THE RATE OF LONGSHORE SEDIMENT TRANSPORT AND BEACH EROSION CONTROL

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ABSTRACT

The main purpose of this paper is to propose an ideal methodology for beach erosion control from the viewpoint of controlling the total rate of longshore sediment transport. For this, a new formulation of the rate of longshore sediment transport is made. The total rate is directly proportional to the longshore component of wave power in field coasts, but not in laboratory ones.

How to control the total rate of longshore sediment transport is considered. There are two ways applicable for practical purposes. The first is to decrease the breaker depth by changing the bottom topography, and the second to decrease the incident angle of breaking waves by changing either the bottom topography or the inclination of shoreline to the incidence of predominant waves. Two typical, but ideal examples are explained for beach erosion control by this methodology.

INTRODUCTION

Beach erosion has advanced actively in many countries of the world, especially in Japan(Tsuchiya, 1980) due to decrease in sediment input from rivers and by construction of coastal structures. Various works have been employed widely to prevent beaches from erosion, but few general concept of beach erosion control has been proposed.

The methodology of beach erosion control must be established by the knowledges of sand drift, as well as of beach processes. By wave power approach, formulations of the total rate of longshore sediment transport have been made by many authorities. Komer and Inman(1970) investigated the applicability of the Bagnold model(1963) for sand transport on beaches to find out some correlation between the model and empirical relation of the total rate of longshore sediment transport. Recently Kamphuis and Readshaw(1978) studied the total rate of longshore sediment transport in terms of the total thrust which is the longshore gradient of the alongshore component of radiation stress. More recently Seymour, Domurat and Pirie(1980) did the same approach which was compared with their observed results of longshore sediment transport and radiation stress.

A very simple model for the formulation of the rate of longshore sediment transport is first explained. Then, an ideal methodology for

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beach erosion control is proposed from the viewpoints of controlling the total rate of longshore sediment transport and providing stable sandy beaches which have the lowest wave reflection coefficient to reduce the offshore sediment transport effectively.

THE RATE OF LONGSHORE SEDIMENT TRANSPORT

On the whole, movements of sediments are thought to be composed of alternating motion and these sediments are transported downstream by longshore currents even as they are undergoing sliding or saltation due to wave action. Thus, the mechanism of longshore sediment transport can be expressed as

$$q_x = \underbrace{\bar{c}_o}_{\text{Wave motion}} \cdot d \cdot \underbrace{u(y)}_{\text{Longshore currents}} \tag{1}$$

in which q_x is the rate of longshore sediment transport, u the velocity of longshore current in the x-direction, and $\bar{c}_o$ the averaged concentration of sediment. Einstein(1972) indicated that the motion of sediment transported by fluid can be expressed universally by a formula for sediment load. When the formula used to determine the rate of sediment transport by winds and currents(Tsuchiya and Kawata, 1971) is applied, the averaged concentration can be expressed as

$$\bar{c}_o = c_o \left(\frac{\rho}{\sigma}\right)\left(1 - \frac{\tau^*}{\tau_c^*}\right) \tag{2}$$

in which c_o is approximately equal to 0.2 although it varies slightly with the Shields parameter τ^*. τ_c^* in Eq.(2) is the value at the critical stage of sediment movement, and τ^* is given as

$$\tau^* = \frac{\tau/\rho}{(\sigma/\rho - 1)\, gD} \tag{3}$$

where

$$\tau/\rho = (1/2) f \bar{v}^2 \tag{4}$$

in which f is the coefficient of bottom friction, D the size of the sediment, σ/ρ the specific gravity of the sediment, g the acceleration of gravity, and $\bar{v}$ the maximum water particle velocity of waves on the sea bottom. The value for $\bar{v}$ can be expressed approximately by

$$\bar{v} = \begin{cases} \alpha\sqrt{gd}, \quad \alpha = \dfrac{1}{2}\left(\dfrac{L}{T\sqrt{gd}}\right)_B \left(\dfrac{H_B}{d_B}\right) & \text{for} \quad 0 \le Y \le 1 \\[2ex] \dfrac{1}{2}\left(\dfrac{H}{H_o}\right)\left(\dfrac{L}{L_o}\right)\left(\dfrac{H_o L_o}{Td}\right) & \text{for} \quad 1 \le Y < \infty \end{cases} \tag{5}$$

in which the subscript o refers to wave quantities at the deep-water limit and B to the breaker point, L is the wave-length, H the wave-height, T the wave-period, d the water depth, $Y = y/y_B$ the dimensionless variable, and y_B the width of surf-zone. Use of the equation for longshore currents of Longuet-Higgins(1970), allows us to rearrange the distribution of longshore sediment transport in the y-direction as

$$\frac{q}{\sqrt{gd_B}d}=\begin{cases}\frac{5\pi}{16}c_o(\frac{\alpha}{f})(\frac{\rho}{\sigma})(\frac{d_B}{D})(\tan\beta\ \sin 2\vartheta_B)(1-R^2F_r^2Y^2)YU(Y) & \text{for } 0\leq Y\leq 1\\ \frac{5\pi}{16}c_o(\frac{\alpha}{f})(\frac{\rho}{\sigma})(\frac{d_B}{D})(\tan\beta\ \sin 2\vartheta_B(1-\frac{R^2F_r^2}{Y}) & \text{for } 1\leq Y<\infty\end{cases} \quad (6)$$

in which $U(Y) = u/u_B$ where u_B is the velocity of longshore currents at the breaker line, $\tan\beta$ is the average slope of the sea bottom, and R and F_r are

$$\left.\begin{aligned}R&=\frac{1}{2}(\frac{H_B}{H_o})(\frac{L_B}{L_o})(\frac{H_o}{H})(\frac{L_o}{L})\\ F_r^2&=16\pi(\frac{d_B}{H_B})^2(\frac{L_od_B}{L_B^2})\frac{(\sigma/\rho-1)d}{fd_B}\tau_c^*\end{aligned}\right\} \quad (7)$$

The theoretical distribution of longshore sediment transport across the surf-zone in the dimensionless form given by Eq. (6) is shown as a

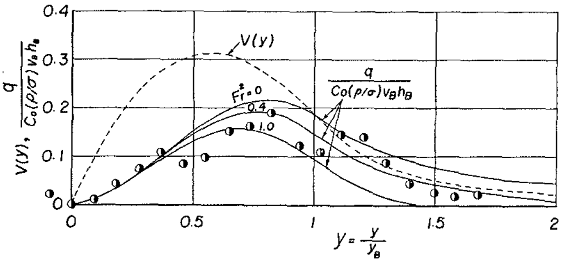


Fig. 1 Offshore distributions of the rate of longshore sediment transport and longshore current velocity

function of Y in Fig. 1 for a comparison with the experimental data obtained by the authors(1978), as well as with the velocity distribution of longshore currents. In the figure, the constant value of P is assumed to be 0.2 for the theory of longshore currents. Favorable agreement for the offshore distribution of longshore sediment transport is seen between the theoretical curves and experimental values. After integrating Eq. (6) with respect to Y over the domain of sand drift between the critical water depth for null sediment mevement and the shoreline(neglecting the so-called swash transport) the total rate of longshore sediment transport Q_x is given by

$$Q_x=C(\frac{\rho}{\sigma})\ I(R,F_r)\,d_B^2\sqrt{gd_B}\sin 2\vartheta_B \quad (8)$$

in which

$$\left.\begin{aligned}C&=\frac{5\pi}{16}\frac{c_o\alpha}{f}\\ I(R,F_r)&=a_o-b_oF_r^2-d_0(RF_r)^{\alpha_o}+e_o(RF_r)^2\end{aligned}\right\} \quad (9)$$

Here a_o = 0.298, b_o =0.124, d_o= 0.373, e_o =0.207 and α_0 = 1.11 when P =

0.2.

The function of $I(R, F_r)$ is shown in Fig. 2. In field coasts, the value of F_r is normally very small, because the parameter F_r includes the ratio of sediment size to wave length. Therefore, the value of $I(R, F_r)$ becomes nearly constant, say 0.3. Then the total rate of long-

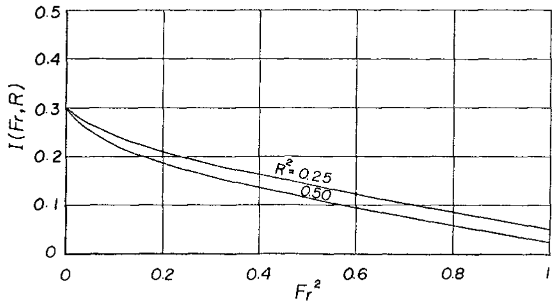


Fig. 2 Change in $I(R, F_r)$ with the parameter R and F_r

shore sediment transport is directly proportional to the longshore component of wave power. This is consistent with the usual empirical relationship for the total rate of longshore sediment transport which

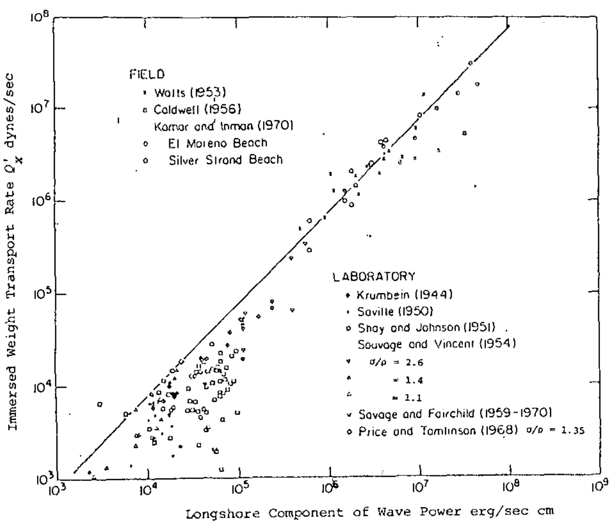


Fig. 3 Data on the immersed-weight sand transport rate as a function of the longshore component of wave power (Komer and Inman, 1970)

was derived by wave power approach. But, in laboratory experiment, the value of $I(R, F_r)$ is more smaller than that in field coasts. The value depends on characteristics of waves and sediment. It has been pointed out that the usual empirical relationship is not applicable for laboratory data of the total rate of longshore sediment transport, so that the data are plotted below the relationship. For example, Fig. 3 which was prepared by Komer and Inman(1970), shows a relationship between the immersed-weight sand transport rate and longshore component of wave power in which the laboratory data are shown below the relationship for the field data.

METHODOLOGY FOR BEACH EROSION CONTROL

Now, consider how to control beach erosion from the viewpoint of controlling the total rate of longshore sediment transport. As explained in Eq. (8), the total rate of longshore sediment transport is expressed by

$$Q_x = C' d_B^2 \sqrt{g d_B} \sin 2\theta_B \tag{10}$$

in which C' is a constant. The total rate of longshore sediment transport is expressed in terms of the breaker depth or breaker height, incident angle of the breaker and some other parameters included in the constant C' in Eq. (10). This formulation indicates that as already explained the total rate of longshore sediment transport is directly proportional to the longshore component of wave power.

An idea of controlling the total rate of longshore sediment transport can therefore be proposed for the conditions of changes in coastal sediment sources. For the conditions of decrease in coastal sediment sources the total rate of longshore sediment transport must be reduced in the given conditions. To reduce the total rate of longshore sediment transport the longshore component of wave power must be decreased effectively along the coast. To reduce the total rate of longshore sediment transport, in other words, two ways would be applicable from Eq. (10) for more practical purposes. The first is to reduce the breaker depth by changing the bottom topography to decrease the total rate of longshore sediment transport. And the second is to reduce the incident angle of breakers by changing either the bottom topography or the inclination of the shoreline to the incidence of predominant waves.

Table 1 A classification of beach erosion control

Method	Practical Works
To reduce the breaker height	To change the bottom topography Offshore beach nourishment Sand groin etc. To construct structures Submerged breakwater Floating breakwater Offshore breakwater etc.
To reduce the incident angle of breakers	Headland control Offshore breakwater etc.

A classification of beach erosion control is shown in Table 1. For controlling the breaker height or breaker depth, there are two ways such as to change the bottom topography and to construct structures. The former is offshore beach nourishment and sand groin, and the latter submerged, floating and offshore breakwaters. For controlling the incident angle of breakers, on the other hand, there are two ways such as headland control and offshore breakwater.

An example of wave reflection coefficients of wave absorbers and natural beaches is shown in Fig. 4, in which K_r is the reflection coef-

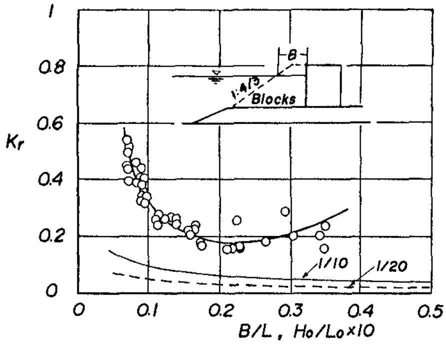


Fig. 4 Wave reflection coefficients of wave absorbers and natural beaches

ficient, B/L the ratio of the width of absorber to wave length, H_0/L_0 the wave steepness at deep water limit, the thick solid curve indicates experimental values of reflection coefficient of wave absorbers with concrete blocks(Tanimoto, Kitatani and Osato, 1979), and the other two thin solid curves are those of sloping beaches of 1/10 and 1/20 respectively. It is well-known that the efficiency of natural sandy beaches in wave energy dissipation is very higher than other wave absorbers, and is nearly independent of wave periods. To reduce offshore sediment transport, emphasis is placed on the reduction of occurrence of reflected waves in considering how to control beach erosion.

From the viewpoint of controlling the total rate of longshore sediment transport, a possible method can be expected for application to practical beach erosion control. In this case, attention should be made in selecting suitable methods of beach erosion control by which be formed stable sandy beaches having the lowest coefficient of wave reflection to reduce the offshore sediment transport by reflected waves most effectively. From the viewpoint of applicability, the second one of the proposed methods would be more applicable for beach erosion control, because the inclination of shoreline can be changed easily by construction of artificial headlands or offshore breakwaters. Especially natural-like sandy beaches will be formed between headlands if necessary conditions for their formation are satisfied.

IDEAL EXAMPLES OF BEACH EROSION CONTROL

Two typical, but ideal examples can be explained for beach erosion by this methodology. The first is for beach erosion due to the decrease in sediment sources such as recent beach erosion near river mouths which has recently been remarkable in many countries of the world, especially in Japan(Tsuchiya, 1980). Surppose that a river is running into the sea as shown in Fig. 5, and the predominant waves are coming from the

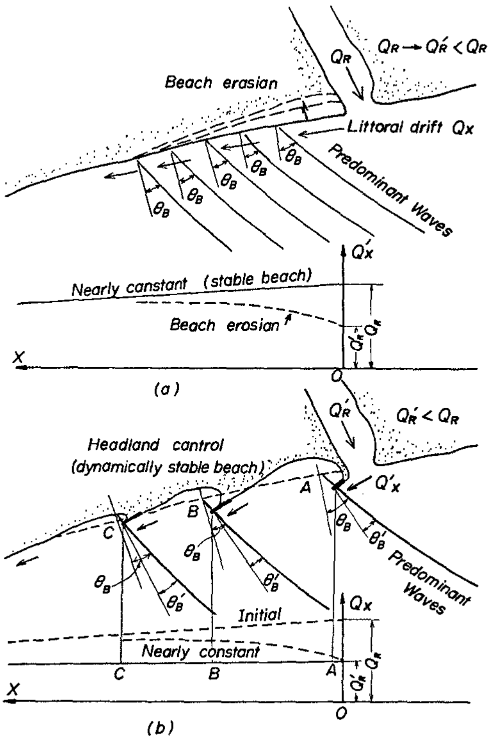
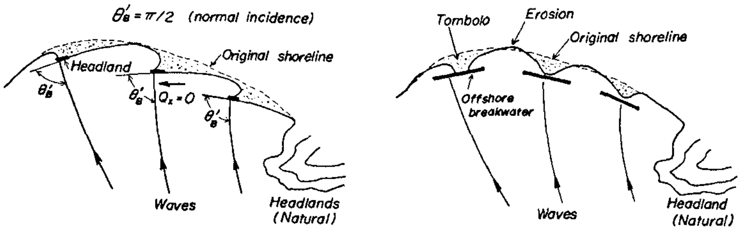


Fig. 5 Beach erosion control for the decrease in sediment input from a river

direction of which the incident angle is θ_B, producing the total rate of longshore sediment transport Q_x. The sediment input from the river was Q_R, but has recently been reduced Q_R'. Beach erosion has therefore advanced on the coast downstream of longshore sediment transport, the left-side coast of the river as shown in the figure.

The total rate of longshore sediment transport by the predominant waves can be assumed to be nearly constant so that the decrease in sediment input from the river takes place beach erosion. Consider how to control the beach erosion from the viewpoint of controlling the total rate of longshore sediment transport. For this the total sediment transport rate must be reduced along the left side coast, according to the decreased sediment input from the river.

There may be many ideas for this, but a possible solution of them is expected as shown in Fig. 5(b), in which a series of headlands is constructed at suitable angles and distances to make the total sediment transport rate decrease at the given total rates. This is to reduce the incident angle of the breakers from θ_B to θ_B' as shown in the figure. It may then be expected that a series of dynamically stable beaches(Silvester, Tsuchiya and Shibano, 1980) be finally formed, and they have the lowest coefficients of wave reflection to reduce the offshore sediment transport most effectively.



(a) Headlands (b) Offshore breakwaters

Fig. 6 Beach erosion control for the lack of sediment sources

The second example is for beach erosion due to the lack of sediment sources by reclamation of river mouth areas or by construction of large coastal structures. A solution for such beach erosion can be proposed by this methodology as shown in Fig. 6, in which a series of headlands (Silvester, 1976) or offshore breakwaters(Detached breakwaters, Toyoshima, 1974) is employed to make the total rate of longshore sediment transport vanish. By construction of such a series of headlands or offshore breakwaters, statically stable beaches(Silvester, Tsuchiya and Shibano, 1980) be finally formed between them.

CONCLUSION

Based on the formulation of the total rate of longshore sediment transport, an ideal methodology of beach erosion control has be proposed, and two typical, but ieal examples have been shown for controlling beach erosion due to the decrease or lack of sediment sources.

I must hereby remember the following two concepts;
"Water shall not be compelled by any fortse(force), or it will return that fortse onto you" which was introduced by Professor Per Brunn

(1972) in his theme lecture at the 13th Coastal Engineering Conference, and

"How to copy nature" which was emphasized by Professor Richard Silvester(1979) in his special lecture at the 1978-Annual Meeting of the Disaster Prevention Research Institute, Kyoto University.

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