CHAPTER ONE HUNDRED TWENTY FOUR

Field Observation on Suspended-load in the surf zone

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ABSTRACT

Both the concentration of suspended-load and the current velocity have been measured continuously in the surf zone. In order to measure the concentration of the suspended-load in the surf zone, a optical densitometer has been developed. The current velocity was measured by means of electromagnetic current meters. According to data analyses, the mean concentration of the suspended-load is high in the final breaking zone and in the breaker zone. In the final breaking zone, the concentration fluctuates with the period of the incident waves. On the other hand, it fluctuates with the period longer than 40 seconds in the breaker zone and it becomes high when the current is offshoreward. The directions of the net transport of the suspended-load in the middle layer in and near the surf zone are offshoreward.

1. INTRODUCTION

The surf zone is a very complicated field with respect to fluid motion owing to the breaking waves, the long period waves, the nearshore currents and the strong turbulences due to wave breaking. The scale and internal structure of this velocity field are being revealed gradually in the field and in the laboratory with the developments of current meters such as electromagnetic current meters and laser doppler velocimeters. The surf zone is also a very important field for sand movement. Scale of fluctuations and structures of sand transport should be corresponding to those of fluid motion. For examples, the sands suspended by the action of the incident waves or its breaking are transported by the nearshore currents. The fluid motion due to long period waves may affect on the sand transport to form the nearshore rhythmic topography such as multiple longshore bars, large cusps and crescentic bars.

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The relationships between the sand movement and the characteristics of fluid motion in the surf zone, however, are not satisfactorily known so far, since in most of the cases the sand movement in the surf zone were measured as the time averaged values, which were difficult to be connected with the features of fluid motion. In order to understand these relationships between the sand movement and fluid motion, they must be measured continuously in the surf zone at the same time.

Therefore, both the concentration of suspended-load and the current velocity have been measured continuously in the surf zone at Ooarai Beach in Japan and the relationships between them are examined in this paper.

2. INSTRUMENTS USED IN THE FIELD OBSERVATION

* Densitometer : In order to continuously measure the concentration of suspended-load in the surf zone, a densitometer was developed (see Fig. 1). This device consists of ten pairs of luminous and photo-electric cells mounted vertically and separated 5 centimeters apart each other. The vertical interval of these pairs of cells is 5 centimeters at the lowest part and becomes larger upward, being 20 centimeters at the highest part as seen in Fig. 1. The distance from the lowest pair of cells to the highest one is 1.20 meters. The pairs of cells are numbered upward from the lowest one, that is, the n-th pair of cells is denoted by the symbol of C_n (n = 1, 2, 3,....., 10). A time constant of response of each pair is 0.1 second and ten pairs of cells are controlled periodically in order with a period of 0.03 second. After the field observation, a calibration of the densitometer was carried out in the laboratory, with the sand taken from the beach under the condition of the water

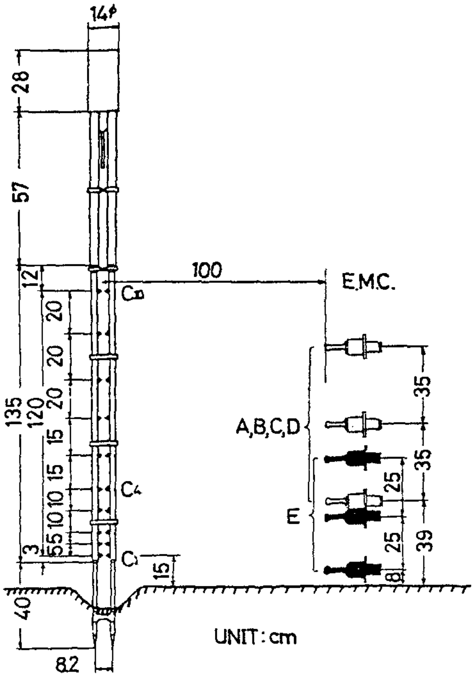

Fig. 1 Densitometer and its arrangement with electromagnetic current meters.

temperature as same as that of the field. The range of calibration was from 0ppt to 20ppt. Figure 2 shows the typical result of the calibration for C_3. The relation between the output voltage and the concentration can be approximated by a dashed curve as shown in Fig. 2. The same tendency was obtained for the other pairs of cells. In the data analysis, however, a linear relation for each pair, e.g. shown by a straight line in Fig. 2, is utilized in order to convert the output voltage into the concentration.

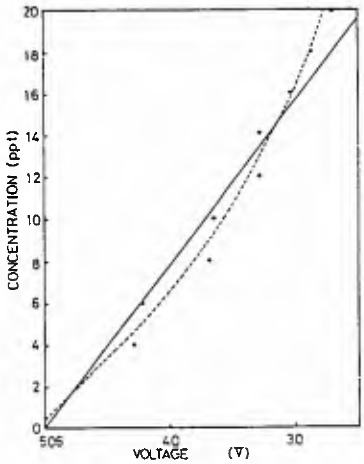

Fig. 2 Typical result of calibration for densitometer (C_3).

* Current meters : Three electromagnetic current meters of two-components type were used to measure the current velocities.
* Wave meters : Two capacitance type wave meters were used to measure the wave profiles.
* Set of instruments : The densitometer was installed outside a tower which was constructed with members of steel pipe of 5 centimeters in diameter shown in Photo. 1. Three electromagnetic current meters were vertically installed inside the tower to measure the on-offshore and vertical components of velocity. A horizontal distance from the densitometer to the electromagnetic current meters was 1.0

Photo. 1 Observation tower

meter. After installing these instruments to the tower on the land, the frog-men carried the tower into the surf zone, and put it on the sea bed by adjusting the direction from the densitometer to the electromagnetic current meters to be parallel to that of the shoreline.

3. SITE OF FIELD OBSERVATION (OOARAI BEACH)

The field observation was carried out at Ooarai Beach in Japan during the periods of August 26 to 27, 1982. This beach is located in the north end of a sandy coast of about 70 kilometers long facing to the Pacific Ocean (see Fig. 3), and is adjacent to Ooarai Port. The observation point was located about 220 meters south from the jetty which has a function of preventing the sand from entering Ooarai Port. The observation point was almost the same level as the datum line (see Fig. 4.). The characteristics of the beach materials (sand) are that the medium diameter is d_{50}=0.24 millimeter; the sorting coeffi-

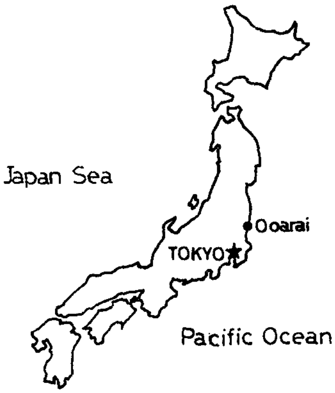

Fig. 3 Location of Ooarai Beach.

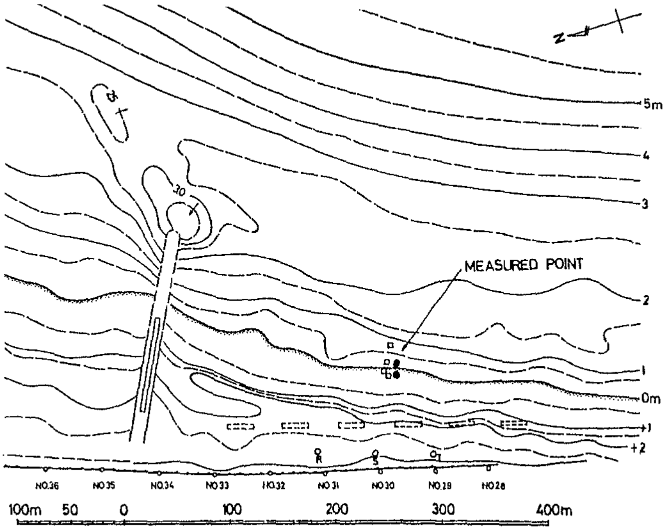

Fig. 4 Beach topography of investigated site relative to datum line and measurement points.

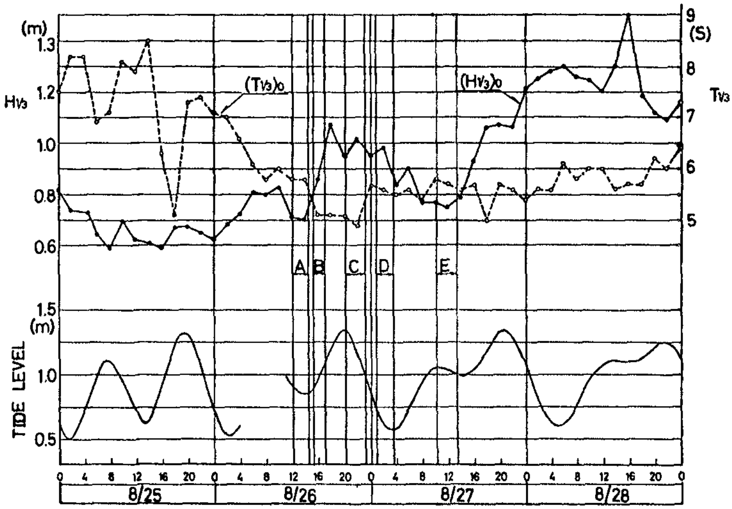

Fig. 5 Significant wave height, wave period and tidal level during the field observation.

cient is S_0=1.34; the skewness parameter, which indicates the degree of asymmetry of grain size distribution, is S_k=1.12.

Figure 5 shows the significant wave height, wave period (measured at the depth of 30 meters under the datum line) and the tidal level (measured inside Oarai Port) during four days, in which the field observation of two days is included. In this figure, symbols of A - E indicate the times while the field observation was carried out (hereinafter referred to as A - E). During these observations, the significant wave height was 0.7-1.0 meter and the wave period was around 5.5 seconds in deep water. The direction of the incident waves at the measurement points was nearly normal to the shoreline and the longshore currents could not be noticed as far as the visual observation could be made.

A detail of the measurement points are shown in Fig. 6, in which opened marks indicate the measurement points of A, B, C, D and closed marks indicate those of E. The arrangement of the densitometer and the electromagnetic current meters is shown in Fig. 1. The beach profile along the measurement line shown in Fig. 6 was surveyed just after the final observation of E, and is shown in Fig. 7. In this figure, the highest and the lowest water levels and the water level in each observation time are also shown.

When the tidal level was relatively low, the pairs of cells from C_7 to C_{10} and the upper two current meters frequently emerged above the water surface. Then, the data obtained at the lower part are analyzed.

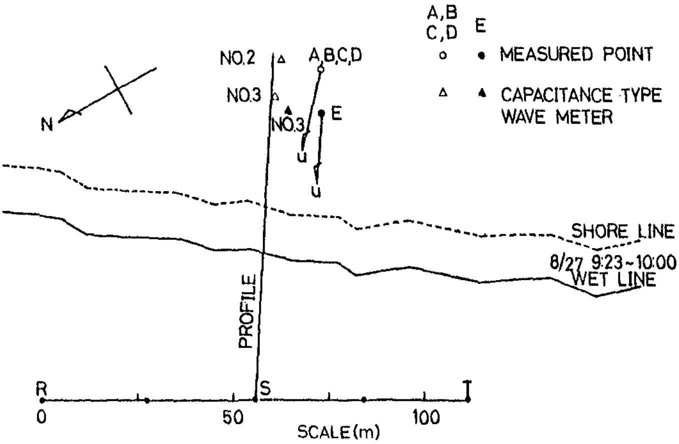

Fig. 6 Detail of measurement points.

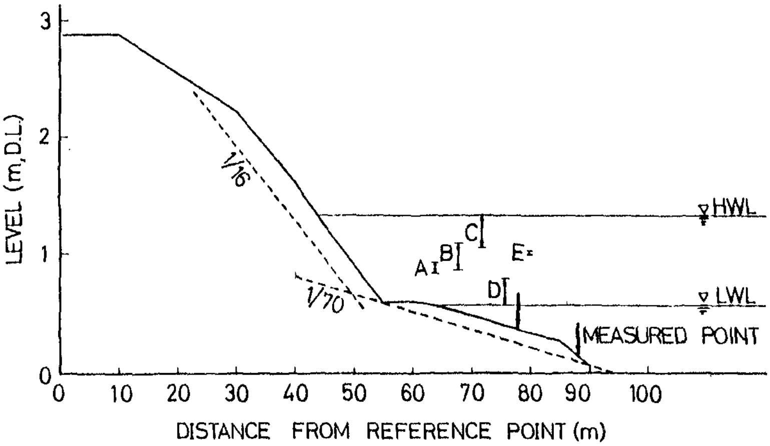

Fig. 7 Beach profile, tidal level during the field observation and measurement points.

4. RELATIONSHIP BETWEEN CONCENTRATION OF SUSPENDED-LOAD AND TIDAL LEVEL

Figure 8 shows the typical examples of the concentration of suspended-load, which were measured at C_1 to C_3 (in the region of 1S to 2S centimeters above the sea bottom) in B and D. One more example will be shown in Fig.13. When the concentration is low in B, the concentration of C_1 is negative, that of C_3 is about 8ppt and that of C_2 is

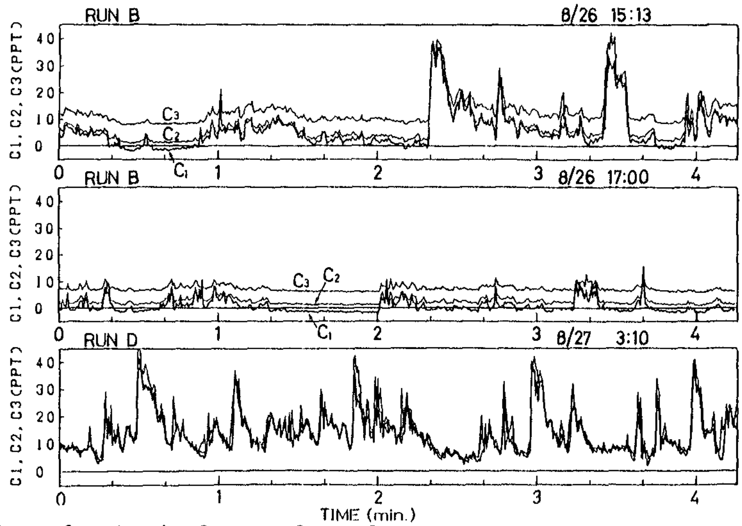

Fig. 8 Typical examples of concentration of suspended-load (C_1 - C_3 in B, D)

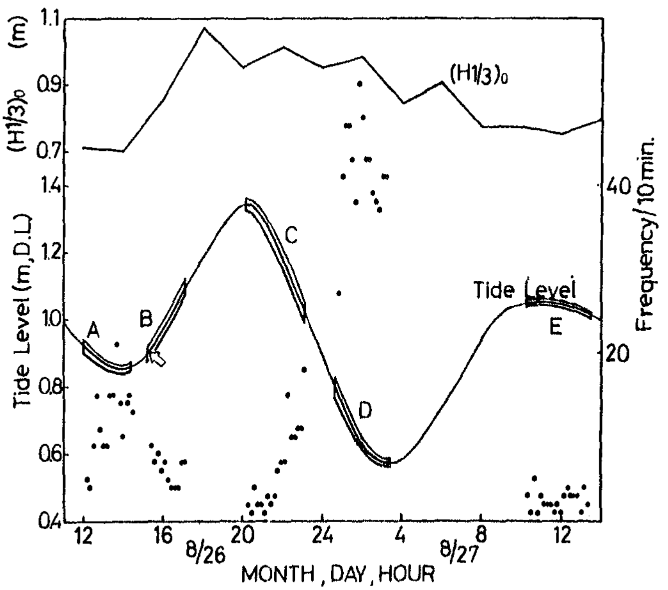

Fig. 9 Relationship between tidal level and occurrence frequency of concentration of suspended-load exceeding 20ppt.

reasonable, although these concentrations fluctuate similarly. This might have been due to that the surface conditions of the luminous and photo-electric cells were different from those in calibration, e.g. the surface of glass was blurred, which yielded the vias voltage in the output signal.

As seen in Fig. 8, the concentration of suspended-load in the region of 15 to 25 centimeters from the sea bottom frequently becomes more than 20ppt, even if we don't take the above errors into account. The high concentration occurs three times in the upper figure, zero time in the middle figure and many times in the lower figure. That is to say, the occurrence frequency of the high concentration depends on the case. Then, the occurrence frequency of the concentration exceeding 20ppt per 10 minutes are examined in the analog record of every ten minutes, and the results are plotted in Fig. 9. In this figure, the significant wave height and the tidal level are also shown. The high concentration occur most frequently of about 40 times in D with the lowest tidal level, whereas it is rare of several times in E and the first half of C during which the tidal level is higher. In A, B and the second half of C with medium tidal level, the frequency is around ten times. Generally speaking, the high concentration is rare at a high tide and is frequent at a low tide. In short, there is a negative correlation between the occurrence frequency of the high concentration and the tidal level. This situation is considered to be related to the position of a wave breaker zone which shifted with the tidal level.

The relative position of the observation points shifted from the inside of the surf zone to the out side of it, and vice versa due to the change of the tidal level. Then taking into account the relative distance from the shoreline to the observation point, the occurrence frequencies of the high concentration exceeding 20ppt are plotted in the upper part of Fig. 10. In this figure, a mean velocity and a distribution of the breaking point of the incident waves are also shown. A method of measurement of the breaking point will be mentioned in the next section. The bottom slope of 1/70 shown with dashed line in Fig. 7 is considered for estimating the relative distance. Based on this result, the on-offshore distribution of the occurrence frequency are shown with a curve after considering the followings:

(1) As seen in Fig. 9, the significant wave height is about 0.9 meter in B, D and E, while it is 0.7 meter in A and 1.1 meters in C.

(2) The difference of the incident wave height induced the displacement of the wave breaker zone, that is, the incident waves broke in the surf zone relatively nearer to the shoreline in A and relatively farther from the shoreline in C.

(3) Therefore, in order to obtain the standard on-offshore distribution of the occurrence frequency, the positions of the occurrence frequency in A and in C must be shifted in

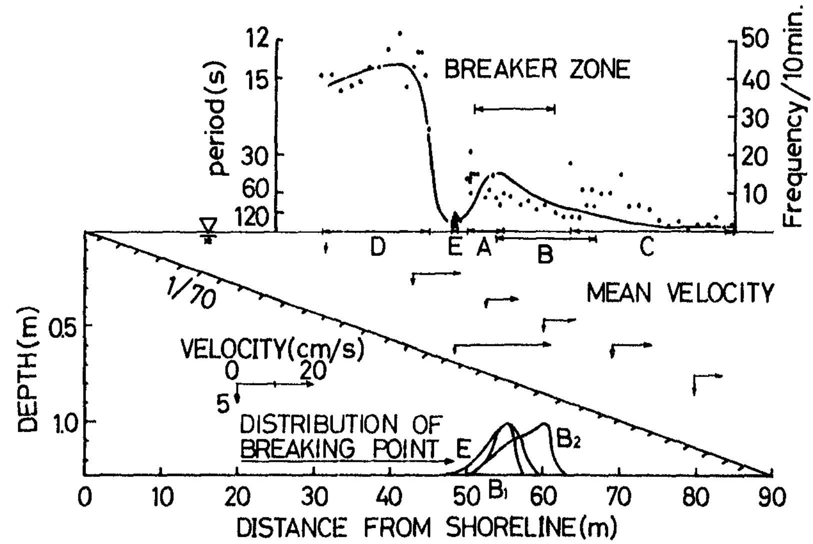

Fig. 10 On-offshore distribution of occurrence frequency of high concentration and mean velocity.

the offshore direction and in the onshore direction, respectively.

As seen in Fig. 10, the on-offshore distribution of the occurrence frequency has two peaks. The onshore-side peak, represented by the data obtained in D, indicates that the mean period of the occurrence of the high concentration is 12 to 16 seconds. The significant wave period, which is calculated by the zero down-crossing method by using every 17 minutes' wave profile data measured at the point of No.2, is 14.2±1.6 seconds. That is, the mean period of the occurrence of the high concentration is almost the same as the significant period of the incident waves. Although the visual observation on the situation around the observation point in D could not be made because it was the middle of the night, the final wave breaking may have occurred there since the water depth at the observation point was about 50 centimeters. The other peak of the occurrence frequency is located at the breaker zone. The mean period of the occurrence at the breaker zone is longer than 40 seconds, which is obviously longer than the period of the incident waves.

5. LONG PERIOD FLUCTUATION OF SUSPENDED-LOAD IN THE SURF ZONE

It has been reported that the concentration of the suspended-load becomes high with the period longer than that of the incident waves in the breaker zone (Brenninkmeyer 1974, Wright et al. 1982). In this section, the long period fluctuation of the concentration of the suspended-load will be examined.

Figure 11 shows the result of a cross-spectral analysis between the on-offshore velocity component and the concentration of the suspended-load which were measured at C_1 in B, during which the observation point was located in the breaker zone. For this analysis, the analog data are digitalized with the interval of 0.1 second, which yield the digital data of 1 second interval by being calculated the mean value of every series of 10 digital data. A sampling interval and a number of data used in the cross-spectrum analysis are Δt=1 second and N=2048 (about 34 minutes), respectively. The equivalent degree of freedom with a filter used for smoothing is r=16. The vertical coordinate in the upper figure is for the values of spectral density of

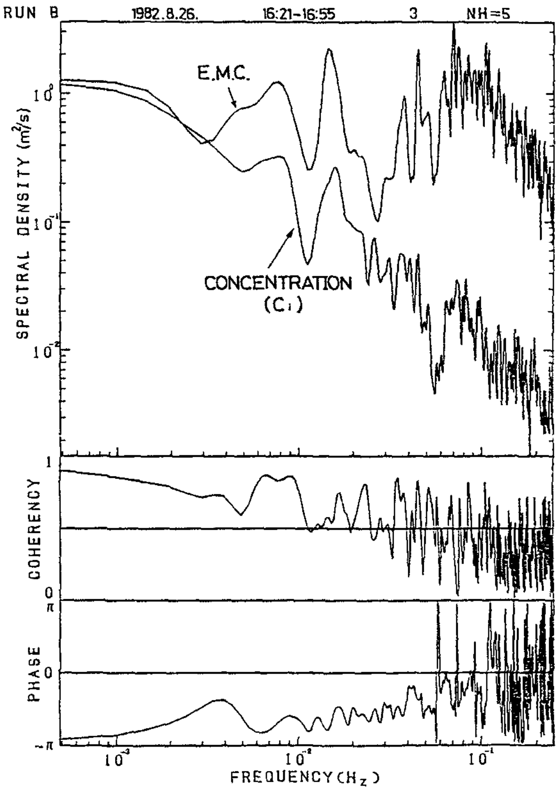

Fig. 11 Cross-spectrum between on-offshore velocity and concentration (C_1).

the velocity. In order to show the spectral density of the concentration in the same figure, the concentration data (ppt) have been divided by 50 in advance.

As seen in Fig. 11, there are two pronounced spectral peaks in both the velocity and the concentration at the frequencies of 0.015Hz (67 seconds) and 0.008Hz (125 seconds). At these frequencies, the coherences of the velocity versus the concentration are high and the phase differences between them are nearly 180 degrees. Therefore, it can be said that the concentration of the suspended-load becomes high when the velocity is negative, i.e. the direction of the current is offshoreward. There is, however, no spectral peak in the concentration at the frequency of the incident waves.

The breaking positions and the breaking types of the incident waves were visually observed in B, and the results were recorded with a voice on a magnetic-tape, on which the velocity and the concentration of the suspended-load were also recorded at the same time by means of a Data Recorder. Figure 12 shows the wave breaking type and the on-offshore distribution of the wave breaking position. In this case, the mean period of wave breaking is about 19 seconds, which is calculated by dividing the visual observation time by a total number of waves observed, being longer than that of the incident waves. Then, the waves of small size may have been ignored in the visual observation since the rate of the spilling type is low. As seen in Fig. 12, the measurement position was located inside the breaker zone and at its position the incident waves broke most frequently.

Figure 13 shows the typical example of the records; the upper figure is the on-offshore velocity; the lower figure is the concentration of the suspended-load. The arrows in the middle part of Fig. 13 show the time when the incident waves broke. The opened arrows indicate that the incident waves broke at the offshore-side of the observation point,

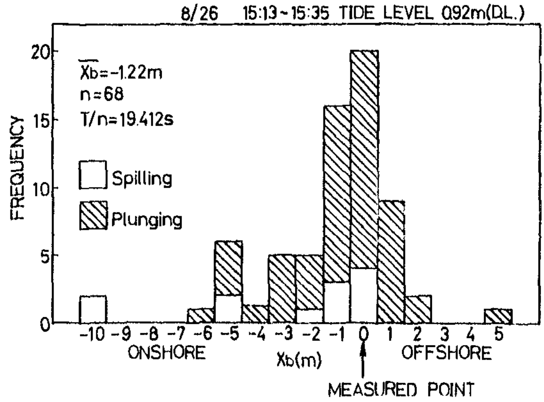

Fig. 12 Wave breaking type and on-offshore distribution of wave breaking position.

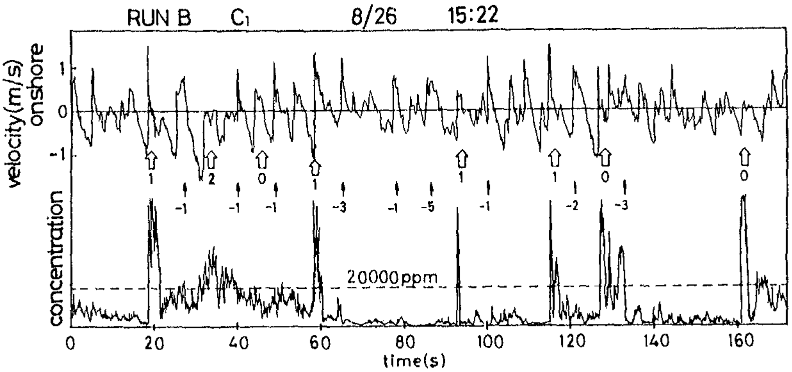

Fig. 13 Typical example of on-offshore velocity, concentration and breaking position.

while the black arrows indicate that they broke at the onshore-side. Moreover, the figure under the each arrow is the distance in meter from the observation point to the breakpoint. All the breaking type in Fig 13 were judged as plungings. According to Fig.13, whenever the concentration of the suspended-load exceeded 20ppt, the incident waves broke at the offshore-side of the observation point which is indicated with the opened arrow. At these times, the concentration suddenly increased, and rapidly decrease except a period of 20 to 60 seconds. This evidence can be explained as follows: The abundant suspended-load due to the wave breaking at the offshore-side of the observation point is transported in forming the suspended-load cloud to the observation point by the onshoreward current under the wave crest. Subsequently it is transported to the offshore direction by the offshoreward current under the wave trough. Since the concentration of the suspended-load rapidly decrease in the second stage, the state of the suspended-load cloud should be maintained without enough diffusion during this process. Almost all of the suspended-load, however, deposit by the time when the following wave crest passes through the observation point without breaking.

During the period of 20 to 60 seconds, the concentration of the suspended-load gradually increased to be more than 20ppt and gradually decreased to be a low level. The condition of the incident waves, which broke at the offshore-side and at the onshore-side of the measurement position alternatively, is different from that of the other periods. Furthermore, the maximum offshoreward velocity occurred at nearly 30 seconds and the duration of the onshoreward velocity was relatively short. Then, the followings are inferred: The tendency of transportation of the suspended-load from the offshore to the observation point is weak due to the short duration of the onshoreward velocity. In this case, the suspended-load due to the wave breaking at the onshore-side likely to be transported to the observation point. The repetitive wave breakings in a short period has an effect of maintaining the sand in suspension over a long time.

6. NET TRANSPORT OF SUSPENDED-LOAD

At first in this section, the mean velocity is examined. As seen in Fig. 1, the height of the electromagnetic current meters from the sea bottom differed from case to case, e.g. that of the lowest one was 8 centimeters in E and 39 centimeters in the other. The electromagnetic current meters in the upper part occasionally emerged above the water surface when the wave trough passed at the observation point during the relatively low tidal level. Therefore, the records obtained by the lowest current meter in level are used for calculating the mean velocity. Figure 14 shows the changes of the mean velocity of the on-offshore component in 5 minutes during each observation case. The onshore direction of the velocity is defined as positive.

The mean velocity in A, B, C are almost constant of 10 cm/s offshoreward. In the first half of D the mean velocity is 15 cm/s offshoreward, while it is nearly zero in the second half of D. In E the mean velocity gradually changes from about 40 cm/s offshoreward to about 25 cm/s offshoreward.

Taking into account the relative distance from the shoreline to the observation point, these mean velocities are shown together with the vertical mean velocities in Fig. 10. A number of data shown is not enough to give the whole

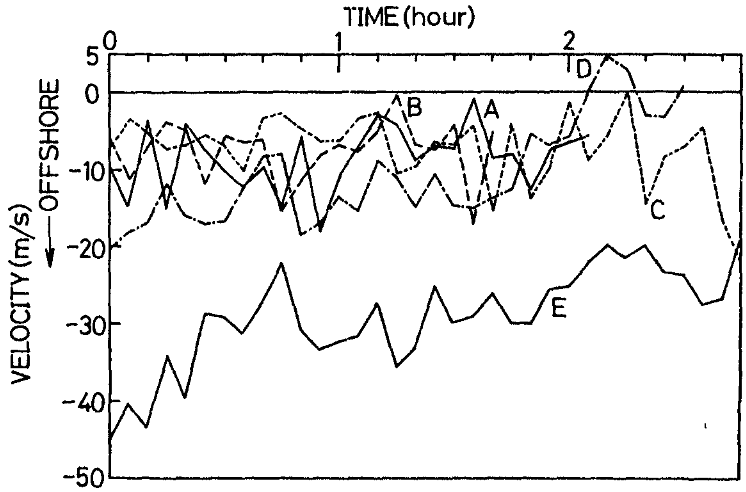

Fig. 14 Changes of mean velocity of on-offshore component in 5 minutes.

structure of the mean velocity in the surf zone. However, comparing with the experimental results of the mean velocity on the constant sloping beach which were measured by means of a laser doppler velocimeter (Nadaoka et al. 1982), we can see the feature of that the horizontal and vertical mean velocities below the trough level of the incident waves are offshoreward and downward respectively everywhere.

If we assume that the suspended-load will be transported with the same velocity as fluid particles, a net transport of the suspended-load Q_{snet} passing through a vertical cross section can be estimated as follow:

$$Q_{snet}=\int_0^t \int_{-h}^{\eta} cu\ dzdt \qquad (1)$$

where c is the concentration of suspended-load and u is the horizontal velocity. Since the vertical arrangement of the three electromagnetic current meters were limited, only the time integration is considered hereinafter. In the calculation of the net transport of the suspended-load, the concentration measured at C_3 is used because it is judged based on the analog record of C_3 that there is almost no effect of the entrainment of air bubbles due to the wave breaking on the concentration measured. As seen in Fig. 8, the vias voltage has been considered to be contained in the record of C_3. Then in the calculation, the concentration is corrected as that the minimum concentration becomes to be 0ppt in each observation case.

The time integration in eq.(1) is conducted numerically with the digital data of both the horizontal velocity component and the concentration of 0.5 second interval which is the mean values of every 5 digital data of 0.1 second interval. The solid lines in Fig. 15 show the accumulation of the net transport of the suspended-load in each

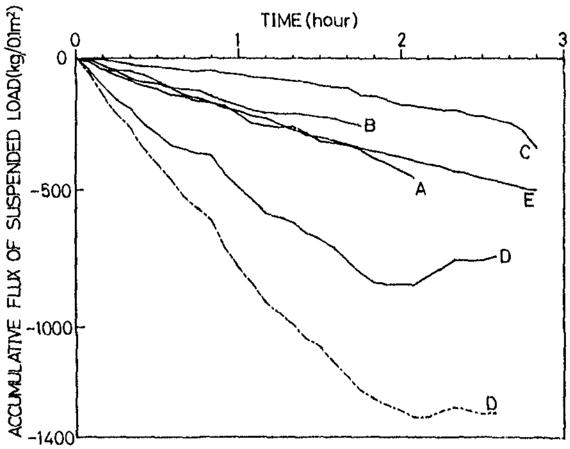

Fig. 15 Accumulation of net transport of suspended-load

observation case. A horizontal axis is for a lapse time and a vertical one is for the accumulation of the net transport passed through the vertical cross section of 1 meter in longshore length and 0.1 meter in height. The accumulation of the net transport was negative, offshoreward, in all cases and the absolute value of it became large in the order of C, B, E, A, D. In the case of D, the onshore net transport occurred in the final 40 minutes because the absolute quantity decreased.

By using the mean velocity and the mean concentration in 5 minutes, the time integration is conducted for D and the result is shown with a dashed line in Fig. 15. The absolute quantity of the dashed line for D is is larger than that of the solid line for D. This difference in the final accumulation is considered to be due to that the concentration of the suspended-load is higher when the direction of the current is onshoreward. The same tendency of the difference between the results of the different calculations is also noticed in the case of A, but the difference is small, being about 10 percent. In the remaining cases, the results of the different calculations are almost the same each other.

The net transports of the suspended-load per one minute, which can be estimated by the slope of the tangent to the solid curves in Fig. 15, are shown with closed arrows in Fig. 16, by taking into account the relative distances from the shoreline to the observation point. In the upper part of Fig. 16, the mean concentrations at C_3 during 10 minutes are

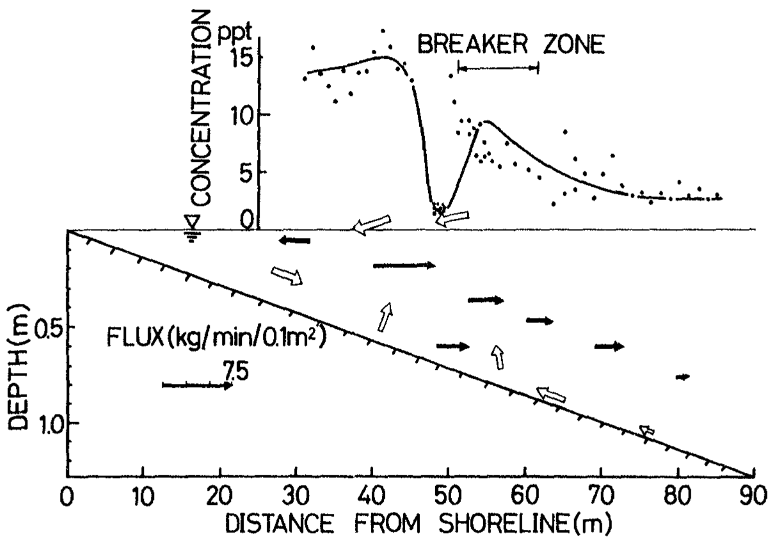

Fig. 16 Mean concentration at C_3 in 10 minutes and net transport of suspended-load.

also shown. As seen in this figure, the directions of the net transport of the suspended-load are offshoreward except at the location nearest to the shoreline. These offshoreward net transport should cause the considerable change of the bottom profile. The bottom profile, however, scarcely changed during the field observation. Then, we cannot help considering the onshoreward transport at the other points of the observation point.

Let's examine the location where the onshoreward net transport of the sand occurs. In the outside of the surf zone where the bed-load is predominant, the skewness of the velocity fluctuation becomes greater to the breaker zone from the offshore due to the wave shoaling, which makes the tracers on the sea bottom to move onshoreward (Nadaoka et al. 1982). Therefore, it is considered that the bed-load should be transported in the onshore direction in the outside of the surf zone.

In the surf zone, the skewness of the velocity fluctuation becomes smaller to the shoreline and the direction of the mean velocity is offshoreward near the sea bottom, and the tracers on the sea bottom are transported to the breaker zone (Nadaoka et al. 1982). Therefore it is difficult to consider the onshoreward transport of the bed-load near the sea bottom. The onshoreward net transport of the suspended-load in the upper layer seems to be rather the most probable. This is because the concentration of the suspended-load in the upper layer becomes higher when the wave crest passes (Tanaka et al. 1979) and the detailed measurement in the flume by means of a laser doppler velocimeter shows that the mean velocity above the level of the wave trough is onshoreward (Nadaoka et al. 1982). As seen in Fig. 16, the net transport of the suspended-load is onshoreward at the location nearest to the shoreline or nearest to the mean water surface which located at the onshore-side of the final breaking zone. This evidence supports the above consideration. By considering the positions of both the breaker zone and the final breaking zone, the directions of the net transport of the sand inferred are shown with opened arrows in Fig. 16.

The mean concentration of the suspended-load is about 7 to 8ppt in the breaker zone and about 15ppt in the final breaking zone, respectively. These results agree approximately with the former ones obtained by the direct sampling of the suspended-load in the field (Tanaka et al. 1979). The mean concentration around the offshore-side peak of it distributes asymmetrically with respect to the breaker zone, decreasing gradually offshoreward. This is considered to be because the sand suspended in the breaker zone is transported in the offshore direction by the mean velocity of the same direction.

7. CONCLUSIONS

The field observation was carried out at Ooarai Beach in

Japan, in order to understand the relationships between the fluid motion due to the incident waves and the concentration of the suspended-load. Both the fluid motion and the concentration have been continuously measured at the same time in the surf zone. The main two conclusions obtained in this paper are as follows:

The mean concentration of the suspended-load is high in the final breaking zone and in the breaker zone. In the final breaking zone, the concentration fluctuates with the period of the incident waves. On the other hand, it fluctuates with the period longer than 40 seconds in the breaker zone and it becomes high when the current is offshoreward.

The directions of the net transport of the suspended-load measured in the middle layer in and near the surf zone are offshoreward. For this transport of the sand, the compensatory transport of the sand is inferred such as that the bed-load is onshoreward at the outside of the breaker zone and the suspended-load is onshoreward in the upper layer in the surf zone.

In the field observation, the fluid motion and the concentration of the sand were measured only at one fixed point. In order to examine the relationships between them in more detail, it is necessary to measure them at many points at the same time. The effect of the longshore currents on the suspended-load and the mechanism of the suspension of the sand from the sea bottom are subjects for a future study.

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