IN-PLACE STRENGTH MEASUREMENT IN POST-TENSIONED APPLICATION USING MATURITY METHOD

POST-TENSIONING INSTITUTE ®

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IN-PLACE STRENGTH MEASUREMENT IN POST-TENSIONED APPLICATION USING MATURITY METHOD

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Post-tensioning (PT) has gained significant popularity over the past 30 years, especially in modern high-rise buildings, industrial floors, and residential structures. This technique is widely used for slabs that cover a large surface area, such as tennis courts or high-rise concrete floor slabs.

KNOWING WHEN TO STRESS TENDONS

Post-tensioned tendons cannot be stressed until the concrete has reached the specified initial compressive strength, before the service loads are applied. For this reason, concrete strength must be monitored very closely to ensure that stressing does not occur too early or too late. This is especially important in cold weather, as concrete gains strength much more slowly in lower temperatures. If stressing occurs too early, concrete is subject to cracking and may be susceptible to blowouts, resulting in schedule delays.

MONITORING CONCRETE STRENGTH

The most common method for monitoring the strength of in-place concrete is the use of field-cured cylinders, in accordance with ASTM C31 for the estimation of real-time strength. However, due to differences in curing conditions, these cylinders may not accurately represent the conditions of all in-place concrete.

Field cylinders are based on the concept that cylinders kept beside the slab or close to the concrete element will be kept at a temperature and humidity approximating those of the slab. This is rarely the case, as the exothermic nature of cement hydration in large structural elements typically leads to a heat rise that is much more significant compared to that for cylindrical samples with a large surface area to volume ratio (Fig. 1). Therefore, the same concrete mixture cured at different temperatures will gain strength at a significantly different pace. Overall, this method could not be as accurate, as the cylinder and the slab will almost never gain strength at the same rate.

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AN ALTERNATIVE TESTING METHOD: CONCRETE MATURITY

The maturity method standardized by ASTM C1074, Standard Practice for Estimating Concrete Strength by the Maturity Method, is a nondestructive testing technique to estimate the real-time strength development of in-place concrete, specifically at early ages less than 14 days. It is based on the principle that concrete strength is directly related to its hydration temperature history. In other words, maturity is a value that represents the progression of concrete curing. A mixture calibration is required to implement this concept in a project (Fig. 2).

The goal of the maturity calibration is to determine a relationship between maturity and strength for a specific mixture. This calibration can be used to determine the in-place strength of the concrete and replace the need for field-cured cylinders. To perform a maturity calibration in North America, the ASTM C1074 standard must be followed.

The following is a summary of five mixture calibration steps:

1. Cast a minimum of 17 cylinders: two are for temperature monitoring, and the others are used for compressive strength breaks. All cylinders are cured together in a moist environment (ASTM C511).
2. Identify a minimum of five testing intervals—for example, 1, 3, 7, 14, and 28 days. For each day, obtain the compressive strength of two cylinders, and test the third cylinder if the results vary more than 10% from the average. Note the time of the testing.
3. At the time of the test, obtain the maturity value from the two cylinders that were used for temperature monitoring and report the average maturity value.
4. At this point, there will be a set of five or more data points relating strength to a maturity value. Plot these

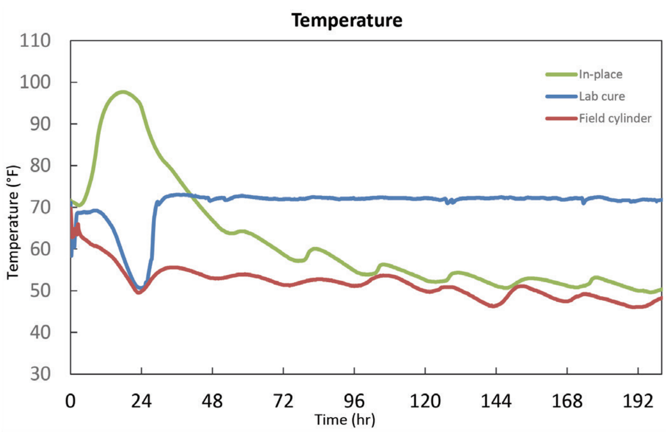


Fig. 1—Temperature in concrete under different conditions.

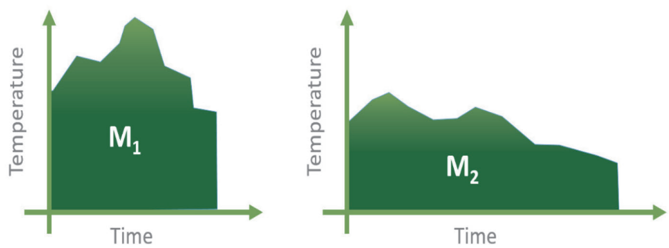


Fig. 2—Hydration temperature history graphs.

data points on a log scale to create the calibration curve.

5. Validate the project/concrete mixture design-specific calibration curve by casting additional cylinders on a future placement, and compare the calculated strength obtained from the maturity value to the compressive strength obtained in the lab. Up to a 10% difference is acceptable according to the standard.

Once a maturity calibration has been established, sensors can be used in the concrete elements to calculate the in-place strength. The concrete maturity sensor allows recording of both temperature and strength data simultaneously. The maturity method replaces the need for field-cured break tests. Wireless sensors are placed within the concrete formwork and secured on the reinforcing bar before placement. Temperature data is collected by the sensor and uploaded to a smart device within an app using a wireless connection. This information is then used to calculate the compressive strength of the in-place concrete element based on the maturity equation that is set up in the app.

This strength data is considered to be accurate and reliable because the sensors are subjected to the same curing conditions as the in-place concrete slab. Using this method also avoids inaccuracies associated with testing labs, such as cracking during transportation or low breaks, that occur when relying on break tests to obtain compressive strength measurements. Equipped with real-time results, contractors can optimize the heating process for cold-weather concreting and save time in the project schedule by knowing more precisely when to begin subsequent construction operations, such as removing formwork or stressing tendons.

Maturity sensors improve the construction process by:

1. Increasing safety of PT operations
2. Providing more accurate strength results
3. Localizing concrete strength measurements
4. Saving time and money

PRACTICAL PT INSTALLATION LOCATIONS OF WIRELESS CONCRETE MATURITY SENSORS

One of the main advantages of using the maturity method instead of traditional field-cured cylinders is the option to monitor concrete strength at a specific location in the element by measuring the temperature exactly where strength monitoring is necessary. Each type of structural element has special considerations and challenges to safely proceed with the critical operations. Each structural element usually requires the strength to be monitored at slightly different locations. There are three main considerations that apply for every type of structure when selecting the position of the maturity meter:

1. Locate the structurally critical locations
2. Identify the concrete placement schedule (end and start)
3. Locate the areas of the structure where lower temperatures are anticipated

Structurally critical locations

The structurally critical location is the most important consideration for strength monitoring; this is the location where the highest loads and stresses on the structure are expected, and it therefore requires the appropriate strength development. The structural engineer can provide more information related to the critical location for specific projects.

Placement schedule

The placement schedule is also an important factor, as the placement can take multiple hours, and the concrete that was placed first might be a couple hours older, and therefore stronger, than the last portion of the element that was cast. It is critical to remove forms or stress tendons as early as possible during the project, because a couple hours can make a difference. Targeting the end of the placement is usually a more conservative approach, as it will typically have the lowest strength of the placement because of the shorter curing time.

Lower-temperature locations

The temperature of the concrete has a direct impact on the strength development. The colder it is, the longer it will take to reach a specified strength. The environment has an important impact on the temperature of the concrete; for example, the face of a building that is exposed to the wind from an adjacent river will experience colder concrete temperatures. Similarly, an area that is always in the shade will have lower temperatures than the face exposed to the sun. The coldest locations for slabs are edges and corners where there is more exposure and surface area for heat loss.

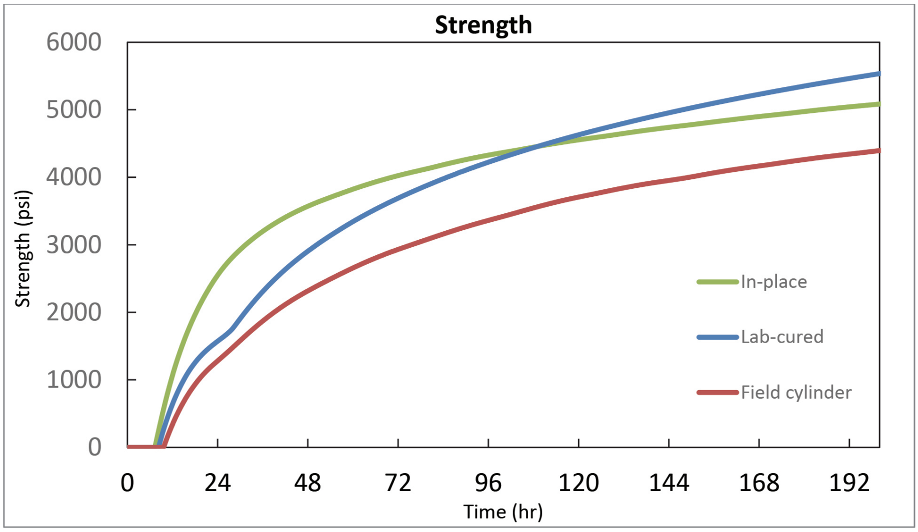
POST-TENSIONING

The critical location for strength monitoring in a PT slab is the slab edges at the anchor location, where the temperature is lower due to greater exposure to the environment, and there is a high-stress concentration during the tendon stressing. The anchorage zones along the edges that are placed last will typically be a conservative location for a maturity sensor. Additionally, interior locations where the concrete is subjected to high stress such as a tendon sweep or an area of low tendon cover are also critical strength monitoring locations. Stressing tendons too early, before concrete gains sufficient strength, can be extremely dangerous for the workers and may result in repairs. Generally, a 3000 to 4500 psi (21 to 31 MPa) concrete strength is required to safely tension tendons. This targeted strength is usually developed within 1 to 7 days, depending on the concrete's mixture proportions and curing conditions (Fig. 3).

Analyzing the data in Fig. 3, it becomes clear that the temperature has a major effect on concrete strength development. A deeper look shows that at one day the in-place strength is approximately 2550 psi (17.6 MPa), yet the field cylinder is at 1280 psi (8.8 MPa). If the jobsite were to use field-cured cylinders to determine the safe stressing time, the wait would be approximately twice as long as measuring the in-place strength.

Another example of the maturity method using PT is during cold weather. Figure 4 represents the thermal behavior of an 8 in. (200 mm) slab with heaters positioned below the bottom surface. The two temperature profiles are taken from the center and close to the concrete surface—4 and 1 in. (100 and 25 mm), respectively. Despite having the same mixture proportions for the same horizontal area, there is no agreement on the thermal behavior at the two different depths. This is largely because the bottom surface absorbs the heat from the heaters positioned on the level below, raising the temperature of the core, whereas the top surface is releasing heat to the environment.

Applying the maturity method to the measured locations tracks the strength development at early ages. Figure 5 demonstrates how the cooler location close to the surface had a slower strength gain when compared to the warmer location at the core/center of the element. The center achieved the target strength (4200 psi [29 MPa]) within 20 hours. The surface achieved the same strength 4 hours later, at 24 hours. If a contractor were only measuring the center, the "green light" to stress tendons would have been given before the surface had enough strength. By always relying on the worst-case scenario, contractors can stress tendons with confidence, ensuring the minimum required strength has been achieved and reduces the chance of issues.



Time	**In-place** concrete strength, psi	**Lab-cured** cylinder strength, psi	**Field** cylinder strength, psi
24 hours (1 day)	2550	1570	1280
72 hrs (3 days)	4025	3690	2930
168 hrs (7 days)	4900	5230	4170

Fig. 3—Example of lab-cured versus field-cured and in-place strength/maturity data of placement. Red text indicates highest compressive strength at each time period. Note: 1 psi = 6.89 kPa.

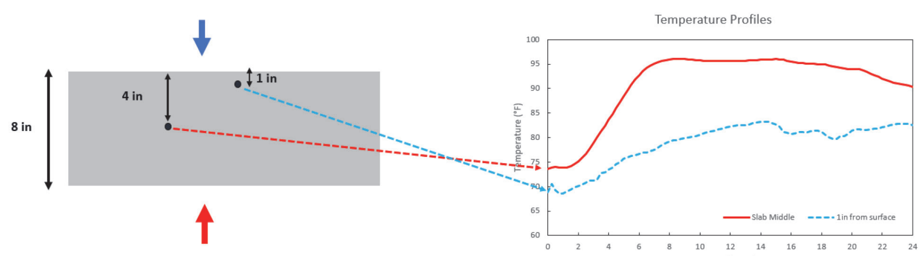


Fig. 4—Impact of ambient temperature on concrete temperature.

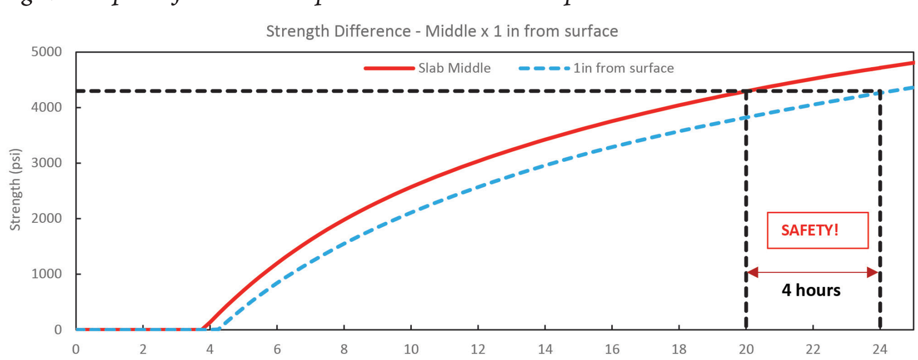


Fig. 5—Strength development at mid-slab and near the surface.

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