CHAPTER 123

A Fundamental Study on Construction Scheme for Rubble Foundation of Deep Water Breakwater from Hopper Barges

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ABSTRACT

This study aims to establish the effective construction scheme of the rubble mounds which are constructed by discharging a large amount of rubble from hopper barges. The numerical simulation technique is developed to estimate the spatial geometry of individual rubble mound discharged from a hopper barge. The effective distance between the discharge sites of the barge which makes the uneven property of the mound surface a minimum is discussed in connection with the change in the spatial geometry of the discharged rubble, the water depth and the direction of barge allocation.

1. INTRODUCTION

In general, deep water breakwaters are caisson type structures. The caissons are placed on a rubble foundation which is constructed by discharging a large amount of rubble from a hopper barge. An advantage of this construction method exists in its rapid "executability", since a volume of rubble at one discharge time is extremely large. However, since the rubble landing on the sea floor widely distributes from the discharge point of the barge, the rubble mounds by individual discharges usually form uneven surface foundations. Fig. 1 shows the illustration of the uneven surface of the rubble foundation, the elliptical lines show the plane profile of the individual rubble mound discharged from a hopper barge. When the distance between the discharge sites of the barge becomes larger, the size of the gap between mounds by individual discharges becomes larger. These are the drawbacks of this method of construction.

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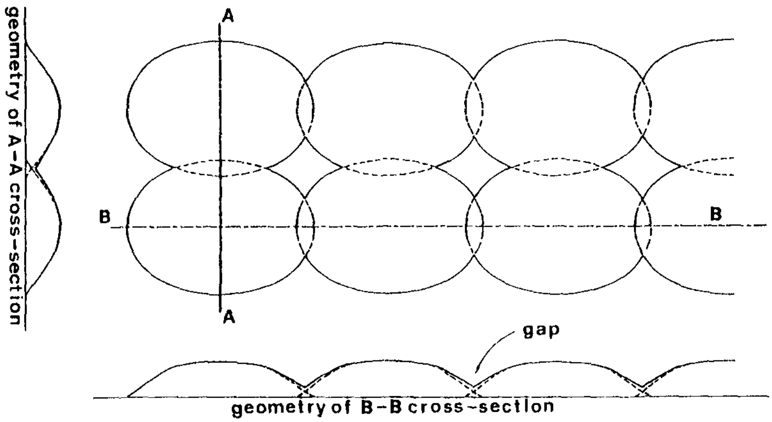


Fig. 1 Illustration of the uneven surface of the rubble foundation.

Recently, the design water depth of breakwateris becoming deeper and the size of the rubble mound is greater. The portion of the rubble foundation work to the total process of breakwater construction is increasing. Therefore, the technique to construct a mound for breakwaters effectively and economically has become very important. To establish effective construction schemes of the rubble mounds which are constructed by the mentioned techniques, this study investigates the fundamental properties of the rubbles discharged from the barge with numerical techniques. The aim of this study is to make clear the optimal distance between the discharge sites of the barge which makes the uneven property of the rubble mound a minimum.

2. NUMERICAL SIMULATION TECHNIQUE

The spatial geometry of individual rubble mound discharged from a hopper barge can be evaluated by combining the volume of rubble at one discharge with a probability distribution of the plane scatter for the landing rubble on the sea floor. This probability distribution is obtained by analyzing numerically the stochastic differential equations of three dimensional motions for the settling rubble.

2-1 THE EQUATIONS OF MOTION FOR THE SETTLING RUBBLE

The equations of three dimensional motion for one piece of settling rubble are given as

$$M \frac{du}{dt} = -\frac{\rho}{2} C_D A u^2 - C_A m \frac{du}{dt} + F_x(t) \tag{1}$$

$$M \frac{dv}{dt} = -\frac{\rho}{2} C_D A v^2 - C_A m \frac{dv}{dt} + F_y(t) \tag{2}$$

$$M \frac{dw}{dt} = -\frac{\rho}{2} C_D A w^2 - C_A m \frac{dw}{dt} + (M-m)g + F_z(t) \tag{3}$$

where u, v and w are the x, y and z components of the velocity of one piece of settling rubble, A is the projected area of the rubble, M and m are the mass of the rubble and the liquid displaced by the rubble, C_D is the drag coefficient, C_M is the added-mass coefficient, ρ is the fluid density, g is the gravity acceleration. In these equations, the first and second terms on the right-hand side are the drag force and the inertia force exerted on the settling rubble, respectively. The last terms, $F_x(t)$, $F_y(t)$ and $F_z(t)$ indicate the x, y and z components of the drift force exerted on the settling rubble. These drift forces are random external forces. This study focus on the scatter range of the landing rubble on the sea floor. Therefore, in this simulation technique, the z component of the drift force exerted on the settling rubble is neglected.

$$\frac{du}{dt} = -\alpha u^2 + \beta F_x(t) \tag{4}$$

$$\frac{dv}{dt} = -\alpha v^2 + \beta F_y(t) \tag{5}$$

where

$$\alpha = \rho C_D A/\{2(M+C_A m)\} \quad , \quad \beta = 1/(M+C_A m).$$

Eqs. (4) and (5) are non-linear stochastic differential equations (i.e. Langevin equation type). Therefore, in this study, these equations are linearized by using the following equations

$$u^2 = Uu \tag{6}$$
$$v^2 = Vv \tag{7}$$

where U and V are assumed to be of constant value in every time step of the numerical calculation. In this simulation technique, the random drifts, $F_x(t)$ and $F_y(t)$, are expressed by Gaussian random forces with zero mean.

Therefore, the variances (σ_x^2, σ_y^2) for the x and y components of the landing position on the sea bottom can be obtained as the solution of the linearized stochastic differential equations.

$$\sigma_x^2 = \frac{\gamma\beta^2}{(\alpha U)^3}\{\alpha Ut - \frac{3}{2} + 2\exp(-\alpha Ut) - \frac{1}{2}\exp(-2\alpha Ut)\} \quad (8)$$

$$\sigma_y^2 = \frac{\gamma\beta^2}{(\alpha V)^3}\{\alpha Vt - \frac{3}{2} + 2\exp(-\alpha Vt) - \frac{1}{2}\exp(-2\alpha Vt)\} \quad (9)$$

where γ is the intensity of the white noise which directly influences the scatter range of the settling rubble. The probability distributions of plane scatter for the landing rubble on the sea bottom are given as follows lastly

$$p(x) = \frac{1}{\sqrt{2\pi}\sigma_x} \exp(-\frac{x^2}{2\sigma_x^2}) \quad (10)$$

$$p(y) = \frac{1}{\sqrt{2\pi}\sigma_y} \exp(-\frac{y^2}{2\sigma_y^2}) \quad (11)$$

in which p(x) and p(y) are the x and y components of the probability for one piece of settling rubble.

2-2 SPEED OF THE SETTLING RUBBLE (U,V)

In Eqs. (8) and (9), U and V must be given in consideration of the random drift force acting on the settling rubble. In this study, therefore, U and V are evaluated as the standard deviations (σ_u, σ_v) for the speed of settling rubble at any position. Eqs. (4) and (5) are rearranged in term of x and y, respectively, as

$$u\frac{du}{dx} + \alpha u^2 = \beta f_u(x) \quad (12)$$

$$v\frac{dv}{dy} + \alpha v^2 = \beta f_v(y) \quad (13)$$

where $f_u(x)$ and $f_v(y)$ are assumed to be expressed in the Gaussian random force with zero mean and the intensity of the white noise (γ'). The variances (σ_u^2, σ_v^2) for the x and y components of the speed of the settling rubble at any position become from Eqs. (12) and (13) as

$$\sigma_u^2 = \beta(\frac{\gamma'}{\alpha})^{1/2}\{1 - \exp(-4\alpha x)\}^{1/2} \quad (14)$$

$$\sigma_v{}^2 = \beta\left(\frac{\gamma'}{\alpha}\right)^{1/2}\{\ 1 - \exp(-4\alpha y)\}^{1/2} \qquad (15)$$

On the other hand, the intensities of the white noise, γ and γ' are included as unknown variables in Eqs. (8), (9), (14) and (15). Basing on the Langevin equation (Hori, 1977), the γ and γ' are related to the mean square of the drift force as following equations

$$2\gamma = \langle F(t)^2\rangle dt \qquad (16)$$
$$2\gamma' = \langle f(\ell)^2\rangle d\ell \qquad (17)$$

where < > indicates the expected value, ℓ is the moving distance of the settling rubble. Since $f_u(x)$ and $f_v(y)$ in Eqs. (12) and (13) are assumed to be equivalent to $F_x(t)$ and $F_y(t)$ respectively, γ' becomes from Eqs. (16) and (17) as

$$\gamma' = U\gamma \qquad (18)$$
$$\gamma' = V\gamma \qquad (19)$$

Therefore, U and V are given as follows lastly

$$U_i = [\beta(\frac{\gamma U_{i-1}}{\alpha})^{1/2}\{1 - \exp(-4\alpha x)\}^{1/2}]^{1/2} \qquad (20)$$

$$V_i = [\beta(\frac{\gamma V_{i-1}}{\alpha})^{1/2}\{1 - \exp(-4\alpha y)\}^{1/2}]^{1/2} \qquad (21)$$

in which U_i and V_i are the x and y components of the speed of the settling rubble in the i-th step of the numerical calculation.

2-3 SPATIAL GEOMETRY OF RUBBLE MOUND DISCHARGED FROM HOPPER BARGE

The probability distribution of plane scatter for the landing position of rubbles discharged from a hopper barge can be evaluated as

$$P(j) = \{\ \sum_{i=1}^{N} p_i(j)\ \}/N \qquad (22)$$

in which $p_i(j)$ is a probability that the rubble which is fallen from the i-th discrete portion in the hopper mouth lands to the j-th discrete portion on the sea floor as shown in Fig. 2. The probability, $p_i(j)$, can be calculated from the probability distribution functions, p(x) and p(y) in Eqs. (10) and (11). Therefore, the spatial geometry of rubble mound discharged from a hopper barge can be simulated by combining this probability with the volume of rubble at one discharge.

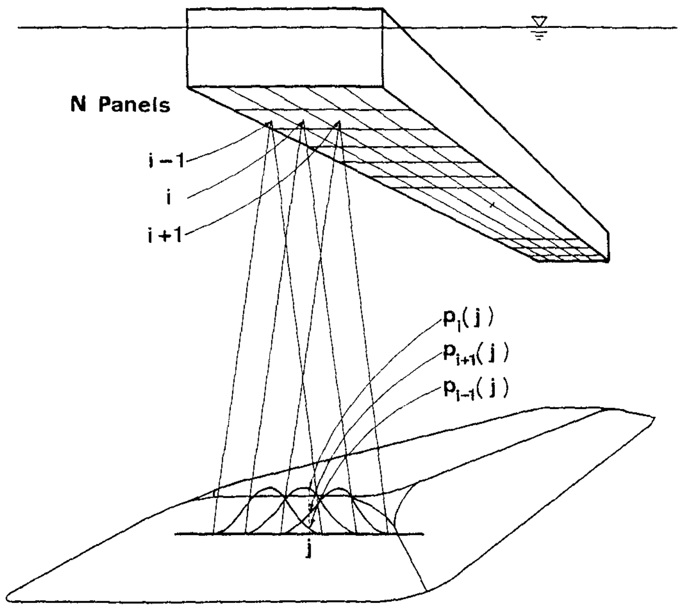


Fig. 2 Mathematical model of hopper barge.

3. OPTIMUM VALUE OF THE INTENSITY OF THE WHITE NOISE

The choice of the value for the intensity of the white noise used in this simulation technique is a problem, because the intensity of the white noise directly influences the scatter range of the settling rubble. In this study, the optimum value of the intensity of the white noise was investigated by comparing the calculated results with the experiments for the probability distribution of the plane scatter of the landing rubble on the sea bottom.

Fig. 3 shows examples of the experimental and calculated probability distribution of the plane scatter for the landing position of rubbles, in which every piece is dropped from the same position. In these cases, the representative size of rubble d=2.64cm is applied. The upper figures are experiments for three kinds of water depth (i.e. h=75cm, h=1m and h=1.5m). These experiments were carried out by Okude et al.(1982). P of the ordinate is the amount of the landing rubbles on unit area divided by the total amount of fallen rubbles. In the calculations, figures (A), (B) and (C) are the case for γ=100000, γ=250000 and γ=400000, respectively. All other parameter but γ are the same in these figures. In the

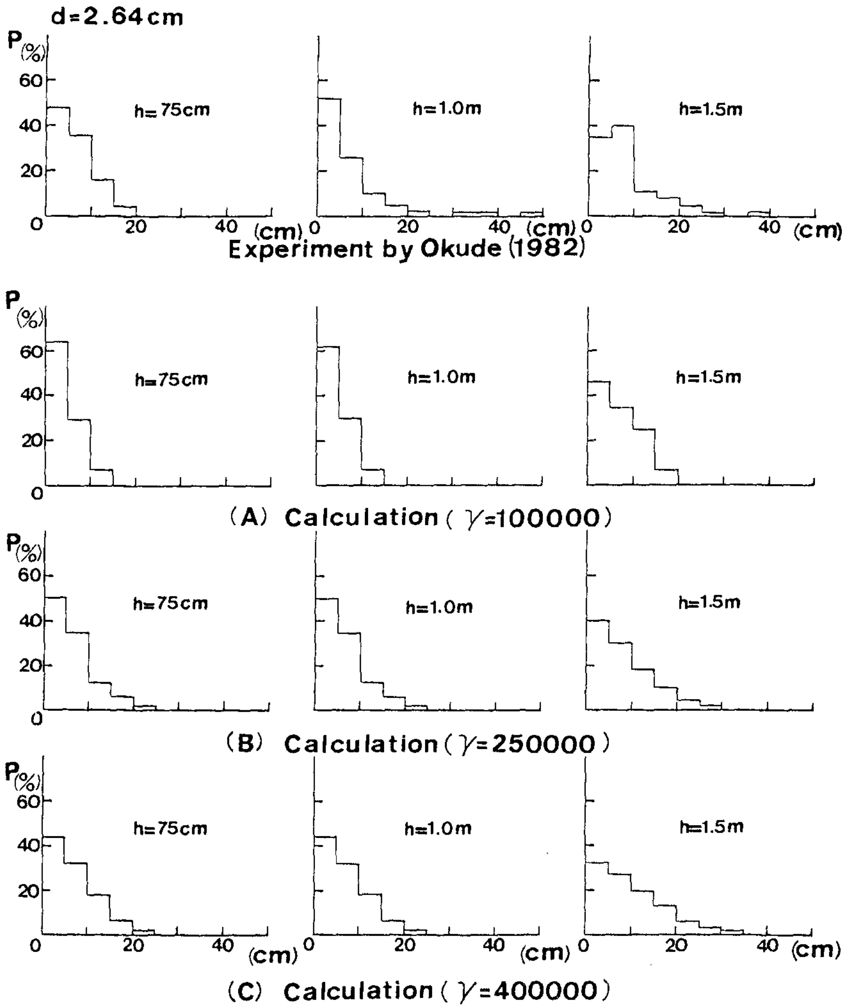


Fig. 3 Experimental and calculated probability distribution of the plane scatter for the landing position of rubbles (d=2.64cm).

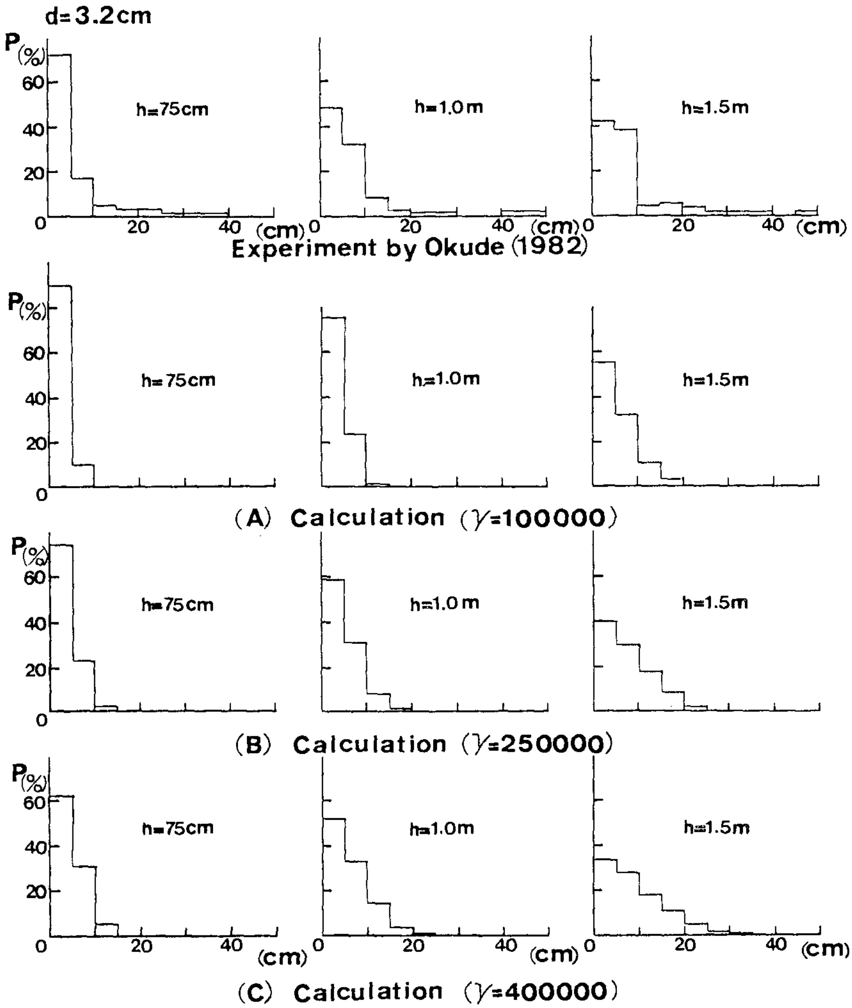


Fig. 4 Experimental and calculated probability distribution of the plane scatter for the landing position of rubbles (d=3.2cm).

calculations, when the value of γ becomes greater, the scatter range for the landing position becomes wider. Comparing these calculated results and the experimental results, it can be found that the calculations of the case for γ=250000 (Fig. 3 (B)) agree well with the experiments.
Furthermore, Fig. 4 shows the experimental and calculated probability distribution of the plane scatter for the landing position of rubbles in the case of d=3.2cm. The calculations for γ=250000 (Fig. 4 (B)) agree well with the experiments again. Therefore, from these investigations, it can be concluded that γ=250000 is the optimum value for the intensity of the white noise in the case of these rubble size. The scale effect of γ is not made clear yet in this study.

4. APPLICATION OF THE NUMERICAL SIMULATION TECHNIQUE

The application of the present simulation technique for the spatial geometry of the rubble mound discharged from a hopper barge was investigated by comparing the calculated results and the experimented results which were carried out by Okude et al.. In their experiment, a 1/20 scale model hopper barge with $100m^3$ hopper volume was employed as shown in Fig. 5. The length of the hopper L is 77.3cm, the width W is 24.4cm. In the numerical calculations, the hopper mouth is divided into small panels as shown in Fig. 2. Size of the panel is d times d, d is the representative size of rubble.

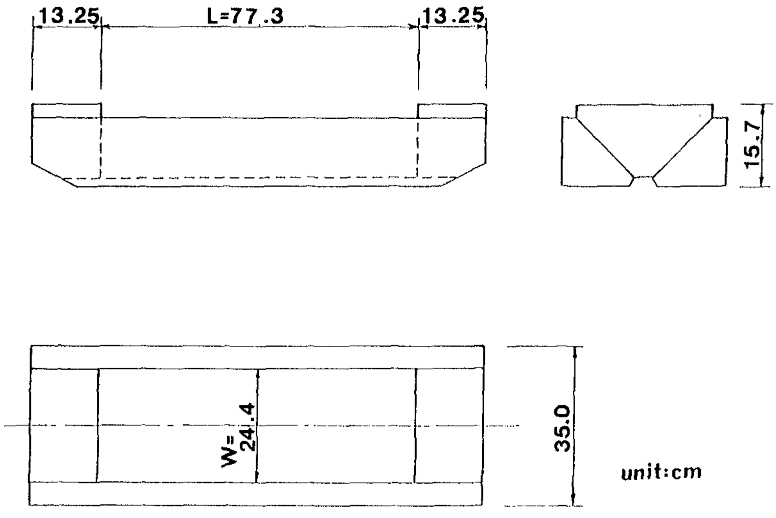


Fig. 5 Definition sketch for the model barge.

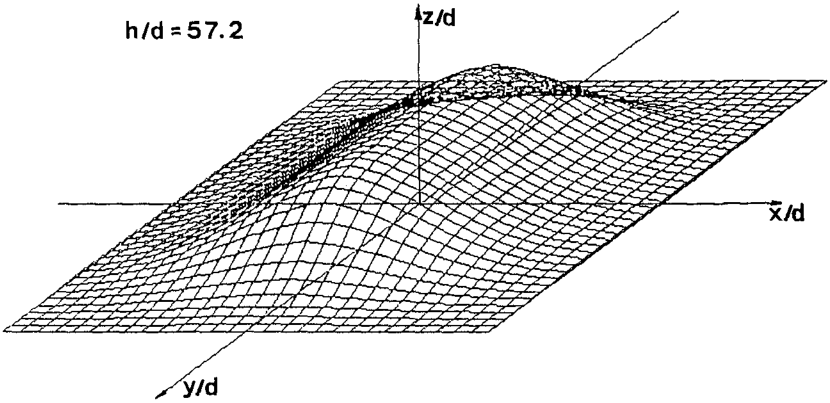


Fig. 6 Calculated spatial geometry of the discharged rubble mound. (h/d=57.2)

Fig. 6 shows an example of the calculated spatial geometry of the discharged rubble mound, in which the x and y are taken to be the direction of width and length of the hopper barge, respectively. This calculation is the case for the relative water depth h/d of 57.2. Next, the application of this simulation technique for the spatial geometry of rubble mound was investigated by comparing these calculations with the experimented results by Okude et al..

Fig. 7 shows a comparison between the shape of the calculated cross sections of rubble mound and those obtained in the experiments, figures (A) and (B) are the cases for h/d=27.2 and h/d=57.2, respectively. The left side from the ordinate in figures shows x-x cross section of the rubble mound (key sketch : top right) and right side shows corresponding y-y cross section. When h/d is 27.2 (Fig. 7 (A)), the simulated results overestimate the experimental results. This simulation technique cannot simulate the rubble sliding down the slope of the mound, which is recognized in the experiments. This overestimate may hence come from this reason. On the other hand, when the water depth becomes deeper, the slope of the mound becomes more mild, therefore the rubble sliding down the slope may hardly occur. In the case of h/d=57.2 (Fig. 7 (B)), the calculated and the experimented results agree reasonably well. From these investigations, it can be concluded that the present technique simulates the spatial geometry of the discharged rubble mound for the deeper water depth with sufficient accuracy. However, the applicable limitation of this simulation technique for the shallow water is not made clear in this study.

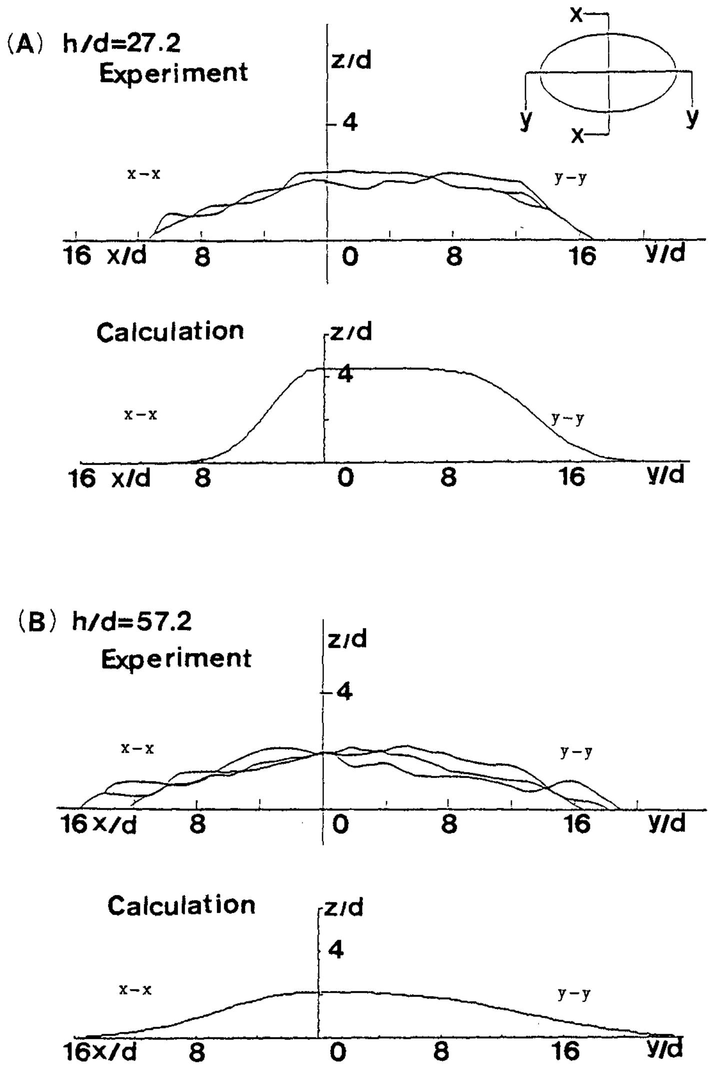


Fig. 7 Comparison between the shape of calculated rubble and experiments.

5. OPTIMAL DISTANCE BETWEEN THE DISCHARGE SITES OF THE BARGE

Fig. 8 shows the change of the calculated spatial geometry of the discharged rubble mound by two barges with respect to the water depth, a is the distance between the discharge sites of the barge. Figure (A) is the case of which the distance a is two times as long as the rubble size d, figure (B) is the case for a/d=12. When the distance between two barges is small (Fig. 8 (A)), the mounds by individual discharges form relatively even surfaces in shallow water. On the other hand, when the distance is larger (Fig. 8 (B)), the mounds form remarkably uneven surfaces in deep water. Therefore, it may be concluded that when deciding the distance between the discharge sites of the barge, the design water depth of breakwater becomes an important parameter.

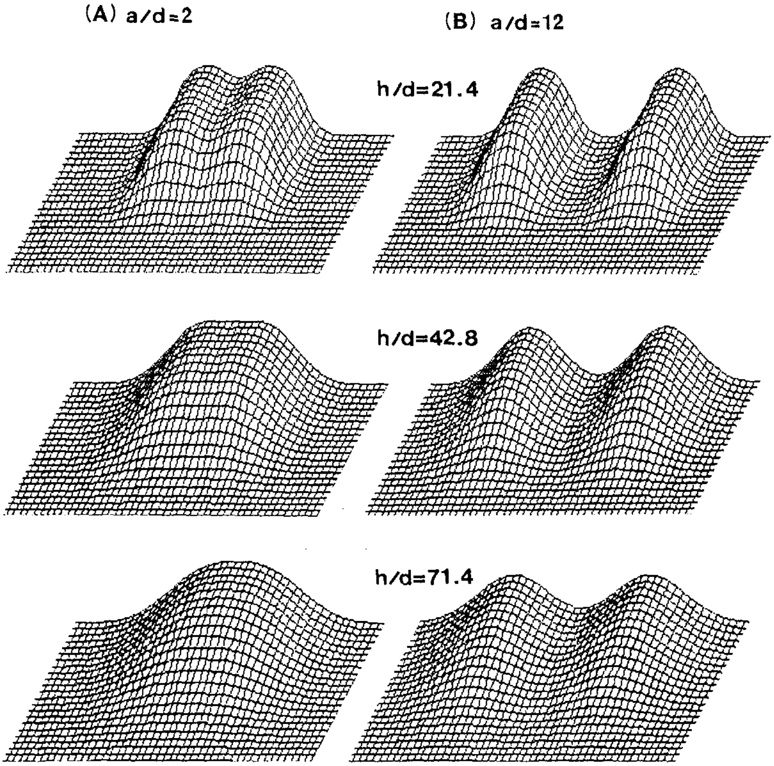
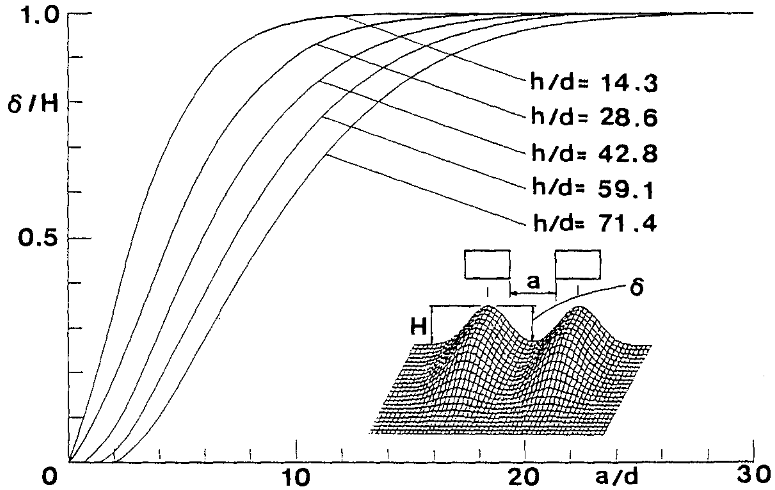
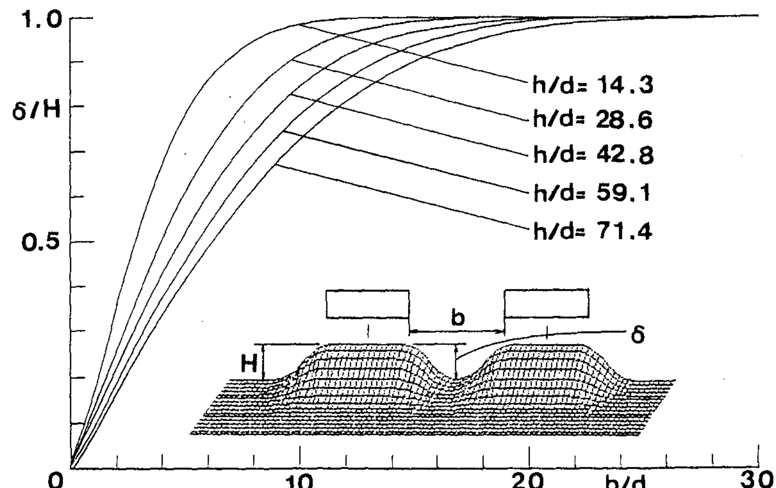


Fig. 8 Change of the discharged rubble mound by two barges with changing water depth.



(A)



(B)

Fig. 9 Change in the size of the gap between the mounds with respect to the distance between the discharge sites of the barge.

Fig. 9 shows the change in the size of the gap between the mounds with respect to the relative distance between the discharge sites of the barge, in which δ is the gap size between individual mounds, H is the representative height of the mound. Figure (A) is the case of which two barges are allocated in the barge width direction, figure (B) is the case for the barge length direction. By using these figures, the effective distance between the discharge sites of the barge which makes the uneven property of the mound surface a minimum can be determined. Comparing the value of δ/H in figure (A) with that in the figure (B), in the region of small distance between the discharge sites of the barge, it is found that a change in the direction of barge allocation gives difference in both values of δ/H, (e.g. focusing the line of $h/d=71.4$, δ/H is equal to about 0.1 at $a/d=4$ in figure (A), on the other hand, at $b/d=4$ in figure (B), δ/H is equal to about 0.3). These extreme difference are caused by the direction of barge allocation. Therefore, it can be concluded that when deciding the distance between the discharge sites of the barge, the direction of barge allocation becomes an important parameter also.

6. CONCLUSION

Concluding remarks are as follows:
(1) The present technique can successfully simulate the spatial geometry of the discharged rubble mound from the hopper barge in the deep water with sufficient accuracy.
(2) The effective distance between the discharge sites of the barge which makes the uneven property of the mound surface a minimum is made clear in connection with the change in the spatial geometry of the discharged rubble, the water depth and the direction of barge allocation.
(3) Applying this simulation technique for the case of the shallow water, the problem of how to deal with the rubbles sliding down the slope of the mound still remains.

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