Innovative technical solution for emergency repair of a pressure tunnel water supply pipeline during its air passage over a river bed

Valeriy Naidenov
Institute of Mechanics
Bulgarian Academy of Science, Sofia, Bulgaria
valna53@mail.bg

Abstract: *The pressure water supply pipeline from the „Iskar Dam", which has existed since 1981, is the main one for the water supply of the city of Sofia with drinking water. The water pipeline, for the most part executed as a concrete vault tunnel (mantel), passes through complex mountainous terrain with a large difference in elevation. During the long-term active operation, the steel part of the air passage of the water pipeline over the „Porkolitsa River" suffered a serious accident - internal pressure implosion of the steel pipe. The latter prevented the normal water supply to the city and an urgent repair was required by replacing the air-passing steel pipe of the water pipeline. The report discusses a proposed and successfully implemented innovative technical solution for monolithic installation of a steel pipeline in existing tunnel excavations with concrete lining by using self-compacting concrete with shrinkage compensated admixture and with the participation of special an internal crystallization chemical admixture, tailored to the specific requirements of the site. A prescribed composition of self-compacting concrete has been developed, the necessary control has been carried out during the batching plant production of the fresh concrete with monitoring of technical indicators. A technological regulation has been developed for the transport, laying and care of the concrete. During the site laying, standard sampling and testing have been carried out to prove the compressive strength at different ages of the concrete. Based on the above, in conclusion, the effectiveness of the developed and implemented innovative technical solution is certified.*

Keywords*:* PRESSURE WATER SUPPLY, SELF-COMPACTING CONCRETE, SHRINKAGE-COMPENSATING CHEMICAL ADMIXTURE, INTERNAL CRYSTALLIZATION CHEMICAL ADMIXTURE, COMPRESSIVE STRENGTH OF HARDENED CONCRETE

1. Introduction

The pressure water supply pipeline from the Iskar Dam, which has been in existence since 1981, is the main one for the water supply of the city of Sofia with drinking water. The water pipeline passes through complex mountainous terrain with a large elevation difference. Most of it is built using a tunnel method with a concrete lining (mantle) with a large diameter of about 3 m. In some of its sections, there is an air passage through ravines and mountain rivers, and in these areas the same passes into steel pipes with a similar, but smaller diameter, anchored to the underground concrete sections built in the slopes of the route. Ensuring the watertightness between the concrete arch lining and the steel pipe is carried out by embedding it in the depth of the tunnel part of the water pipeline and performing a concrete monolithic. In the process of many years of active operation, the steel part of the air passage over the Porkolitsa River suffered a serious accident - internal pressure implosion of the steel pipe. The latter prevents the normal water supply to the city and urgent repairs are required according to a previously developed project.

This project does not include a specific technical solution for the monolithic construction of the newly constructed steel pipe route in the area of the existing concrete tunnel excavations (mantle).

In this regard, the technical solution presented below is for the implementation of a monolithic completion of the concrete lining in the sections of the two opposite tunnels around the new steel pipe parts of the overhead part of the pipeline with a total length of about 38 m.

2. Technical solution

From the inspection of the construction site, it is evident that the length of the necessary additional monolithic construction after the construction of the new steel pipe distribution in the area of "tunnel 1" is of the order of 3 m, respectively about 2.5 m in the area of "tunnel 2".

In this case, the technical proposal contains reasons for the construction of the monolithic construction in question by using a prescribed mix design of self-compacting concrete (SCC - self compacting concrete), through which the desired monolithic construction can be performed in an original innovative way using simplified technology without the use of sealing agents (given the inaccessibility of the monolithic construction area) at an optimal price.

2.1. Self-compacting grouting concrete

Using the method of dense volumes and successive approximations, **a prescribed mix design of innovative self-compacting high-strength concrete with fully compensated shrinkage*) and with the participation of an internal-crystallizing chemical admixture**) for achieving full waterproofness of the constructed concrete section to the tunnel contour,** has been designed, in accordance with the requirements of BDS EN 206:2013+A2:2021 Concrete. Specification, properties, production and conformity (item 3.1.1.10) and BDS EN 206:2013+A2:2021 Concrete, updated in 2021. Specification, properties, production and compliance/National Application NA:2021, with compressive strength class C 35/45 MPa.

KEPTONITE*) is an innovative product capable of counteracting the natural shrinkage processes of cement composites, by reducing their micro-porosity and causing a sealing effect. The specific action of **KEPTONITE** compensates for volumetric shrinkage, and in special cases can completely overcome it to a degree of controlled self-tensioning. In this way, when designing the composition of the concrete, a certain controlled level of expansion can be achieved, through which the physics-mechanical properties of the concrete can be increased, as well as its corrosion resistance. After homogenization in the composition of the concrete, **KEPTONITE** directly affects the ongoing hydration processes, causing volumetric expansion, which counteracts the shrinkage processes in its various phases. In this way, the intermolecular structural parameters are increased, which in turn increases the physis-mechanical and structural characteristics of the hardened concrete, while also increasing its corrosion resistance and durability [1,2].

KRYSTALIN Add1)** is an innovative product of the latest generation - a crystallizing waterproofing admixture for cement concrete and mortars with permanent action, designed to waterproof and increase the durability of concrete by applying a new internal crystallization technology based on hydrophilic development of additional hydration processes in the concrete structure. It has the ability to reduce the water-cement ratio and self-fill cracks up to 0,5-0,7 mm wide in the concrete cross-section (self-healing ability) [3].

The designed composition of the concrete also complies with the requirements for resistance to corrosive environmental and production factors.

Given the location of the site (mountainous location and remoteness from a concrete manufacturer), all specific environmental and operational environment impact factors for external application should be taken into account during the design, complying with the requirements of BDS EN 206:2013+A2:2021 Concrete. Specification, properties, production conformity and BDS EN 206:2013+A2:2021/NA:2021 Concrete. Specification, properties, production conformity. National Annex (NA).

In this case, in accordance with the classification in BDS EN 206:2013 + A2:2021 (Table 1 - Impact classes, p. 24), the possible aggressive factors of the environmental and operational environment are:

- Corrosion caused by carbonation XC4 - cyclic wetting and drying of concrete surfaces in contact with water, which do not belong to impact class XC2;
- Impact of cyclic "freeze/thaw" without de-icing agents XF3 - strong water saturation without de-icing agent, concrete surfaces exposed to rain and freezing.

The limit values of the concrete composition for each of the specified aggressive environments are determined in accordance with the requirements of BDS EN 206:2013 + A2:2021/NA:2021 (Table NA.F.1a - Limit values for composition and properties of concrete).

The dominant requirements for the composition of the concrete are:

- Compressive strength class C30/37;
- Maximum water-cement ratio 0,50;
- Minimum cement content (without CRM) 320 kg/m^3;
- Frost resistance C_{fr}150 (150 cycles);
- Mineral aggregates with frost resistance F1, MS18;
- Air content 5%.

In addition to the above, there are additional specific requirements arising from the specifics of the site. They are determined by the location of the site, long transport conditions in mountainous conditions, climatic conditions during execution, mandatory laying with a truck-mounted concrete pump, if it is impossible to use conventional dencification equipment (vibrators of different types), as well as the need to ensure an absolutely impermeable connection between the existing concrete lining, resp. newly constructed steel pipe, and newly laid self-compacting concrete sealing the contour.

The above also requires:

- alternative inclusion in the composition of the concrete, in addition to highly range water-reducing chemical admixtures, and such according to atmospheric conditions - retardants at high temperatures;
- compensated free deformations of the concrete from shrinkage, which is achieved by using a special anti-shrinkage agent **Keptonite*)** with an optimal consumption rate and ability to achieve a certain degree of self-tensioning for sealing the concrete section;
- to ensure the required degree of frost resistance C_{fr}150, in accordance with the requirements of the standards, instead of ensuring air entrainment in the concrete mix (5% with a maximum size of the additives D_{max} 25 mm), it is permissible to work with other means to ensure such a degree of frost resistance.

In this case, given the transport distance, I decide to use an innovative internal crystallization chemical admixture **Krystaline Add1****)** instead of air entrainment in the composition of the concrete mix, provided with air-entraining chemical admixtures, which has a proven highly positive effect in increasing the density of the section and its frost resistance:

- increasing the compressive strength class of the concrete to C35/45, as well as ensuring a consistency of the concrete mix typical of self-compacting concrete, in accordance with the requirements of BDS EN 206:2013 + A2:2021, Annex G (Guidelines for self-compacting concrete requirements in the fresh-state – G1 to G2) and SF2 (slump-flow test in accordance with EN 12350-8).

In addition to the above, there are additional specific requirements arising from the specifics of the site. They are determined by the location of the site, long transport conditions in mountainous conditions, climatic conditions during execution, mandatory laying with a truck-mounted concrete pump, if it is impossible to use conventional sealing agents (vibrators of different types), as well as the need to ensure an absolutely impermeable connection between the existing concrete lining, resp. newly constructed steel pipe, and newly laid self-compacting concrete sealing the contour.

In accordance with all of the above, and based on the materials used by HYDROBETON OOD as the nominated manufacturer and supplier of concrete, I specify the following concrete composition (Table 1):

Table 1: *Prescribed concrete mix design*

Concrete component	**Quantity ***), kg/m^3**
Portland cement cement CEM II A-LL 42,5R Cement plant "Devnya"	420
Fly ash TPP "Sliven"	40
River sand, fr. 0-4 mm, "Chelopechene" site	400
Crushed sand, fr. 0-4 mm, "Hydromineral" site, village of Studena	444
Crushed stone, fr. 4-11,2 mm, "Hydromineral" plant, village of Studena	407
Crushed stone, fr. 11,.2-22,4 mm, "Hydromineral" plant, village of Studena	442
Polycarboxylate high range water-reducing chemical admixture PC 130 Don Construction Products	4,20
Setting and hardening retarder R50 Don Construction Products	1,05
Internal crystallization chemical additive Krystaline Add1	1,00
Shrinkage compensator Keptonite	15,00
Mixing water	190
Water-cement ratio	0,45
Consistency (slump-flow test), mm	SF2 – 660-750

***) for dry components

2.2. Ready-mix fresh concrete production

The production of the concrete mix was organized and carried out at the concrete batching plant HYDROBETON OOD, Gorublyane base, adhering to the developed recipe (see Table 1), and the special additives **Krystaline Add1** and **Keptonite** (Photos 1 and 2) were added at the specified consumption rates during the homogenization of the concrete mix (Photos 3 and 4).

Photo 1

Photo 2

Photo 3

Photo 4

2.3. Specialized sampling and testing for concrete quality

During laying, specialized standard sampling, laboratory standard aging and testing were organized and conducted with analysis of the results obtained and issuance of a report by an accredited testing laboratory for the characteristics of the self-compacting monolithic concrete.

Sampling and testing of the test specimens (cubes 15x15x15 cm) was carried out by the UNIVERSITY CONSTRUCTION TESTING LABORATORY (USIL) of the UNIVERSITY OF ARCHITECTURE, CIVIL ENGINEERING AND GEODESY, Sofia, with an Accreditation Certificate in accordance with BDS EN ISO/IEC 17025:2018 of the Bulgarian Accreditation Service - reg. No. 239 LI of 10.01.2023. with validity until 10.01.2027 (Annex 3), as well as the relevant Order No. A10/10.01.2023 on the scope of accreditation of the Bulgarian Accreditation Service (Annex 4), which includes all the necessary competencies on the topic.

Standard sampling is illustrated in Photos 5-10.

Photo 5

Photo 6

Photo 7

Photo 8

Photo 9

Photo 10

The results obtained for the compressive strength of concrete at 7 and 28 days of age are and are presented in Table 2.

Table 2 *Compressive strength of concrete*

Compressive strength, MPa		**Value and tolerance of the indicator**
At 7 days of age	41,70 36,90 42,40 **Mean: 40,20**	**No requirements**
At 28 days of age	58,60 56,60 52,50 **Mean: 55,90**	**55,90 for class 35/45, acc. to BDS EN 206:2013 + A2:2021, Appl. NA.B. with number of results 2 to 4, each single result must be ≥ 0.95 f_{ck} (42.5 MPa), resp. average result ≥ 0.95 f_{ck} +1 (46 MPa)** **Check completed!**

2.4. Transportation, laying, handling and care after concreting

Before the concrete is delivered, the opening of each of the two tunnels is closed with a tight formwork, and technological measures have been taken to prevent the cement milk from leaking out of the concrete mixture by installing a sealing strip along the periphery of the contour, plus additional installation foam at individual positions. The laying is carried out by inserting the flexible hose of the positioned pump as far inward as possible through the technological opening left in the formwork. The concrete mixture is discharged and compacted by gravity, without the use of sealing agents. The consistency of the concrete mixture allows such an action while ensuring the quality of the concrete (Photos 11-19). For each of the two tunnels, the concrete is laid in two stages – initially up to about half of the volume of the opening, after which, the next day, the remaining amount necessary to fill the entire contour is delivered and laid. In this way, additional security is achieved regarding the exact positioning of the steel pipe axially and at the design level. Concrete care after placement consists solely of maintaining the formwork for a minimum of 2 days, after which the de-moulded concrete surface is periodically watered with water for up to 1 week.

Photo 11 Tunnel 1 – preparing for formwork

Photo 12 Tunnel 2 – preparing for formwork

Photo 13
Formwork completed

Photo 14
Formwork completed

Photo 15 Concreting

Photo 16 Concreting

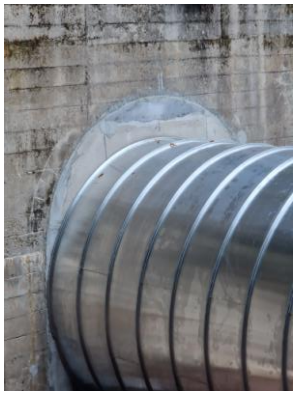

Photo 17
Tunnel 1 contour completed

Photo 18
Tunnel 2 contour completed

Photo 19 Site completed

3. Conclusion

In conclusion of the above, it can be confirmed that the developed innovative technical solution for grouting of steel pipeline in existing tunnel works with concrete lining by using self-compacting shrinkage-compensated concrete was implemented qualitatively by main-contractor **Promenergomontazhe AD** fully corresponding to the specific requirements of the site.

3. References

1. V. Naidenov**,** Innovative self-compacting fiber-reinforced concrete with compensated shrinkage for machinery steel anchors grouting, VI International Scientific Conference "INDUSTRY 4.0", Varna, June 2021, Year V, Volume 1/11, ISSN (PRINT) – 2535-0153, ISSN (on line) -2535-0161, p. (12-15.)

2. V. Naidenov, I. Rostovski, M. Mironova**,** Hybrid reinforced concrete with controlled volume deformations for hydrotechnical facilities, VII International Scientific Congress **"**INNOVATION 2022", Varna, 20-23. June, 2022, p. (41-45) ISSN 2603-3771 (Online) ISSN 2603-3763 (Print)

3. V. Naidenov, Extended research on the efficiency of internal crystallization chemical admixtures for cement concrete - mechanical and structural characteristics, Proc. of the IX International Scientific Congress "INNOVA' 2023", ISSN 2603-3771 (on line), ISSBN 2603-3763 (print), p. (40-45).