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# Reflection Characteristics of Eco Block on Seabed

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**Abstract** : *In order to protect coastal facilities mainly from wave and current actions, the self-locking eco blocks constituting elements of protecting shore structures against scouring were designed. These blocks are adapted to the sloping bottom, coastal dunes, and submerged coastal pipelines, counteracting the destructive and erosive impulse action. A series of laboratory experiments has been conducted to investigate the reflection of water waves over and against a train of protruded or submerged shore structures and compare the reflecting capabilities of incident waves including wave forces. In this study the hydraulic model experiment was conducted to identify the performance of newly designed water affinity eco blocks to keep the coast slope and bottom mound from scouring by reduction of the wave reflection and to convince stability of the block placement. Revised design of each block element was also tested for field conditions. From the result of experiments, the field applicability of the developed blocks and placement was discussed afterward.*

**Key words** : *scouring, eco block, hydraulic model test, wave reflection, bottom mound*

## 1. Introduction

Pipelines in the coastal waters are very important links to convey oil, chemical product, and gas across or into the sea. They are used as sleeve for carrying communication cables and power cables across the sea, too. For outfall system for municipal waters into the sea, pipes are also commonly used. They are usually laid on the seabed and sometimes are buried into the bottom, if the wave and current actions are severe near the coastal area. These may cause pipe floatation, roll over, breakage, and self burier due to the vibration in the pipeline. Rubble mound cover is commonly introduced to protect and support for the pipelines under the sea bottom from fishing gears and nets. In the vicinity of marine pipelines scouring is also an important factor of damages. Pipeline scour may progress under the pipe which may finally break due to wave and current forces and its own weight. Although various ocean plant and terminal facilities near the coastal area for energy demand and supply are being constructed, these are endangered due to coastal erosion. Therefore, it is necessary to develop new technologies to respond to the ocean environment change and protect these facilities. As the merit and demerit of various coastal erosion protection technologies and the qualitative evaluation of the effect of construction are known some degree, and the existing erosion protection methods are not enough to stop the erosion, it needs to have erosion control technology. It also needs to take similar approaches to design the erosion protection blocks. Pre survey of the structure, design and construction experience plays an important role for optimization of erosion protection block. In order to improve the design technologies with these experiences, it is important to figure out the reason of erosion, to take model experiment of design and a series of modification processes, and to construct the basis of monitoring for the field experimental installation. By doing that, it could help establishing coastal disaster protection plan for the coastal plant complex and following up development of the proper unit structures. The purpose of this study is to test the developed eco blocks for the existing bottom slopes with alternative block conditions under various wave and water level conditions and report the relative effectiveness of eco bock lay out with respect to wave reflection and block

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stability.

## 2. BLOCK DESIGN CONCEPT AND HYDRAULIC MODEL TEST

### 2.1 Eco Block Design Concept and Model Setup

Intended block is to protect from erosion and scouring by controlling the bottom flows in the vicinity of beach and coastal plant complex. And also the blocks developed might contribute the safety of submarine laid pipeline and formation of the submarine eco environment accelerating the growth of the natural kelps on the structures forming the kelp forest. Design concept is minimization of the coastal bottom change and enforcement of block stability by adopting the ripple of the sea bottom and mid-hole Giwa (Korean traditional roof material) shaped block as shown in Fig.1 and thus, reduction of uplift pressure force and linking block groups. In order to increase surface friction effect, the block model was modified as shown in Fig.2 with cross stripes and couplings. Fig.2 shows also a placement example of blocks covering pipeline. The purpose of the rectangular hole of each block is for planting corals or seaweeds depending on the local water condition. Both corals and seaweeds serve a wide variety of ecological functions in nearshore ecosystems, not just for the erosion control and are critically linked to many other productive marine organisms such as shellfish, crabs, and small fishes, etc. The block size with respect to the local wave condition was depicted from the laboratory model test result by Takewaka et al (1998). The form of block on the sea bottom resembles to the natural ripple. The bottom orbital diameter of wave do to ripple length λ approaches 1.7, which suggests that the optimum size of each block should be set to be this ratio as in Fig.3.

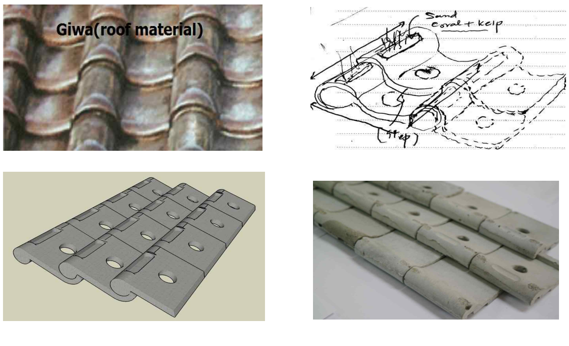


Fig. 1 Initial design concept and the first deduced block model

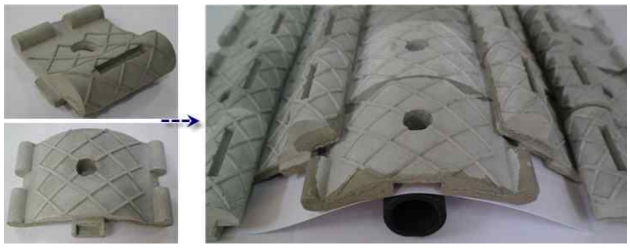

Fig. 2 Modified eco block model and an example of placemen.

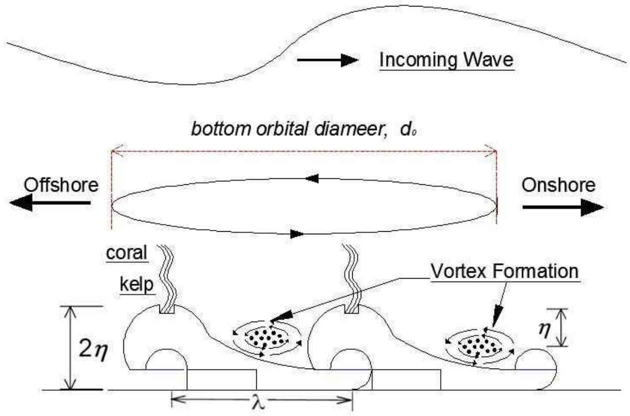


Fig. 3 Schematic diagram for water motion and eco blocks

A number of engineering studies to stabilize the coastal bottoms are available (Irie et al, 1994; Ono, 2002; Pilarczyk, 2005), but still not many done for bio or eco blocks. For this study, the model is based on the wave asymmetry and ripple distortion at the bottom. The distortion rate of which is 1:3 the length between ripple crest and trough and the height of ripple head is twice(2η) of ripple tail height(η) of the eco block. Technical aspects studied in a hydraulic model were the amount of wave reflection over the bottom mounted eco blocks and the stability of the armor layer on the mound as shown in Fig.4.

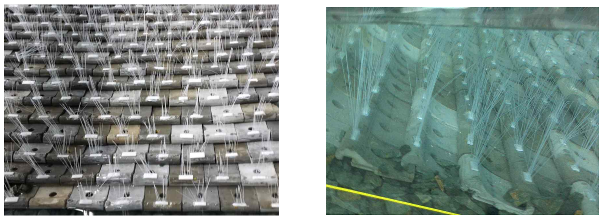

Fig. 4 Example of eco block model placement to the bottom slope

### 2.1 Experiment Equipment

Eco block model was constructed as a sloping fixed bed covering the coastal area and offshore. The linear scale was selected at 1:25 (model: prototype) in a flume 25m long by

1m wide with 1m height. A geometrically undistorted hydraulic model was used. After selection of the linear scale, the model was designed and operated in accordance with the Froude Number scaling criteria. Knowing the conditions for dynamic similarity, the relationship between the various ratios needs to be known for the design of the model. The scale relations used for the design and operation of the model are listed in TABLE 1 as (Lee et al, 2005, 2009; KORDI, 2005). The water depth was 20~30cm (5~7.5m in field) considering the general condition of the future construction field and the bottom slopes paved with the eco blocks was 1:3.73~1:5.67. Fig.5 shows the experimental setup in the wave flume of the Hydraulics Laboratory at the Korea Maritime University. The flume is equipped with a computer controlled piston type of wave generator capable of producing regular and random waves.

Table 1 Scale Relationships

| Characteristics | Symbol | Dimensions | Scale | Prototype | Model |
|---|---|---|---|---|---|
| Length | $L_r$ | $L_r$ | 1/25 | 3m | 12cm |
| Depth | $h_r$ | $L_r$ | 1/25 | 10m | 40cm |
| Wave Height | $H_r$ | $L_r$ | 1/25 | 2.5m | 10cm |
| Wave Length | $\lambda_r$ | $L_r$ | 1/25 | 50m | 2m |
| Wave Pressure | $p_r$ | $L_r$ | 1/25 | 20ttf/m$^2$ | 80g/cm$^2$ |
| Period & Time | $T_r$ | $L_r^{1/2}$ | $(1/25)^{1/2}$ | 6sec | 1.2sec |
| Weight of Armor Unit | $W_r$ | $L_r^3$ | $(1/25)^3$ | 25tf | 1600g |
| Weight/Width | $w_r$ | $L_r^2$ | $(1/25)^2$ | 100tf/m | 1600g/cm |
| Overtopping/ Width | $q_r$ | $L_r^{3/2}$ | $(1/25)^{3/2}$ | 0.1m$^3$/sec/m | 800cm$^3$/sec · cm |

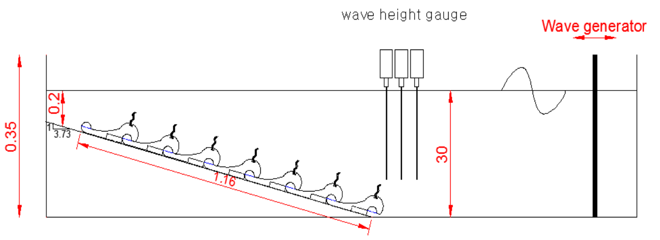


Fig. 5 Wave flume and experimental setup

The wave generator controlled by servo motor system was installed at one end of wave flume. A software developed and installed in a PC with the D/A converter to control the wavemaker and the A/D converter to get the feed back signals. At the other end of flume, a wave absorbing slope made of crushed stones, wire net, and metal scraps. Three wave gages were installed in front of the wave maker to measure the wave reflection.

### 2.3 Experiment Condition

Considered in this study were the criteria listed above, due only waves. The effects of wind and wave sets were not modeled, and tides were modeled only as constant water levels. A wave paddle displacement signal corresponding to the modified Bretschneider-Mitsuyasu spectrum as described by Goda(1985).

$$S(f) = 0.205 H_s^2 T_s^{-4} f^{-5} \exp[-0.75(T_s f)^{-4}] \quad (1)$$

where *S(f)* is the wave energy density function, $H_s$ and $T_s$ are the significant wave height and period, and $f$ is the frequency. A number of incident wave spectra were calibrated using 3 gauges with 0.4m intervals at 5.8m from a wave absorber without any bottom structure for 100 seconds as shown in Fig.6. The example of incident spectrum analyzed from the middle wave gauge is given in Fig.7. The incident spectrum is in excellent agreement with the target spectrum. The spectra with different water level show that the disturbances introduced by the wave absorber are negligible. After this, we carried out two different experiments with varying bottom slope, water depth, and direction of wave with respect to block crest: normal block model and eco block model. Eco block model contains artificial seaweeds at the rectangular hole on the block. Throughout the whole model experiments, no transmission was allowed after block placement to the impermeable bottom slope. Experiments have been conducted to measure variation of the water level and wave force on the structure, and focused to discuss for the wave reflection coefficient and stability of the block placement.

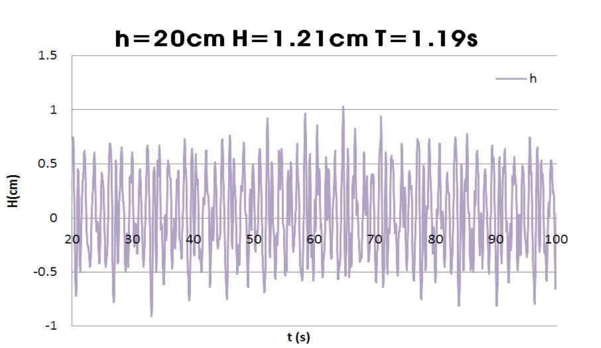


Fig. 6 An example of time series record of irregular incident wave

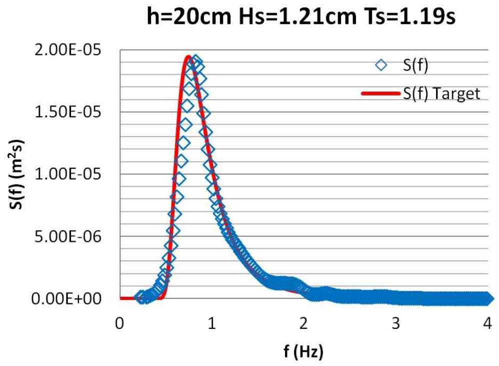


Fig. 7 Comparison of target and incident wave spectra

# 3. RESULT OF EXPERIMENT AND ANALYSIS

## 3.1 Reflection Ratio

Reflection coefficients were determined by the energy of the respective spectra, following the method of Goda and Suzuki (1976).

$$K_r = \sqrt{\sum_i \sigma_{ref}^2(\omega_i) / \sum_i \sigma_{inc}^2(\omega_i)} \tag{2}$$

where $\sigma_{inc}^2(\omega_i)$ , $\sigma_{ref}^2(\omega_i)$ are the discrete measured incident and reflected wave spectrum, respectively. On the basis of the waves record performed, it is possible to calculate the discrete wave energy spectrum both the incident and the reflected by using F.F.T. In Fig.8 the spectral shapes are compared at 20cm water depth with 1:3.732 slope for eco block (reverse direction) and the reflection coefficient calculated by equation (2) is 0.342. A total of 324 tests were carried out, corresponding to 3 bottom slopes, 3 water levels, 3 wave heights, 3 wave periods, 2 wave directions, and normal block and eco block placement. Only a brief summary is given here.

The following tables show the experimental result of reflection coefficient $K_r$ applying different water depths and bottom slopes for incoming irregular waves: wave periods ranged 1.5 to 2.5 sec, and wave heights were in the range of 1.0 to 3.0cm. There is a tendency for reflection coefficient to decrease with increasing wave periods at normal blocks in reverse direction placement, although there are some abnormal responses such as: the maximum of $K_r$ is about 0.77 at the 20cm depth for 1:3.732 slope of normal block placement. So 0.69 has shown at the 20cm depth for 1:3.732 slope of normal block placement, too (see TABLE 2 and Fig.9). Although the responses are scattered, the most values of $K_r$ are of about 0.2~0.6. On the other hand, eco block placement shows a tendency to increase $K_r$ from 0.22~0.42 with increasing wave periods as in TABLE 3 and Fig.10. TABLE 4 through TABLE 4 are for eco blocks with different bottom slope. Except the extraordinary value 0.68 of $K_r$ for eco block experiment, the representative value of $K_r$ is 0.3. Both cases have been plotted as function of the wave steepness ($H/gT^2$) in Fig.11 and Fig.12. Variation of reflection coefficients with wave period, for the condition of changing the slope of eco block placement, are given in Fig.13 through Fig.15. The results show that the reflection coefficients increase with respect to wave periods and are higher at steep slope of 1:3.732 (Fig.15), giving 0.12~0.35. For a mild slope of 1:5.671 (Fig.13), they are lower, giving 0.1~0.25. On the other hand, the medium slope (Fig.14) shows 0.12~0.28. From these figures, it is easy to draw a comparison between normal and eco block placement. The reflection coefficient from the eco block model shows 25% lower than the normal block model.

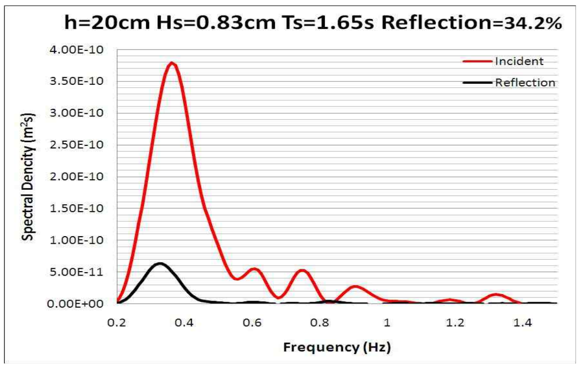


Fig. 8 Comparison of incident and reflective wave spectra for eco block

Table 2 Reflection ratio for normal block (reverse direction, slope 15°, 1:3.732)

| Depth.1 (30cm) | | | Depth.2 (25cm) | | | Depth.3 (20cm) | | |
|---|---|---|---|---|---|---|---|---|
| $T_s$ (sec) | $H_s$ (cm) | $K_r$ | $T_s$ (sec) | $H_s$ (cm) | $K_r$ | $T_s$ (sec) | $H_s$ (cm) | $K_r$ |
| 1.52 | 3.63 | 0.593 | 1.62 | 3.08 | 0.434 | 1.52 | 2.83 | 0.765 |
| 1.54 | 2.73 | 0.233 | 1.89 | 2.57 | 0.303 | 1.65 | 2.00 | 0.284 |
| 1.43 | 1.16 | 0.443 | 1.98 | 1.81 | 0.117 | 1.65 | 0.83 | 0.392 |
| 1.50 | 3.02 | 0.604 | 1.55 | 3.62 | 0.574 | 1.18 | 2.53 | 0.415 |
| 1.30 | 2.49 | 0.515 | 1.61 | 2.00 | 0.327 | 1.23 | 1.85 | 0.526 |
| 1.51 | 2.08 | 0.234 | 1.73 | 1.12 | 0.263 | 1.09 | 1.48 | 0.432 |
| 0.94 | 3.10 | 0.434 | 1.24 | 3.09 | 0.285 | 1.60 | 2.35 | 0.171 |
| 1.08 | 2.11 | 0.252 | 1.23 | 2.23 | 0.393 | 1.72 | 1.56 | 0.412 |
| 0.93 | 1.14 | 0.305 | 1.10 | 1.69 | 0.220 | 0.89 | 0.86 | 0.687 |

Table 3 Reflection ratio for eco block (reverse direction, slope 15°, 1:3.732)

| Depth.1 (30cm) | | | Depth.2 (25cm) | | | Depth.3 (20cm) | | |
|---|---|---|---|---|---|---|---|---|
| $T_s$ (sec) | $H_s$ (cm) | $K_r$ | $T_s$ (sec) | $H_s$ (cm) | $K_r$ | $T_s$ (sec) | $H_s$ (cm) | $K_r$ |
| 2.19 | 3.20 | 0.297 | 1.55 | 3.62 | 0.380 | 1.52 | 2.83 | 0.360 |
| 2.56 | 3.27 | 0.681 | 1.89 | 2.57 | 0.363 | 1.60 | 2.35 | 0.347 |
| 1.98 | 0.91 | 0.334 | 1.98 | 1.81 | 0.257 | 1.65 | 0.83 | 0.342 |
| 2.13 | 2.55 | 0.316 | 1.62 | 3.08 | 0.255 | 1.65 | 2.00 | 0.287 |
| 2.01 | 2.46 | 0.283 | 1.61 | 2.00 | 0.402 | 1.72 | 1.56 | 0.339 |
| 2.13 | 1.63 | 0.321 | 1.73 | 1.12 | 0.414 | 1.23 | 1.85 | 0.244 |
| 2.01 | 3.40 | 0.260 | 1.24 | 3.09 | 0.359 | 1.18 | 2.53 | 0.263 |
| 1.50 | 1.96 | 0.252 | 1.23 | 2.23 | 0.288 | 1.09 | 1.48 | 0.220 |
| 1.27 | 1.25 | 0.255 | 1.10 | 1.69 | 0.255 | 0.89 | 0.86 | 0.277 |

Table 4 Reflection ratio for eco block (slope 15°, 1:3.732)

| Depth.1 (30cm) | | | Depth.2 (25cm) | | | Depth.3 (20cm) | | |
|---|---|---|---|---|---|---|---|---|
| $T_s$ (sec) | $H_s$ (cm) | $K_r$ | $T_s$ (sec) | $H_s$ (cm) | $K_r$ | $T_s$ (sec) | $H_s$ (cm) | $K_r$ |
| 2.339 | 6.225 | 0.242 | 2.38 | 4.027 | 0.311 | 1.701 | 2.523 | 0.223 |
| 2.419 | 3.373 | 0.322 | 2.287 | 2.336 | 0.306 | 1.907 | 1.308 | 0.406 |
| 2.424 | 2.099 | 0.285 | 2.262 | 1.503 | 0.314 | 1.923 | 0.813 | 0.407 |
| 2.505 | 7.090 | 0.238 | 2.410 | 6.173 | 0.351 | 2.020 | 3.487 | 0.158 |
| 2.441 | 4.420 | 0.238 | 2.262 | 3.877 | 0.314 | 1.928 | 2.055 | 0.213 |
| 2.368 | 2.035 | 0.251 | 2.071 | 1.709 | 0.294 | 1.638 | 0.941 | 0.173 |
| 1.440 | 6.269 | 0.236 | 1.655 | 5.179 | 0.137 | 1.199 | 3.641 | 0.113 |
| 1.404 | 4.077 | 0.229 | 1.627 | 3.372 | 0.136 | 1.167 | 2.343 | 0.142 |
| 1.389 | 1.941 | 0.283 | 1.624 | 1.636 | 0.161 | 1.190 | 1.212 | 0.212 |

Table 5 Reflection ratio for eco block (slope 12.5°, 1:4.512)

| Depth.1 (30cm) | | | Depth.2 (25cm) | | | Depth.3 (20cm) | | |
|---|---|---|---|---|---|---|---|---|
| Ts (sec) | Hs (cm) | Kr | Ts (sec) | Hs (cm) | Kr | Ts (sec) | Hs (cm) | Kr |
| 2.380 | 4.027 | 0.296 | 1.701 | 2.523 | 0.205 | 2.630 | 2.967 | 0.214 |
| 2.287 | 2.336 | 0.237 | 1.907 | 1.308 | 0.216 | 2.522 | 1.630 | 0.243 |
| 2.262 | 1.503 | 0.267 | 1.923 | 0.813 | 0.277 | 2.426 | 0.999 | 0.235 |
| 2.410 | 6.173 | 0.271 | 2.020 | 3.487 | 0.116 | 1.890 | 3.391 | 0.144 |
| 2.262 | 3.877 | 0.265 | 1.928 | 2.055 | 0.169 | 1.911 | 2.265 | 0.158 |
| 2.071 | 1.709 | 0.166 | 1.638 | 0.941 | 0.192 | 1.891 | 1.102 | 0.165 |
| 1.655 | 5.179 | 0.131 | 1.199 | 3.641 | 0.113 | 1.447 | 3.633 | 0.129 |
| 1.627 | 3.372 | 0.119 | 1.167 | 2.343 | 0.111 | 1.443 | 2.367 | 0.151 |
| 1.624 | 1.636 | 0.162 | 1.190 | 1.212 | 0.115 | 1.273 | 1.091 | 0.175 |

Table 6 Reflection ratio for eco block (slope 10°, 1:5.671)

| Depth.1 (30cm) | | | Depth.2 (25cm) | | | Depth.3 (20cm) | | |
|---|---|---|---|---|---|---|---|---|
| Ts (sec) | Hs (cm) | Kr | Ts (sec) | Hs (cm) | Kr | Ts (sec) | Hs (cm) | Kr |
| 2.368 | 4.027 | 0.220 | 1.701 | 2.523 | 0.173 | 2.630 | 2.967 | 0.160 |
| 2.287 | 2.336 | 0.248 | 1.907 | 1.308 | 0.157 | 2.522 | 1.630 | 0.166 |
| 2.262 | 1.503 | 0.373 | 1.923 | 0.813 | 0.118 | 2.426 | 0.999 | 0.179 |
| 2.410 | 6.173 | 0.178 | 2.020 | 3.487 | 0.201 | 1.890 | 3.391 | 0.120 |
| 2.262 | 3.877 | 0.198 | 1.928 | 2.055 | 0.108 | 1.911 | 2.265 | 0.141 |
| 2.071 | 1.709 | 0.235 | 1.638 | 0.941 | 0.160 | 1.891 | 1.102 | 0.143 |
| 1.655 | 5.179 | 0.108 | 1.199 | 3.641 | 0.103 | 1.447 | 3.633 | 0.327 |
| 1.627 | 3.372 | 0.107 | 1.167 | 2.343 | 0.109 | 1.443 | 2.367 | 0.184 |
| 1.624 | 1.636 | 0.142 | 1.190 | 1.212 | 0.119 | 1.273 | 1.091 | 0.188 |

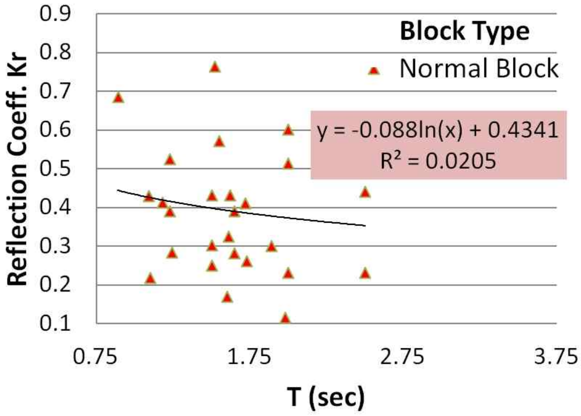


Fig. 9 Reflection ratios for normal block placement in terms of wave period and reverse direction.

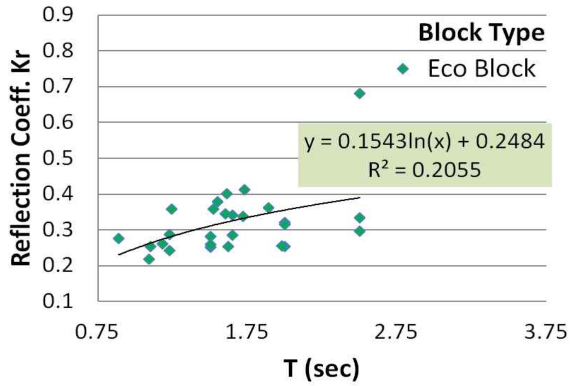


Fig. 10 Reflection ratios for eco block placement in terms of wave period and reverse direction.

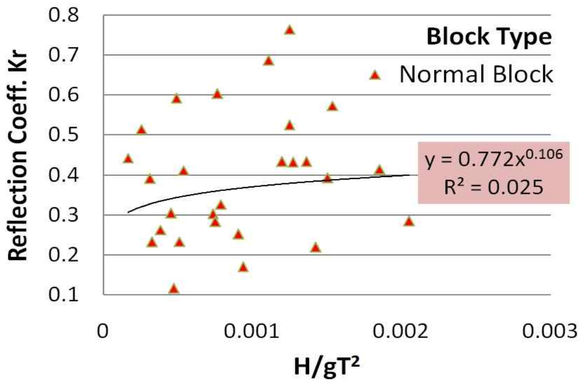


Fig. 11 Reflection ratios for normal block placement and reverse direction.

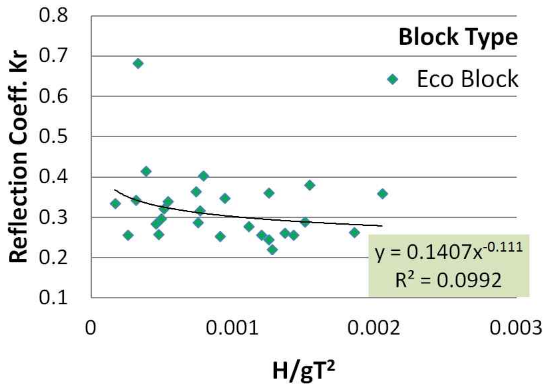


Fig. 12 Reflection ratios for eco block placement and reverse direction.

The variation of wave reflection coefficients for three bottom slopes for eco block model with respect to the wave steepness($H/gT^2$) is shown in Fig.16. In this figure, the direction of the block placement is right order. The black solid line indicates averaged trend of reflection coefficients and it converges to 0.13 minimum with respect to higher wave steepness. Thus, compared this result with 0.4 the average value of $K_r$ for normal block model as shown in Fig.11, about 33% reduction effect on reflection rate was achieved.

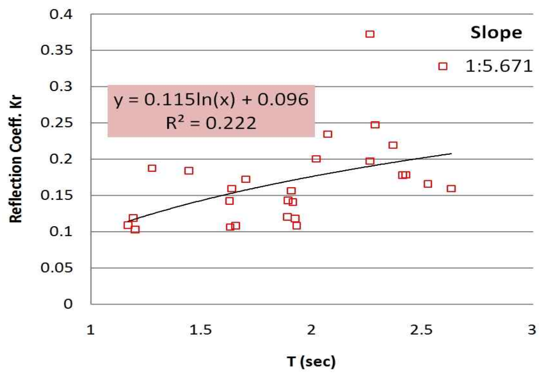


Fig. 13 Reflection ratios versus wave period for eco block placement. (slope 1:5.671)

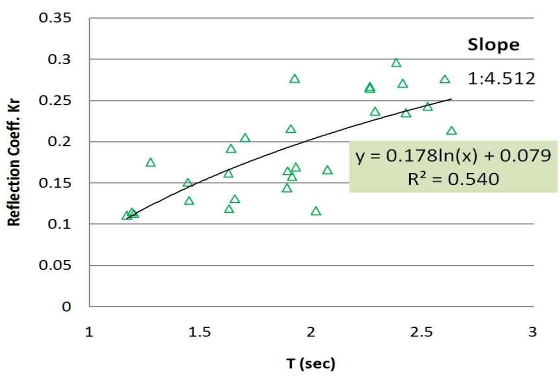


Fig. 14 Reflection ratios versus wave period for eco block placement. (slope 1:4.512)

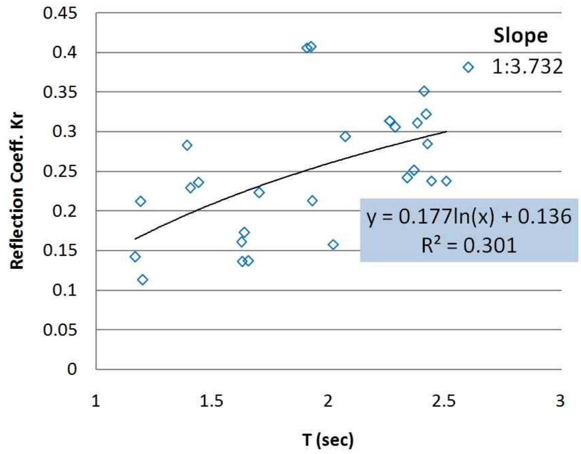


Fig. 15 Reflection ratios versus wave period for eco block placement. (slope 1:3.732)

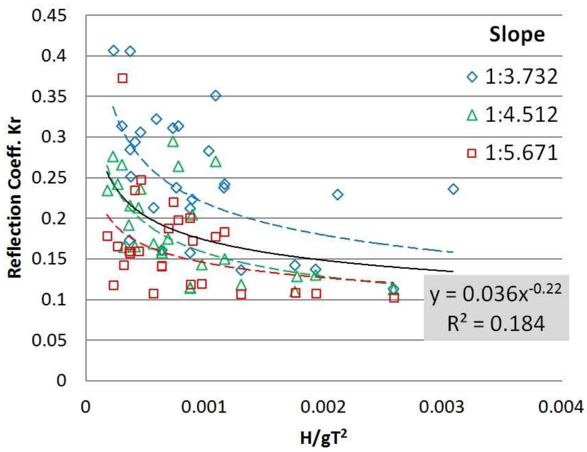


Fig. 16 Reflection ratios for eco block placement with respect to slopes

### 3.2 Stability

Furthermore, the stability of block placement was tested. The responses of the structure were analyzed by using a video camera. Apparently, 135 repetitions of the input signal have not caused significant disturbances for each slope, except some minor movement of blocks at the foot of the placement. If this is the case, then piling in the middle hole of the block can help to hold the motion. The experiments were done for steep slopes and a mild slope placement is stable structurally than the steep. In summary, therefore, most of all cases are stable even for the steep slopes. Fig.17 shows the unit blocks of erosion and pipeline protection, and the schematic view of combined eco blocks for field application, which are under experiment and presented later.

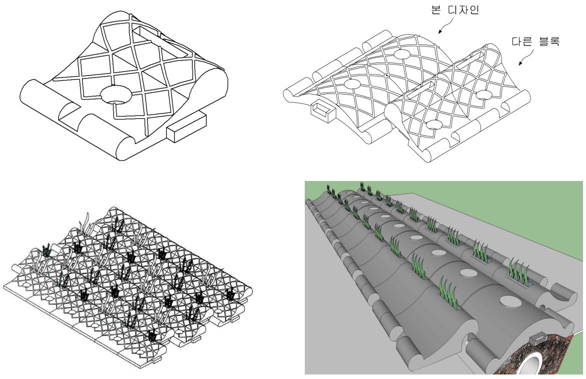


Fig. 17 Schematic view of developed bio blocks

## 4. CONCLUSION AND DISCUSSION

### 4.1 Conclusion

In general about 33% reduction effect on reflection rate of eco block slope was achieved at the final design hydraulic experiment as shown in Fig.16. Although partial displacements appeared at the foot blocks from the block stability experiment with the available wave conditions, it might be soluble by replacing them with the mid-hole blocks and piling and enhancing the unit block weight. It is expected to use the developed blocks as a hard method to control directly the applied forces by reduction and scattering of wave forces on the laid pipelines near coastal waters or at the eroding area. And it might contribute to the coastline erosion protection and bottom stabilization by control of landward wave forces and bottom flow with the use of blocks as the armor units of artificial reefs at the surfer zone.

### 4.2 Discussion

The following recommended research is the continuation of the present work such as the wave force analysis on the bio blocks and experiments with different pipeline arrangement with respect to wave direction. Successful joint research with the highly experienced group is encouraged for coral raising and other marine vegetation on this block under different wave and temperature conditions.

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