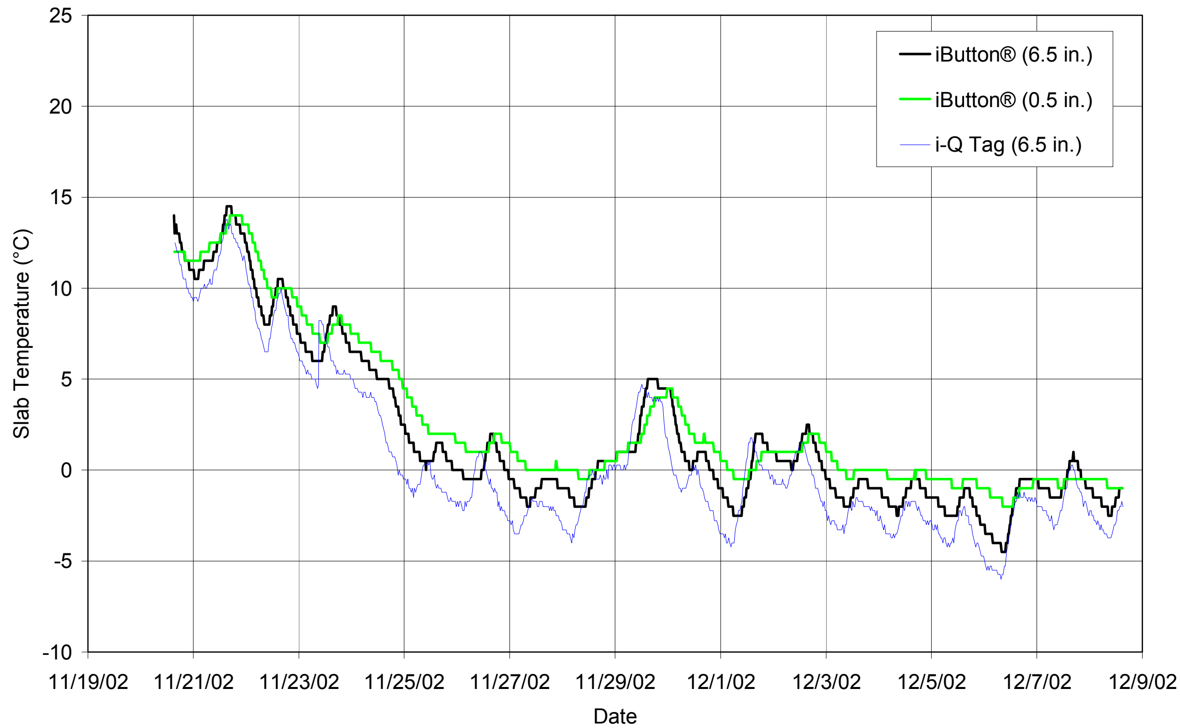


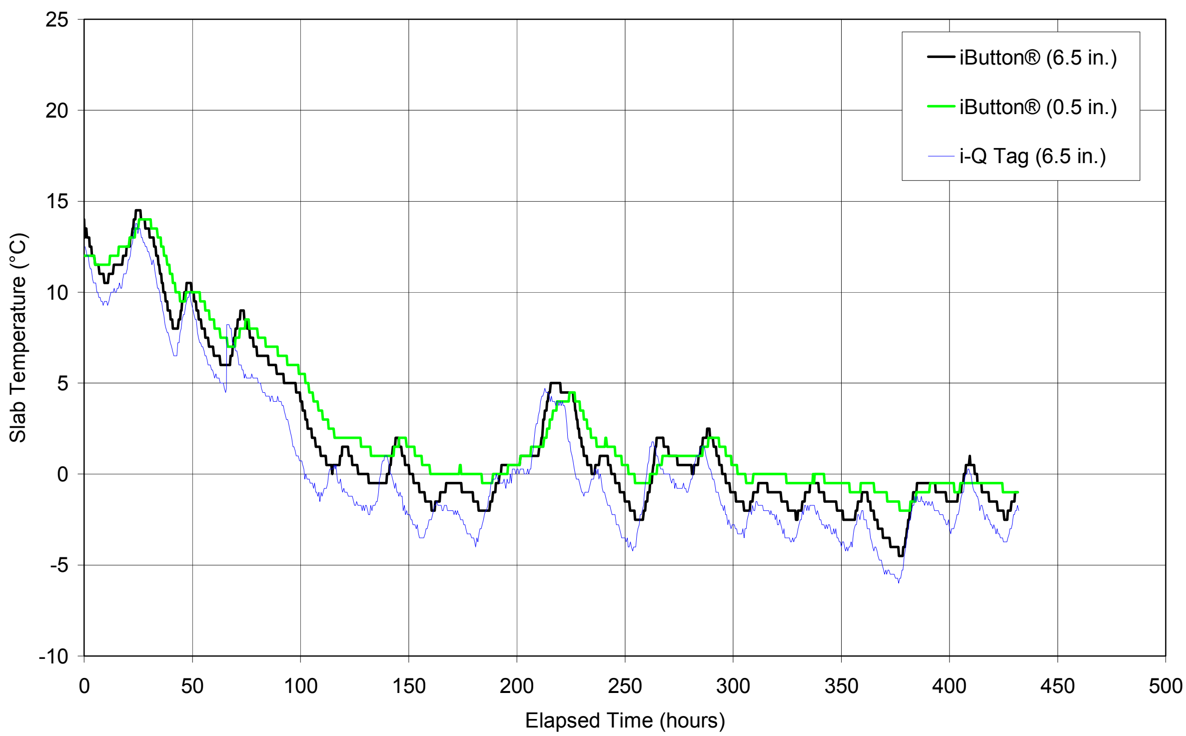
B.37 LOCATION 10 – MECHANICAL PLACEMENT.

Concrete Placement	11/20/02 3:13 PM
Fresh Concrete Temperature	14.0°C (57.2°F)
Air Temperature	13°C (56°F)
Relative Humidity	47%
Windspeed	27 kph (17 mph)
Mix Design	Slipform

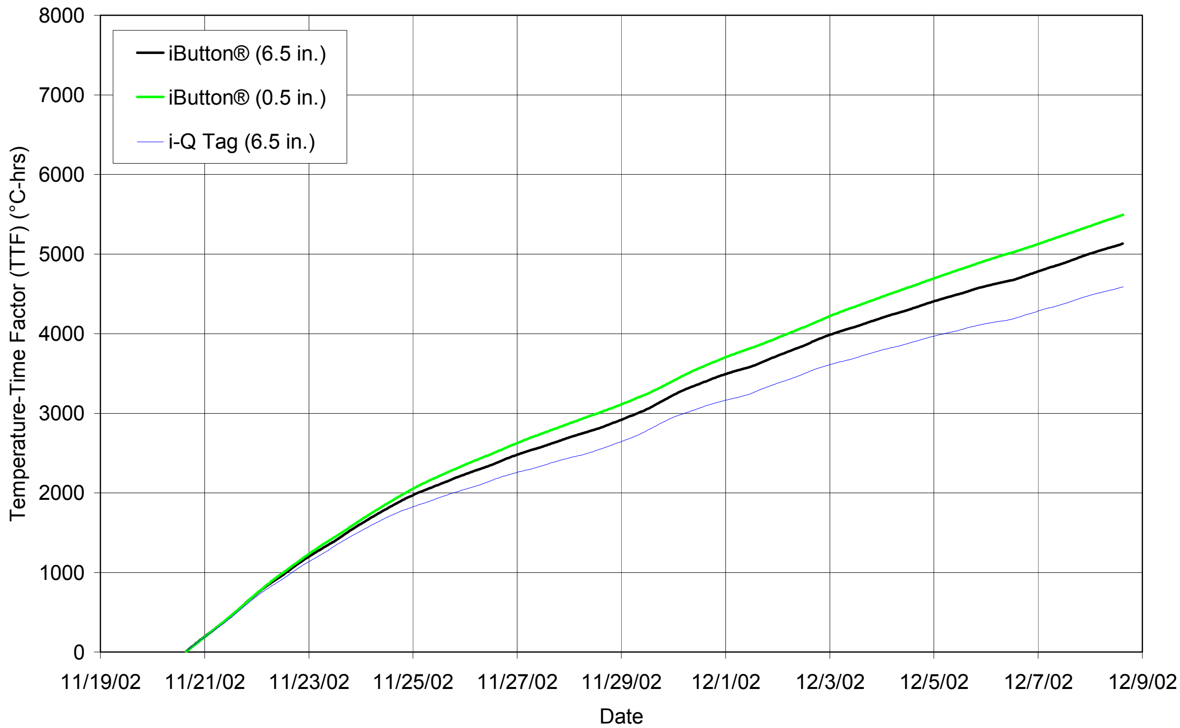


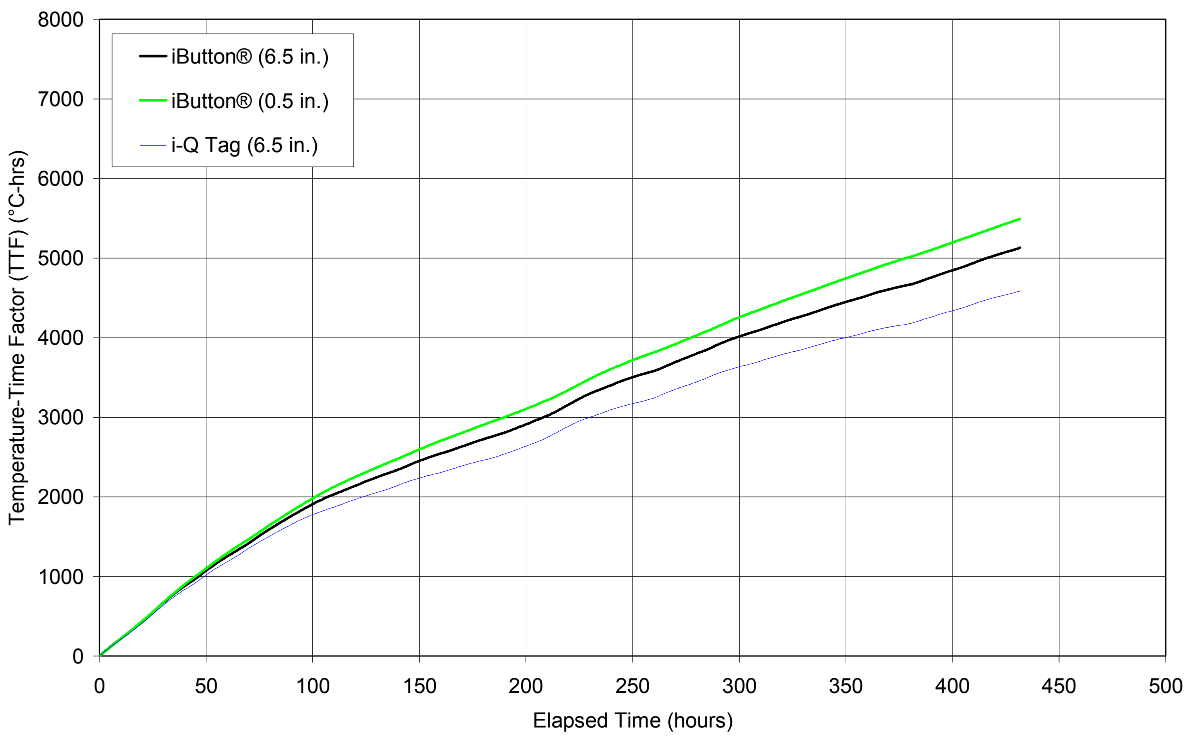
B.38 LOCATION 10 – SLAB TEMPERATURE.



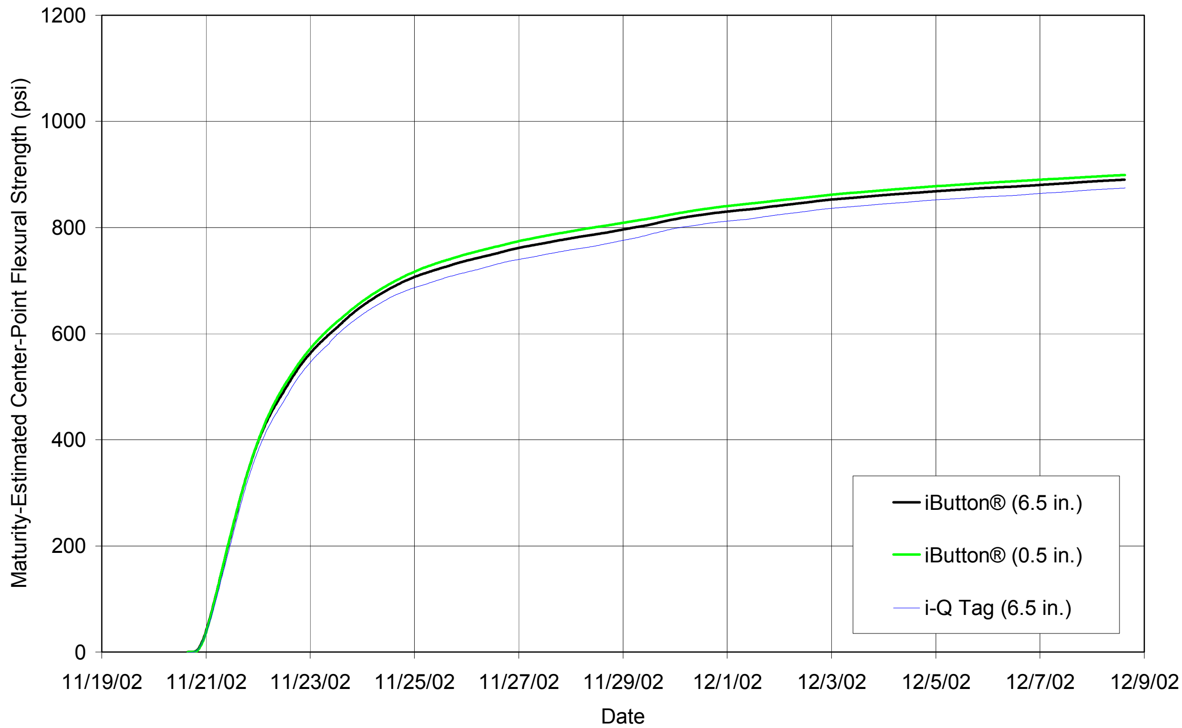


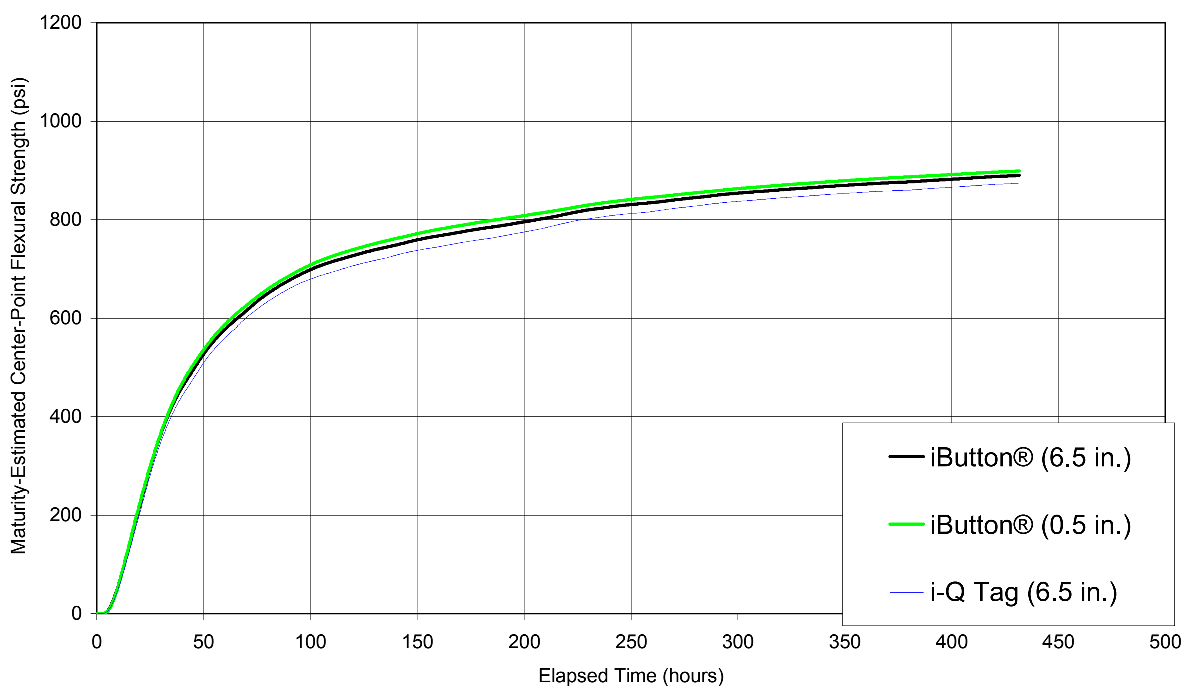
B.39 LOCATION 10 – MATURITY.





B.40 LOCATION 10 – MATURITY-ESTIMATED STRENGTH.





APPENDIX C – VENDOR LITERATURE AND DOCUMENTATION

DS1921L-F5X

Thermochron iButton

www.maxim-ic.com

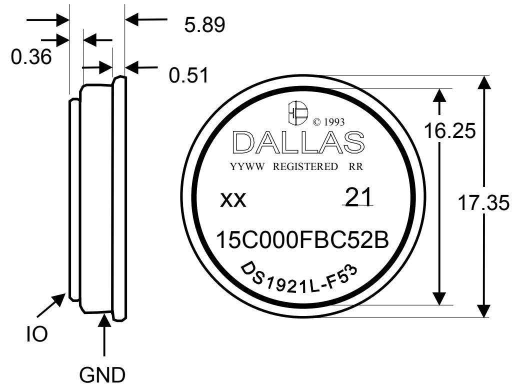
SPECIAL FEATURES

- Digital thermometer measures temperature in 0.5°C increments
- Built-in real-time clock (RTC) and timer has accuracy of ±2 minutes per month per month from 0°C to 45°C
- Automatically wakes up and measures temperature at user-programmable intervals from 1 to 255 minutes
- Logs up to 2048 consecutive temperature measurements in protected nonvolatile (NV) memory
- Records a long-term temperature histogram with 2.0°C resolution
- Programmable temperature-high and temperature-low alarm trip points
- Records up to 24 time stamps and durations when temperature leaves the range specified by the trip points
- 512 bytes of general-purpose read/write NV memory
- Communicates to host with a single digital signal at 14.1kbits or 125kbits per second using 1-Wire® protocol

COMMON iButton FEATURES

- Digital identification and information by momentary contact
- Unique, factory-lasered and tested 64-bit registration number (8-bit family code + 48-bit serial number + 8-bit CRC tester) assures absolute traceability because no two parts are alike
- Multidrop controller for 1-Wire net
- Chip-based data carrier compactly stores information
- Data can be accessed while affixed to object
- Button shape is self-aligning with cup-shaped probes
- Durable stainless steel case engraved with registration number withstands harsh environments
- Easily affixed with self-stick adhesive backing, latched by its flange, or locked with a ring pressed onto its rim
- Presence detector acknowledges when reader first applies voltage
- Meets UL#913 (4th Edit.). Intrinsically Safe Apparatus: approved under Entity Concept for use in Class I, Division 1, Group A, B, C and D Locations (application pending)

F5 MICROCAN



All dimensions are shown in millimeters.

ORDERING INFORMATION

DS1921L-F51	-10°C to +85°C	F5 iButton®
DS1921L-F52	-20°C to +85°C	F5 iButton
DS1921L-F53	-30°C to +85°C	F5 iButton
DS1921L-F50	-40°C to +85°C	F5 iButton

EXAMPLES OF ACCESSORIES

DS9096P	Self-Stick Adhesive Pad
DS9101	Multi-Purpose Clip
DS9093RA	Mounting Lock Ring
DS9093A	Snap-In Fob
DS9092	iButton Probe

1-Wire, Microcan, and iButton are registered trademarks of Dallas Semiconductor

iButton DESCRIPTION

The DS1921L Thermochron iButtons are rugged, self-sufficient systems that measure temperature and record the result in a protected memory section. The recording is done at a user-defined rate, both as a direct storage of temperature values as well as in the form of a histogram. Up to 2048 temperature values taken at equidistant intervals ranging from 1 to 255 minutes can be stored. The histogram provides 63 data bins for a resolution of 2.0°C. If the temperature leaves a user-programmable range, the DS1921L will also record when this happened, for how long the temperature stayed outside the permitted range, and if the temperature was too high or too low. An additional 512 bytes of read/write NV memory allow storing information pertaining to the object to which the DS1921L is associated. Data is transferred serially via the 1-Wire protocol, which requires only a single data lead and a ground return. Every DS1921L is factory-lasered with a guaranteed unique 64-bit registration number that allows for absolute traceability. The durable stainless steel package is highly resistant to environmental hazards such as dirt, moisture, and shock. Accessories permit the DS1921L to be mounted on almost any object, including containers, pallets, and bags.

APPLICATION

The DS1921L Thermochron iButton is an ideal device to monitor the temperature of any object it is attached to or shipped with, such as perishable goods or containers of temperature sensitive chemicals. Using TMEX, the read/write NV memory can store an electronic copy of shipping information, date of manufacture and other important data written as clear as well as encrypted files.

OVERVIEW

The block diagram in Figure 1 shows the relationships between the major control and memory sections of the DS1921L. The device has seven main data components: 1) 64-bit lasered ROM, 2) 256-bit scratch-pad, 3) 4096-bit general-purpose SRAM, 4) 256-bit register page of timekeeping, control, and counter registers, 5) 96 bytes of alarm time stamp and duration logging memory, 6) 126 bytes of histogram memory, and 7) 2048 bytes of data-logging memory. Except for the ROM and the scratchpad, all other memory is arranged in a single linear address space. All memory reserved for logging purposes, counter registers and several other registers are read-only for the user. The timekeeping and control registers are write-protected while the device is programmed for a mission.

The hierarchical structure of the 1-Wire protocol is shown in Figure 2. The bus master must first provide one of the seven ROM function commands: 1) Read ROM, 2) Match ROM, 3) Search ROM, 4) Conditional Search ROM, 5) Skip ROM, 6) Overdrive-Skip ROM or 7) Overdrive-Match ROM. Upon completion of an Overdrive ROM command byte executed at standard speed, the device will enter Overdrive mode, where all subsequent communication occurs at a higher speed. The protocol required for these ROM function commands is described in Figure 12. After a ROM function command is successfully executed, the memory functions become accessible and the master may provide any one of the seven available commands. The protocol for these memory function commands is described in Figure 10. **All data is read and written least significant bit first.**

Point Six Wireless
Unique, High Value Wireless Solutions

1-Wire/iButton ™
Transceivers

900 MHz./2.4GHz. Spread Spectrum Frequency Hopping Transceivers

FEATURES

TZR HA6

DALLAS SEMICONDUCTOR ASD

- **ASCII command support for all 1-Wire™ and iButton devices**
- **Operating range: Indoor - 600' to 1300'**
- **Operating range: Outdoor - 7mi. with dipole, >20 mi. w/ high gain antenna**
- **Supports up to 26 1-Wire™ radio nodes per host network**
- **Each node supports up to 200 1-Wire devices**
- **Supports up to 10 host networks**
- **DDE and OPC compliant software**
- **Automatically provides smart strong-pull-up for wired sensors**
- **Network and node address parameters stored in EEPROM**
- **LED power and configuration activity indicator**
- **RJ-11 connector for standard 1-Wire connection**
- **Provides Search, Conditional Search and Family Search commands**
- **Supports TMEX Structure for Dallas Semiconductor iButtons™**
- **Automatically generates and checks CRC16 for TMEX™ files**
- **Block mode commands support all 1-Wire™ device functions**
- **ESD Protection more than 27kV(IEC801-2 Reference Model.)on the 1-Wire™ bus**
- **Low power, 6-24 VDC at 200 milliAmp. transmitting, 70 milliAmp. receiving**
- **Astron AXH900RP SMA R Reverse Polarity SMA 6.5" Antenna**
- **High Impact ABS enclosure**

DESCRIPTION

The 1-Wire/iButton Transceiver is a 900 MHz/ 2.4 GHz. Spread Spectrum Frequency Hopping radio that provides ASCII command sets for Dallas Semiconductor 1-Wire/iButton devices for a wide variety of applications. The Transceivers use an embedded 100-milliwatt wireless modem that communicates using an asynchronous serial data stream. The radio operates within the 900 MHz/ 2.4 GHz. ISM Band under Part 15 of the FCC Rules and Regulations to provide wireless interface between a 1-wire/iButton host applications and remote 1-Wire networks.

The Transceivers relieve the host PC of the burden of generating the time critical 1–Wire communication waveforms while supporting all 1-Wire devices with simple ASCII commands that can be easily generated. The 1-Wire Transmitter does all the hard work of interfacing 1-Wire networks. The 900 MHz/ 2.4 GHz. modem provides as many as 26 1-Wire nodes from a single host radio interface providing for hundreds of 1-wire devices over a large area with wireless connection to the host application using a 1-Wire Receiver host radio.

The 1-Wire Transceiver can perform Search, Conditional search and Family search functions making it easy to acquire the unique 64 bit serial numbers of all connected devices using standard DDE or OPC communications. It also provides the extra current some devices require with a built in smart strong-pull-up. Dallas Semiconductor iButtons™ which store data in TMEX™ Touch Memory File format can be read or written with simple ASCII commands. The Transceiver automatically generates and checks the CRC16-error checks from Touch Memory File records. It supports analog, digital, and temperature 1-Wire™ devices, all Dallas Semiconductor iButtons™ and Point Six sensors.

intelliRock™ Systems

IntelliRock - Concrete Maturity System

NOMADICS Construction Labs

Low cost solution for multiple job sites!

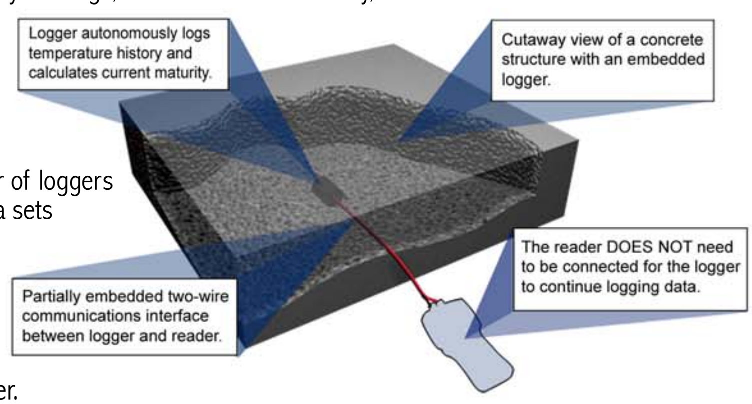
Resists damage due to: ✓Vandalism ✓Theft ✓Weather

Nomadics' intelliRock™ concrete maturity metering system uses state-of-the-art technology to overcome many of the problems associated with traditional concrete maturity meters. The Nomadics system uses an embedded microprocessor and high-precision temperature sensors in place of the external recording devices and thermocouples used by other systems. Nomadics' system does not require temperature calibration and allows the temperature sensors to function independently, without permanent connection to any external devices. This arrangement allows multiple embedded sensors to be controlled and accessed by a single handheld reader, making it ideal for use at multiple job sites and eliminating product damage due to vandalism, theft, and weather! In addition, the data from up to 200 loggers can be downloaded into the handheld reader. This data can then be transferred to a PC for convenient record keeping and data post-processing.

Starter kit includes:
Reader, 25 loggers, software, download cable, and a carrying case

Features

- Loggers embedded in and protected by concrete structure and can operate unattended for months
- The reader displays real-time maturity readings, accumulated data history, and max. and min. temperatures
- Connect/disconnect reader at any time without disrupting the logging process
- One reader can operate any number of loggers and can store up to 200 logger data sets

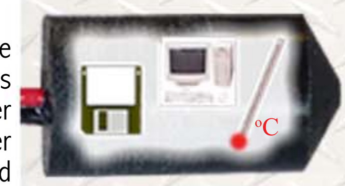


Patents Pending

The Software

The IntelliRock software provides a convenient interface to download maturity data from the handheld reader. The software runs under Microsoft Windows (95 and newer). As the data is downloaded, two file formats are created. One is a convenient text format that can be handled by most commercial software packages such as Microsoft Excel, and the other is a secure, tamper-proof format that can be distributed and decrypted by other parties (such as DOT's). This process reduces the need for independent data verification since 1) each logger is permanently mounted in the structure, 2) each logger is uniquely serial numbered, and 3) data is transferred from the logger to the end user securely, without manual data transcription or manipulation.

What's inside the Logger?



- Memory
- Temperature Sensor
- Microcomputer
- Battery

Logger data is downloaded to the reader. The data stored in the reader is then downloaded to a PC.

From the PC, data files can then be generated and exported to Excel or other type software. Secure files can also be generated.

For more information contact:
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Phone: 405.372.9535
Fax: 405.372.9537
Email: information@nomadics.com
Web: www.concretematurity.com

www.nomadicsconstruction.com

intelliRock™ Systems

Concrete Maturity and Temperature Loggers

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

Patents Pending

TPL-01
Temperature Logger

- Records concrete's internal temperature profile for 28 days
- Use when temperature data is required but not strength measurements

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 LGR-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 thermistors to provide highly accurate temperature measurements. The precision thermistors eliminate any need for temperature calibration.

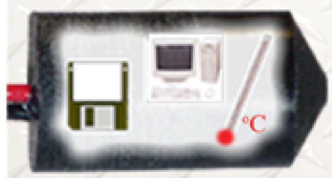
LGR-01 Maturity Logger Specifications

Temperature Accuracy:	+/- 1° C
Maturity Integration Period:	15 minutes
Maturity Technique:	ASTM C 1074[1] (Nurse-Saul Method)
Stored Historical Temperature and Maturity Points:	Temperature and 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 and value of min./max. temperature and maturity
Logger Dimensions:	1-1/2 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 (-64° 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 Temperature 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 and 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

What's inside the Logger?



- Memory
- Temperature Sensor
- Microcomputer
- Battery

[1] ASTM C 1074. (1987). "Standard Practice for Estimating Concrete Strength by the Maturity Method." *1992 ASTM Standards Vol. 04.02.* Philadelphia, PA: American Society for Testing and Materials.

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www.nomadicsconstruction.com

*intelli*Rock™ Systems

Real-Time Strength Logger

Reports and logs in-place strength in REAL-TIME!

Patents Pending

Patents Pending

Resists damage due to:

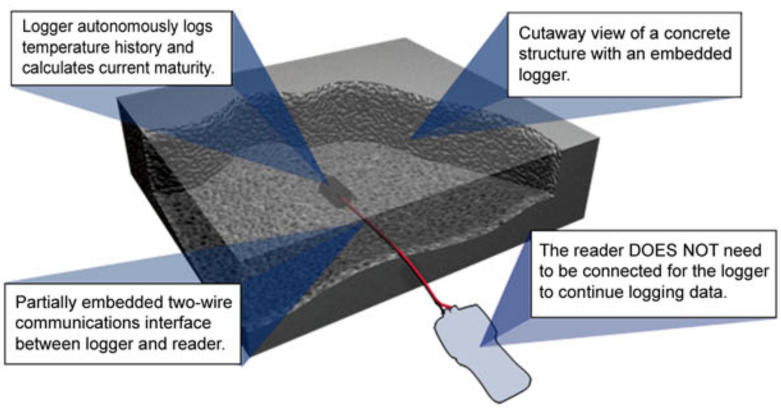
✓ Vandalism ✓ Theft ✓ Weather

Real-Time Strength Logger (LGR-01-RTS)

Nomadics' *intelli*Rock™ **patent-pending** technology reports and logs concrete strength in real-time. As opposed to manual conversion from concrete maturity to concrete strength, the real-time strength system converts from maturity to strength automatically, in real-time. The Nomadics system uses an embedded microprocessor and high-precision temperature sensors in place of the external recording devices and thermocouples used by other systems. Nomadics' system does not require temperature calibration and allows the temperature sensors to function independently, without permanent connection to any external devices. This arrangement allows multiple embedded sensors to be controlled and accessed by a single handheld reader, making it ideal for use at multiple job sites and eliminating product damage due to vandalism, theft, and weather!

What's inside the Logger?

- Memory
- Temperature Sensor
- Microcomputer
- Battery



The Logger

- Embedded in and protected by concrete structure
- Calculates and logs strength and maturity readings
- Logs and time stamps the max. and min. temperature
- Operates unattended for months

Preliminary Specifications

Strength Calibration Points:	5
Temperature Accuracy:	+/- 1° C
Maturity Integration Period:	15 minutes
Maturity Technique:	ASTM C1074 (Nurse-Saul Method)
Stored Historical Strength/Temperature/ Maturity Points:	Start, 4 hrs, 12 hrs, 1 day, 2 days, 3 days, 4 days, 5 days, 6 days, 7 days, current stregnth/temperature/maturity
Additional Data Stored:	Time/value of min./max. temperatures
Logger Dimensions:	1-1/2 in. x 1-1/8 in. diameter
Standard Cable Length:	4 ft. (custom lengths offered up to 30 ft.)
Operating Temperature:	-18° C to 85° C (-64° F to 185° F)
Logging Battery Life:	3 months
Battery Shelf Life:	5 years (preliminary)

The Reader

- Communicates with loggers to view real-time strength, real-time maturity readings, accumulated data history, and max. and min. temperatures
- Reader can be connected and disconnected to the logger at any time, without disrupting the logging process
- One reader can operate any number of loggers

*intelli*Rock™ Reader (MTR-01S-RTS)

Ordering Information

- Available in 2003

For more information contact:
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Email: information@nomadics.com
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International Road Dynamics Inc. develops and maintains traffic management products and systems technology that make highways talk. What are they saying? They are providing information that roadway administrators need to manage traffic, preserve infrastructure and provide safety warnings to drivers.

IRD's multi-discipline, innovative and customer-focused team is expert in advanced technologies, advanced traffic solutions and custom-designed systems.

CUSTOMER DRIVEN

JUNE, 2002 REV A
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CONCRETE MATURITY MONITOR:

NEW!!!

Wireless Technology In the Palm of Your Hand

Let IRD's cutting-edge technology do the work for you. IRD has created a system which allows you to perform WIRELESS concrete maturity testing – right in the palm of your hand!

Wireless Tag

Handheld PC communicating with a buried tag

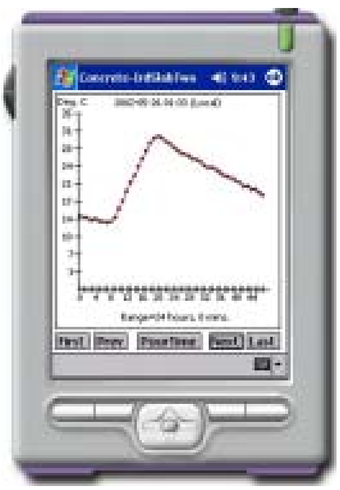
The days of using the extensive Core Test Method or plugging a cluster of wires into a laptop computer and a box affixed into the cement are a thing of the past. With the introduction of the IRD Concrete Monitor, the process of Concrete Maturity Testing has been simplified to three easy steps:

1. Place and position the temperature monitoring tag
2. Bury the tag with concrete
3. Record information

It really is as easy as that! The use of two-way RF communication between the buried tag and a handheld PC, each having the ability to read and write information to each other, makes IRD's Concrete Monitor *first* in its class.

CONCRETE MATURITY TESTING ALLOWS FOR TIGHTER QUALITY CONTROL, AS WELL AS THE ABILITY TO MONITOR THE QUALITY OF THE CONCRETE AT MORE FREQUENT TIME INTERVALS, AS COMPARED TO OTHER MORE COSTLY AND TIME-INVOLVED METHODS OF CONCRETE TESTING.

WIRELESS CONCRETE MATURITY MONITORING



ADVANTAGES

Economical	Low cost; quick return on investment
Wireless	Quickly and efficiently collect data from temperature monitoring tags
Unobtrusive	No affixed above ground equipment needed to obtain maturation information
Portable	Use the same handheld PC for multiple locations at multiple sites
Versatile Software	Easily transfer files from handheld PC to desktop PC Microsoft Office applications
	Perform graphical evaluations and comparisons
	Store notes for each individual tag (i.e. concrete was poured 1 hour after others)
Accuracy	Maturity is calculated using the Nurse-Saul equation with Datum Temperature of -10°C (14°F)
	Temperature accuracy exceeds ASTM C1074-93 requirements
	The predicted strength of the concrete is based on actual site compression results rather than controlled lab readings
Range	Two monitoring tag models are available:
	1) Standard monitoring tags can be read at depths of up to 8" (20.32 cm)
	2) Range Extension Tags allows for temperature monitoring at depths greater than 8" (20.32 cm)
Low Maintenance	The temperature monitoring tags have a 5 year battery life

SYSTEM COMPONENTS

Each IRD Concrete Monitoring System consists of the following components:

- 1 Pocket PC running Microsoft Pocket PC 2002
- 1 PCMCIA adapter
- 1 Concrete Monitoring Software
- Temperature monitoring tag(s) (IRD uses the i-QT® wireless tag that is manufactured and patented by IDENTEC Solutions, Inc.)
- OPTIONAL antenna for tag which allows the tag to be buried at almost any depth

IRD is registered with the ISO 9001 Quality Control program and is committed to “Total Quality” in all areas of expertise, from design and development to manufacturing and installation to long-term service. IRD’s services range from equipment supply to provision of fully integrated turnkey systems and long term operation, management and service support.

International Road Dynamics Inc.

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