

CHAPTER 150

Control of Cross-shore Sediment Transport by a Distorted Ripple Mat

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ABSTRACT

A method to control cross-shore sediment transport by a distorted ripple mat which is the artificial ripples of distorted cross section has been studied through hydraulic experiments and numerical simulation. First of all, the relative importance of factors affecting cross-shore sediment transport on fixed bed ripples and the condition on which sediment is definitely transported on-shoreward are obtained. Based on this condition, experiments with movable bed are carried out to see how efficiently the distorted ripple mat can be utilized in stabilizing natural/artificial beaches. Furthermore, a numerical model of beach profile change in which effects of ripple distortion are considered has been developed and beach stabilizing effects of the mat are also reproduced numerically.

INTRODUCTION

Recently, the needs of preventing beach erosion without installing such bulky structures as offshore or submerged breakwaters have increased so as to keep a beautiful view and to enable various maritime recreational activities. In order to prevent people's lives and properties from natural disasters, sandy beach needs to be expanded so that land behind is efficiently protected even with the

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temporary retreat of shoreline under severe storm waves. The idea of supplying sediment from other sources to fulfill those demands, however, will become very difficult to be adopted as the general shore protection methods in the future because every coast is more or less suffering from the shortage of sediment and cannot afford to supply for other coasts. The supply from land sources will also have by itself limitation. The expected sea level rise in coming century will make the situation more serious. Thus, the shore protection measures utilizing sandy beach can be established only when beach expansion is carried out on self sufficiency bases, that is to say, some measures must be developed to preserve shoreline through sediment supply from beaches themselves, probably from offshore sources. Controlling cross-shore sediment transport by a distorted ripple mat composed of precasted concrete blocks could be one of the hopeful measures to fulfill those demands, but no positive study seems to be carried out since the study by Innian et.al. (1972). In the present paper, effectiveness of the distorted ripple mat in stabilizing natural/artificial beaches has been studied by hydraulic experiments and numerical simulation.

Methods of Experiments on Sediment Movement Velocity

Artificial ripples of fixed bed of different distortion as shown in **Figure 1** were set in two dimensional wave channel whose length, width and height is $28m$, $0.3m$ and $0.5m$ respectively. The length of installation of fixed bed ripples was $3m$ and the average water depth was $27cm$. The length and height of sinusoidal ripples in **Figure 1** was originally determined from the ripple dimensions of preliminary experiments with movable bed, in which standard waves of $8cm$ in height and 1.5 sec. in period were acted on the horizontal movable bed composed of sediment $0.16mm$ in median diameter (settling velocity $W = 1.6cm/s$ at $20^\circ C$). In the troughs of the fixed bed ripples shown in **Figure 1**, sediment of the same diameter as the movable bed experiments were placed with a certain volumes and the same waves were acted. After the wave action,

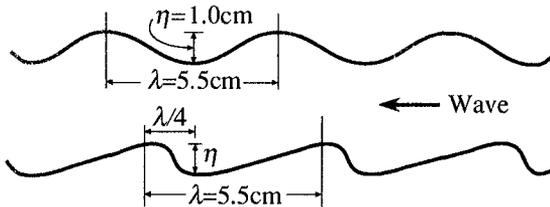


Fig.1 Shape and scale of fixed bed ripples

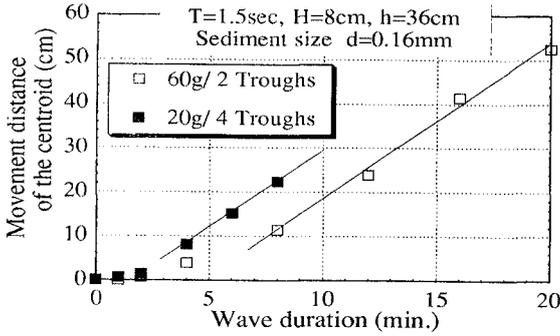


Fig.2 Movement of the centroid of sediment placed on the fixed bed ripples

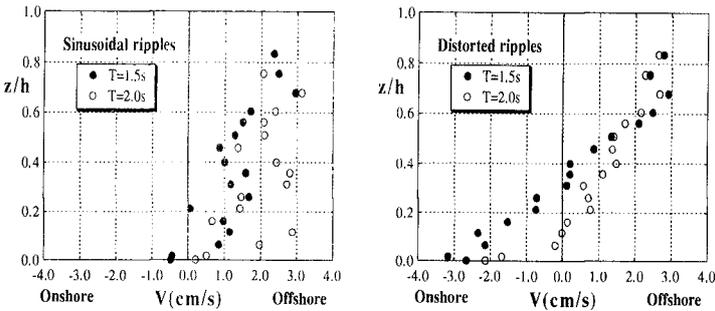


Fig.3 Vertical distribution of mean velocity for sinusoidal ripples and distorted ripples

sediment of each trough of ripples was sucked up by a nozzle and weighed by drying. From the change of horizontal distribution of sediment, movement of its centroid is obtained. As shown in **Figure 2** in which sediment movement is traced for sinusoidal ripples, the velocity of centroid movement becomes constant after a certain time of wave action and more time is required as the volume of sediment per one trough of ripples increases. The steady state of centroid movement is considered that the ratio of suspended part and settled part of sediment has attained equilibrium condition and thus the centroid movement velocity is nothing but the average movement velocity of suspended sediment. **Figure 3** shows the velocity profiles measured by a magnetic type current meter when waves of 8cm in height and 1.5 or 2.0 sec. in period are acted on sinusoidal ripples (Left) and distorted ripples (Right). It is seen that for distorted ripples, the mean velocity is onshoreward within the range of 0.2~0.3 of relative water depth above the bottom whereas it is mostly offshoreward in sinusoidal ripples. Distortion of ripples clearly creates onshore

current near the bottom and this feature could be utilized for controlling cross-shore sediment transport.

Factors Affecting Cross-shore Sediment Transport

The velocity and direction of cross-shore sediment transport on fixed bed ripples may largely depend on the relative magnitude of vortices formed on the onshore/offshore side of a ripple. As shown in **Figure 4**, three factors are picked up as the dominant factors determining the relative magnitude of vortices, that is, the unsymmetry of wave crest height and trough depth $S_1 = (H_c - H_b)/H$, the tilt of wave profile $S_2 = (L_R - L_F)/L$ (related to the bottom slope $\tan \beta$), and the distortion of ripples $S_3 = (\lambda_R - \lambda_F)/\lambda$ (negative in the figure). The mean velocity of sediment placed on the fixed bed ripples is considered to be expressed (Irie et al., 1993),

$$V_g^* = \sum a_i S_i \quad (i = 1, 2, 3) \tag{1}$$

where V_g^* is nondimensional form of the mean velocity of sediment movement V_g which is positive offshoreward, that is, $V_g^* = (V_g/U_m)(W/U_m)(h/\eta)$ in which U_m , W , h and η are the maximum orbital velocity at the bottom, the settling velocity of sediment, the water depth and the height of ripples respectively. The coefficients a_1 , a_2 and a_3 are determined empirically through the experiments with fixed bed ripples by changing wave characteristics (for the wave height $H = 8\text{cm}$, $T = 1.0 \sim 2.0$ sec.), the bottom slope ($0 \sim 1/15$) and the rate of distortion of ripples (for $\lambda = 5.5\text{cm}$ and $\eta = 1.0\text{cm}$, $\lambda_R = 0 \sim \lambda/4$). According to the experiments, $a_1 = 0.044$, $a_2 = -0.028$ and $a_3 = 0.033$, respectively. **Figure 5** shows the correlation of the mean velocity of sediment movement V_g between hydraulic experiments and calculation using Eq.(1). As shown in the Figure, the correlation coefficient was 0.91, indicating satisfactory validity of the empirical equation.

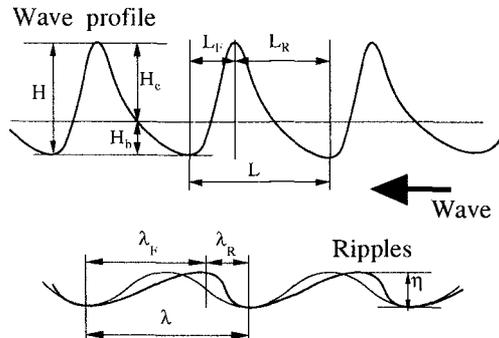


Fig.4 Definition of dimensions

The criteria of onshore/offshore sediment movement when the distortion of fixed bed ripples is $\lambda_R = \lambda/4$ ($\lambda = 5.5cm, \eta = 1cm$) are examined by Monte Carlo Method using Eq.(1). **Figure 6** shows the result of calculation where the direction and extent of sediment movement are shown with respect to the bottom slope and relative wave height. The figure depicts that definite onshore sediment movement is expected if the relative wave height H/h is less than 0.5 (corresponding to the offshore zone) although it varies with the bottom slope $\tan \beta$.

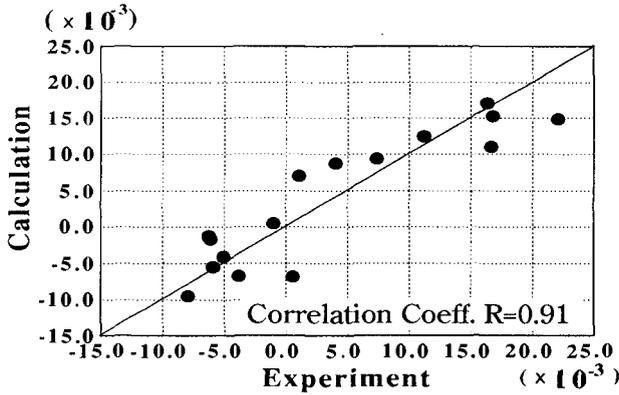


Fig.5 Comparison of V_g/U_m between calculation and experiments

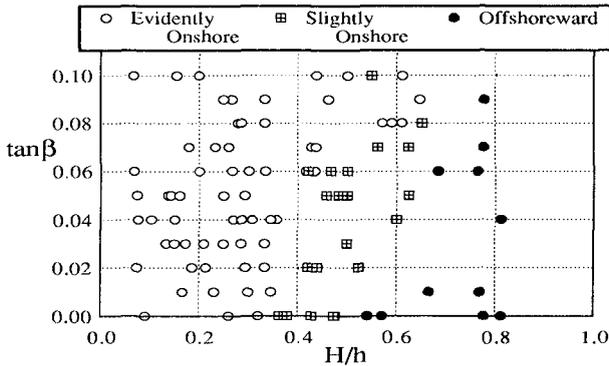


Fig.6 Criteria of onshore movement

Effectiveness of Distorted Ripple Mat

A distorted ripple mat made by precasted concrete blocks is developed as shown in **Figure 7**. As shown in the figure, one end of a unit block is

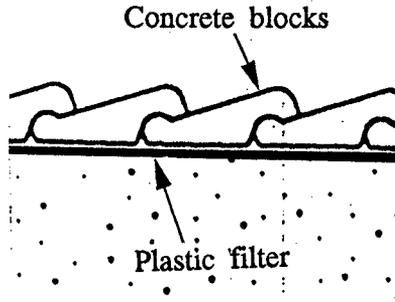


Fig.7 Distorted ripple mat

piled on the end of the other block and the plastic filter is stuck on the bottom face of the block, and thus it flexibly adapts itself to the change of movable bed and no settlement is expected. The surface profile of the distorted ripple mat is made to have the distortion characteristics of $\lambda_R = \lambda/4$, which corresponds to the maximum distortion in preserving strength of the concrete blocks. The effectiveness of the distorted mat in controlling cross-shore sediment transport is examined by movable bed experiments, where the distorted ripple mat was set in the offshore zone based on the results of **Figure 6**. **Figure 8** shows one result of small scale experiment carried out as the preliminary experiment in a wave flume 4m in length, 15cm in width and 20cm in height. The bed material used was glass beads with 0.08mm in diameter. After the action of waves of 2cm in height and 0.9 sec. in period, an equilibrium beach was formed and a distorted mat whose scale was almost 1/3 of the blocks shown in **Figure 7** was set in the offshore zone and waves were acted again. Sediment was supplied intermittently for beach fill at the location just onshore of the distorted mat. The distorted ripple mat checked the offshore sediment movement effectively, and most of the supplied sediment moved onshoreward and finally, as seen in the figure, a new beach is formed. **Figure 9** shows the medium scale experiment; the same scale as the experiments shown from **Figure 1** to **Figure 6**. An equilibrium beach was formed by acting waves of 8cm in height and 1.6 sec. in period on the initial each slope of 1/5 in the surf zone and 1/20 in the offshore zone. A distorted ripple mat was set in a limited range of the offshore as shown in the figure and waves were acted again. Sediment was supplied just onshore side of the distorted ripple mat. Movement of sediment can be more easily detected by spatially integrating bottom profile change onshoreward from the offshore point where no significant change takes place. The result of calculation of the present experiments is shown on the bottom of **Figure 9**. From the figure, the direction of net sediment movement on the distorted ripple mat is seen to be definitely onshoreward in spite of much sand

supply on the onshore side of it. Because of the strong effect of distorted ripple mat, the bottom is scoured just offshore side of the mat although a portion of scoured sediment is offshoreward which is considered to have caused because the initial profile was not completely in equilibrium.

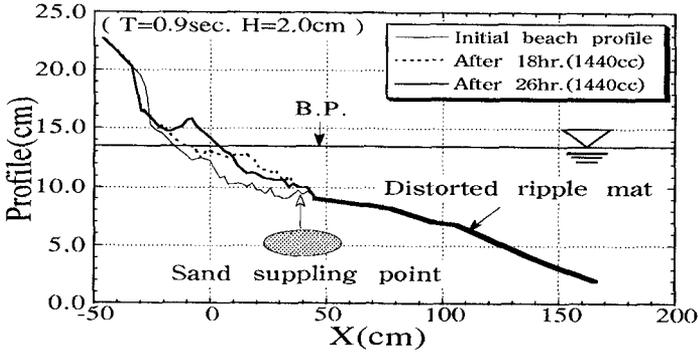


Fig.8 Beach fill by dumping (small scale experiments)

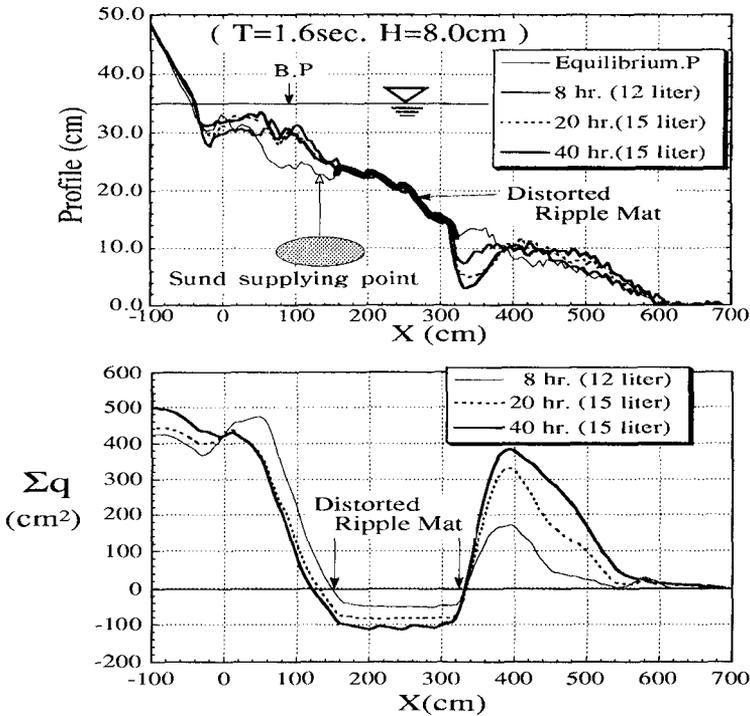


Fig.9 Beach fill by dumping (medium scale experiments)

Reproduction by Numerical Calculation

A numerical model of beach profile change has been developed by taking consideration of the effects of ripple distortion on cross-shore sediment transport. In Eq.(1), the average velocity of sediment movement V_g on fixed bed ripples could be considered to represent also the velocity of suspended part of sediment on movable bed if the rate of distortion of ripples S_3 is same as the one of movable bed. Thus the transport rate of suspended part of sediment in one pitch length of ripples can be obtained by multiplying V_g with the potential rate of sediment suspension. Here, we give;

$$QSS = \lambda \int C dz \quad (2)$$

$$VSG = V_g \quad (3)$$

where λ is the pitch length of ripples and C is the density of potential suspension of sediment at the height z . In the present study, C is obtained by the suspension formula by Skafel et.al.(1984). The important phenomena not included in the fixed bed ripples are the movement by bed shear at the surface of ripples on onshore and offshore phase of orbital velocity. As shown in **Figure 10**, sediment entrained by bed shear near the tips of ripples will be transported onshore or offshore up to the range of orbital length d_0 and during this process, the entrained sediment will be partly enrolled in the rear vortices of ripples at a rate, say, R as shown by the shaded parts in the figure. The enrolled parts could be considered to contribute directly to suspended sediment whereas the rest of sediment will settle down on the bottom during half period. In finite amplitude waves, the characteristics of orbital velocity is different between onshore phase and offshore phase and thus the rate of bed shear transport is different between both phases. The rate of bed shear transport $\Phi(t)$ is obtained from Madsen and Grant(1976) as follows:

$$\Phi(t) = 40\Psi^3(t) \quad (4)$$

where $\Psi(t)$ is the Shields Number. In **Figure 10**, we define;

QBO :Integration in space and time of sediment volume transported by bed shear and settled on the bottom on onshore phase (related to the rate of vortex enroll= R)

QBF :ditto but on offshore phase (also related to the rate of vortex enroll= R)

Figure 10 indicates that the centroids of QBO , QBF and QSS have moved by the distance, XGL , XGR and XBG in one period. Further we denote;

VBG :Average movement velocity of ($QBO + QBF$)

VT :Total average movement velocity of ($QBO + QBF + QSS$)

The following equation is formulated(Hashimoto et.al.,1993);

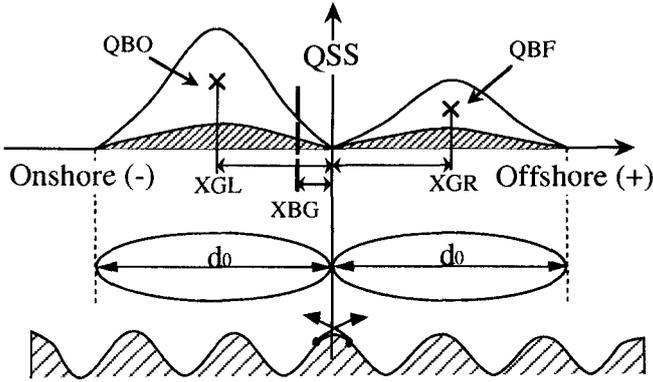


Fig.10 Onshore/Offshore sediment movement by bed shear

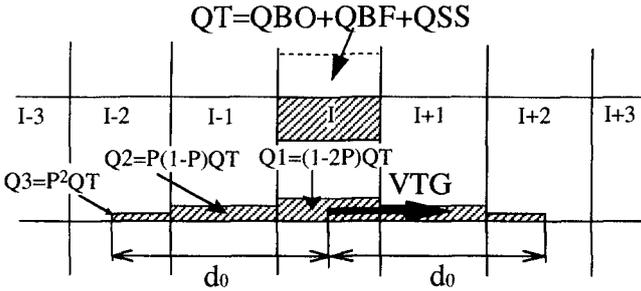


Fig.11 Movement and expansion of sediment in a ripple pitch length during one period of waves

$$(QBO + QBF + QSS) \times VT = (QBO + QBF) \times VBG + QSS \times VSG \quad (5)$$

Defining $QT = QBO + QBF + QSS$,

$$VT = (QBO + QBF)/QT \times VBG + QSS/QT \times VSG \quad (6)$$

The total average movement velocity VT should be modified by the effect of gravity, that is, the local bottom slope θ . Defining the modified velocity to be VTG ,

$$VTG = VT + J \cdot \sin \theta \quad (7)$$

where J is the empirical constant value.

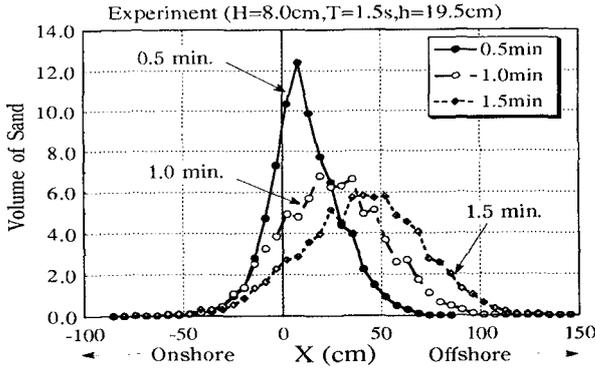


Fig.12 Movement and expansion of sediment placed on the trough of sinusoidal ripples of fixed bed(experiment)

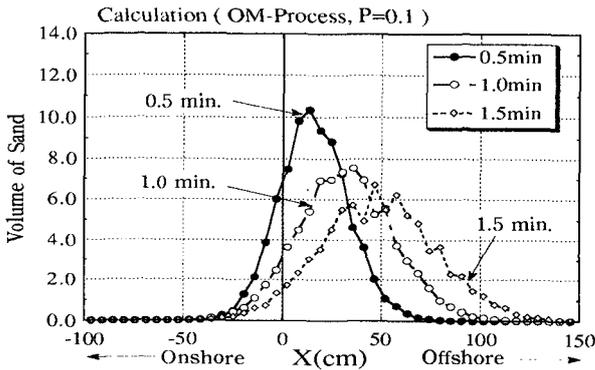


Fig.13 Movement and expansion of sediment placed on the trough of sinusoidal ripples of fixed bed(calculation)

As shown in **Figure 11**, the total volume QT in one pitch length of ripples is considered to move with the modified velocity VTG and scattered at a rate P in the range of orbital length d_0 during one period. Further, this movement in one pitch of ripples is assumed to take place at random throughout the profile and each ripple experiences only one time during one period. This idea enabled to calculate dispersion process of sediment due to wave action. **Figure 12** shows the scattering process of sediment placed on the trough of sinusoidal ripples of fixed bed (at $X = 0$ in the figure) by wave action, and the results of numerical calculation in the same condition is shown in **Figure 13**. The rate of dispersion P was selected to be 0.1 empirically. The process of sediment dispersion seems to be reproduced satisfactory. Another important feature of

the present model is the adoption of equilibrium profile. Natural beaches could be considered to be in quasi-equilibrium on long term basis. Once the beaches experience a certain impact of change such as excavation or beach filling, the beach profile change will take place being governed by the hydraulic condition in equilibrium state. In the present study, the equilibrium condition is given by the following condition.

$$VTG = VT + J \cdot \sin \theta = 0 \quad (8)$$

Here, two empirical constant values, that is, R in definition of QBO and QBF , and J in Eq.(8) could be determined if another definitive equation is available in addition to Eq.(8). In the present study, R and J were determined by comparing the beach profile change calculated by substituting a trial value of R and J (on the condition that Eq.(8) is satisfied) with movable bed experiments. As shown in **Figure 14**, initial equilibrium profile is given from laboratory experiments.

$$Z = 0.184X^{0.81} \quad (9)$$

The horizontal axis is divided into average ripple pitch length and sediment movement only in the offshore zone is calculated.

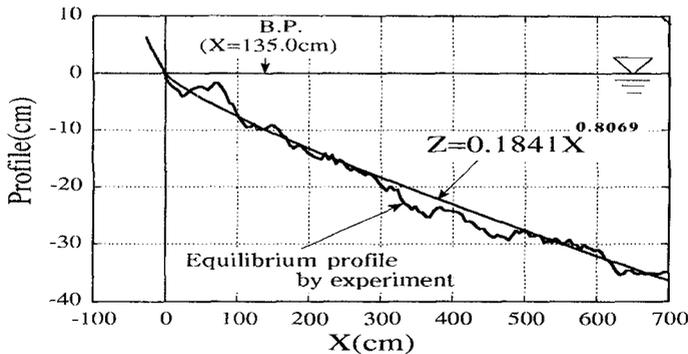


Fig.14 Equilibrium profile used as the initial condition

Effectiveness of Distorted Ripple Mat by Numerical Calculation

Effectiveness of distorted ripple mat is reproduced by numerical model explained above. **Figure 15** shows the idea in calculation. Suppose the original beach profile is $AFBC$ in the figure. We consider the case when the profile is partly excavated as $AFGH$ and calculate resulting change of profile. We

secondly calculate the change of profile when most steep part FG is protected by the distorted ripple mat. This calculation would also correspond to the case when the original beach $AFBC$ is filled to form $ADEBC$, that is to say, the beach fill is cut at half way $E \sim B$ and thus it is examined whether or not the filled beach can be preserved by the distorted ripple mat. The results of calculation are compared with experiments and actual initial profile and excavation section are shown in **Figure 16**.

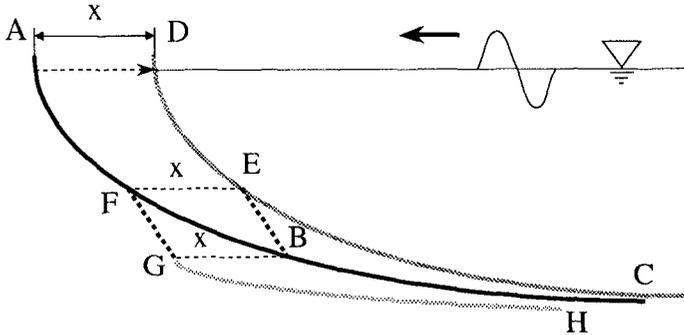


Fig.15 Conception showing that beach cut $AFGH$ is virtually same as beach fill $ADEBC$

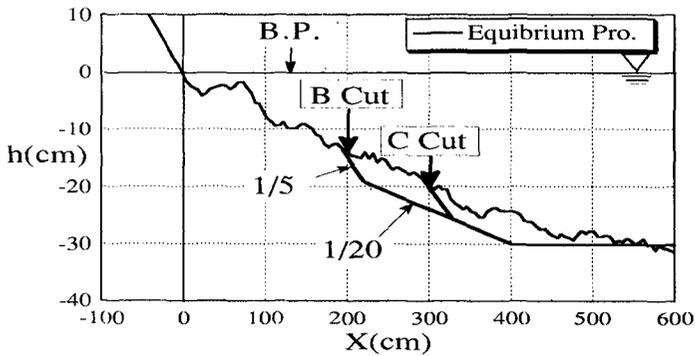


Fig.16 Method of beach cut

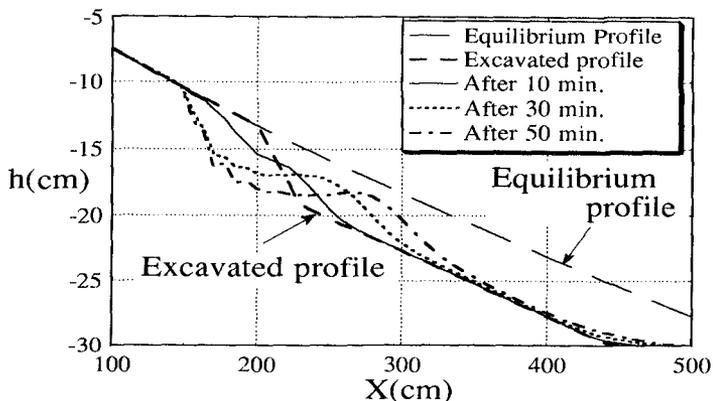


Fig.17 Deformation of the slope by calculation without distorted ripple mat

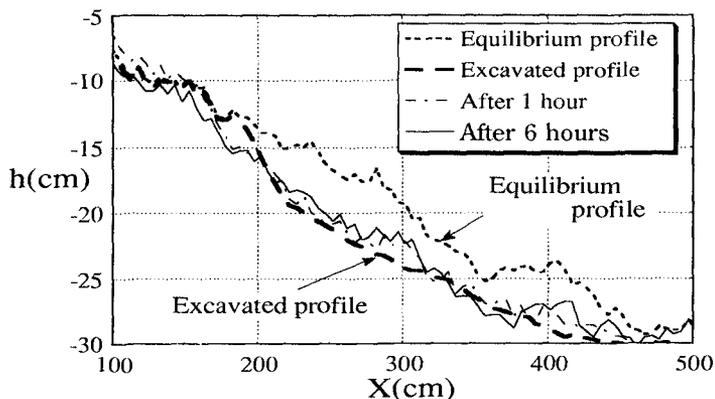


Fig.18 Deformation of the slope by experiments without distorted ripple mat

Figure 17 is the result of calculation when steep slope face is not protected and Figure 18 is the result of experiments. The steep face is rapidly collapsed by wave action in both cases. Figure 19 and 20 show the result when the steep slope is protected by the distorted ripple mat for the case of calculation and experiments respectively. The initial profile is seen to be almost preserved even after 3 ~ 4 hours of wave action for both cases. This is because offshore sediment movement is checked by the distorted ripple mat and only the local minor change took place.

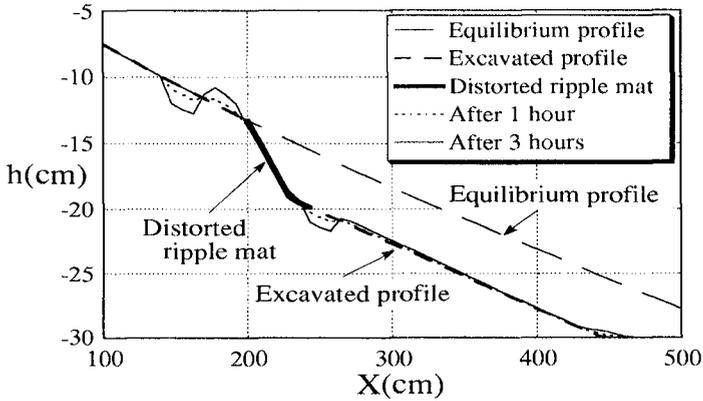


Fig.19 Stabilized slope by calculation with distorted ripple mat

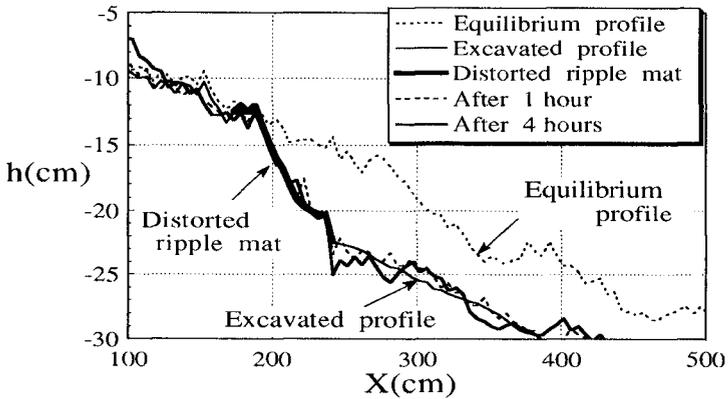


Fig.20 Stabilized slope by experiments with distorted ripple mat

Conclusions

Three factors, that is, the unsymmetry of wave crest height and trough depth, the distortion of wave profile and the distortion of ripples are the dominant factors affecting cross-shore sediment transport on fixed bed ripples. In the present distortion of ripples, definite onshore sediment movement is expected if the relative wave height H/h is less than 0.5, depicting that the distorted ripple mat is effective only in the offshore zone. The effectiveness of the distorted ripple mat is confirmed by both experiments with movable bed and numerical calculation.

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