Modeling the hardening process of monolithic reinforced concrete structures in Elcut Pro software package

S Korobkov$^1$, D Mikhailov$^1$, A Gnyrya$^1$ and M Titov$^{2,*}$

$^1$Tomsk State University of Architecture and building 634003, Siberian Federal District, Tomsk Region, 2, Sq. Solyanaya, Tomsk, Russia

$^2$Novosibirsk State University of Architecture and Civil Engineering (Sibstrin), 113, Leningradskaya str., Novosibirsk, 630008, Russia

E-mail: *m.titov@sibstrin.ru

Abstract. Modeling of heating a monolithic tape grillage using heating insulated wires in the ELCUT Pro 6.3 software and computing complex and the WinConcret add-on are discussed in the article. This type of concrete heating is used at a multi-storey residential complex “Alye Parusa” in Microdistrict “Severn”, a rural settlement of the Tomsk region near the river. The initial parameters were introduced for the object under construction in Elcut Pro software package with the WinConcret add-in. As a result of the calculation, an analysis of the temperature fields in the section of a monolithic tape grillage was carried out, as well as graphs of the temperature dependence on time and graphs of the strength dependence on the heating time. It was found that when concrete was heated with the help of insulated heating wires, the thermal energy was distributed more evenly over the entire cross section of the grillage, which led to an increase in the entire structure strength.

1. Introduction

The only way to carry out concrete work in conditions of minus temperatures and in order to avoid strength characteristics violation of reinforced concrete structures is the use of traditional methods of winter concreting. There are recommendations for choosing a winter concreting method, based on reinforced concrete structures and conditions. All of them are associated with thermal effects on the concrete mix during monolithic housing construction. Heating method is used for monolithic structures of residential and civil buildings, namely heating with wires. The essence of the method consists in laying a heating cable of a certain cross-section and voltage level in a concrete mixture with subsequent connection to a transformer [1]. Wire is heated and heat is transferred to the concrete mixture under the influence of an electric current. The advantage of this method lies in the economic efficiency and independence of the concrete electrically conductive properties. However, the disadvantage of this method is that manual calculations are approximate and do not take into account all factors affecting temperature. In the manufacture of concrete structures, temperature gradients have a significant effect on the hardening mechanisms [2 - 14]. The main factor that has a significant impact must be attributed to the processes of heat and mass transfer [9]. Modeling using modern software systems can solve the problem of accurate calculation, taking into account all factors affecting the temperature. One of such complexes is ELCUT with the WinConcret add-on. The program is capable of compiling graphical changes in temperature and concrete strength over time, both in individual layers of the structure and a whole one [15, 16].
The purpose of this work is to study distribution of temperature fields and gaining strength process of a concrete mixture during winter concreting of a reinforced concrete grillage. The subject of the research is heating of reinforced concrete grillage in winter using insulated heating wires. The object of the research is concreting choice of a monolithic reinforced concrete grillage produced at a minus ambient temperature. The main task of the work is computer modeling of thermodynamic processes in the ELCUT software package during heating of concrete with heating insulated wires.

2. Materials and Methods
We should take a look at the example of a multi-storey residential complex under construction "Alye Parusa" located in Microdistrict "Severny" in the rural settlement of the Tomsk region near the river.

A monolithic strip foundation with a width of 1500 mm and a height of 700 mm is concreted at a minus outside temperature \( t_{\text{out,air}} = -10 \, ^{\circ}\text{C} \) and a wind speed of 5 m/s (Figure 1). Concrete mixture of B25 class with a temperature \( t_{\text{conc.mix.}} = +15 \, ^{\circ}\text{C} \) is placed in a formwork, made of waterproof laminated plywood 18 mm thick. The open surfaces of the grillage are covered with insulation - Styreks foam polystyrene plates to keep heat in concrete.

![Figure 1. Cross-section of a monolithic reinforced concrete grillage.](image)

Heating wires of HWC brand with a core diameter of 1.2 mm were selected as a heat source (Figure 2). AW wire with a core diameter of 2.5 mm was used as cold ends, and SSI-1 wire was used as the main wire. The heating transformer PCTS - 80 with a capacity of 80 kW was chosen as a transformer.

![Figure 2. General view of the monolithic grillage construction: a) winding of heating insulated wires HWC on the reinforcement cage; b) laid concrete in the formwork.](image)
Table 1. Characteristics of the used materials.

| №  | Material name          | Thermal conductivity coefficient, W / (m²/°C) | Specific heat J / (kg °C) | Density kg / m³ |
|----|------------------------|-----------------------------------------------|---------------------------|-----------------|
| 1  | Armature               | 46                                            | 470                       | 7850            |
| 2  | Monolithic grillage concrete | 1.51                                           | 840                       | 2400            |
| 3  | Formwork               | 0.17                                          | 1700                      | 600             |
| 4  | Mineral wool slab      | 0.032                                         | 1340                      | 20              |
| 5  | Gravy concrete         | 0.012                                         | 1000                      | 2200            |

Computational model of finite elements was implemented in the ELCUT-6.3 Pro software package to simulate the thermodynamic processes of concrete hardening. The computational model with the construction of a finite elements mesh is shown in Figure 3.

![Figure 3](image1.png)

**Figure 3.** Calculation model of the grillage with the construction of a finite elements mesh.

The time for heating the concrete mixture was two days. After that, temperature holding was created with cooling of the concrete mixture for twenty-four hours. The solution to the problem was carried out in the ELCUT-6.3 Pro software package, taking into account parameters of the heat capacity and thermal conductivity of the construction materials. On-line graphics show the spread of heat in the concrete structure during hardening, gradients, as well as places with excessive heat loss. Finite element modeling allows you to vary the initial heating parameters in order to achieve optimal characteristics of the temperature distribution in hardening structures of any complexity. From the obtained results of calculating the temperature fields of the concrete mixture, it can be concluded that the structure heating is carried out uniformly. Local areas near the wires warm up faster and slower in places where temperature is lost (see Figure 3, 4).

![Figure 4](image2.png)

**Figure 4.** Temperature field of the structure after solving the problem in ELCUT Pro 6.3.
As an illustration, we used the grillage heating parameters in the construction site. The obtained solutions of the temperature distribution after 48 hours of hardening, shown in the central region (Figure 5c), are close to the optimal values of structure’s heating regimes. However, in the upper part and in the areas adjacent to the side faces, they indicate excessive and insufficient heating areas of the structure, Figure 5c.

**Figure 5.** Temperature fields at different time intervals of electric heating: a) - after 24 hours; b) - after 36 hours; c) - after 48 hours.

I would like to note that the Elcut software package does not take into account such parameters as heat release and concrete resistivity, and there is also no opportunity to view the strength gain graph of the concrete mix over time. The additional add-in WinConcret is used to solve these shortcomings. This add-in breaks the structure into blocks, solving a problem. After that, the problem is solved and each block has its own temperature and strength. Characteristic blocks are selected in the cross-section of the grillage structure to analyze the obtained results (Figure 6).

**Figure 6.** Typical blocks for building dependency graphs.

For the selected blocks, graphs of temperature versus heating time (Figure 7), as well as graphs of strength versus heating time (Figure 8) were built in the WinConcret superstructure.
3. Results

After analyzing the results obtained, the following conclusion can be drawn: thermal energy is distributed more evenly over the entire cross-section of the grillage, when the concrete is heated with the help of insulated heating wires, this leads to an increase in the strength of the entire structure. Comparing the results obtained, it can be concluded that the temperature and strength, obtained directly on the object and in the Elcut software package, have minor discrepancies.
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References
[1] Mokshin D I, Gauss K S, A.V. Rubanov A V, Mokshin R I 2019 Simulation of Curing Processes in Cast-in-place Thin-walled Structure under Different Climatic Conditions, IOP Conf. Series: Materials Science and Engineering 597 012035 doi:10.1088/1757-899X/597/1/012035
[2] Gnyrya A I, Abzaev Yu A, Korobkov S V 2018, Mechanical properties of cement paste curing at different isothermal conditions [Tekcr], IOP Conf. Series: Earth and Environmental Science 193 (012010. doi:10. 1088/1755-1315/193/1/012010. 2018)
[3] Zhu Yu, Yang Y-Z, Xiaojian Gao, H.-W. Deng, Effect of curing temperature on the mechanical properties of engineered cementitious composites. Journal of Shenzhen University Science and Engineering 28(1):72-77 ·
[4] Dhananjay M 2014 Global Journal of Researches in Engineering: E Civil And Structural Engineering, Vol. 14, Issue 5
[5] Prasanna W G J 2010 Cracking due to Temperature Gradient in Concrete [Tekcr], International Conference on Sustainable Built Environment (ICSBE-2010) Kandy, 13-14 December pp 496–504
[6] Le, Quang X 2018 Effects of temperature and temperature gradient on concrete performance at elevated temperatures, Advances in Structural Engineering. Vol 21(8) pp 1223–1233
[7] Hamid H. Hussein 2013 International Journal of Engineering and Innovative Technology (IJIEIT), Vol. 3, Issue 5, pp 86–93
[8] Jian.Gong, International Journal of High-Rise Buildings, Vol 4, 4. pp 283–290
[9] Kumar C S 2017 Vijaya, International Journal of Scientific Research in Science and Technology (IJSRST), Vol 3, Issue 7. pp 766–772
[10] Le Q X, Dao V T N, Maluk C 2017 Mechanics of Structures and Materials: Advancements and Challenges – Hao & Zhang (Eds). PP.951-956.
[11] Le Q X 2016 A study of temperature gradient effects on mechanical properties of concrete at elevated temperatures 130 p. DOI: 10.14264/uql.2016.566.
[12] Vineethraj B. Math, Akshatha Sherregar, G. Kavitha. European Journal of Applied Engineering and Scientific Research, 2015, 4 (2). Pp. 35-43.
[13] José Tadeu Balbo, Andrãa Arantes Severi. Thermal Gradients in Concrete Pavements in Tropical (Hot- wet) Environment: An experimental Appraisal Transportation Research Record: Journal of the Transportation Research Board (TRB) DOI: 10.3141/1809-02.
[14] Abhijeet S, Gandage V, Vinayaka R 2018 Thermal Gradient in Self Compacting Concrete—An Experimental Investigation Proceedings of the 5th GeoChina International Conference 2018 – Civil Infrastructures Confronting Severe Weathers and Climate Changes: From Failure to Sustainability, China- Pp. 25-44.
[15] Komarinsky M V 2017 Simulation modeling of winter concreting of wall structures 7. pp 18–31
[16] Elcut Pro 6.3. User's manual. - LLC “Tor”: St. Petersburg, p 291 (2018)
[17] Titov M M Using the software of the android operating system to calculate the cold weather concreting technology Research conference on «Geotechnical issues on buildings and structures» and Mongolian-japan 2nd joint seminar on «Earthquake engineering»P, 149-155.
[18] Titov M M and Baiburin A Kh 2018 Pre-calculation and design of equipment for electric heating of concrete mix, IOP Conf. Series: Materials Science and Engineering 451 012070
[19] Titov M M 2018 Dugersuren Enkhbaatar Improving The Technology of Designing Winter Concrete in Modern Construction/ Herald TGASU No.3-2018.S. - 159-168