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"Modified Hexablock" and "Modified Tetrablock" – new constructions for protecting abrasive banks of reservoirs from being washed away

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ABSTRACT:
The paper presents the results of laboratory studies on new constructions used to protect the abrasive banks of mountain reservoirs from being washed away – the "Modified Hexablock" and "Modified Tetrablock". Their high wave-absorbing ability is established; sustainability is confirmed due to their interdependence; reduction in the height of waves on the slope is proven; and a universal approach to the calculation of the optimal mass of the blocks is given. Currently, there are very few armor units specifically designed to increase their stability by interlocking with adjacent blocks. The "Modified Hexablock" and "Modified Tetrablock" offer a new perspective, suggesting that the stability of armor units can be significantly improved not only by significant weight and effective interlocking, but also by securely interlocking them.

KEYWORDS:
abrasive banks; brack water stock; shaped blocks; "Modified Hexablock"; "Modified Tetrablock"; reservoirs

1. Introduction

Protecting reservoir abrasion banks with modern, wave-damping coastal-protection structures is a pressing issue. Many countries have already abandoned the use of these massive and expensive constructions. Concrete structures weighing up to 60 tons have been created. Currently, there are a number of concrete blocks that can be used to strengthen the abrasive steep slopes of reservoirs. The main factor that effects the efficient operation of constructions made of shaped arrays is the suppression of wave energy and reduction of the height of their waves on the slope (2-3 times) [1-6].

2. Designs using shaped blocks

The development of coastal protection concrete blocks began in the 1950s (Fig. 1). The main existing concrete blocks used for coastal protection are described below:

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- ***Dolos***: Dolosse are commonly employed for the protection of shorelines and rubble structures, and their design is primarily based on hydrodynamic stability [7].
- ***Accropode***: Accropode units are known for their excellent structural strength and are used in coastal protection projects [8].
- ***Core-Loc***: Core-loc offers an optimized concrete armor solution for coastal erosion control and wave energy dissipation [10].
- ***Xbloc:*** The Xbloc is a compact, randomly placed, interlocking concrete armor unit [11].
- ***A-Jacks***: The A-Jacks, also known as A-Jacks 3, is a three-dimensional interlocking concrete block system. A-Jacks are commonly used in breakwater and revetment applications, offering a stable and durable solution for coastal protection [12].
- ***Crablock***: The Crablock is a new single-layer concrete protection block. It has been developed to provide efficient coastal protection by dissipating wave energy and resisting erosion [13].

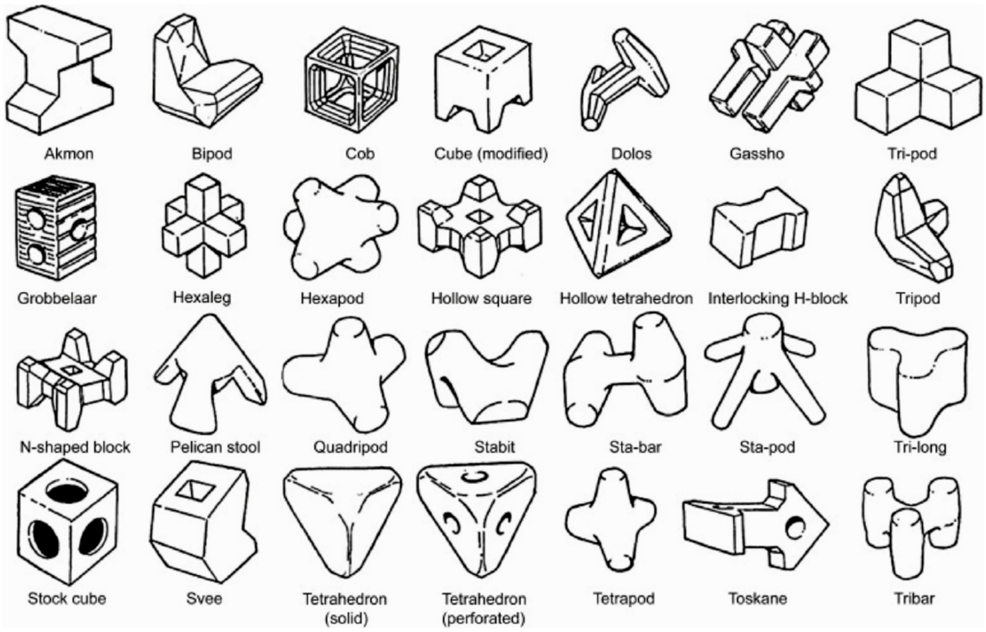

Fig. 1. Wave protection units made of concrete [9]

A summary of the geometric parameters and weight of selected shaped block systems is provided in Table 1.

In Georgia, tetrapods were used at the bridge on the Liakhvi River (Fig. 2) and in Anaklia on the Black Sea coast (Fig. 3), and tetrablocks were used in the port of Poti (Fig. 4). One of the latest studies on the creation of new coastal protection blocks is the "Pentapod", which is still in the research process [14].

A group of scientists from the Ts. Mirtskhulava Institute of Water Management developed new concrete blocks, the "Modified Tetrablock" and "Modified Hexablock" (Figs. 5 and 6).

A “Modified Hexablock” (1) consists of three rectangular prisms (2) of square cross-sections connected at 90 degrees and connected by central areas. Each prism has two oppositely directed rectangular prism-shaped ribs at its ends, the height of each rib being equal to half the width (S) of the prism, the width and length being equal to the width (S) of the prism, the length, width and height (H) of the block being 5 S.

A "Modified Tetrablock" (1) consists of rectangular prisms (2) with square cross-sections connected to each other at 90 degrees and connected by a central region.

Table 1
Values of the optimal mass (M) of shaped blocks

No	Location / type of blocks	Actual values							Reporting values
		H	$h_{\%}$	$\lambda_{\%}$	$\sqrt{\lambda/h}$	ctg α	M	Const. norms M	M
		m	m	m	–	–	tons	tons	tons
1	Humboldt (USA) / Dolos	14.0	12.2	244	4.47	4.0	43.0	31	41
2	Richard Bay (Arabia) / Dolos	17.9	9.0	134	3.86	2.0	30.0	29	29
3	Hay Point Australia) / Dolos	10.0	6.1	90	3.84	2.0	10.0	9	9
4	Mina-Raisun (Oman) / Dolos	13.0	7.0	140	4.47	1.5	20.0	22	21
5	Hans Bay (South Arabia) / Dolos	11.8	6.0	153	5.05	1.5	13.5	16	15
6	Table Bay (South Arabia) / Dolos	8.8	4.5	130	5.38	1.5	6.0	7	7
7	Crescent City (USA) / Tetra-pod						25.0	22	24
8	Hawaii / Tribar						17.8	16	17
9	England / Stabit						25.0	23	24

Fig. 2. Tetrapods at the bridge on the Liakhvi River, Georgia [15]

Fig. 3. Tetrapods in Anaklia, Georgia

Fig. 4. Tetrablocks in Poti Port, Georgia, [11]

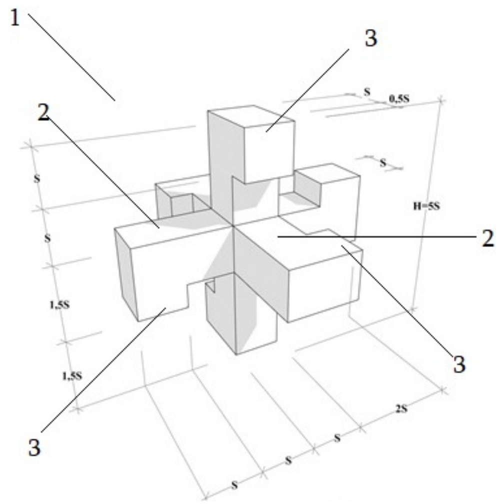

Fig. 5. "Modified Hexablock" scheme (own research)

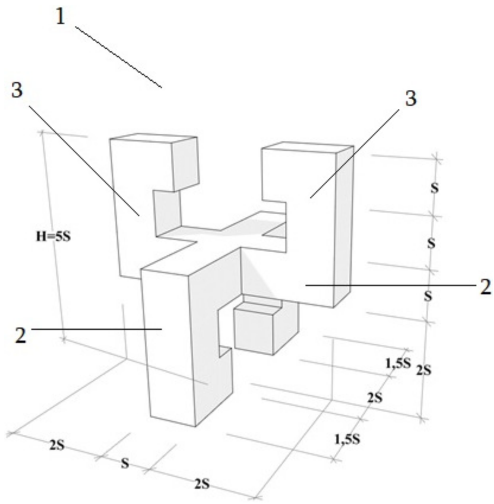

Fig. 6. “Modified Tetrablock" scheme (own research)

Each has a G-shaped rib (3) at its ends, oriented in the same direction, with the ends facing each other, and the ribs of one prism facing opposite the ribs of the other prism. The base and head of each rib are in the shape of a rectangular prism with square cross-sections. The height of the base is equal to the width (S) of the prism, the width and height of the head are equal to the width (S), and the length is 1.5 times the width of the prism, the length, width and height (H) of the block are 5 S.

The objective of these utility models is to create bank-retaining blocks that are easy to manufacture and erect. Block structures will effectively protect the abrasive slopes of water bodies (seas, lakes, reservoirs) from erosion by reducing wave loads.

The optimal mass of the modified blocks (M) is written in the form of a universal ratio.

The geometric and mass parameters of the new types of shape blocks are shown in Table 2.

Table 2
Geometric parameters and mass of new shape blocks

No	Location / type of blocks	Actual values						Reporting values
		H	$h_{\%}$	$\lambda_{\%}$	$\sqrt{\lambda/h}$	ctg α	Const. norms M	M
		m	m	m	–	–	tons	tons
1	Georgia / "Modified Hexablock"	2.3	6.9	69	3.16	3.0	8.0	4.6
2	Georgia / "Modified Tetrablock"	3.0	10	70	4.9	4.0	7.8	10.0

As a result of tests conducted in laboratory conditions (Fig. 7), it was established that coastal protection structures in the form of a “Modified Hexablock” and a “Modified Tetrablock”, due to the high adhesion between the edges of the blocks, are distinguished by high stability on the coastline and are more effective (up to 40 %) at damping wave energy compared to existing blocks.

To study the efficiency of wave damping using sketches from “Modified Hex-ablocks” and “Modified Tetrablocks” in laboratory conditions, the law of mechanical similarity was used, on the basis of which geometric, kinematic and dynamic similarity was preserved while observing the boundary and initial conditions.

Georgian patents (U 2025 2210 Y and U 2025 2211 Y) have been obtained for both of the studied blocks - “Modified Hexablock” [16] and a “Modified Tetrablock” [17].

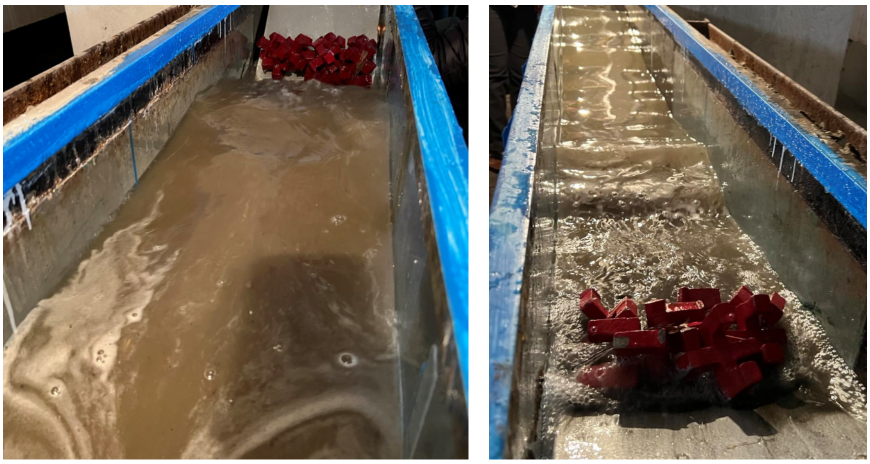

Fig. 7. Study of the wave dampening efficiency of fill on a slope with "Modified Hexablocks" and "Modified Tetrablocks" in a small hydraulic tray (10.0 m × 0.3 m × 0.70 m) (own research)

The comparison of the mass (M) of the proposed "Modified Hexablock" and “Modified Tetrablock" and the existing arrays – “Stabit”, "Tetrapod", "Dipod" and "Dolos" – is presented in Figure 8.

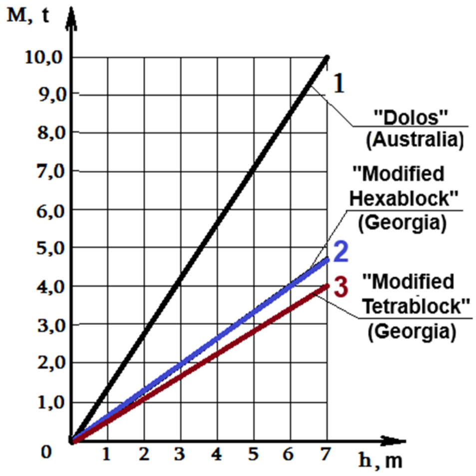

Fig. 8. Calculated mass of block stability (M) dependence of the wave 1 % – with the height of provision ($h_{\%}$) (own research)

3. Possibilities of additional application of shaped blocks

One of the most pressing problems that occasionally occur on the coasts of seas and oceans is tsunamis. They have often led to significant human casualties and damage to coastal infrastructure. A study [18] presents a wide range of different coastal protection structures and systems used against tsunamis. It highlights the often-poor effectiveness of these types of protection, which are intended to mitigate the effects of tsunamis. Significant challenges arise with the appropriate selection, consisiting of high construction costs, and the operational efficiency of such structures. Consequently, there is considerable scientific interest in finding solutions that are more effective than those currently used. The authors of the paper [18] state that broad collaboration between specialists from various scientific disciplines, such as hydraulic engineers, construction engineers, geologists, geographers, seismologists, and sociologists, is essential to developing new approaches and improving existing solutions. Only by compiling relevant data for these groups of scientists will it be possible to adapt appropriate tsunami mitigation measures for specific coastal areas. This approach should largely ensure the success of local tsunami mitigation measures and properly plan the management of a given area [19].

Regarding specific technical solutions, the most promising seems to be the combination of various structures, such as blocking systems (e.g., seawalls), slowing solutions (e.g., buffer structures, vegetation), and guiding systems (e.g., channels, topographic depressions) [20].

In this context, the "Modified Hexablock" and "Modified Tetrablock" solutions analyzed in the paper could be one element of a comprehensive system for protecting coastal areas against tsunamis.

4. Conclusions

Conducted studies have shown that the height of the wave crests on a slope strengthened by the “Modified Hexablock” and “Modified Tetrablock” proposed by the figure arrays is 35 % - 40 %, and their mass is 45 % - 50 % less than the existing blocks.

In the future further research could greatly enhance our knowledge, about the characteristics and uses of "Modified Hexablock" and "Modified Tetrablock". Including as one of the elements of comprehensive protection of the coasts of the seas and oceans from very high waves, accompanying hurricanes, tornadoes or tsunamis.

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„Zmodyfikowany Hexablock” i „Zmodyfikowany Tetrablock” – nowe konstrukcje chroniące brzegi zbiorników wodnych przed erozją

STRESZCZENIE:
Przedstawiono wyniki badań laboratoryjnych nowej konstrukcji chroniącej brzegi górskich zbiorników wodnych przed erozją – „Zmodyfikowany Hexablock" i „Zmodyfikowany Tetrablock". Uzyskano wysoką efektywność tłumienia fal wysokich, co wskazuje na zrównoważoną współzależność parametrów technicznych opracowanych konstrukcji bloków betonowych i skalę obniżenia wysokości fal na brzegu. Podano uniwersalne podejście do obliczania optymalnej masy bloku betonowego. Aktualnie można znaleźć niewiele projektów bloków tlumiących fale, zwiększających swoją skuteczność dzięki splataniu się sąsiednich bloków betonowych. „Zmodyfikowany Hexablock" i „Zmodyfikowany Tetrablock" oferują nowe możliwości, zapewniając stabilną i skuteczną ochronę wybrzeży. Efektywność danego rozwiązania została znacząco poprawiona, nie tylko dzięki znacznej masie i skutecznemu zasiatkowaniu splotów, ale także dzięki bezpiecznemu ułożeniu siatki splotów bloków betonowych.

SŁOWA KLUCZOWE:
brzegi erozyjne; zasoby wodne; bloki formowane; „zmodyfikowany hexablock"; „zmodyfikowany tetrablock"; zbiorniki