Early-Release Cylinder Strengths Predicted by the Maturity Method

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Figure 1. Aerial photo of the southbound main span unit of the Pearl Harbor Memorial Bridge during winter construction conditions. Photo: Connecticut Department of Transportation.

Construction of the recently-completed Pearl Harbor Memorial Bridge in New Haven, Conn., involved placement and curing of concrete elements year-round in a variety of New England weather conditions, in order to meet the challenging construction schedule. Nowhere on the project was the schedule under more pressure than the construction of the main span unit over the Quinnipiac River.

The extradosed cable-stayed, main-span box girder was built in balanced cantilever using post-tensioned concrete segments cast-in-place with self-launching form travelers. With this method, the erection schedule is highly linear and the elapsed times for releasing the form traveler, stressing post-tensioning tendons, and launching the form traveler to the next segment are all dependent on achieving certain minimum concrete compressive strengths in the newly placed segment. A minimum concrete compressive strength of 3.5 ksi was required to be able to release the support of the form traveler and launch it forward to the next casting position. A compressive strength of 4 ksi was needed before stressing the longitudinal and the transverse post-tensioning tendons.

The high-performance concrete used Type III portland cement; ground, granulated blast-furnace slag; and silica fume to achieve a combination of high early compressive strength gain and low permeability. Typically, compressive strengths of 3.5 ksi and greater could be achieved in approximately 16 hours, but the rate of early strength gain was influenced significantly by the curing temperatures. Thus, progression of the segment casting schedule could potentially be negatively affected by environmental conditions during the harsh cold of the New England winters (Fig. 1).

Just as important as protecting the segment during curing was the need to get an accurate compressive strength result from the concrete test cylinders cast and cured with the segment. These early-release cylinders were produced from the last 20 yd^3 of the concrete placement, cured with the segment, and then broken at an on-site lab to determine the in-place concrete strength. On many previous projects, the cylinders had been simply placed under the curing blankets on the top slab of the segment. That method has several potential sources of inaccuracy:

- The cylinders can be inadvertently damaged during or after handling and covering.
- The segment has a complex cross-sectional shape and curing temperatures are not uniform throughout the element. The top slab where the cylinders are located may not be the most critical curing location.
- Cylinders need to be carefully located away from heating sources such as forced air vent hoses.
- The cylinders don't provide any direct data on the curing temperatures at their location or anywhere else in the segment.
- A large number of cylinders need to be produced to determine the point when the minimum compressive strength is achieved.

To reduce these potential inaccuracies and increase efficiency in the early strength gain monitoring process, a quantitative method for monitoring in-place curing temperatures and predicting the resulting test cylinder strengths was adopted for this project.

Based on the maturity method of ASTM C1074,[1] baseline testing was performed that established the relationship between compressive strength and maturity. A test batch of cylinders was cured and broken at regular time intervals. Break results were plotted against the curing temperature history (the maturity index) to establish a predictive relationship specific to the concrete used for this baseline test (Fig. 2). Any subsequent change in constituent materials or their proportions required a new baseline test.[2]

For each segment, several temperature sensors were embedded in the concrete at locations deemed likely to be the most critical for curing temperatures and for structural strength, focusing on locations most sensitive to cold weather conditions and most critical for post-tensioning loads. Generally, this included locations in the thinnest portion of the top slab. Temperatures were also regularly monitored in the bottom slab and in the edge beam near the transverse tendon anchorages.

The project team elected to use a proprietary temperature sensor with excellent long-term durability that had on-board memory for storing recorded data. An additional benefit of this system was the ability to set up a wireless data collection network that transmitted recorded temperatures back to a central computer with automatically updated sensor readings every hour. Thus, the contractor, the owner, inspector personnel had instant access to the raw data via an internet connection and could evaluate the curing system in real time. The on-board memory of the sensors proved useful at times when the wireless communication system had to be turned off or connected to other sensors.

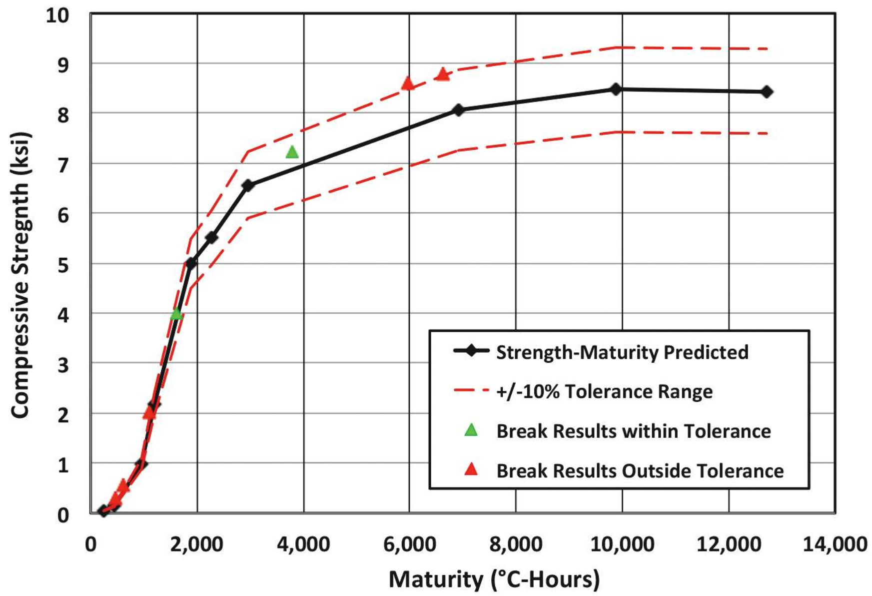

Figure 2. Graph of compressive strength versus maturity index. Figure: FIGG Bridge Engineers Inc.

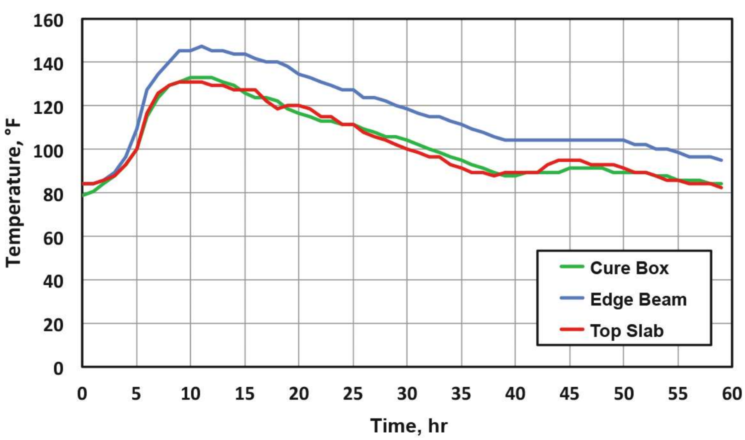

Figure 4. Graph of curing temperatures from segment and cure box cylinder. Figure: FIGG Bridge Engineers Inc.

Monitoring curing temperatures using embedded temperature sensors is not a new idea, and field-curing a set of cylinders to evaluate early-release compressive strength is common. The key piece of hardware that tied these two concepts together and allowed consistent application of the maturity method was a thermostatically controlled curing box that housed the early-release cylinders and one cylinder cast with an embedded temperature sensor.

As shown in the diagram in Fig. 3, the curing box temperature was controlled by one of the sensors embedded in the segment. The selection of the controlling sensor was based on temperatures observed in previous segments. If the selected sensor was not recording the lowest concrete temperature, it could be switched to a cooler sensor as needed. The curing temperature of the early-release cylinders used to calculate the maturity index was recorded by the sensor embedded in a cylinder cast with the early-release cylinders.

Using this network of sensors and the controllable match-cure box, the project team had a high level of assurance that the early-release cylinders were being cured at temperatures consistent with the lowest observed in-situ temperatures in the segment concrete. This could be easily verified by plotting each sensor's temperature and time stamp on the same graph (Fig. 4). The maturity index for the cylinders was calculated on an ongoing basis and was used to determine the appropriate time to break an early-release cylinder. It should be noted that this system did not eliminate the need to physically test cylinders for compressive strength due to possible variations in the mixture proportions and curing temperature profile compared to the original baseline testing. This temperature monitoring and controlled cylinder curing system provided a number of benefits to the project team:

- The predictable and quantifiable process for determining when to break an early-release cylinder reduced the number of field-cured cylinders that needed to be produced.
- Accurate estimation of the test cylinder strength reduced the number of repetitious cylinder strength tests and shortened unplanned stand-by time of the form traveler crews.
- Multiple sensor locations could be evaluated quickly to ensure that the test cylinders were cured using conservative and appropriate temperatures.
- Temperature data could be acquired remotely and in real time, allowing contractor and owner representatives to evaluate curing data simultaneously and during nonwork hours.

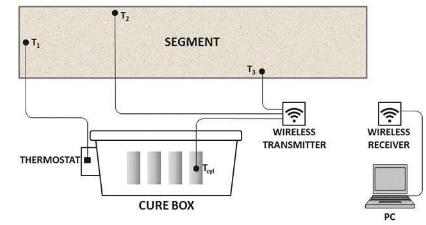

Figure 3. Diagram of sensor and curing box network for curing early release cylinders. Figure: FIGG Bridge Engineers Inc.

Use of the maturity method and the associated temperature recording and curing hardware helped the Pearl Harbor Memorial Bridge project team maintain the segment casting schedule even during cold New England winters. It eliminated the guesswork involved in breaking early-release cylinders and provided a reliable and quantifiable method for monitoring segment curing temperatures.

For more information on the Pearl Harbor Memorial Bridge project, see the Fall 2012 issue of *ASPIRE*.™

References

1. ASTM International. 2004. *Standard Practice for Estimating Concrete Strength by the Maturity Method*. ASTM C1074-04, West Conshohocken, PA.
2. National Ready Mixed Concrete Association. 2006. "CIP 39: Maturity Methods to Estimate Concrete Strength." Concrete in Practice, Washington, D.C., www.nrmca.org. <accessed 6 July 2015>.

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EDITOR'S NOTE

Lessons learned from this project are included on the website at www.aspirebridge.org