OPEN ACCESS

ISAR Journal of Multidisciplinary Research and Studies

Volume 3, Issue 10, 2025 | pp: 1-5

Abbriviate Title- ISAR J Mul Res Stud

ISSN *(Online)*- 2583-9705

https://isarpublisher.com/journal/isarjmrs

UDC 624.012.4

ENSURING TEMPERATURE AND HUMIDITY CONDITIONS FOR CONCRETE CURING DURING CONSTRUCTION OF MASSIVE REINFORCED CONCRETE STRUCTURES

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Article History
Received: 20.07.2025
Accepted: 08.09.2025
Published: 03.10.2025

Abstract: *This article presents a systematization of methods for regulating concrete curing temperatures, with regard to the operational parameters of string-rail transport (SRT) supports. An analysis of existing technologies conducted, and recommendations developed for optimizing concrete composition and curing conditions to increase strength and durability thereof under dynamic loads and significant temperature gradients. Particular attention is drawn to the performance characteristics of concrete in massive string-rail transport supports, including the influence of climatic conditions and mechanical stress. The article examines the specifics of ensuring temperature and humidity conditions of concrete curing during the strength gain period, suitable for the construction of structures for the uST string-rail transport-infrastructure complexes.*

Keywords: *massive reinforced concrete structure, thermal crack resistance, concrete curing, heat release, temperature and humidity conditions.*

Cite this article:

UNITSKY, A.E., PODVORNY, V.O., (2025). ENSURING TEMPERATURE AND HUMIDITY CONDITIONS FOR CONCRETE CURING DURING CONSTRUCTION OF MASSIVE REINFORCED CONCRETE STRUCTURES. *ISAR Journal of Multidisciplinary Research and Studies*, *3*(10), 1-5.

Introduction

When building massive monolithic reinforced concrete structures, especially those subject to significant loads (for example, when constructing supports for string-rail transport (SRT), which has high potential for use in India [1]), it is possible for a stress field to develop that exceeds the concrete's strength properties during the structure formation stage. This can result in early crack formation and subsequent crack development, which not only negatively impacts the operational properties of the structure but may even render it unusable. SRT supports are characterized by specific operating conditions and load types, which requires a special approach to their design and construction (Figure 1).

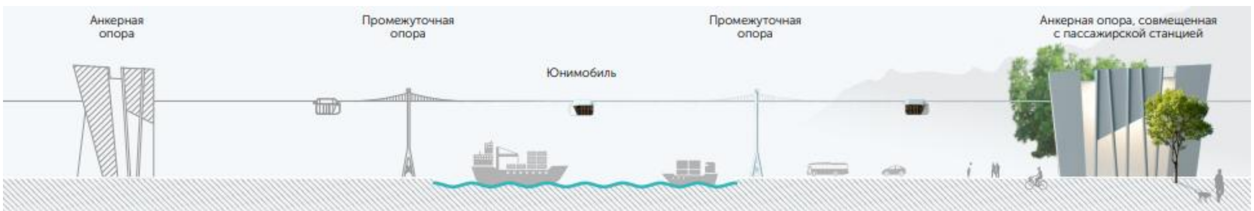

Figure 1 – Schematic representation of the composition of the uST transport and infrastructure complex

Анкерная опора – Anchor support; Промежуточная опора – Intermediate support; Юнимобиль- Unimobile; Анкерная опора, совмещённая с пассажирской станцией – Anchor support combined with a passenger station

Based on Figure 1, the following key load parameters in string-rail transport infrastructure complexes [2] should be highlighted, including:

1. Dynamic loads from a moving vehicle

- High travel speeds (up to 500 km/h and above) create significant inertial and vibration loads on supports.

- The impact of acceleration and braking, as well as vibrations caused by track irregularities and external influences.

2. Tensile and compressive loads

- The primary load is the tension of the strings, transmitted to the supports through the fastening elements.

- The impact of wind loads and vibrations, causing additional tensile stresses.

3. Wind and atmospheric loads

- Wind pressures and stresses caused by changing atmospheric conditions, especially relevant in open and high areas.

- Humidity and temperature fluctuations, causing expansion and contraction of structural elements.

4. Thermal loads

- Significant temperature gradients causing expansion and contraction of support elements and strings, affecting their geometric stability.

- Uneven heating and cooling, especially under extreme climatic conditions.

5. Mechanical impacts from operation

- Vibrations and impacts associated with the passage of vehicles, as well as possible mechanical damage during operation or maintenance.

6. Additional loads

- In case of emergency situations or extreme conditions – earthquakes, snow and ice loads, as well as the effects of corrosion and wind loads.

As practice shows, the risk of early cracking is due to temperature and shrinkage deformations, especially for high-grade concrete [3]. Therefore, the task arises of defining a set of methods for regulating the temperature and humidity conditions for concrete curing in order to improve thermal crack resistance during curing thereof.

The impact of factors on thermal crack resistance of concrete

Thermal crack resistance is a material characteristic that reflects its ability to maintain integrity and strength during cyclic heating and cooling, preventing the formation of thermal cracks. For this reason, it is one of the key parameters determining the durability and operational reliability of massive reinforced concrete structures, especially under conditions of significant temperature fluctuations and dynamic loads typical of supports for string-rail transport infrastructure systems.

According to [4], the main parameters influencing crack formation include five indicators (Figure 2).

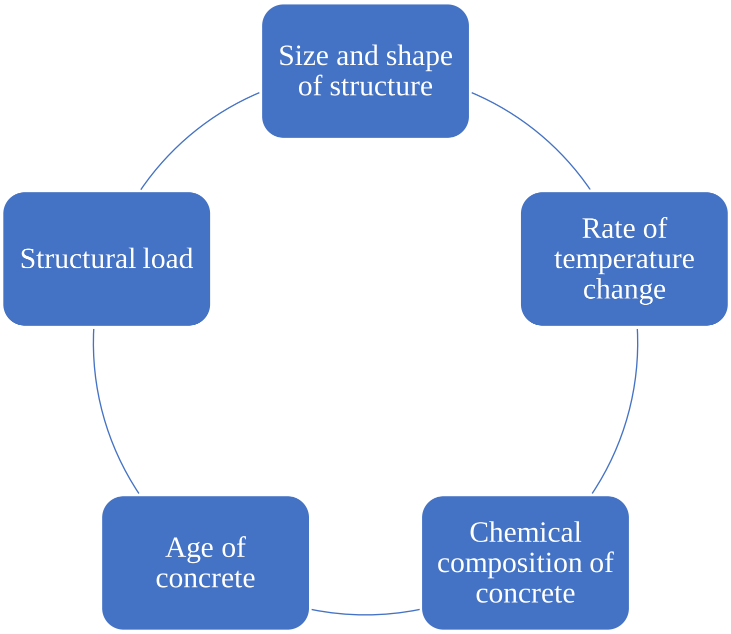

Figure 2 – Factors influencing the occurrence of cracks in concrete

1) Size and shape of structures – massive structures store a large amount of heat and are more susceptible to internal stress, as the temperature at the center and on the periphery will be different;

2) Rate of temperature change – sudden temperature changes increase the risk of cracking, especially when concreting in winter and hot conditions with fluctuations between ambient and curing temperatures;

3) Chemical composition of concrete – the composition of binders and fillers influences crack formation;

4) Age of concrete – the younger the concrete, the higher the internal temperature due to the active hydration process, but over time, it loses thermal reserves, increasing its thermal stability;

5) Structural load – anchor supports of the uST transport and infrastructure complex bear significant pretensioning forces, which requires a special focus on the quality of the anchorage area. Temperature gradients during concrete curing can lead to localized cracks and reduced adhesion of embedded elements to the concrete, which is critical for the load-bearing capacity of the structure [4].

Therefore, to prevent cracks in the SRT supports, it is vital to comprehensively consider all of the listed parameters during the design and operation of concrete structures.

Methods for improving thermal crack resistance

To improve thermal crack resistance, the following methods are used:

- use of additives and modifiers (microsilica, polymer additives, superplasticizers, etc.);

- control of concrete temperature during curing (temperature control using sensors, use of thermal joints, heating or cooling of concrete);

- selection of binders with low heat generation at high ambient temperatures, as well as the use of fillers with low coefficient of thermal expansion to reduce thermal stress;

- concrete reinforcement – use of heat-resistant steel reinforcement or composite materials resistant to thermal expansion (fiber, basalt fiber);

<u>Groups of additives that improve thermal crack resistance.</u>

All concrete additives can be divided into several groups [5]:

1. Those that regulate the rheological properties of concrete mixtures, modifying workability, water drainage, etc.;
2. Those that regulate the setting and hardening of concrete mixtures, influencing the rate of setting and hardening;
3. Those that regulate porosity;
4. Those that impart additional properties to concrete, for example, increasing resistance to aggressive environments, changing electrical conductivity, etc.;
5. Mineral additives.

Of these groups, for adjusting the temperature during the curing process, of interest – those that regulate the setting and hardening of concrete, rheological properties, as well as mineral additives. These additives include: accelerators, retarders, antifreeze, plasticizing, superplasticizing, and water-retaining polymer and mineral additives.

In general, the combined use of superplasticizers, retarders and water-retaining additives allows to accomplish correction of heat and moisture transfer in the concrete mass and the reduction of the intensity of internal stresses.

<u>Temperature control and monitoring method</u>

Next, we will consider the temperature control method. As mentioned earlier, temperature fluctuations can be a factor in crack formation. For example, in winter, it’s necessary to avoid cooling the concrete surface during the curing process by warming the concrete or conserving internal heat. In elevated temperatures, strong thermal gradients must be avoided by monitoring and gradually heating the concrete in a controlled manner.

An example is the use of the “thermos” method when pouring the foundation of a steel anchor support. In winter conditions (average daily air temperature below 5°C), the concrete mixture placed in the formwork must have a temperature of at least 5°C and be maintained using the “thermos” method shown in Figure 3 [6, 7].

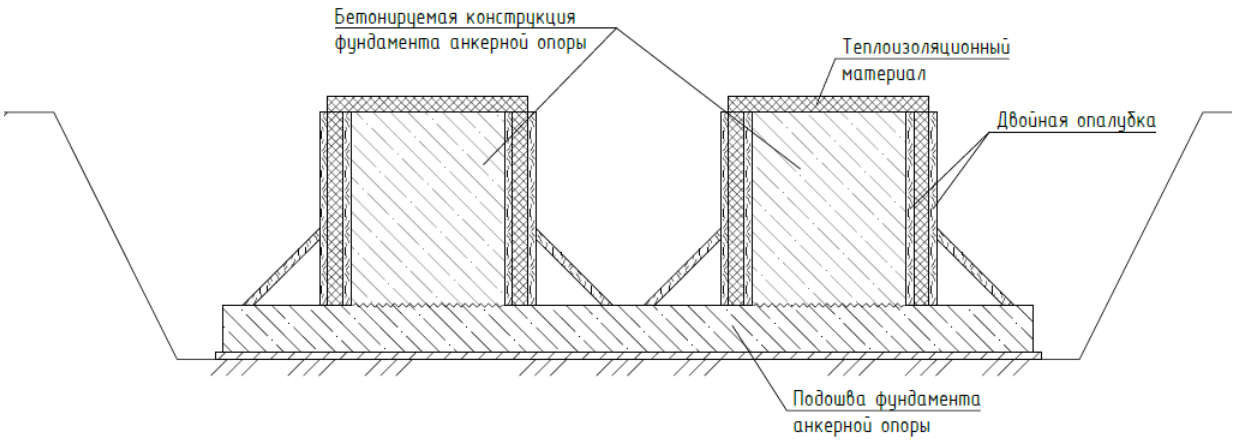

Figure 3 – Schematic diagram of curing concrete mixture using the “thermos” method

Бетонируемая конструкция анкерной опоры – Concreted anchor support structure; Подошва фундамента анкерной опоры – Anchor support foundation base; Теплоизоляционный материал – Thermal insulation material; Двойная опалубка – Double-sided formwork

Ensuring thermal crack resistance of a structure comes down to adhering to the principle of controlling the temperature parameters of concrete and the structure, which is schematically shown in Figure 4 [4].

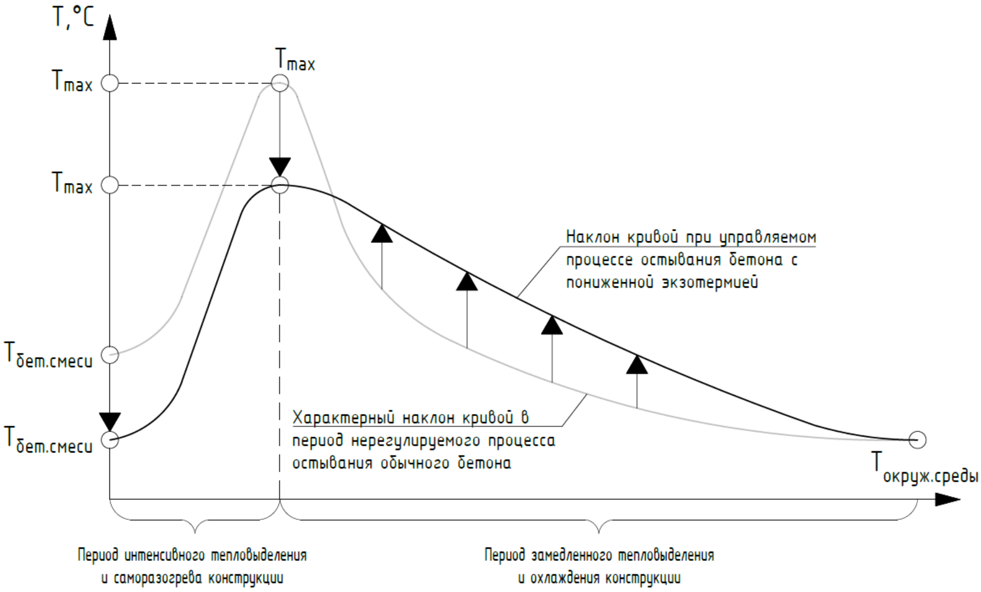

Figure 4 – Schematic diagram of temperature control of concrete mix

$T_{\text{бет.смеси}}$ – $T_{\text{бет.смеси}}$; Характерный наклон кривой в период нерегулируемого процесса остывания обычного бетона – Characteristic slope of the curve during the uncontrolled cooling process of ordinary concrete; Наклон кривой при управляемом процессе остывания бетона с пониженной экзотермией – Slope of the curve during controlled cooling process of concrete with reduced exothermy; $T_{\text{окруж.среды}}$ – $T_{\text{environment}}$;Период интенсивного тепловыделения и саморазогрева конструкции – Period of intense heat release and self-heating of the structure; Период замедленного тепловыделения и охлаждения конструкции – Period of slow heat release and cooling of the structure

The “thermos” method is a method for curing concrete during winter. The method involves conserving the internal heat released during concrete hardening. IoT-based systems have been recently used for temperature monitoring.

An IoT-based temperature monitoring system includes [8]:

- temperature sensors installed either on the surface of the concrete structure or in the “thermos” structure, or in the concrete itself (in reinforced structures);

- network devices that ensure uninterrupted wireless data transmission;

- a monitoring platform that processes and visualizes data, as well as generates reports;

- analytics and notifications – if the temperature deviates from the specified range, the system automatically sends data to responsible persons;

- forecasting – potential risks can be predicted based on the collected data.

Operation of monitoring systems involves the following steps:

- Placing temperature sensors on reinforcing bars before concreting the structure and connecting them to the monitoring system.
- Monitoring and recording the entire concrete hardening process after concreting the structure. The temperature sensors remain permanently embedded in the concrete. If necessary, they can also be used during the operation of the structure. The monitoring system regularly takes readings from the sensors connected to the concrete. This guarantees highly accurate monitoring of the concrete heating (or cooling) regime and adjustments as necessary.

The use of such technologies in the construction of UST transport and infrastructure complexes will enable obtaining of highly accurate data on the concrete hardening process and prompt introduction of necessary adjustments to prevent cracking.

<u>Structural materials and their impact on crack resistance.</u>

One effective method for reducing cement hydration temperature is the use of low-heat-release binders, such as slag Portland cement, magnesite cement, and gypsum cement. However, the use of slag Portland cement slows down the hardening kinetics, which causes prolongation of construction time. Magnesite and gypsum binders have a limited range of applications, primarily in specialized structures, such as finishing layers or flooring. In comparison, ordinary Portland cement and high-alumina cement exhibit heat release rates 2–2.5 times higher than those of these materials, significantly increasing the likelihood of thermal cracking due to uneven temperature distribution. To improve the operational reliability of concrete mixtures based on slag Portland cement, it is advisable to additionally introduce the previously discussed functional additives [5].

In addition to replacing the concrete binder to reduce the likelihood of cracks caused by heat release during hydration of binders, the reinforcement material of the structure may be changed.

When selecting reinforcement, it is necessary to consider the material’s modulus of elasticity, its adhesion to concrete, and thermal expansion. The higher the thermal expansion coefficient, the lower the thermal crack resistance. The closer the reinforcement's thermal expansion coefficient is to that of the concrete, the lower the risk of cracking.

The selected reinforcement material must ensure good adhesion to the concrete to effectively transfer internal stresses to the reinforcement. Poor adhesion can lead to delamination and cracks on the surface and in the contact zone with the reinforcement. The reinforcement material must have the highest modulus of elasticity to resist tensile stresses due to thermal expansion.

Materials considered for reinforcement include steel rebar, composite rebar (fiberglass and basalt-reinforced plastic), and fiber (metal, basalt, polymer, glass, carbon, etc.).

Among the materials considered, steel is the best option for reinforcement, thanks to the highest elastic modulus of 200-210 GPa thereof. In aggressive environments, composite reinforcement with an elastic modulus of 40 GPa can be used, ensuring the required load-bearing capacity of the structure. To limit the occurrence of microcracks and prevent their development, fiber with an elastic modulus of 3.5-250 GPa can be used. Fiber is available in lengths of 5-150 mm and thicknesses of 0.2-1.0 mm and is used as dispersion reinforcement, increasing the strength of the structure in various directions (three-dimensional strengthening). However, it cannot replace steel reinforcement in heavily loaded elements [5].

The use of binders based on slag Portland cement will result in the most durable structure, however, it also increases the construction time due to the slow strength gain of concrete. It is better to reinforce the structures of UST complexes with steel reinforcement to withstand high operational loads, and to use dispersion reinforcement with carbon fiber in order to prevent the appearance or spread of microcracks.

Conclusion

The study systematized and analyzed the key methods for ensuring temperature and humidity conditions for concrete curing in massive reinforced concrete structures of SRT supports. Particular attention was paid to the impact of dynamic and thermal loads typical for these structures, which made it possible to identify critical risk factors for crack formation.

As it was revealed during the study, the following measures must be comprehensively applied to improve the thermal crack resistance of concrete during the construction of reinforced concrete structures:

1. Optimizing the concrete composition using binders with reduced heat generation (e.g., slag Portland cement) and functional additives that help control the hydration rate and reduce internal stresses.

2. Using reinforcement that matches the thermal expansion coefficients of the concrete and reinforcement, which is especially important for supporting high tensile loads from prestressed strings.

3. Implementation of modern IoT-based thermal monitoring methods for timely monitoring and control of temperature conditions during the curing process, which minimizes temperature gradients and prevents localized cracking.

4. Use of the "thermos" method during winter concreting to maintain thermal balance and improve concrete curing quality.

Using an integrated approach to managing temperature and humidity conditions during curing significantly improves the durability and operational reliability of massive reinforced concrete supports for the RST, considering their unique dynamic and climatic loads. The obtained results demonstrate the effectiveness of integrating modern materials and digital control technologies in the construction of high-tech transport structures, which helps reduce the risk of early defects and extend the service life of the structures.

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