UDC 699.82
DOI: 10.54338/27382656-2021.1-9

Artavazd Avetik Arzumanyan[1], Avetik Artavazd Arzumanyan[1]*,
Hasmik Hamlet Qaramyan[1], Nelli Gagik Muradyan[1]
[1] *National University of Architecture and Construction of Armenia, Yerevan, RA*

CONCEPTUAL APPROACHES TO SOLVING THE ISSUE OF REINFORCING THE ROCK - CUT STRUCTURES OF GEGHARD MONASTERY COMPLEX

The article presents a visual and instrumental research of the technical condition of the main rock-cut structures and their masonry additions, the documentation of their damages (cracks, crevices, destructions and erosions) and deformations, thorough complete laboratory studies of rock samples and their physical and mechanical characteristics, conceptual approaches to preventive and reinforcing measures necessary for the further safe survival of structures, as well as the comprehensive development and implementation of measures to prevent further damages (elimination of causes) and ensure the long-term existence of structures. Based on the analyses carried out, it is recommended to use a ready-made dry mixture mortar of the "Mapegrout" brand produced by the Italian company "Mapei" to fill cracks if necessary. It is available in the market of the country and is successfully used in the reconstruction of tunnels and other underground structures. The issues of compatibility of reinforcing materials with sandstone rock are also considered on the basis of some averaged data of the main decisive physical and mechanical characteristics of the strength and deformation of sandstone.

Key words: *fine concrete, cement adhesive, basalt-fiber, reinforcing, dry mortar "Antique I".*

Introduction

Geghard Monument Complex generally includes rock-cut, as well as attached masonry structures and adjacent rock mass. In addition to the destructive phenomena of decomposition under freezing and weathering of rocks and adjacent rock masses, the complex has also been heavily affected by earthquakes in the region, and the current damage to it is the sum of the aforementioned water factors and seismic effects [1]. At the same time, damages from the former have steadily increased and continue to increase the seismic vulnerability of the Complex. There are many other dangerous damages of various degrees to the rock-cut and masonry additions of the structures. Therefore, for a comprehensive development of the main measures related to the subject, all structures and the adjacent slope cliffs should be subjected to a thorough professional visual and instrumental examination. After a comprehensive analysis of the data obtained, the correct scientific and technical solutions should be proposed.

Materials and Methods

The envisaged works will make it possible to quite subjectively develop and apply a set of technically justified measures for the water protection of the considered monumental structures and the strengthening of the adjacent rock mass, which is of decisive importance for their further safe existence. However, the preliminary studies and observations already conducted allow us to propose the following basic conceptual approaches to the required measures.

1. To protect monumental structures from slope waters of the nearby area, it is necessary to implement slope surface water catchment and safe drainage streams at the bottom of the slope before reaching the structures. For this reason, by involving an environmental specialist in the process and based on the geodetic surveys to be performed on the site, more efficient stream contours should be developed, and in this case minimal interference with local masonry additions and cuttings on the rock should be made, while making maximum use of the natural slope relief structure. Masonry additions forming the streams should be implemented after removing a weak upper layer of weathered rock in their place, with a mass made of covering of unprocessed rock pieces and fine-grained concrete or cement-sand mortar made with the implementation of calmatron, aquatron additives having good adhesion and ensuring water resistance or another inorganic additive having similar purpose. If the required height of masonry additions is up to *30 cm*, it can be carried out without spring anchors attached to the rock, and if they are much thicker, the addition must be attached to the rock with additional grooving with reinforcement anchors. At the same time, taking into account the known facts (Table) about further easy corrosion of steel reinforcement bars and incomparably higher coefficient of thermal expansion in comparison with the stone, it is recommended to make reinforcement anchors from basalt-fiber composite reinforcement rods of 10, 12, 14 and 16 *mm*, which are already produced in the country and are not so dangerous.

With their lower edge, the reinforcement anchors should be placed in the preliminary perforated and at least 100 *mm* deep holes in the lower harmless part of the rock with an anchoring adhesive, while with their upper edge they should enter to the cement or mortar part of the addition. In case of applying a large number of rock pieces on the rock side of the addition, the upper edge of reinforcement rods can be placed in the perforated holes of such stones too.

The bottom and walls of the natural looking water stream, formed mainly by natural relief lines and small masonry additions and excavations, should then be made water permeable by immersing them in a water-repellent solution of the durable inorganic type GS Pronitrate (or another inorganic liquid substance having a similar function). Water repellent solution should be applied to the specified surfaces at intervals of not more than 10 minutes by spraying 3…4 times or abundantly applying with a brush.

In order to ensure the smooth operation of the catchment and drainage stream for the slope water, it will need current repair services at least twice a year after the spring and fall abundant rainy seasons.

2. On the surface of the slope it is necessary to exclude the possibility of water accumulation in the local catchment pits, causing deep erosion of the rock mass and to provide an automatic rapid flow of surface water to the stream designed to catch and drain water from the slopes. In this case as well, based on the principle of not deteriorating the natural form of the slope, it is necessary to be satisfied with solutions with minimal interference. Depending on the size and depth of the pit location, and with the advice of an environmental specialist, this problem can be solved in two ways or by combining those options.

The first option is to fill a local low land, and *the second* is to create local excavation streams to drain the water accumulating in the low land. In some cases, by the decision of the environmental specialist, a mixed option of partial filling of the low land and of creating a stream for the remaining part may be used. The choice of any of the solutions should be based on the peculiarities of the relief of a particular site and the opinion of the environmentalist, so as not to deteriorate the form of the slope. Moreover, the environmentalist must consider that the existing catchment pits are not at all the original condition of the slope and have arisen as a result of further disproportionate erosion of the rock.

The filling of the local lowlands on the slope should be carried out according to the similar technology as for the addition of drainage streams presented in the previous point removing a weak weathered layer of rock, in the intermediate part, reinforced (using the same non-corrosive basalt plastic reinforcement rod) with the same well adjoining water permeable concrete and lining of local unprocessed rock piece or with a mass formed without it. In the second option, drainage streams of low land sections should be carried out at regular or irregular local excavations on the rock mass. Afterwards, the surfaces of both excavated streams and protected low lands should be treated in the same way: by soaking in the aforementioned water-repellent, long-lasting inorganic liquid.

3. Based on hydrogeological and deep geophysical studies of structures and the adjacent rock mass with the work presented in stage 3 [2], deep rock distortions (layerings, cracks, crevices), as well as from documenting data obtained by identifying water veins and watercourses and their sources of supply within the stratosphere (location, depth, direction, etc.), rock pieces with different levels of separation from the overall rock mass should be divided into two groups:

1. No longer suitable for strengthening and storage and subject to removal,
2. Suitable for strengthening and preservation.

Safe removal of rock pieces of the 1st group, i.e. priority works on neutralization of the rocky slope adjacent to the structures should be organized with the involvement of specialized services of the Ministry of Emergency Situations of the Republic of Armenia. Moreover, healthy types of rock pieces up to 30 *cm* in size can be accumulated for the implementation of slope streams and other masonry additions.

To reinforce the rock pieces of the 2nd group, first of all it is necessary to carry out a set of measures to blind the sources of upper layer waters in these areas, as well as to restore the density and stability of the rock mass fragmented from the existing deformations.

It should be noted that particular care should be taken with the materials to be used in the restoration of such valuable monumental structures. Given the currently widespread organic polymeric regeneration substances, the relatively short duration of their effective action over time due to the known tendency to depolymerization and aging, their use should be limited in valuable monumental structures subject to long-term storage, and in extreme cases their use should be limited to only indoor environments not exposed to factors that promote rapid aging (sunlight, significant temperature fluctuations, etc.). Based on the same principle, corrosive black metals should be avoided in such structures or should only be used in areas where there are absolutely no corrosive conditions. In this regard, we believe that stainless steel and other metals or stainless non-metallic reinforcing materials should be used in monumental structures to provide high durability, such as fiberglass and basalt-fiber composite reinforcement, carbon fiber ropes, bands and canvas, etc. Some averaged data on the physical-mechanical decisive key characteristics of strength and deformity of these materials and the observed sandstone rocks are shown in the Table.

Now, based on the data in the Table, the comparability of the listed possible reinforcing materials with sandstone rocks under interference has been considered. It is obvious that when rigid steel reinforcing bars with a high deformation modulus is inserted into the rock, especially in case of dynamic influences, it can become a source of pressure concentrations in the rock with rather low deformation modulus. On the other hand (Table), both black and stainless steels have some incompatibility with the existing rock material in terms of thermal deformation. In this regard, it is obvious that the nonmetallic reinforcing bars listed in the Table, in addition to the positive property of non-corrosion, has a relatively low modulus of deformation and a certain flexibility, as well as close characteristics of thermal deformity have favorable combination characteristics with the rocks and the ability to easily adapt to the environment.

To restore the density and stability of the rock mass fragmented from the existing deformations, it is advisable to implement the following solutions:

3a) Attach large rock pieces of the 2nd group surface layers, which are separated from the general rock mass, but are to be preserved, to the lower dense rock mass creating groove anchors. To do this, a hole with a diameter of 50 ... 150 *mm* and at least 100 ... 300 *mm* straight deep, depending on the mass of the attached piece, should be drilled on the given rock piece and into the lower rock mass with a special drilling instrument, and a reinforcement cement groove with basalt fiber reinforcement frame should be implemented in them. Grooves should be concreted with the aforementioned adhesive and water permeable non-shrinking heavy concrete mix not less than B20 with the adequate implementation of corresponding expanding additive. The number of grooves on a given rock piece depends on the planned size and weight of it, which should be calculated. The adjacent separated rock pieces should then be connected at the top by means of a carbon fiber rope or band connecting the tips of their grooves. The latter must be placed in a pit drilled on the surface of the rock and covered with the above mentioned type of concrete and unprocessed rock covering.

3b) At the most accessible level the lower marks of cracks and crevices with contours of rock pieces separated from the overall rock mass and of all cracks and crevices on the rock mass as a whole, using a syringe first inject a water-resistant adhesive containing a liquid consistency or fine-powder grained additives, which easily penetrate into the crumbling interlayers, consolidate the flowing mass in it and glue the separated parts of the rock mass together, for example, from the above-mentioned type GS Pronitrate, Aquatron or Calmatron, Cerezite and other materials of similar function. If necessary, ready-made dry mixture mortar "Mapegrout" produced by the Italian company "Mapei" available in the market of the country can also be used to fill the cracks.

3c) After the initial measures listed above, all cracks and crevices in the rock should be firmly filled. Depending on the size of the openings in the latter, their filling should be carried out from the injection of fine adhesives to the application of gravel up to 20 *mm* grain size and with the insertion of gravel plasticized self-flowing fillable concrete mix with plasticizer [3-5]. Both adhesives and concrete must be non-shrinking, water resistant and well adhered to the rock mass through the use of appropriate additives. The upper surfaces of large cracks should also be covered with local unprocessed rock pieces. It should be noted that the covering with the same rock type of both the given cracks and the additions of previous points to be implemented, besides providing the same texture of the slope, firstly has a well-founded technical goal of proportional weathering of the rock surface and not creating local pits again in the future.

3d) Interlayer waters blinding works of deformed rock masses adjacent to main monumental structures should be carried out by appropriate measures developed by hydro-geological and geophysical studies based on the identified data on their locations and features.

Table. Relative average indices of firmness and deformity of sandstone rock and some reinforcing materials

Name of the materials		Compressive (tensile) strength, *MPa*	Average density, *kg/m³*	Modulus of elasticity, E, *MPa*	Thermal expansion coefficient, $10^{-6} \cdot {}^oC^{-1}$
Steel reinforcing bars	Class A-I	225 (225)	7850	$2.1 \cdot 10^5$	13…15
	Class A-II	280 (280)	7850	$2.1 \cdot 10^5$	13…15
	Class A-III	355…365 (355…365)	785	$2.0 \cdot 10^5$	13…15
	Class A500C	500 (435…455)	7850	$(1.9…2.0) \cdot 10^5$	13…15
	B_p-I class	360…375 (360…375)	7850	$1.7 \cdot 10^5$	13…15
Stainless steel	Ferritic	190…310 (190…310)	7850	$(1.94…2,0) \cdot 10^5$	16.6
	Austenitic	190…310 (190…310)	7850	$(1.93…2,0) \cdot 10^5$	17.3
Non - metallic reinforcing bar	Basalt Plastic	- (700…1300)	1200	$0.6 \cdot 10^5$	9…12
	Glass Plastic	-(600…1200)	1900	$0.45 \cdot 10^5$	9…12
Carbon fiber band	Sika carbondur-S	-(3050)	-	$1.65 \cdot 10^5$	-
	Sika carbondur-M	-(2900)	-	$2.1 \cdot 10^5$	-
	Sika carbondur-H	-(1450)	-	$3.0 \cdot 10^5$	-
Sandstone		15…30	1350…1450	$0.14 \cdot 10^5$	7…11

4. Given the variety of mostly water-related damages in structures, the problems of eliminating each of these and strengthening the structures as a whole should be approached individually, according to the decisions made as a result of a thorough professional study.

As for the problem of restoring and putting back to service bearing walls and coverings of rock-cut structures that were originally dense but are now fragmented and cracked and do not fully perform their role, the density of the deformed stones must be restored after removing the weak surface layers of cracks and crevices and after injecting water resistant and non-shrinkable during fastening mortar and mastic materials giving good adhesion to the rock into the healthy rock inside them, which has adequate characteristics with modulus of deformation and coefficient of thermal expansion.

In this case, only special cement-based fine-grained mortars close to the existing rock material can be used as injection materials. Cement mortars can be produced with the complex implementation of high quality quartz sand, Portland cement and non-shrinkable, adhesive calmatron, aquatron or other additives with similar function, as well as plasticizers, adhesives and other additives having the same purpose [6,7]. Grain composition of the mortar should be adjusted according to the size of the crack or gap to be filled. In addition, in the case of microcracks adhesive mastic, made on the basis of fine grained sand and the same additives should be applied.

In rock-cut structures, walls and enclosures of ground anchoring parts damaged by prolonged wetting and deconstruction under freezing require a special approach. In this case, before dealing with the damaged elements themselves, you must first eliminate the root cause of the damage - abundant water infiltrating the bottom of the structure. Speaking about the rock-cut church, for example, it should be noted that besides the aforementioned blinding of random interlayer water streams above the structure, here measures should be taken to prevent the wetting of the dense rock mass of the structure's ground layer as well as the constant wetting of ground anchoring parts of its walls with capillary action from the open basin of the stream operating in the internal area. To do this, it is necessary to temporarily collect spring water directly from the outlets and take it out through pipes, drain water from the existing pool and watercourses using specially installed pumps. Then the surfaces of the latter related to water should either be blinded by absorbing reliable and durable water-repellent mortars, or covered with water permeable reinforced concrete pits reinforced with non-corrosive basalt-fiber reinforcing bars and with the implementation of streams, which is preferable. Reinforced concrete pits and streams can be covered with pieces of unprocessed rocks from the same rock along with covering with concrete. Regarding water outflows from an existing stream, it is possible to create these waters in the back of the walls by local drilling in those parts of the property, assembling a controlled permeable initial basin from which the water flows inside the church through a permeable pipe.

After carrying out the aforementioned water protection measures, it is necessary to give time for the sufficient drying of the stone mass of the church floor, after which only to begin restoration and reinforcement work of the lower parts of the walls and pillars deconstructed under freezing. The restoration of the lower loaded part of this responsible constructive part of the structure with the previous section should be done with an additive capable of working with a healthy stone cutting. Therefore, the most important prerequisite for additive material is to provide strength and thermal deformation and strength values similar to the existing rock material, which in the case of the given rock type, as well as in the case of cracking and filling, can be performed with a quality quartz sand, Portland cement and calmatron, aquatron or other similar function, which provides good adhesion and is non-shrinking, as well as with special mixtures made with the complex use of other target additives, simultaneously providing high adhesion (for example, the highly effective proprietary adhesive addition "Planicrete" by "Mapei"). Before carrying out restoration work, carefully remove the weak surface layer deconstructed under freezing from part of the structure and thin reinforcement, consisting of basalt-fiber thin anchors 2...3 *mm* thick attached to it and basalt fiber reinforcement net, put it on the hard rock freed from it, as well as in the drilled holes in the floor. After that, clean this part of the dust, rinse it with a jet of water and use pressure plastering to install a special fine-grained concrete with the above-mentioned characteristics.

If desired, to ensure greater reliability and durability of the structure, after sufficient reinforcement of the reinforced concrete layer, a high-strength carbon fiber band (Table) can be applied with epoxy adhesive and then covered with protective stone. Restoration to the original dimensions of the remaining sections of surface layers of the roof, walls and pillars deconstructed under freezing should be carried out in the same way as described above, using the same materials. As for the issues of reconstructing rock masonry constructions implemented with lime-sand mortar and now having damages added to the rock-cut parts of the structure, then, in their restoration work, both for upper masonry layer and for injection, it is necessary to use the assortments of complex dry lime-sand mortars prepared by the Italian company "Mapei" for the purpose of special restoration works using special complex additives or on the basis of local raw materials to develop complex lime-sand compositions providing the proposed technical and economic characteristics of the mentioned dry mixtures. Such is "Antique I" dry mortar, made with the mixture of hydraulic lime, eco-pozzolana, natural fine and ultrafine sand, a range of special targeted additives. It is intended for injection into cracks, crevices and voids of damaged walls made of lime-mortar to restore their density and structural integrity.

Conclusion

Complex work on the elimination of the damages of water impacts, as well as the restoration and reinforcement of the original monumental structures with rock-cut and masonry additions [8-10] should be carried out by a complex implementation of the data recorded by thorough professional technical studies and their adequately developed measures. Moreover, both the choice of materials to be used and the solutions, must be guided by the above-mentioned provisions, which do not disturb the creation of the structure and ensure great durability and reliability, and in general by the preservation of internationally accepted standards for the restoration of monumental structures.

References

[1]. L.I. Dvorkin, Stroitel'noe materialovedenie: russko - angliyskiy spravochnik, 2-e izd. Infra - Inzheneriya, Moscow, 2020 (in Russian).

[2]. Ar.A. Arzumanyan, Av.A. Arzumanyan, H.H. Qaramyan, N.G. Muradyan, Geghardi vanakan hamaliri zhayrrap’vor karruyts’neri jrapashtpanut’yan himnakhndri lutsman hayets’akarg. Bulletin of National University of Architecture & Construction of Armenia, 3, 2020, 3-12 (in Armenian).

[3]. Yu.M. Bazhenov, B.C. Dem'yanova, V.I. Kalashnikov, D 32 Modifitsirovannye vysokokachestvennye betony. Association of Construction Universities, Moscow, 2006 (in Russian).

[4]. V.A. Shevchenko, Tekhnologiya i primenenie spetsial'nykh betonov. Siberian Federal University, Krasnoyarsk, 2012 (in Russian).

[5]. K.I. L'vovich, Peschanyy beton i yego primenenie v stroitel'stve. OOO “Stroy - beton”, Sankt - Peterburg, 2007 (in Russian).

[6]. V.N. Smirenskaya, S.A. Antipina, S. Sokolova, Khimicheskaya tekhnologiya vyazhushchikh materialov. Tomsk Polytechnic University, Tomsk, 2009 (in Russian).

[7]. Ye.I. Shmit'ko, A.V. Krylova, V.V. Shatalova, Khimiya tsementa i vyazhushchikh veshchestv. Voronezh State University of Architecture and Civil Engineering, Voronezh, 2005 (in Russian).

[8]. A.G. Karamyan, G.G. Manukyan, V.P. Toroyan, V.R. Harutyunyan, N.B. Knyazyan, Issledovanie sostava shtukaturki tserkvi Surb Ovannes (Surb Sargis) v Megri. NPUA Materials on Chemical and Environmental Technologies, 2, 2018, 78-85 (in Russian).

[9]. V. Harutyunyan, G. Nalbandyan, A. Grigoryan, Chartarapetakan hushardzanneri verakangnumy. Dar, Yerevan, 2003 (in Armenian).

[10]. N.A. Melikyan, V.M. Harutyunyan, Restavratsiya pamyatnikov arkhitektury. Vek, Yerevan, 2003 (in Russian).

[11]. A.A. Arzumanyan, V.G. Tadevosyan, N.G. Muradyan, H.V. Navasardyan, Study of "Saralsk" Deposit for Practical Applications in Construction. Journal of Architectural and Engineering research, 1 (1), 2021, 3-6. DOI: 10.54338/27382656-2021.1-1

[12]. M.M. Badalyan, A.K. Karapetyan, N.G. Muradyan, S.S.Ratevosyan, Possibility of Tuff Waste Application in the Production of Thermal Insulation Materials. Journal of Architectural and Engineering research, 1 (1), 2021, 7-12. DOI: 10.54338/27382656-2021.1-2

***Artavazd Avetik Arzumanyan*, Doctor of Philosophy (PhD) in Engineering, Associate Professor** *(RA, Yerevan) - National University of Architecture and Construction of Armenia, Head of the Chair of Production of Construction Materials, Items and Structures, artavazd@inbox.ru*

Avetik Artavazd Arzumanyan, Doctor of Philosophy (PhD) in Engineering, Associate Professor *(RA, Yerevan) - National University of Architecture and Construction of Armenia, Lecturer at the Chair of Production of Construction Materials, Items and Structures, avetikarzumanyan@gmail.com*

Hasmik Hamlet Qaramyan *(RA, Yerevan) - National University of Architecture and Construction of Armenia, Assistant at the Chair of Production of Construction Materials, Items and Structures, qar-has@mail.ru*

Nelli Gagik Muradyan *(RA, Yerevan) - National University of Architecture and Construction of Armenia, Head of the Research Laboratory at the Chair of Production of Construction Materials, Items and Structures, nellimuradyan06@gmail.com*

Submitted: *10.01.2021*
Revised: *20.02.2021*
Accepted: *12.07.2021*