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An Innovative Construction for Protecting Reservoir Abrasive Banks from Washout

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(Presented by Academy Member Givi Gavardashvili)

Abstract. This paper discusses the peculiarities of mountain reservoirs in Georgia. These reservoirs are located in deep and steep mountain river valleys, where protection of the banks against abrasive processes is essential. The study presents the results of laboratory investigations of a new bank protection construction – the innovative wave absorber bank revetment "Modified Hexablock". The experimental findings demonstrate its high wave-absorbing capacity and structural stability, achieved through the interlocking interaction of the blocks and a significant reduction in wave height along the protected slope. A universal method for determining the optimal block mass is also proposed, and the priority of scientific novelty is confirmed by a Georgian patent certificate. The results show that the wave crest height on slopes reinforced with the proposed system is reduced up to 40%, while the required block mass is approximately 50% lower compared to comventional block systems. © *2026 Bull. Natl. Acad. Sci. Georg.*

Keywords: reservoir, abrasive banks, "Modified Hexablock"

Introduction

Currently, various types of concrete blocks are used to strengthen the abrasive steep slopes of reservoirs. The main factor of effective performance of constructions made of shaped arrays is suppression of wave energy and reduction of the height of their waves on the slope (2÷3 times).

Materials and Methods

Concrete protection units are widely used in coastal protection to provide a high level of protection against wave action and erosion. Their application in coastal areas is vital for mitigating wave action and erosion. These units are commonly employed to safeguard harbor and coastal structures such as breakwaters, sea walls, and bridge foundations. They are specifically designed to absorb energy and endure erosive forces, thereby upholding slope stability and safeguarding critical infrastructure. The main existing types of figure areas are shown in Fig 1.

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Protection of the abrasive shores of reservoirs using modern, low-cost shore protection structures with high wave-absorbing ability is a very urgent issue. In many countries, the use of massive, standardized and expensive coastal defense structures has been largely discontinued. Penetrating constructions with a weight range of 0.5-60.0 tons are created from shaped concrete arrays of various contours (Bilyay, et al., 2016; Iordanishvili, 2002; Litvinenko and Strekalov, 2002; Soares, et al., 2017; Sherenkov and Skladnev, 1971; Burcharth and Liu, 1987; Hall, 1997; Van der Meer, et al., 2015).

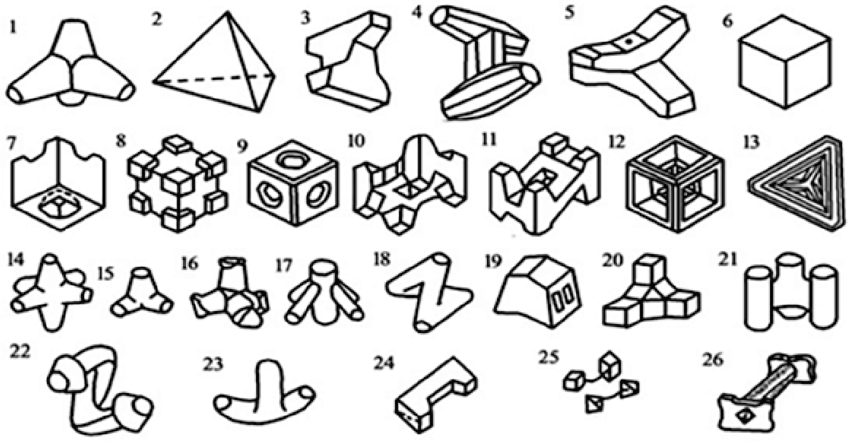

Fig. 1. The main existing types of figure arrays: 1 – Tetrapod; 2 – Tetrahedron; 3 – Dipod; 4 – Dolos; 5 – MC-Type; 6 – Cubus; 7 – Modified Cubus; 8 – WBB3 block; 9 – Styblock; 10 – H-shaped block; 11 – I-shaped block; 12 – Cubic block; 13 – Hollow tetraehedron; 14 – Hexapod; 15 – Quadripod; 16 – Stabilopod; 17 – Stapod; 18 – Stabit; 19 – Sviblok; 20 – Tripod; 21 – Tribar; 22 – Dinosaur; 23 – Artilis; 24 – P-block; 25 – Bound blocks; 26 – Dumbbell block.

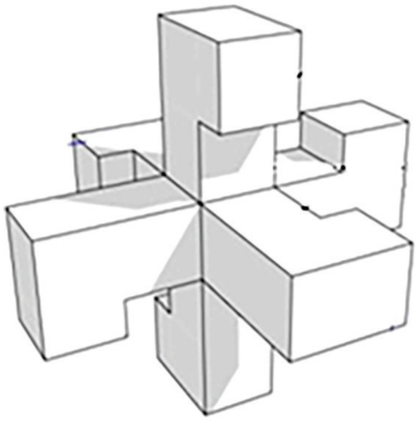

Fig. 2. “Modified Hexablock” scheme.

By using shaped arrays, it is possible to strengthen abrasive steep slopes. The main factor of efficient operation of constructions made of shaped arrays is suppression of wave energy and reduction of the height of their waves on the slope (2÷3 times).

In order to reduce the wave-damping energy of the blocks, to improve mutual performance and to reduce the height of the wave crests on the slope, a new type of shaped blocks – the “Modified Hexablock” was developed (Fig. 2). The priority of this scientific novelty is confirmed by a Georgian patent certificate (Iordanishvili, et al., 2025).

A comparison of the mass (M) of the proposed “Modified Hexablock” with that of existing arrays – “Tetrapod”, “Dipod” and “Dolos” is presented in Fig. 3.

a)

“Modified Hexablock“, ρ_m = 2.60 t/m^3		
M, t	0.21	1.64
H, m	0.75	1.50
S, m	0.22	0.44
V, m^3	0.08	0.63

b)

“Tetrapod“, ρ_m = 2.60 t/m^3		
M , m	1.00	6.00
H, m	1.30	2.30
d, m	0.30	0.60
D, m	0.50	1.01
S, m	0.60	1.10
b_1, m	1.07	1.95
b_2, m	0.75	1.40
tgα	0.22	0.22

“Dipod“, ρ_m = 2.60 t/m^3		
M, m	1.00	6.00
H, m	1.20	2.20
b_1, m	0.41	0.76
b_2, m	0.26	0.48
l_1, m	0.75	1.40
l_2, m	0.28	1.52
l_3, m	0.45	0.82
L_4, m	0.57	1.04

“Dolos“, ρ_m = 2.60 t/m^3		
M, m	1.00	6.00
H, m	1.38	2.50
b_1, m	0.43	0.80
b_2, m	0.28	0.51
b_3, m	0.11	0.81
l_1, m	0.18	0.33
l_2,m	0.27	0.49
d, m	0.30	0.55

“Tetrapod“ **“Dipod“** **“Dolos“**

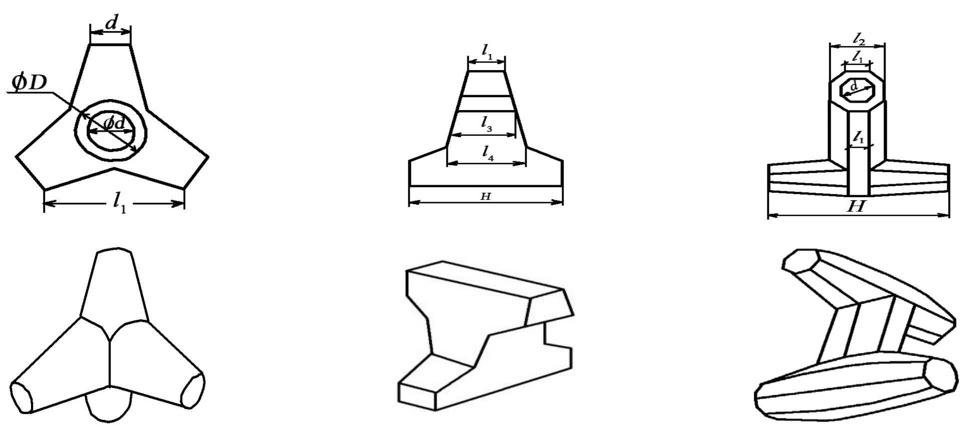

Fig. 3. Schemes of figurative arrays: a) “Modified Hexablock”, b) “Tetrapod”, “Dipod” and “Dolos” and their characteristics (ρ_m – concrete density, t/m^3).

To determine the most effective dimensions and shape of the “Modified Hexablock” bulk on the slope, laboratory investigations were conducted at the Technical University of Georgia. In the existing hydraulic channel of the Mirtskhulava Institute of Water Management, laboratory studies were conducted to determine the wave load and the height of waves on the slope ($h_{\text{run up}}$).

The prediction of the upper boundary of the bulk with “Modified Hexablocks” on the slope is determined according to the following relationship:

$$h_{\text{run up,max (mod.hex.)}} = k_{\text{(mod.hex.)}} \cdot k_w \cdot k_{\text{run up(Sm)}} \cdot h, \text{ (meter)}, \quad (1)$$

where $k_{\text{(mod.hex.)}}$ = 0.60 is the coefficient of stiffness of the slope reinforced with “Modified Hexablocks”, the value of which is determined on the basis of laboratory studies. Their value is obtained by dividing the height of wave crests on a slope reinforced with “Modified Hexablocks” ($h_{\text{run up-mod.hex..}}$), by the height of wave crests on a smooth slope ($h_{\text{run up-Sm.}}$) – $k_{(\text{mod}.hex)} = \dfrac{h_{run\ up\ \text{mod}.hex.}}{h_{run\ up\ sm}} = 0{,}60$; k_w = 1.5 – coefficient, (СНиП 2.06.04-82); $k_{\text{run up(Sm)}}$ = 0.1 – the value of the coefficient depends on the wave breaking on a smooth slope (λ/h) and the slope of the slope ($\alpha°$), h = 10.0 m. Then ($h_{\text{run up- mod.hex..}}$) = 0.60 · 0.1 · 1.5 · 10.0 = 0.90 m. The optimal block mass (M) is written as the following universal relationship:

$$M = \frac{0.0165\rho_m h^3}{(\rho_m - \rho)^3 ctg\alpha} \cdot \sqrt{\frac{\lambda}{h}}, \text{ (tons)}, \quad (2)$$

where 0.0165 is the value of the universal coefficient, which depends on the density of the blocks; ρ_m, ρ are density of blocks and water (tons/m^3); h, λ are the wave height and length (m); α is the slope angle.

Table 1 and Fig. 4 show the actual and calculated optimal mass values of Dolos, Tetrapod, Tribar, Stabit, "Modified Hexablock" arrays.

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

Location/ type of blocks	Actual values							Reporting values, *M*, t
	H, m	*h*, m	λ, m	$\sqrt{\frac{\lambda}{h}}$	ctg α	*M*, t	Const. norms, *M*, t	Formula (2)
Humboldt (USA)/ Dolos	14.0	12.2	244	4.47	4.0	43.0	31	41
Richard Bay (Arabia)/ Dolos	17.9	9.0	134	3.86	2.0	30.0	29	29
Hay Point Australia)/Dolos	10.0	6.1	90	3.84	2.0	10.0	9	9
Mina-Raisun (Oman)/ Dolos	13.0	7.0	140	4.47	1.5	20.0	22	21
Hans Bay (South Arabia)/Dolos	11.8	6.0	153	5.05	1.5	13.5	16	15
Table Bay (South Arabia)/ Dolos	8.8	4.5	130	5.38	1.5	6.0	7	7
Crescent City (USA)/ Tetrapod						25.0	22	24
Hawaii/Tribar						17.8	16	17
England/Stabit						25.0	23	24
Georgia/"Modified Hexablock"	2.3	6.9	69	3.16	3.0		8.0	4.6

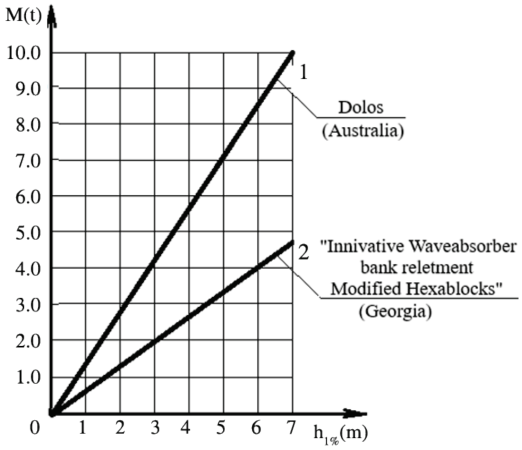

Fig. 4. Calculated block stability mass (M) in dependence of the wave height (h).

The analysis of laboratory studies of wave energy suppression and equilibrium on the slope with bulk interaction with "Modified Hexablock" together with corresponding natural data are given in Fig. 4.

Hydrodynamic and physical laboratory characteristics are calculated at full scale up to the wave-breaking zone (i.e., within the region where the process occurs in the auto-model zone). This is achieved using circular modeling scale and Froude criterion (Fr). This approach assumes the identity of gravity (gravitational) forces ($A_L = L_{nat}/L_{mod}$) (see Table 2).

Table 2. Laboratory recalculation of hydrodynamic natural characteristics of "Modified Hexablock" (using Froud criterion $F_r = \frac{V}{\sqrt{gL}}$, g = idem, p = idem)

Physical quantities	Scaled mass multiplier $a_L = L_{nat} / L_{mod}$	Model quantities up to the breaking zone of waves	Model values in the wave breaking zone considering the scaling factor K = 0.75
Linear dimensions			
h (wave height), m	$a_w = a_L = h_{nat} / h_{mod}$	$h_{mod} = h_{nat} / a_L$	$h_{mod} = h_{nat} / a_L$
λ (wave length), m	$a_\lambda = a_L = \lambda_{nat} / \lambda_{mod}$	$\lambda_{mod} = \lambda_{nat} / a_L$	$\lambda_{mod} = \lambda_{nat} / a_L$
H_w (water depth), m	$a_w = a_L = H_{nat.w} / H_{mod.w}$	$H_{mod.w} = H_{nat.w} / a_L$	$H_{mod.w} = H_{nat.w} / a_L$
$l = 3{,}0 \cdot S$ * (the height of the hexablock), m	$a_h = a_L = l_{nat} / l_{mod}$	$l_{mod} = l_{nat} / a_L$	$l_{mod} = l_{nat} / a_L$
Ω (area), m^2	$a_\Omega = a_L^2$	$\omega_{mod} = \omega_{nat} / a_L^2$	$\omega_{mod} = \omega_{nat} / a_L^2$
W (volume), m^3	$a_W = a_L^3$	$W_{mod} = W_{nat} / a_L^3$	$W_{mod} = W_{nat} / a_L^3$
$h_{run\ up}$ (height of wave crests on the slope), m	$a_{run\ up} = a_L$	$h_{run\ up\ mod} = h_{run\ up\ nat} / a_L$	$h_{run\ up\ \text{მოდ}} = h_{run\ up\ \text{ნატ}} / a_L$
t (time, period), sec.	$a_t = a_L^{1/2}$	$t_{mod} = t_{nat} / \sqrt{a_L}$	$t_{mod} = t_{nat} / \sqrt{a_L}$
V (linear velocity), m/sec.	$a_V = a_L^{1/2}$	$V_{mod} = V_{nat} / \sqrt{a_L}$	$V_{mod} = V_{nat} / \sqrt{a_L}$
α° (slope angle), degrees	$a_\alpha = 1$	$\alpha_{mod.} = \alpha_{nat.}$	$\alpha_{mod.} = \alpha_{nat.}$
M (Mass), tons	$a_M = a_L^3$	$M_{mod} = M_{nat} / a_L^3$	$M_{mod} = M_{nat} / a_L^3$
F (power), t (f)	$a_F = a_L^3$	$F_{mod} = F_{nat} / a_L^3$	$F_{mod} = F_{nat} / a_L^3$
$E_{perm.}$ (permeability)	$A_{perm} = 1$	$E_{perm.W.mod} = E_{perm.W.nat}$	$E_{perm.W.mod} = E_{perm.W.nat}$
P (pressure), t/m^2	$a_P = a_L$	$P_{mod} = P_{nat} / a_L$	$P_{mod} = P_{nat} / a_L$
where $l = 3{,}0 \cdot S$ * is the most effective size of the "Modified Hexablock" due to their high wave-damping effect, slope stability and simplicity of their construction technology.			

After the zone of falling waves (where the auto-modeling is no longer completed), the wave height on the slope and the corresponding wave pressure on the slope are calculated taking into account the scale correction coefficient (K = 0.75).

Conclusion

The conclusion drawn from this comprehensive series of experiments provide valuable insights into the effectiveness and adaptability of the "Modified Hexablock" system in various coastal protection scenarios. The findings highlight the innovative aspects of using "Modified Hexablock" to enhance coastal armor stability and offer practical guidance for its future application and research in coastal protection and erosion control.

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ნაშრომში განხილულია საქართველოს მთის წყალსაცავების თავისებურებანი. აღნიშნული წყალსაცავები განლაგებულია მთის მდინარეების ღრმა და ციცაბო ფერდობებიან ხეობებში, სადაც საჭიროა ნაპირების აბრაზიული პროცესებისგან დაცვა. მოყვანილია ახალი კონსტრუქციის – „ტალღაჩამქრობი ნაპირსამაგრი მოდიფიცირებული ჰექსაბლოკის" ლაბორატორიული კვლევის შედეგები, რომლის მეცნიერული სიახლის პრიორიტეტი დამოწმებულია საქართველოს პატენტის მოწმობით. დადგენილია ნაყარის მაღალი ტალღაჩამქრობი უნარი; მდგრადობა, რომელიც განპირობებულია მათი ურთიერთშეჭიდებითა და ფერდზე წყლის ტალღების აგორების სიმაღლის შემცირებით. შემოთავაზებული „ტალღაჩამქრობი ნაპირსამაგრი მოდიფიცირებული ჰექსაბლოკით" წყლის ტალღის აგორების სიმაღლე ნაყარით გამაგრებულ ფერდობზე 40%-ით, ხოლო მათი მასა 50%-ით ნაკლებია არსებულ ბლოკებთან შედარებით.

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