Temperature-time monitoring of concrete hardening of a wind farm foundation

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Abstract The foundations of wind farms are massive structures that require temperature control of concrete hardening during their construction. This is due to the need to ensure crack resistance and specific operating conditions of engineering networks located in the body of the structure. The work describes a comprehensive study of the foundations construction on the Zaporizhzhya wind farm. The study included calorimetric analysis using adiabatic calorimetry and on-site temperature monitoring of the object using a continuous temperature measurement system. Laboratory studies allowed verify the composition of concrete proposed by the concrete manufacturer and develop recommendations for concreting. The data obtained showed that the hardening conditions approach adiabatic ones with a foundation slab thickness of more than 2.5 m. This leads to a temperature gradient of more than 25 °C between the internal and external parts of the structure. The adopted recipe and technological solutions have ensured the achievement of acceptable conditions for the foundation slab construction in the winter.

1. Introduction

Wind power as an alternative renewable source of electricity in Ukraine is going through a period of active development. Structurally, a wind power station (wind farm) is a group of wind generators, which consist of an electric generator driven by wind energy, a mast and a foundation. The architectural expressiveness of the landscape with the working wind farms is characteristic.

Despite the apparent structural simplicity, the concrete foundation of the wind generator is a complex structure of massive reinforced concrete, which is designed to guarantee the long-term stability of the wind farm under the influence of the environment, including wind loads, climatic and corrosive effects. The massive foundation in this context requires special measures in its manufacture [1].

The concept of massive concrete is clearly defined by the normative document of the American Institute of Concrete ACI 207.1R-05 [2] as “any volume of concrete with dimensions large enough to make decisions to minimize cracking due to heat generation during cement hydration and changes in
concrete volume”. The heat-stressed state of the hardening mass is the object of comprehensive research and a number of regulatory documents aimed at obtaining defect-free durable concrete [3-7].

2. Purpose of the study
Verification of recipe and technological solutions for the reinforced concrete foundations construction of the first stage of the construction of a 500 MW wind farm in Priazovsky and Melitopol districts of Zaporizhzhya region. Construction is developed by the company EuroCape Ukraine I. The number of foundations is 27. It is planned to install up to 167 wind generators.

3. Research methodology
The study was performed by two methods:
- calorimetric analysis of the additives effect on the hardening of cement and concrete by determining the heat release parameters accompanying the hydration of cement and exothermy of concrete [8];
- continuous temperature-time monitoring of concrete hardening at the facility to obtain temperature values at different points and sections of the foundation.

4. The study performance
4.1. General technological information
The reinforced concrete construction of the foundation slab has a rounded shape. The lower part of the base is in the form of a cylinder with a diameter of 19 m and a height of 1.1 m. The middle part is a truncated cone with a height of 1.4 m, which goes into a cylindrical sole with a diameter of 6.2 m and a height of 0.7 m for fastening the mast of the wind generator. In the center of a heavily reinforced foundation, a system of plastic cable channels is installed on the frame (Fig. 1, a). The temperature of their operation should not exceed 70 °C.

Figure 1. The foundation plate of the wind farm
a) the cable channels location; b) foundation concreting in progress.

Concrete volume – 585 m³. Concrete class C35 / 45.
Concreting conditions are winter, at a temperature of -5 °C ... + 5 °C.
The initial temperature of the concrete mixture is 15 °C.
Slump class – S4 (16-20 cm).
Concrete mixture supply – concrete pump (Fig. 1, b).
Concreting time – 24 hours.
Materials and compositions provided by the concrete manufacturer (table 1).
Characteristics of materials:
- cement – Portland cement CEM II/A-S 32.5-LH;
- crushed stone – granite, fractions 5-10 and 10-20;
- sand – quartz, particle size modulus – 1.5;
- additives: polycarboxylate type superplasticizer with an admixture of lignosulfonates, an antifrosty accelerating additive and a hardening retardant.

| Table 1. The compositions of concrete |
|--------------------------------------|
| Components                           | #1   | #2   |
| Cement, kg                           | 560  | 560  |
| Coarse aggregate 5-10, kg            | 325  | 325  |
| Coarse aggregate 10-20, kg           | 835  | 835  |
| Sand, kg                             | 550  | 550  |
| Water, kg                            | 190  | 185  |
| Superplasticizer,%                   | 0.8  | 0.8  |
| Antifrosty additive,%                | 0.5  | -    |
| Hardening retarder,%                 | -    | 0.3  |

4.2. Calorimetric analysis

The study was performed at the KNUCEA calorimetric center. To assess the maximum temperature of concrete heating, the ability to control the intensity and completeness of cement hydration with the addition of chemical additives, the adiabatic calorimetry method was used [9-10]. Figure 2 shows the temperature dependences of the hardening of concrete samples for 72 hours.

![Figure 2. Temperature of concrete samples in an adiabatic calorimeter](image)

The results of measurements of the concrete hardening temperature indicate an initial delay in hydration for 9 hours for composition 1 and 24 hours for composition 2. After that, in both cases there is an intensive temperature increase for 24 hours. A significant difference in the indicators of the initial temperature of both compounds is leveled by 72 hours. The absolute value of the temperature during this period was 70.5 °C, and its excess relative to the initial value was 55.5 °C. This indicates the possibility of a significant increase in the temperature of concrete and the achievement of a
critically acceptable value of 70 °C during hardening of concrete in the body. The adding of the hardening retarder to reduce the heating temperature is inefficient and can lead to a prolonged initial deceleration at low temperatures with freezing of the liquid phase [11]. It is concluded that it is necessary to change the initial temperature of the concrete mixture from 15 °C to 6-8 °C. For work in the summer period, this composition cannot be used or it is required to organize layer-by-layer concreting [1].

4.3. Temperature-time monitoring of concrete hardening in the foundation structure
A measurement system with a special monitoring features was developed. There are eight temperature sensors (Pt100 resistance temperature transducer) connected to a multi-channel temperature meter (Fig. 3). The measured data is automatically transferred to a computer.

![Figure 3. Measurement system structure](image_url)

Temperature sensors were installed at the characteristic points of the foundation plate (Fig. 4). Sensors 1-3 were located in the center of the structure with a maximum height of 3.2 m (section I-I), sensors 4 and 5 – at the point of transition from the basement pedestal to the base with a section height of 2.5 m (section II-II). Sensors 6-7 – were located at a distance of 60 cm from the edge of the plate with a section height of 1.2 m (section III-III). Sensor 8 was used to measure the ambient temperature under the tent, which was installed above the slab after concreting. The results of monitoring the hardening temperature of the foundation slab after concreting are presented in Fig. 5.

![Figure 4. Sensor layout](image_url)
Figure 5. The hardening temperature of the foundation plate
The maximum temperature of 62.5 °C is observed at point 2 of section I-I, where the hardening conditions approach adiabatic ones. The initial temperature was 7.5 °C, and the temperature increase was 55 °C. Due to the significant time interval of concreting of the lower and upper parts of the foundation, there is a significant lag in the rate of temperature rise over 60 hours, after which the temperature values are equalized. The temperature gradient between the inner (2) and outer (3) parts of the foundation is significant. Its maximum value of 27 °C was observed after 38 hours of hardening. Then this value decreased to 20-25 °C.

In section II-II, the maximum temperature was 58 °C, and the temperature gradient was 16-18 °C. The minimum rate of temperature rise was recorded in section III-III, where the maximum was 38 °C, and the gradient was from 15 to 8-10 °C. The installation of the tent over the foundation creates favorable conditions for hardening to reduce temperature gradients. At the same time, the temperature of concrete rises by 15-20 °C compared with the temperature of the outside air.

Due to significant temperature gradients, for further equable cooling condition of the foundation structure, sheltering of the foundation surface was organized with a 10 cm thick insulator. The cooling rate did not exceed 1-2 °C per day until the temperature in the center of the foundation dropped to 30 °C. The data obtained made it possible to establish the nature of the development of temperature hardening conditions in different sections and to develop organizational and technological solutions for concreting subsequent foundations.

5. Conclusion

The temperature regime of concrete hardening is one of the key factors in the construction of wind farm foundations. The adopted recipe and technological solutions ensure the achievement of acceptable conditions for the construction of the foundation slab in the winter. However, it is advisable to continue research on improving the concrete recipe to reduce temperature gradients in the central part of the foundation of the wind farm.

References

[1] Yuwen J. Honggang L. Actual temperature evolution of thick raft concrete foundations and cracking risk analysis. Advances in Materials Science and Engineering. V.2019, 2019. 7029671.
[2] ACI 207.1R-05:2012. Guide to Mass Concrete. Reported by ACI Committee 207. 2005. 30 p.
[3] Kiernozycki W. Betonowe konstrykcjt masywne. PC, Krakow. 2013. 320 s.
[4] Han S. Assessment of curing schemes for effectively controlling thermal behavior of mass concrete foundation at early ages. Construction and Building Materials. 2020. 230. 117004.
[5] Troyan V.V. Technological bases of increase and forecasting of durability of concretes of massive constructions. K.: «Interservice». 2017. 238 p.
[6] Trapeznikov, L.P. Temperature crack resistance in massive concrete. M.: Energoatomizdat. 1986. 272 p.
[7] Semenov K.V., Barabanschikov Y.G. Crack resistance of massive concrete foundation slabs and its provision during the construction period in winter. Construction of Unique Buildings and Structures, 2014. №2 (17). p. 125-135.
[8] Usherov-Marshak A.V., Kabus A.V. Functional kinetic analysis of the effect of admixtures on cement hardening. Inorganic Materials. 2016. V.52 (4). pp. 435-439.
[9] RILEM TC 119-TCE. Avoidance of thermal cracking in concrete at early ages. Materials and Structures. 1997. V.30. pp. 451-464.
[10] EN 12390-15:2019 Testing hardened concrete. Adiabatic method for the determination of heat released by concrete during its hardening process.
[11] Usherov-Marshak A., Zlatkovski O., Sopov V. Calorimetric study of frost attack during cement hardening. Journal of Thermal Analysis and Calorimetry. V.68 (1). 2002. p. 223-230.