"Moving Advancements into Practice"

MAP Brief Spring 2025

Best practices and promising technologies that can be used now to enhance concrete paving

Maturity Method for Early Opening of Concrete Pavements

SPRING 2025

PROJECT TITLE
Maturity Method for Early Opening of Concrete Pavements

AUTHORS
Armen Amirkhanian, The University of Alabama

EDITORS
Neeve Funston
Peter Hunsinger
Oksana Gieseman

DESIGNER
Alicia Hoermann

SPONSORS
Technology Transfer Concrete Consortium
TPF-5(437)

MORE INFORMATION
National Concrete Pavement Technology Center
515-294-5798
cptech@iastate.edu

www.cptechcenter.org/national-concrete-consortium

Utilizing the Maturity Method for Early Opening of Concrete Pavements: A Practitioner's Summary

The need for efficient and timely construction practices in the transportation infrastructure sector has led to increased interest in methods that can accurately assess the in-place strength of concrete pavements at early ages.

One such technique, the concrete maturity method, has gained recognition for its ability to estimate strength development by considering the combined effects of curing time and temperature (Carino and Lew 2001). This approach offers a significant advantage over traditional methods that rely on laboratory- or field-cured specimens, which may not accurately reflect the actual conditions experienced by the pavement (FHWA 2019). Furthermore, the maturity method is insensitive to specimens that become damaged during the curing or transportation process. The maturity method is particularly relevant for determining the appropriate time for early loading or opening of pavements to traffic, a critical factor in minimizing construction delays and costs.

This MAP brief focuses on the maturity method outlined in AASHTO T 413, which is a recently adopted standard that specifically addresses the issues of early pavement opening.

A Short History

The concept of concrete maturity has its roots in the late 1940s and early 1950s in England, stemming from research focused on understanding the effects of steam curing on concrete (Carino and Lew 2001). Researchers like McIntosh, Nurse, and Saul were instrumental in developing the initial ideas around quantifying the combined influence of time and elevated temperature on the rapid strength gain observed in steam-cured concrete. Notably, Saul's 1951 publication is often credited with formalizing the "maturity rule," which posits that two identical concrete mixtures will achieve similar strengths at equivalent maturity levels (Carino and Lew 2001).

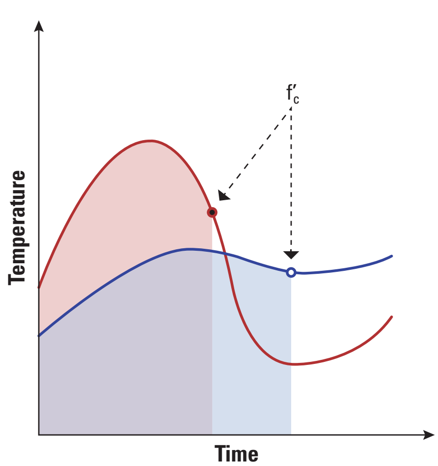
In the United States, interest in the maturity method experienced a resurgence in the 1970s, partly driven by construction failures that underscored the limitations of relying solely on traditional strength testing, particularly for early-age strength assessment under variable temperature conditions (Carino and Lew 2001). Research conducted at the National Bureau of Standards (NBS), now the National Institute of Standards and Technology (NIST), played a crucial role in validating the maturity method for use in estimating compressive strength under different curing regimes (Carino and Lew 2001). This research provided the scientific foundation for the development of standards for the application of the maturity method. A significant milestone was the standardization of the Nurse-Saul method in ASTM C1074, first published in 1987 (Carino and Lew 2001), which provided an approved procedure for estimating in-place concrete strength.

The Nurse-Saul Maturity Method: Fundamental Principles

The first step in understanding the application of the maturity method is to understand the underlying theory. At its core, the maturity method operates on the principle that two identical concrete mixtures will attain approximately equal strengths when they achieve the same level of maturity, irrespective of the specific combination of time and temperature that contribute to that maturity (Carino and Lew 2001).

This concept recognizes that the rate of cement hydration is directly influenced by temperature. Higher temperatures accelerate hydration, leading to faster strength development, while lower temperatures slow down the process. However, when a curve relating temperature to time is plotted and the area under that curve is examined, mixtures with the same proportions of materials (i.e., cement, aggregates, water) will have the same strength when their respective areas under the curve are the same.

A concern that often arises is how to determine strength when the temperature swings during construction. For the maturity method, the determination of strength and thus when to open the pavement is simply an area-under-the-curve calculation. For example, consider the two temperature profiles shown in Figure 1 for the same mixture placed on different days. On Day 1 of construction (indicated by the red line and the area shaded red in Figure 1), the temperature is warm, and the concrete gains sufficient strength to open in 33 hours. On Day 5 of construction (indicated by the blue line and the area shaded blue in Figure 1), the temperature has cooled down, and that same mixture may take 39 hours to reach the same area under the curve as on Day 1. Since the mixture proportions are identical on both days but the mixture is just placed at different temperatures, the strength of the mixture on each day and the point in time at which the mixture reaches the opening strength can be readily estimated.



Recreated from Armen Armirkhanian, used with permission

Figure 1. Two temperature profiles over time for a single mix design

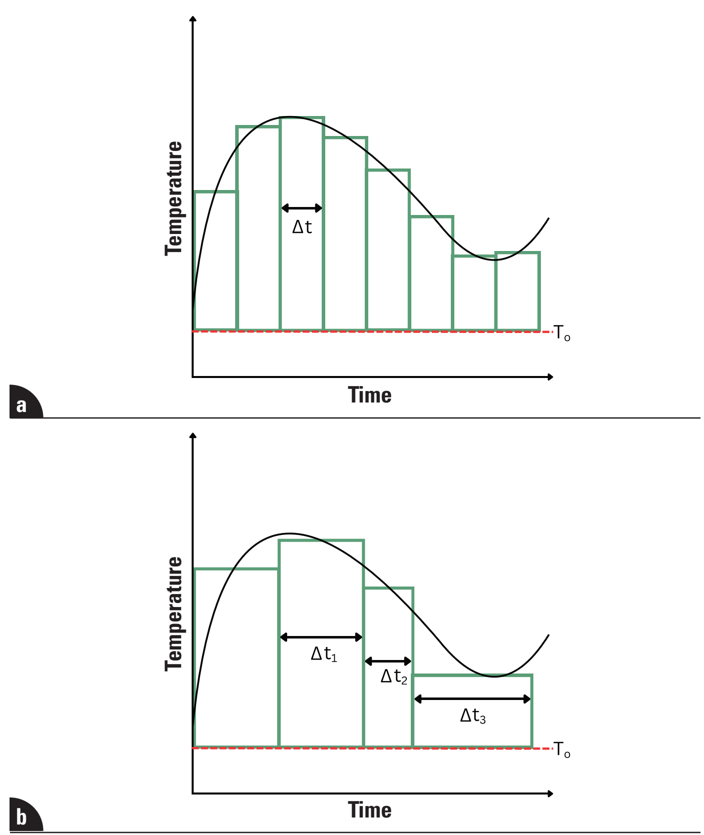
There are two primary methods to calculate the area under the curve: the Nurse-Saul method and the Arrhenius method. This MAP brief focuses on the Nurse-Saul method because it is sufficiently accurate at early ages and is the method specified in the AASHTO T 413 standard. (Note that the Nurse-Saul method should never be used to assess long-term strength because it does not capture long-term hydration effects sufficiently.)

The Nurse-Saul method utilizes the temperature-time factor (TTF) as its maturity index. The TTF is typically expressed in units of degree-hours or degree-days.

The mathematical formulation of the Nurse-Saul maturity function is given by the following:

$$M = \Sigma(T - T_0)\Delta t$$

where M represents the maturity index (TTF), T is the average concrete temperature during a given time interval, T_0 is the datum temperature, and Δt is the duration of the time interval. The summation (Σ) indicates that the maturity index is the cumulative sum of these products over the entire curing period, i.e., the area under the curve. Note that the time intervals do not have to be even (Figure 2), which makes this method extremely robust for instances in which there is a small gap in data collection due to construction challenges.



Armen Armirkhanian, used with permission

Figure 2. Schematic of calculation for maturity (i.e., TTF) or area under the curve, with a consistent and short time interval represented by (a) and a longer, inconsistent time interval represented by (b)

The datum temperature (T_0) is a crucial parameter representing the temperature below which it is assumed that cement hydration and strength gain effectively cease (Carino and Lew 2001). While the traditional value for the datum temperature has been -10°C (14°F), ASTM C1074 suggests that a value of 0°C (32°F) may be more appropriate for many applications and even recommends determining this value experimentally for specific concrete mixtures. The Nurse-Saul method operates under the fundamental assumption that the rate of strength development exhibits a linear relationship with temperature above this datum temperature (Carino and Lew 2001).

Early Opening of Concrete Pavements: A Key Application

The general procedure for using the Nurse-Saul method to determine pavement opening time involves the following steps:

1. **Develop a Maturity-Strength Relationship:** This crucial step involves laboratory testing of the specific concrete mix intended for the pavement. Concrete specimens (typically beams or cylinders, depending on the strength criteria for opening [i.e., flexural or compressive]) are cast with embedded temperature sensors or maturity microprocessors to monitor their temperature history, as shown in Figure 3. These specimens are cured under conditions that aim to simulate the expected field conditions in a broad sense. A common misconception is that the specimens being used to develop the maturity curve must be cured at the same cyclic temperature swings as seen in the pavement. A constant and moderate curing temperature, identical to what many agencies and firms use to cure concrete, is all that is needed.

   At various ages, the strength of the specimens is tested using destructive methods, and simultaneously the temperature history is recorded to calculate the corresponding TTF values using the Nurse-Saul equation with an appropriate datum temperature. The resulting data are used to develop a maturity curve, which plots the measured strength against the logarithm of the TTF, representing the unique strength gain characteristics of the concrete mix.

Armen Armirkhanian, used with permission

Figure 3. Concrete specimens in the process of being cast

2. **Monitor Pavement Temperature in the Field:** During placement of the concrete pavement, temperature sensors are embedded at critical locations within the slab, such as mid-depth, to continuously monitor and record the internal temperature of the concrete over time.
3. **Calculate Maturity of the Pavement:** The temperature data collected from the embedded probes are then used with the Nurse-Saul equation to calculate the TTF value for the pavement at any given time. This calculation can be done manually or, more commonly, using automated maturity meters or software. A number of maturity sensors are available on the market that offer a range of abilities such as real-time monitoring, wireless data transmission, and connectivity to construction management platforms.
4. **Estimate Pavement Strength:** By comparing the calculated TTF value for the pavement to the previously established maturity-strength curve, the current in-place strength of the concrete pavement can be estimated.
5. **Determine Opening Time:** The pavement can be opened to traffic when the estimated strength, derived from the maturity-strength curve, reaches the required opening strength criteria specified for the project. The required opening strength is determined based on factors such as the anticipated traffic loads, pavement design, and foundation support and is often specified by the agency.

Maturity Curve Validation

A common misconception is that the maturity curve for a particular mixture design needs to be constantly checked. For early opening applications, the values obtained from maturity measurements are not used for acceptance, but rather for constructability purposes. For this reason, the following curve validation requirements from AASHTO T 413 are relatively simple:

"A curve validation is required once every 60 calendar days…" A curve validation requires four specimens. Three of the specimens are tested for strength at the target pavement opening value and the fourth specimen is used to monitor the maturity of the mixture.

Failure to match the maturity curve during validation or mixture design changes can also require the development of a new maturity curve under the following circumstances:

- The calculated strength is outside of 10% of the original maturity curve, with certain stipulations:
  - Some agencies allow for the validation value to be higher than 10%, as a higher value means that the current concrete is actually stronger than indicated and thus is more conservative when determining opening times.
  - In no situation can the validation value be less than 10% of the original maturity curve.

- The water-to-cementitious materials (w/cm) ratio during production changes by more than 0.02 compared to the w/cm ratio of the mixture used to develop the original maturity curve.
- There is a change in mixture proportions greater than 5% by weight.
- There is a change in cementitious materials and/or aggregate source(s).

Some researchers and agencies have noted that changes in chemical admixture (i.e., accelerator, retarder) dosages can affect the maturity behavior. On a theoretical basis, the use of chemical admixtures will not affect the determination of the maturity values. Practically, however, there can be some effect when the dosages change significantly from those used to develop the original maturity value. It is best practice to proactively perform a simple validation test when the admixture dosage changes significantly.

Case Studies and Examples of Successful Implementation

Numerous examples and case studies demonstrate the successful implementation of the Nurse-Saul method for determining early pavement opening (Carino and Lew 2001). State departments of transportation (DOTs), such as the Iowa DOT (Ouyang 1996, Iowa DOT n.d.), have been utilizing the maturity method for pavement opening decisions for over two decades, reporting consistent and reproducible results. The Federal Highway Administration (FHWA) Mobile Concrete Technology Center (MCTC) has also performed extensive testing at various locations across the country (FHWA n.d.). These long-standing practices highlight the practical reliability of the maturity method. Specific projects have shown that using the Nurse-Saul method can lead to earlier pavement opening compared to traditional time-based approaches, resulting in reduced construction time and associated costs.

In some instances, maturity curves have been successfully developed in the field using production concrete, with the calibration process streamlined and the curve verified to be representative of the actual materials and curing conditions (FHWA 2019). This is permitted by the AASHTO T 413 standard. The maturity method has also proven valuable in making informed decisions about opening pavements under challenging weather conditions, such as cold weather, where strength gain might be slower than anticipated. Furthermore, maturity data have been used for quality control and acceptance testing on various projects, providing an additional layer of assurance regarding the achieved strength of the concrete (FHWA n.d.).

Challenges and Considerations for Implementing the Nurse-Saul Method

While the Nurse-Saul method offers significant benefits, practitioners should be aware of potential challenges and important considerations for its successful implementation in determining early pavement opening. Establishing the initial maturity curve requires up-front effort and costs associated with laboratory testing. It is crucial to recognize that a unique maturity curve is needed for each specific concrete mix design used on a project, and any changes in materials or proportions will necessitate recalibration. The AASHTO T 413 standard outlines the specific thresholds with respect to changes that necessitate the regeneration of the maturity curve.

Proper installation of temperature sensors in the pavement is also essential for accurate data collection, and managing and interpreting these data requires appropriate tools and trained personnel. A sufficient data collection strategy that is representative of the project is critical, and the AASHTO T 413 specification outlines both the placement of sensors and how many should be used.

Conclusion and Recommendations for Practitioners

The maturity method outlined in AASHTO T 413 offers a practical and relatively simple approach for estimating the early opening strength of concrete pavements by considering the combined effects of time and temperature. Its fundamental principle, reliance on the TTF, and the concept of a datum temperature have been proven with decades of research and real-world studies. While the method has a rich history and numerous successful applications, practitioners must be mindful of its limitations, particularly regarding extreme temperatures and variations in mix design.

For those considering implementing the maturity method for early pavement opening, the following recommendations are crucial:

- **Develop a Thorough Calibration Curve:** Invest the necessary effort to establish an accurate maturity-strength relationship for the specific concrete mix design intended for the project, strictly adhering to the guidelines outlined in AASHTO T 413.
- **Ensure Proper Sensor Installation:** Pay close attention to the correct placement and functionality of temperature sensors within the pavement to obtain reliable temperature history data.

- **Implement Careful Data Monitoring and Analysis:** Utilize appropriate equipment and software for continuous monitoring of temperature data and accurate calculation of the maturity index.
- **Acknowledge and Understand Limitations:** Be aware of the inherent assumptions and limitations of the Nurse-Saul method, especially when dealing with extreme temperature conditions or significant deviations in the concrete mix.
- **Incorporate Validation Procedures:** Implement periodic verification of the maturity curve as outlined in the AASHTO T 413 standard.
- **Provide Adequate Training and Expertise:** Ensure that all personnel involved in the implementation of the maturity method are properly trained and possess a thorough understanding of the underlying principles and procedures.

References

Carino, N. J., and H. S. Lew. 2001. The Maturity Method: From Theory to Application. *Proceedings of the 2001 Structures Congress & Exposition*, May 21–23, Washington, DC.

FHWA. 2019. *Utilizing the Maturity Concept for Determining Early Opening Strength of Concrete Elements*. FHWA-HIF-19-005. Federal Highway Administration, Washington, DC.

FHWA. n.d. MCTC's Experience with using Maturity Concept for Early Opening. Federal Highway Administration. https://www.intrans.iastate.edu/wp-content/uploads/sites/7/2024/07/Maturity-Slides.pdf.

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

Iowa DOT. n.d. Maturity in Iowa: A Construction Perspective. Iowa Department of Transportation. https://www.intrans.iastate.edu/wp-content/uploads/2018/08/Maturity-Merryman.pdf.