Innovative method for repair of reinforced concrete water facilities by "wet" shotcreting

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Abstract: *The report presents the different stages of development and implementation of two similar innovative technical solutions for repair and restoration of defected reinforced-concrete constructions of existing swimming pool and artificial lake using the methods of "wet" shotcreting. In the first case, the object of renovation is a seriously defected outdoor mineral pool of a prestigious hotel in the town of Hissarya. Given the significant leaks of water from the pool in the surrounding area over the years, a specialized technical inspection was initially conducted to determine the causes of defects in the main load-bearing monolithic steel-reinforced concrete construction - walls and bottom slab. An innovative technical solution has been proposed to restore the operational suitability of the pool, based on the possibility of using the existing load-bearing structure as external formwork for a new built-in load-bearing structure of the facility. The proposed solution envisages jointless thickening of the existing walls through additional reinforcement and concrete laying of new high-tech sprayed concrete. The bottom of the pool is being renovated by additional new layer of a hybrid fiber-reinforced jointless concrete slab and machine power-floated of the finishing surface. A composition of high-tech concrete with the participation of an internal crystallization chemical admixture and shrinkage-compensating one is proposed. A similar solution has been applied for the repair and restoration of the walls and bottom of an artificial lake in West Park, Sofia. Implementation of the project creates a unique art vision of the lake, the rock garden and the surrounding park space. This pilot implementation creates objective preconditions for expanding the range of innovative concrete structural systems, which, in addition to specific functions, are also applicable as opportunities for aestheticizing the urban and park environment.*
Keywords*: WATER FACILITIES, HYBRID FIBER-REINFORCED CONCRETE, INTERNAL CRYSTALLIZATION CHEMICAL ADMIXTURE AND SHRINKAGE-COMPENSATING ADMIXTURE, CONCRETE JOINT-FREE SLAB, SHOTCRETING*

1. Introduction

It is well-known that shotcreting is a special building technology patented in 1911 by Dr. Carl Akeley, curator at the Field Columbian Museum in Chicago. The system enables one to deposit a cement-sand mix or concrete on various surfaces via high pressure and without shuttering (forming) using a special equipment- a shotcreting machine and air compressor. In fact, this is a method of conveying concrete or mortar through a hose and pneumatically projecting it at high velocity onto a surface without additional compaction. This predetermines a number of essential advantages - high density and strength, low permeability (high water impermeability), high corrosion resistance, minimized shrinkage etc.

Two basic methods of shotcreting exist – "dry" and "wet" method.

A mix with cement and added sand, fraction (0-4 mm), prepared "dry" and deposited on a surface is known as "dry" shotcrete while that with aggregate fraction up to 20 mm - as "dry" sprayed concrete. Water is separately supplied through another hose.

The system for "wet" shotcreting employs special machines and supposes deposition of a specific concrete "wet" mix design. Its preparation is centralized at concrete batching plant and its consistency is précised (the usual water/cement ratio is below 0,45). Wet" shotcreting is based on work with certified concrete mixes, being "intentionally" designed and industrially prepared. Their optimization is flexible to meet the specific technical requirements and conditions of exploitation. A potential of multi-factor optimization of the mix composition also exists. It consists in the variability of selection of cement, aggregates, special chemical admixture with high-range water reduction effect, special in-depth crystallizers and polymer modifiers, fiber-reinforcement consisting of various types of fibers etc. The basic advantages of the method are its increased productivity, possibilities of a single-stage deposition of a thick layer, minimal operational subjectivity and increased ecology-friendliness of mix homogenization and deposition. A disadvantage of the method is the impossibility of its application if there is no certified concrete plant nearby.

Summarizing all advantages and possible specific building applications of "wet" shotcreting it could be concluded that new innovative methods for repair of damaged reinforced concrete water facilities (as swimming and spa-pools, artificial lakes etc.) by "wet" shotcreting is very attractive one [1].

It should be preliminary added that most of these types of reinforced-concrete structures are with special geometrical shapes - oval, elliptical, variable sizes in plan and height. That's the reason to estimate all conventional formworks available as unappropriated for using ones. Logically observe, in such specific cases, damage repairing by shotcreting is should be estimated as most preferable one.

In this connection below are discussed two specific innovative technical solutions for repairing works in such facilities - spa outdoor swimming pool in a prestigious hotel in Hissarya, and an artificial lake in West Park in Sofia.

2. Spa-outdoor swimming pool

2.1. Pool characteristics

The pool complex was designed and built in 2003 and contain 3 closely connected areas located in different design levels – main pool, children pool and water bar. Total area of the pool is around 1500 m^2 - (Photos 1 and 2). Main load-bearing structure is monolithic reinforced concrete - walls and bottom slab with plumbing channels located in it. From the provided reinforcement plans it is seen that the steel reinforcement for the bottom slab and walls of the pool should be double (Ø12 every 15 cm in both directions). The designed concrete is intended to have a compressive strength class C12/15 (water tightness 0,4). The thickness of the walls and bottom of the pool is 20 cm.

During the nearly 20 years of operation in the construction of the pool, many defects were observed (mainly visible structural cracks and damage to the ceramic cladding on the walls and bottom slab), which led to abundant water leakage and flooding of the surrounding area**.**

In order to establish the causes of such defects, a detailed constructive inspection was initially carried out.

In the scope of the constructive survey performed are included:

- Study of the available technical documentation;
- Technical inspection on site, verification of the geometry according to the provided geodesy survey, establishment of dimensions of characteristic sections of the structural elements, establishment of local defects;
- Cracks width measuring – Photos 3 and 4;
- Determining the compressive strength of concrete by testing test specimens (cores) cut from the structure of the site and checking their compliance with standard requirements – Photos 5, 6 and 8;
- Determining the degree of carbonization of existing concrete – **Photo 7**;
- Establishing the type and technical parameters of existing steel reinforcement by direct scanning – Photos 9 and 10.

All tests are performed in accordance of actual national BG and EN standards.

Photo 1 *Pool general view*

Photo 2 *Pool general view from above*

Photo 3 *Crack width measuring*

Photo 4 *Crack width measuring*

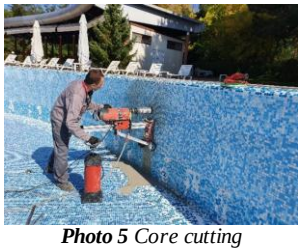

Photo 5 *Core cutting*

Photo 6 *Bottom slab core №3 with length 25 cm (lower steel reinforcement Ø8 cm, located at 17 cm from the upper edge of the bottom, only)*

Photo 7 *Zero concrete carbonation established by colorization method*

Photo 8 *Concrete compressive test*

Photo 9 *Direct scanning existing steel reinforcement*

Photo 10 *Direct scanning existing steel reinforcement - visualization*

The most of obtained objective results from the implementation of the planned specialized measures within the framework of the constructive inspection for the condition of the bearing steel-reinforced concrete construction of the facility can be summarized as follows:

- The experimentally determined compressive strength class of the executed concrete for the walls and bottom slab is C30/37, exceeding the design one (C12/15);
- It was found zero carbonization in the cross section, which means that the steel reinforcement is reliably protected against corrosion;
- The design details for the implementation of the bottom slab are not performed correctly, both in terms of design thickness and in terms of the method of reinforcement - the waterproofing of the "lower edge" elevation provided in the project is missing, design thickness of 20 cm has not been observed (there are thicknesses between 7 and 27 cm), only the lower steel reinforcement of Ø8 in 20 cm is made, instead of the designed double one of Ø12 in 15 cm;
- The design details for the construction of the walls of the pool have not been fulfilled, too - Instead of two rows steel reinforcement with Ø12 in every 15 cm, two rows Ø8 in every 20 cm are made, the project lacks a connection detail (with watertightness provided) between the individual stage of the walls casting.

Summarizing all mention above, these are the main reasons for the defects and damages found during the operation of the facility.

2.2. Technical solution for repairing

Taking into account all structural and technological consideration, plus the results and conclusions from the structural investigation performed, innovative technical solution for repairing works is proposed - Fig. 1 and 2:

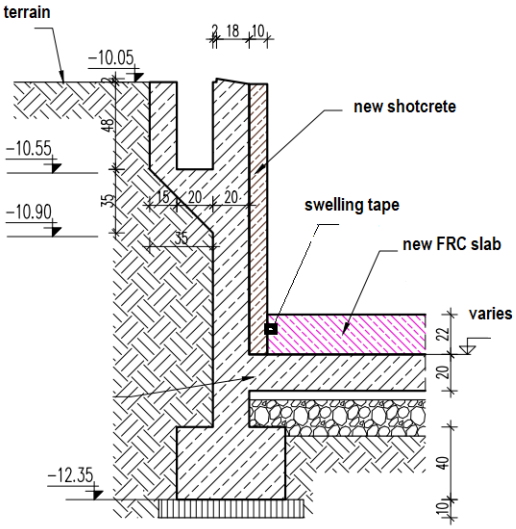

Fig. 1 *Principal cross-section*

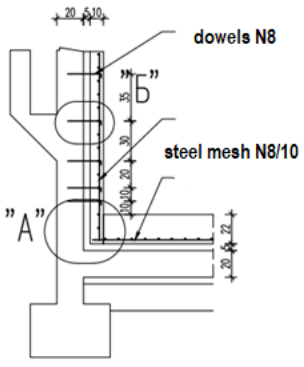

Fig. 2 *Cross-section steel-reinforcement*

- **NEW WALLS - thickness 10 cm, reinforced with N8/10 mesh made of B500 steel (doweled in the existing walls), executed by on the existing walls without removing the existing finish. One-stage execution without any joints.**

Concrete requirements: High-tech fine-grained (D_{max} 8 mm) fiber-reinforced waterproof sprayed concrete with compressive strength class C35/45, micro-polypropylene fiber-branched 12/18 mm (dosage rate 1,00 kg/m^3), 4G-internal crystallization chemical admixture KRYSTALINE Add1 (dosage rate 1,0 kg/m^3), shrinkage compensating admixture KEPTONITE (dosage rate 15,00 kg/m^3), high-range water reducing agent, with additionally resistance to aggressive environmental factors XC3, XF3, XD2 and consistency class S2 with water-cement ratio below 0,45.

- **NEW BOTTOM SLAB - thickness 22 cm, reinforced with N8/10 lower mesh made of B500 steel, executed on the existing bottom slab without removing the existing finish. One-stage execution by power floating machines without any joints.**

Concrete requirements: High-tech ordinary-grained (D_{max} 22,4 mm) fiber-reinforced waterproof pumpable concrete with compressive strength class C35/45, micro-polypropylene fiber-branched 12/18 mm (dosage rate 1,00 kg/m^3), steel firbres HE 0,75x35 mm (dosage rate 25,00 kg/m^3), 4G-internal crystallization chemical admixture KRYSTALINE Add1 (dosage rate 1,0 kg/ m^3), shrinkage compensating admixture KEPTONITE (dosage rate 15,00 kg/m^3), high-range water reducing agent, additionally with resistance to aggressive environmental factors XC3, XF3, XD2 and consistency class S3 with water-cement ratio below 0,45.

The main principle of the proposed technical solution is the requirement that the repair work on the walls and bottom slab to be carried out in one technological cycle (stage), without any joints. In this way the best adhesion connection between the walls and the bottom is achieved and the watertightness of the facility is ensured. In such a direction is the need to install in detail and water-swellable tape in the contact zone between the bottom and the bottom. The security of the proposed jointless solution is based on the specific action of the included special chemical admixtures [2,3] and the method of hybrid reinforcement - a combination of conventional steel reinforcement and disperse reinforcement, including different types of fibers.

2.3. Execution of the solution

All designed structural repairing works are executed in one-stage in the of February, 2022. Fresh concrete is produced in the new equipped respective batching plant ECOMIX in accordance of specially prepared concrete mix design.

Photo 11 *ECOMIX concrete batching plant*

Photo 12 *Walls and bottom slab steel mesh fixing*

The concrete casting sequences fully complied to the planned one – at first all walls shotcreting works are finished and after them the bottom slab casting was started.

Shotcreting is performed by using 2 specialized machines and compressors, working in parallel - Photos 11-14. After that bottom slab concreting was started by using additional stationary concrete pump. The finishing works were based on special power floating machines.

Photo 13 *Concrete pumps used*

Photo 14 *Piping for concrete horizontal transport*

Photo 15 *Walls shotcreting*

Photo 16 *Walls shotcreting*

Photo 17 *Botom slab concrete casting*

Photo 18 *View of finished concrete works*

Approximately 250 m^3 innovative sprayed and conventional concrete were casted, as the entire structural repairing works are completed and finished in range of 18 hours. After respective concrete curing measures additional polymer-finishing works will be in progress. Dead line of all repairing works is the end of April, 2022.

3. Artificial lake

In pursuance of the investment program of the SOFIA CITY MUNICIPALITY, in the period 2019-2021 a complete renovation of "West Park", the second largest park in Sofia, was in progress, including emblematic for the city parts of it - the artificial lake and rock garden.

We proposed an innovative technical solution for the execution of concrete works on walls and bottom slab by using high-tech hybrid fiber-reinforced sprayed concrete according to a specially developed recipe of a multifunctional capillary crystallization system for permanent autogenous waterproofing of concrete, based on the use of a deep crystallizing chemical additive KRYSTALINE Add 1 (dosage rate 1,0 kg/m^3 concrete) - Fig. 3.

One stage of concrete slab and walls spraying in participation of KRYSTALINE Add 1 and special admixture KEPTONITE (dosage rate 15,00 kg/m^3) for full range shrinkage controlling, leads to form completely joint-free water-tight structural system. This innovation makes it possible to eliminate the need for all additional waterproofing works.

The implementation was carried out in the autumn of 2020 by TORCREET EXPERT Ltd. in a continuous production process for 20 hours with parallel use 3 teams with three sets of mechanization - modern shotcrete machines and technological kits to them, pipelines and spray nozzles.

After two weeks of curing the sprayed concrete, in accordance with the developed architectural and landscape project, the

installation of the lining of part of the lake walls with natural stone (granite), laid and adhered to the executed sprayed concrete using high quality polymer-modified silicate binder material.

After nearly a year of trouble-free operation, the overall implementation of the project creates a unique art vision of the lake, rock garden and the surrounding park area.

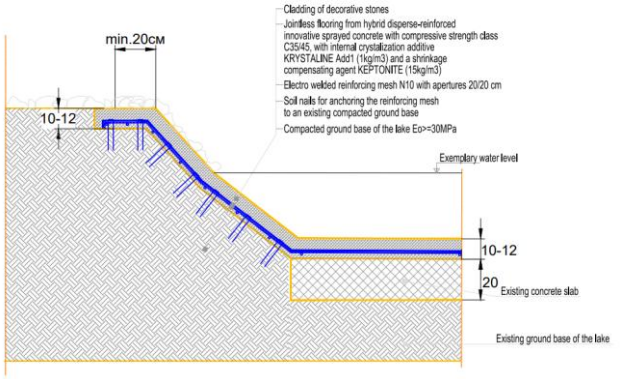

Fig. 3 *Cross-section detail*

This pilot implementation creates objective preconditions for expanding the range of innovative structural systems, which, in addition to specific structural functions, are also applicable as opportunities for aestheticizing the urban and park environment.

Photo 19 *Deployment of two concrete pumps for simultaneous operation*

Photo 20 *Wall spraying*

Photo 21 Wall spraying

Photo 22 Finished area – walls and bottom slab

Photo 23 Final art vision with natural rocks lining

Photo 24 Final art vision with natural rocks lining

4. Conclusions

In summary of the above, it can be argued that the use of high-tech hybrid reinforced sprayed "wet" concrete for the construction and repair of water facilities is an innovative approach with certain advantages. The inclusion in the concrete mix design high-performance special chemical internal-crystallization chemical admixtures improve the watertightness of the cross-section with additional benefits for self-heling of cracking. Additionally proposed shrinkage compensating admixture allows to design and execute some join-free surface concrete structures (walls and bottom slabs), without organization of different types of joints – daily, cold and saw cut etc.

The proposed and successfully implemented innovative technical solutions for specific water facilities are a good prerequisite for successful expansion of the scope of this approach, which increases the efficiency of the performed repair works and shortens the construction period.

Acknowledgments

The financial support of the National Science Fund of Ministry of Education and Science, Bulgaria, contract H 27/29, 2018, is gratefully acknowledged.

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