CHAPTER 206

On the change of velocity field in nearshore zone due to coastal drain and the consequent beach transformation

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ABSTRACT

It is essential to understand the details of the mechanisms by which a coastal drain works in order to build up the method which enables us to estimate discharge requirement for effective operation in field conditions. Some measurements on the changes of quantities which may be relevant to the function of coastal drain are discussed. Then, an attempt to implicate the current components produced by drainage in a numerical model of beach profile evolution is discussed.

INTRODUCTION

The coastal drain has been considered to be an effective soft approach to coastal erosion control and beach erosion. From the practical point of view, it is indispensable to know how to estimate discharge requirement for effective operation in field conditions. Small scale physical experiments give us qualitative information on some physical aspects related with the coastal drain. There seems, however, to be a difficulty in estimating discharge needed for a coastal drain system based on experimental results due to scale effects. Hence, when we consider the remarkable recent progress of numerical models on beach profile evolution, it will be a practical way to construct a numerical model which enables us to estimate beach profile change under the operation of a coastal drain system. To do this, it is essential to understand the details of the mechanisms by which the coastal drain works.

Authors have shown the following results on forced coastal drain experimentally(1994),

1) seaward area of a shoreline is most appropriate for the installation of a drain pipe
2) as the discharge increases, the drain system becomes effective even for storm wave conditions.

Figure 1 is an example of beach profiles under erosive wave condition. In this case, sediments on the initial shoreline moved mainly toward the upper beachface and the bottom level lowered. But, the erosion in the shoreward part of the drain pipe was

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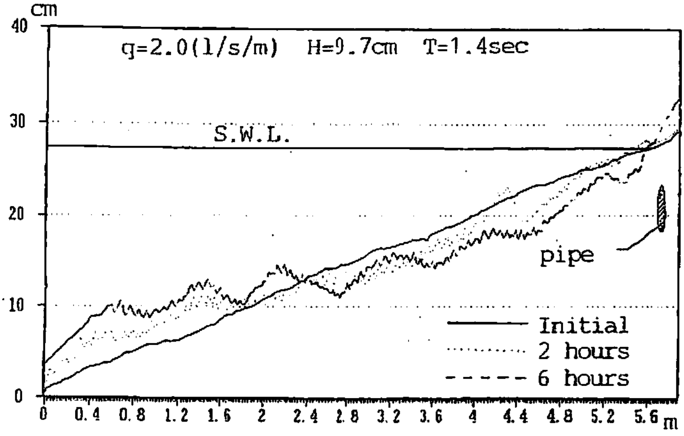


Figure 1 Beach profile change (1)

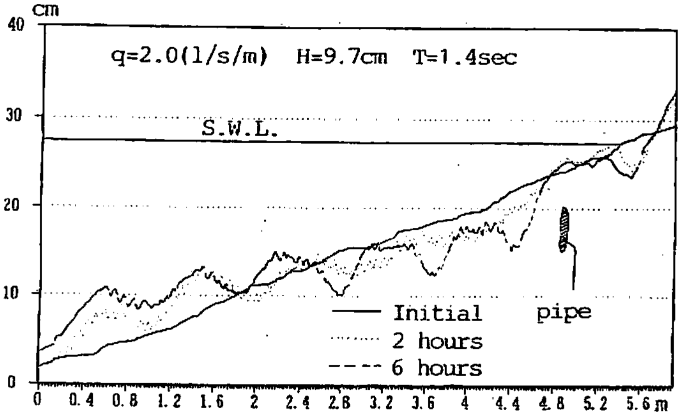


Figure 2 Beach profile change (2)

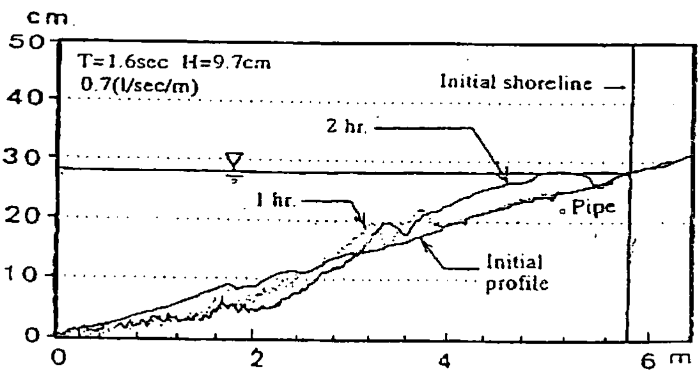


Figure 3 Beach profile change (3)

restrained on the whole. This example made us have expectation the landward area of a drain pipe to be protected at the worst, when the drain pipe was installed in seaward area of a shoreline.

Figure 2 shows an example of the case in which drain was done under the shoreline. Erosion due to erosive waves attained almost to the initial shoreline for the same drainage as the case mentioned above.

Figure 3 is the case which attracted our attention specially in that it showed remarkable accretion in the inshore area after wave action of two hours. The wave condition was less steeper compared with the cases in Figures 1 and 2, but it was not accretive one at all for the cases of without or smaller drainage. This result suggests that, when a storm passes by a shore, similar situation may occur in some stages of the storm passage according to wave condition and drainage. And the process which brought the accumulation of sediments is expected to retard erosion and accelerate restoration of an eroded beach. So, our main interest has been directed to determine under what conditions the accretion takes place.

Generally, the reason a coastal drain system works has been explained by relating effects of drainage to the net sediments carried due to runup-down wash processes of waves on a beachface. Our observation, however, showed that the changes of the hydraulic conditions in the nearshore zone were important. Especially, shoreward flow component induced by drainage in and out of a surf zone, which carried suspended sediments and migrated a bar toward the beachface, seemed to play the dominant role for the accretion when the drain pipe was installed in the seaward area of a shoreline.

In this paper, some measurements on the changes of quantities which may be relevant to the function of coastal drain are discussed. Then, an attempt to implicate the current components produced by drainage in a numerical model of beach profile evolution is discussed.

EXPERIMENTS

The changes of wave runup, wave setup and mean velocity fields due to coastal drain were investigated experimentally by using a wave flume of 13m long, 0.4m wide and 0.4m deep (Figure 4). Water elevation was measured by capacitance type wave gages and velocity fields were measured with an electromagnetic current meter. The measurements were limited in the range between the level about 1cm lower from wave trough and the level 2cm above the bottom.

RESULTS AND DISCUSSIONS

Wave set-up : In their experiments on the gravity drainage system which utilize permeable layer artificially placed under a beach, Kanazawa et.al.(1996) observed no wave set-up, the gradient of which in on-offshore direction provides one of the driving force of undertow. We also anticipated similar result for our cases in early stage. Our measurements of mean water level, however, did not show any definite change in the mean water level as shown in Figure 5. The difference may be considered to reflect the difference of mechanisms which make each system effective.

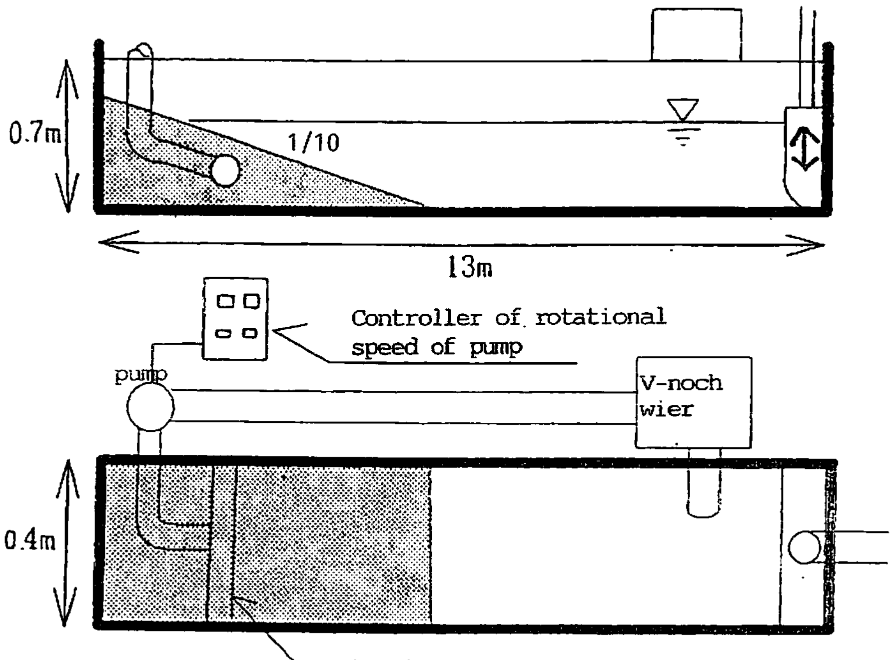


Figure 4 Experimental setup

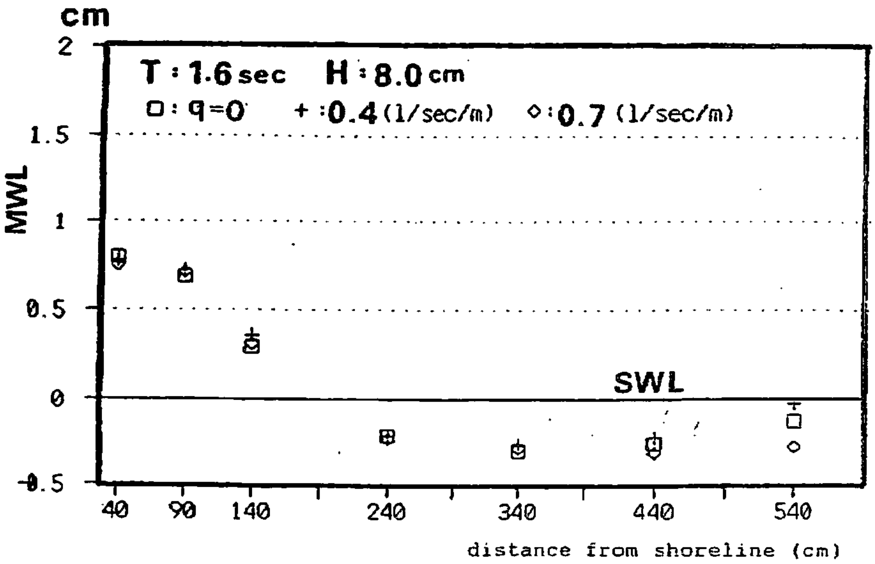


Figure 5 Wave setup

Wave runup : Wave runup was measured visually. The change of wave runup was small. This was supported by the numerical model of wave runup including the effects of coastal drain (Figure 6). These results reveals the change of runup-down wash process due to coastal drain is not necessarily the dominant mechanism when a drain pipe is buried in the seaward part of a shoreline.

Numerical computation was done based on the equations of continuity and motion for nonlinear shallow water waves implicating infiltrating flow from the bottom surface due to drain. The non-dimensional form of the equations are as follows.

$$\frac{\partial h}{\partial t}+\frac{\partial}{\partial x}(hu)=-\nu^{*} \tag{1}$$

$$\frac{\partial}{\partial t}(hu)+\frac{\partial}{\partial x}\left(hu^{2}+\frac{h^{2}}{2}\right)+\theta h+f_{w}|u|u+u\nu^{*}=0 \tag{2}$$

$$x=\frac{x'}{\sqrt{gh'}T'},\quad t=\frac{t'}{T'},\quad h=\frac{h'}{H'},\quad u=\frac{u'}{\sqrt{gh'}}\quad,\quad \nu^{*}=\frac{\nu^{*}}{H'/T'}$$

$$\theta=\frac{\tan\theta'}{H'/\left(\sqrt{gH'}T'\right)},\quad \tau_{b}=\frac{\tau_{b}'}{\rho gH'^{2}/\left(\sqrt{gH'}T'\right)}$$

where h is water depth, t is time, u is fluid velocity in x-direction, ν^{*} is infiltration velocity, H is wave height, T is wave period, τ_{b} is shearing stress on the bottom, g is the gravitational acceleration and f_{w} is friction factor. Prime denotes the dimensional variables.

The infiltration velocity ν^{*} was given as the velocity $-(a'q')/\{\pi(x'^{2}+a'^{2})\}$ of the flow induced along x'-axis by a source at $z'=i\,a'$ with the intensity of $-q'/2\pi$ and a sink at $z'=-i\,a'$ with the intensity of $q'/2\pi$ in z'-plane (Figure 7). The non-dimensional form of the velocity for the coordinate system in Figure 8 is given by the following equation.

$$\nu^{*}=-\frac{aq}{\pi\left\{(x-x_{0})^{2}+a^{2}\right\}} \tag{3}$$

In conducting the numerical computation, Kobayashi et.al.(1987) was referred to.

Mean velocity : Measurements of the mean flow field over the beach in the wave channel were carried out. The beach was plane uniform one of 1/10 slope initially. Wave action of several minutes, however, changed the beach profile to the extent we could ignore. Then, the bed was flattened in every several minutes. Nevertheless, the measurements seems to contain the influence due to the bottom change in the course of measurement.

Figure 9-A shows the mean velocity distribution induced by waves without drain. Figure 9-B and C are the velocity field induced by drain without wave action. And Figure 9-D and E are the velocity field due to waves and drain.

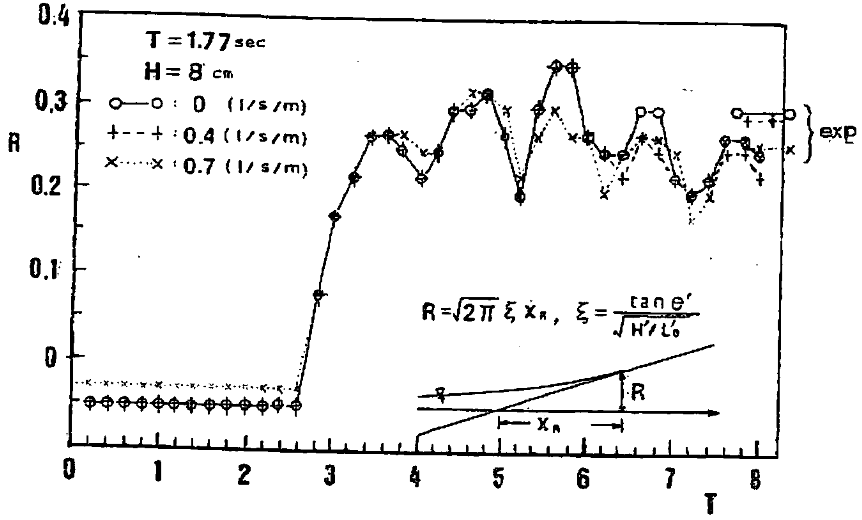


Figure 6 An example of measured and calculated runup

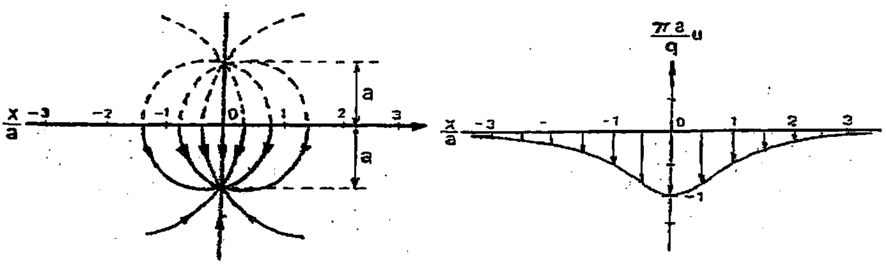


Figure 7 Infiltration velocity model used in the calculation of wave runup

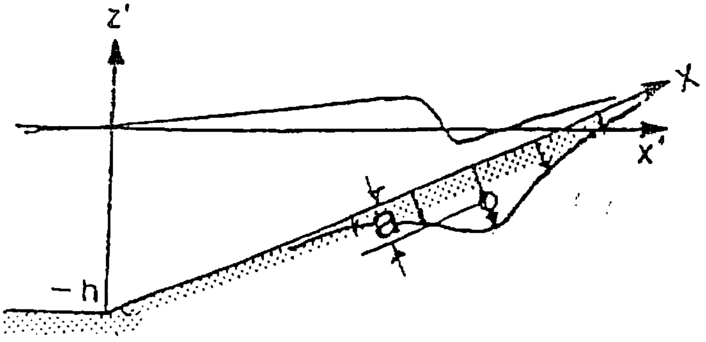


Figure 8 Difinition sketch

From these measurements we can see that the flow in the direction of offshore decreases the intensity near the drain pipe. And the reverse of the flow direction was observed in close proximity to the pipe.

BEACH PROFILE EVOLUTION AND COASTAL DRAIN

In an attempt to know what changes in beach profile evolution will result when the following two effects are taken into consideration, numerical simulations of beach profile evolution based on a modified existing model (Dally and Dean(1984)) were done.

1. the horizontal velocity component of the flow produced by drainage reduces the wave induced offshore-directed mean current,
2. the vertical velocity component of the flow adds to the settling velocity of sediment particles and modify the vertical distribution of suspended sediments.

The flow components due to drain were simply modeled by the flow in a wedge shaped region produced by a point sink on a side of the wedge(Figure 10). The velocity components (u, v) are given by

$$u - iv = \frac{m\pi}{\theta} \cdot \frac{(z/a)^{\pi/\theta}}{z\left\{(z/a)^{\pi/\theta} - a\right\}} \tag{4}$$

where $z = x + iy$ and $i^2 = -1$. The calculated flow distributions are shown in Figure 11.

Sediment transport rate Q_{SS} was given by

$$\begin{aligned} Q_{SS} &= \int_{-h}^{0} \overline{u}(z) \cdot C(z) dz \\ &= \int_{D_p-h}^{0} \left\{u_1(z) + u_{Dx}(z)\right\} \cdot C(z) dz + \int_{-h}^{D_p-h} \left\{u_2(z) + u_3(z) + u_{Dx}(z)\right\} \cdot C(z) dz \end{aligned} \tag{5}$$

where $\overline{u}$ is mean velocity, $C(z)$ is concentration of suspended sediments, u_{Dx} is x-component of the velocity induced by drain (Figure 12).

The concentration of suspended sediments was given by

$$C(z) = C_A \exp\left\{-15(w + u_{Dz}) \cdot (z - z_A) / \left(h\sqrt{\tau/\rho}\right)\right\} \tag{6}$$

where C_A is reference concentration, w is the settling velocity of sediments, u_{Dz} is z-component of the velocity induced by drain.

Beach profile evolution was calculated by

$$\frac{dh}{di} = \lambda \frac{dQ_{SS}}{dx} \tag{7}$$

Figure 13 shows the calculated results. For the case of without drain, specious results were obtained. Addition of the flow due to drain makes the sediment transport rates several times larger in magnitude and the sediment transport direction onshore over the whole beach area. And accretion of the shore-side area of the pipe was obtained

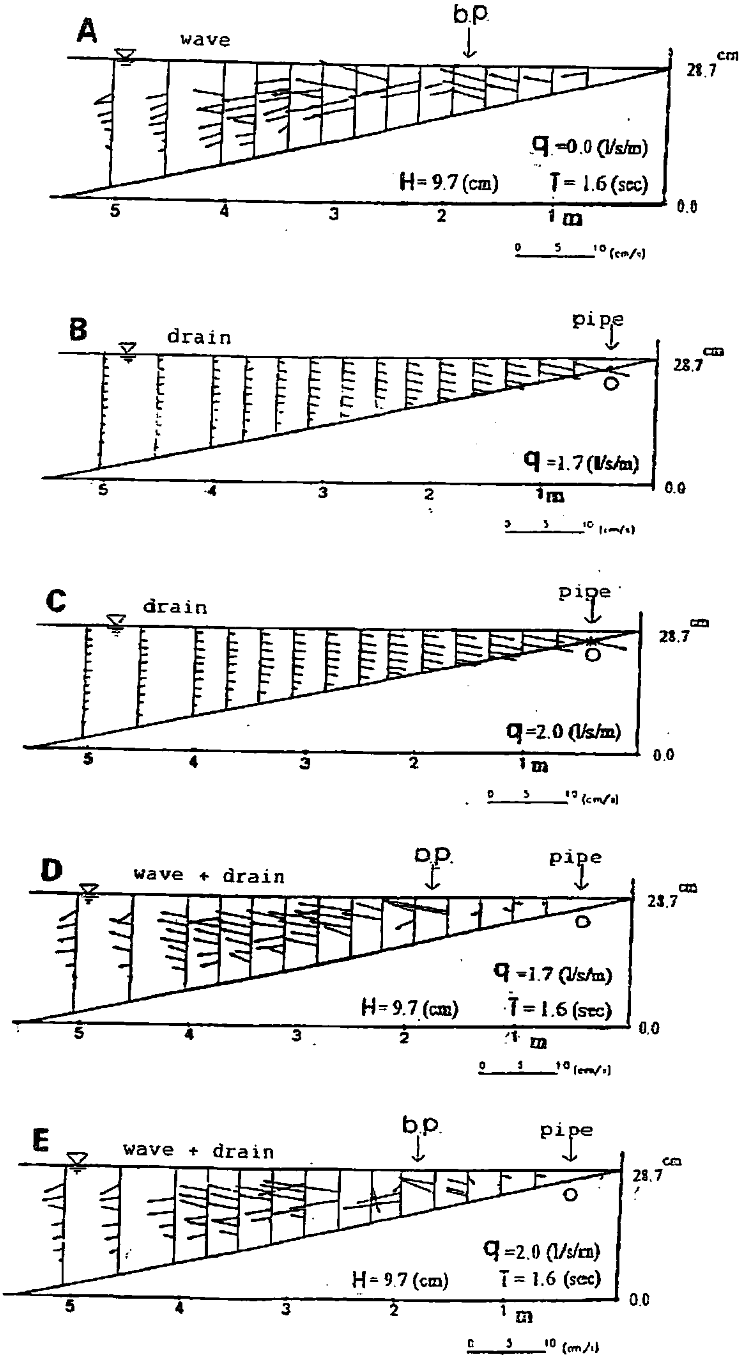
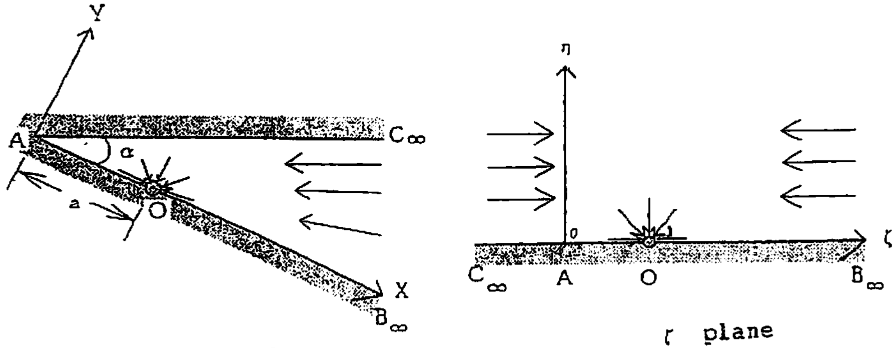


Figure 9 Measured mean velocity



z plane

ζ plane

Figure 10 Model of the drain induced flow

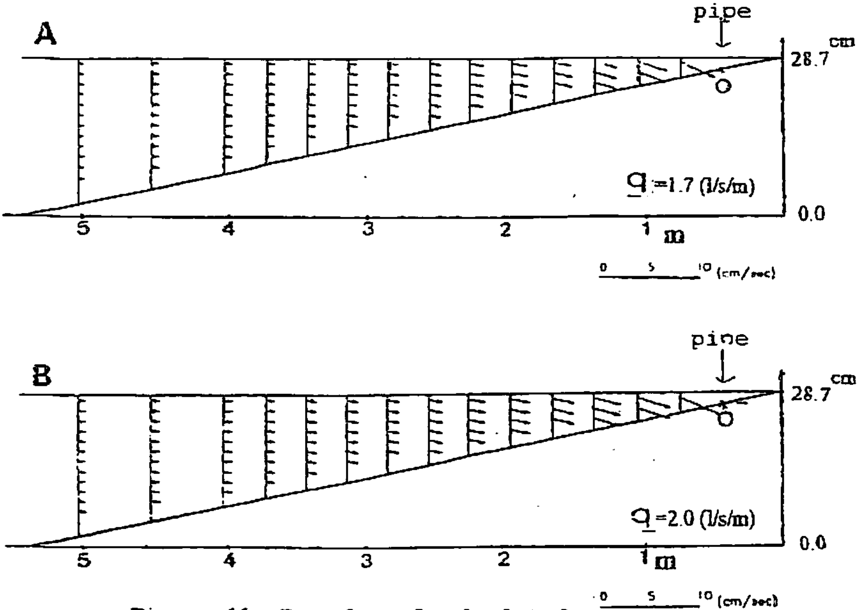
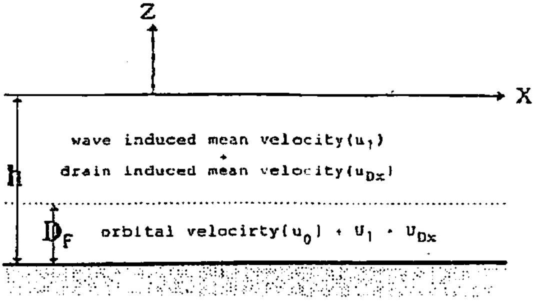


Figure 11 Examples of calculated velocity distribution

Figure 12 Difinition of variables in Eq.(5)



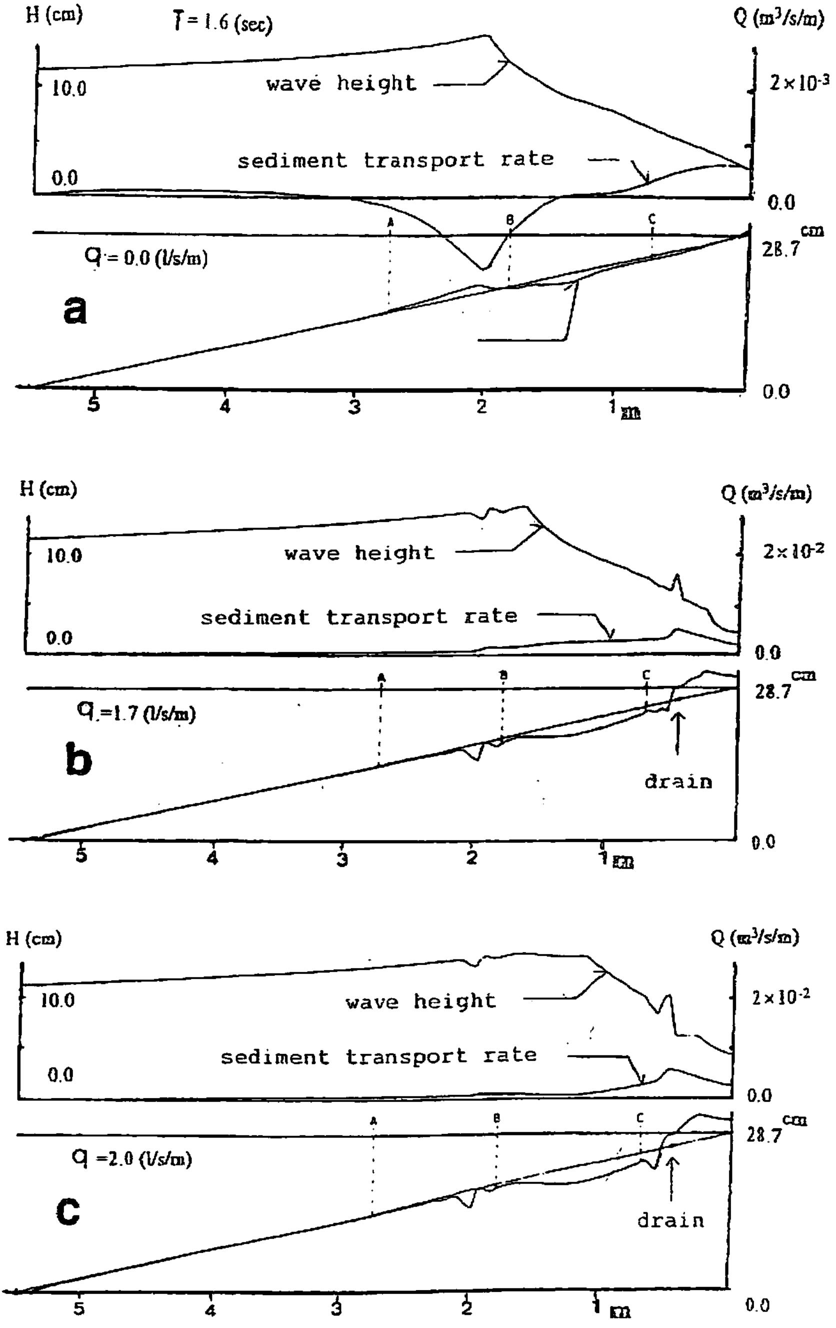


Figure 13 Calculated beach profile evolutions

Therefore, the calculated results show some features of beach profile evolution and they are considered to account for one of possible mechanisms how a coastal drain works though in a qualitative sense, when the pipe is installed under the bottom of the seaward area of a shoreline. The results, however, show fairly bumpy transformation of wave height and bottom topography. Some trials to improve the situation have been done. But, they are not successful so far. Besides, this model does not include bed load sediment transport.

To complete the numerical model for the coastal drain, it will be essential to take the bed load into consideration. However, there are some problems remained to be investigated on the bed load sediment transport under the operation of a coastal drain system like the change in flow within a wave bottom boundary layer over a drain pipe due to suction by forced drain and its effect on bed load sediment transport.

CONCLUSIONS

The following conclusions were drawn from the study:

When a drain pipe is installed in the seaward area of a shoreline,

1. the mean flow in the offshore direction over the whole beach area is reduced by the onshore current induced by drainage. This will results in the reduction of offshore suspended sediments transport in stormy conditions.
2. In this case, the changes in wave runup and wave setup, which are connected with the processes on a uprush zone, were small.

Then, an attempt to implicate the current components produced by drainage in a numerical model of beach profile evolution is discussed. To complete the numerical model, however, there are some problems remained to be investigated, especially on the effects of forced drain on bed load sediment transport.

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