HYBRID FIBER-REINFORCED SPECIAL CONCRETES FOR UNDERWATER CONCRETING

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Abstract

The forthcoming repair works on the pier wall of the port of Bourgas envisage the construction of a combined structural and protective barrier against the ongoing processes of suffusion from the quay wall to the sea. On the water side of the quay, the construction of a pilot system with two types of poured concrete piles with different diameters for barrier counteraction against suffusion is envisaged.

The forming wavy vertical protective wall is at a distance from the existing quay wall, built of concrete blocks with relatively displaced geometry, which does not provide a smooth vertical surface for direct contact with the pilot system.

In this regard, the need to design a technological option for dense filling of the volume between the existing concrete blocks and the pilot system designed for construction is in favor of the effective solution of the complex technical task.

The report proposes an innovative technical solution based on the specific characteristics of specially designed sulphate-resistant hybrid fiber-reinforced concrete for underwater concreting with high strength-deformation characteristics, resistant to the aggressive effects of operation in seawater. The developed working concrete mix design includes special corrosion-resistant steel fibers and special chemical admixtures – high range water reducing admixture (HRWRA), internal crystallization chemical one and anti-washout admixture (covering the specific requirements of the US Army Corps of Engineers - CRD - C661-06 Specification for Anti-Washout Admixtures).

The obtained main strength-deformation indicators of the proposed composition of the special concrete are discussed, which confirms the possibility of satisfying all technological requirements for the project.

Keywords: *suffusion, concrete for underwater pouring, environmental factors, pilot concrete structures, concrete mix design, drying shrinkage, high-range water reducing agents, anti-wash-out admixtures, internal cristaization admixtures, concrete test characteristics*

1. INTRODUCTION

The forthcoming repair works on the pier wall of the port of Bourgas envisage the construction of a combined structural and protective barrier against the ongoing processes of suffusion from the pier wall to the sea. On the water side of the quay, the construction of a specially designed pilot system with two types of poured concrete piles with different diameters (250 and 800 mm) for barrier counteraction against suffusion is already envisaged.

The forming wavy vertical protective wall is at a distance from the existing quay wall, built of concrete blocks with relatively displaced geometry, which does not provide a smooth vertical surface for direct contact with the pilot system.

In this regard, the need to design a technological option for dense filling of the volume between the existing concrete blocks and this pilot system for construction is in favor of the effective solution of the complex technical tasks.

2. TECHNICAL SOLUTION

The respective technical solution proposed for detailing discussion is based on the strength-deformation characteristics of the hybrid fiber-reinforced concretes – **Figure 1.**

It is well-known that 3D-fiber-reinforcement with steel fibres transforms the hardened concrete into a more deformable composite system with the same characteristics of the whole section, capable of absorbing higher tensile stresses, including at alternating loads and after the development of crack formation processes. This sharply increases the resistance to brittle fracture, increases the residual strength after the first crack, fatigue strength under long-term load and impact strength, which ensures the integrity of the concrete even when the load-bearing capacity is exhausted. All qualitied steel fibres have respectively capability to reduce the width of some cracks, also. All these gives enough reason for expecting good structural and mechanical behaviors of those type of concrete.

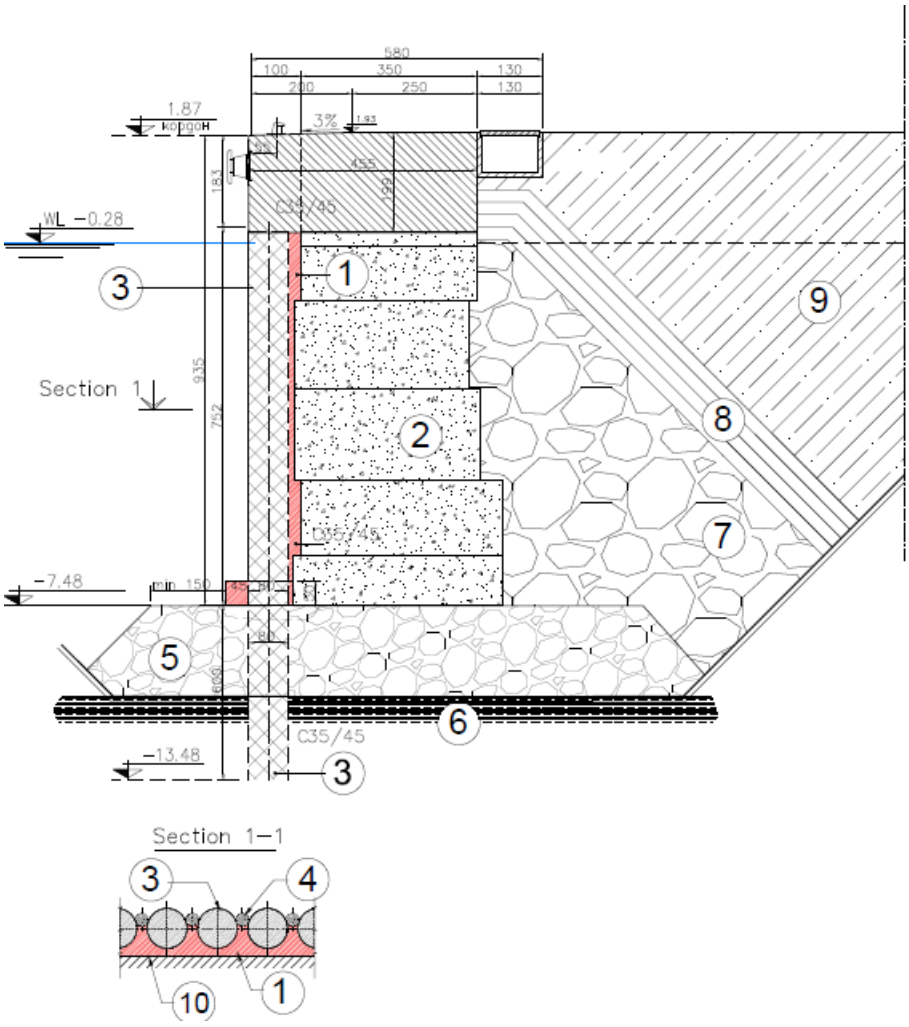


Figure 1. Vertical cross-section of the underwater structure

1- new underwater structure based on innovative hybrid-reinforced concrete with internal crystallization admixture; 2- existing concrete blocks; 3- new poured pilots with diameter 800 mm; 4 - new poured pilots with diameter 250 mm; 5 – existing rocks massive; 6 – clay base; 7 – crashed stones; 8 – clay based on old design; 9 – backfilling; 10 – existing pier wall

In addition, there is a direct need for the proposed concrete mix design to comply with the technological requirements of underwater concreting, as follows:

- specifying degrees of resistance against the current factors of the environment;

- strength-deformation characteristics;

- suitability for underwater concreting technology;

- special chemical admixtures for underwater concrete – high range water reducer (HRWRA) and anti-wash ones;

- the need to ensure the design durability of the concrete exposed in seawater by including an innovative high-performance internal-crystallizing chemical admixture with permanent action in time, capable of compacting additionally formed concrete structure, ensuring impermeability of the protective section.

3. CONCRETE

All considerations for proper innovative concrete mix design are summarized below:

3.1. Requirements

Early from the very beginning it should be noted that in terms of the characteristics of concrete intended for underwater concreting, the basic regulations in Bulgaria, the EU and the world are very limited.

BDS EN 206: 2016 / NA: 2017 "Concrete. Specification, properties, production and conformity. National application (NA)" includes a clause directly aimed at concrete for underwater concreting - NA.5.3.4. Requirements for the concrete mixture laid under water:

(1) stipulates that in such cases the concrete mix should have a consistency of more than 180 mm, according to the requirements of BDS EN 12350-2 “Testing of concrete mix. Part 2: Determination of slump”. Also, the water-cement ratio should always be below 0.60, regardless of the specified class on resistance to exploitation factors;

(2) stipulates that during laying the fresh concrete must flow under the influence of its own weight, maintaining its cohesion and compacting without additional vibration action. All this implies a content of fine particles exceeding the maximum allowable according to the requirements of Table. NA.F.4 of the same document.

With regard to all other parameters of the fresh and hardened concrete intended for underwater concreting, the basic requirements for ordinary concrete are strictly applied.

Relatively complete information on concretes intended for underwater concreting can be found in ACI Committee Report 304R-00 "Guide for Measuring, Mixing, Transporting, and Placing Concrete (American Concrete Institute), Chapter 8 - Concrete placed underwater". The document contains general information, basic methods and techniques of underwater concreting, suitable materials, design of concrete mixes, production and transportation, testing methods, concrete laying technology, characteristics of hardened concrete and safety measures.

Another document of high level of information and significance available to NATO member countries is the Technical Report INP-SL-1 (September 1999), developed by the US Army Corps of Engineers (Research and Development Center) entitled "Assessment of Underwater Concrete Technologies for In-the-Wet Construction of Navigation Structures". To some extent, this document is considered fundamental for the implementation of specialized construction work related to underwater concreting of building structures.

Within the same department of special importance is the developed specialized document CDR-C 61 "Test Method for Determining the Resistance of Freshly Mix Concrete to Washing out of Water" [5], which allows for an objective laboratory evaluation of the effectiveness of various chemical admixtures used for reducing the washability of the fine-grain particles in the fresh concrete during underwater concreting.

The composition of the designed concrete for underwater concreting is subject to specific requirements that determine the effectiveness of its application, namely the ability to:

- low washability of fine particles in contact with sea water;

- self-compaction and self-leveling;

- maintaining the design consistency for time (slump retention) in accordance with the work schedule;

- high cohesiveness of the fresh concrete, preventing sedimentation and segregation;

- low degree of heat release during hydration**;**

- bleeding water minimizing;

- controlled setting time (initial and final);

- controlled increase of strength characteristics over time;

- minimizing the creep and relaxation of stresses;

- high degree of abrasion resistance in seawater.

In summary of all the above, it can be said that the responsibilities of the concrete mix design specifier of concrete intended for under water pouring, which should take into account existing European and world guidelines and regulations, as well as good manufacturing practice, are greatly increased in this specific segment of concrete works.

3.2. Environmental factors

The concept of ensuring design durability based on the specification of minimum requirements for the composition of concrete in accordance with the requirements of BDS EN 1992-1-1: 2005 Eurocode 2: "Design of concrete reinforced concrete structures, Part 1-1: General rules and rules for buildings", resp. National Annex (NA: 2011) to it, is specified below.

In addition to the technological and mechanical characteristics, the marine structure is simultaneously subjected to long-term action of environmental and operational factors - physical and chemical influences. The latter are classified in BDS EN 206: 2016 "Concrete. Specification, properties, production and conformity", resp. National Annex/NA: 2017 - **Table 1.**

The impact factors related to this specific marine structure are accordingly highlighted in the **Table 1** in green and summarized in **Table 1.**

Corrosion factor classes	**Short description**
Corrosion due to carbonation XC2	Concrete surfaces durably washed by water
Corrosion due to sea water chlorides XS3	Sections of sea structures
Freezing/thawing impacts with or without thawing agents XF4	Areas of splashing of sea structures exposed to freezing
Chemical impacts XA2	Concrete surfaces durably washed by sea water

Table 1. Summarized corrosion factors

In BDS EN 206: 2016 "Concrete. Specification, properties, production and conformity", in Annex F are given the relevant recommendations for the limit values of the concrete mix design in order to effectively counteract various aggressive factors affecting the environment and production conditions - **Table 2.**

	Without risk of corrosion or aggressive impacts	Carbonation generating corrosion				Chlorides generating corrosion						Impacts of freezing/thawing				Chemically aggressive environment		
						Sea water			Non-sea water chlorides									
	X0	XC1	XC2	XC3	XC4	XS1	XS2	XS3	XD1	XD2	XD3	XF1	XF2	XF3	XF4	XA1	XA2	XA3
Maximal water/cement ratio *w /c*	–	0,65	0,60	0,55	0,50	0,50	0,45	0,45	0,55	0,55	0,45	0,55	0,55	0,50	0,45	0,55	0,50	**0,45**
Minimal strength-reflecting class	C12/15	C20/25	C25/30	C30/37	C30/37	C30/37	C35/45	C35/45	C30/37	C30/37	C35/45	C30/37	C25/30	C30/37	C30/37	C30/37	C30/37	**C35/45**
Minimal cement content [c] (kg/m³)	–	260	280	280	300	300	320	340	300	300	320	300	300	320	340	300	320	**360**
Minimal air contents (%)	–	–	–	–	–	–	–	–	–	–	–	–	4,0[a]	4,0[a]	4,0[a]	–	–	–
Other requirements	–	–	–	–	–	–	–	–	–	–	–	Aggregates pursuant to EN 12620, with sufficient resistance to freezing/thawing				–	**Sulfate resistant cement [b]**	

[a] When there is no air in concrete, mix exploitation properties should be tested pursuant to appropriate methods, and the results found should be compared to those for concrete with proved resistance to freezing/thawing considering the subsequent class of environmental impacts.

[b] When environmental sulfates yield the use of impact-reflecting classes of concrete XA2 and XA3, it is important to use sulfate resistant cement conforming to EN 197-1 or to additional national standards.

[c] Applying the concept of *k*-value, the maximal water/cement ratio *w/c* and the minimal cement contents vary in conformity with 5.2.5.2.

Table 2. Accordance Annex F, BDS EN 206: 2016 – Classes reflecting environmental impacts

Comparing the specific requirements for concrete in accordance with the degree of impact of individual aggressive factors is the most unfavorable satisfaction of the requirements dictated by the impact class of seawater chlorides XS3, compliant with the additional requirements for the use of sulfate-resistant cement as part of the requirements in chemical aggression (seawater sulphates) XA2.

So, the latter requires the use of concrete with:

- compressive strength class C35/45;

- maximum water-cement ratio 0,45;

- minimum cement content 340 kg/m^3;

- use of sulphate-resistant cement.

With regard to the need to use sulphate-resistant cement, the efficiency and affordability of its selection should be assessed.

The technical requirements for cement are regulated in the harmonized European standard BDS EN 197-1: 2011 “Cement. Part 1: Composition, requirements and conformity criteria for ordinary cements”.

According to the current standard, cements are divided into 5 (five) types and 27 (twenty-seven) sub-types. Sulphate-resistant cements are those that meet the additional requirements for sulphate resistance, which are related to the composition of the cements and / or the mineral composition of the clinker (tricalcium aluminate content - C_3A), which is used for their production. The mentioned requirements are described in **item 6.2** of the referred standard.

In **Table 3** below are given the seven products from the family of sulphate-resistant ordinary cements included in EN 197-1.

Type	Description		Composition, mass %[a]				
			Basic components				Additional components
			Clinker (K)	Slag (S)	Natural pozzolans (P)	Fly ash (V)	
CEM I	Sulphate resistant Portland cement	CEM I-SR 0 CEM I-SR 3 **CEM I-SR 5**	95 - 100	-	-	-	0 - 5
CEM III	Sulphate resistant slag cement	**CEM III/B–SR**	20 - 34	66 - 80	-	-	0 - 5
		CEM III/C–SR	5 - 19	81 - 95	-	-	0 - 5
CEM IV	Sulphate resistant pozzolanic cement[b]	CEM IV/A–SR	65 - 79	-	21 - 35		0 - 5
		CEM IV/B–SR	45 - 64	-	36 - 55		0 - 5

a - Table indexes are intended to the sum of basic and additional components.

b - In CEM IV /A-SR и CEM IV /B-SR the basic components different by clinker, have to be declared by cement's indexes

Table 3. Sulphate-resistant ordinary cements

It is visible that the sulphate-resistant Portland cements ordinary cements are grouped as follows:

- **CEM I – SR 0** (quantity of C_3A in clinker = 0 %);
- **CEM I – SR 3** (quantity of C_3A in clinker ≤ 3 %);
- **CEM I – SR 5** (quantity of C_3A in clinker ≤ 5 %).

Concerning the sulphate-resistant slag cements, they are:

- **CEM III/B – SR** (no limits for quantity of C_3A in clinker);
- **CEM III/C – SR** (no limits for quantity of C_3A in clinker).

And for sulphate resistant pozzolanic cements:

- **CEM IV/A – SR** (quantity of C_3A in clinker ≤ 9 %);
- **CEM IV/B – SR** (quantity of C_3A in clinker ≤ 9 %).

From the mentioned above cements, some of them are produced in Bulgaria:

- **CEM I - SR 5 42,5 R** from TITAN CEMENT, town of Zlatna Panega;
- **CEM III/B – SR 42,5 N** FROM DEVNYA CEMENT**,** town of Devnya.

In this case, the expectations are for greater efficiency in the use of **CEM III/B - SR 42,5 N** (from DEVNYA CEMENT, Devnya), given the significant amount of ground blast furnace slag - involved in a specific way in the processes of hydration in underwater concreting, providing reduced exotherm and minimizing the risk of cracking by temperature gradient.

3.3. Mechanical characteristics

The requirements for project concrete with guaranteed resistance to the above environmental factors determine the use of concrete with a minimum compressive strength class C35/45 when using sulfate-resistant cement of the type specified above - CEM III/B - SR 42,5 N.

From a constructive point of view and in order to increase the stability of the additional intermediate layer between the existing concrete blocks of the pier wall and the pilot strengthening, it is necessary to include a suitable reinforcing system.

Given the limiting conditions for the construction of the protective structure under water, the installation of conventional rod reinforcement or steel welded mesh is highly complicated and, in practice, impossible.

That's the reason the technical solution proposed is to be based on a simplified technological possibility for underwater concreting using fiber-reinforced PRESCRIBED CONCRETE with a prescription mix design that meets the specific requirements.

According to the requirements of BDS EN 206: 2016 "Concrete. Specification, properties, production and conformity, National Annex / NA: 2017, item NA.5.1.7 Fibers, item NA. (2), the approval of the use of steel fibers is carried out only in the cases of reinforcement of PRESCRIBED CONCRETE, in the sense of the requirements of BDS EN 206: 2016, item 6.3. Specification of prescribed concrete.

The steel fibers used must comply with the requirements of BDS EN 14889-1: 2009 "Fiber for the reinforcement of concrete. Part I: Steel fibers - Definitions, requirements and conformity", as well as the National Annex to it BDS EN 14889-1/NA. The assessment and verification of the constancy of their performance must be performed according to "System 1" of the regulations on the essential requirements for construction products.

The use of steel fibres for structural purposes provides an excellent opportunity for effective 3D-reinforcement of the commented filling concrete layer, thus providing three-dimensional uniform characteristics of the concrete section, able to effectively withstand alternating loads. Selection of suitable fibers for the given technological application must comply with two key requirements:

- to allow their inclusion in the PRESCRIBED COMPOSITION OF CONCRETE FOR UNDERWATER CONCRETE, incl. the use of conventional methods for homogenization, transport and pouring with an ordinary auto-concrete pump;

- to be effective in underwater operation in sea water - with provided anti-corrosion surface protection.

In construction practice, steel fibers with factory surface corrosion protection are used relatively rarely. Most often such protection is carried out by surface brazing, galvanizing or by using stainless steels.

Taking into account some specific conditions of nowadays Bulgarian building practice it would be reasonable to use of stainless fibers for reinforcement, type "Hooked End" ZS/I 1,05x50 mm (manufacturer SPAJIC DOO, Republic of Serbia) at a dosage rate of 25 kg/m^3 concrete, with the following characteristics - **Table 4**:

Designation	**Length (L), mm**	**Diameter (d), mm**	**Aspect ratio L/d**	**Cross section**	**Tensile strength, N/mm^2**
ZS/I 1,05x50	50 ± 5 %	1,05 ± 5%	± 47	circle	2100

Table 4. Stainless steel fibres characteristics

3.4. Underwater concreting technology

There are two main methods for underwater concreting - the so called "Tremie-method", based on gravity pouring of fresh concrete in a vertical system of slightly inclined steel pipes reaching the bottom of the concrete surface, and by pouring under pressure using a conventional concrete pump with appropriate accessories – casings pipes. In both cases, additional compaction of the applied concrete mixture is impossible (*Christeena Kurian, M. Gandhi, P. Selvi, 2021).*

In this case, the pouring technology, respectively the concrete mix design, should be based on the possibilities for underwater concreting with an ordinary concrete pump - **Figure 2.**

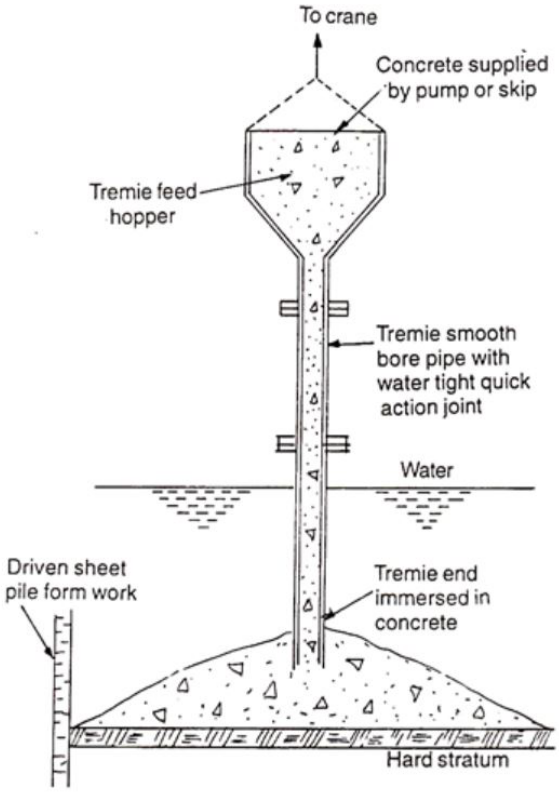


Figure 2. Tremie method for underwater concreting

3.5. Special chemical admixtures for underwater concreting

According to the requirements of the current legislation, for the selected concreting technology, as well as based on the principles of good manufacturing practice, the composition of the dispersed-reinforced PRESCRIBED CONCRETE should include special chemical admixtures in accordance with the specific conditions of underwater concreting.

To achieve the required workability with a limited water-cement ratio below 0,45, it could be used the high range water-reducing chemical admixture BASF Master Glenium SKY 691 - an innovative second-generation superplasticizer based on polycarboxylates (PCE) polymers. The admixture complies with BASF's concept of Total Performance Control™, based on guaranteed uniformity of product specifications. Master Glenium SKY 691 is specially developed for high-consistency rheo-plastic concrete as well as self-compacting concrete. Provides excellent preservation of the workability of the concrete mixture (more than 90 minutes), without a tendency to delamination, with low water-cement ratio - recommended dosage of 0,4 to 1,25% by weight of cement.

To preserve the characteristics of the designed concrete mixture in underwater concreting conditions, it is necessary to include a special anti-washout admixture, which prevents leaching of fine particles in the fresh concrete - binder and fine-aggregate fractions. It is possible to use a high-quality product for this purpose - BASF Master Matrix® UW450. The product is a patented, ready-to-use cellulose-based liquid with a special purpose for underwater concreting. Included in the composition of the concrete mixture, in contact with water, provides an effective barrier against leaching of fine fractions - cement, cement-replacement materials, fine-aggregate particles. Covers specific requirements of the US Army Corps of Engineers - CRD - C661-06 Specification for Anti-Washout Admixtures. It additionally eliminates the segregation of the concrete mixture and its tendency to delamination, improves thixotropy and eliminates water separation – recommended dosage rate of 260-1200 ml/ 100 kg of cement.

Trying to ensure the best quality performance of the concrete mix design an innovation approach is proposed by additionally inclusion of a deep-crystallizing internal chemical admixture KRYSTALINE Add1 HD with permanent action in time, capable of compacting additionally formed concrete structure, ensuring the impermeability of the built protective section *(Naidenov V., 2019), (Naidenov V., M. Mironova, I. Rostovsky, 2020).*

KRYSTALINE Add1 HD is a new generation crystallizing admixture for concrete and mortar, 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. In the presence of water, KRYSTALINE Add1 HD reacts with the active hydration products of the cement, resulting in the formation of new insoluble calcium silicate hydrate formations that fill the pores and capillaries in the cross section. They become an integral part of the cement paste in the concrete structure, as a result of which the concrete acquires the ability to prevent the water penetration.

KRYSTALINE Add1 HD technology eliminates the porosity of the concrete section, its inherent heterogeneity and the presence of micro-defects, which increases its durability. The ongoing additional hydration processes not only provide increased watertightness of the concrete, but also create opportunities for self-healing of microcracks of various origins without additional treatment. KRYSTALINE Add1 HD is added directly to the concrete batching plant in time of the fresh concrete homogenization, or at the construction site in the transport truck – dosage rate of 1,0 kg/m^3.

3.6. Prescribed concrete mix design

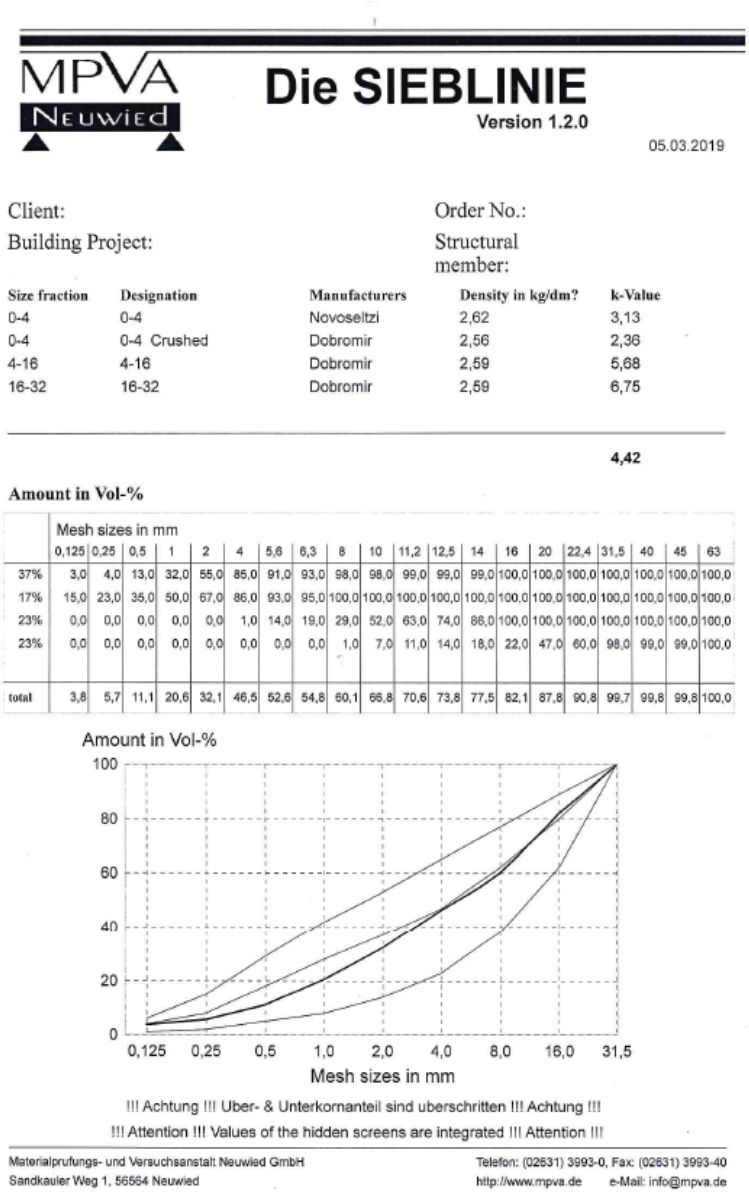
Taking into account all above mention consideration respective innovative prescribed concrete mix design for underwater concreting is proposed – **Table 5.**

№	**Components**	**Quantity, kg/m^3**
1.	Sulphate resistant slag cement **CEM III/B – SR 42,5 N** (DEVNYA CEMENT)	355,00
2.	Fly ash	80,00
3.	River sand, 0-4 mm (quarry "Novoseltsi")	629,00
4.	Crashed stone sand, 0-4 (quarry “Dobromir")	282,00
5.	Crashed stone, 4-16 mm (quarry “Dobromir ")	387,00
6.	Crashed stone, 6-32 mm (quarry “Dobromir")	387,00
7.	High range water reducing admixture (HRWRA), PCE type BASF Master Glenyum SKY 691 – 0,8% from the binder	3,48
8.	Anti-washout admixture BASF Master Matrix® UW450 - 900 ml/100 kg binder	3,92

9.	Internal crystallization admixture KRYSTALINE Add1 HD	1,00
10.	Macro-stainless fibres "Hooked End" type ZS/I 1,05x50 (tensile strength 2100 MPa)	25,00
11.	Mixing water	179,00
12.	Water-cement ratio	0,42
13.	Slump S4, cm	200-210
14.	Slump retention, h	≥1

Table 5. Prescribed concrete mix design

The optimal sieve curve of fine and coarse aggregate (all-in) is calculated and presented in **Figure 3.**


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Size fraction	Designation	Manufacturers	Density in kg/dm³	k-Value
0-4	0-4	Novoseltzi	2,62	3,13
0-4	0-4 Crushed	Dobromir	2,56	2,36
4-16	4-16	Dobromir	2,59	5,68
16-32	16-32	Dobromir	2,59	6,75

4,42

Amount in Vol-%

	Mesh sizes in mm																			
	0,125	0,25	0,5	1	2	4	5,6	6,3	8	10	11,2	12,5	14	16	20	22,4	31,5	40	45	63
37%	3,0	4,0	13,0	32,0	55,0	85,0	91,0	93,0	98,0	98,0	99,0	99,0	99,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
17%	15,0	23,0	35,0	50,0	67,0	86,0	93,0	95,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
23%	0,0	0,0	0,0	0,0	0,0	1,0	14,0	19,0	29,0	52,0	63,0	74,0	86,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
23%	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	7,0	11,0	14,0	18,0	22,0	47,0	60,0	98,0	99,0	99,0	100,0
total	3,8	5,7	11,1	20,6	32,1	46,5	52,6	54,8	60,1	66,8	70,6	73,8	77,5	82,1	87,8	90,8	99,7	99,8	99,8	100,0

!!! Achtung !!! Uber- & Unterkornanteil sind uberschritten !!! Achtung !!!

!!! Attention !!! Values of the hidden screens are integrated !!! Attention !!!

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Figure 3. All-in sieve curve of prescribed concrete mix design

The basic mechanical characteristics obtained by laboratory tests are indicated in **Table 6.**

Mechanical characteristics	**COMPOSITION TESTED (at equal workability)**	
	Reference concrete (RC) without admixtures	**Prescribed mix with** **Master Glenium SKY 691** **Master Matrix® UW450** **KRYSTALINE Add 1 HD**
Compressive strength, MPa	**52,36**	**71,47**
Compressive strength increasing compared to RC, %	**-**	**36,72**
Tensile splitting strength, MPa	**2,31**	**3,10**
Tensile splitting strength increasing compared to RC, %	**-**	**34,20**
Static modulus of elasticity, GPa	**30,4**	**32,1**
Static modulus of elasticity increasing compared to RC, %	**0**	**5,56**
Depth of water penetration under pressure, mm	**22**	**4**
Water penetration decreasing, compared to RC, %	**-**	**450**
Freeze-thaw resistance - accelerated method (by mass lost - up to 2%):		
- mass lost (%), after 2 cycles (C_{frost} 75);	**0,46 (passed)**	**0,25 (passed)**
- mass lost (%), after 3 cycles (C_{frost} 100);	**1,88 (passed)**	**0,34 (passed)**
- mass lost (%), after 4 cycles (C_{frost} 150);	**2,17 (failed)**	**0,92 (passed)**
- mass lost (%), after 5 cycles (C_{frost} 200)	**-**	**1,37 (passed)**
Freeze-thaw resistance - **accelerated method (to reduce the speed of the ultrasonic pulse - up to 15%):**		
- reduce the speed (%), after 2 cycles (C_{frost} 75);	**9,34 (passed)**	**3,28 (passed)**
- reduce the speed (%), after 3 cycles (C_{frost} 100);	**11,29 (passed)**	**4,76 (passed)**
- reduce the speed (%), after 4 cycles (C_{frost} 150);	**15,28 (failed)**	**7,34 (passed)**
- reduce the speed (%), after 5 cycles (C_{frost} 200)	**-**	**8,42 (passed)**

Table 6. Mechanical characteristics

On the lab test data could be concluded that **prescribed mix** specially developed for underwater concreting covers all requirements for this application. It is clearly visible the advantages of all 3 different innovative admixtures in the mix design.

4. CONCLUSIONS

Taking into account all specific requirements concerning the forthcoming repair works on the piers of the port of Bourgas an innovative technical solution for concrete wavy vertical protective wall execution is proposed.

The solution is composed by step-by-step solving specific set of technical tasks, connected to clarifying the suffusion's nature and function of building structure to stop it, all environmental factors with potential corrosion actions, specific requirements for underwater concreting and innovative building practice.

A special prescribed concrete mix design, based on proper type of sulphate resistant cement, standard well-graded aggregates and very innovative chemical admixture, is developed. The new mix design is laboratory tested and the mechanical properties obtained is compared to the respective concrete without any admixtures.

Based on these comparisons, it is clear that the developed technical solution fully meets all technical and technological requirements related to this specific application.

Now respective pier's repairing works for the construction of barrier against suffusion based on this innovative technical solution, are in progress.

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