# ON THE EFFECT OF 2-LAYER THICKNESS BY HIGH-SPECIFIC GRAVITY ARMOR BLOCKS ON WAVE REFLECTION

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## Abstract

*High-specific gravity (HSG) armor blocks have high stability for waves compared with the same size blocks made with normal concrete. Since an armor layer constructed with HSG armor blocks is thinner than the equivalent layer built with normal concrete, it is expected that it will produce significantly higher wave reflection. The goal of the present study is to investigate experimentally the effect of a double layer of HSG tetrapods (referred to as 2-tetrapod layer) on wave reflection. During the tests, regular waves were generated against a breakwater covered with the 2-tetrapod layer, and wave reflection was recorded for several layer thicknesses. Six sizes of tetrapod models were used ranging from 3.1 to 16.6 cm in vertical height, i.e., the 2-tetrapod layer thickness varied from 5.2 to 22.5 cm. Based on the laboratory test data, the effect of the layer thickness on wave reflection was examined using dimensionless factors derived from dimensional analysis. It was concluded that wave reflection increases as the specific gravity of armor blocks becomes larger, in a manner that depends on the deep water wave steepness.*

## Introduction

Normal concrete armor blocks have been widely used in many countries as armor units or construction units for wave absorbing works, detached breakwaters, artificial reefs, and so on. Armor blocks stable weight against wave action has been usually evaluated by Hudson's formula. Yet the use of armor blocks is a difficult technique associated with a number of typical problems and weak points. Here are some of them :

1. Armor blocks positioning vs wave action :

① Armor blocks are subjected to the combined action of waves and wave-induced currents on the seaward slope and at the crest of breakwaters, groins, wave absorbing works, submerged breakwaters, and artificial reefs. Corners at the sea side front of reclaimed lands also experience complex wave actions.

② In the swash zone, in front of breakwaters, armor blocks may be entrained due to the multiple effect of wave breaking, runup and backwash.

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2. Use in construction :
③ The construction area for the armor blocks casting yard and for the armor layer is usually limited in size.
④ Large scale manufacturing devices are difficult to transport in remote places such as distant detached islands.

3. Sea-landscape and coastal structures :
⑤ Harmony between natural beaches and coastal structures requires a good balance between armor block size and natural beach scale.

High-specific gravity (HSG) armor blocks can provide very effective solutions to these problems compared with normal concrete blocks {unit weight: 22.54kN/$m^3$ (2.3tf/$m^3$)}. Given the design wave height and the angle of the armor layer slope relative to the horizontal, coastal structures made with HSG concrete blocks are more compact and smaller in size.

Authors (1994) analyzed the effect of a change of specific gravity on the stability of armor blocks relative to wave action. Results are based on a series of laboratory tests conducted with tetrapod models. It was found that a scaling effect prevails in tests carried out at small or medium scale, which is not accounted for by Hudson's formula. Yet, once corrected for this effect, the formula can be applied to evaluate the stable weight of HSG armor blocks. If the same wave acts against both normal concrete blocks and HSG concrete blocks, the latter can be smaller in size. Thus, at the scale of the incident waves, the thickness of a layer of HSG concrete blocks appears relatively thin. Indeed, the change of relative armor layer thickness has a considerable influence on wave reflection from armored coastal structures.

About ten years ago, Chevalier at SOGREAH Co. Ltd. in France (1994) developed the Accropod, not only aimed at protecting the slope-surface of breakwaters made with rubble stones and at absorbing the waves, but also designed to present high stability for waves when used in single armor layers. Turk and Melby (1994) at CERC, USA developed the Core-Loc that has also high stability for wave action under a single armor layer. Thus, new types of armor blocks are successively developed by seeking stability for waves, economical efficiency and ease of construction. These high-performance armor blocks are designed to be used in a single layer. Therefore, wave reflection and wave runup cannot be neglected when these blocks are made out of HSG concrete, because the absorption of incident wave energy becomes increasingly worse as the layer thickness decreases.

However, current investigations in this field are incomplete. It is the goal of this study to measure experimentally wave reflection from 2-tetrapod layers under the action of regular waves. The effect of a change of layer thickness is examined by using tetrapods of different sizes. Dimensionless hydraulic parameters such as relative water depth at the toe of the structure, deep water wave steepness, and relative 2-tetrapod layer thickness are used to analyze the data and to discuss the characteristics of wave reflection.

Dimensional Analysis on Wave Reflection

(1) Dimensional Analysis

We examine the effect of a change of specific gravity of armor blocks on wave reflection from an armor layer by means of dimensional analysis. Considering the 2-D case of a wave striking perpendicularly a seawall covered with a 2-tetrapod armor block layer, wave reflection from the seawall is expected to be dependent on the following hydraulic parameters.

a) Armor blocks characteristics

$B_{2h}$ ; 2-tetrapod layer thickness

$B_r$ ; methods of placement

$B_\varepsilon$ ; porosity

$B_u$ ; under layer roughness (crushed stone or smooth surface)

$\theta$ ; angle of armor layer slope, measured from the horizontal

b) Properties of Waves

$h$ ; water depth at the toe of the structure covered with armor blocks

$H$; wave height

$T$; wave period

$\rho$ ; mass density of water

$\mu$ ; viscosity of water

$g$ ; gravitational acceleration

The reflection coefficient $K_r$ is expected to be a function of these eleven hydraulic parameters :

$$K_r = f_1 (h, H, T, \mu, \rho, g, B_\varepsilon, B_{2h}, B_T, B_u, \tan\theta) \tag{1}$$

In dimensionless form, this equation becomes

$$K_r = f_2 \left[ \frac{h}{H}, \frac{T}{\sqrt{H/g}}, \frac{\sqrt{gh}\cdot H}{\nu}, \frac{B_{2h}}{H}, B_\varepsilon, B_T, B_u, \tan\theta \right] \tag{2}$$

The right hand second term in Eq.(2) , $T/\sqrt{H/g}$ , is rewritten as $L/H$, using the relationship, $L=\sqrt{gH}\cdot T$. This dimensionless parameter $s/H$ represents the deep water wave steepness. The right-hand second term, divided by the fourth term, becomes

$$\frac{T}{\sqrt{H/g}} \propto \frac{\sqrt{gH}\cdot T}{B_{2h}} \tag{3}$$

which can be rewritten as $UT/B_{2h}$ is possible to rewrite as $UT/B_{2h}$, because the term $\sqrt{gh}$ has the dimension of a velocity and is a direct function of the particle velocity U induced by the waves. This term has the form of a *KC* number, which is a dimensionless number relating to the generation and separation of eddies. More precisely, the right-hand second term of Eq. (2) can be considered as the *KC* number based on wave characteristics and layer thickness. Also, multiplying the third term by the fourth term, we obtain

$$\frac{\sqrt{gh}\cdot H}{\nu} = \frac{\sqrt{gH}\cdot B_{2h}}{\nu} \tag{4}$$

which is the Reynolds number based on wave celerity and layer thickness. So far, we can see that several choices of dimensionless parameters are permitted and Eq. (2) may take the equivalent form:

$$K_r = f_3\left\{\frac{h}{L},\ \frac{L}{H}\left(or\frac{\sqrt{gH}.T}{B_{2h}}\right),\ \frac{B_{2h}}{L},\ \frac{\sqrt{gH}\cdot B_{2h}}{\nu},\ B_T,\ B_\varepsilon,\ B_U,\ \tan\theta\right\} \tag{5}$$

In these laboratory tests, tetrapods are randomly placed and the under layer is made out of crushed stone. Therefore, $B_T$ and $B_U$ may be considered as constant and disregarded. The porosity rate $B\varepsilon$ is measured by a submerging method. A box-type basin (90cm wide x 100cm long x 50cm high) is used for this purpose. The method consists of filling the basin with water up to the top level of the tetrapods placed randomly on its base. This test is performed with a series of tetrapod models ranging from 3.0 to 16.0cm in vertical height. Porosity values are summarized in Table 1. They vary from 53% to 63% but only tetrapods of 3.1cm height have a porosity of 53%. Taking into account the size of the tetrapods and the accuracy of the present method, we may consider that the scattering of porosity is small and that the porosity term in Eq. (2) can be omitted. Furthermore all tests are carried out with the same breakwater slope: tan $\theta$ =3/4, so that this term can also be neglected. Taking wave characteristic parameters in deep water as a reference, the dimensionless expression of the reflection coefficient reduces to

**Table 1 Characteristics of tetrapods used for the tests and figure reference marks**

| Classification type No. | Vertical block hight l (cm) | Two tetrapod leyers thickness $B_{2h}$(cm) | Procity rete $B_\varepsilon$ (%) | Total number of tetrapod | Marks |
|---|---|---|---|---|---|
| C-1 | 3.1 | 5.2 | 53 | 1800 | ✡ |
| E-1 | 5.7 | 8.3 | 61 | 1048 | ▽ |
| E-2 | 7.8 | 12.0 | 57 | 572 | ◇ |
| E-3 | 10.4 | 14.6 | 63 | 287 | □ |
| E-4 | 14.2 | 18.5 | 61 | 223 | ⊙ |
| D-5 | 16.6 | 22.5 | 59 | 108 | △ |

$$K_r = f_4\left[\frac{h}{L_0}, \frac{H_0}{L_0}(or\ KC), \frac{B_{2h}}{L_0}(or\ \frac{B_{2h}}{H_0}), \frac{\sqrt{gH_0}\cdot B_{2h}}{\nu}\right] \qquad (6)$$

From Eq. (6) we can see that the reflection coefficient is governed by four factors only : the relative water depth $h/L_0$, the deep water wave steepness $H_0/L_0$, the relative armor layer thickness $B_{2h}/H_0$ and the Reynolds number $\sqrt{gH_0}\cdot B_{2h}/\nu$ .

## Laboratory Tests

The laboratory tests for wave reflection were performed in the same basin that was already used for stability tests (Ito et al. 1994). This wave basin is divided into seven flumes by separating walls. The breakwater models which were set to measure wave reflection were constructed within every other flume. They were covered with two layers of tetrapods (referred to as 2-tetrapod layer), placed randomly over an underlayer of crushed stone. The sea-side slope was set to 1V:4/3H. During the laboratory tests, tetrapods were covered by a steel net to prevent accidental displacement due to wave action. Recall that the purpose of the tests is to measure wave reflection in terms of the 2-tetrapod layer thickness only, not including any entrainment by the waves. In order to absorb multiple wave reflections between breakwaters and wave paddle, a slope of 1V:10H was constructed with wave absorbing net-mats within every intermediate flume, i.e. in those flumes where no breakwaters were installed. With this method, stable wave conditions could be sustained for long durations in the flumes with breakwaters, and it is there that wave reflection was recorded Test conditions are summarized in Table 2. As shown in this table, six sizes of tetrapod models were investigated: 3.1, 5.8, 7.8, 10.5, 14.2 and 16.6cm in vertical height. Time histories of the wave profile, in which the incident wave and the wave reflected from the 2-tetrapod layer overlap, were recorded by a wave meter at the toe of the slope of the breakwater. These analog data were converted to numerical data by an A to D board converter connected to a personal computer. The reflection coefficient was computed from the incident reflected waves separation method proposed by Goda et al. (1976). During the entire duration of the tests, flow characteristics such as nonbreaking waves,

**Table 2 Test conditions and characteristics of breakwater model**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Regular waves | Water depth at the toe of breakwater slope | h(cm) | 50 | | | | | |
| | Wave height | H(cm) | 5 ~ 30 | | | | | |
| | Wave period | T(sec) | 1.0 ~ 3.0 (interval 0.5 sec) | | | | | |
| | Wave steepness in deep water | Ho/Lo | 0.002 ~ 0.12 | | | | | |
| Breakwater covered with 2-tetra layer | Sea bed slope | | horizon | | | | | |
| | Slope angle | tan $\theta$ | 1:4/3 | | | | | |
| | Armor block model | | Tetrapod | | | | | |
| | Tetrapod vertical height | B h(cm) | 3.1 | 5.7 | 7.84 | 10.4 | 14.2 | 16.6 |
| | Tetrapod 2-layer thickness | B 2h(cm) | 5.2 | 8.3 | 12.0 | 14.6 | 18.5 | 22.5 |

collapsing or surging breakers, as well as plunging breakers were also recorded visually along the slope of the 2-tetrapod layer.

Relationship between Relative Layer Thickness and Specific Gravity

(1) Armor block size

Hudson (1959) made comprehensive investigations and proposed a formula to determine the stability of armor units on rubble structures. The stability formula resulted from extensive model testing, in the form:

$$W = \frac{w_r\, H^3}{K_D\, (S_r - 1)^3 \cot\theta} \tag{7}$$

where

$W$: weight of an individual armor unit
$w_r$ : unit weight of armor unit
$H$: design wave height
$S_r$: specific gravity of armor unit to water ($=w_r/w_w$)
$w_w$ : unit weight of water
$\theta$ : angle of the breakwater slope measured from the horizontal, in degrees
$K_D$ : stability coefficient of an armor unit

Given $H$, $K_D$, and tan $\theta$ , we shall consider the relationship between the weight of an armor block, $W$, and its characteristic height $l$. Without loss of generality, this relationship may be expressed as

$$W = kl^3\, w_r \tag{8}$$

Where, $k$ is a constant. Using Eq. (8) , Eq.(7) becomes

$$l^3\, k = \frac{H^3}{K_D\, (S_r - 1)^3 \cot\theta} \tag{9}$$

Now, let's denote $l_n$ and $l_h$, $S_n$ and $S_h$ the characteristic heights and the specific gravities of blocks made out of HSG concrete and normal concrete, respectively. Eq. (9) can be rewritten, for each type of block, as:

$$l^3_n\, k = \frac{H^3}{K_D\, (S_n - 1)^3 \cot\theta} \tag{10}$$

$$l^3_h\, k = \frac{H^3}{K_D\, (S_h - 1)^3 \cot\theta} \tag{11}$$

From Eq. (10) and Eq. (11), assuming the design wave height to be a constant and taking a value of $S_n$=2.3 for the specific gravity of normal concrete, the size of any HSG block relative to a normal concrete block, $l_h/l_n$, can be expressed as

$$\frac{l_h}{l_n} = \frac{S_n-1}{S_h-1} = \frac{1.3}{S_h-1} \tag{12}$$

It can be seen from that equation that the block size ratio $l_h/l_n$ is inversely proportional to the high-specific gravity of concrete in water, $S_r$-1. The block size ratio is indicated by a thick solid line in Fig. 1. The case of sea water is also considered and represented by a dashed line. As can be deduced from this figure, the difference between fresh water and sea water is very small. The ratio of the stability weights $W_h/W_n$ is also sketched in this figure by a solid line and a dashed line, for fresh water and sea water, respectively. This ratio decreases as the 3rd-power of the specific gravity in water as can be deduced from Eq. (7).

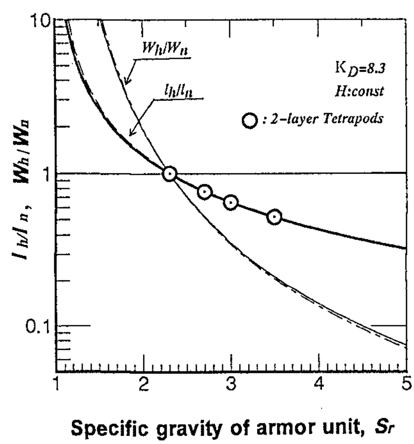



**Fig. 1 Armor block size ratio, $l_h/l_n$, and stable weight ratio, $W_h/W_n$, in terms of specific gravity**

(2) Relative Armor Layer Thickness

As discussed in the previous section, the relationship between the size of the armor blocks and their specific gravity was derived from Hudson's formula. We shall now examine the relationship between the 2-tetrapod layer thickness and the specific gravity of armor units. Let's define the relative layer thickness by the ratio of the 2-tetrapod layer thickness to the design wave height. From Eqs.(10) and (11), the following relationship is obtained

$$\frac{l^3}{H^3}k = \frac{1}{K_D\,(S_r-1)^3\cot\theta} \tag{13}$$

The relative armor layer thickness $B_{2t}/H$ may be assumed to be proportional to $l/H$, where $l$ is the height of a single armor block. Then,

$$\frac{B_{2h}}{H} \propto \frac{l}{H} \tag{14}$$

From Eqs. (13) and (14),

$$\frac{B_{2h}}{H} \propto \frac{1}{(K_D \cot\theta)^{1/3}(S_r - 1)} \tag{15}$$

$K_D$ and $\tan\theta$ being usually constant, it can be seen from Eq(15) that the relative layer thickness is inversely proportional to the specific gravity in water, $S_r$-1. Given the design wave height, it is possible to evaluate the stability weight of tetrapod ($K_D$=8.3), for various specific gravities, by using Hudson's formula. From the specific gravity and the stability weight, the 2-tetrapod layer thickness $B_{2h}$ can be estimated; it is commonly taken as 4/3 of the tetrapod height. Define the relative layer thickness $B_{2h}/H_c$ as the ratio of the 2-tetrapod layer thickness to the design wave height. $B_{2h}/H_c$ can be considered as the relative layer thickness under critical conditions. It is interesting to derive the critical layer thickness, $B_{2h}/H_c$, for several sizes of tetrapods. Results are summarized in Table 3 which indicates, for each size of tetrapod, the design wave height and the relative layer thickness, for four values of the specific gravity $S_r$=2.3, 2.7, 3.0 and 3.5, respectively. In this table, the designed wave height is derived from Hudson's formula, and the relative layer thickness is obtained from the design manual published by TETRAPOD Co., Ltd. Note, from this table, that the relative layer thickness is nearly independent on the tetrapod size. As listed in Table 3, the values of $B_{2h}/H_c$ = 0.70, 0.54, 0.45 and 0.36 depend only on the specific gravity $S_r$. Block size ratios are indicated with circle marks in Fig.1. As can be seen in this figure, for a high-specific gravity of $S_r$=3.5, block size is reduced by a factor of two compared to normal blocks ($S_r$=2.3). As expected, values of the relative layer thickness derived in Table 3 are in the same ratio.

**Table 3 Tetrapod weights, design wave heights and relative 2-tetrapod layer thicknesses. for different values of the specific gravity**

| Specific gravity | | 2.3 | | 2.7 | | 3.0 | | 3.5 | |
|---|---|---|---|---|---|---|---|---|---|
| Weight ( tf ) | 2-layer thickness (m) | Hc (m) | B2h/Hc | Hc (m) | B2h/Hc | Hc (m) | B2h/Hc | Hc (m) | B2h/Hc |
| 0.46 | 1.2 | 1.7 | 0.71 | 2.2 | 0.54 | 2.6 | 0.46 | 3.3 | 0.36 |
| 0.92 | 1.5 | 2.1 | 0.71 | 2.8 | 0.53 | 3.3 | 0.45 | 4.1 | 0.36 |
| 9.20 | 3.2 | 4.6 | 0.69 | 6.0 | 0.53 | 7.1 | 0.45 | 8.8 | 0.36 |
| 46.00 | 5.5 | 7.9 | 0.69 | 10.3 | 0.53 | 12.1 | 0.45 | 15.1 | 0.36 |
| 80.00 | 6.7 | 9.5 | 0.71 | 12.4 | 0.54 | 14.6 | 0.46 | 18.2 | 0.37 |

**H** : Design wave height ( based on $K_D$ =8.3)
**B2h/Hc** : Relative two tetrapods layers thickness

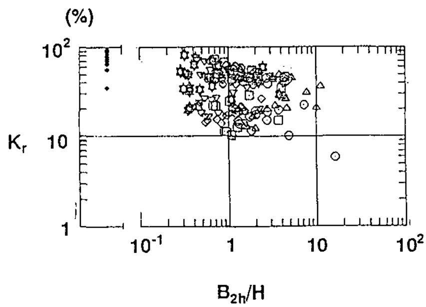



Fig. 2 Relationship between wave reflection and relative 2-tetrapod layer thickness

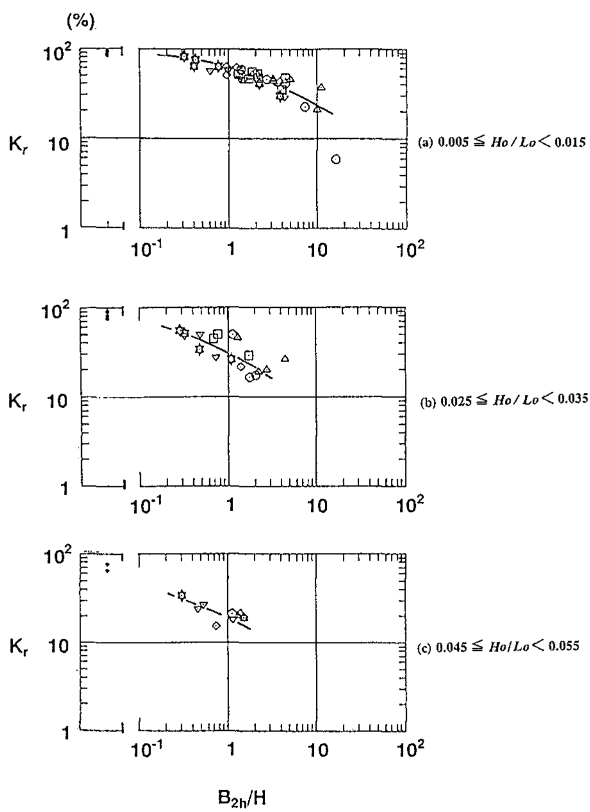



Fig. 3 Effect of deep water wave steepness on the relationship between wave reflection and relative 2-tetrapod layer thickness

Relative Armor Layer Thickness and Wave Reflection

(1) Wave Reflection

We classified the data according to the ratio of the 2-tetrapod layer thickness to the wave height at the toe of the seawall, $B_{2h}/H$, corresponding to the term $B_{2h}/H_0$ in Eq. (6), and plotted them in Fig. 2. As shown in this figure, the relationship between the reflection coefficient $K_r$ and the relative layer thickness $B_{2h}/H$ scatters widely. In this figure, dark circles denote reflection from a smooth slope. Data points were obtained by covering the sea-side slope of the seawall with a steel plate; this corresponds to the case where both armor layer thickness and underlayer porosity are zero. We investigated the effect of the relative water depth $d/L_0$ on the relationship between $K_r$ and $B_{2h}/H$, by plotting data according to the parameter $d/L_0$. The effect of $d/L_0$, however, couldn't be found : data points remain widely scattered. In a similar way, we examined the effect of the Reynolds number, $\sqrt{gH_0}\cdot B_{2h}/\nu$ : the effect of the Reynolds number couldn't be found either. Then, by separating the data into seven range-values of the deep water wave steepness, $H_0/L_0=\ \sim 0.005,\ 0.005\sim 0.015,\ 0.015\sim 0.025,\ 0.025\sim 0.035,\ 0.035\sim 0.045,\ 0.045\sim 0.055$ and $0.055\sim$, the relationship between the reflection coefficient and the relative layer thickness was rearranged, as displayed in Fig. 3 (for the sake of clarity, only three values of $H_0/L_0$ have been represented). It can be deduced, from this figure, that the deep water wave steepness strongly affects the relationship between $K_r$ and $B_{2h}/H$. Here again, reflection from a smooth slope is indicated with dark circles, as a reference. In each subfigure, Fig. 3(a) to Fig. 3(c), the trend of the reflection coefficient is shown by fitting the data with a solid curve. The relationship between $K_r$ and $B_{2h}/H$ is rearranged in Fig. 4 by plotting all solid curves together in the same graph, based on the parameter $H_0/L_0$. Each value of $H_0/L_0$ is the mean value of another range of wave steepnesses examined. Dashed lines stand for estimates of the reflection coefficient there where experimental data couldn't be obtained. It can be seen in this figure that the relationship between $K_r$ and $B_{2h}/H$ changes considerably depending on $H_0/L_0$.

(2) Wave reflection for storm waves

From this diagram, characteristics of wave reflection, when the design wave acts on the 2-tetrapod layer, can be analyzed. Since the relative layer thickness $B_{2h}/H$, which depends on the specific gravity of armor units only, is already given in Table 3, Fig. 4 can be used directly to derive the reflection coefficient from the wave steepness. For this purpose, values of the relative layer thickness $B_{2h}/H$ have been represented with vertical dashed lines in Fig. 4. The reflection coefficient is easily obtained by reading the $K_r$ values at the intersection between these vertical lines and the solid curves of wave steepness $H_0/L_0$. From these $K_r$-values, it is possible to evaluate the increasing rate of wave reflection $(K_r)_{hc}/(K_r)_{nc}$ when HSG tetrapods are used rather than normal concrete tetrapods. Fig. 5(a) indicates the relationship between $(K_r)_{hc}/(K_r)_{nc}$ and the specific gravity in water, $S$-1, according to the parameter $H_0/L_0$. As can be seen in this figure, for armor blocks designed to sustain the same critical wave height, wave reflection becomes bigger as tetrapod

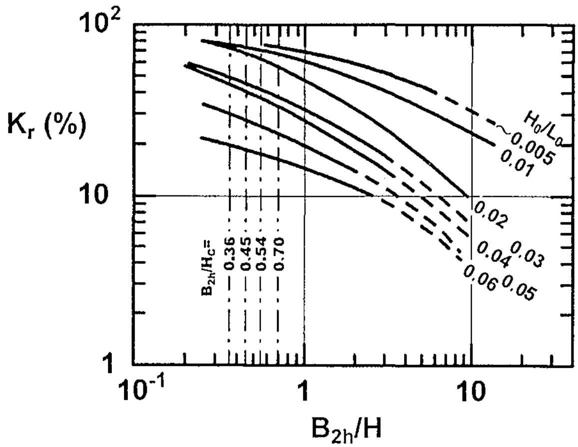
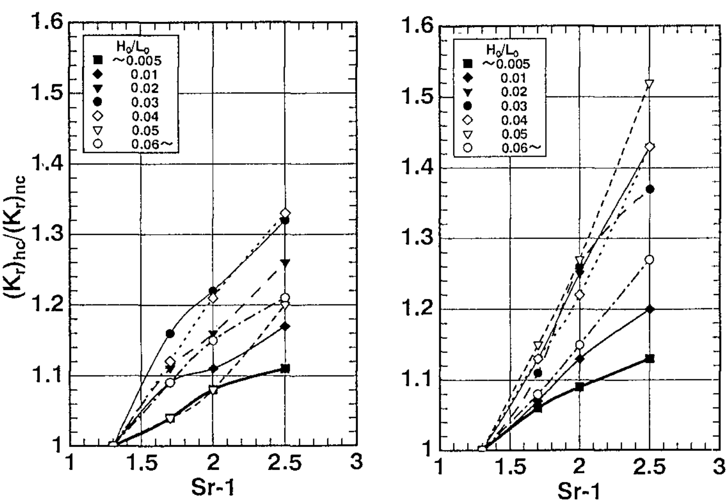



Fig. 4 Relationship between wave reflection and relative 2-tetrapod layer thickness, based on the deep water wave steepness




(a) In case of the design wave height (b) In case of half of the design wave height

Fig. 5 Increase of relative wave reflection for increasing values of specific gravity specific gravity gets larger. Fig. 5(a) also shows that this increase is proportional to specific gravity, with a rate that depends strongly on the parameter $H_0/L_0$.

(3) Wave reflection for mild waves

As mentioned in the previous section, the effect of HSG tetrapods on wave reflection was analyzed using the design wave height, which corresponds to the strongest waves the tetrapods are able to resist and which may, in practice, represent storm waves. Now we shall also examine the increase of wave reflection under the condition of mild waves. This condition is set by taking half of the design wave height for the estimate of the reflection coefficient from Fig. 4. The same graphical method is used with values of the relative thickness $B_{2h}/H$ simply doubled. As for the previous case, the rate of wave reflection, $(K_r)_{hc}/(K_r)_{nc}$ is plotted in terms of the specific gravity of tetrapod in water, in Fig. 5(b). From this figure, it can be seen that for mild waves too, the rate of reflection increases proportionally to the specific gravity of the blocks.

For both storm waves, Fig. 5(a), and mild waves, Fig. 5(b), the amount of reflection tends to increase with the specific gravity of the tetrapods. Yet, the rate of increase is strongly affected by the deep water wave steepness. As the wave becomes steeper, and as long as the wave steepness remains within the range $0.005<H_0/L_0<0.04$ (storm waves) and $0.005<H_0/L_0<0.05$ (mild waves), the rate of increase tends to become larger. Above these values, i.e. for steeper waves, it shows the opposite tendency and drops. In the case of blocks of HSG $S$=3, the reflection coefficient for storm waves is from 1.07 to 1.22 times bigger than the reflection coefficient for normal concrete (from 1.09 to 1.27 times bigger for mild waves), depending on the wave steepness.

## Conclusions

This study was intended to investigate experimentally the effect of a change of specific gravity of armor blocks on wave reflection using tetrapod units. From the results of this work, the following conclusions can be drawn:

(1) Given the specific gravity of armor units in water, the relative 2-tetrapod layer thickness, $B_{2h}/H$, is a constant, regardless of the tetrapod weight and of the design wave height.
(2) Given the design wave height, the relative layer thickness, $B_{2h}/H$, is inversely proportional to the specific gravity of armor units in water.
(3) The relationship between the reflection coefficient and the relative layer thickness is considerably affected by the deep water wave steepness.
(4) The reflection coefficient for high-specific gravity concrete blocks relative to the reflection coefficient for normal concrete blocks increases proportionally to the specific gravity, in a manner that depends on the deep water wave steepness.
(5) For both storm waves and mild waves, the larger the specific gravity of the blocks, the bigger the reflection coefficient.

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