Experience of Application of High Durability Concrete for Transportation Structures in Severe Conditions of the Far North

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Abstract. The article presents the experience of using concrete of increased durability for transport structures in the harsh conditions of the North. The main factors determining the durability of concrete are considered, first of all, the quality of local materials for concrete preparation and methods for producing concrete on its basis for arranging road and airfield pavements both from monolithic and prefabricated reinforced concrete slabs of PDN and PAG grades. The results of laboratory studies of PFM-NLK effect complex modifier, specially designed for use in the Far North on the properties of concrete mixture and concrete, which determine its durability are analyzed. The results of testing preparation of concrete at various industrial enterprises, with introduction of products production and production of monolithic coatings at various objects of transport construction are presented. The possibility of developed technologies spreading for production of increased durability concretes in the Far North regions, including during development of the Arctic regions of Russia and the Republic (Sakha), due to the difficult conditions of the region’s harsh climatic and freezing and soil conditions, and economic and environmental conditions is shown.

1. Introduction

One of the most important and urgent tasks of ensuring the safety of transport facilities operating in the harsh conditions of the Far North is the task of ensuring the durability of concrete and reinforced concrete structures. When choosing the material of structures, it is necessary to take into account the actual working conditions of structures and influence of external environment, both during the operation of the object and during construction. About 65% of the territory of the Russian Federation is in a sharply continental climate, including almost the entire territory of the Republic of Sakha (Yakutia). Here, the severity of climate is characterized by low temperatures in winter and high temperatures in summer, the annual temperature difference is more than 100°C with the lowest winter temperature (down to -64°C in Yakutsk region, about 70°C next to the cold pole - in Oimyakon) and 38°C (st. Yakutsk). Short hot summers are characterized by average daily relative air humidity below 25% with daily average air temperature + 25°C and above. In addition, almost the entire territory of Yakutia is characterized by complex hydro geological conditions, due to the presence of permafrost.
In such extreme conditions for the development of oil fields in the marshy regions of Western Siberia in the 60-70s of the XX century, the use of precast concrete slabs for the construction of roads was chosen. The experience of its operation showed the advantage of roads with cement concrete pavement, on the basis of which they were recommended for the construction of automobile roads in the I and II road-climate zone (VSN84-89, 1989, SP34.13330). As is known, precast concrete slab coatings have significantly greater rigidity than asphalt concrete and especially crushed stone coatings, which significantly increases the durability of roads. In addition, the use of cement concrete coatings reduces the requirements for lower layers of pavement. However, precast concrete slabs as pavements in Yakutia did not find application, mainly due to the lack of manufacturing enterprises for production of precast concrete slabs, significant transportation costs during transportation over long distances.

In the past 15 years, road builders of Russia have once again become interested in technology of building hard pavements, as they collided closely on asphalt concrete pavements of roads with problems with low bearing capacity of pavements. A significant increase in the intensity of traffic on modern roads, as well as an increase in the axle load, caused a massive increase in formation of ruts on roads, the intensive development of holes and hollows, and a grid of cracks on surfaces. Nowadays, roads with non-rigid surfaces dominate in Russia, which do not provide modern road safety requirements, are short-lived and cannot be competitive in their costs of its maintenance and operation. Therefore the direction of using concrete for the construction of roads and airfields has acquired considerable relevance.

In this regard, this article discusses the experience of ensuring the durability of concrete on local materials for coating roads and airfields operating in Yakutia.

2. Technical requirements for concrete pavement roads and airfields

Cement concrete roads are widely used in many foreign countries such as the USA, Austria, Belarus, Great Britain, Germany, Poland, Turkey, Japan, as well as in the northern territories of Canada and Alaska [1-4]. Many years of experience in operation of cement concrete pavements in these countries convincingly show the promising and cost-effective use of hard coatings for road and airfield installations. This is also confirmed by creation in recent years of road concrete of increased strength and durability. However, in our country, especially in our region, the use of cement concrete in construction of roads and airfields has not yet found wide application. One of the reasons for small use of cement concrete in road construction is higher cost of building roads with cement concrete pavement is higher than building roads with asphalt concrete paving. But there is evidence that with appropriate compliance with the requirements of construction technology, savings can be obtained by reducing costs during the operation of such a road [3-7]. Thus, according to Goncharov M. [4], LafargeHolcim developed a project for construction of a cement concrete road for a 54-km-long section in the Ferzikovsky district of the Kaluga region. According to their estimates, the total cost of the project was 5% more than construction of asphalt concrete. At the same time, the cost of servicing 1 km with a service life of 25 years turned out to be almost half as much as servicing an asphalt concrete road. The northern bypass road in the city of Novosibirsk was made with cement concrete paving in 2009 with a significant reduction in maintenance costs more than 1.5 times lower than that of asphalt paving [7]. A significant reduction in operating costs for the maintenance of highways is also confirmed by the fact that roads with cement concrete pavement, built in the 50s of the last century, served more than a standard period (20-30 years), for example, the Moscow-Volgograd, Moscow-Gorkiy motorways, Moscow-Brest, MKAD, MKAD-Kashira, MKAD-Serpukhov, Omsk-Novosibirsk, Yekaterinburg-Serov, etc. On Lomonosovsky Prospekt (Moscow), a road was constructed using the injection molding method according to the technology developed in the State Unitary Enterprise NIIMosStroy without concrete pavers and sealing equipment. The road has been in good condition for over 20 years. Thus, the analysis of experience in using cement concrete pavements in Russia convincingly confirms its great durability, almost twice. In this case, the normalized average life of asphalt pavement is 12-14 years, concrete is 25 years. And world practice has shown that cement-concrete roads are 5-6 times more durable than asphalt concrete, its service life can reach 50
years or more. All this indicates the promise of introducing technologies for installation of cement concrete pavements for roads and airfields.

To date, a large amount of theoretical, experimental and practical knowledge has been accumulated in the field of construction technology for durable cement concrete pavements and foundations, which are reflected in regulatory documents [2, 7-17]. Technical requirements for concrete pavement and airfield pavements are established by the following regulatory documents: SP 34.13330.2012 “Automobile Roads. Updated version of SNiP 2.05.-85 **”; SP 121.13330.2012 “Airfields. Updated edition of SNiP 32-03-96” and GOST 26633-2015 “Heavy-weight and fine sand concretes. Specification”.

Transport facilities are operated in harsh climatic conditions [8, 12, 17-19]. The main aggressive factors of external conditions are the effect of alternating temperatures with a decrease in temperature to minus 54°C (the coldest five-day week with a security of 0.92 in Yakutsk station according to SP 131.13330.2012) and with an absolute minimum air temperature of minus 64°C. The impact of external environment is characterized by alternate freezing and thawing under the combined action of rain and frost and is classified as XF3 according to Appendix A of SP 28.13330. The degree of aggressiveness of environment in relation to concrete of reinforced concrete structures is assessed as non-aggressive during normal humidity operation of the structure in accordance with SP 50.13330 and does not require the use of measures of secondary protection of structures. The main requirement for ensuring the durability of reinforced concrete structures under the specified operating conditions in relation to the reinforced concrete elements unprotected from corrosion of roads and airfields according to Appendix F SP 28.13330.2012 is the requirement for concrete by frost resistance grade not less than F200. Therefore, the primary method of protecting structures from external influences was used in the studies, namely, the control of pore structure.

Introduction of high regulatory requirements aimed at ensuring the durability of concrete structural elements of transport facilities, and provides for special requirements for materials for concrete preparation. So for concrete road and airfield pavements should be used brand of cements not less than 400 standardized composition. Requirements for mineralogical composition of cement are established by GOST 33174-2014 and GOST R 55224-2012. At the same time, cement should be made on the basis of clinker with a C_A content of not more than 7%, C_A + C_AF not more than 24%, and C_S less than 55%.

There are some restrictions on the use of aggregates to ensure required performance of concrete.

To provide a given frost resistance in road and bridge construction, the most widely used complex additive is S-3 + SNV, which contributes to production of concrete with high durability of concrete at W/C = 0.35-0.45. To reduce water absorption of concrete, in addition to plasticizing-air-entraining additive, micro-fillers are added to concrete [11]. It is known that all indicators of concrete quality depend not only on the quality of raw materials and properties of concrete mix, but also on managing the formation of concrete structure. An important role is played by correct choice of production technology of concrete work, since the strength, frost resistance, water absorption and corrosion resistance of concrete will depend on pore structure of concrete.

One of the most effective ways to increase frost resistance is use of air-entraining additives. In this case, the choice of type and consumption of air entraining additives is carried out from condition of ensuring the regulatory requirements of GOST 26633 on the content of entrained air in concrete mix. In accordance with it, concretes of buildings structures and structures exposed to water and alternating temperatures should be made of concretes with frost resistance mark F200 (F100) and above using air-entraining (gas-forming) additives. The standard imposes particularly high requirements on this indicator to concrete constructive layers of roads and airfields. Prior to updating the standard, concrete mixtures with a volume of entrained air of 3-4% were widely used.

However, despite the large number of studies of entrained air effect on the properties of concretes, currently there are conflicting data in the literature related to the fact that content of entrained air leads to a decrease in strength [17, 20, 21]. At the same time, according to various studies, when the volume of air entrained was from 2.8 to 3.7%, the grade of frost resistance concrete F1300 and higher was
provided. It is known that each percent increase in air entrained results in a loss of strength of 4-5%. Thus, an increase in the volume of entrained air in concrete mix leads to an increase in cement consumption, which can often lead to a decrease in frost resistance of concrete. There is evidence that a decrease in entrained air from 5.6 to 3.5% does not reduce the frost resistance of concrete at 300 test cycles, but increases their strength and reduces water absorption by 16% [20]. Therefore, the question of appointment of air volume involved in concrete mix requires further study.

3. Experience in ensuring the durability of concrete road and airfield pavements and bases

3.1. Characteristics of local materials

3.1.1. Binder. For manufacture of road and airfield concretes used Portland cement brands PC 400-D20-N, PC 500-D0-N, produced by OAO PO “Yakutcement” in accordance with GOST 10178-85*. In general, local cement meets the requirements of GOST 10178 for road and airfield pavements: $C_3A = 6.15\text{--}8.3\%$; $C_3A + C_3AF = 17.0\text{--}22.0\%$; $C_3S = 55.42\text{--}62.26\%$.

3.1.2. Aggregates. Local manufacturers of concrete mix widely use river sand from the floodplain of the river, which belongs to the group of “very small” and “small”. This sand is clean (the content of dust particles is not more than 1.2%). Size modulus usually ranges from 0.9 to 1.3. The grain composition of sand does not meet the requirements of regulatory documents for design of concrete pavements for roads and airfields. Nevertheless at present, a reduction in water demand of concrete mix can be achieved with help of effective plasticizing agents. GOST 26633-2015 requires that the frost resistance of crushed stone is not lower than the frost resistance of concrete. From local aggregates, only diabase crushed aggregate from the Yelovsky deposit, which is located on the left bank of the r. Lena is 245 km lower from Yakutsk. Earlier studies have shown that when using diabase crushed stones, it is possible to obtain concrete of class B30 ÷ B45, F1,300-F1,400, F2,200. However, at present, mining and processing of diabases at the Yelovsky deposit is suspended. The largest volume of concrete and reinforced concrete works is concentrated in Central Yakutia. Here, to obtain concrete with frost resistance F1,300, F1,400 and F2,200, limestone crushed stone from the Bestyakhskoye deposit is used, which is characterized by frost resistance brand F50 ÷ F150. This became possible due to appearance of PFM-NLK modifier developed by YakutPNIS JSC with participation of NIIZBB (RF Patent No 2245857), which is currently manufactured by chemical plants of the Polyspast group companies. Thus, in development of compositions for road and airfield coatings, local limestone crushed stone was used.

3.1.3. Additives. When developing compositions of increased durability concrete, intended for pavement structures and airfield pavements, multifunctional modifier of concrete PFM-NLK (according to TU 5745-022-58042865-2007) was used, that reduces water demand of concrete mix by 20-25%, air entrainment into concrete mix to 3 and 5%, increase strength by 20-35%, increase frost resistance to F400 and higher.

3.2. Concretes on local materials for road and airfield pavements

In order to substantiate the expediency of using hard pavements of roads and airfields in the conditions of the Far North, properties of concrete mix and concretes on local materials obtained using PFM-NLK modifier were investigated. At the same time, by direct testing of concrete samples it was established that required cold resistance grades are provided. To provide a guaranteed grade of concrete for frost resistance F1,100 and F2,200, it is sufficient that air entrainment in concrete mix is from 3 to 5%. The obtained results are confirmed by data from other studies [20, 21]. Studies of concretes with PFM-NLK, PFM-NLK + SNV additives also showed that this ensures concrete grade with tensile strength of Btb4,02 and Btb5.2. Studies have shown that using local materials, it is possible
to obtain concretes with specified indicators, ensuring the design life of structures according to SP 28.13330.

4. Production testing of concrete road and airfield coatings

The first large object, which introduced the compositions of increased durability, developed by YakutPNIIS specialists was the runway No 2 of the Yakutsk Airport. The project was developed in 2007 by the State Unitary Enterprise GUI GA “Dalairoproekt” (Khabarovsk). To reinforce and build a new project, a two-layer cement-type hard concrete coating is envisaged. Design indicators of concrete elements: for lower layer - BSG B30 B₄₀ 4.0 F₂00; for upper layer of BSG B30 B₄₀ 4.0 F₂00 reinforced with reinforcement mesh of 014 mm class A500 (AI11).

Concrete mix was made on two concrete mixing plants (JSC “YKSMK” and LLC “Stroyindustriya”), where following local materials were used:

- Cement-Portland cement PC-500 D0, produced by OJSC PO “Yakcement”, the content of C₃A in clinker is not more than 8%, activity during steaming is 32.4 MPa, true density is 3.1 g/cm³, normal consistence is 26.5%. Cement meets the requirements of regulations for preparation of concrete for airfield pavements.

- Crushed limestone, mix fr. 5–20 mm produced by OJSC Production Association “Yakutcemint”, silt content is 1.2%, the frost resistance grade is F25, the lamellar and needle particles content is 14.3%, and strength grade is I200. In terms of physics and mechanical properties, crushed stone meets the requirements of regulatory documents, with exception of frost resistance. Water is water supply, meets the requirements of the standard. Chemical additive PFM-NLK according to TU 5745-022-58042865-2007, manufactured by LLC “Polyplast-UralSib”.

Prepared concrete mix was transported to the construction site by concrete mixers, duration of transportation of concrete mix was from 20 to 40 minutes.

Concrete work on construction of airfield pavement has been performed for 10 years by “IRMAST-HOLDING”. When developing compositions of concrete in 2008 and in the future during concreting period, at construction site, accredited EC “YakutPNIIS” JSC conducted control tests on concrete consistency (slumpK) and density of concrete mix, as well as samples of concrete mix were taken to control strength in a timely manner and control frost resistance. Concrete samples were stored in a normal storage chamber.

The results of concrete mixtures control under production conditions showed that the concrete consistence laid in a single-layer coating corresponds to concrete grade on workability P2, average air entrainment of concrete mixture was 2.5%, the bending tensile strength class was Bb5.2, the compressive strength class was B35 ... B40, frost resistance grade was F₂00. Testing the composition of concrete and production control over the quality of concrete mix and concrete at the facility “Reconstruction of paved runway-2 of “Yakutsk” airport showed high concrete stability in strength: the coefficient of variation in strength at “Stroyindustriya” LLC and YAKSMK JSC was respectively 6.33 ... 6.41 and 3.48 ... 5.38%. The site is guaranteed, provided specified quality indicators B30B₄₀ 4.0F₂00 for bottom layer of coatings, B30B₄₀ 4.0F₂00 for coating.

Monitoring the condition of concrete of airfield pavements for ten years has shown that concrete is currently in good condition. This indicates the high efficiency of the PFM-NLK modifier in concrete on local materials, which are distinguished by a lack of conformity in some characteristics to requirements of regulatory documents. Introduction to composition of concrete PFM-NLC contributes to creation of concrete structure that is resistant to repeated freezing and thawing.

The second major project for introduction of road concretes is production of precast reinforced concrete pre-stressed road slabs with high quality indicators of B₄₀ 4.0 B30P3F₂200G1W10 concrete with content of entrained air in concrete mix of 3-4% at production base of JSC “Yakutcemint” (“Ekom” LLC), supplied for construction of a field road to the “Power of Siberia” gas pipeline. For
concrete preparation, PFM-NLK additive was used, the effectiveness of which was once again confirmed by impressive production volumes of PDN plates. For the period from 2015 to 2017 more than 67 thousand pieces or 128 thousand cubic meters of high quality products produced. The products manufactured by “Ekom” LLC are certified for compliance with TU 5846-001-97553102-2015 (until 01.01.2017) “Prestressed concrete reinforced road slabs PDN” and GOST 25912-2015 “Prestressed reinforced concrete slabs for airfield pavements. Specifications”.

The third object, on which new technology of road cement concrete pavements made of cast concrete mixes was tested, is the access road to residential building at the object “140 apartment house in the 130th block in Yakutsk” (2012). At the test site, two cement concrete pavement structures were tested: with a basalt-reinforcing (BPA) mesh of 6mmØ rods and a slab section 60 and 37 m long with continuous reinforcement with a mesh of the same reinforcement with cells of 500-200 mm. Concreting of parking lots was carried out with plates with dimensions of 6 * 6 and 4 * 6 m, reinforcement of plates was carried out with reinforcement mesh of basalt-plastic reinforcement with a mesh of 400 * 400 mm. Design indicators of concrete coating - B25Bt3,2P4 F2200. Source materials are the same as in construction of airfield pavements. Concreting of coating in this area was carried out by caps 6 ∙ 6.4 ∙ 6m. Part of coating (sections No 19, 20, 21) is reinforced with grids of metal fittings 3mmØ with cells 100 ∙ 100mm.

Preparation of concrete mixture was organized in concrete mixing plant JSC “DSC”. The concrete mix at experimental site was placed directly from concrete mixer after delivery to the object without vibration compaction, leveling the mixture with scrapers and slats. Roughness was created on the surface of coating with a metal brush. After treatment, the surface of coating for the care of concrete was applied water-dispersed film-forming composition of VPS-D.

The quality control of concrete mix of the test site was carried out directly at the site by specialists of YakutPNIIS, while controlling the consistence, density and air entrainment of concrete mix, and samples of concrete mix were taken to control the strength, density, porosity, abrasion and frost resistance of concrete. Confirmed that specified design requirements B30 Bt4.0 F2150 provided.

5. Conclusion
Experimental laboratory studies on development of concrete compositions for road and airfield pavements using local materials and subsequent development of concretes under production conditions, quality control of concrete mixtures and concretes have shown that using PFM-NLK modifier with plasticizing properties is an effective way of ensuring the durability of concrete air entraining ability. The possibility of spreading the developed technology for production of concretes of increased durability in the Far North regions, including the development of the Arctic regions of Russia and the Republic (Sakha), due to the difficult conditions of both the harsh climatic and freezing and ground conditions of the region, and economic and environmental conditions is shown.

The study of concrete properties on local materials with PFM-NK modifier showed the possibility of providing the required indicators of road concrete. Based on this, it can be concluded that the use of concrete and reinforced concrete pavements of roads and airfields in the conditions of the Far North is expedient.

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