CHAPTER 238

Experimental Study on Sediment Transport in Surf and Swash Zones Using Large Wave Flume

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Abstract

In the present study, experiments were conducted using CRIEPI's Large Wave Flume (205m long, 3.4m wide and 6m deep) to investigate cross-shore hydrodynamics, sediment transport and beach change processes. On the experiments, suspended sediment transport in the surf and swash zones was directly measured under the condition of random waves. Moreover, the long wave effect to sediment transport was also investigated.

Introduction

Suspended sediment transport rate must be evaluated accurately to predict beach change, especially in a calm basin behind an artificial island, because suspended sediment in a surf zone is transported into the calm basin by circulating nearshore current. Recently, it was mentioned that low frequency component in a wave group influences remarkably suspended sediment transport(Sato et al.;1993). Sediment transport rate in a swash zone has to be estimated correctly to expect shoreline change, because erosion and accretion in a swash zone causes shoreline change directly. Ogawa et al.(1981) and Katori(1983) observed sediment transport in a swash zone by using sand traps.

In this study, large scale experiments on beach profile changes due to irregular waves were performed in the Large Wave Flume. Suspended sediment transport and sediment transport rate in a swash zone were measured directly. Effects of irregularity of waves on a sediment transport and influences of low frequency component in a wave group were discussed.

Experimental method

Uniform slopes of sand were piled up in the Large Wave Flume(Kajima et al; 1982) as shown in Fig.1. The bottom of offshore side 90m length of the flume is 1/15 slope. Horizontal coordinate X was defined as an seaward distance from the onshore side end of the flume. An origin of a vertical coordinate Z was defined on a still water level. Still water depth was 4m in cases of 1/10 and 1/20 slope of sand and 3.2m in a case of 1/50 slope of sand. A toe of the sand slope of 1/50 was cut

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off by a 1/10 slope, because the still water level can't be smaller than 3.2m for wave generating and the sand volume was limited.

A measuring vehicle that runs on the flume onshore-offshore was used for measurement in a surf zone. The measuring vehicle is equipped with a capacitance type wave gauge(W) and an installing arm going up and down just beside each other. Two sets of an electromagnetic current meter(C), an optical turbidity meter(T) and a pumping tube(P) for water sampling were assembled to the installing arm. Vertical distance between two sets is 40cm. Water sample including suspended sediment was sucked up by an engine pump, and a volume of sampled water was measured by a water counter. Between the pump and the counter, the suspended sediment was filtered out by a 97μ mesh plankton net and weighed. Median diameter of the sand was 1mm, and the grain size distributed from 0.2mm to 1.3mm as shown in Figure 2. Output of turbidity meter was calibrated individually by the time averaged sediment concentration based on the water sampling data. A wheel type sand surface profiler was loaded on a trolly dragged by the measuring vehicle. The profiler can trace the beach profile under the still water and in the air continuously, accurately and speedy.

In some cases, sediment transport due to uprush and sediment transport due to downrush of individual waves were measured respectively by sand traps(S) in a swash zone. The sand traps are original hand made with metal frame and 97μ mesh plankton net as shown in Photo 1. A mouth of the trap is 5cm wide and 20cm high. The length of the trap is 1m. Fifty traps were prepared and numbered. Two footings was built up in a swash zone, and sediment transport was trapped by three persons on the footings as shown in Photo 2. Right one of this side in the photo is trapping sediment transport due to downrush pressing the under edge of the mouth of the trap against the sand surface. Right one of back side is taking a trap away from the one of this side and going to stack it in a bucket. Left one is preparing the next trap. Trappings of sediment transport due to uprush were continued for fifty waves, and after the collection of trapped sand, sediment transport due to fifty downrushs were trapped. A trapping of sediment transport due to uprush was started when a front edge of an uprush reached the trapping point, and was finished when the water started to flow down. But if the front edge of the next uprush reached the trapping point before the water started to flow down, the trap was changed quickly to the next trap. A trapping of sediment transport due to downrush

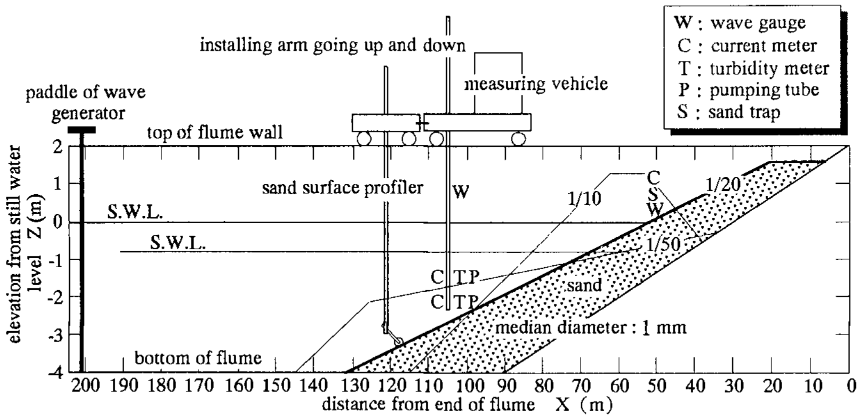

Figure 1. Arrangement of experiments

was started when the water started to flow down, and was finished when the front edge of the next uprush reached the trapping point or the down flow of the water sank into the sand. A wave gauge and a current meter was set up just beside the sand trapping. Bottom end of the wave gauge was stuck in a sand. Head of the current meter was set 1 or 2cm above the sand surface. The wave gauge on the measuring vehicle was set 8m offshore the trapping point. Outputs of wave gauges and a current meter were recorded in a memory of a personal computer and on a chart of linear-corder with trap numbers called by the trapper.

Irregular waves were generated by piston type wave generator. The wave train was repeated every hundred waves. Sampling of outputs of a wave gauge, current meters, turbidity meters and sampling water were continued for one hundred waves at every measuring points in a surf zone. Trappings of sediment transport in a swash zone was performed in the first half of the wave train and in the second half separately. In some cases, the free long wave generated at the paddle of the wave generator was canceled by the method after Ikeno et al.(1996).

Experimental cases and conditions

Table 1 shows experimental cases and conditions. In the case L1, sand slope "tan-β" was 1/20 and regular waves were generated. Offshore wave height "Ho" was 1m and wave period "To" was 5s. In the case L2, irregular waves were generated using JONSWAP spectrum. Significant wave height and significant wave period was same to the case L1. Sharpness parameter "γ" is 1 according to the wind wave condition. Conditions of the case L3 were same to the case L2 except for the sharpness parameter is 7 according to the swell condition. In the case L4, free long wave cancel method was adopted to the condition of the case L2, but the significant wave height had to be reduced to 0.6m because the stroke of the paddle of wave generator is limited up to 2.1m. Conditions of the case L5 were same to the case L3 except for the sand slope and the wave was steeper than the case L3. Condition of the case L6 was same to the case L5 except for the free long wave was canceled. Conditions of the case L7 was same to the case L3 except for the sand slope and the wave was more gentle than the case L3.

Photo 1. Sand trap

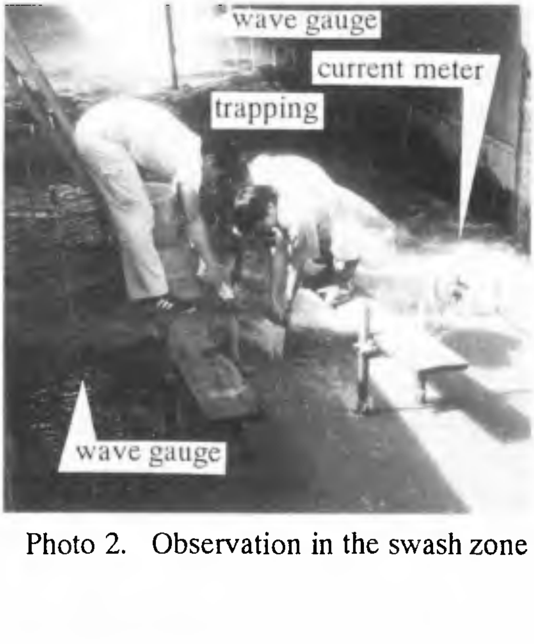

Photo 2. Observation in the swash zone

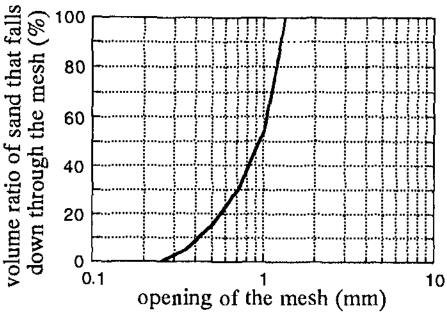

Figure 2. Sand particle diameter distribution

Table 1. Experimental cases and conditions

case	tan β	H_0 (m)	T_0 (s)	γ	wave generation
L1	1/20	1.0 m	5.0 s	r.w.	p.m.
L2	1/20	1.0 m	5.0 s	1	p.m.
L3	1/20	1.0 m	5.0 s	7	p.m.
L4	1/20	0.6 m	5.0 s	1	f.l.w.c.m.
L5	1/10	1.2 m	3.0 s	7	p.m.
L6	1/10	1.2 m	3.0 s	7	f.l.w.c.m.
L7	1/50	0.5 m	8.0 s	7	p.m.

γ : sharpness parameter of JONSWAP spectrum
r.w.: regular wave
p.m.: previous method
f.l.w.c.m.: free long wave cancel method

Experimental results

Figure 3 shows the initial beach profiles of each cases as dotted lines and final profiles as solid lines. Profile changes of the cases L1, L2 and L3 are bar and berm system. Profile change pattern is decided by significant wave characteristics, not by sharpness of spectrum or irregularity. Profile change due to swell is more rapid than due to wind waves of the same significant wave characteristics. Profile changes of the cases L5 and L6 are typical erosional pattern with remarkably developed bar. Profile change in the case L7 is accretional pattern with sediment transport from offshore zone to surf zone.

Figure 4 shows fluctuation of suspended sand concentration "c" due to wave motion near the breaking point in the cases L1 and L6 together with horizontal velocity "u" and water surface elevation " η ". Suspension of sediment due to regular wave motion takes place at the phase when the horizontal velocity changes from onshore to offshore. Sediment is suspended due to irregular wave motion at the phase when horizontal velocity changes not only from onshore to offshore, but also from offshore to onshore.

Figure 5 to 8 show vertical distributions of suspended sediment transport flux in the cases. The graph at the top is cross-shore distribution of significant wave height and beach profiles. The graphs in the second row are vertical distributions of time averaged suspended sediment concentration. The graphs in the third row are vertical distributions of time averaged horizontal velocity. Thc graphs at the bottom is vertical distributions of time averaged product of suspended sediment concentration and horizontal velocity namely suspended sediment transport flux. In the cases L5 and L6, suspended sediment concentrations are higher than the other cases. In the almost cases, suspended sediment transport fluxes near the bottom are directed offshore, even in the accretional case L7.

Figure 9 shows low and high frequency components of suspended sediment transport flux in the cases L5 and L6. In the case L6 where the free long wave is canceled, long wave components of suspended sediment transport fluxes are directed offshore when the sort wave components are directed onshore. In the case L5, the above mentioned property is not clear.

Figure 10 shows synchronized data observed at the point A in a swash zone and at the point B in a surf zone of the case L5. The graph at the top of four is volume of sand par unit width trapped at the point A. Length of right side of each triangle is trapped volume. Left vertex points to the starting moment of trapping. Right

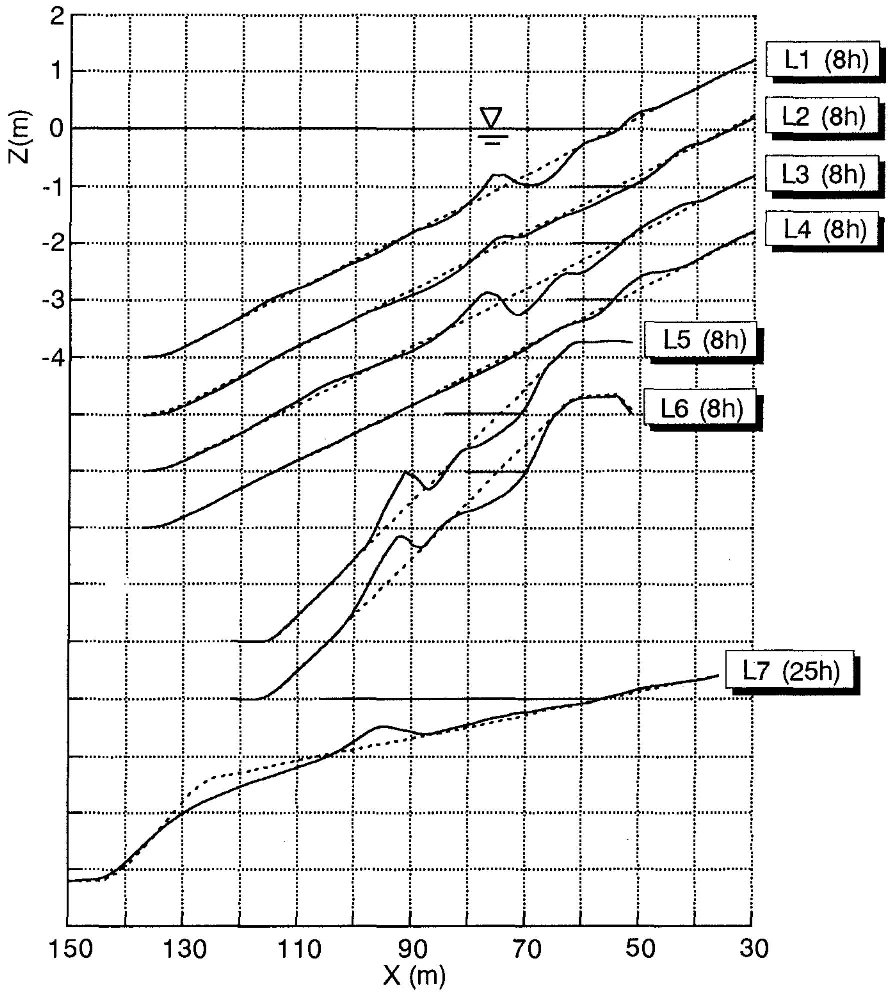

Figure 3. Beach profile change

vertices point to the finishing moment of trapping. For convenience' sake, sediment transport due to uprush and downrush are shown in one graph. The second graph is horizontal velocity 1 or 2cm above the sand surface at the point A. The curve is interrupted in the middle of downrush, because the head of current meter is exposed in the air. The third and the bottom graphs are water surface elevation at the points A and B. The waves corresponding to each other are connected by dotted lines. Number of waves reduces by half propagating from the point A to B. Waves in a swash zone are apt to be grouped and uprush velocity due to the first wave of the group is strong and uprush sediment transport is remarkable under the action of the first wave. Crest level of the last wave of the group in a swash zone is highest and downrush velocity due to the last wave is strong and the downrush sediment transport due to the last wave is striking and drags on.

Table 2 shows the uprush and downrush data of individual waves in a surf zone of the case L5. "H" is crest height measured from the trough just before the crest. "h" is water depth under the trough. "Uu" is horizontal velocity under the crest. Positive data is onshore velocity. Three data are negative, because the bottom velocity remains offshore when the front of the next uprush reached the trapping point. "Qu" is trapped volume of sediment transport due to uprush par unit width. "Ud" is trapped volume of sediment transport due to downrush par unit width. Total volume of Qu is 65.7 litter par meter and total volume of Qd is -84.4 litter par meter. Net volume of sediment transport during one hundred waves is -18.7 litter par meter. It is converted to the net sediment transport rate $-6.2\times10^{-5}m^3/m/s$.

Figure 11 shows sand transport rate counted back from profile change in the case L5. The net sediment transport rate at the trapping point $-6.3\times10^{-5}m^3/m/s$ is read

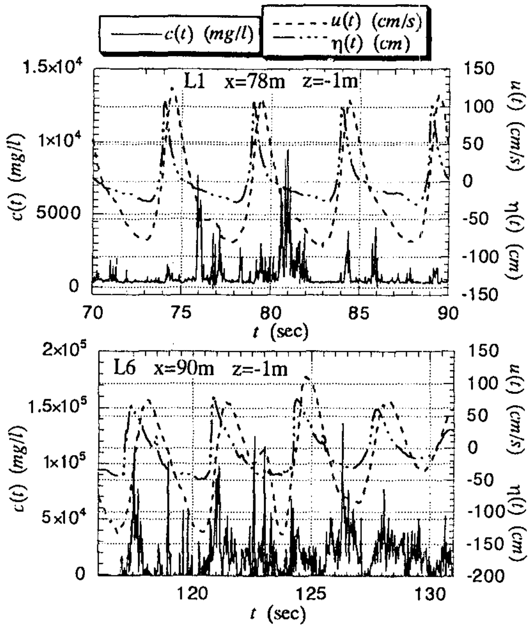

Figure 4. Fluctuation of suspended sand concentration due to wave motion in the case L1 and L6

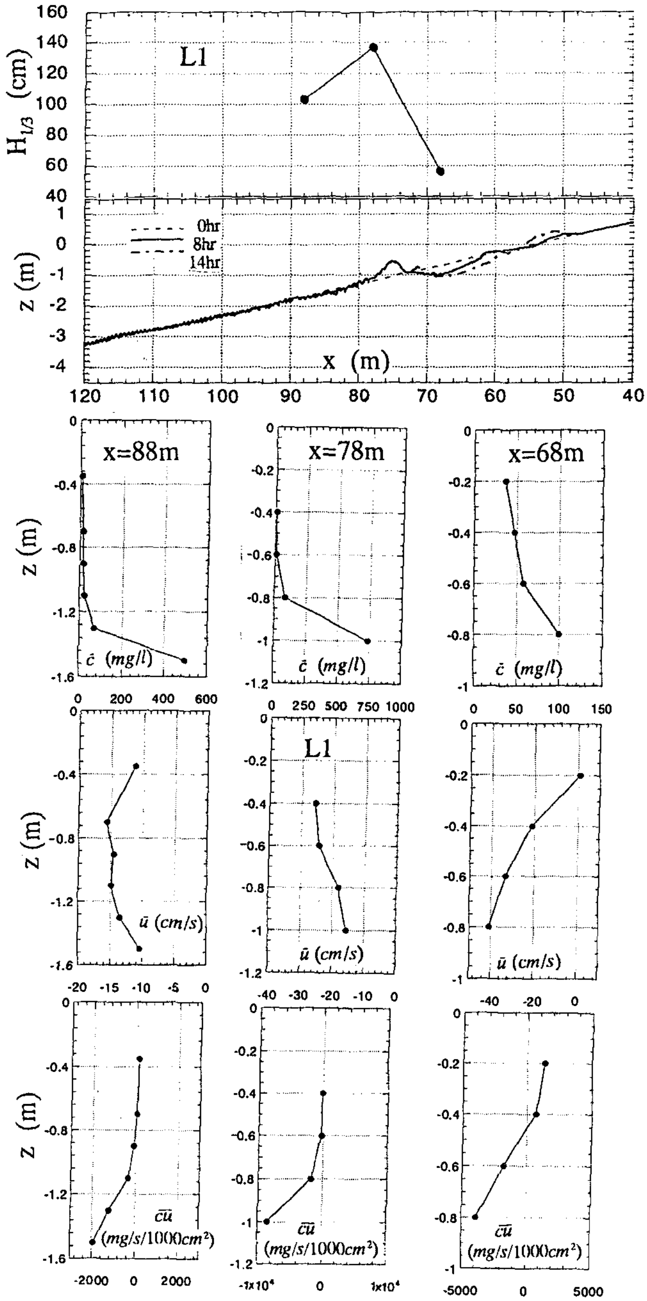

Figure 5. Virtical distribution of suspended sand transport flux in the case L1

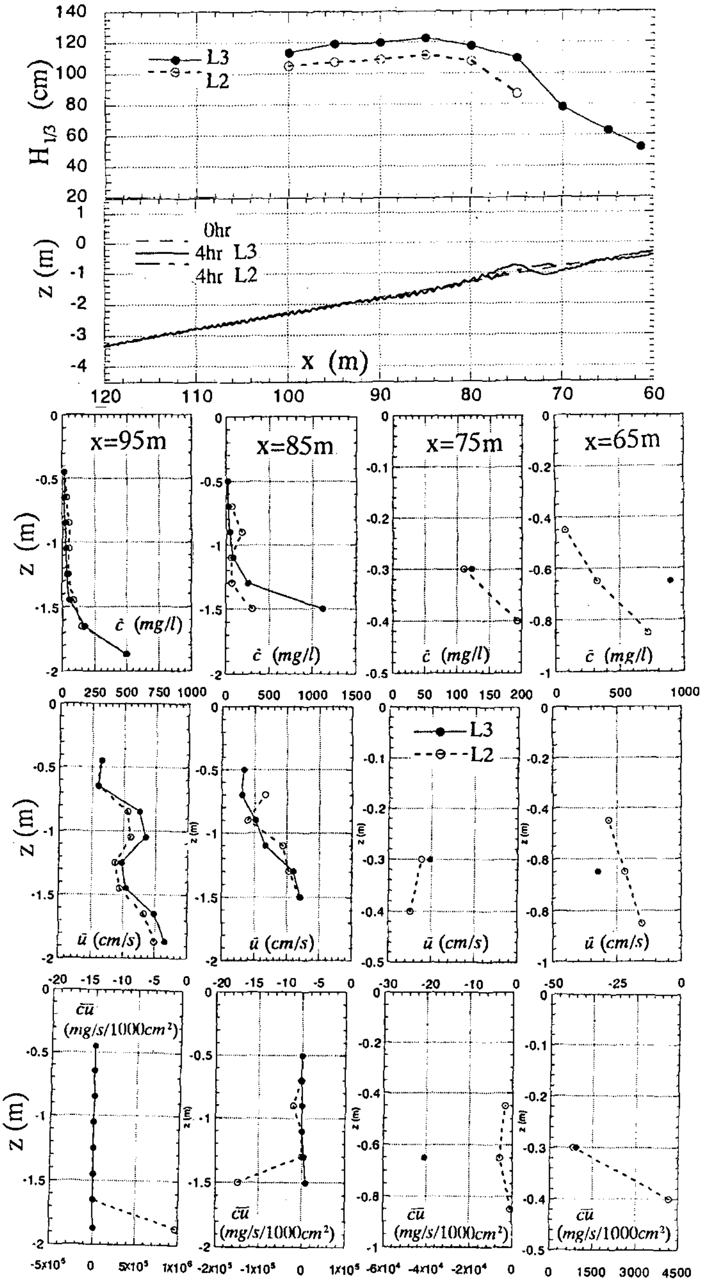

Figure 6. Virtical distribution of suspended sand transport flux in the cases L2 and L3

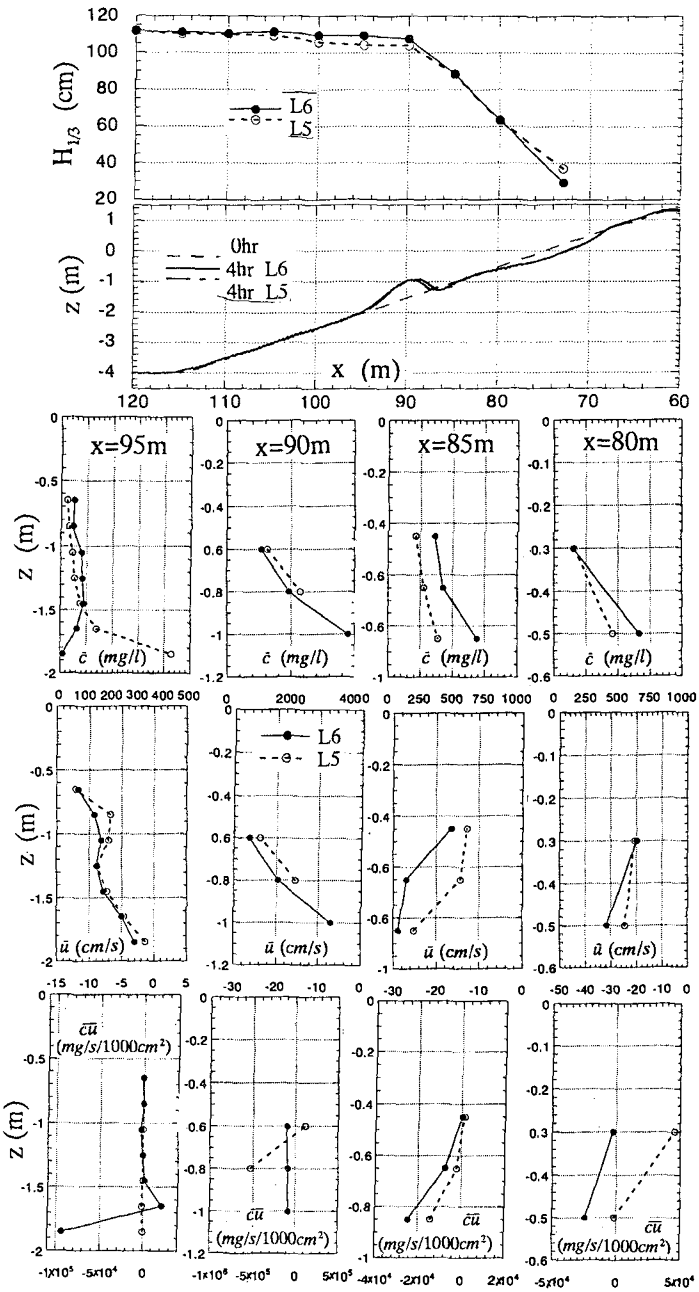

Figure 7. Virtical distribution of suspended sand transport flux in the cases L5 and L6

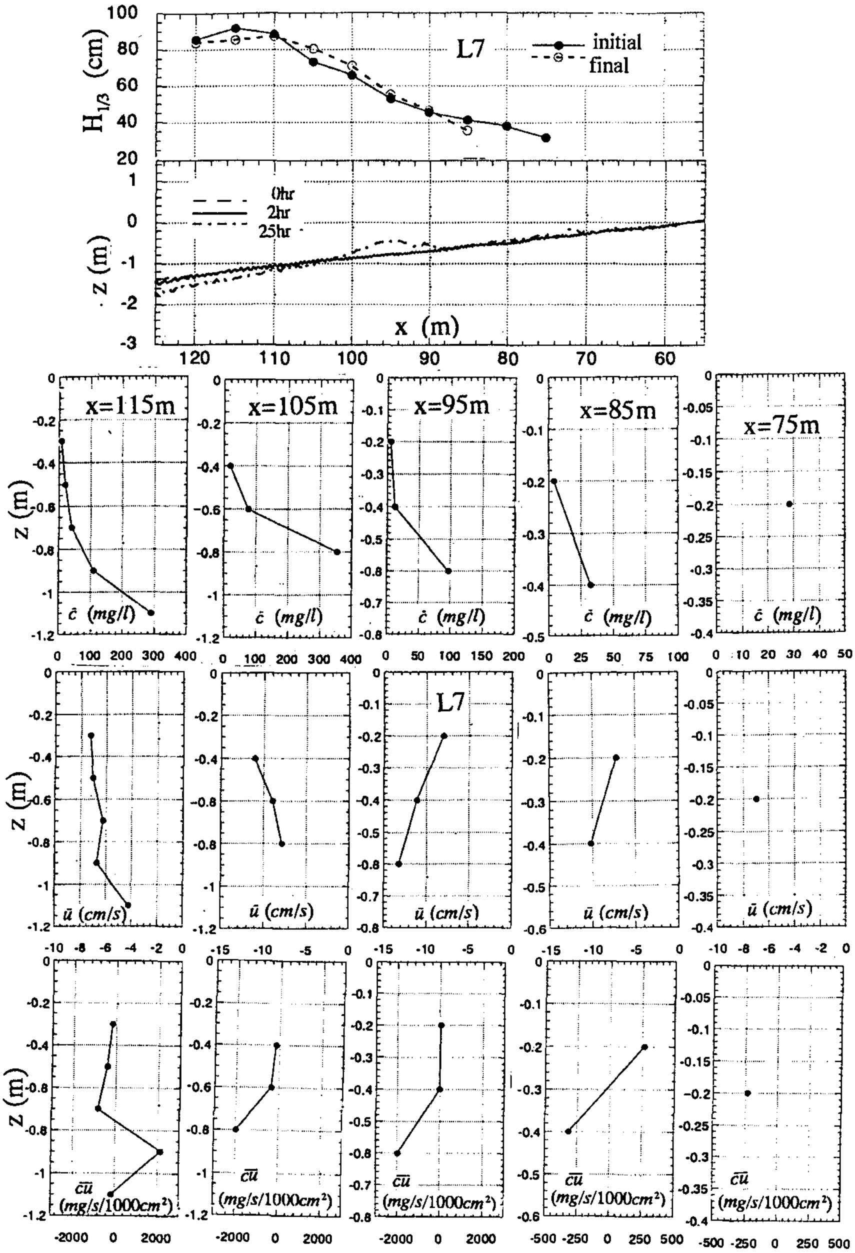

Figure 8. Virtical distribution of suspended sand transport flux in the case L7

from the figure. Good agreement of two independent values indicates high accuracy of the sand trapping method.

Figure 12 shows relationship between nondimensional sediment transport rate Φ' due to individual downrush and nondimensional bottom friction Ψ'. Φ' and Ψ' is defined by the following equations;

$$\Phi' = Q/(wD) \tag{1}$$

$$\Psi' = U^2/(s'gD) \tag{2}$$

where Q is sediment transport rate in the half period of wave, w is settling velocity of sand particle, D is median diameter of sand, U is amplitude of bottom velocity, s' is submerged specific gravity of sand and g is gravity acceleration. Sediment transport rate due to downrush is modeled by following equation;

$$\Phi' = -0.037\,\Psi'^{1.29} \tag{3}$$

Figure 13 shows relationship between nondimensional sediment transport rate Φ'

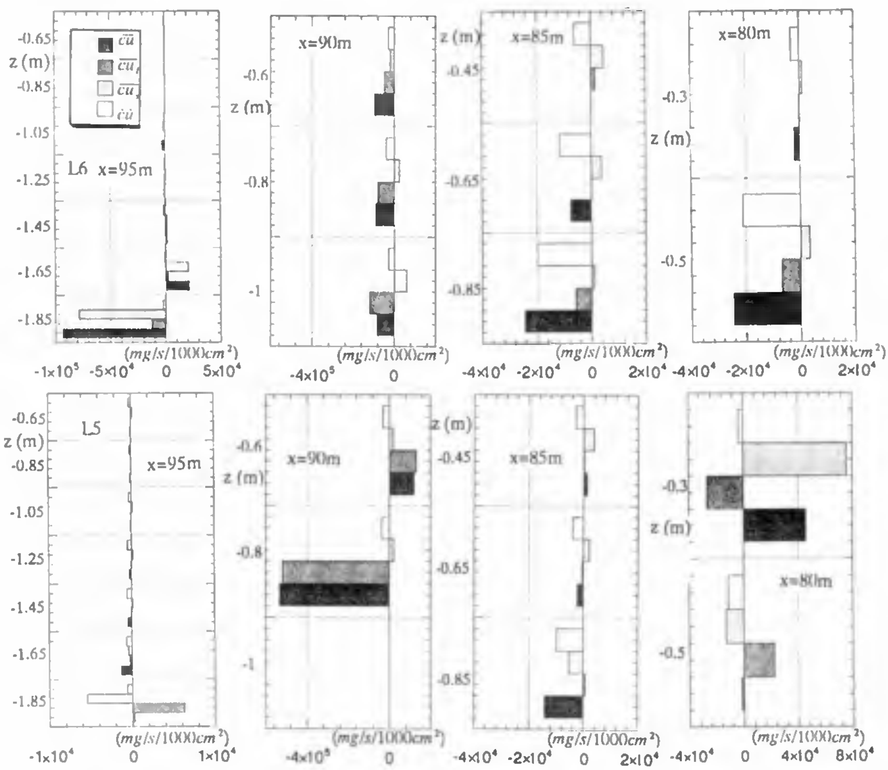

Figure 9. Low and high frequency components of suspended sand transport flux in the case L5 and L6

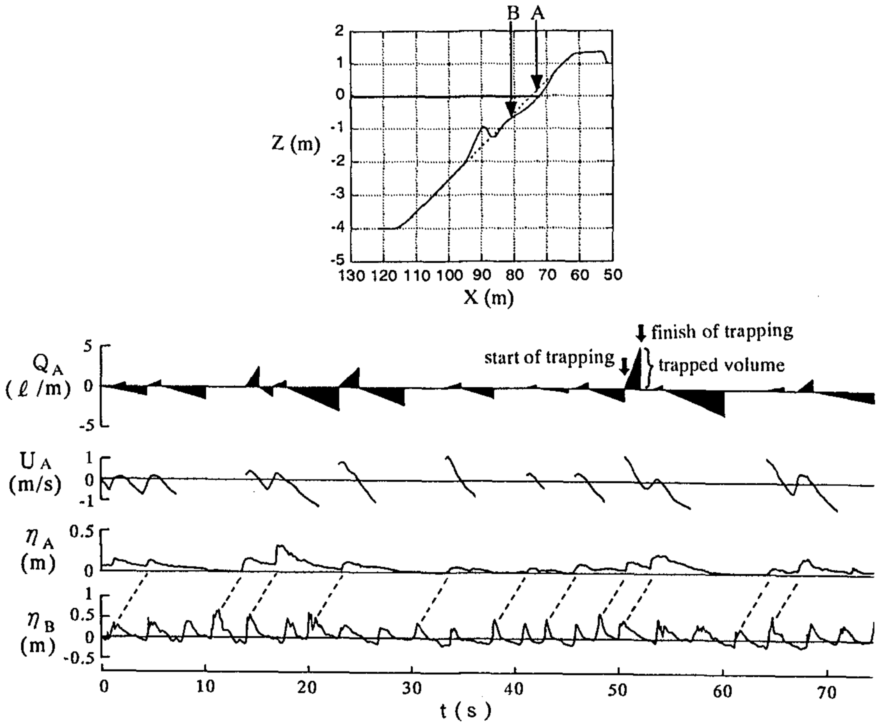

Figure 10. Synchronized data observed in the swash zone and the surf zone

Table 2. Uprush and downrush data of indivisual waves in the swash zone of case L5

H (m)	h (m)	Uu (m/s)	Qu (l/m)	Ud (m/s)	Qd (l/m)
0.225	0.000	0.90	3.15	-1.15	-2.74
0.150	0.000	0.90	1.43	-0.60	-0.23
0.100	0.025	0.40	0.29	-0.80	-0.70
0.175	0.013	0.65	1.69		
0.225	0.112	0.20	0.70	-1.30	-3.03
0.100	0.050	0.25	2.45	-1.00	-1.89
0.062	0.013	0.70	0.23	-0.60	-0.33
0.150	0.000	0.50	1.40	-1.00	-0.87
0.213	0.050	0.60	9.30		
0.200	0.125	0.35	0.23	-1.10	-3.21
0.138	0.000	0.60	1.05		
0.150	0.062	0.60	0.31	-1.00	-1.13
0.100	0.112	0.50	0.29	-0.60	-0.47
0.062	0.000	0.50	0.17	-0.30	-0.21
0.162	0.038	0.60	0.58		
0.213	0.087	0.00	0.64	-0.90	-1.54
0.150	0.000	0.60	2.45		
0.200	0.038	0.45	0.65		
0.125	0.138	-0.20	0.12	-0.80	-2.74
0.075	0.000	0.90	0.30		
0.138	0.038	-0.10	0.24	-0.50	-0.73
0.200	0.000	0.85	2.81	-1.10	-3.26
0.200	0.025	0.90	2.52	-1.10	-0.61
0.150	0.075	-0.20	0.45		
0.125	0.025	0.60	1.11	-0.90	-0.23
0.175	0.038	0.60	4.31	-1.20	-2.51
0.200	0.000	0.60	5.48		
0.138	0.100	0.00	0.12	-1.40	-1.07
0.062	0.000	0.80	0.27		
0.250	0.062	0.60	0.64	-1.30	-3.73
0.075	0.000	0.90	0.82	-1.20	-0.90
0.125	0.000	0.90	1.63	-1.20	-2.04
0.150	0.000	0.70	2.02	-1.00	-1.14
0.200	0.050	0.80	2.45		
0.350	0.125	0.90	3.21	-2.00	-15.51
0.087	0.000	0.85	0.97		
0.213	0.050	0.30	1.19	-1.30	-3.50
0.087	0.000	0.75	0.17		
0.125	0.000	1.25	0.58	-1.30	-3.11
0.200	0.025	0.90	0.12		
0.225	0.150	0.80	3.73	-1.80	-17.49
0.075	0.000	0.60	0.22		
0.275	0.050	0.70	1.14	-1.40	-4.90
0.125	0.000	1.00	1.35		
0.250	0.050	0.70	0.73	-1.35	-4.57
		Qu total	65.7	Qd total	-84.4

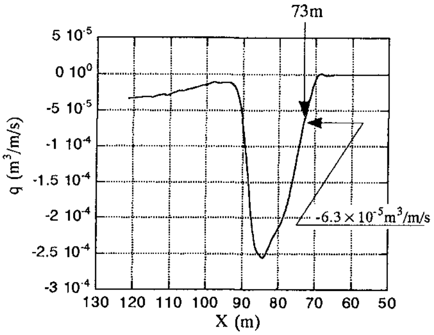

Figure 11. Sand transport rate counted back from profile change

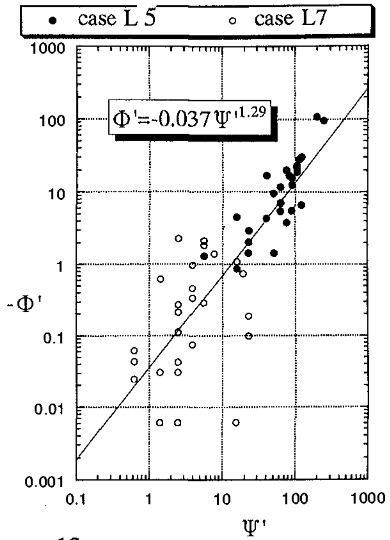

Figure 12. Nondimensional sediment transport rate Φ' due to individual downrush and non dimensional bottom friction Ψ'

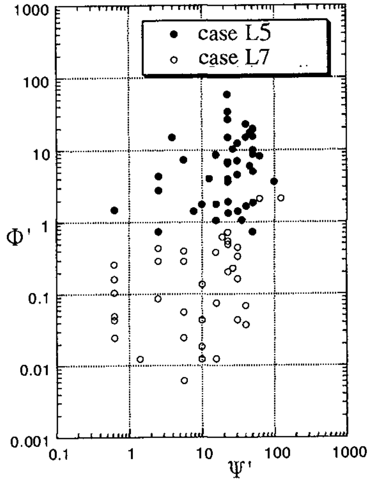

Figure 13. Φ' due to individual uprush and Ψ'

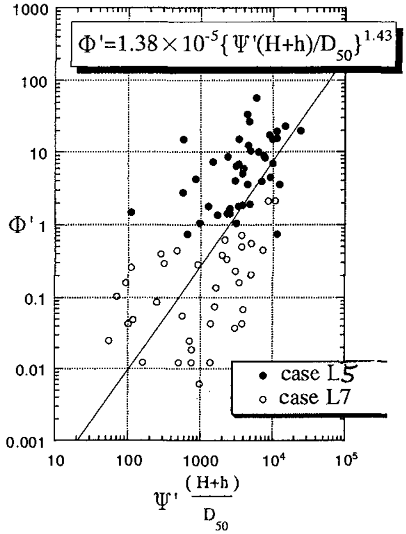

Figure 14. Φ' due to individual uprush and Ψ'(H+h)/D_{50}

due to individual uprush and nondimensional bottom friction Ψ'. Relationship between Φ' and Ψ' is bad, because uprushing bore involves suspended sediment according to not only bottom friction but also thickness of the bore.

Figure 14 shows relationship between nondimensional sediment transport rate Φ' due to individual uprush and
product of nondimensional bottom friction Ψ' and nondimensional thickness of the front bore of uprush. Sediment transport rate due to uprush is modeled by following equation;

$$\Phi'=1.38\times10^{-5}\{\Psi'(H+h)/D\}^{1.43} \quad (4)$$

Conclusions

❶Beach profile change due to swells is more rapidly than that due to wind waves.

❷Around the breaking point, there is the case that low frequency component of suspended sediment transport due to long waves is offshore, and high frequency one is onshore.

❸The number of waves decreases immediately in the swash zone, because a downrush prevents runup of the next wave in trough phases of long wave.

❹Waves in a swash zone are apt to be grouped and uprushing bottom flow due to the first wave of the group is strong. Hence, uprush sediment transport is remarkable under the action of the first wave.

❺Crest level of the last wave of the group in the swash zone is highest and downrush bottom flow due to the last wave is strong. So, downrush sediment transport due to the last wave is striking and drags on.

❻Sediment transport rate due to uprush and downrush in a swash zone was modeled relating to bottom friction and thickness of uprushing bore.

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