CHAPTER 187

LONG PERIOD WAVE AND SUSPENDED SAND TRANSPORT IN THE SURF ZONE

Tomoya Shibayama[1], Akio Okayasu[2] and Mikio Kashiwagi[2]

Abstract

The effect of long period wave to local sand transport rate in the surf zone is analyzed by laboratory and numerical experiments. In the laboratory experiment, surface profile, near-bottom velocity and suspended sand concentration are measured simultaneously and resultant net sand transport rate is measured by mass difference during the experimental runs. It appears that the net sand transport rate is determined by three driving forces which are undertow, long wave and short wave. In mild slope condition, the effect of long wave becomes large. In order to simulate this process, a new numerical model is formulated.

1. Introduction

When irregular waves travel to the shoreline, the long wave component of velocity becomes an important consideration in determining sand transport in the surf zone where sands are transported by both wave motion and turbulence due to wave breaking. For beach deformation process in field, Katoh and Yanagishima (1990) explained the erosion process of berm by the long wave effect. Irregular wave motion consists of a variety of wave periods from long wave to short wave. In this study, the role of long wave to local sediment transport rate is analyzed by laboratory experiments. Investigations are mainly

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[1] Associate Professor, Department of Civil Engineering, Yokohama National University, Hodogaya-ku, Yokohama 240, Japan

[2] Research Associate, Yokohama National University

[2] Graduate Student, Yokohama National University

focused on sands which are suspended by vortex motion and transported under the influence of long wave velocity. The major difference from the work by Shibayama *et al.* (1991) is that suspended sand flux is considered to be the main factor to control the effect of long wave to total transport rate in this study. In the previous work (Shibayama *et al.* , 1991), near bottom velocity and net sand transport were measured. In their analysis, bed load formula was used to simulate the process and there was no discussion on suspended sand transport because they did not measure the suspended sand concentration.

Shibayama *et al.* (1991) performed numerical simulation to estimate net sand transport rate when near-bottom velocity is given. Their analysis was based on the regular wave analysis of sediment transport rate formula proposed by Shibayama and Horikawa (1985) (also Shibayama and Irie, 1987). In their analysis, it was not possible to include suspended sand movement which is suspended more than one wave cycle. In the present analysis, suspended sand movement will be more directly included in the model.

2. Laboratory Experiment

Laboratory experiments were performed with the use of a wave flume which is 17 m long, 0.5 m wide, and 0.55 m deep. Uniform slopes of 1/40 (series A) and 1/20 (series B) were set at the bottom. Figure 1 shows the view of set-up. In the shallow water area, an inspection area of 3 m long and 0.5 m wide was installed where sorted sands of 0.2 mm in diameter were laid. Two inspection sections were set at the inspection area in order to compare the effect of long wave in different depth. An ultra-sonic velocimeter, optical type concentration meter and capacitance wave gage were positioned at the center of the inspection sections. Within the area, a tray was set in order to measure net sand transport rate. The tray was divided into three sections: the onshore, middle and offshore part. By measuring the change of sand mass in each section before and after the experiment, the net sand transport rate in cross-shore direction was obtained for two inspection sections. Table 1 show the conditions of waves which were used in the experiments.

Spectrum analysis was performed from the velocity history measured by the ultra-sonic velocimeter. From the calculated spectra of velocity history, it was determined that long wave component, short wave component and turbulence component had to be separated by frequencies of 0.25 Hz and 5 Hz. The velocity history and concentration time history were then divided into four components: steady flow, long wave, short wave and turbulence with the use of a band passing filter. Fig. 2 shows an example of separation of near-bottom velocity. In the figure, original time history, long wave component, short wave

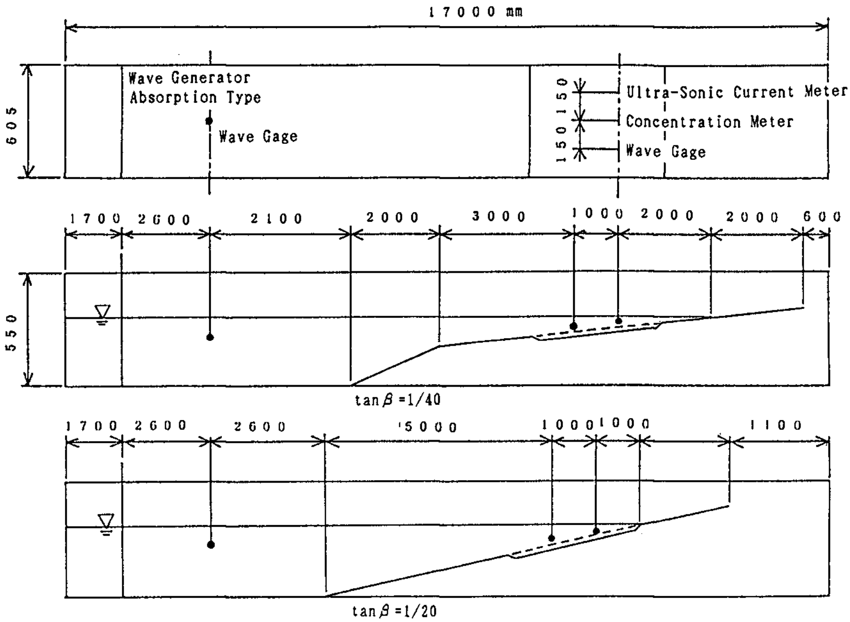

Figure 1: Experimental set-up.

Table 1: Experimental conditions.

Case	Sand Diameter	Constant Depth	Slope	Significant Wave		Mean Wave	
	d_{50} (mm)	h (cm)	$\tan\beta$	$H_{1/3}$ (cm)	$T_{1/3}$ (s)	$\overline{H}$ (cm)	$\overline{T}$ (s)
A – 1				8.2	1.0	5.3	0.9
2				4.9	0.8	3.9	0.7
3				6.9	0.9	4.5	0.8
4				10.0	1.0	6.6	0.9
5			1/40	9.5	1.2	6.1	1.0
6				6.6	1.2	4.2	1.0
7				10.7	1.3	7.0	1.2
8	0.18	35.0		8.9	1.3	5.7	1.1
B – 1				8.1	1.0	5.3	0.9
2				5.2	0.9	3.3	0.8
3				8.1	1.0	5.3	0.9
4				6.6	1.0	4.2	0.9
5			1/20	9.5	1.2	6.1	1.0
6				4.8	1.4	2.9	1.0
7				10.6	1.3	6.8	1.1
8				6.8	1.3	4.4	1.2

Bredschneider-Mitsuyasu Type Spectrum

and turbulence are shown. Figure 3 shows an example of the time histories of surface profile, near-bottom velocity and suspended sand concentration. Long wave components are also shown in the figure. Amplitude and period of each wave were also defined for both long wave and short wave by using the zero-down-crossing method.

The effect of long waves to local sediment transport rate were analyzed by comparing the following quantities: steady current, long wave velocity, short wave velocity, long wave concentration of suspended sand concentration, short wave concentration, and the net sand transport rate.

3. Results of experiment

From the above experiment, we tried to explain the net sand transport rate by using long wave and short wave component of the near- bottom velocity. This is the same way which was done by Shibayama et al. (1991). Figure 4 shows the result for the cases of which bottom slope was 1/40. From the figure, we can conclude that the larger long wave component causes the larger net sand transport even if the significant values for short wave take almost the same values. For the slope 1/20, the effect of undertow is large and therefore we judged that it is better to analyze the cases for the slope 1/40 to elucidate the effect of long wave.

Figure 5 shows the relationship between the amplitude ratio of long wave velocity to short wave velocity and the net sand transport rate for the slope of 1/40. From the figure, it can be concluded that the ratio has become larger, the net sediment transport rate has increased. In this case, the net transport direction is onshore. During the experiment, when a short wave crest comes over trough of long wave, high concentration area was frequently observed with certain phase lag. This high concentration area is transported to onshore and finally results in net sand transport in onshore direction.

Then we have tried to explain sand transport direction by using the long wave component of velocity and long wave component of suspended sand concentration. Our explanation can further be illustrated in Figure 6. If it is possible to assume that the time history of these two quantities are sinusoidal, $-\frac{\pi}{2}$ to $\frac{\pi}{2}$ of the phase shift between results to onshore sand transport. If it is greater than $\frac{\pi}{2}$, the flux becomes lesser than zero and results to offshore transport. This relationship is clearly defined in Figure 6 which shows the results of the experiments. There are 32 results in total and in 22 cases, the direction of calculated suspended sand flux and the direction of net sand transport agree. It can therefore be concluded that the transport direction can be explained by the suspended sand flux for these experimental cases.

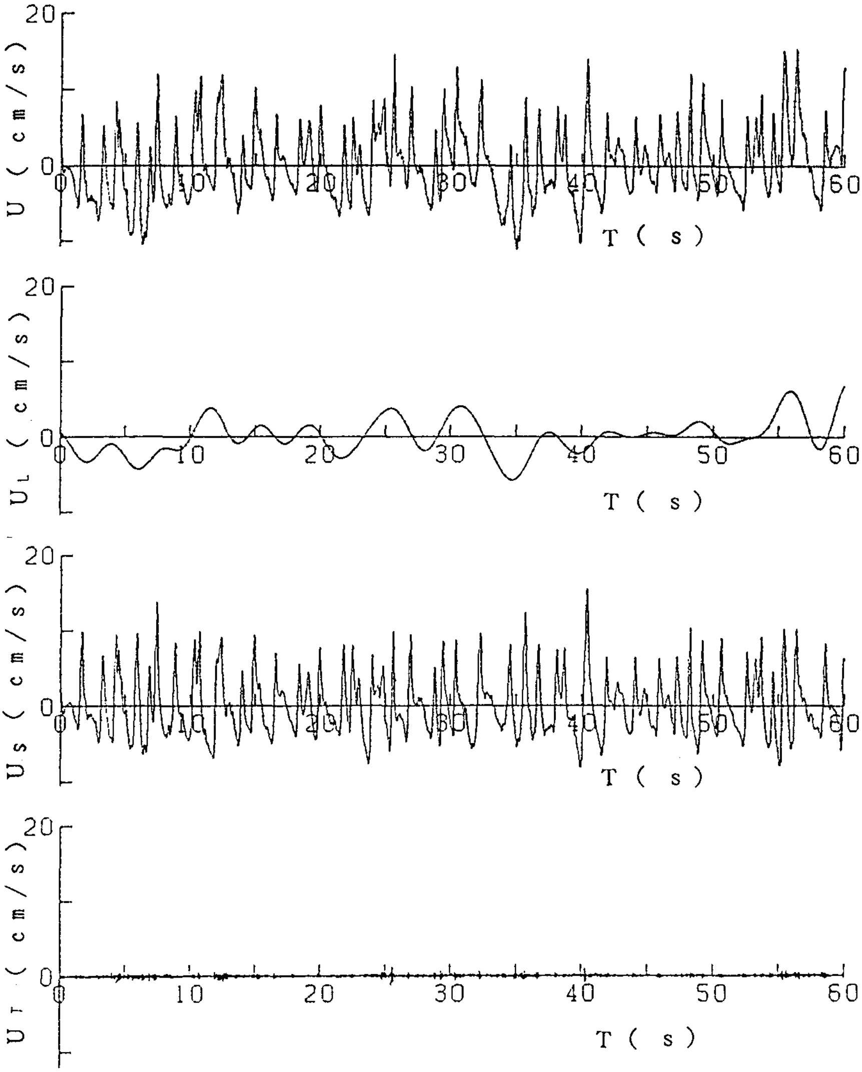

Figure 2: Example of separation.

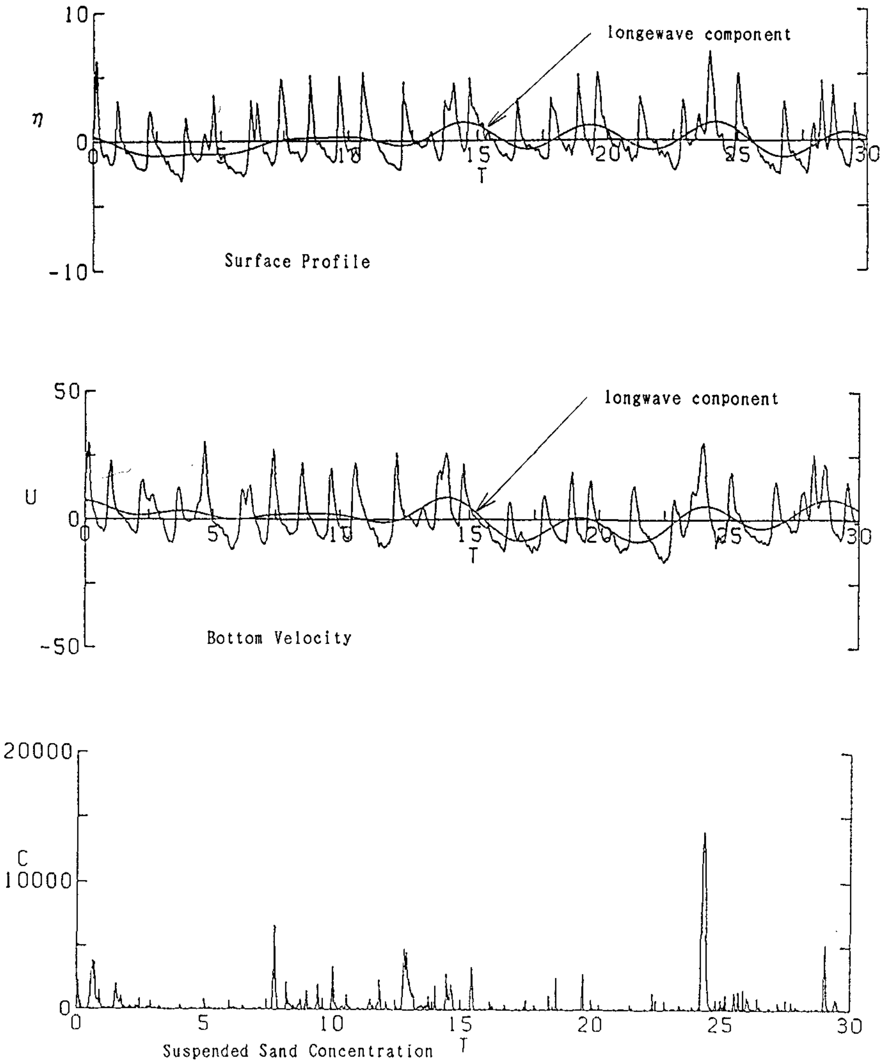

Figure 3: Example of time history.

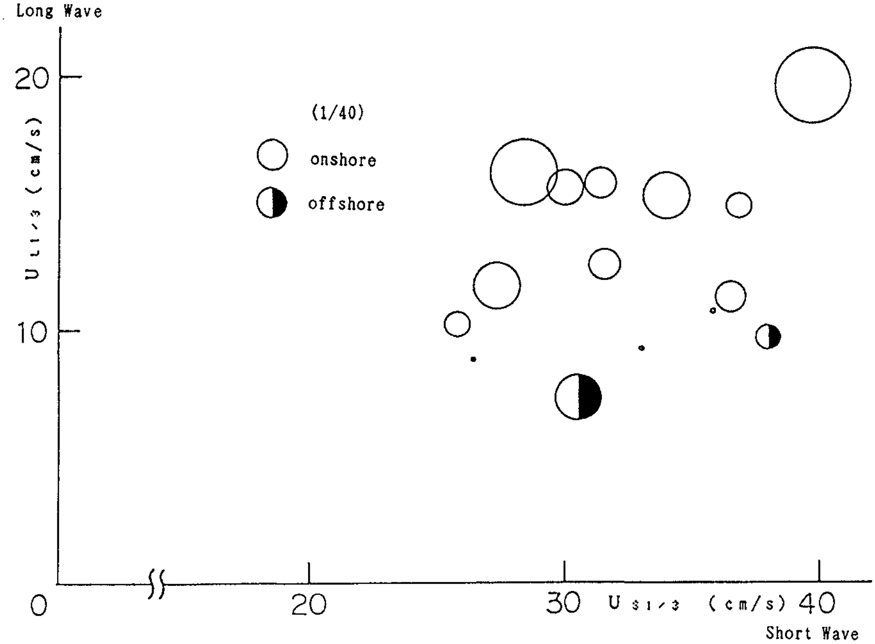

Figure 4: Effect of short wave and long wave to net sand transport rate.

4. Numerical simulation

A numerical model is formulated to examine the movement of suspended sand and the resultant net sand transport rate. From the observation, it is noticed that whether suspended sand in the vicinity of sand ripples are confined in the vortex area or not is a very important point to determine the suspended sand transport direction. Therefore it was tried to distinguish these two processes, confined or not, by using the ratio of the diameter of water particle excursion distance to ripple wave length. This value was used by Shibayama and Horikawa (1985) and the critical value of the ratio was 3. If the ratio is greater than 3, the suspended sand is not confined in vortex and transported to the same direction with flow. If the ration is smaller than 3, the suspended sand is confined in vortex area, and transported after flow direction changes. Figure 7 shows the schematic view of the difference of these two patterns.

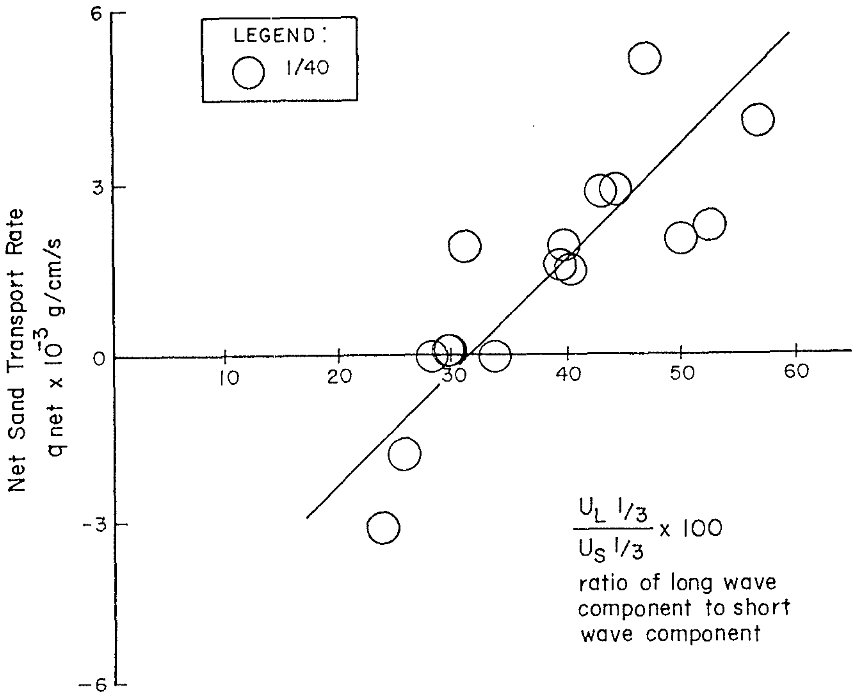

Figure 5: The ratio of long wave component of velocity to short wave component and net sand transport rate.

For the case of suspended sand confined in the vortex area, the model of Nielsen (1988) was used (Sato *et al.* , 1991). The transport rate is given by the following formula,

$$Q = \alpha_b w_s D(\Psi - \Psi_c)u/\sqrt{sgD} \tag{1}$$

where α_b is 0.2, w is fall velocity, D is sand diameter, Ψ is shields parameter, Ψ_c is critical value for initiation of the movement, u is bottom velocity and s is specific gravity of sand particle. The transport rate is integrated in time for half wave period and will be confined one ripple area and then is transported when flow direction changes. When the ratio is greater than three, suspended sand will not confined in the vortex and Eq. (1) is directly used for transport process.

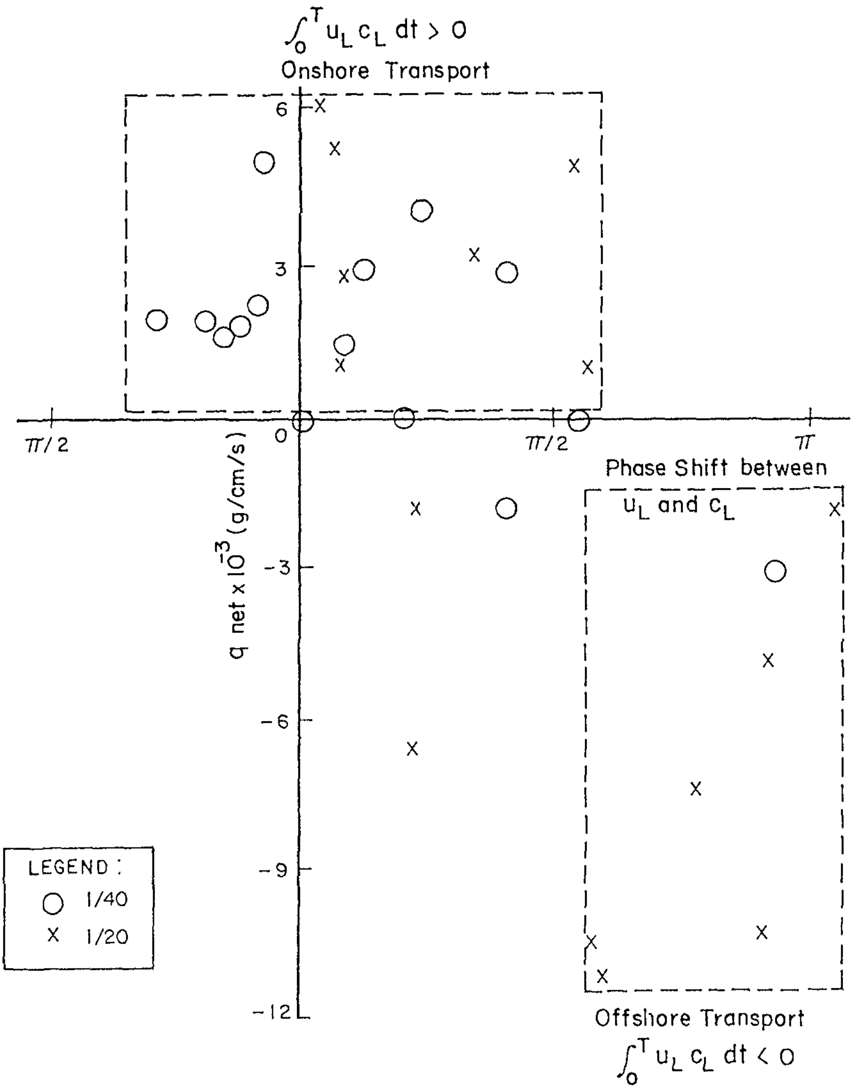

Figure 6: Phase shifts between long wave component of velocity and concentration and their effects to the net transport rate.

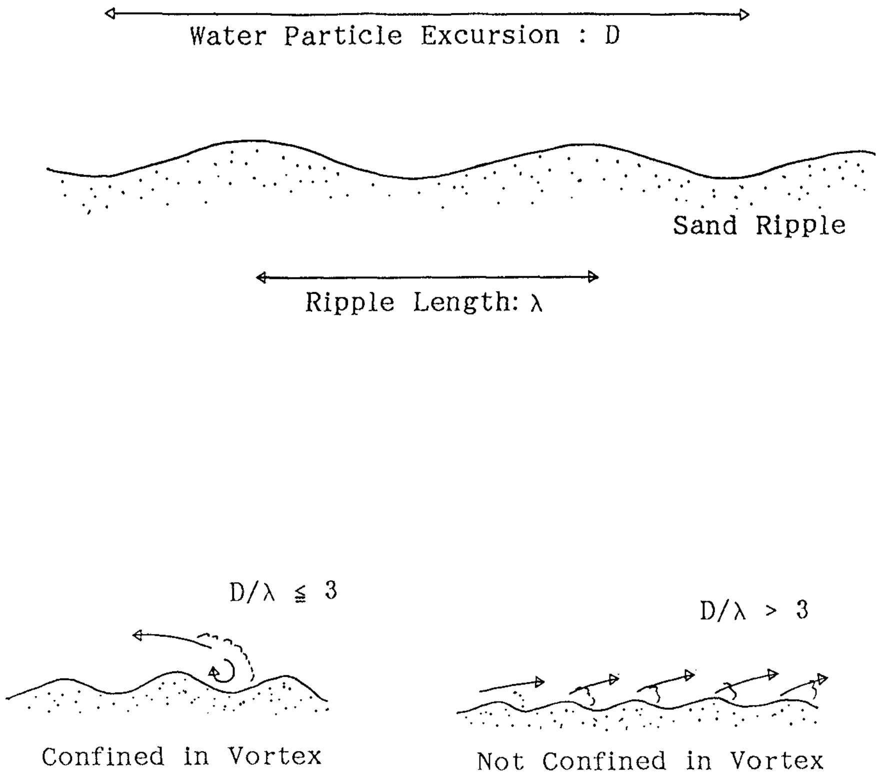

Figure 7: Explanation of sand movement.

Table 2: Results of numerical simulation.

SLOPE 1/40

CASE	DEPTH:7.5cm		DEPTH:5cm	
	CALCULATION	MEASUREMENT	CALCULATION	MEASUREMENT
A 1			$2.904*10^{-3}$	$9.044*10^{-3}$
A 2	$-3.104*10^{-3}$	$-3.033*10^{-2}$	$-0.042*10^{-3}$	$-2.704*10^{-1}$
A 3	$-0.046*10^{-3}$	$-8.193*10^{-2}$	$1.677*10^{-3}$	$-9.806*10^{-4}$
A 4	$0.039*10^{-3}$	$-1.140*10^{-2}$	$2.040*10^{-3}$	$1.602*10^{-2}$
A 5	$1.902*10^{-3}$	$2.135*10^{-2}$	$2.317*10^{-3}$	$8.135*10^{-4}$
A 6	$-1.821*10^{-3}$	$-3.734*10^{-3}$	$1.940*10^{-3}$	$3.250*10^{-5}$
A 7	$5.132*10^{-3}$	$8.425*10^{-3}$	$4.137*10^{-3}$	$.1.421*10^{-3}$
A 8	$1.518*10^{-3}$	$2.130*10^{-3}$	$2.973*10^{-3}$	$1.581*10^{-3}$

UNIT(g/cm/s)

For sand deposition process, one-dimensional diffusion equation is used to evaluate the deposition and diffusion process. It is

$$\frac{\partial c}{\partial t} = \varepsilon \frac{\partial^2 c}{\partial z^2} + w_s \frac{\partial c}{\partial z}. \tag{2}$$

The diffusion coefficient ε is given by the following formula (Nielsen, 1988),

$$\varepsilon = w_s \eta \left\{ 1.24 \exp[-40(w_s/u_b)^2] + 0.2 \right\} \tag{3}$$

Table 2 shows the comparison between present calculation and measured net sand transport rate. The general tendency of the predictions agrees with the laboratory results but we still have discrepancy. This may be due to the effect of bed load which is not included in the present model.

5. Conclusions

By laboratory experiments, it was confirmed that long wave component of velocity and suspended sand concentration has an important effect on local sediment transport rate particularly in the vicinity of shoreline areas where the long wave component is large. In these areas, the relationship between the long wave component and the net sediment transport rate can be empirically obtained. It is possible to explain the direction of net sand transport from the product of long wave component of velocity and long wave component of suspended sand concentration. From numerical experiment, we can say that if movement of suspended sand is correctly estimated, then sand transport rate is correctly evaluated.

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