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Overtopping Wave Reduction Capability of Rakuna IV Armor Block Used for Rubblemound Breakwater

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Abstract— **Run up, overtopping are the main reasons that damage and unstabilize the coastal and basin protective structures. So, overtopping wave is an inevitable load during coastal structures designing process, particularly at present very complicated real situation of global sea level rise and climate change. Based on the early researches, allowable mean overtopping wave discharges play an important roll in determining breakwaters' dimension such as top elevation, slope protective alternatives in the port side and so on. The more permissible average overtopping wave discharges, the lower breakwater top elevation needed. Moreover, the weight of armor blocks used on a seaside slope can be reduced. However, the port side slope needs to be properly protected against the impact of overtopping wave. Thus, researching the application of new armored unit blocks with high overtopping wave reduction capability that is corresponsive to typhoon-generated wave conditions is totally in need. Rakuna IV is one of the newly developed wave-dissipating blocks invented by Nikken Kogaku (Japan) in 2007, and the stability of this block for rubble mound breakwaters has been investigated under non-wave overtopping conditions by many researchers in Japan, Korea, China, and Vietnam. To be more exhaustive in the design of breakwaters with this kind of block, this study carried out experimental research on wave overtopping performance of RAKUNA-IV (overtopping reduction by roughness factor γr) in wave flume at Ha Noi Water Resources University. Based on the physical model tests' results, the author has determined the overtopping wave reduction coefficient γr of Rakuna IV block and its relationship with Irribaren number ξm–1,0.**

Keywords— **rubble-mound breakwater; run-up, overtopping wave; roughness coefficient; amour blocks.**

I. INTRODUCTION

At present, most breakwaters and shore protection work in Vietnam are armored with conventional, patent-free types of concrete blocks like Tetrapods, Cubes, and Haros. Under particular design circumstances, local design consultants do not have much choice for better alternatives. A variety of block types would, therefore, be very beneficial both in finance and technique side. In recent years, a number of deep-water seaports as well as high-level safety coastal protection works have been constructed which requires better alternatives of wave-dissipating blocks. A better armor type is proposed the need dissipate the wave load better and reduce construction cost as well.

In this context, Nikken Kogaku has invented some types of wave-dissipating blocks including Rakuna-IV, Graps-P, and Graps-R. Previous small-scale model studies conducted in Japan such as by Mase et al. in 2011 have shown that these new types of blocks are advantageous over some common ones. In a previous collaborative study, Ha Noi Water Resources University were requested by NIKKEN-KOGAKU to carry out experimental research on the hydraulic behavior of three new wave-dissipating blocks kinds, including RAKUNA-IV, GRASP-P, and GRASP-R. The stability of these blocks for rubble mound breakwaters has been investigated under non-wave overtopping conditions. To be more exhaustive in the design of breakwaters with the aforementioned blocks, studies of their wave overtopping performance are therefore necessary. As a follow up to the previous study with a particular focus on RAKUNA-IV, this study aims at wave overtopping performance of RAKUNA-IV (overtopping reduction by roughness factor γ_r).

II. MATERIALS AND METHODS

Currently, there are now many formulas for calculating average overtopping wave discharges on rubble-mound breakwaters such as CEM-2006; EurotOp-2018 [1] and TAW-2002 [2]. Among these, two methods are commonly used in predicting overtopping wave on rubble mound breakwaters, namely Van der Meer [1] and Owen [1].

- Van der Meer 1999 [1]

$$Q^{*} = \frac{q}{\sqrt{gH_{m0}^{3}}} = 0,2.\exp\left(-2,6\frac{R_c}{H_{m0}}\frac{1}{\gamma_r}\right) \tag{1}$$

- Owen (1980, 1982) [1]

$$\frac{q}{gH_sT_m} = a.\exp\left(-b.\frac{R_c}{H_{m0}}\sqrt{\frac{s_{om}}{2\pi}}\frac{1}{\gamma_r}\right) \tag{2}$$

Roughness factor depends on each block type's roughness or its shape. In general speaking, there are two basic parameters that govern the overtopping discharge: (1) the overtopping reduction factor (roughness factor γ_r); (2) the relative crest freeboard (R_c/H_{m0}). The purpose of this study is focusing on overtopping wave reduction capability of researched armor block (Rakuna IV) that evaluated through its roughness coefficient γ_r. Within the research, Van der Meer's formula is used (Equation 1) [2].

As studied by Van der Meer et al. [2], roughness coefficient for smooth slope γ_r will be 1.0. Nevertheless, according to physical model tests' results conducted by Bruce et al. in 2009 [3] indicated that Equation 1 underestimated the mean discharges by 5 percent. This means that the roughness coefficient γ_r should be 1.05 in Equation 1. The values of all other coefficients in Equation 1 are retained originally. The result is that the roughness coefficient of each armored slope needs to be appropriately selected.

Generally, the overtopping wave decrease capability of an armor block type complexly depends upon its roughness (or its shape) and armor porosity as well. These two influences are complicated to decouple from each other in physical model tests [3]. Therefore, the overtopping wave reduction factor (γ_r) collected from physical model experiments in this research includes both of them.

It is generally accepted that the roughness coefficient γr used in formulas of run-up calculating can be used for wave overtopping prediction. Besides, in real situations, run-up wave is not used in breakwater design; the way γr behaves in run-up wave can also be relevant to wave overtopping. One important characteristic observed in wave run-up of non-breaking waves ($\xi_{m-1,0} \geq 1.80$) is that the roughness factor is not a constant but increases linearly with the breaker index or Iribarren number $\xi_{m-1,0}$ as shown below [1]:

$$\begin{aligned} \gamma_{r,surging} &= \gamma_r + \frac{(\xi_{m-1,0}-1.8)(1-\gamma_r)}{8.2} && 1.8 \leq \xi_{m-1,0} \leq 10 \\ \gamma_{r,surging} &= 1.0 && \xi_{m-1,0} > 10 \end{aligned} \tag{3}$$

There have been many studies on the wave overtopping reduction coefficient γr for some types of armor blocks [1], [2]. The most recently published values of the factor for common armor systems can be found in EurOtop, 2018 [1]. The main objective aimed at predicting the capability of overtopping wave at coastal protective structures.

RAKUNA-IV is one of the new armor concrete blocks, which was invented by Japanese experts in 2007. Although newly invented, RAKUNA-IV blocks have been gradually researched. However, they are limited to the stability of non-overtopped rubble mound breakwaters only. This means that the water caused by the wave is not allowed to come over the top of the protective structure, which leads to a sometimes too high top elevation of dikes and reduces economic efficiency. Therefore, the author would like to study further on RAKUNA-IV blocks' overtopping wave reduction efficiency for rubble mound breakwaters by means of physical model experiments in a wave flume.

RAKUNA IV has four legs like TETRAPOD, but more notably, it has 4 hollows on the surface. As a result, these hollows bring back some advantages: wave dissipation effect improves; The leg is caught in the hollow and stability will be improved; The void ratio is high (56,5%) so required block number can be decreased; the hollows create spaces to ocean flora and fauna [4].

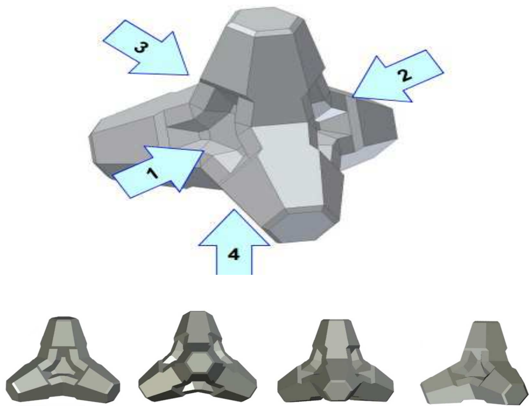

Fig 1. RAKUNA IV block, Japan

A. *General Layout and Model Cross-Section*

The Holland wave flume is 45 m long, (effective length of 42 m), 1.2 m high, and 1,0 m wide. The wavemaker, which is equipped with an advanced automated system of Active Reflection Compensation, is capable of generating regular and irregular waves (JONSWAP) up to 0,3m in height and 3,0 s in peak period. The general experimental layout is illustrated in Fig. 2.

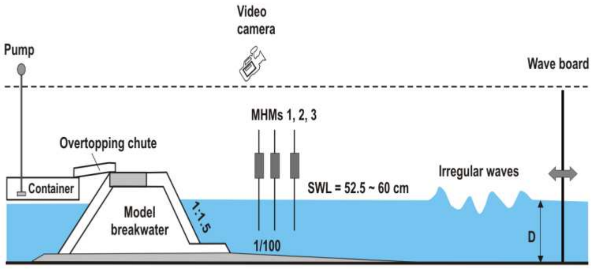

Fig 2. Experimental layout.

The tested cross-section is shown in Fig. 3. Water depth is taken at least equal to $2.5H_{m0}$ (H_{m0} is the wave height at the construction site) to ensure that there is no breaking wave before the building. The model of the top of the dike top is placed at the position of + 0.75m compared to the bottom of the trough (at the bottom of the trough is at the height of 0.0m). The non-dike peak storage height (Rc) depends on the static water level and is changed from $0.6H_{m0}$ to 1.5Hm0, corresponding to the condition that the spill from less to more.

In all experiments, the model slope is 1: 1,5 even when using Tetrapod blocks. The size of the top concrete block is selected to ensure stability during the test and generally selected as 25cm and 16cm (length x thickness).

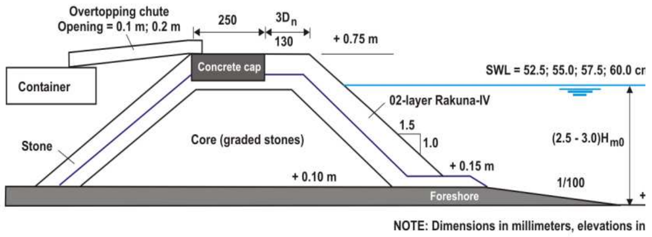

Fig 3. The model cross-section for testing.

For overtopping wave analysis, all of the overtopped water is collected into a chute located behind the dike (Fig. 2 and Fig. 3). To facilitate the discharge measurement, the author used two types of chutes which are 10 cm and 20 cm type depending on the level of spilling in each experiment. Some pictures of the model are shown in Fig. 4 and Fig 5.

Fig 4. Model cross-section as built.

Fig 5. Overtopped water collecting chute and container

B. *Test Conditions and Measurements*

1) *Similitude and model scale*

Similitude: to have similitude on dynamics, kinetics, and wave factor as well, it is necessary to design the model according to the geometrically undistorted model. Scale factors on horizontal and vertical direction must be similar and based on Froude standard.

Model scale: Based on the fact context such as wave parameters in Vietnam, the dimensions of wave flume, the model length scale factor has been chosen as 1/50. However, the core layer would be required a different scale [5]-[12] to ensure the similitude of porous flow more appropriately in the core layer and avoid the instability of the cover layer caused by internal setup. The results are shown in Table 1.

TABLE I
RESULTING SIZES OF MODEL CONCRETE BLOCKS, SECONDARY AND CORE LAYER

Block type	**Prototype**	**Scale**	**Model**
	Dn(cm)		**Dn(cm)**
RAK IV	205,5	$\lambda_l = 50$	4,11
TET	210	$\lambda_l = 50$	4,20
Secondary	-		2,3
Core	20,7	$\lambda_l = 9$	2,3

2) *Test program*

To study overtopping waves, the overflow rate is measured for at least first 1000 wave each experiment. This period ensures that the primary frequency (cycle) of the spectrum is created entirely. For the sake of cross-comparison in terms of wave overtopping reduction with other block types, 08 experiments with Tetrapod were also selected for testing. In summary, there are 58 experiments (including repeated experiments) are shown in Table 2.

TABLE II
SUMMARY OF THE TEST PROGRAM

Series	**RAK-IV**	**TET**
No. of exp.	36 (50)	08
Hm0 (m)	0.145 - 0.214	0.145 - 0.180
Tp (s)	1.50 - 2.60	1.5 - 2.5
ξ0m (-)	2.93 - 5.12	3.00 - 5.14
Rc (m)	0.136 - 0.211	0.137 - 0.210
Rc/Hm0	0.66 - 1.45	0.76 - 1.45
Note	Overtopping and stability	only overtopping

3) *Measurement parameters*

Measurement parameters include wave height H, wave period T, mean overtopping discharge q. These parameters are determined as follows:

$$H_{m0} = 4.005\sqrt{m_0} \tag{4}$$

$$T_{m\alpha,\beta} = \left(\frac{m_\alpha}{m_\beta}\right)^{\frac{1}{\beta-\alpha}} \tag{5}$$

The breaker index or Irribaren number ξm is another important parameter that characterizes the interaction between waves and slope structures:

$$\xi_m = \frac{\tan\alpha}{\sqrt{s_m}} \qquad s_m = \frac{2\pi H_{0m}}{gT_m^2} \tag{6}$$

Amount of water overtopped the breakwater crest is pumped out from the container and scaled carefully. Then, the average overtopping discharge q is determined as the following:

$$q = \frac{V_{ovt}}{T_{ovt}} \tag{7}$$

4) Experimental steps

The following steps are used strictly for every test series:

- Leveling the middle layer surface carefully and locate the model armor units by random;
- Taking photos of the sloped armor layer;
- Filling the wave flume with water to the determined level (0.52 or 0.55 m);
- Measuring the water level in wave flume before testing;
- Checking carefully 03 wave gauges;
- Placing the chute and container to collect overtopping wave;
- Starting the experiment;
- Recording signals from 03 wave gauges;
- Pumping water out from container removing the chute after 1000 waves;
- Taking pictures of slope every 1000 waves and after testing;
- Scaling the total volume of water collected from the container.

III. RESULTS AND DISCUSSION

The experiments' results are summarized in Table 3

TABLE III

OVERALL TESTING PROGRAM AND WAVE OVERTOPPING PARAMETER

STT	**Thí nghiệm**	**Thời gian (s)**	**Thể tích (lít)**	**Chiều rộng máng (m)**	**H_{m0} (m)**	**T_p (s)**	**$Tm_{-1,0}$ (s)**	**$T_{m0,1}$ (s)**	**q (l/s/m)**	**Rc (m)**	**$\xi_{m-1,0}$ (-)**
RAKUNA IV											
1	H12T25	2820	48.4	0.2	0.150	2.51	2.35	2.10	0.086	0.186	5.061
2	H12T25_R1	2820	54.6	0.2	0.149	2.51	2.35	2.10	0.097	0.186	5.078
3	H15T20	2280	20.2	0.2	0.169	1.56	1.46	1.40	0.044	0.185	2.961
4	H15T20_R1	2280	20.3	0.2	0.168	1.56	1.46	1.39	0.045	0.185	2.958
5	H15T25	2820	214.0	0.2	0.180	2.51	2.35	2.04	0.379	0.188	4.606
6	H17T18	2100	97.8	0.2	0.186	1.81	1.76	1.58	0.233	0.186	3.401
7	H17T20	2280	164.0	0.2	0.188	2.16	1.94	1.71	0.360	0.187	3.734
8	H17T20_R1	2280	177.0	0.2	0.190	2.08	1.95	1.71	0.388	0.187	3.733
9	H17T25	2820	242.0	0.2	0.192	2.51	2.36	2.03	0.429	0.188	4.479
10	H20T20	2280	172.0	0.2	0.200	2.08	2.00	1.73	0.377	0.187	3.723
11	H20T25	3220	532.0	0.2	0.200	2.51	2.36	2.02	0.826	0.191	4.396
12	H20T25_R1	1860	342.0	0.2	0.200	2.51	2.36	2.01	0.919	0.189	4.391
13	H20T25_R2	2820	512.0	0.2	0.201	2.51	2.36	2.02	0.908	0.191	4.377
14	H12T25	2820	372.0	0.2	0.153	2.51	2.35	2.12	0.660	0.139	5.011
15	H12T25_R1	2820	198.0	0.1	0.155	2.6	2.35	2.11	0.702	0.137	4.96
16	H15T15	1800	190.0	0.2	0.172	1.5	1.46	1.4	0.528	0.137	2.938
17	H15T15_R1	1800	93.0	0.1	0.172	1.56	1.46	1.40	0.517	0.136	2.939
18	H15T15_R2	1800	86.0	0.1	0.170	1.56	1.46	1.40	0.478	0.136	2.948
19	H15T20	2280	412.0	0.2	0.182	2.01	1.89	1.70	0.904	0.140	3.694
20	H15T20_R1	2280	190.0	0.1	0.183	2.08	1.89	1.7	0.833	0.137	3.684
21	H15T20_R2	2280	185.0	0.1	0.180	2.01	1.89	1.70	0.811	0.137	3.709
22	H15T25	2820	585.0	0.2	0.183	2.60	2.36	2.08	1.037	0.142	4.593
23	H17T18	2100	230.0	0.1	0.194	1.81	1.74	1.59	1.095	0.138	3.291
24	H17T18_R1	2100	180.0	0.1	0.194	1.80	1.74	1.59	0.857	0.137	3.289
25	H17T20	2280	340.0	0.1	0.198	2.08	1.93	1.72	1.491	0.139	3.606

26	H17T20_R1	2280	355.0	0.1	0.196	2.08	1.91	1.72	1.557	0.139	3.600
27	H17T25	2820	580.0	0.1	0.200	2.60	2.37	2.08	2.057	0.142	4.414
28	H17T25_R1	2820	560.0	0.1	0.199	2.60	2.36	2.07	1.986	0.142	4.410
29	H20T20	2280	430.0	0.1	0.211	2.08	1.97	1.75	1.886	0.140	3.580
30	H20T25	3000	870.0	0.1	0.214	2.60	2.37	2.06	2.900	0.145	4.265
31	H12T25	2820	74.0	0.1	0.151	2.51	2.35	2.11	0.262	0.161	5.041
32	H15T15	1800	46.0	0.1	0.170	1.50	1.46	1.40	0.256	0.161	2.956
33	H15T20	2280	99.0	0.1	0.180	2.01	1.90	1.70	0.434	0.161	3.730
34	H15T25	2820	210.0	0.1	0.179	2.51	2.35	2.07	0.745	0.163	4.635
35	H17T18	2100	118.0	0.1	0.191	1.81	1.75	1.58	0.562	0.161	3.333
36	H17T20	2280	148.0	0.1	0.193	2.08	1.94	1.72	0.649	0.162	3.686
37	H17T25	2820	364.0	0.1	0.195	2.51	2.35	2.04	1.291	0.164	4.438
38	H20T20	2280	227.0	0.1	0.206	2.01	1.99	1.73	0.996	0.163	3.645
39	H20T25	2820	530.0	0.1	0.208	2.60	2.36	2.03	1.879	0.166	4.306
40	H12T25	8760	16.0	0.1	0.145	2.51	2.34	2.06	0.018	0.210	5.118
41	H12T25_R1	2820	20.0	0.2	0.146	2.51	2.34	2.05	0.035	0.210	5.090
42	H15T15	2100	1.3	0.1	0.164	1.56	1.46	1.39	0.006	0.210	3.001
43	H15T15_R1	2100	2.9	0.2	0.164	1.56	1.46	1.39	0.007	0.210	3.000
44	H15T20	2280	9.7	0.1	0.172	2.08	1.93	1.69	0.043	0.210	3.884
45	H15T25	3900	39.0	0.2	0.172	2.00	1.92	1.68	0.050	0.210	3.853
46	H17T18	2100	26.0	0.2	0.179	1.81	1..77	1.58	0.062	0.210	3.482
47	H17T20	2280	31.0	0.2	0.184	2.08	1.96	1.70	0.068	0.210	3.802
48	H17T25	2820	98.0	0.2	0.182	2.60	2.34	2.00	0.174	0.211	4.572
49	H20T20	2280	27.0	0.1	0.193	2.08	2.00	1.72	0.118	0.210	3.798
50	H20T25	2820	90.0	0.1	0.196	2.60	2.35	1.99	0.319	0.211	4.419
TETRAPOD											
1	H12T25	2820	5.5	0.1	0.145	2.51	2.35	2.09	0. 020	0.210	5.141
2	H15T20	2280	2.8	0.1	0.172	2.08	1.92	1.69	0.012	0.210	3.863
3	H12T25	2820	20.0	0.1	0.147	2.51	2.34	2.07	0.071	0.185	5.073
4	H15T15	2280	14.0	0.2	0.166	1.50	1.46	1.39	0.031	0.185	2.978
5	H12T25	2820	59.0	0.1	0.150	2.51	2.35	2.11	0.209	0.161	5.055
6	H15T20	2280	85.0	0.1	0.179	2.08	1.90	1.70	0.373	0.161	3.737
7	H12T25	2820	132.0	0.1	0.148	2.60	2.34	2.11	0.468	0.137	5.064
8	H15T20	2280	185.0	0.1	0.180	2.08	1.89	1.70	0.811	0.137	3.705

Firstly, the author investigates the impact of $\xi_{m-1,0}$ on the overtopping wave reduction factor γ_r for RAKUNA IV and Tetrapod armor blocks. The overtopping wave reduction factor γ_r could be inferred from Equation 1 as follows:

$$\gamma_r = \frac{\log(Q_{TAW})}{\log(Q_m)} \tag{8}$$

After being calculated from experimental results, the relationship between overtopping wave reduction factor γ_r and breaker index $\xi_{m-1,0}$ can be described in Fig. 6.

Fig. 6 shows clearly that the overtopping wave reduction factor γ_r is not a constant but depends linearly on breaker index $\xi_{m-1,0}$. This trend is very suitable for the experimental results of Bruce et al. in 2009 [3]. Moreover, two distinct sub-ranges of breaker index $\xi_{m-1,0}$ are realized clearly: (1) in the range from 2.0 to 4.0 and (2) larger than 4.0. On each of sub-range, a representative overtopping wave reduction factor γ_r can be found. Moreover, the overtopping wave reduction coefficient of RAKUNA IV block is slightly larger than Tetrapods.

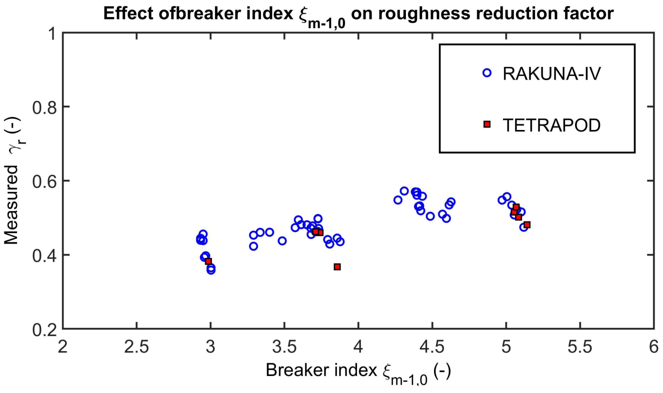

Fig 6. The dependence of roughness factor on Irribaren number.

A. *Overtopping Reduction Factor of - TETRAPOD*

Although there have been many studies on the roughness coefficient of Tetrapod blocks, the results in this study are only used to test and confirm the general reliability for experiments with Rakuna IV block. In addition, the reliability of the research results on the roughness coefficient of Rakuna IV block is further confirmed by comparing the roughness coefficient of Tetrapod from previous studies.

The overtopping wave reduction factor of the TETRAPOD block is also determined in two distinct ranges of breaker index: (1) in the range from 2.0 to 4.0 and (2) larger than 4.0 (Fig 6). The result of these factors are found as follows: $\gamma_r = 0.39$ in range (1) and $\gamma_r = 0.49$ in range (2) (Fig 7).

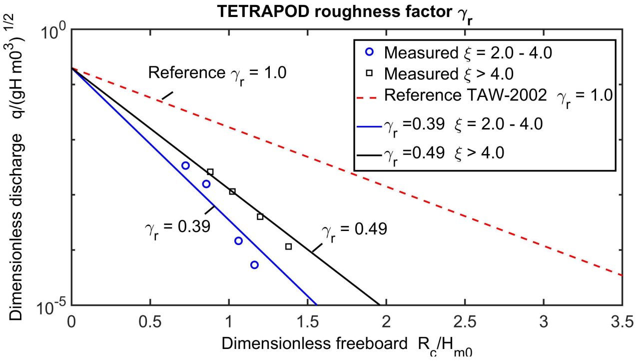

Fig 7. Tetrapod's roughness factor.

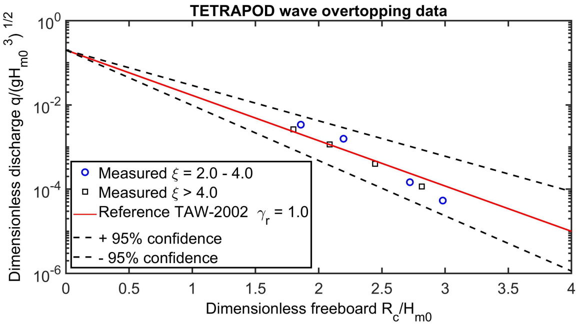

Fig 8. Re-elaborated was overtopping wave data to Tetrapod roughness factors.

Then, overtopping wave data are re-elaborated according to Equation 1 and presented in Fig 8. The result is suitable for Van der Meer's [10].

B. *Overtopping Reduction Factor of RAKUNA-IV*

Similarly, the overtopping wave reduction factor of RAKUNA IV is also considered in 2 breaker index ranges, as mentioned above. The results of these factors are found as follows: $\gamma_r = 0.41$ in range (1) and $\gamma_r = 0.51$ in range (2) (Fig 9). These overtopping wave reduction factor of RAKUNA IV are a bit bigger than Tetrapods.

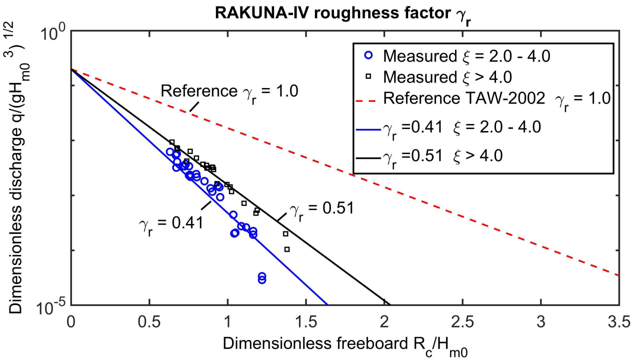

Fig 9. Rakuna IV roughness factor.

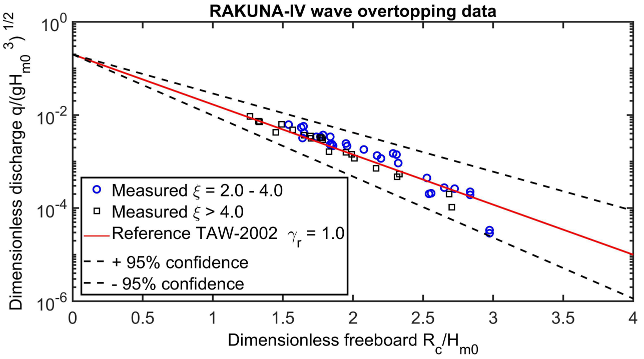

Fig 10. Re-elaborated is overtopping wave data to Rakuna IV roughness factors.

With values of roughness, coefficients that have found above, overtopping wave data are re-elaborated according to Equation 1 and presented in Fig 10. The result is suitable for Van der Meer's [2]. Finally, the average overtopping wave reduction factors γ_r of RAKUNA IV in two distinct sub-ranges of breaker index $\xi_{m-1,0}$ could be taken as follows:

- in range from 2.0 to 4.0: $\gamma_r = 0,41$
- larger than 4.0 : $\gamma_r = 0,51$

IV. CONCLUSIONS

Very detailed and careful 2D physical model experiments (58 tests in total) were conducted in the wave flume at Hanoi Water Resource University-Viet Nam to research on the roughness effect of 2 kinds of armor units-Tet and Rak IV to overtopping wave discharges. The above analysis has demonstrated clearly that the experiments' results in this investigation are reliable in the comparison between this study data quality and that researched by Bruce et al. in 2009 [3]. Note that, in this study, the experiments are carried out with a wider range of $\xi_{m-1,0}$ (up to $\xi_{m-1,0} = 5.1$) and also somewhat at a larger scale.

Roughness or overtopping wave reduction coefficient is not a fixed value but changes almost linearly with breaker index (or Iribarren number). With a quite exact experimental result set, it could be said that to predict better-overtopping wave discharge, the overtopping wave reduction coefficient should be applied in two ranges of breaker index value as mentioned above. Although, the upper limit of $\xi_{m-1,0}$, where $\gamma_r = 1.0$ is found (no roughness reduction), is not yet known for wave overtopping. It is interesting to note that the same average increase gradient of overtopping wave reduction coefficient by $\xi_{m-1,0}$ is observed herein for both Tetrapod and Rakuna, viz. $\Delta\gamma_r/\Delta\xi_{m-1,0} = 0.06$. Though Tetrapod and Rak-IV are quite similar in shape, overtopping wave reduction coefficient of Rakuna IV is a bit higher than Tetrapod's (TET_γ_r = 0.39 vs. RAK_γ_r = 0.410). This can be physically explained that Rakuna IV has a higher porosity (56.5%), so it has a higher and longer water retention capacity when the wave comes up and down leading to water filling in porosity space called "water buffer.” Owing to this water buffer, the surging waves feel less roughness on a Rakuna slope than on Tetrapod one.

According to EurOtop 2018 [1], the Tetrapod roughness factor is recommended $\gamma_r = 0.38$ with breaker index $\xi_{m-1,0}$ in range of from 2.0 to 4.0. From the results in this research that compared with Bruce's results [3], Rakuna IV roughness factor can be interpreted $\gamma_r = 0.40$. Roughness coefficients with their ± 95 % confident limitation are shown in Table 4.

TABLE IV
ROUGHNESS FACTOR OF RAKUNA-IV

Irribaren number	**Mean Roughness coefficient**	**95% CI, low γ_r**	**95% CI, high γ_r**
$\xi_{m-1,0}$ = 2.0 - 4.0	0.41 (0.40)	0.39 (0.38)	0.42 (0.41)
$\xi_{m-1,0}$ > 4.0 - 5.0	0.51 (0.50)	0.49 (0.48)	0.52 (0.51)

NOMENCLATURE

H_{m0}	the wave height at the structure	m
m_0	zeroth moment of measured incident wave spectra	
m_α; m_β	moments α-*th*; β-*th* of change density spectra	
tanα	slope coefficient of the rubble-mound breakwater (1:1.5)	
s_m	wave slope	
V_{ovt}	the total measured the overtopping volume	m^3
T_{ovt}	overtopping duration	s
Q_{TAW}	the dimensionless reference discharge predicted by TAW-2002	
Q_m	the measured dimensionless discharge	
q	unit overtopping discharge	l/s/m
R_c	the top freeboard	m
Greek letters		
γ_r	overtopping wave reduction factor or roughness factor roughness	
$\gamma_{r,\ surging}$	roughness coefficient used in calculating run-up (non-breaking) waves	
λ_l	the model length scale factor	
$\xi_{m-1,0}$	the breaker index or Iribarren number	

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