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The effect of formworks on the temperature regime in the mass concrete

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Abstract. This paper presents the results of numerical studies about the temperature regime and thermal stress state of an erected concrete block with various design forms of formwork. The influence of formwork on the formation of the temperature regime is considered taking into account the influence of the main factors: the air temperature, the cement consumption per cubic meter of concrete and its maximum heat dissipation. An assessment of the risk of temperature cracks is given for three formwork cases: metal (steel) and wooden without thermal insulation and with insulation. Based on the results obtained, nomograms are constructed in order to estimate the temperature difference between the center of the concrete mass and its surface, depending on the values of the factors. It is shown that under the considered conditions during construction from the point of view of temperature crack formation, wooden formwork is more preferable than metal (steel). Thus, when concreting in the cold season and using a large amount of cement or large-heat cement then formwork insulation is necessary. In this work, results from the nomograms are obtained may be used as reference material in the design and construction of mass concrete structures such as dams, foundations, bridge supports, etc.

1. Introduction

The heat release due to cement hydration during the construction of massive structures often leads to significant heating of the inner zones of the concrete structure and the development of a large volume change [1–4]. There is a large temperature difference between the outer surface and the inner zone of the concrete mass. When this difference exceeds the allowable value then tensile stresses and cracks were formed in the concrete structure [5–7]. Concrete is a material with a sufficiently low thermal conductivity, so the release of heat to the outside of concrete blocks is quite slow and can last for months or years [8].

For the problem control temperature regime during construction massive concrete is very much interested scientists [9]. The formation temperature during construction mass concrete was affected by a large number of factors: the cement consumption per cubic meter of concrete and its maximum heat release, the intensity of concreting, layer thickness and concrete block sizes, the temperature of the concrete to be laid, etc. [10, 11].

In the construction period, there are many methods are used in order to control the temperature in the mass concrete such as cooling mass - through external watering cold water or using the Internal cooling system by cooling pipe [12]. A large temperature difference can be avoided by thermal insulation on the surface of mass concrete, which prevents the cooling of surfaces in the winter and their heating in the summer. The structural thermal insulation that can be used by formwork is necessary during construction. To enhance its thermal insulation properties, materials with low thermal conductivity can be used [13].

Currently, in the construction of concrete structures, there are several types of formwork made of different materials and are used in many applications. Common types of formwork such as wooden formwork, metal formwork, plastic formwork and, combined formwork, etc. [14].

The traditional and oldest in-use time is the wooden formwork, currently performed using laminated plywood. Wooden formwork is a rather time-consuming type with high costs for its manufacture. In addition, wooden formwork often cannot be reused multiple times. The development of concrete technology has led to the appearance of metal formwork, which is reused many times during construction [15, 16]. Currently, reusable plastic formwork has many applications in the construction industry and is widely used.

The choice of formwork is carried out for each specific case with an assessment of its manufacturability and cost. Formwork is often used not only to obtain the shape of the structure but also to control the temperature regime in the mass concrete structure. It protects the surface of the concrete block from cooling in the winter and heating in the summer. In order to increase the thermal insulation properties of the formwork, various types of thermal insulation materials are used [17].

The issue of using insulated formwork to control the temperature regime and the thermal stress state in the mass concrete structures were considered in many works [18]. However, today a full-fledged analysis of the impact of this technological measure in conjunction with other factors acting on the state of the concrete structure during construction has not been completed. This paper presents some research results on the influence of the formwork type and the main factors acting on the temperature regime in the mass concrete during the construction period. Besides, this study assesses the possibility of the formation of thermal cracks in the mass concrete depending on the combination of factors used in numerical experiments.

2. Materials and Methods

2.1. Mathematical foundations of numerical modeling for solving the temperature problem

Numerical modeling of the temperature non-stationary problem taking into account heat release during cement hydration is based on the solution of the well-known equation of the theory of thermal conductivity [19–21]:

$$k\nabla^2 T + q = \rho c \frac{\partial T}{\partial t} \tag{1}$$

where T is temperature function, °C;

k is the thermal conductivity of the material, m^2/s;

c is the specific heat of the material, kJ/kg.°C;

ρ is the density of the material, kg/m^3;

q is the heat released during the hydration process, kJ/m^3;

t is time, days.

Equation (1) can be written as follows:

$$\frac{k}{c\rho}\nabla^2 T + \frac{q}{c\rho} = \frac{\partial T}{\partial t} \tag{2}$$

The International Conference on Structural Analysis by finite element method in 1985 in Tokyo – Japan, Tanabe was proposed to determine heat source due to cement hydration given by formulas (3) and (4). In 1986 the American Society of Civil Engineers – ASCE was agreed with the formula of Tanabe [22].

$$q = \frac{1}{24}\rho c K e^{\frac{-\alpha t}{24}} \tag{3}$$

$$T(t) = K(1 - e^{-\alpha t}) \tag{4}$$

where CC is the cement consumption per cubic meter of concrete, kg/m^3;

E is the maximum heat release of cement, kJ/kg;

K is the maximum temperature in concrete under adiabatic conditions, $K = CC*E/c*\rho$, °C;

α is the degree of hydration (ranges from 0 to 1).

The degree of hydration (α) depends on many factors such as cement content, the initial temperature of concrete mixture, age of concrete etc. It is defined as the ratio of the heat generated from the beginning of hydration to the time t, and the total heat generated by hydration of cement.

The boundary condition for the case of convective heat transfer on the surface of a concrete block can be written in the form [23]:

$$q = h(T_s - T_a) \tag{5}$$

where q is the heat flux per unit area, W/m^2;

T_s and T_a are the temperatures at the surface of the block and the ambient air, respectively, °C;

h_{eq} is equivalent convection coefficient, W/(m^2.°C) (depends on the type and design of the formwork).

The equivalent convection coefficient, taking into account the type and design of the formwork, was determined by the formula [24]:

$$h_{eq} = \left(\frac{1}{hA} + \sum_{1=1}^{n} \frac{L_i}{k_i A} \right)^{-1} \tag{6}$$

where h is the heat transfer coefficient between the concrete surface and the environment (9.9–17.9 W/(m^2.°C));

A is unit through which heat transfer is occurring, and for the i-th layer;

L_i is the thickness;

k_i is the thermal conductivity coefficient for the i-th layer.

In the study to solve temperature problems taking into account the influence of formwork on the temperature regime in the mass concrete, a numerical method for solving differential equation (1) was used – the finite element method (FEM) [25]. All tasks in this work were solved using the Midas civil 2011 software package [26, 27].

2.2. Relationship of thermal stress and temperature field in concrete mass

According to research [28, 29] indicates that the relationship between thermal stress and temperature in mass concrete is determined by equation (7):

$$\sigma = R \times E(t) \times \alpha \times \Delta T, \tag{7}$$

where σ is thermal-stresses, MPa;

R is restraint (0 < R < 1), the restraint coefficient which is dependent on the size of the concrete mass and the ratio of elastic module of concrete and foundation: $R \in f(V; Ec/Ef)$ and can be calculated using the computer program Midas Civil;

α is coefficient of thermal expansion,1/°C;

$E(t)$ is concrete elasticity modulus, MPa;

ΔT is temperature drop, °C.

Data for example, according to standards ACI 209.2R-08 “Guide for Modeling and Calculating Shrinkage and Creep in Hardened Concrete». A creep coefficient and an unrestrained shrinkage strain at any time depend on [30]: age of concrete when drying starts, usually taken as the age at the end of moist curing, days; age of concrete at loading, days; curing method; ambient relative humidity expressed as a decimal; volume-surface ratio or average thickness, m; concrete slump, m; fine aggregate percentage, %; cement content, kg/m^3; air content of the concrete expressed in percent, %; and cement type.

The compliance function J(t,to) that represents the total stress-dependent strain by unit stress is given by equation (8):

$$J(t, t_o) = \frac{1 + \phi(t, t_o)}{E_{cmto}}, \tag{8}$$

where E_{cmto} is the modulus of elasticity at the time of loading to, MPa;

$\phi(t, t_o)$ is the creep coefficient as the ratio of the creep strain to the elastic strain at the start of loading at the age to.

The secant modulus of elasticity of concrete E_{cmto} at any time to of loading is given by equation (9):

$$E_{cmto} = 0.043\gamma_c^{1.5}\sqrt{f_{cmto}} \quad (9)$$

where γ_c is the unit weight of concrete, kg/m^3;

f_{cmto} is the mean concrete compressive strength at the time of loading, MPa.

The general equation for predicting compressive strength at any time t is given by equation (10):

$$f_{cmto} = \left[\frac{1}{a+bt}\right] f_{cm28} \quad (10)$$

where f_{cm28} is the concrete mean compressive strength at 28 days, MPa; a, b are functions of both the type of cement used and the type of curing employed.

2.3. Evaluation criteria for thermal cracking in mass concrete

Currently, both in Russia and in various countries of the world, there are many standards for controlling the formation of temperature cracks in the mass concrete during construction. Each standard presents different criteria to match the climatic conditions and construction technology in the countries' respective.

Currently, when laying concrete the possible temperature difference ΔT between the surface and the central zone of the structure is limited. The common temperature difference in the type of concrete is usually equal to 20 °C [30].

A number of Russian regulatory documents [31, 32] somewhat share the requirements for temperature differences. So, for example, in accordance with the standard SP 357.1325800.2017 [33] in the contact zone, the ΔT drop should be no more than (16–18) °C when concreting with long blocks and (20–27) °C when using columnar. The contact zone means a zone of construction at the base with a height equal to 0.2 of the largest block size in the plan. In the contact, the zone is not allowed to supercooling concrete below the calculated lowest temperatures. For concrete in the free region, the temperature difference between the core and the surfaces of the mass concrete ΔT is allowed no more than (20–25) °C.

Similar requirements for the temperature regime in the mass concrete during construction are imposed in the international construction practice. So, according to the Vietnamese norms and standard 305.2004 “mass concrete blocks, inspection and production”, two factors are controlled during the construction of massive concrete structures, which influence the appearance of cracks in the mass concrete. The first factor is the temperature difference between the center of the mass concrete and its surface ΔT. In order to avoid cracking, the following condition is necessary ΔT < 20 °C. The second factor is the temperature gradient, the value of which should be M_T ≤ 50 °C/m [34].

In Japan, the assessment of crack formation in the mass concrete is performed using the index of thermal cracking and defined as follows [35, 36]. The cracking tendency is estimated by the value of the thermal crack index based on the criteria values presented in Table 1.

$$I_{cr} = \frac{f_{sp}(t)}{f_t(t)} \quad (11)$$

where: I_{cr} is the index of thermal cracking;

$f_t(t)$ is tensile strength, respectively, the "age" of concrete t;

fsp(t) – maximum temperature stress caused by the process of cement hydration per day t.

Table 1. Criteria for controlling the cracking tendency in the mass concrete.

Controlled Cracking Criteria	Temperature crack index (I_{cr})
To prevent any temperature cracks	I_{cr} ≥ 1.5
Limited cracking possible	1.2 ≤ I_{cr} ≤ 1.5
The possibility of dangerous cracks	0.7 ≤ I_{cr} ≤ 1.2

In accordance with the criterion for evaluation of cracking CIRIA C600 (Great Britain) standard, the maximum temperature difference between the inner zone of the concrete mass and its external surface ΔT_{max} is defined by the formula [37, 38]:

$$\Delta T_{\max} = \frac{3.7\varepsilon}{\alpha} \quad (12)$$

where ε is ultimate tensile strength of early-age concrete;

α is the coefficient of thermal expansion of concrete.

After substituting the known values $\alpha = 13.10^{-6}$ and $\varepsilon = 70.10^{-6}$ into expression (12), we obtain the value of the maximum allowable difference ΔT_{max} = 19.9 °C.

Thus, all the above requirements for the temperature regime in the mass concrete during construction are reduced to one general requirement: the temperature difference between the center and the surface of the concrete mass should not exceed 20 °C. The given requirements for temperature differences are based on the practice during construction and do not always take into account the features of the process. In more detail, the requirements for the temperature regime in the mass concrete during construction are established on the basis of calculations of temperature fields and the thermal stress state of the constructed concrete structures.

3. Results and Discussion

3.1. Object of study

In this paper, we examined the influence of the formwork type on the temperature regime of the concrete block during construction. A concrete block of size 8×6×3 m is placed on the foundation with dimensions 16×12×4 m. The structure of the studied is shown in Fig. 1a. We considered three cases for formwork on the surfaces of a concrete block: wooden, metal (steel) and combined with thermal insulation (polystyrene foam) (Fig. 1b).

In studies, for standard formwork thicknesses were considered: wooden – 2.5 cm, metal (steel) – 2 mm. For the accepted thicknesses, the equivalent convection coefficient calculated by the formula (6) is: h_{eq} = 9.9 W/(m^2.°C) for steel formwork h_{eq} = 2.6 W/(m^2.°C) for wooden formwork [24]. The combined formwork (Fig. 1b) is made of wooden boards 2.5 cm thick and 3 cm thick polystyrene foam. The physical characteristics of the materials used in the calculations are presented in Table 2.

The studies also examined the influence of the main factors in order to determine the temperature regime of a concrete block: air temperature, cement consumption (CC) and its maximum heat dissipation (E). There are different climate factors that must be considered: during construction in North Vietnam in summer (with an average temperature of 26.5 °C); during construction in North Vietnam in winter (an average temperature of 17.0 °C); during construction in mountainous Vietnam (an average temperature of 5 °C).

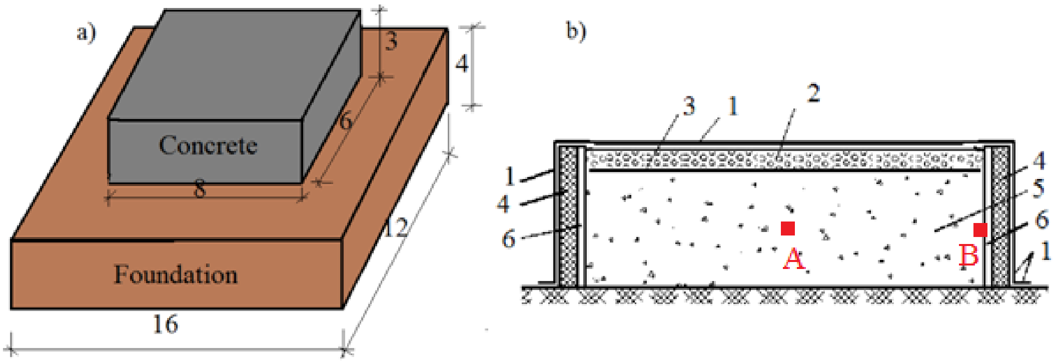

Figure 1. Diagrams for concrete blocks a – Dimensions of the computational domain; b – Formwork installation of formwork combined with thermal insulation; 1, 3 – polyethylene coating; 2 – mineral wool thickness of 10 cm; 4 – 3 cm thick polystyrene; 5 – concrete; 6 – wooden formwork 2.5 cm thick.

Table 2. The estimated physical characteristics of the materials.

Characteristics, units	Values		
	Concrete	Foundation	Polystyrene foam
The coefficient of thermal conductivity (W/(m.°C)	2.60	2.00	0.029
Specific heat (kJ/kg.°C)	0.95	0.84	1.13
Density of the material (kg/m^3)	2400	2650	20
The coefficient of convective heat transfer (W/m^2.°C)	12.0	14.0	0.93
Modulus of elasticity (N/m^2)	2.7×1010	1.8×1010	3.0×109
The coefficient of linear expansion (1/°C)	1×10-6	1×10-5	1×10-5
Poisson's ratio	0.18	0.20	0.20

The initial temperature of the concrete mixture depends on the temperature of the aggregate component. The change in the initial temperature of the concrete mixture by changing the temperature of the aggregate components. In this study, the initial temperature of the concrete mixture is assumed to be constant and equal to 25 °C. Besides that, the cement consumption (CC) was considered in the range of (200–450) kg/m^3, maximum heat emission of cement E_{max} in the range of (120–350) kJ/kg. Using the Midas civil 2011 software package, for all design cases and combinations of the factors considered in order to determine the temperature regimes, maximum temperature and, the temperature difference between the center of the block and its surface during construction.

3.2. Research results

3.2.1. The temperature differential in mass concrete for different types of formwork

The results of numerical experiments under the form of the temperature difference between the center (location A) of the concrete block and its surface (location B) (see Fig. 1) for two formwork cases (wood and metal) under various external temperature influences are presented in Tables 3-5. In these tables, color indicates cases for which the temperature difference exceeds the value of the temperature allows 20^{o}C. From the results obtained, the following features can be noted.

When pouring concrete in the summer (air temperature T_{air} = 26.5 °C), the use of wooden formwork for almost all the considered cases for cement consumption and its maximum heat generation do not exceed the allowable temperature value of 20^{o}C. The only exceptions are the cases with the maximum cement consumption in (400–450) kg/m^3 and the maximum heat release of 350 kJ/kg, the temperature difference is in the range of (20.2–23.7) °C. Metal formwork has a much lower heat-insulating ability compared to wood. It contributes more cooling on the surface of concrete blocks. Therefore, the results lead to an increase the temperature difference between the surface and the center of mass concrete block.

Table 3. The temperature difference in the mass concrete when T_{air} = 26.5 °C.

E_{max} kJ/kg	Wood formwork						Metal formwork					
	CC is the consumption of cement, kg/m^3						*CC* is the consumption of cement, kg/m^3					
	200	250	300	350	400	450	200	250	300	350	400	450
120	3.08	4.01	4.94	5.86	6.79	7.72	5.56	7.22	8.88	10.54	12.19	13.85
180	4.94	6.32	7.72	9.11	10.49	11.89	8.88	11.36	13.85	16.32	18.80	21.29
240	6.79	8.64	10.49	11.35	14.20	16.06	12.2	15.49	18.80	22.11	25.43	28.74
300	8.64	10.96	13.28	15.59	17.91	20.23	15.5	19.63	23.77	27.91	32.05	36.19
350	10.2	12.89	15.59	18.30	21.00	23.70	18.3	23.08	27.91	32.74	37.56	42.43

As can be seen from Table 3, a much larger number of cases has an excess of the permissible temperature difference. When concreting under the air temperature of 17 °C, temperatures across the surface of a concrete block will drop sharply due to the influence of air temperature. Therefore, it increases the temperature difference between the center and the surface of the concrete block. As can be seen from Table 4, wooden formwork creates a safe temperature difference for most cases.

When using metal formwork, the temperature difference is in the permissible range only for cases with low cement content and low heat cement. For cases with cement content in the range of (200–450) kg/m^3 and its maximum heat release from 240 to 350 kJ/kg, the temperature difference between the center of the block and its surface significantly exceeds the permissible value and is in the range of (30.2–48.9) °C.

Table 4. The temperature difference in the mass concrete when T_{air} = 17.0 °C.

E_{max} kJ/kg	Wood formwork						Metal formwork					
	CC – The consumption of cement, kg/m^3						CC – The consumption of cement, kg/m^3					
	200	250	300	350	400	450	200	250	300	350	400	450
120	6.76	7.68	8.61	9.53	10.45	11.38	12.1	13.72	15.37	17.02	18.67	20.32
180	8.61	9.99	11.38	12.77	14.15	15.54	15.4	17.85	20.32	22.77	25.25	27.73
240	10.5	12.30	14.15	16.00	17.86	19.71	18.7	21.95	25.25	28.57	31.88	35.19
300	12.3	14.61	16.93	19.25	21.56	23.88	22.0	26.08	30.22	34.36	38.50	42.64
350	13.8	16.54	19.25	21.95	24.65	27.35	24.7	29.53	34.36	39.19	44.02	48.89

Concreting under conditions of lowest ambient temperatures was considered. So, this worsens the temperature regime in mass concrete and is presented in Table 5. For all cases with metal formwork, the temperature difference in concrete blocks reaches a large value and exceeds the allowed temperature difference. Approximately half of the cases obtained a temperature difference exceeding 30.5^{o}C. Opposite, when using wooden formwork was obtained satisfactory results in all cases. Only for cases with the high cement content and high maximum heat dissipation, the temperature difference was obtained, varying from 21.3 °C to 32.1 °C.

Table 5. The temperature difference in the mass concrete when T_{air} = 5.0 °C

E_{max} kJ/kg	Wood formwork						Metal formwork					
	CC – The consumption of cement, kg/m^3						CC – The consumption of cement, kg/m^3					
	200	250	300	350	400	450	200	250	300	350	400	450
120	11.51	12.43	13.36	14.28	15.21	16.13	20.48	22.10	23.73	25.38	27.03	28.68
180	13.36	14.74	16.13	17.52	18.90	20.29	23.73	26.20	28.68	31.12	33.60	36.07
240	15.21	17.05	18.90	20.75	22.60	24.45	27.01	30.30	33.60	36.89	40.19	43.48
300	17.05	19.36	21.67	23.98	26.30	28.61	30.30	34.42	38.54	42.66	46.78	50.89
350	18.60	21.29	23.98	26.68	29.38	32.08	33.05	37.85	42.66	47.46	52.27	57.14

In order to quickly assess the temperature differences depending on the considered climatic conditions, the type of formwork, and the factors (CC, E), nomograms were constructed to predict (Fig. 2).

The matrix of the relationship between the cement content and maximum heat emission of cement E_{max} combined with the approximate evaluation criteria (temperature difference according to CIRIA C600 of Great Britain standard) can give the following notes:

- The use of nomograms in order to determine the maximum temperature difference between the center and the surface of concrete blocks is made by the vertical lines from the ox (the consumption of cement) and from the horizontal line oy (the maximum heat release) (see Fig. 2).

For example, when T_{air} = 26.5 °C; CC = 375 kg/m^3 and E = 250 kJ/kg:

Use wooden formwork: $\Delta T \approx$ 13.40 °C; use steel formwork: $\Delta T \approx$ 25 °C.

- Preliminary prediction about the risk of forming cracks due to temperature difference in excess of the allowable value (20 °C).
- The use of wooden formwork can help to adequately control temperature difference values in most climatic conditions. The exception is the cases with high cement content and high maximum heat dissipation. For example, when CC = 450 kg/m^3 and E = 350 kJ/kg, the temperature difference is 23.7 °C, 27.4 °C and 32.1 °C at air temperatures of 26.5 °C, 17.0 °C and 5.0 °C, respectively.
- In order to accurately assess the formation of cracks in mass concret, it is necessary to determine the tensile stress at any time t and compare with the permissible tensile stress.

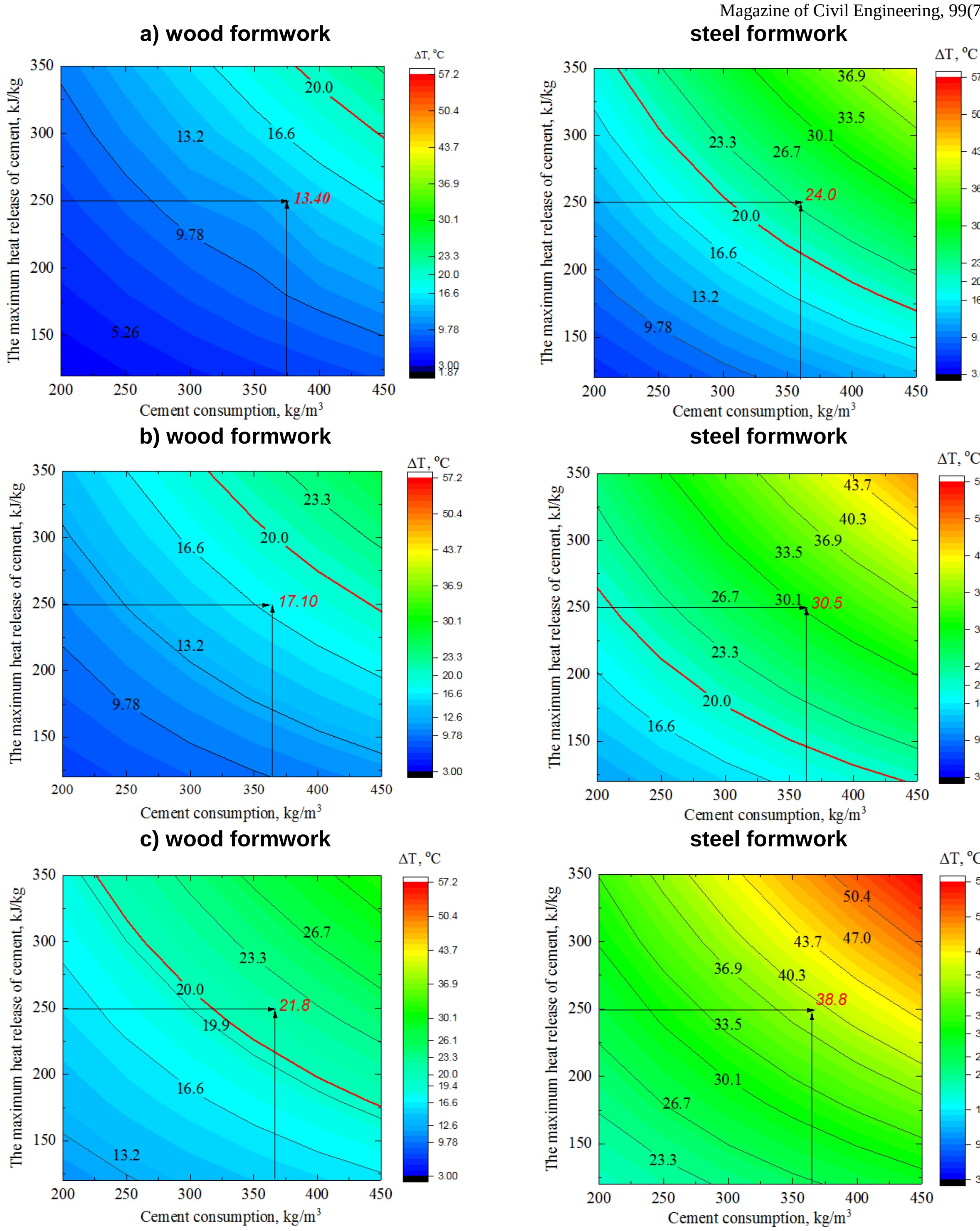

Figure 2. Nomograms in order to determine the temperature difference between the center of the block and its surface, which depending on the consumption of cement and its maximum heat release when: a) T_{air} = 26.5 °C; b) T_{air} = 17.0 °C; c) T_{air} = 5.0 °C.

3.2.2. The use of insulated formwork to reduce the risk of cracking in the mass concrete

Obviously, the measure to reduce the temperature difference in these cases, it is necessary to use a formwork with thermal insulation. That will prevent the heat transfer of concrete to the air environment while increasing the temperature on the surface of the concrete block. Calculations were performed for the case with insulated formwork (Fig. 1b) for the case of the concrete block with the values of the factors CC = 450 kg/m³, E_{max} = 350 kJ/kg. Fig. 3 shows the temperature changes of the center point and surface point of concrete blocks with air temperature conditions of 26.5 °C (Fig. 3a) and 5 °C (Fig. 3b). As is seen in Fig. 3, the change in the temperature difference between the center and the surface of the block is also shown. The values of the maximum temperature T_{max} in the center of the block and the temperature difference ΔT for all the considered formwork cases with values of factors CC = 450 kg/m³, E_{max} = 350 kJ/kg are presented in Table 6.

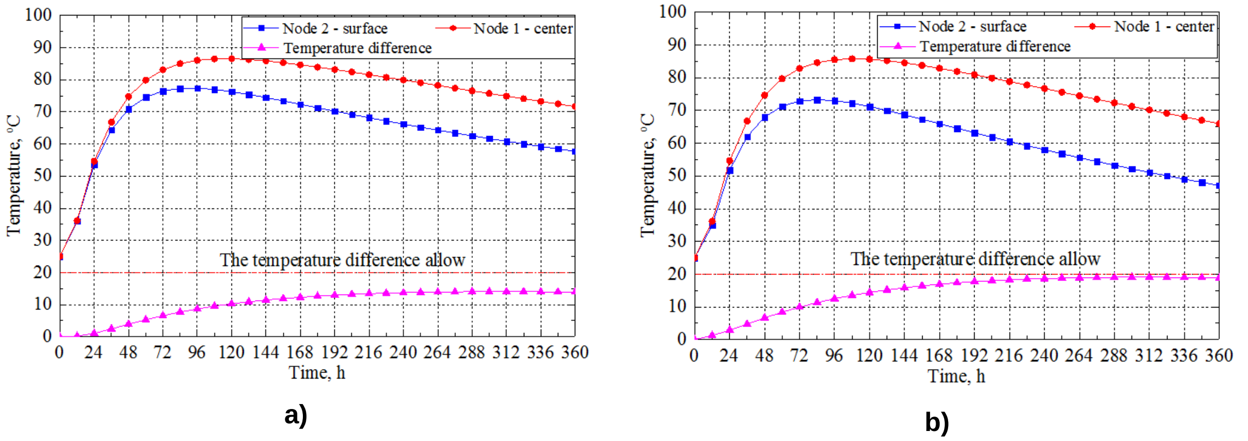

Figure 3. The temperature at the center and the surface of the concrete block and their temperature difference changes over time: a – when the air temperature T_{air} = 26.5 °C, b – when the air temperature T_{air} = 5.0 °C.

Analyzing the results, we can note the following. The temperature in the center of the mass concrete depends little on the ambient temperature. That is explained that mass concrete blocks have a large volume of concrete and low thermal conductivity of concrete mix. The difference between the maximum temperatures in the center of the mass concrete for all air temperature cases and formwork types does not exceed 3.4 °C (~ 4 %). Opposite, the surface temperature of concrete blocks depends largely on air temperature and especially depends on the type of formwork used. This is illustrated by the values of the temperature difference (Table 6). Therefore, from a cracking point of view, concreting in the coldest period is the most dangerous state with the following temperature difference values: for metal formwork – ΔT_{max} = 57.14 °C; for wooden formwork – ΔT_{max} = 32.08 °C; for formwork with thermal insulation – ΔT_{max} = 19.06 °C. Thus, for the case under consideration with high heat release (CC = 450 kg/m³, E_{max} = = 350 kJ/kg), only the use of thermal insulation of the formwork with polystyrene thickness of 3 cm to obtain the temperature difference does not exceed the allowable temperature difference for all air temperatures.

Table 6. Maximum temperature and temperature difference of the concrete block.

Air temperature	Wood formwork		Steel formwork		Thermally insulated formwork	
	T_{max}	ΔT_{max}	T_{max}	ΔT_{max}	T_{max}	ΔT_{max}
T_{air} = 26.5 °C	84.68	23.70	84.76	42.43	86.52	14.04
T_{air} = 17.0 °C	83.97	27.35	84.05	48.89	86.12	16.21
T_{air} = 5.0 °C	83.15	32.08	83.21	57.14	85.76	19.06

In order to assess the formation of cracks, it is necessary to determine the maximum thermal stress appearing at the center and surface of concrete blocks. Calculations of the maximum thermal stress of the concrete block confirm these results (see Fig. 4). Fig. 4 shows the change in maximum thermal stress at the surface and center points of the concrete block for three variants of air temperature. Also shown is a graph of the change in permissible tensile stress, it is possible to assess the possibility of temperature cracks developing in the concrete.

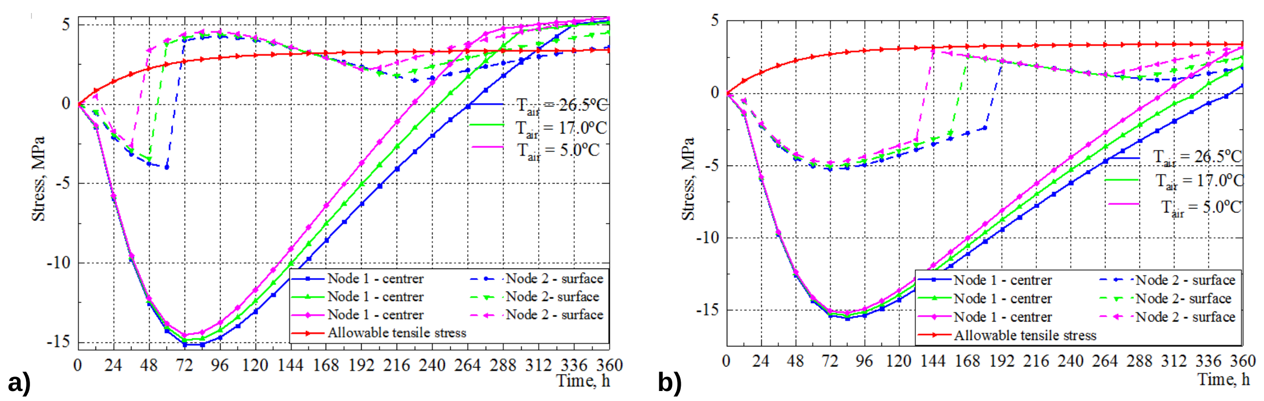

Figure 4. Changes in temperature stresses in the center and surface of the concrete block: a – for wood formwork; b – for insulated formwork.

It can be seen on the chart that: when using wooden formwork (Fig. 4a), the possibility of forming cracks due to stresses on the surface of concrete blocks exceeds the permissible tensile stresses. At the same time, the wooden insulation formwork with polystyrene foam 3 cm thick helps to completely eliminate the appearance of thermal cracks in the mass concrete blocks (Fig. 4b).

It is obvious that after removing the formwork, the surface stress increases (due to the temperature difference between the center and the surface increases) and then decreases over time.

4. Conclusions

Based on the studies and the results obtained, the following conclusions can be drawn:

1. The use of formwork in order to reduce the risk of temperature cracking during the construction of massive concrete structures is an affordable and economical tool. In this sense, metal (steel) formwork is much less effective than wood formwork.

2. The use of insulated formwork is necessary not only for concreting at low temperatures but also to prevent cracking of concrete blocks with the high cement content and high maximum heat dissipation.

3. The research results and the nomograms are obtained may be used as a reference in the design and construction of mass concrete such as dams, foundations, bridge supports, etc.

4. It can further study the effect of the erection of formwork and their materials on the thermal regime in the mass concrete blocks.

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