Implementation of the "quality" concept in the construction of transport infrastructure facilities

Ivan Pulyaev and Anastasia Mihaylova
Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, Russia
E-mail: ivanes50@mail.ru

Abstract. The article deals with issues related to the implementation of the concept of "quality" in the construction of transport facilities. Based on the fact that a large number of transport facilities designed for individual projects have been built in our country in recent years, we can say with confidence that this problem is currently relevant. The purpose of this work is to generalize and systematize the main methods and techniques for conducting concrete works that minimize the formation of defects and cracks in the construction of transport infrastructure. The article uses the example of a sufficient number of different technologies to show the developed methods for obtaining high-quality concrete products, taking into account the use of modern construction materials, which have been repeatedly tested and proved their effectiveness in the real construction sector. The obtained results formed the basis of projects for the production of works, technological regulations for the production of works, technical conditions and standards of organizations, manuals, and also allowed us to implement the concept of "quality" in transport construction, based on obtaining defect-free reinforced concrete structures with specified properties, taking into account the use of modern building materials. The research made it possible to carry out the construction of non-class complex transport structures of various massiveness and length and can form the basis of construction technology for other industrial and civil construction projects, in which reinforced concrete is widely used.

1. Introduction

It is known that a huge number of buildings and structures are being built in Russia, which are designed with the help of individual projects. They combine complex geometric dimensions in plan with the use of modern building materials and systems. Construction of structures designed according to standard solutions also has a mass scale, however, based on market conditions, taking into account increasingly stringent requirements for ensuring the quality, reliability and durability of these structures, they also have increased requirements for ensuring the necessary consumer properties. At the same time, the fact that the construction of these objects is caused by the constrained conditions of dense urban development, the conduct of work in difficult cross-country areas, and other technological and production factors often have a huge impact on the ongoing processes. As a result, it is quite difficult to provide the main criterion for evaluating the degree of readiness of the object and the "maturity" of the contractor, provided that the above conditions are met, without the use of modern up-to-date solutions, - it is the quality and provision of required consumer properties of constructed new, reconstructed and repaired existing facilities demanded modern approaches to the development of
effective technologies of construction and repairs using modern materials that meet the needs of customers and operational requirements of various types of structures. During the Soviet period and the period of the early formation of capitalist society in our country, many transport structures designed according to standard projects were built most often using unified technological maps. When using precast concrete, the issues of ensuring the quality of constructed structures were often reduced to a clear compliance with the requirements of the regulatory documentation in force at that time and approved standard technological maps for the production of works. The widespread use of monolithic reinforced concrete, which gradually replaced precast concrete at the turn of the century and finally replaced it today (in terms of construction of transport infrastructure), often required the adoption of new technological solutions related primarily to the implementation of various architectural and design innovations. This factor required the involvement in the construction of various research associations and institutions designed to quickly solve emerging issues and problems in order to ensure the required quality, reliability, durability of structures, their environmental friendliness and economic feasibility of construction.

2. Methods

Researchers have established that during the construction of transport facilities there is a high probability of the formation of temperature cracks during the heating of concrete due to different speeds of temperature set up of low-mass and massive parts of the structure. When cooling, longitudinal and oblique cracks may occur due to temperature differences over the cross section of the structures, as well as due to lower temperatures at different speeds in massive and low-mass parts of the structure. In this regard, great attention should be paid to the issues of cracking, which violates the continuity of concrete and leading to accelerated corrosion of reinforcement. Therefore, in the construction of large-sized structures made of monolithic concrete (tunnels, bridges, overpasses and other structures) in the design process, it first seems appropriate to solve the problem of localizing the influence of temperature fluctuations on the properties of concrete both in the process of hardening and in the process of operation of the object. Experience in the construction of transport facilities has shown that to prevent crack formation to be guided solely by the norms of current regulatory documents is not always enough. For example, according to the current regulatory documents, in order to ensure crack resistance in monolithic structures, it is necessary to arrange permanent temperature-sedimentary expansion joints at a distance of no more than 40 m. associated with the influence of the temperature regime of hardening concrete on its crack resistance at the stage of construction, which often leads to the appearance of numbered cracks, the elimination of which requires significant financial and human resources. In each particular case, additional studies are needed that are aimed at preventing cracking that occurs due to the influence of the temperature factor and is necessary for the preparation of reasonable regulatory documents and work projects.

The requirements to optimize and take into account the temperature factor are most fully generalized for hydrotechnical construction facilities [1, 2], as well as for the conditions for the construction of cement-concrete coatings for roads and airfields [3]. With regard to the construction of tunnels, bridges, overpasses, the problem was first solved by representatives of the school of Professor A. Solovyanchik [4, 5], which created a targeted package of applied programs for calculating temperature fields, thermal stresses and growth of concrete strength, which made it possible to take into account real thermophysical and thermodynamic characteristics of concrete and its composition, heat exchange conditions with the environment, types of formwork equipment used, and many other previously unaccounted moments and to develop principles for reducing the likelihood of cracking at the stage of construction of structures [6, 7]. In addition, in contrast to the principles of calculating the thermal stress state in hydraulic engineering and road construction, an important indicator was substantiated in assessing the thermal stress state of transport structures, namely, it was shown that the starting point in determining the degree of influence of temperature on the quality of the structure should be the analysis of the temperature field of zero stresses, which are forming by the time of the formation in the hardening cement stone of a spatial crystallization structure of calcium hydrosilicates, for which the
time taken for the concrete to transition to its elastic state, characterized by compressive strength within 25 ... 30% of the strength at the age of 28 days [8 ... 10], is taken.

To select a method for controlling the thermal regime of concrete according to the design decisions of a particular building, structural units are selected in which high temperature stress concentrators are possible, the design of formwork panels for these nodes is determined, the cement supplier plant to the region of construction of the object in question and the composition of the concrete mixture is taken into account to ensure the concrete class laid down in the project. Further, on the basis of the design documentation and the obtained initial information on the software package, the temperature changes and the growth of concrete strength are calculated with an assessment of the resulting temperature deformations. Based on the obtained calculation material, it is concluded that it is necessary to use a specific method for controlling the temperature regime of concrete and, as a result, the quality of the entire construction process, and also the parameters of this method are determined [11 ... 13].

3. Results

The first important problem that was solved with the help of temperature field calculation programs was related to the need to build such long tunnels as tunnels (especially ramp sections at the entrances and exits) in the assigned short time [14 ... 16]. The structural and technological unit, in which, as a rule, there is a high probability of temperature cracking, is associated with the staged execution of concrete work and relates to the interface between hardened and newly laid concrete. In this zone, during the hardening of the laid concrete, its "jamming" with concrete of the previously constructed part of the structure is formed and it prevents the appearance of free deformations at the stage of cooling the structure. The desire to concrete tunnel structures with large-sized grips without breaking them into concrete blocks in order to reduce the time of work and reduce the number of working joints required a comprehensive assessment of the temperature regime of concrete hardening and pointed to the need to take into account the “jamming” of concrete blocks in the contact zone with previously constructed structural elements, for example, when concreting walls after the device bottom. It was found that to prevent the occurrence of temperature cracks, the size of the concrete block in these cases should not exceed 15 ... 17 m, if at the time of closure of the seam the temperature difference between the most heated part of the structure and the temperature in the zone of closure of the seam is not more than 20 °C (Figure 1).

![Figure 1. Conceptual diagram of splitting of the bottom of the tunnel on the blocks of concrete.](image)

The calculations performed by the calculation complex made it possible to determine the modes of additional heating of previously concreted elements that contribute to a decrease in the temperature difference between the structural zones under consideration and an increase in the size of concrete blocks to a value of 20 ... 21 m. Experience in the implementation of additional heating modes of previously constructed elements in practice has shown that for local supply of thermal energy to
concrete, it is preferable to use a heating wire, the installation of which in the zone is interfaced. The wall with a bottom allows concreting wall sections with grips up to 30 m long.

To accelerate the construction of tunnel structures, conditions were also developed for their construction in blocks of 30 m in length with a technological (working) joint between them 1.5 ... 2.0 m wide between them. At the same time, the correctness of the design assumptions was confirmed by the absence of cracks in the constructed blocks of the bottom and walls of structures.

In some cases, it becomes necessary to concrete sections of a tunnel longer than 40 m in one go. Based on the studies, a number of technological methods have been developed, including layering first of a concrete mixture with a temperature of 20 ... 25 °C and then with a temperature 6 ... 10 °C. This method of concreting made it possible to halve the temperature difference between the maximum heated core and the minimum heated edge of the structure, to ensure high uniformity of the temperature field and, together with incomplete in relation to the design concrete compression, successfully solve the problem. To speed up the timing of the installation of floors, a technology has been developed for concreting wall blocks and floors up to 38 m long in one go. The technology provides for a comprehensive heating of the concrete of piles to a predetermined temperature, both before laying the concrete and when it is kept, including using a special technique that allows directing the heat of cement hydration to the zone of heated piles. The temperature fields in the zone of wall mating and overlapping with the base of piles in the proposed method, in comparison with the traditional one, show a decrease in the temperature differences at the time of formation of the temperature field of zero stresses and during the period of maximum heating of concrete, which allows you to build a tunnel without cracks, and the terms reduce construction by 1.5 times due to the enlargement of concreted grabs, reduce the complexity of work and reduce the number of technological joints. Another example of improving the technology of erection of structural elements of tunnel structures, tested in practice, can be considered the technology of erecting the bottom (tray) of the tunnel simultaneously with the technological protrusions ("hemp") of the walls to a height of 0.6 ... 0.8 m (Figure 2).

![Figure 2](image)

**Figure 2.** Schematic diagram of the breakdown of the bottom of the tunnel on the capture of concreting with technological protrusion.

The formation of such "hemp" simplifies the heating of the base before concreting walls in the cold season, and also creates the prerequisites for concreting tunnel walls with longer blocks. During the construction of the tunnel-flyover sections, another method for implementing the advanced technology can be used - the so-called "Milan way", in which the tunnel is first erected, and then the bottom and walls.

The use of this method of construction is especially effective in conditions of dense urban development, since the presence of overlap helps protect nearby residential and public buildings from noise and dirt during construction work. When erecting the tunnel structures in the "Milan way", the ceiling is supported and "pinched" into the enclosure from the cutting piles. In the presence of such a
“jamming” to localize the manifestation of temperature stresses in the case of traditional methods of work, it becomes necessary to concrete the upper part of the walls and block them with blocks of no more than 15 ... 16 m.

The second type of structures, for which it was necessary to develop conditions that exclude crack formation in the structure, includes plate-ribbed spans of bridge passages and trestles with massive load-bearing ribs, low-mass consoles and a central intercostal part. Studies in this case showed that in a massive rib already at the stage of heating the concrete from cement exothermy, deformations can occur that cause the appearance of temperature cracks (Figure 3).

![Figure 3](image)

Figure 3. Distribution of temperature stresses in the superstructure without the use of special measures to equalize the temperatures in the concrete.

The reason is that the concrete in the peripheral layers, being cooled due to contact with the environment, deforms relatively slightly, while the concrete in the core, heating up to high temperatures, undergoes more significant temperature deformations, which ultimately lead to rupture of the external surface layers that do not yet have sufficient tensile strength. Therefore, to develop methods for preventing the appearance of temperature cracks at the stage of heating, it is necessary to analyze in detail the magnitude of temperature deformations in various sections of the structure and design the composition of concrete with a minimum amount of cement per cubic meter of concrete mix. An analysis of the temperature development during concrete curing in plate-ribbed span structures showed that due to more intense heating of the rib, the curing rate of concrete in it is higher than in the cantilever and at a certain stage of curing the cantilever becomes conditionally pinched into the rib. The temperature difference is quite significant, and can lead to the formation of transverse cracks in the console. The search for temperature equalization options over the cross section of structures with heterogeneous zones showed that the most effective way to prevent crack formation is to cover the console with more powerful thermal insulation and additional insulation of the console formwork from below with an additional shelter in the form of a canopy from below, which allows redistributing thermal energy between the ribs and the cantilever buildings (Figure 4).

![Figure 4](image)

Figure 4. Scheme of additional thermal insulation of the superstructure plate in the technological shelter.

The temperature field during the implementation of this set of measures turned out to be sufficiently uniform, which allowed for the first time in bridge building practice to provide defect-free concreting in one run of a span 179 m long. Studies have also shown that in the conditions of work
during the warm period of the year hermetically sealed on top of low-mass translucent consoles coatings with a given thermal resistance instead of additional thermal insulation ensures not only heat preservation, but also additional heating of the concrete of the cantilever by solar radiation flux, which even more reduces the likelihood of the formation of temperature cracks [17 ... 20].

It is known that cast concrete is also widely used in the construction of grillages, foundations and bridge supports, and despite the fact that at present our country has accumulated a lot of experience in ensuring high quality concrete work, periodically there are a number of issues to ensure consumer properties of concrete that require competent solutions. In particular, in recent years, a large number of impressive grillages have been erected, for example, during the construction of bridges across the Moscow River, Oka, and the Crimean Bridge. The existing experience in the construction of such large-sized reinforced concrete structures and thermophysical calculations show that in order to ensure the necessary crack resistance of concrete and to prevent the occurrence of temperature cracks that occur when concrete is heated from exothermic cement and its subsequent cooling, it is necessary to break down massive structural elements into height grips and into concrete blocks in plan, as well as setting additional thermal insulation in places of the greatest temperature difference along the section of the structure (Figure 5).

![Figure 5. The scheme of the breakdown of the Crimean bridge support stand on the concreting blocks and its shelter with additional thermal insulation.](image)

When choosing methods for controlling the temperature regime of hardening concrete in the case of erecting high (more than 5 m) struts of supports at one time in the cold season, it should be noted that it is necessary to install shut-off diaphragms with bypass valves in the heaters, which allow regulating the heat supply to the upper zones of the racks and thereby prevent overheating of concrete.

Ensuring the required quality of the constructed new, reconstructed and repaired existing facilities requires modern approaches to the development of effective technologies not only for design and construction, but also for repair work based on the use of modern materials that meet the requirements of the operation of various types of transport facilities. Repair work, as a rule, is carried out both at the stage of construction of objects, and during their operation. During the period of construction of structures, the elimination of defects made during construction and the treatment of various cracks are usually carried out. During the operation period, various types of repairs are carried out, including those related to the restoration and increase of the bearing capacity of individual structures under construction or the entire structure as a whole. In all cases, repairs must be carried out in a timely manner, efficiently, ensuring the required durability and duration of the overhaul periods of the structure. The quality of the repair of reinforced concrete structures depends on the proper organization of the repair work, the reasonable choice of repair materials and the use of modern technologies that have been tested in practice. All these issues should be reflected in the normative and technical documents under development for the repair work, and the presence of gaps in the rules of
technical regulation for the design and implementation of construction, installation and repair work, unfortunately, often leads to the fact that low-quality materials fall on the construction site quality, and repair work is carried out at a low level. In order to systematize the issues related to the need to fully reflect the requirements for repair work at transport facilities, a Guide to repair concrete and reinforced concrete structures of transport structures was developed taking into account the compatibility of materials that has withstood several reprints.

The main task when performing repair work is the correct choice of repair material (based on a feasibility study and taking into account the requirements that ensure the specified operating conditions and the duration of the overhaul periods). However, quite often the choice of material is determined solely by the financial capabilities of the customer, as well as taking into account the elements of risk associated with insufficient knowledge of the conditions for the subsequent operation of the facilities and the actual technical characteristics of the new materials.

For the effective repair of structures made of concrete and reinforced concrete and the selection of the necessary materials that ensure the quality of the structure, it is necessary to have a certain concept and a clearly established sequence of work to make it possible to justify the correct choice of material planned for use in the repair of structures. In practice, structures are usually repaired using materials similar to the starting material of the structure being repaired. When choosing it, it is necessary to comply with this rule and clearly comply with the requirements for compatibility of materials, due to the fact that the same materials may be incompatible for a number of reasons. The compatibility of materials implies the nature of their behavior both in uncured and in hardened state. It is based on the physical foundations of the interaction of repaired and repair materials. The choice of material is a compromise process based on reliable information, and materials about which there is no complete and accurate information should not be allowed into production. When choosing repair materials, it is required to observe clear principles of compatibility of the properties of repair and existing materials. When choosing a repair material, the following should be taken into account: degree of responsibility of structures; depth of damage / destruction; planned operating conditions (primarily temperature conditions); humidity and aggressiveness of the operating environment, dynamic effects; aesthetic requirements; position and accessibility of the structure being repaired; scope of work to be performed (Figure 6).

![Figure 6. The process of preparing the support of the overpass for the production of repair work.](image)

The choice of materials directly affects: the type of repair; depth of destruction; Operating conditions; as well as the type of repair: current repair of structures that does not require restoration of their bearing capacity; repair of structures with restoration of their bearing capacity; repair of structures with an increase in their bearing capacity in relation to the bearing capacity laid down in the initial design of the structure. Numerous other factors can influence the choice of material, including such as the length of time required to transfer the operating load to the repaired structure, the available working time for the work, the rate of curing of the repair material during hardening, and other factors.
When choosing materials, it should be taken into account that materials on the market very often change for many reasons, including in connection with the replacement of raw materials, environmental standards and the introduction of new advanced technologies. As a result, the physical and technical properties of these materials change. To confirm the possibility of using such materials, it is recommended to carry out independent tests of repair materials, especially in those cases when the repair gives priority to reliability and durability of the structure.

Of particular note is the elimination of cracks in concrete and reinforced concrete structures, which are divided into active and inactive. Active cracks change the width of the opening under the influence of the applied load and temperature changes. Inactive cracks do not change the width of the opening under external influences. In addition, active (“breathing”) cracks can turn into inactive by appropriate reinforcement of the structure, restoring its continuity. One of the effective options for repairing active cracks can be considered the method of filling them with mastics or elastic epoxy resins that are not subject to tensile load when changing their opening. To eliminate active cracks in bridge and tunnel structures, elastic epoxy resins have been widely used in recent years, the introduction of which proved to be most appropriate in conditions of high humidity and the strength of the presence of groundwater. Inactive cracks are sealed by injecting into them a composition that adheres to concrete, but is not able to prevent changes in the opening under external influences. Fragile and elastic protective coatings are used to seal the hair cracks, creating a film on the concrete surface. In recent years, dry concrete mixtures that do not require dosing of components at the place of work are finding wider application for repair work. To harden the materials, increase their water resistance, resistance to aggressive environments, as well as increase the frost resistance of concrete, clogging materials are used. Such materials are also recommended for injection work.

Summing up, it should be noted that only with the correct integrated approach to the appointment of repair of reinforced concrete structural elements of transport structures and the scientifically-based choice of technologies and materials for repair, it is possible to ensure high quality of work and significantly extend the life of repaired structures at reasonably reasonable economic costs.

4. Conclusion
The developed measures described in this article were successfully implemented during the construction of transport facilities in Moscow, St. Petersburg, Sochi and other large cities, in the Moscow Region, Crimea (Figure 7) and other regions of our country, showed their viability and relevance, avoided mass formation of temperature cracks in the erected structures, to reduce the construction time of facilities with strict observance of quality standards for construction work.

But in general, it is clear that the temperature factor has a significant impact on the quality of concrete work and at the moment there is a real opportunity to reduce this effect in several ways, including:
the use of low-heat cements for concreting massive concrete structures (however, at present this issue is difficult to resolve due to the lack of mass production of such cements in the Russian Federation);

- ensuring reduction of cement consumption per 1 m³ of concrete mix.

The issue of ensuring a reduction in cement consumption can be solved on the basis of the mass use of new-generation chemical additives based on polycarboxylates and the use of modified concrete. Studies have also shown that the use of such additives can significantly reduce cement consumption per 1 m³ of concrete while ensuring the required high strength, water resistance and frost resistance. The use of chemical additives and the production on their basis of self-compacting concrete mixtures that are more and more widespread in Russia allows us to solve another problem associated with concrete compaction during the construction of high supports, densely reinforced structures of various types, thin-walled structures and other structures. In addition, today there are a number of materials and mixtures that have been successfully tested and used in the construction of a number of objects, but which are waiting for their recognition in a wide range of builders and wider application in practice.

Thus, the examples of regulating the temperature regime of hardened concrete considered by the authors do not fully reflect the issues and problems that today are faced not only by builders at a construction site, but also by scientists in scientific organizations. Despite this, the accumulated experience and available knowledge allow us to ensure the competent and reasonable use of scientific and technical support for concrete work using modern building materials and systems. As a result, this allows us to fully ensure the required quality standards when carrying out concrete work at a construction site.

References

[1] Zhu H, Hu Y, Li Q and Ma R 2020 Construction and Building Materials 244 118318
[2] Xin J, Zhang G, Liu Y, Wang Z and Wu Z 2018 Construction and Building Materials pp 381-390
[3] Wu J, Liu X, Wu H, Li L and Liu Z 2020 Journal of Testing and Evaluation 48(4)
[4] Nosov V P, Dobrov E M, Chistyakov I V, Borisiuk N V and Fotiadi A A 2017 International Journal of Applied Engineering Research 12(23) pp 13158-13164
[5] Solov'yanchik A R and Shifrin S A 2000 Management of thermally stressed state of monolithic reinforced concrete structures in high-speed year-round construction of transport facilities (Moscow: Scientific works OAO TSNIIS) 203 pp 25-32
[6] Tarasov A M, Bobrov F YU and Pryakhin D V 2007 Scientific and technical journal «Bridge building messenger» 1 pp 21 - 26
[7] Pryakhin D V 2009 Scientific and technical journal «Transport construction» 10 pp 11-13
[8] Machelski C and Pustelnik M 2019 Proceedings of the fib Symposium 2019: Concrete - Innovations in Materials, Design and Structures pp 1461-1468
[9] Solov'yanchik A R, Smirnov N V and II'in A A 2004 Determination of the modulus of elasticity of concrete at an early age and features of its account in the calculations of the thermally stressed state of structures (Moscow: Scientific works OAO TSNIIS) 204 pp 27-32
[10] Shifrin S A 2007 Scientific and technical journal «Appliances» 5 pp 18-22
[11] Pulyaev I, Pulyaev S, Bazhenov Y, Fetisova A and Shcherbeneva O 2019 Web of Conferences E3S
[12] Pulyaev I S and Dudayeva A N 2019 Investigation of the temperature regime of hardening concrete of the upper layers of the upper part of the pylons during the construction of the bridge over the Oka River on the bypass of the city of Murom (Moscow: Scientific works OAO TSNIIS) 251 pp 45-52
[13] Sokolov S B 2002 Influence of air temperature fluctuations in hotbeds on the temperature of hardening concrete during the erection of monolithic slab-ribbed spans during the cold period of the year. (Moscow: Scientific works OAO TSNIIS) 213 pp 167-172
[14] Solov'yanchik A R, Korotin V N, Shifrin S A and Veytsman S G 2002 Scientific and technical journal «Bridge building messenger» 3 - 4 pp 53-59
[15] Ginzburg A V 2014 Scientific and technical journal «MGSU messenger» 1 pp 98-110
[16] Solov'yanchik A R, Shifrin S A, Korotin V N and Veytsman S G 2003 Realization of the concept of "quality" in the construction of the Gagarinsky tunnel in Moscow (Moscow: Scientific works OAO TSNIIS) 217 pp 206-212
[17] Kolchunov V I and Iliushchenko T A 2020 Journal of Physics 1425(1) 012095
[18] Vasil'yev A I and Veytsman S G 2015 Scientific and technical journal «Bridge building messenger» 1 pp 2-17
[19] Kosmin V V and Mozalev S V 2014 Scientific and technical journal «Bridge building messenger» 1 pp 19-24
[20] Balyuchik E A and Chernyy K D 2010 Increasing the crack resistance of bridge supports made of solid concrete with constructive methods (Moscow: Compilation of scientific papers TSNIIS) 257 pp 49-57