# INCREASING LONGEVITY OF NOURISHED BEACHES BY CHANGING THE DIRECTION OF CROSS-SHORE SAND TRANSPORT

Nobuyuki Ono*, Isao Irie**, and Hiroshi Yamaguchi***

* *Research Associate, Dept. of Civil Engineering, Kyushu University, 6-10-1 Hakozaki Higashi-ku, Fukuoka 812-8581, Japan.*

** *Emeritus Professor of Kyushu University, Tokyo Codoo, 3-1-21-506 Kasumigaoka Kamifukuoka-city, Saitama 356-0006, Japan.*

*** *Coastal/Ocean Engineer, Wakachiku Construction Co. Ltd., 2-23-18 Shimomeguro Meguro-ku, Tokyo 153-0064, Japan.*

## ABSTRACT

The Distorted Ripple Mat (DRIM) is a low-relief submerged block developed to control sediment movement in the offshore. One practical utilization of the DRIM is for preservation of beach nourishment by controlling cross shore sediment transport. In the present paper, the applicability of DRIM is tested as to whether it enhances longevity of the nourished beach. Through movable bed experiments and numerical simulations, it is confirmed that installing DRIM onto the bottom of offshore zone is effective in keeping beach profile stable. A field test has been underway since June 2004 at Ashiya Beach in Japan. By analyzing the data from the field surveys, the performance of DRIM installed in the field is discussed by comparing with the results of physical and numerical model tests.

## INTRODUCTION

Protection against beach erosion generally takes two measures as either hard or soft protection, or as a combination. Hard protection is represented by the construction of shore-protection structures such as seawalls, revetments, and detached/submerged breakwaters. These solid structures are effective for coastal defense, but they often induce beach erosion at the downstream site of littoral sand drift or hamper beach recreational activities. Soft protection is represented by beach nourishment. Beach nourishment is a widely applied shore protection measure having low impact and positive benefit to the coastal environment. However, it can be short-lived, and re-nourishment is required for beach maintenance. In addition, the shortage of sand resource for beach nourishment and sea level rise due to the global warming will become more apparent in the future. These will make beach erosion problems more serious and indicate that beach protection by only beach nourishment may not be adequate at some locations. In order to preserve beaches while keeping their natural characteristics, new methods to increase the longevity of nourished beach will be required.

As a new device to retain sand nourishment, the authors have developed a Distorted RIpple Mat (DRIM) composed of precast concrete blocks (Irie et al. 1994, 1998). The

* Corresponding author: Presently at U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, 3909 Halls Ferry Rd., Vicksburg, MS 39180.

DRIM is an artificial ripple, the surface profile of which is a distorted sinusoidal curve. The distorted ripple shape creates an asymmetric pair of vortices around the ripple crest during a wave period and generates a current near the bottom under wave action. The function of asymmetric ripples was originally studied by Inman et al. (1972). We have studied basic features of the DRIM through numerous physical and numerical simulations, and have confirmed its applicability as a shore protection measure. In particular, Ono et al. (2002, 2004) experimentally examined beach profile change under erosive waves and confirmed that not only the offshore sand transport due to an undertow flow, but also the onshore sand transport in the offshore contribute to the formation of a longshore bar and make the beach profile stable. As a result, it was found that the DRIM installed in the offshore is effective for promoting beach profile stability because it enhances onshore sand movement in the offshore. In addition, a strong point of DRIM is that it has little impact on the surrounding hydraulic and ecological conditions, whereas most of the shore protection works control waves and currents directly, and modify the environment.

This paper discusses how the DRIM contributes to stabilization of the beach profile. First, basic functions of the DRIM are explained. Second, effects of the DRIM examined thorough movable bed experiments and numerical simulations are discussed. Finally, some findings on DRIM installed in the field are described by analyzing the data from the field surveys that have been carried out since June 2004 at Ashiya Beach in Japan.

## BASIC FUNCTIONS OF THE DRIM

Sand ripples are usually formed on the sea bottom by wave action. The shape is symmetric in cross-shore direction or inclined onshore in shallow area. Once ripples are formed, sand transport is significantly influenced by the existence of the ripples. The DRIM is an artificial ripple developed based on the sediment transport mechanism of a natural ripple. Figure 1 shows the shape of the DRIM. As shown in the figure, the upper surface shape is a distorted sinusoidal curve, the distortion rate of which is $\lambda_R$:$\lambda_F$ = 1:3, where $\lambda_R$ and $\lambda_F$ are length between ripple crest and trough. The curve is aimed at creating a stream near the sea bottom due to the difference in vortex intensity on the onshore and the offshore sides of the ripple crest under wave propagation. The orbital stream of offshore phase (wave trough passing) generates remarkable vortices in the lee of the ripple crest because of its steeper rear face. The hydrodynamic reaction between vortex and ripple surface causes the vortex to rise, and subsequent reversal (onshore)

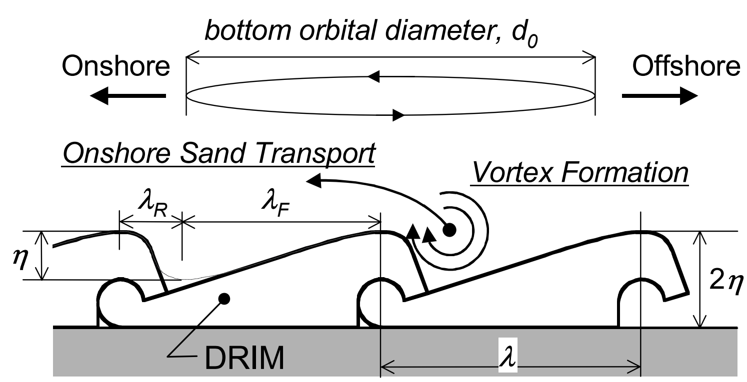


Figure 1. DRIM shape

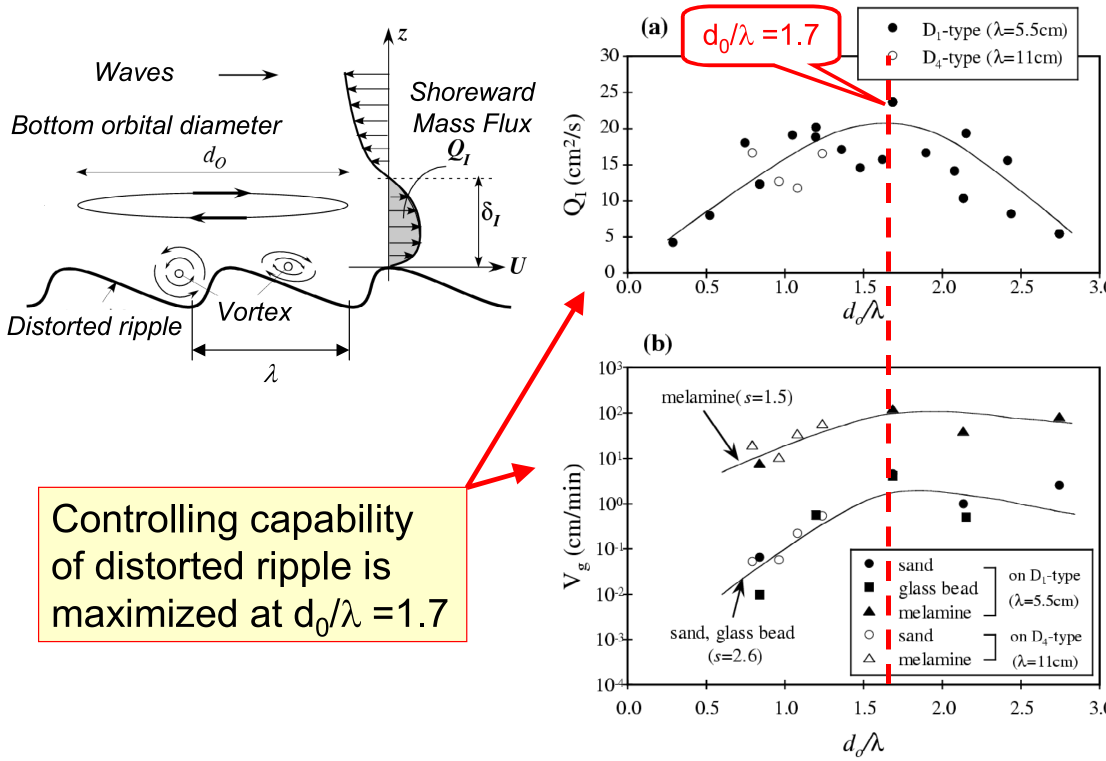


Figure 2. Bottom flow rate $Q_I$ and centroid movement velocity $V_g$ with respect to $d_0/\lambda$

flow sweeps the rotating water mass onshore. On the reverse phase, formation of vortex is limited because of the milder slope of onshore face of the ripple. As the result, a clear onshore current is generated on the DRIM.

The optimum condition for controlling capability was examined experimentally by measuring the bottom mass flux $Q_I$ and the sediment movement velocity $V_g$ on the distorted ripples under several incident waves. Here, $Q_I$ is obtained by integrating the onshore time-averaged velocity near the bottom, and $V_g$ is obtained as the centroid movement velocity of sediment placed on the ripple troughs. The results of experiment are shown in Fig. 2. Both $Q_I$ and $V_g$. are shown with respect to $d_0/\lambda$, where $d_0$ is the bottom orbital diameter and $\lambda$ is the pitch length of the distorted ripples. The experiment is conducted by using two different distorted ripples; one is of $\lambda$ = 5.5 cm and $\eta$ = 1.0 cm and the other is of $\lambda$ = 11 cm and $\eta$ = 2.0 cm. Also, the velocity $V_g$ is measured by using three kinds of sand; glass bead ($D$ = 0.08 mm, $s$ = 2.5), synthetic particle of melamine ($D$ = 0.32 mm, $s$ = 1.6), and fine sand ($D$ = 0.16mm, $s$ = 2.65), where $D$ is the grain size and $s$ is the specific density. From $Q_I$ and $V_g$ in Fig. 2, the averaging curves is seen to be maximum when $d_0/\lambda$ ~1.7. This depicts that the optimum controlling capability of DRIM can be attained by selecting the pitch length $\lambda$ of the distorted ripples so that it satisfies $d_0/\lambda$ ~1.7, where $d_0$ is given from the wave climate in the field.

The physical meaning of this could be supported by sand ripples formed by waves. It is well known that the simplest expression of ripple length is as a liner function of the orbital diameter $d_0$. For example, Watanabe et al. (1989) proposed a relation between ripple length and orbital diameter as $\lambda$=0.6 $d_0$ within the range of $d_0/D$ < 1,300. This relation leads to $d_0/\lambda$ ~1.7, which is the same as the optimum condition for efficient performance of the DRIM. This means that natural sand ripples are formed under the condition in which the energy of oscillatory flow by waves is transmitted most effectively to the vortex formation in the lee of ripple crest, and the performance of the DRIM is also highest for this condition.

## BEACH STABILIZATION BY DRIM IN PHYSICAL AND NUMERICAL MODELS

One possible application of DRIM is as an installation to the offshore side of a nourished beach. The concept of preserving a nourished beach by DRIM is shown in Fig. 3. The profile of a nourished beach is usually designed with a wider berm width and a steeper slope than the existing beach as shown in Profile-(2) in the figure. In this case, however, the nourished sand may erode on a long-term basis. If the DRIM is set on the bottom of the offshore zone, it will check the sand loss by controlling sediment transport in the onshore direction. As a result, the new stable profile (Profile-3 in Fig. 3) will be formed, advancing the existing equilibrium profile offshore. The followings describe results of movable bed experiments and numerical simulations conducted to confirm the above effects of the DRIM.

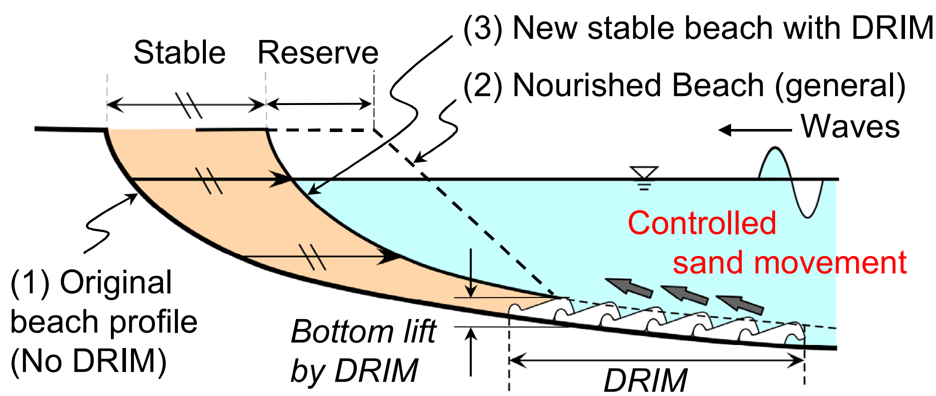


Figure 3. Concept of creating a new stable profile by DRIM

### *Physical Model Tests*

The movable bed experiments were conducted under the conditions below. A model beach of 1/15 in slope was made in the wave flume as shown in Fig. 4. The bed material was used the melamine which is a light weight material of 0.2 mm in grain size and 1.5 in specific density. Two experiment cases were conducted, i.e., 'without DRIM' and 'with DRIM,' and compared. The dimensions of DRIM were 4.5 cm in pitch length and 0.8 cm in height. The DRIM blocks were set in the range of about 1 m in cross shore direction and the depth for installation is 11 cm at the onshore side of the blocks. The incident wave condition is shown in Fig. 5, where an E-wave (Erosional wave) of high steepness ($H_0$=7 cm, $T$=1.2 s) and A-wave (Accretive wave) of low steepness ($H_0$=4 cm, $T$=2.0 s) are used alternately in order to reproduce storm and calm sea for 0.5 and 3.5 hr respectively until the total wave action time reached to 20 hr.

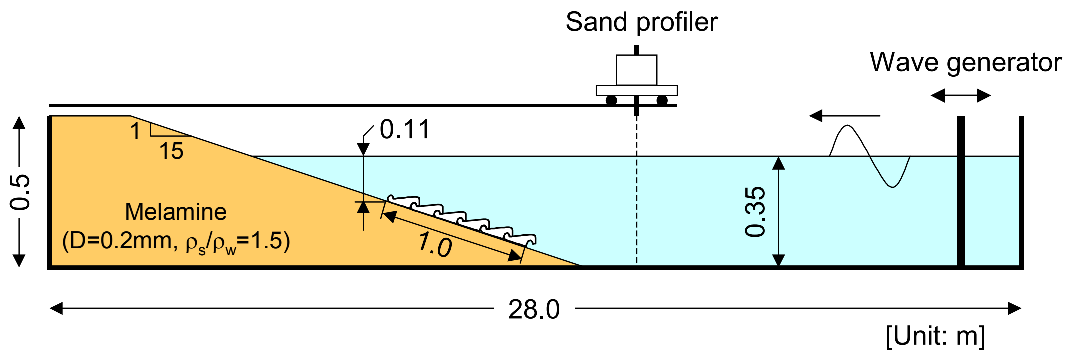


Figure 4. Experiment arrangement

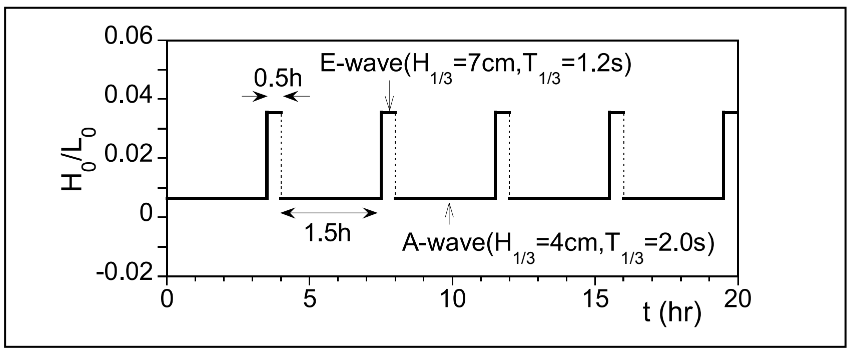


Figure 5. Time variation of the incident wave for the tests

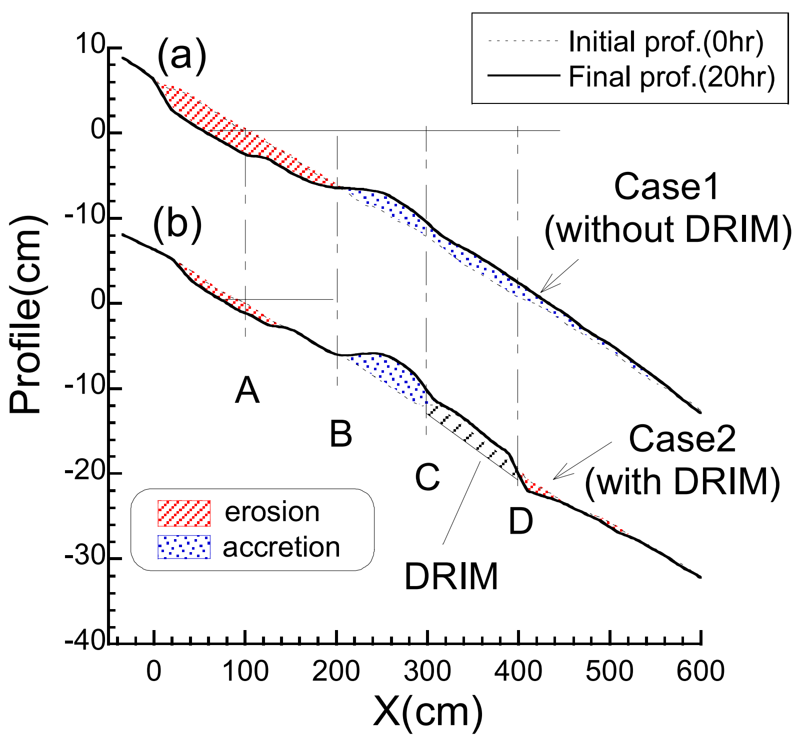


Figure 6. Final beach profile; (a) without DRIM, (b) with DRIM

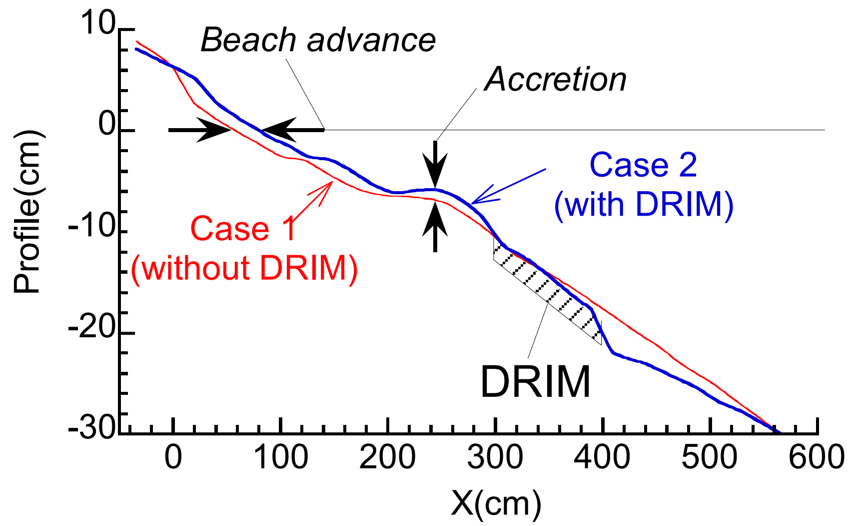

Figure 7. Comparison of two final profiles

The profile after 20 hr of wave action in each case is shown in Fig. 7. The erosion and accretion areas in comparison with the initial profile are shown in the figure. Comparing between two profiles, one can find that in the case 'without DRIM,' sand in the surf zone was eroded and transported offshore zone, whereas in the case 'with DRIM,' sand was not transported to the offshore of the DRIM, resulting in larger bar formation and less erosion in the surf zone. The two final profiles are directly compared in Fig. 8. From the figure, it is found that the DRIM generated the accretion and beach advance just as illustrated in Fig. 3. These results clearly indicate that the DRIM promoted bar formation and decreased beach erosion. Also, it is notable that the effect of the DRIM approached the shoreline although the DRIM only controls sand movement of its installed area.

***Numerical Model Tests***

**1. Features of the numerical model**

Numerical simulations were conducted by using the OM-Process Model. The OM-process is short for 'Oscillatory Movement process' and has been developed to estimate the effect of the DRIM. The model is based on the sediment transport on a ripple and estimates sediment transport rate considering wave asymmetry and ripple distortion. In addition, because the DRIM is a structure for stabilizing the beach profile, it is important to reproduce the phenomena that a beach profile approaches an equilibrium profile for long-term wave action. For this reason, the model implemented the condition of an equilibrium profile (Ono et al. 2004) is used in the numerical tests below.

The computational procedure consists of three major parts, calculations of wave deformation, sediment transport rate, and morphology change. For the wave deformation, the Boussinesq-model (Madsen and Sørensen 1992) is used to estimate the wave asymmetry. Also, the sediment transport rate is estimated by using an empirical formula including the parameters of wave asymmetry and ripple distortion, and then the depth change is calculated taking into account the sand dispersion process from one ripple to neighboring ripples. These are the main features of the OM-process Model and are explained in more detail in Ono et al. (2004).

## 2. Effects of DRIM in 2-Dimensional model tests

A test of the numerical model was carried out under the same condition as the movable bed experiment described in the physical model tests. The results of 2-dimensional beach profile simulation are shown in Fig. 8 and Fig. 9, comparing with the results of the physical model test. Figure 8 shows the beach profiles of 19.5-hr of wave action, the profile of 'without DRIM' and that of 'with DRIM' are compared on the top (experiment) and the bottom (calculation). From the figure, it is confirmed that the model successfully reproduces the effect of no sand loss and beach advance due to DRIM. Figure 13 shows the sand volume $V$ which has passed through the cross-section B and C

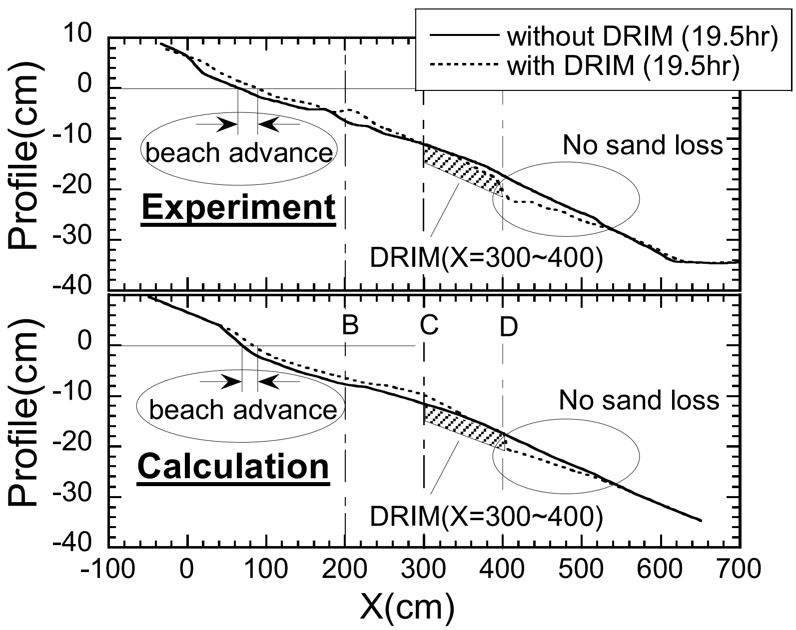


Figure 8. Comparison of beach profiles of experiment (top) and calculation (bottom).

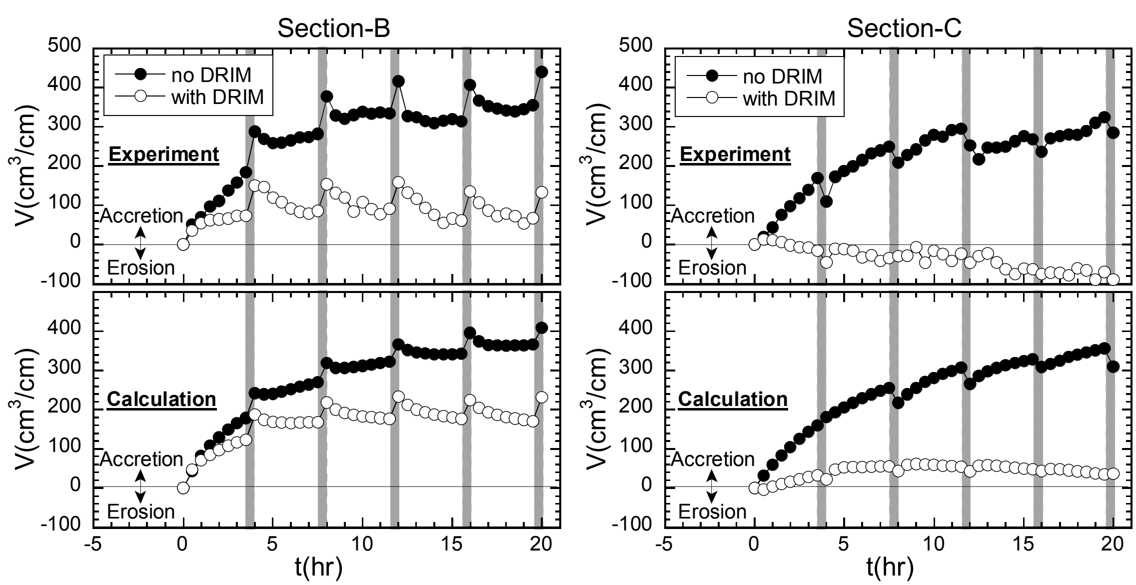


Figure 9. Time variation of the sediment volume passing through the Section B (left) and C (right)

with respect to the time $t$. The $V$-value is calculated by integrating the depth difference between the depth at $t$=0 and each time from the offshore end to each section. In each graph, the gray column denotes the time of E-wave action. From the figure, it is confirmed that the response due to the change of wave (the saw-shaped variation of $V$), the process that the beach approaches an equilibrium state, and also the DRIM's effect to check the offshore sand loss and keep the beach stable are reproduced quantitatively.

Both experimental and computational results indicate that installing DRIM is effective to increase the stability of beach profile. In particular, the situation that the averaging $V$-value at Section-B keeps a certain constant value as is seen in the case of 'with DRIM' can be important evidence of the effectiveness of DRIM

## 3. Effects of DRIM in 3-Dimensional model tests

Some basic features on 3-dimensional effects of DRIM have been examined by Yamaguchi et al. (2003), and it is confirmed that sand transported onto DRIM moves approximately in the normal direction with the crest line of the DRIM. For practical application of the DRIM, however, it is important to examine how sand moves around the DRIM. In that case, not only wave effects but also current effects become important. Then, numerical simulations have been carried out to know the characteristics of sand movement around DRIM under coexistence of waves and currents.

Simulations were conducted in the condition as shown in Fig. 10, where the model beach composed of melamine ($D$=0.2 mm, $s$=1.5) was set up with 1/15 in slope in a wave tank of 6.4 m long, 4.0 m wide, and 0.5 m high, and a DRIM unit was installed in the center of the tank to control sediment movement in the onshore direction. The condition of incident wave was 5 cm in wave height and 1.0 s in wave period, and an additional current is 0.5 cm/s in the depth-averaged velocity in the longshore direction. (A movable bed experiment was actually conducted in this condition by Yamaguchi et al. (2004) and the additional current was generated by a pump.)

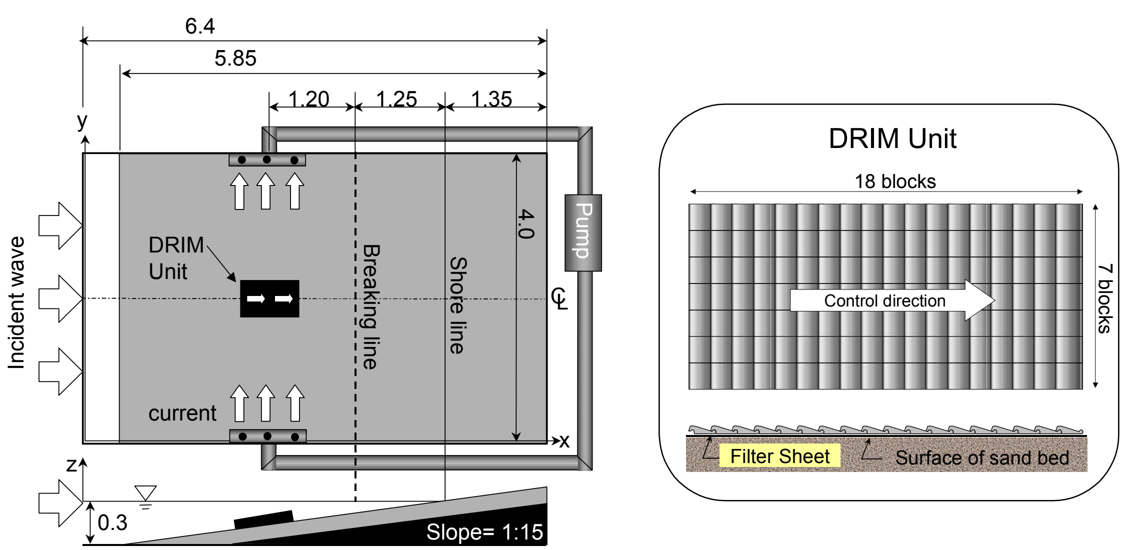


Figure 10. Model Setup for 3-dimensional test (unit: m).

Figure 11 shows the topographic change after 30-min simulation. The case of 'wave alone' and that of 'waves + current' are shown in Fig. 10(a) and (b), respectively. Because the direction of sediment transport is offshore in the wave condition, it is seen that accretion in the onshore side and erosion in the offshore side of the DRIM are induced on both cases. However, in the case of 'waves + current,' erosion at the downstream side of the current seems to be apparent because sand transported from the upstream side onto the DRIM is controlled and transported to the onshore side of the DRIM.

Fluorescent tracer movement simulation experiments were conducted to examine the characteristics of sand movement around the DRIM. The results are shown in Figs. 12 and 13. In the simulations, the fluorescent tracer is assumed to be set 0.1 m aside from the DRIM Unit as shown in each figure, and the movement is represented as the

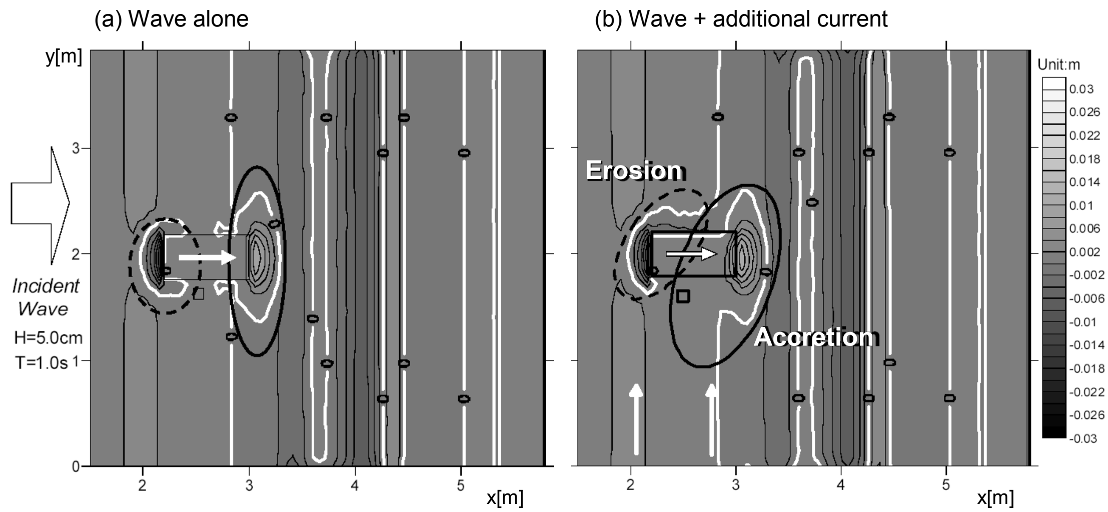


Figure 11. Topography change after 30-minute simulation; (a) Waves alone, (b) Waves + Current

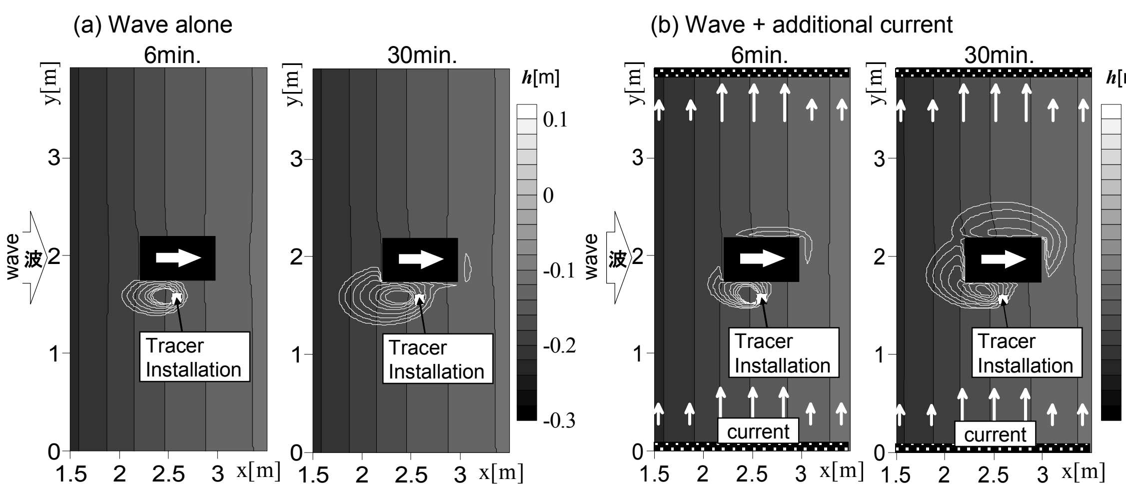


Figure 12. Tracer movement by erosive wave ($H_0$=5cm, T=1.0s); (a) Waves alone, (b) Waves + Current

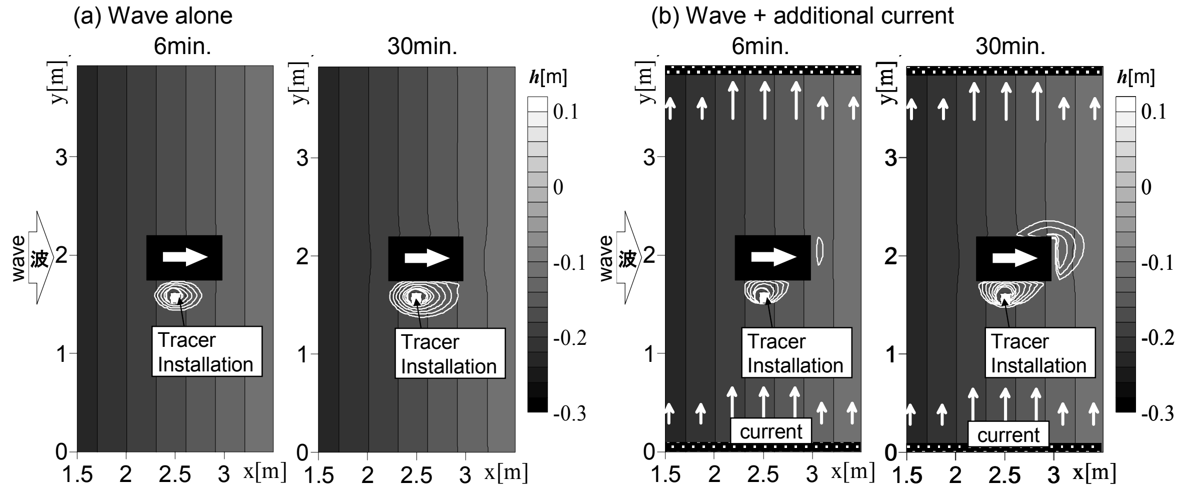


Figure 13. Tracer movement by accretive wave ($H_0$=3cm, T=2.0s); (a) Waves alone, (b) Waves + Current

white-colored contour lines. In each figure, the results of 'waves alone' and 'waves + current' are compared. Figure 12 is the result in case of the erosive wave action ($H_0$=5.0 cm, $T$=1.0 s), where the dominant direction of sediment transport due to wave is offshore. It is seen that the tracer movement in the case of 'waves alone' is mainly toward offshore, whereas that of 'wave + current' is added the effect of current, and a part of the tracer distributes even onshore side of the DRIM. This is because the DRIM controlled the movement of sand transported onto it by the current. Figure 13 is the result in case of the accretive wave ($H_0$=3.0 cm, $T$=2.0 s), where the dominant direction of sediment transport due to wave is onshore. In the figure, it is seen that the tracer is mainly transported onshore, and the tracer movement in the onshore direction is accelerated due to the current effect as well, as seen in Fig. 12.

## PERFORMANCE OF DRIM IN A FIELD TEST

### *Outline of the field installation of DRIM*

A field test has been underway since June 2004 at Ashiya Beach of Fukuoka Prefecture facing to the Genkai Sea in Japan. The test is an important opportunity as a full-scale investigation of the DRIM for the first time, and subsequent surveys after the installation are being conducted on bottom sounding, sampling of fluorescent tracer, and collection of wave and current information.

The installation site is as shown in Fig. 14. The site is located near the mouth of the Onga River, and 7 detached breakwaters are located there. A prototype DRIM unit was installed on the offshore of the opening between breakwaters. The depth of the installation was 3.5 m as shown in Fig. 15, and the sand grain size is 0.18 mm.

The DRIM blocks used in the test are 1.5 m in pitch length $\lambda$, 0.27 m in height $\eta$, 1.0 m in width, and 0.6 m in total height. The block is designed that the most efficient performance will be exercised when the representative wave of 1.7 m in significant wave height and 6.0 s in wave period attacks. The DRIM blocks were installed with the

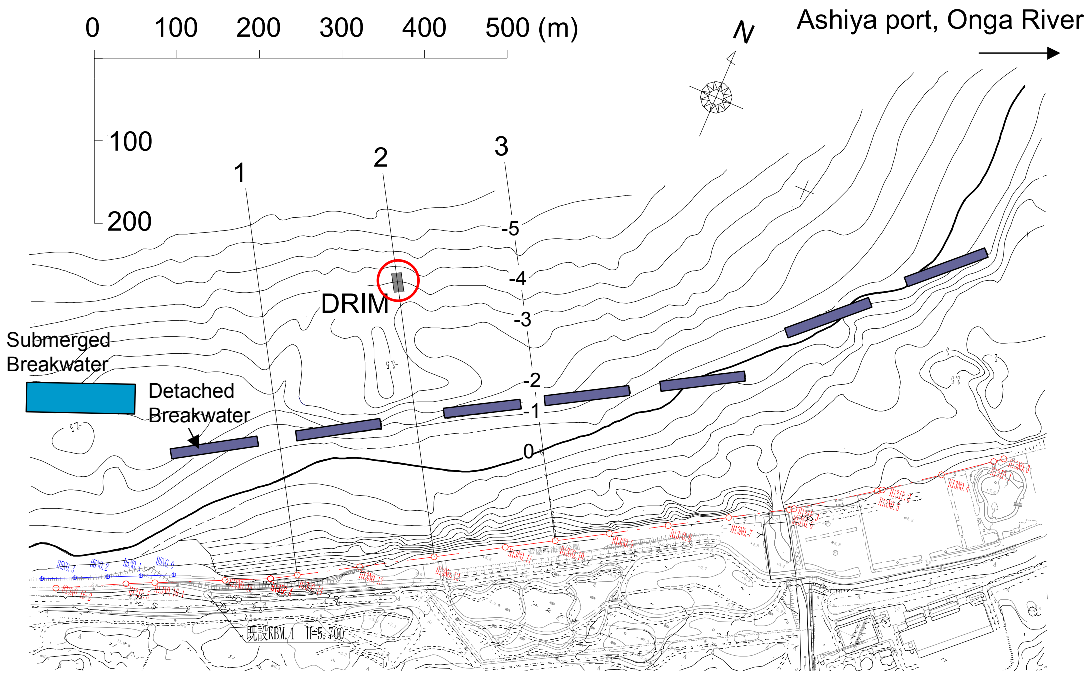


Figure 14. Field installation site of DRIM

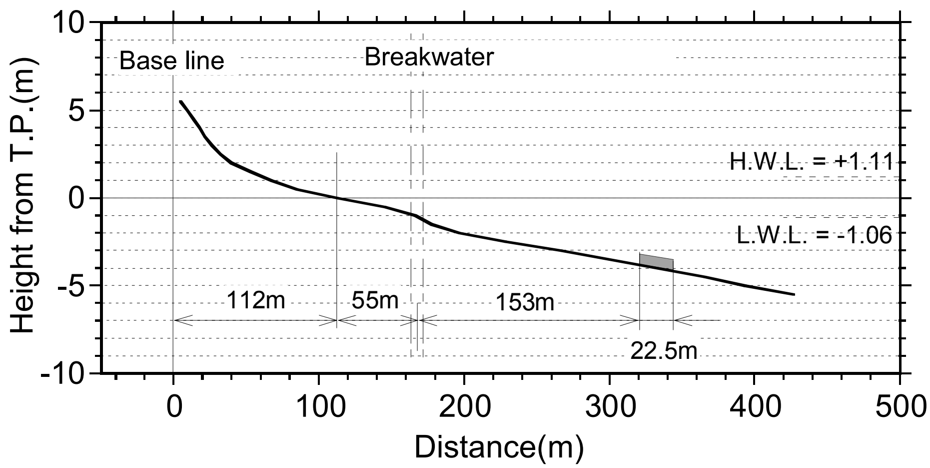


Figure 15. Cross-section of line-2 (Profile is average of profile lines 1, 2, and 3.)

arrangement as shown in Fig. 16. The size of the DRIM unit is 23 m (15 blocks) in cross shore direction and 12 m (12 blocks) in longshore direction. A part of the blocks is composed of improved sulfur concrete which is developed by Nippon Oil Corporation. When the DRIM units were constructed, a small unit composed of 6 blocks linked with a rope was made at first, and a plastic filter was adhered under the small unit as shown in the photograph in Fig.16. Also, gabions were set at the offshore side of the DRIM unit to prevent scour. These are measures to increase durability of the DRIM. In addition, some measuring instruments, such as wave gage, velocimeter, and sand profiler, were installed, and three sets of fluorescent tracer were placed around the DRIM unit.

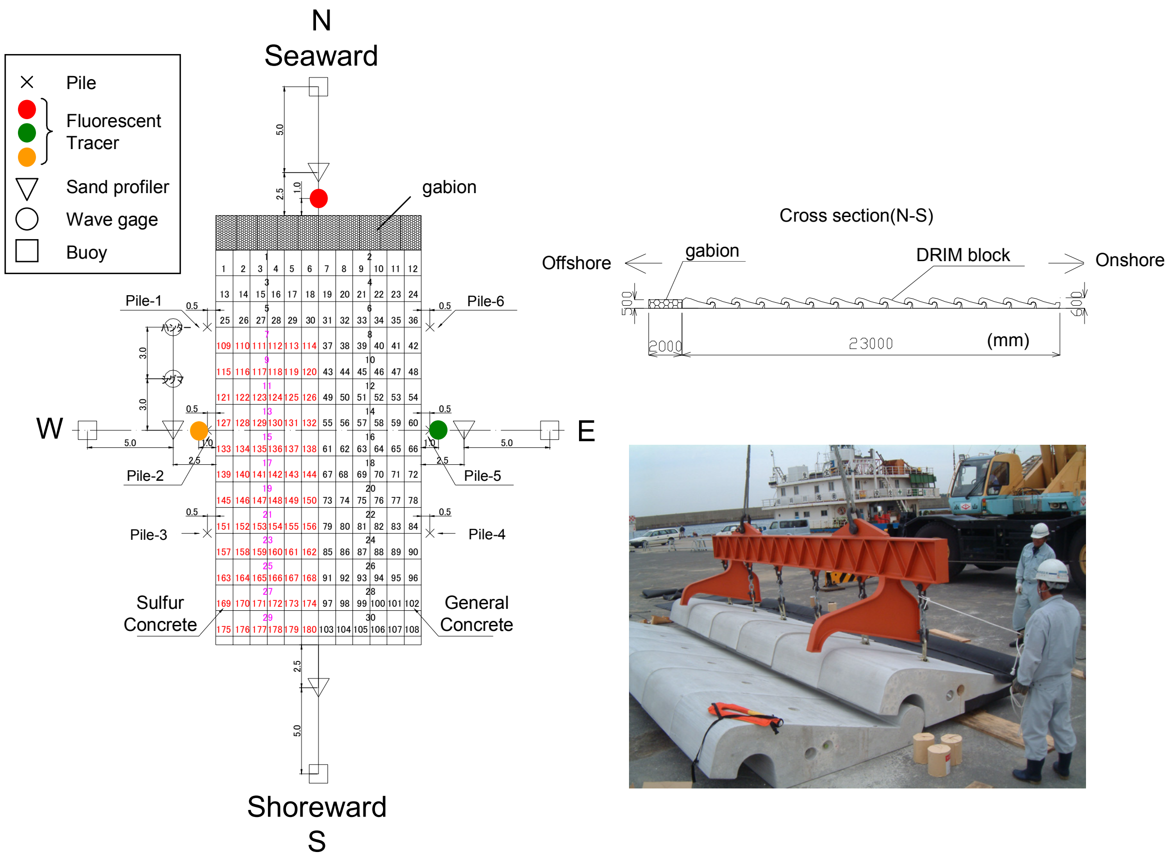


Figure 16. Arrangement of DRIM blocks and measuring instruments

## *Analysis of Survey Data*

The construction of the DRIM was completed on June 6, and the measuring instruments and fluorescent tracer were installed on June 15. After that, Typhoon-0406 attacked the site on June 21. The bottom sounding surveys were conducted on June 15 and 28, and the following mainly discusses the performance of DRIM based on the data obtained during that period. (The detail data are summarized by DRIM Research Group, 2005.)

The wave forcing condition is shown in Fig. 17. Figure 17 (a) shows day-averaged significant wave height and period as the offshore wave data obtained from two offshore wave stations of Shirashima and Genkai. Figure 17(b) shows the day-averaged significant wave height and period measured from wave gage installed near the DRIM, where Root-Mean-Squared and simple averaged data are shown. Figure 17(c) shows the direction and intensity of mean horizontal velocity measured near the DRIM. From the figures, it is confirmed that wave climate was calm (wave height was mostly less than 0.3 m) except the day typhoon attacked (June 21). Also, the mean current was mostly from east to west during the period.

Contour maps of measured topography around the DRIM are shown in Fig. 18. From the figure, it is seen that contour lines of June 28 moved shoreward near the onshore and west side of the DRIM. Figure 19 shows the variations of sand bed elevation measured

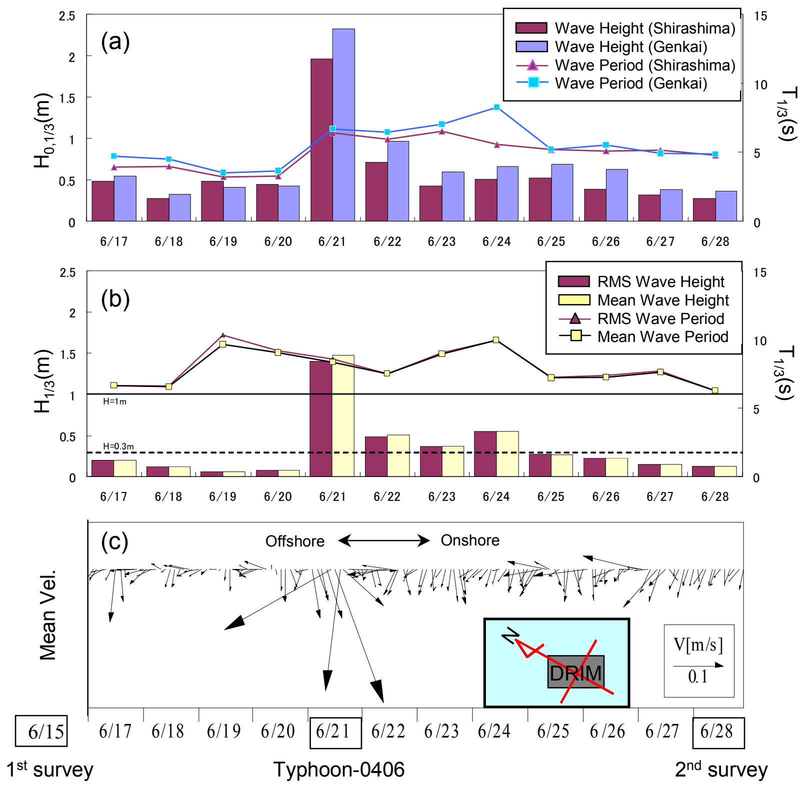


Figure 17. Condition of exerting force; (a) Offshore wave stations, (b) Wave data at the site, (c) Direction and intensity of mean flow velocity at the site.

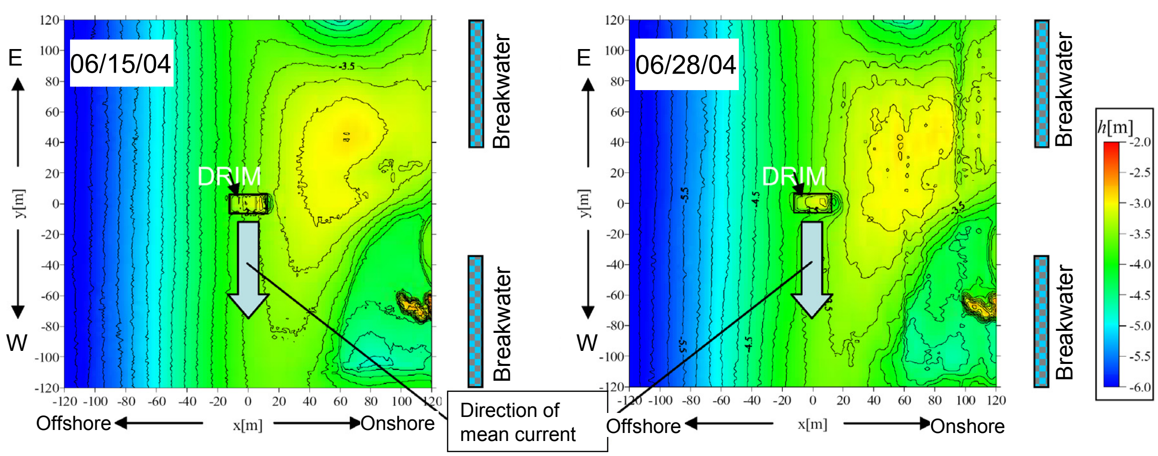


Figure 18. Contour maps of the measured topography around DRIM

with sand profilers installed at onshore, offshore, east, and west side of DRIM. Bed elevation rapidly changed between June 21 and June 23, and this means that remarkable morphology change in the period was caused by the typhoon. Also, considering that the mean current was in the west direction, the tendency of that bed erosion of west side was more remarkable than that of east side corresponds to the result of numerical simulation (Fig. 11), even if the erosion around the DRIM was mainly caused by scour.

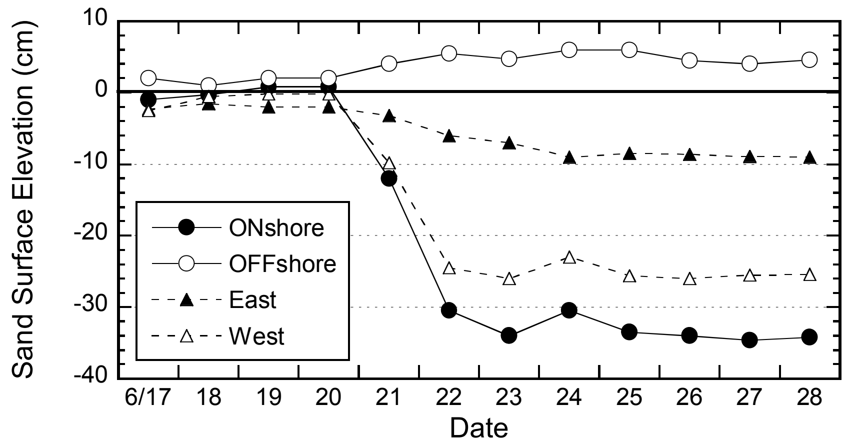


Figure 19. Bed elevation measured with sand profilers near the DRIM Unit

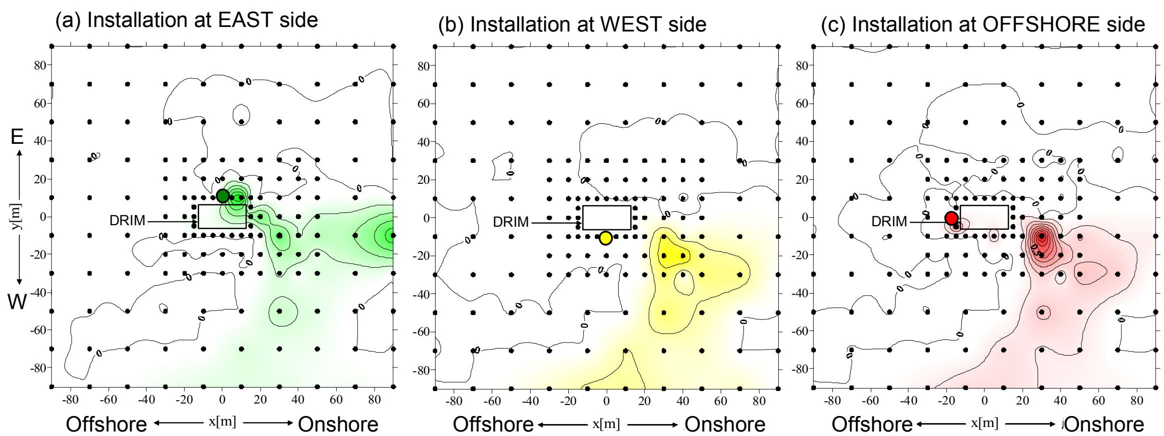


Figure 20. Distributions of Fluorescent Tracer (sampled at 06/28/04)

Figure 20 shows the fluorescent tracer distributions sampled on June 28. Dots in the figure are the sampling points. It is seen that all tracers moved onshoreward. This result is interpreted as follows. First, the storm waves at the typhoon generated strong turbulence around the DRIM. The turbulence could also pick-up most of sand tracer near the DRIM from the bed. Then, the mobilized tracer would be transported onshore by the DRIM's effect. In addition, the west-directed mean current transported the tracer in the west direction. Calm waves after the typhoon generated weakly onshore sediment transport, and therefore the tracer did not distribute offshore of the DRIM. Also, the results of numerical simulation shown in Figs.12 and 13 support the fact that the tracer installed at east side was primarily transported onshore. Thus, it is confirmed that the DRIM performs well in the field as well as in the laboratory experiments.

Figure 21 shows the bed configurations around DRIM. Because the sounding survey is conducted by using a narrow-multi-beam system, topography data with high resolution are obtained. In the figure, the result of latest survey conducted at October 30 is added. From the figure, it is found that not one of the DRIM blocks is scattered through

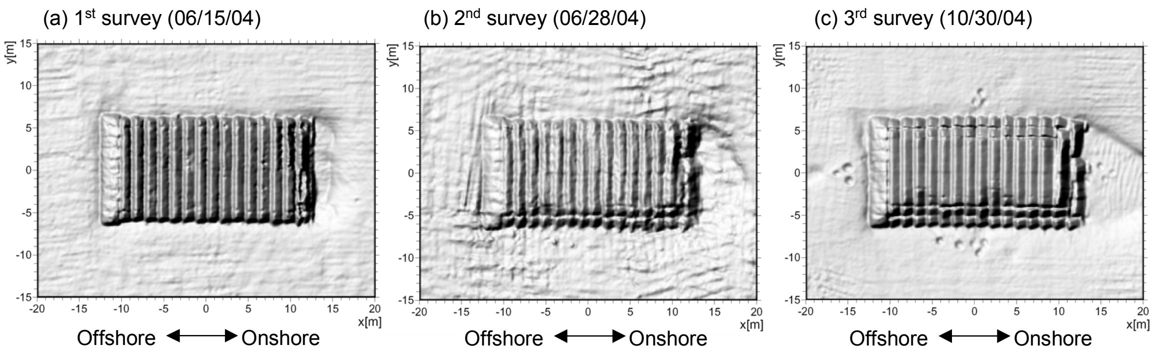


Figure 21. Bed configuration around DRIM

typhoons even after many attacks of typhoons. However, the edge blocks seem to be fairly inclined except for the offshore edge with a gabion. For increasing stability of blocks, the use of gabion to protect DRIM blocks from scour may be required for a practical use of DRIM.

## CONCLUSIONS

In the present work, a new erosion control method called the DRIM was tested thorough movable bed experiments, numerical simulations, and field data. Conclusions are summarized as follows:

1. The optimum pitch length $\lambda$ of DRIM for the most efficient performance is $d_0/\lambda = 1.7$, which gives a basis for design of DRIM.
2. The effectiveness of DRIM was confirmed through 2-dimensional movable bed experiments. DRIM installed in the offshore can control sediment transport in onshore direction and create beach advance.
3. The numerical simulation model which has been developed to estimate the effects of DRIM successfully reproduced the phenomenon that the DRIM prevents offshore sand loss and keeps the beach profile stable.
4. Sand movement around the DRIM was examined through numerical simulations by using the 3D-expanded OM-Process Model. In particular, characteristics of the sand movement under the condition of wave plus current are clarified.
5. A field test was conducted. By analyzing the survey data of soundings, bed elevation change, and fluorescent tracer distribution, the effects of sediment transport control by the DRIM have been confirmed. The effects seen in the field test correspond to the results of laboratory-scale examinations. The favorable field performance indicates that the DRIM can be a very useful measure for increasing longevity of nourished beaches.

## ACKNOWLEDGEMENTS

The field test of DRIM is being conducted in cooperation with Fukuoka Prefecture, Nippon Oil Corporation, and the DRIM Research group comprised of Toa Corporation, Wakachiku Corporation, and Suikogiken Corporation. Particularly, it is acknowledged that manufacture, installation of the DRIM, and carrying out of oceanographical surveys for field tests are financially supported by Nippon Oil Cooporation. Prof. Haruyuki Kojima at Kyushu Kyoritsu University has greatly contributed in the analysis of the fluorescent tracer survey. The authors would like to thank all of them for providing us the valuable opportunity and much important data.

## REFFERENCES

DRIM Research Group, 2005. Interim report on the field test of DRIM at Ashiya beach (in Japanese), in press.

Inman, D.L. and E. B. Tunstall, 1972. Phase dependent roughness control of sand movement, *Proc. of 13th ICCE*, ASCE, 1155-1171.

Irie, I., N. Ono, S. Hashimoto, S. Nakamura, and K. Murakami, 1994. Control of cross-shore sediment transport by a distorted ripple mat, *Proc. of 24th ICCE*, ASCE, 2070-2084.

Irie, I., S. Takewaka, N. Ono, K. Murakami, H. Sakamoto, and O. Shimada, 1998. Retaining beach sand by a distorted ripple mat, *Proc. Coastlines, Structures & Breakwaters'98*, ICE, 264-265.

Madsen, P. A. and O. R. Sørensen, 1992. A new form of the Boussinesq equations with improved linear dispersion characteristics Part 2, *Coastal Engineering*, Vol. 18, 183-204.

Ono, N., I. Irie, M. Yokota, and H. Yamaguchi, 2002. Mechanism of Stabilization of Beach Profile under Storm Waves, *Proc. of 12th ISOPE*, 567-571.

Ono, N., I. Irie, and H. Yamaguchi, 2004. Preserving system of nourished beach by a distorted ripple mat, *Proc. 29th ICCE*, ASCE, in press.

Watanabe, A., M. Sakinada and M. Isobe, 1989. On the shape of ripples and the rate of sand transport in the field coexisted by waves and currents (in Japanese), *Annual Journal of Coastal Engineering*, JSCE, Vol. 36, 299-303.

Yamaguchi, H., N. Ono, and I. Irie, 2003. Low cost shore protection method using precasted concrete blocks, 'DRIM', *Proc. Coastal Sediments'03*, CD-ROM

Yamaguchi, H., N. Ono, I. Irie, Y. Murase, and R. Matsumoto, 2004. Study of the effectiveness of DRIM to control sediment transport in wave-current coexistent field (in Japanese), *Annual Journal of Coastal Engineering*, JSCE, Vol. 51, pp.591-595.