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Numerical modeling of slipforming operations

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Abstract. Slipforming is a construction method in which the forms move continuously during concrete placement. This paper presents a numerical procedure based on the finite element method to simulate the thermal behavior of concrete during slipforming operations. The validity of the model was successfully tested by simulating a very complex but well documented field case of actual slipforming operations performed during the construction of an offshore concrete oil platform structure. The results obtained have been related to the shape of the concrete "hardened front" in the forms, which allows quick evaluation of the operation. The results of the numerical investigation have shown that the shape of the "hardened front" can be affected by the temperature of the fresh concrete and ambient conditions. For a given initial concrete temperature, there are limitations for the ambient temperature that, when exceeded, can create an unfavorable shape of the concrete "hardened front" in the forms. Similarly, for a given ambient temperature, the initial concrete temperature should not be fall below an established limit in order to avoid unfavorable shape of the "hardened front".

Keywords: setting time; concrete; slipforming; mock-up times; hardened front; finite element analysis.

1. Introduction

Slipforming is a placing technique of concrete that is used when cold joints have to be avoided in order to make a perfectly tight concrete structure. This technique is intensively used to build tall concrete structures such as offshore oil platforms, particularly the construction of the Hibernia offshore platform. Hibernia is Canada's first major offshore oil project off the coast of Newfoundland (Woodhead 1993, Elimov 2003). The approach consists of raising the forms by leaning them on special steel rods embedded in the freshly cast concrete wall. The forms are usually 1 to 1.3 m in height and consist of vertical panels, walings, yokes, horizontal cross bars, jacks, jack rods, and a working platform (Fig. 1) (Fossa 2001). The rate of movement depends on the concrete characteristics (Neville 1999). The concrete that is left out should be able to support its own weight, keep its shape, and resist the vertical and lateral loads. Moreover, form movement has to occur before the concrete hardens to prevent the fresh material from adhering to the forms. Therefore, the parameters controlling the hardening rate of concrete are critical in a slipforming operation.

The concrete should be designed according to the required slipforming rate so as to remain in the forms until initial setting has been achieved. Safely controlling concrete setting time is a prerequisite for safely controlling the slipforming operations. Slipforming technique proved to be very useful if implemented with an appropriate planning schedule. A detailed starting plan for filling the forms

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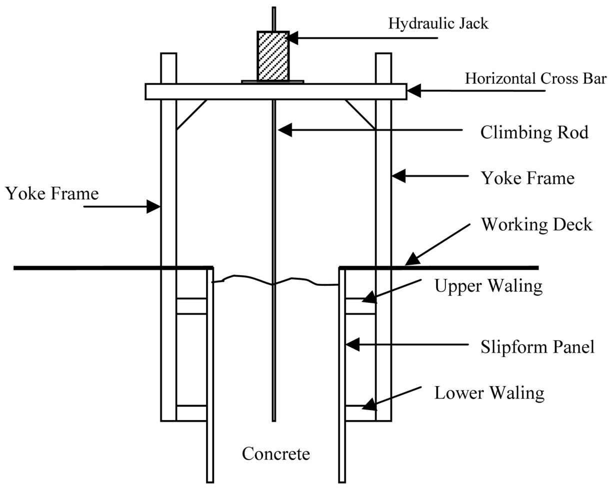

Fig. 1 Schematic representation of a typical slipform system

should be prepared in advance, including a schematic sketch of the slipform showing the thickness of each layer, the rate at which the concrete will be placed during the filling, the setting time for each layer, and the time at which lifting should commence. The beginning of the lifting process should be based on the initial setting of the first layer of the fresh concrete so that the concrete left behind has all the above-mentioned properties but has not yet hardened in order to prevent adherence to the forms.

The early-age behavior of concrete plays an important role in the timing of slipforming and other construction operations. The concrete setting process represents the transition phase between a fluid and a rigid state and is an observable physical consequence of chemical activity in the concrete mixture. This gradual stiffening process is caused by continuous cement hydration. Temperature strongly affects the rate of hydration of cement, with high temperatures hastening the rate of cement hydration and accelerating setting (Mather 1987, Kjellsen and Detwiler 1992).

Before the slipforming technique is used for actual structures, a very costly mock-up operation is usually built on the site in order to define the two parameters key to the success of a slipforming operation: the mix design proportion and the rate of slipforming, according to the setting and hardening characteristics of the concrete to be used. The hardening rate of the freshly placed concrete is usually monitored using the penetration test, which consists in driving in a steel rod into the fresh concrete until it hits concrete that is hard enough. While this technique works quite well and can be used in different ways to control quality, it has some limitations. This is especially true in predicting the slipforming rate when ambient conditions vary or when the dosage of some concrete admixtures-which significantly affects setting and hardening-has to be changed to facilitate concrete placement, particularly in highly congested areas of reinforcement.

The research described herein, which is based on available data from the Hibernia project (Elimov 2003), aims at developing a numerical model for slipforming operations that could be used to predict and adjust the slipforming rate, taking into account various parameters that affect concrete setting and hardening. The development and use of such a model could limit the role of the costly mock-up construction as it could be used as a tool for investigating the most unfavorable situations expected for slipforming operations with different configurations and under different conditions. For example, the temperature of the fresh concrete could be adjusted to take into account the variations of ambient temperature and wind conditions, so that the slipforming rate would not be influenced by such parameters. Moreover, the usefulness of using thermally insulated forms in the winter (to avoid overly delayed setting) and in the summer (to avoid overly accelerated setting) could be established.

2. Significance of the numerical investigation

The purpose of the numerical modeling is not to replace or eliminate field and laboratory trials, but rather to fill the existing gaps in terms of available data and to reduce the costs associated with the mock-up operation. The numerical model can be used in all phases of preparation and execution of the slipforming operation. During the mix-design development phase, for instance, the box test is routinely performed in the laboratory and in the batching plant to obtain the times of initial setting and stiffening of the concrete under different temperatures and with various quantities of retarder in the mixture. The box technique is not a standardized testing method, but it has been used extensively by Norwegian contractors (Elimov 2003). A concrete sample of 30-40 L produced at a predetermined temperature is placed in an insulated box and a thermocouple is installed at the centre of the fresh concrete. The time-temperature history is monitored: an increase in temperature of 2°C within 1 hour corresponds to the initial set of the concrete.

If a reliable analytical model is available, having limited box or mock-up tests for a particular situation in terms of initial concrete temperature, ambient conditions, and mixture properties, numerical simulation could be used to generate information about the state of concrete in various scenarios. This reduces the number of tests and dramatically shortens the time for laboratory and field tests, which allow the concrete materials designer to evaluate the mixture efficiently and accurately. In the preliminary stage of the project, having a proven slipforming model could be a very useful and powerful tool in evaluating whether slipforming is an appropriate concrete placement method for a particular structure. When slipforming is accepted and selected as a construction method, then various expected cases during the operation could be simulated and evaluated. This would provide for minimizing unexpected situations that could cause slipforming problems involving potential major financial losses. This is particularly important for slipforming operations lasting for long periods of time, as in the case of offshore concrete oil platforms.

3. Numerical modeling

In this study, analytical modeling and numerical calculations of thermal behavior of the concrete walls were performed using the CESAR-LCPC finite element code (Humbert 1989, Dubouchet 1992). The temperature distribution in the studied walls was modeled during concrete stiffening using the TEXO module. This module predicts the temperature and degree of hydration fields at early age from the geometry, internal heat sources (dissipation of heat curve due to cement hydration), and surrounding conditions (temperature or heat flux conditions at the element boundary, including installation of insulating tarpaulins or heating resistors). This module makes it also possible to model concreting operations on older concrete.

TEXO is primarily a computation module intended for the simultaneous resolution of the heat equation (Acker 1986, Ulm and Coussy 1995):

$$C\frac{dT}{dt} = -divq + l\frac{d\xi}{dt} \tag{1}$$

with

$$q = -K \cdot gradT$$

and the macroscopic kinetic law of hydration that specifies the evolution of degree of hydration ξ:

$$\frac{d\xi}{dt} = \tilde{A}(\xi)e^{-E_a/RT} \tag{2}$$

In these expressions, C is the volumetric heat capacity; T is the temperature of the concrete; $\boldsymbol{K} = K\boldsymbol{1}$ is the tensor of isotropic conductivity coefficients; $l > 0$ is the supposed constant hydration heat per degree of hydration unit, which is determined in TEXO on the basis of a calorimetric test; E_a/R is the Arrhenius constant; and $\tilde{A}(\xi)$ is the normalized affinity, which depends solely on the degree of hydration ξ and the composition of the concrete used. This function is determined in TEXO based on a calorimetric test.

The entire set of computations relies on the calorimetric test results, which are to be provided as input data. This test consists of recording the time-temperature history of a concrete sample placed in a calorimeter. In the TEXO module, these results serve to sample the function $\tilde{A}(\xi)$ with the following equation:

$$\tilde{A}(\xi) = \frac{1}{T_\infty - T_0}\frac{dT^{ad}(t)}{dt}e^{E_a/RT^{ad}(t)} \tag{3}$$

with respect to the degree of hydration, as determined from:

$$\xi = \frac{T^{ad}(t) - T_0}{T^{ad}_\infty - T_0} \tag{4}$$

with, $T^{ad}(t)$, temperature history, as measured in the adiabatic test, T_0 initial temperature of the sample, and T^{ad}_∞ asymptotic temperature.

Running the TEXO module necessitates initializing the temperature field and specifying adequate boundary conditions. For initial conditions, TEXO accepts initialization of temperature nodal values on the basis of any input values by prescribing the temperature distribution throughout the studied walls at the initial time. The "imposed flow" type of boundary conditions using TEXO are most often associated with a linear exchange condition and allow heat losses through formworks, free surfaces, and the like to be incorporated. This type of condition is of the form:

$$q.n = \lambda(T - T_{imp}) = \lambda(\theta - \theta_{imp}(t)) \tag{5}$$

with λ being the exchange coefficient on the contour; the temperature $\theta_{imp}(t) = T_{imp}(t) - T_0$ is imposed temperature on the contour from the outside; and T_0 is the initial temperature.

4. Numerical simulations

Field data from the Hibernia project have been used for the numerical simulations presented in this paper. Data include the time-temperature history of concrete mixture in a tie wall of the gravity base structure in the Hibernia project. The tie wall had embedded thermocouples located at three different positions within the 950-mm-wide wall. One thermocouple lies at the centre of the wall, while the two others are at 25 mm from both side surfaces of the wall.

The details of the concrete mixture used in the tie wall are presented elsewhere (Elimov 2003). A blended silica-fume cement (8.5% silica fume), a naphthalene-based superplasticizer, a hydrocarboxylic-based retarder, and a fatty acid-based air-entraining agent were used in the concrete mixture. The particle size of the fine aggregate varied from 0 to 5 mm, while the particle size of the coarse aggregate varied from 5 to 14 mm.

In order to simulate the thermal behavior of the walls during the stiffening of the concrete, a numerical study by finite element method was undertaken using the TEXO module of the CESAR-LCPC program. Wall geometry, the surface exposure conditions, and the cement hydration heat dissipation rate were introduced into the model. The studied walls were modeled by introducing boundary elements taking into account the exchange between the concrete mass and the external environment, and the properties of the insulating material. For example, the Styrofoam used as an insulating material is characterized by a thermal resistance for a given thickness. For this case, the exchange coefficient, which represents the thermal transmittance factor, is the inverse of the thermal resistance factor. Since the studied walls have prismatic sections and much greater length than width and thickness, the thermal behavior model was performed in two-dimensional (2-D) plane strain. This considerably reduces the calculation time for the finite element analysis. Fig. 2 represents the slipforming model used in the numerical procedure.

The placement of thin concrete layers during the slipforming operations is represented in the model by three concrete layers. The central layer is the one closely studied; the two other layers simulate the influence to which the targeted layer is exposed during actual operations. The thickness of the first layer is assumed to be 500 mm in order to simulate the temperature influence of the lower layers. The thickness of the second and third layers is 200 mm. The first layer is placed over the previously placed concrete, which has a predetermined temperature. It was determined that this temperature could be considered to be 20°C, but it can be varied if deemed necessary. The concrete below the first layer is considered to be “inactive” in the numerical model. The times for placing of

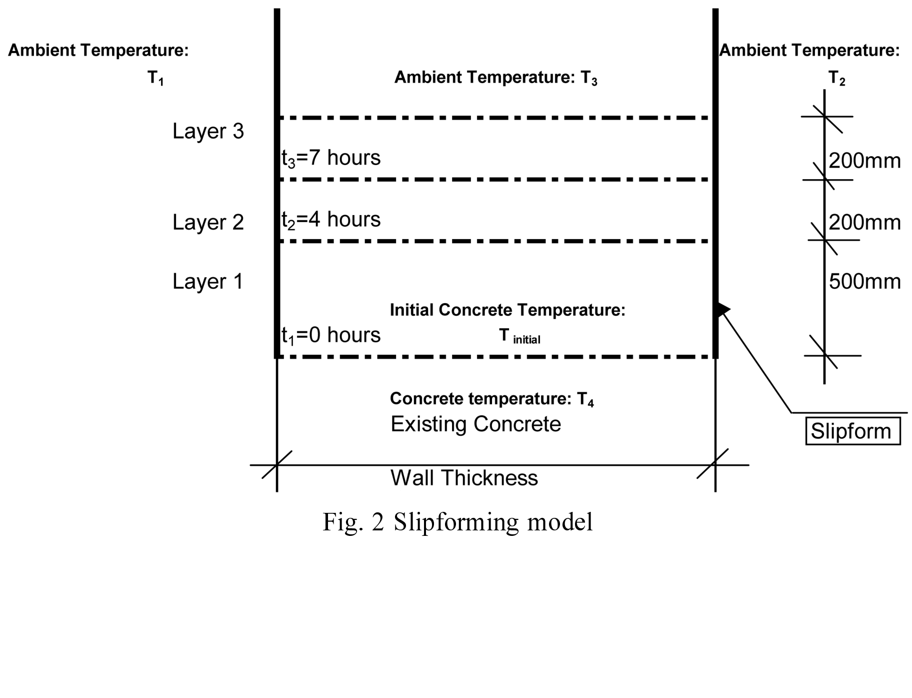

Fig. 2 Slipforming model

the layers are defined as time zero for the first layer, time +4 hours for the second, and time +7 hours for the third layer. These are the values that correspond to actual situations. All other values are variables that are entered as input into the model and constitute the modeling parameters. Form characteristics depend on the material, the presence of insulation, and special treatment of the form such as flowing water for cooling. This parameter is introduced as an exchange coefficient representing the form.

The ambient temperature can be varied separately for each side of the wall and on the top of the form, where the concrete is placed. This allows introduction of different cells in the complex slipforming operations of offshore oil platforms. The initial concrete temperature is the temperature at placement, which is generally the same for all three layers. The semi-adiabatic temperature developments for the mixture used must be introduced as required data to simulate the heat generation resulting from cement hydration. If modifications to the concrete mixture alter retardation time, the change is introduced by modifying the semi-adiabatic time-temperature history for the new concrete mixture.

Concrete placement is simulated by the time delay for placing each layer. The first layer is being placed at time zero. At this time, the hydration process for the first layer starts as defined by the semi-adiabatic curve input. This is the only active layer for the first four hours. The boundary conditions for the layer are defined by exchange coefficients between the layer and the lower concrete, between the layer and the forms for each side of the wall, and with the ambient conditions at the top of the layer. The second concrete layer is placed 4 hours after the first; the heat exchange between the two layers is taken into account in the model. The third layer is placed 7 hours after the first. The influence of the previously placed concrete in terms of heat exchange is also taken into consideration. From this point on, the model works with all three layers altogether.

Some comparisons between numerical and experimental results are presented below. Additional investigations for the finite element model to predict the thermal behavior of young concrete walls are given.

5. Validation of the model

The validity of the model was performed by simulating a complex and well-documented field case of actual slipforming operations during the construction of the Hibernia platform. The field case schematically presented in Fig. 3 is a case in which the studied wall has enclosed cells on both sides with different curing conditions. On one side, cold water was continuously and uniformly poured over the form through perforated hoses. The cell on the other side of the wall was intensively ventilated using large and powerful ventilators. The wall thickness was 950 mm. The slipform panels were composed of 2-mm-thick steel plates. The concrete was placed with an initial temperature of 21°C. In Fig. 3, Sb07 and Sb08 represent the locations of thermocouples at 25 mm from the left and right sides, respectively, of the wall.

For direct comparison, the temperature development curves for the individual measurement locations obtained by the numerical analysis and the field measurements for the field case are shown in Figs. 4 and 5. These figures clearly show that the numerical model reflects well the temperature history of the concrete in the walls. The numerical model reproduced the maximum temperature reached at the instrumented locations with a precision of 1 to 2°C and the time at which the maximum temperature was reached within 2 hours. The model also accurately represents

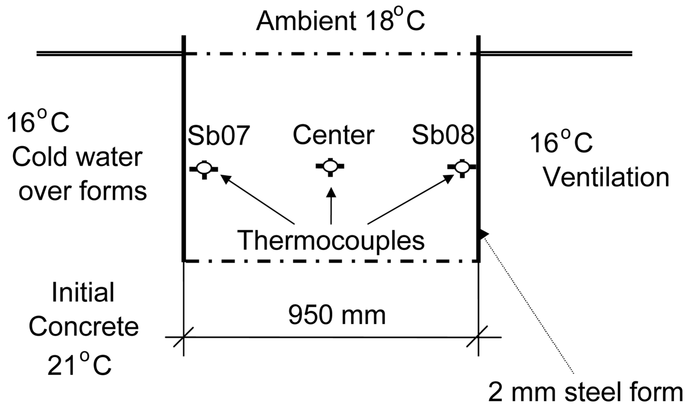

Fig. 3 Field modeling case

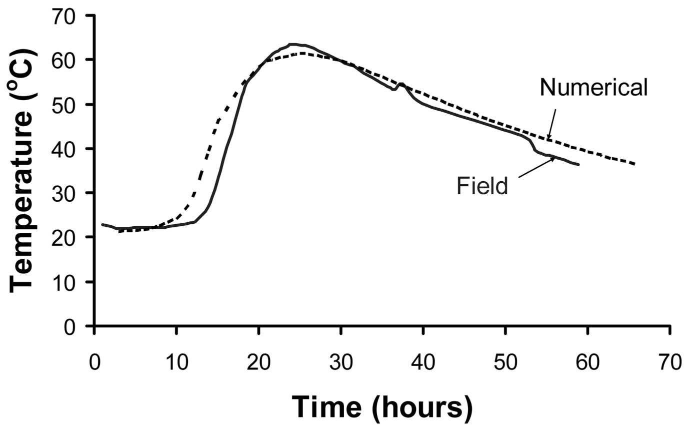

Fig. 4 Numerical and field measured temperature development curves for the wall center

the rise in temperature and the cooling of the concrete over time. On the other hand, the numerically obtained curves do not show as many fluctuations caused by ambient conditions near the concrete surface as the experimental curves. This is due to variations in ambient temperature, variations in intensity of the cold water applied over the surfaces, and ventilation of the cells in the field during actual measurements. The numerical modeling ignored such variations and the external conditions were considered stable.

Based on the results obtained here and elsewhere (Elimov 2003), it can be concluded that the model was capable of simulating the thermal behavior of the concrete in the forms. The results obtained were accurate enough to consider the numerical model a good predictive tool for the purpose of the study. The peak temperatures, the timing of the peaks, and the shape of the temperature development curves obtained by finite element analysis were, in fact, very similar to those obtained from monitoring concrete temperature during construction. The selected field case was complex and represented a challenging and difficult slipforming case. The good agreement between the finite element results and the experimental results indicates that the model can confidently be used for slipforming simulations.

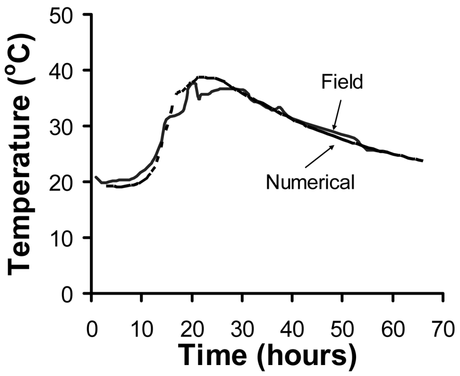

Fig. 5 Numerical and field measured temperature development curves for Sb07 location

6. Comparative studies

Once the model was validated, it was used for a parametric study of critical cases that could be of interest for the slipforming operations. Various ambient conditions, concrete mixture properties, initial concrete temperatures, formwork materials, and form insulations can be simulated to determine the most effective ways to optimize slipforming operations. Based on the results of the numerical investigation, preventive measures can be planned in advance, if necessary. This can yield substantial financial benefits, since the cost of the slipforming operation can be optimized.

6.1. Slipforming cases of interest

During slipforming operations, the concrete "hardened front" should be convex. This means that the concrete at the centre of the wall starts setting before the concrete close to the form surfaces. This shape better withstands the shearing action of the lifting forces created by the friction of the upwardly moving slipforms. The two different limit cases of concrete "hardened front" in the forms are shown in Figs. 6 and 7. Breaking lines in Figs. 6 and 7 represent the lines at which concrete failure may occur.

Figs. 6 and 7 show that the "breaking line" for a concave shape is much shorter than that of a

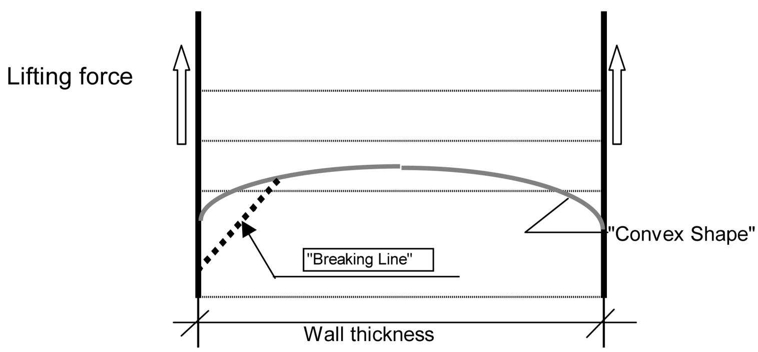

Fig. 6 "Convex shape" of the concrete "hardened front" in the slipforms

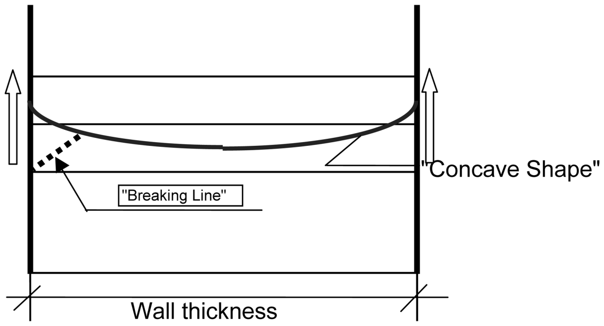

Fig. 7 “Concave shape” of the concrete “hardened front” in the slipforms

convex shape, leading to significantly lower internal forces that resist the influence of the lifting action of the slipforms. The higher values of the resistance forces that develop in the convex shape are desirable, since they prevent surface breaking of the concrete. The concrete separated at the “hardened front” level and moved with the forms can ultimately stick to the forms and create substantial damage.

In this comparative study, the conditions leading to a concave shape of the “hardened front” are investigated. Some practical means to control the concrete “hardened front” shape are also considered. For a given concrete mixture and formwork material, the shape of the “hardened front” depends on the fresh concrete temperature at placement and the ambient temperatures of the wall sides. Two general cases are of interest:

- For a fixed initial concrete temperature, there is a critical ambient temperature above which the shape of the “hardened front” becomes concave. Specifically, the increased ambient temperature can heat up the concrete close to the forms. As the ambient temperature increases further, the concrete close to the form surface will be warmer than the concrete in the middle of the wall, where the ambient temperature has no influence (Lachemi and Aïtcin 1997). The concrete with the higher temperature will start setting first.
- The second general case is when the ambient temperature remains constant. In this case, the initial concrete temperature is the variable. The challenge is to find the initial concrete temperature below which the shape of the “hardened front” becomes concave.

6.2. Approach used to define the “hardened front”

The “hardened front” in the forms is actually created at the time of concrete initial setting. This is the critical time at which the forms must be lifted. Later in operations, the “hardened front” will always hold a convex shape since the concrete at the centre of the wall is warmer than the concrete close to the form surface. This is of no interest since the concrete is exposed below the forms then.

Usually, there is definite relation between the shape of the “hardened front” in the forms and the temperature profile across the wall section. Thus, the shape of the “hardened front” in the form can be investigated by studying the temperature profile across the wall. This can be done by comparing the concrete temperatures at the wall center and close to the wall surfaces, as illustrated in Fig. 8. The concrete temperature profile can have three shapes in the forms at the time of concrete initial set:

1) Convex: The concrete temperature near the form surfaces is lower than at the wall center

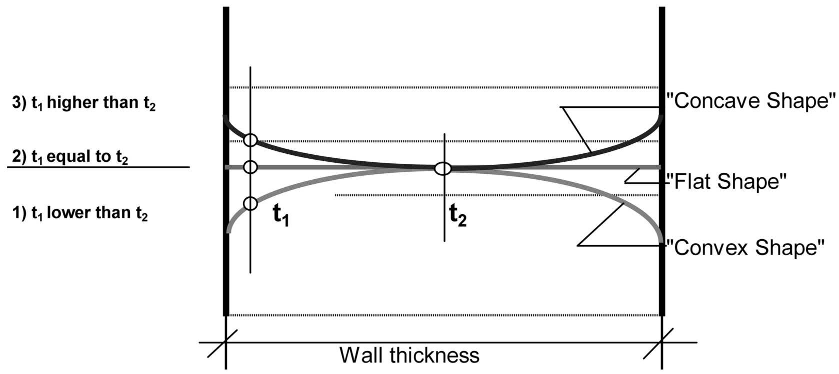

Fig. 8 Possible shapes of temperature profile across the wall at the time of concrete initial set

(t_1<t_2).

2) Flat: The concrete temperature near the form surfaces is about the same as that at the wall center (t_1=t_2).

3) Concave: The concrete temperature near the form surfaces is higher than that at the wall center (t_1> t_2).

The same approach applies to the degree of hydration profile. Temperature monitoring and its relation to the "hardened front" shape is a general method that has been used and proven to be reliable. Nevertheless, the temperature of the concrete in the forms can change as the result of the external temperature, and not just due to the reaction of cement hydration. This means that the temperature does not always give a full picture of the beginning of the initial set of concrete. This is particularly true in the case of the concrete close to the surface, where the external temperature directly affects concrete temperature. An alternative must therefore be found in terms of numerical modeling to represent the true shape of the concrete "hardened front." The degree of hydration profile across the wall is similar to the shape of the concrete "hardened front" as they are directly related at the time of initial set. This qualifies the method based on the degree of hydration profile as suitable for implementation in the numerical modeling. In addition, the external temperature affects concrete temperature but does not affect the degree of hydration during the dormant period, making the degree of hydration method more reliable than the technique based solely on temperature monitoring. In the numerical modeling procedure, the time of initial set corresponds to the moment when the first significant increase in degree of hydration occurs.

6.3. Influence of ambient temperature

With reference to the field case presented in section 5, the concrete initial temperature is assumed to be 16°C. The external ambient temperature is considered to be equal on both sides of the wall and is varied to obtain the three possible shapes of the "hardened front." The results are obtained at mid-height of Layer 2 in the slipforming model (Fig. 2). The degree of hydration profile across the wall as well as the temperature development at the wall centre and close to the form surfaces are reported below.

Figs. 9 and 10 present the results of the numerical simulation when the ambient temperature is 18°C on both sides of the wall. The results correspond to a case where the concrete "hardened

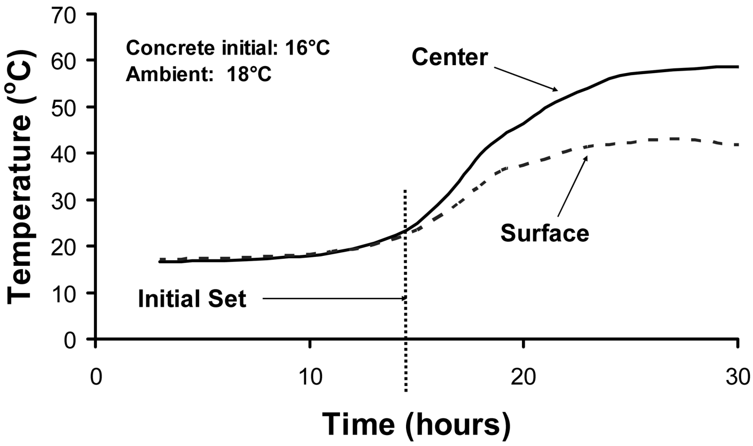

Fig. 9 Temperature development at the wall center and close to the forms (Fresh concrete at 16C and ambient temperature at 18C)

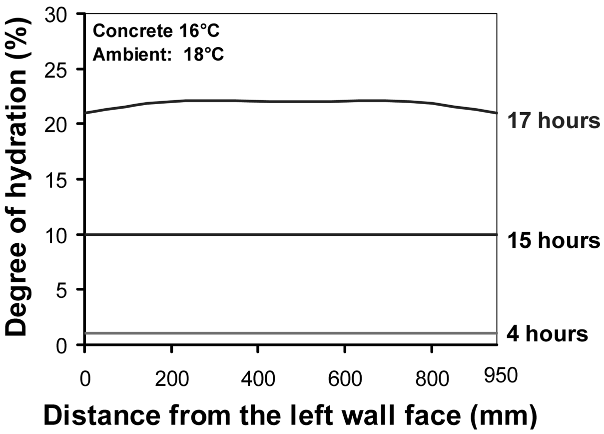

Fig. 10 Degree of hydration profile across the wall (Fresh concrete at 16C and ambient temperature at 18C)

front" has developed a favorable "convex shape." Fig. 9 shows the method of evaluating the results by drawing a line parallel to the vertical axis when initial set occurs. This line intercepts both temperature curves and if the interception with the wall centre temperature curve is above the surface area temperature curve, the setting will start at the wall centre and move towards the wall surfaces. In Fig. 10, the degree of hydration profile across the wall is shown at various times, and particularly at a time close to the initial set. As can be seen in Fig. 10, the degree of hydration profile across the wall and the "hardened front" have a favorable convex shape.

With an initial concrete temperature of 16°C and an external temperature of 22°C on both sides of the wall, the numerical simulation results are somewhat different. Fig. 11 shows that the degree of hydration of the concrete close to the wall surfaces, at the time of initial set, is higher than the degree of hydration at the wall centre. The shape of the "hardened front" has changed compared to the previous case: concave, as confirmed from the degree of hydration profile at a time close to the initial set (see Fig. 11).

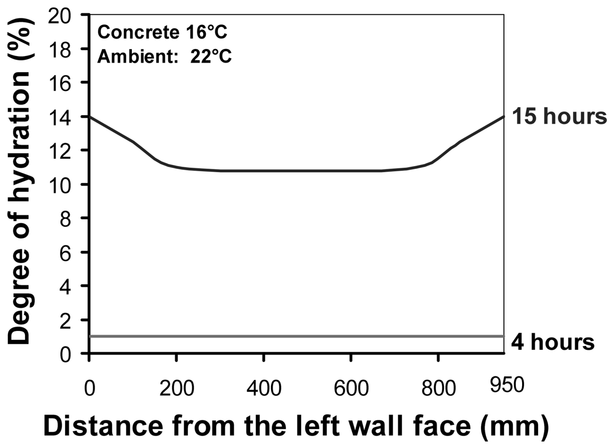

Fig. 11 Degree of hydration profile across the wall (Fresh concrete at 16C and ambient temperature at 22C)

6.4. Influence of fresh concrete temperature

This case deals with a given stable ambient temperature; the challenge is to find the initial concrete temperature below which the "hardened front" will correspond to a concave shape. For the numerical simulation, a case with an ambient temperature of 20°C and initial concrete temperature of 10°C, was selected. The results of the numerical investigation show that these conditions have created a concave shape for the "hardened front" in the wall, as illustrated in both Figs. 12 and 13.

Fig. 12 shows that the temperature close to the surfaces at the time of initial set is higher than that at the wall centre, and that the shape of the concrete "hardened front" is concave, as illustrated in Fig. 13. Further increases in the initial concrete temperature made it possible to establish the initial concrete temperature for which the "concave shape" of the concrete "hardened front" changes to the preferred convex shape. From the results obtained here, it can be concluded that the benefits of

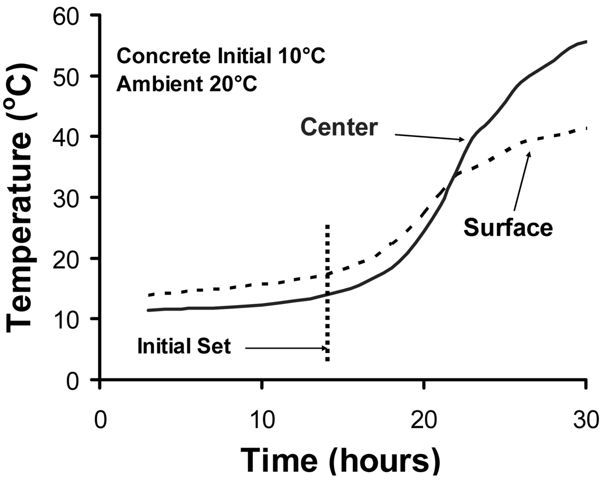

Fig. 12 Temperature development at the wall center and close to the forms (Fresh concrete at 10C and ambient temperature at 20C)

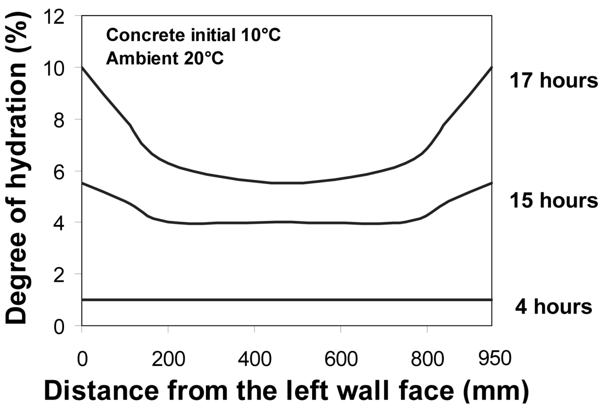

Fig. 13 Degree of hydration profile across the wall (Fresh concrete at 10C and ambient temperature at 20C)

lowering the initial concrete temperature are limited to the value below which the "hardened front" shape becomes concave.

6.5. Measures to correct the concave shape of the "hardened front"

The purpose of this part of the comparative study is to establish the measures that can be taken to prevent the concrete "hardened front" from becoming concave. An extreme case corresponding to an external ambient temperature of 30°C and an initial concrete temperature of 16°C was selected. The results of the temperature development at the wall centre and close to the forms are shown in Fig. 14. These temperature conditions have produced a concave "hardened front" across the wall.

For the same case, insulation with 50-mm-thick Styrofoam was simulated over the slipforming panels (see Figs 15 and 16). Both figures show that very simple insulation of the slipforming panels can prevent the concrete near the form surfaces from being overheated by high external ambient temperatures, thereby preventing formation of a concave concrete hardened front. Normally, the

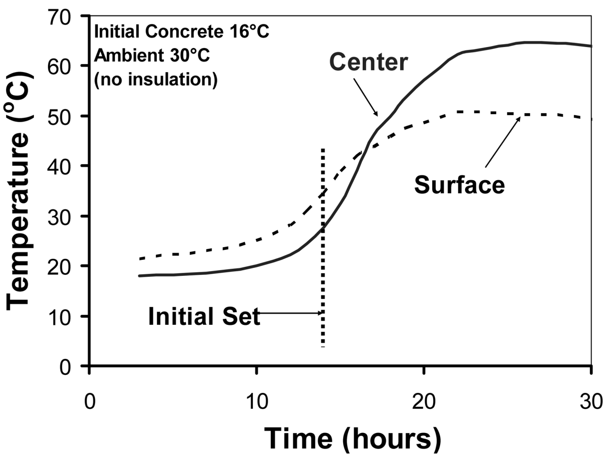

Fig. 14 Temperature development at the wall center and close to the forms (Fresh concrete at 16C and ambient temperature at 30C)

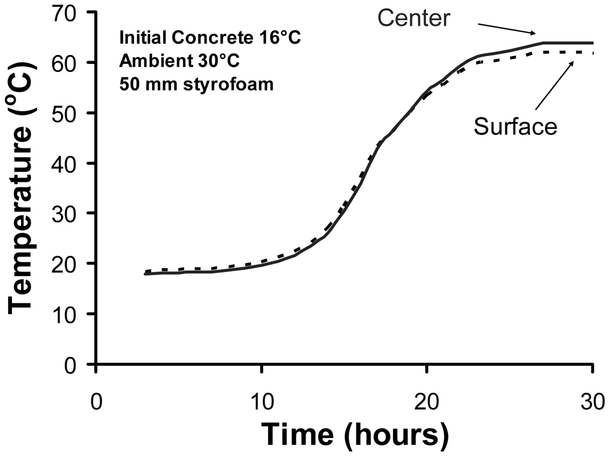

Fig. 15 Temperature development at the wall center and close to the forms for high ambient temperature of 30ºC and 50-mm Styrofoam insulation over the slipforms

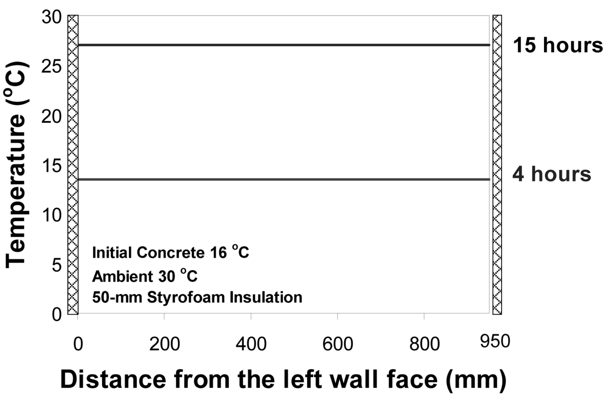

Fig. 16 Temperature profile across the wall for high ambient temperature of 30ºC and 50-mm Styrofoam insulation over the slipforms

wall surfaces are treated with water, which could be a very expensive operation. This study shows that insulating the forms can very effectively prevent surface concrete from overheating during period of high ambient temperatures.

7. Conclusions

This paper discusses the use of a numerical model to simulate the early-age thermal behavior of concrete during slipforming operations. The performance of the model was established by successfully simulating a well-documented field case. Such a numerical model can be used for daily simulations, during slipforming operations, of expected changes in ambient conditions, curing methods, mixture proportions, and form materials and insulation. The principal conclusions of the numerical investigation are:

- The numerical model has been proven to be an effective tool for predicting the thermal behavior of the concrete in slipforms. Comparison between field measurements and numerical results for complex slipforming situations showed that such behavior can be simulated with great confidence.
- The comparative study showed that critical parameters for slipforming operations could be analyzed and accurately predicted.
- There are limitations for the external temperature beyond which, for certain initial concrete temperatures, the shape of the "hardened front" becomes unfavorable. This can lead to significant damage to the concrete surface.
- There are limitations for the initial concrete temperature beyond which, for a constant external temperature, the shape of the "hardened front" in the forms becomes unfavorable. Measures that appear beneficial to the operation, such as excessively lowering the initial concrete temperature during hot weather, can actually produce adverse effects.
- During hot weather, the installation of insulation over the slipform panels could improve the curing conditions of the concrete in the forms and reduce the cost of the slipforming operation.

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