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Demoulding vertical elements: Recommendations for apply maturity functions

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HIGHLIGHTS

- A demoulding methodology for SCC vertical elements based on maturity functions is studied.
- Three different experimental methods for determining the resistance are studied.
- Eleven columns at a construction site are tested to validate the methodology.
- Four types of SCC are studied.

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ABSTRACT

Many standards recommend different minimum demoulding times depending on site conditions. Different parameters are taken into account in determining the minimum demoulding time, but the only one that is always taken into account is concrete temperature. Therefore, a methodology for determining the minimum demoulding times for vertical elements of self-compacting concrete (SCC) based on maturity functions is studied.

Maturity functions establish a relationship between maturity and in-situ resistance. While maturity may be measured by measuring the temperature over time, there are different option for determining resistance in-situ, and thus the objective of this work is focused on methods for measuring resistance at early ages.

An experimental study was carried out to establish which method for determining resistance in-situ is best suited to the determination of the resistance-maturation curve. To that end, the suitability and consistency of each method were studied.

In addition, an experimental validation of the methodology was carried out, in which the demoulding methodology was applied to 11 columns tested at a construction site. The validation was carried out with two different types of SCC and different types of formwork.

1. Introduction

Many standards recommend different minimum demoulding times, depending on site conditions. Article 75 of the EHE-08 standard [1] suggests 9–30 h as reference values for demoulding vertical formwork. This value depends on the concrete's temperature during setting. In the 2010 CEB-FIP Model Code [2], Article 11.9 establishes the same demoulding time as EHE-08 [1]. However, both state that the demoulding times can be reduced by accelerated curing methods or when sliding forms are used. Furthermore, BS 8110-2 [3] gives demoulding times that are slightly higher than or equal to the EHE standard, except in the case of low temperatures.

ACI Committee 347 [4] addresses the issue in the same way that EHE-08 [1] does, establishing at least 12 h for the demoulding of vertical elements with normal setting cement, when the concrete is cured at 10 °C. Authors such as Hurd [5] and Gregory [6] make reference to the minimum demoulding time recommended by ACI Committee 347 [4].

Article 6.6 of the "Manuel de Technologie Coffrage" [7] states that the vertical formwork must be maintained until the concrete has gained sufficient hardness to withstand the stresses that occur during demoulding without damage. The formwork can be removed after the concrete has a compressive strength of 2 MPa in cubic specimens of 150 mm, or of 2.5 MPa in cylindrical

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specimens, provided these have been cured under the same conditions as the concrete in the structure.

In “Manual Technology: Formwork”, put out by the CIB, Article 76 [8] states that the time needed to reach the concrete strength required for demoulding depends on the size of concrete piece, compressive strength, the cement type, concrete temperature, and ambient temperature.

In German standard DIN 1045 [9], Article 12.3 states that minimum demoulding times depend on the cement type, and they can vary between 1 and 4 days for columns and walls, provided the concrete temperature is greater than 5 °C.

According to Rudeli et al. [10], currently there is no single accepted method for determining the minimum demoulding time for vertical formworks. In addition, depending on the standard, there are many parameters that are taken into account in determining the minimum demoulding time, but the only parameter that is repeated in all cases is concrete temperature.

Therefore, the aim of this research is to analyse a demoulding methodology based on maturity functions and find the best option for determining when demoulding should occur.

1.1. Demoulding vertical elements

Rudeli et al. [10] and Santilli et al. [11] describe a demoulding methodology that uses the maturity method detailed in ASTM C 1074 [12] to predict demoulding times in vertical concrete elements. ASTM C 1074 [12] establishes a relationship between maturity and in-situ resistance. This standard states that for a given dosage of concrete, the concrete’s resistance–maturity curve is unique and it can therefore be considered to be project data. The method consists of determining maturation graphics in order to estimate the development of compressive resistance and other mechanical properties of concrete under different temperature conditions. The ASTM C 1074 standard recommends calculating the maturity coefficient using Eq. (1).

$$M = \sum_{0}^{t} (T - T_0)\Delta t \quad (1)$$

where:

M is the maturity value at age t (°C.h),
T is the average curing temperature of concrete during interval Δt (°C),
T_0 is the datum temperature (Masana [13] recommended a T_0 of −10 °C),
t is time (h),
Δt is the period of time at temperature T (h).

Maturity methods use the fundamental concept that concrete properties develop with time as the cement hydrates and releases heat. In addition, it is a relatively simple approach for estimating the in-place compressive resistance of concrete, specifically at early ages that are less than 14 days. Once the maturity curve is developed in the laboratory for a specific project, it can be used to estimate the compressive resistance of concrete on-site and in real-time. The maturity method is governed by the fundamental assumption that a given concrete mix design poured during the course of a specific project has the same compressive resistance when it has the same “maturity index”.

Based on the maturity method described in Fig. 1, the demoulding methodology consists of:

1) Setting the demoulding resistance at the construction site.

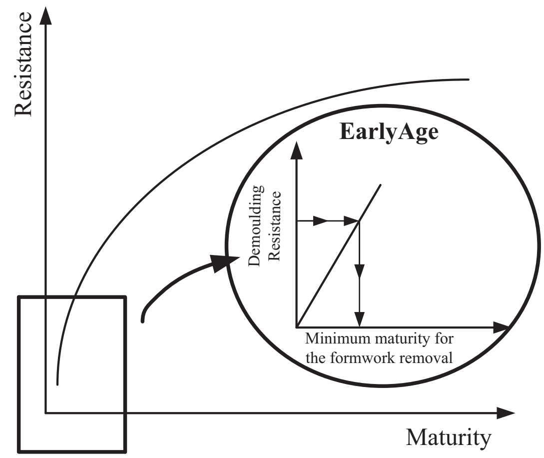

Fig. 1. Resistance-maturity curve.

2) Determining the corresponding minimum maturity value for formwork removal using the resistance–maturity curve, as shown in Fig. 1. The linear behaviour of the resistance–maturity curve is considered at early ages (less than one day).
3) Measuring the maturity of the concrete vertical piece.
4) Once the piece has reached the minimum maturity corresponding to the selected resistance in 1), the formwork can be removed.

Rudeli et al. [10] validated this methodology in the laboratory for two different mixes of vibrated concrete. Despite their validation, the authors stated that it would be of interest to carry out a larger number of experiments in order to validate the methodology with different concrete types.

Furthermore, as part of the research presented here, a survey was conducted with 122 construction managers from different companies in over 20 countries; 75.5% of construction managers stated that the methodology could be used at construction sites. For this reason, this article presents an in-depth study of the resistance–maturity curve methodology when self-compacting concrete (*SCC*) is used for the construction of vertical elements.

2. Parameters considered in the methodology

Another part of the survey asked the construction managers which parameters they believe to be important in determining

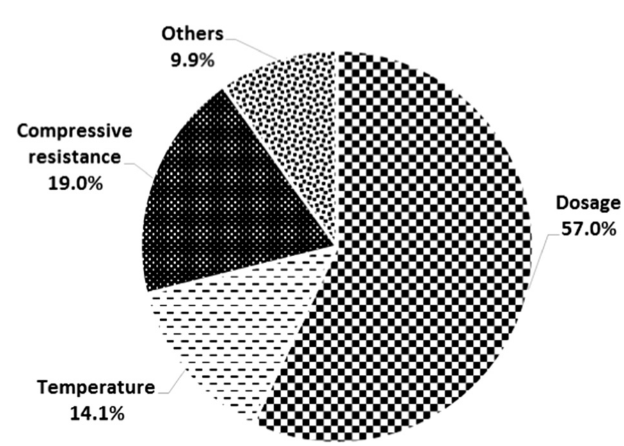

Fig. 2. Parameters that the surveyed construction managers considered in determining minimum demoulding times.