CHAPTER 35

FIELD INVESTIGATION ON SAND DRIFT AT PORT KASHIMA FACING THE PACIFIC OCEAN

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INTRODUCTION

Port Kashima has been constructed since 1963 on the coast of Kashimanada located north-east of Tokyo. Fig. 1 is the general plan of Port Kashima showing the layout of breakwaters and inner basins. The length of south and north breakwaters will be 2,800 and 1,380 m, respectively. The depth of fairway will be 16 m below L.L.W.L. (lowest low water level) aiming to accomodate 100,000 ton class vessels.

The coast of Kashimanada is a bowshaped sandy beach of some 70 km long facing the Pacific Ocean; Naka River flowed out at the north end and Tone River at the south end, as shown in Fig. 2. The northern portion has a narrow beach with the cliff of Kashima Plateau behind it and the southern portion is of alluvium zone by Tone River with the sand dunes. Port Kashima is being constructed at about 25 km north from the south end of Kashimanada Coast and this place is geologically called as the south alluvium zone.

In the coast around Kashima Port, there runs a sand dune along the coast. The crest of this dune is about 8 m above L.L.W.L. in elevation. The back shore in front of the dune is 50-80 m in width and 3-4 m above L.L.W.L. in elevation. There are alongshore bars at 100-150 m seaward from the shore line on a usual day and at 100-400 m on a stormy day in beach profile. The bottom materials are composed of mainly fine sand and the mean spring tide range is about 1.4 m. The wave, large or small, attacks this coast every day.

From the above-mentioned, the sand drift should be estimated to be remarkable at the constructing site of the harbor. Therefore, the field investigation concerning sand drift has been conducted since tow years before the beginning of the works of harbor construction. In this paper, a few recent investigations will be presented in detail, after a brief description of main field investigations conducted until 1965.

OUTLINE OF INVESTIGATION

Prior to the start of this investigation, an observation-tower and an observation-station have been built on the dune northside the north breakwater. The top floor of this tower is 25 m above L.L.W.L. in elevation. The items and methods of

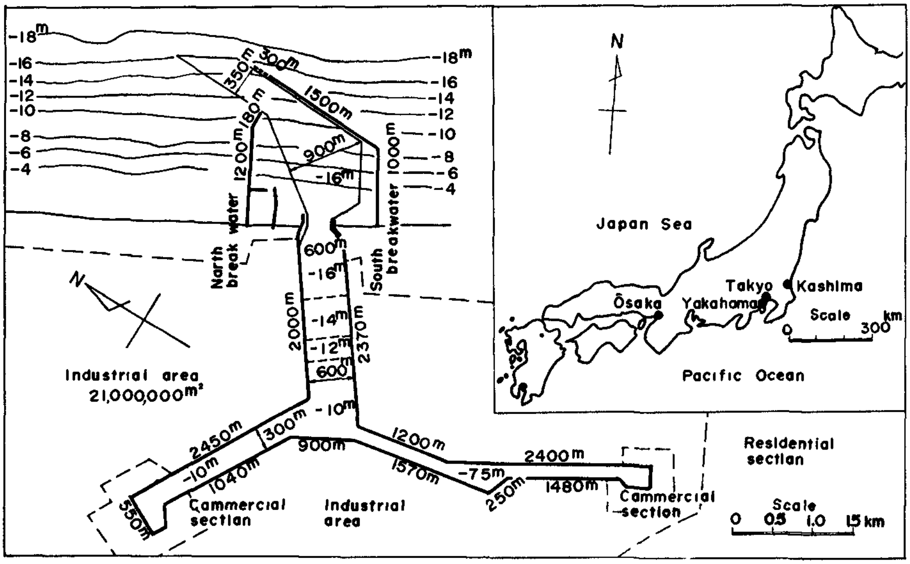


Fig. 1. General plan of Port Kashima.

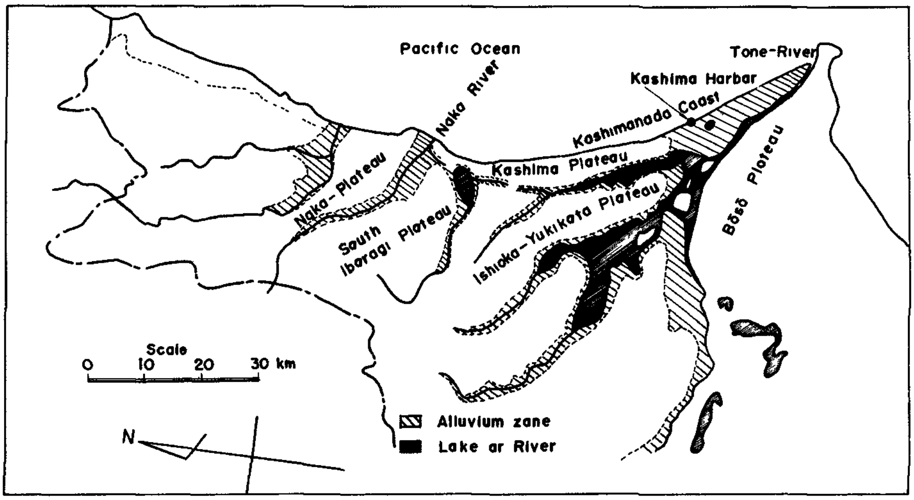


Fig. 2. Geological map of Kashımanada Coast.

this investigation concerning sand drift will be described in the following sections.

SOURCE OF SAND DRIFT

In summer and winter of 1962, the materials on the foreshore along the shoreline have been collected at the spots of 1 km distance to be subjected to grain size analysis. Fig. 3 shows its results and equi-contour lines of depth. The median grain size of material along the shore gradually decrease from the mouth of Naka River to Otake, is nearly constant between Otake and Hirai, is changeable between Hirai and Suda with space and time, and is roughly constant from there to the mouth of Tone River. The northern part of the coast, north of Hirai, belongs to Kashima Plateau and the southern part from Hirai corresponds to the alluvium zone of old Tone River. The heavy mineral composition of materials in the central portion of this coast is different from it in the north and south end portion near to Naka and Tone River, respectively, as shown in Table 1. The contour lines of 20-40 m depth project seawards with many apexes in the central portion.

From the above mentioned, the source of sand drift in the central portion where the site of Port Kashima is located should be the coast itself, and the influence of the discharge from Tone and Naka River is restricted in the area near to their river mouthes.

WAVES

The height and period of wave have been observed by means of an underwater pressure gauge every tow hours; its pick-up has been bolted on the top of 1 m above the sea bottom of the steel pipe driven into the sea bottom of 10-11 m depth in the vicinity of the planning entrance of harbor and its recoder connecting with an armored cable to the pick-up has been placed in the above-mentioned observation-station on the dune. Wave direction has been observed by means of rotating a transit on the top floor of the above-mentioned observation-tower so as for its horizontal cross hair to coincide with the crest line of wave at the 10 m depth. This observation by a transit has been conducted at 9 a.m. and 4 p.m. every day.

Fig. 4 shows the cumulative frequency curves of the height and period of significant wave measured by the above-mentioned wave gauge during April 1962 to March 1963. The maximum significant wave since 1961 was caused by the typhoon October and it has 5 m in height and 10.3 sec in period. The predominant wave direction is WN-NNW nearly perpendicular to the shore line at 10 m depth. But the southerly waves prevail in summer and the northerly waves do in winter.

In addition to the above-mentioned, the measurement of wave

Table 1. Heavy mineral composition of sand along the shore line.

Section / Heavy mineral	Mouth of Tone River	Central portion of Kashimanada Coast Southern part Northern part	Oarai Coast	Mouth of Naka River
Pyroxene	20 %	14 ~ 23 %	10~20%	40 %
Hypers thene	60	40 ~ 50	65~ 85	40
Amphibole	20	30 ~ 40	5~10	20
Blue green Amphibole / Blown green Amphibole	06	15 ~ 3	07~16	07

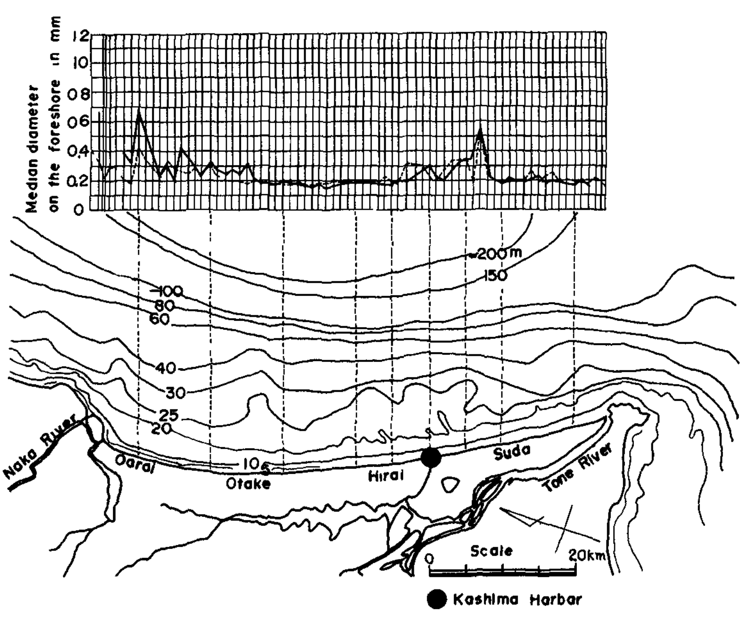


Fig. 3. Variation of median grain size along the coast and contour lines of depth.

direction by a rader and that of wave height by an ultrasonic wave meter have been started to catch more precisely the characteristics of waves since 1964.

CURRENTS

In order to know the tidal current, the measurement of current was conducted using a generator type current meter at the planning entrance of the harbor of 15 m depth on a calm day of the spring tide. The harmonic analysis of this data showed the tidal current to be less than 10 cm/sec at nearly one meter above the bottom. The current on a stormy day has been measured with self-recording current meters shown in Fig. 5 in the offshore zone. While in the surf zone, the current has been measured using floats and dyes.

BOTTOM TOPOGRAPHY

In the offshore zone, the echo-sounder has been used to know the change of bottom topography. In the surf zone, a scale stuff attached on the steel slede shown in Fig. 6 has been used, because there is scarecely such a calm day when there are no surf zone. This stuff is pulled across the surf zone with the ropes connected to its sled between the shore and the boat anchored outside the surf zone in order to be leveled from the shore.

Moreover, a series of steel rods of 20 cm in diameter have been installed on the sea bottom of 6-12 m depth, in reference of which the elevation of the sea bottom has been measured by divers in order to know the depth change of sea bottom more precisely. The data obtained from this method have shown that the depth change of the bottom throughout the year is of the order of ±0.1-0.2 m at 8-12 m depth.

SUSPENDED SAND

The vertical distribution of suspended sand has been investigated with bamboo-samplers, which are installed during some days in the offshore zone, as shown in Fig. 7. Also, steel-pipe samplers having two stages and two holes of 30 mm in diameter have been set on the base plate of the flame of the above-mentioned current meters, as shown in Fig. 5.

Fig. 8 shows an example of vertical distribution of suspended sand collected cumulatively by the bamboo-samplers, where the heights of significant wave during the collecting time were 0.7-0.9 m for (a) and 37, 32, 22, and 9 % of them are 0.5-1, 1-1.5, 1.5-2, and 2-3 m for (b). Fig. 9 is an example of the data by the above steel-pipe samplers, where the maximum significant wave during the collecting time of sand is 1.2 m in height for (a) and 2.1 m in height for (b). From those figures, the suspended sand in the offshore zone of this coast would be assumed to have the following properties.

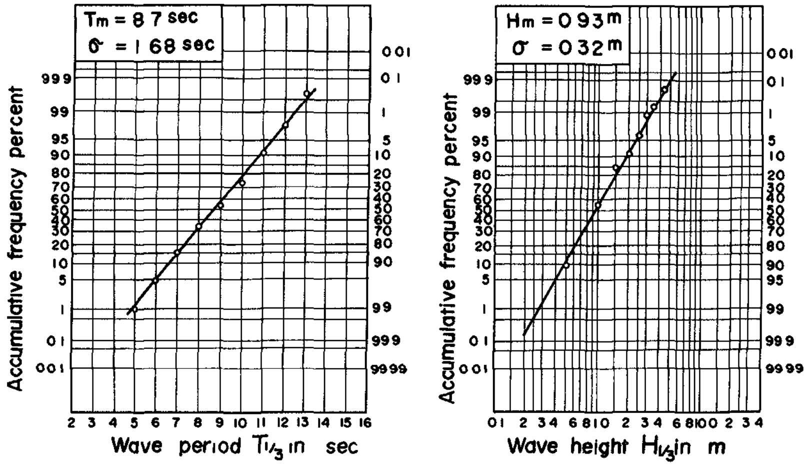


Fig. 4. Frequency curves of significant waves measured by underwater pressure gauge.

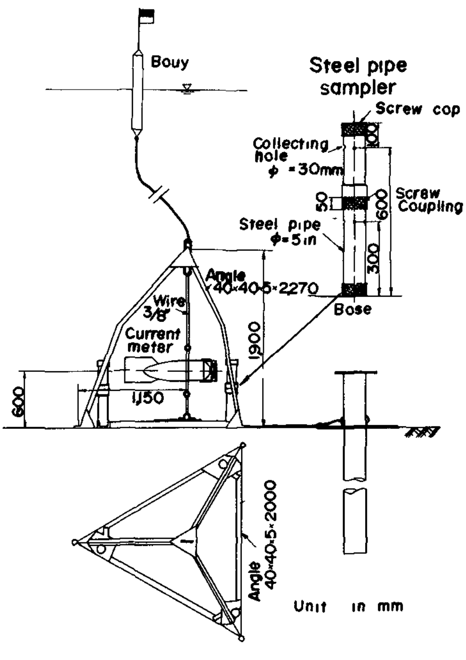


Fig. 5. Self-recording current meter attached with steel pipe samplers.

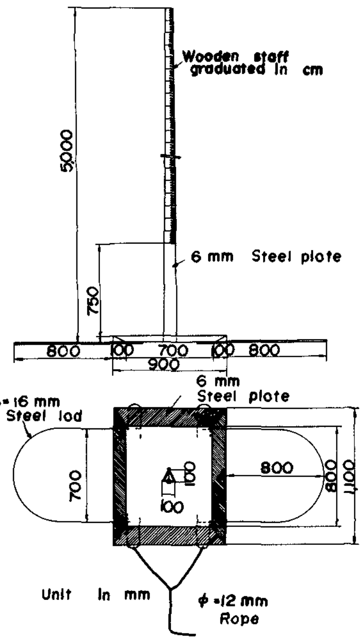


Fig. 6. Scale stuff for the survey in the surf zone.

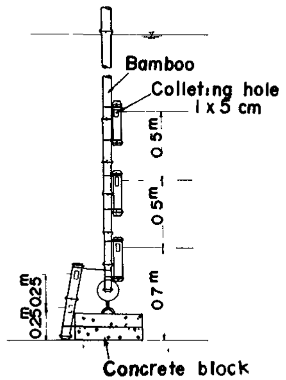
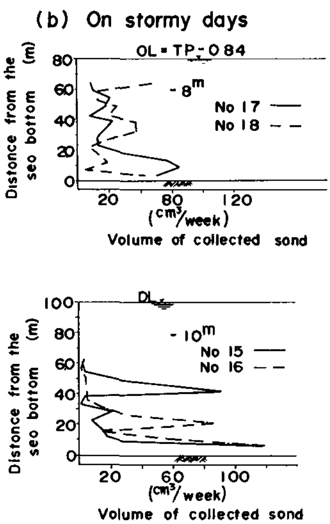


Fig. 7. Bamboo-sampler.



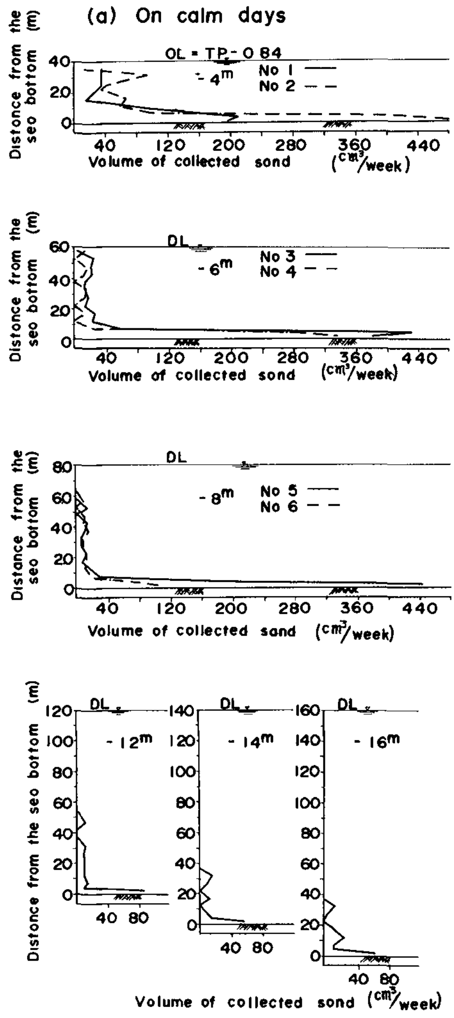


Fig. 8. Examples of vertical distribution of suspended sand collected cumulatively by bamboo-samplers.

(1) The vertical distribution curve of suspended sand conoentration is generally of L-figure shape. The sediment concentration of the portion more than 2-3 m above the sea bottom decreases with the increase of the depth of the sea and the decrease of the wave height.

(2) In the portion near to the bottom, where the concentration is high, the concentration does not change but increases in layer thickness with the increase of wave height, when the significant wave height is more than about 1.5 m.

(3) The portion of high concentration appears sometimes in the middle layer in the vertical distribution of suspended sand. This fact should be assumed to depend on the suspended sand flowed seaward from the surf zone by the seaward or rip currents.

SAND MOVEMENT

Radioactive tracers of Co-60 or Sc-46, brick segments of 3-5 cm in diameter, and fluorescent tracers were used to trace the sand movement. Radioactive tracers were injected by a few hundred to a few ten millicuries per one point in the offshore and surf zone. The observation was done during 1962 to1964. Brick segments were dropped down by 5-7 cubic meters per one time in the outside of the surf zone and inspected where they were flowed on the shore line. The observation was done in 1962-1963. The observation by means of fluorescent tracers will be shown in detail in the later section.

From these observations, the following properties were estimated on sand movement at this coast.

(1) In the offshore zone, the predominant direction of sand movement near the sea bottom generally coincides with the wave direction, but when the wave height is smaller it coincides with the direction of tidal currents.

(2) In the surf zone, the predominant direction of sand movement coincides with the direction of longshore component of waves or that of rip currents.

BOTTOM MATERIALS

Bottom materials have been sampled and analysed on the grain size to know the change of plane distribution of sand size in process of harbor-warks. Fig. 10 shows the typical accumulative ourves of grain size in the area where the influence of the breakwaters will not be seen.

INVESTIGATION OF THE RATE OF LITTORAL TRANSPORT

The rate of littoral transport should be computed at present by the volume change of materials trapped by a substantially complete littoral barrier. But it is also available for the coastal works to know what portion of the total transport is trapped by a partial barrier. Then, the amount of materials in the vicinity of breakwaters have been calculated on the basis of sounding data in process of the extention of breakwaters.

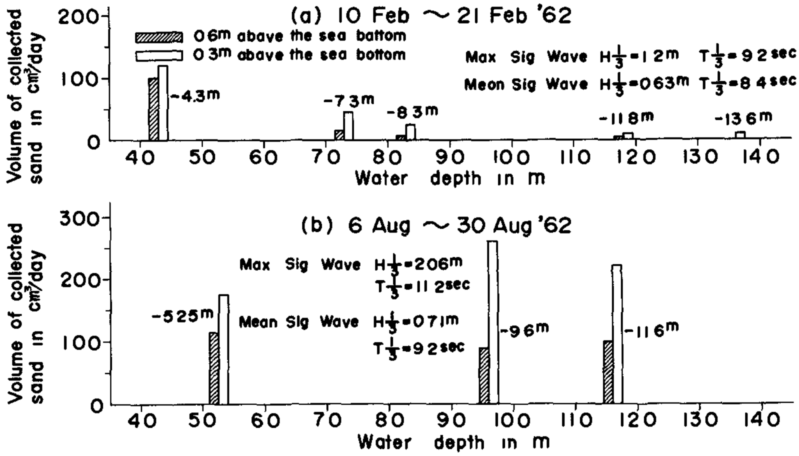


Fig. 9. Examples of the distribution of suspended sand collected cumulatively by steel pipe sampler.

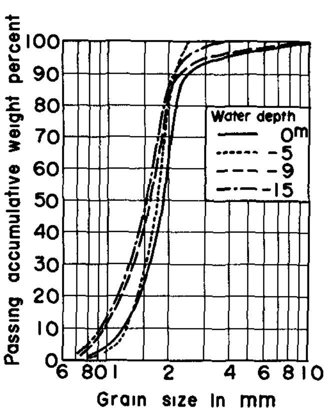


Fig. 10. Typical accumulative curves of grain size.

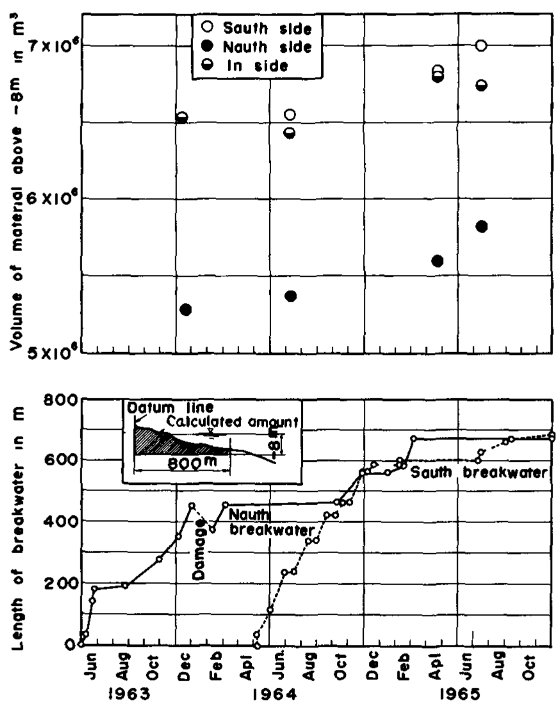


Fig. 11. Volume change of materials in three areas shown in Fig. 12 and extension of breakwaters.

The construction of north and south breakwaters began in June 1963 and May 1964. Fig. 11 shows the extension of the length of breakwaters and the volume change of materials in each area shown in Fig. 12. The range of each area is bounded by the datum line and the line of 800 m seaward from the datum line, which corresponds to the contour line of 6-7 m depth. The south and north side areas are 1600 m long in the direction along the shore and the inside area is 1500 m long in the same direction. The volume change of materials in each area is shown by the time change of the amount of materials above the horizontal plane of 8 m below L.L.W.L., as schematically shown in the lower portion of Fig. 11.

From Fig.12, it is seen that the change of amount of sand during one year from July 1964 to July 1965 is 49×10^4, 31×10^4, and 44×10^4 cubic meters in the south, in, and north side areas, respectively. The increase of amount in the inside area would mainly attribute to materials transported in beyond the seaward ends of the south and north breakwaters from the outside of them, because these breakwaters could not be still considered as a complete littoral barriers. But the most of littoral material transported around the seaward ends of both breakwaters must have been trapped in the inside area during the above one year, on the view-point of wave height as shown in Fig. 4.

On the other hand, the alongshore components of wave energy calculated from the significant waves at the contour line of 6 m depth are 20×10^5 and 21×10^5 ton.m per meter of beach length in the southerly and northerly direction, respectively, during this one year.

From the above-mentioned, the net alongshore littoral transport per year would be roughly estimated by distributing the amount of materials trapped in the inside area into the north and south area, proportionately with the above alongshore wave energy components. Then, if the amount of materials transported southerly and northerly from the south and north side areas, respectively, was neglegible small, the alongshore littoral transport per year would be as follows;

$(49 + 15)\times10^4 = 64\times10^4\ m^3$ in the southerly direction

$(44 + 16)\times10^4 = 60\times10^4\ m^3$ in the northerly direction

The above calculation would contain errors of a few ten percent on account of the error of sounding in addition to the above rough computation. But the difference between the above northerly and southerly littoral transport, that is, the net transport rate would be estimated to be less than $10^5\ m^3$ per year. The direction of net alongshore component of wave energy per year has been estimated to be changeable with the year from the calculation on the basis of the past data, so that the direction of the net alongshore littoral transport should be southerly in some years and northerly in the other years. This result coincides with the facts that this coast is of stable beach and that the source of sand drift is the coast itself, as shown in the previous section.

INVESTIGATION OF SAND MOVEMENT BY FLUORESCENT TRACERS

In many countries, fluorescent tracers have been already extensively used in field observations and experiments of sand movement. In this field investigation, less than 100 kg of fluorescent tracers had been injected per one point until 1965, in order to observe sand-movement in natural beach and sand-passing through the breakwaters. At that time, in order to make fluorescent tracers, polyester resin had been used as adhessive, so that dryed mixtures of natural sand, resin, and fluorescent dye had to be crushed in seperate particles. So, it was very hard to prepare a large amount of tracers.

A large amount of tracers, however, has been necessary to investigate the behavior of sand discharged on the shore outside the south breakwater in the excavation-works of fairways, which have started in fall 1965. Therefore, the method of production of tracers have been improved to meet this necessity.

PRODUCTION OF TRACERS

In order to avoid the necessity of crushing, methyl-methacrylate resin has been chosen as adhessive. Thus, fluorescent resin has been made in a plant by means of enough mixing of acetonic solution of organic fluorescent dye with methyl-methacrylate and canned to send to the site. This fluorescent resin contains 20 % of fluorescent dye in weight.

The tracers have been prepared by only mixing the above fluorescent resin and dry natural sand, for example, in the weight ratio of 10 : 100 for sand particles of 0.25-0.125 mm in diameters. In process of mixing, aceton contained in this fluorescent resin evapolates so as for a thin layer of fluorescent dye to adhere on the surface of separated each particle of sand.

INJECTION AND DETECTION

The tracers are mixed with the same amount of natural sand, before the injection. The tracers are injected in the way to release ropes fastening a mouth of a jute bag containing tracers on the sea bottom, or to place them on the foreshore at the tide of L.W.L.. In order to investigate the distribution of tracers, bottom materials around the injection-point of tracers are collected with grabe-type samplers, which are weighted with lead and hung down from a boat. After each collected sampler is spread uniformly in a box of 1000 cm^2 in bottom area, the tracers on its surface are counted under an ultra-violet light of mercury lamp. Vertical samplings are also conducted using an undisturbed thin wall sampler operated by divers in order to make certain the vertical distribution of tracers in the bottom sediment.

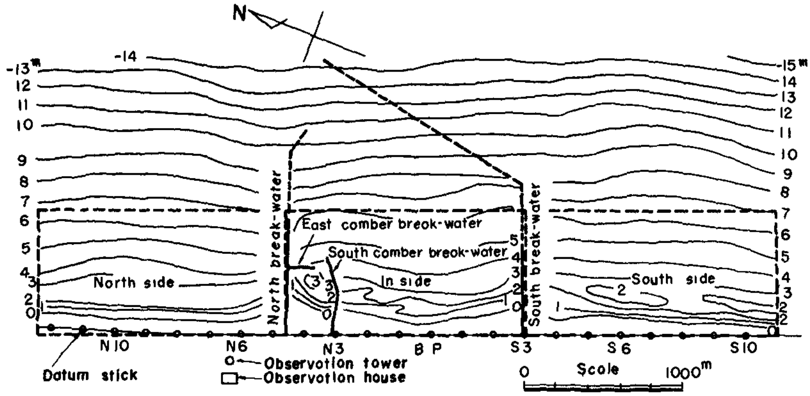


Fig. 12. Calculated areas of the volume change of materials.

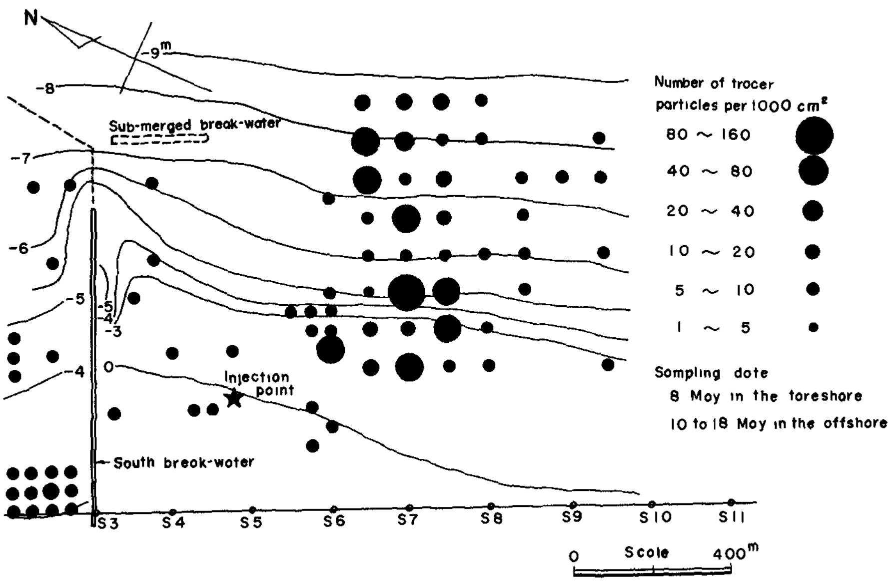


Fig. 13. An example of the distribution of fluorescent tracers.

DISTRIBUTION OF TRACERS

A series of investigation using fluorescent tracers has been started in March 1966 in order to trace the behavior of sand discharged on the shore outside the south breakwaters. Until now, tracers have been injected at four points by about 0.3 m^3 per point on 18 to 19 March and at four points by one cubic meter per point on 7 July.

Fig. 13 shows an example of the plane distribution of tracers. The tracers of 0.3 m^3 have been placed on the foreshore on 18 March 1966. The collection of bottom materials has been done on 8 May on the foreshore and 10 to 18 May in the inshore zone. Tracers seem to have spread mostly offshoreward in the direction of west and some part of them have moved around the head end of the south breakwater into the inside of the south breakwaters.

INVESTIGATION OF LITTORAL CURRENT

Longshore currents have been measured using a float which consists of a ball of 13.4 cm in diameter connecting to another ball of 6.7 cm in diameter with a fishing-line of 3 m in length. After the larger ball is filled with sea water using a medical injector, this float is thrown by hand into the surf zone from the shore, so that the smaller ball should be moved floating in accord with the movement of the submerged larger ball. Then, the position of the float on each time is measured by the eye-sight of the smaller ball.

Fig. 14 is an example of the results, in which the seaward distance depends entirely upon the eye-sight and the longshore distance depends upon the eye-sight on the basis of datum sticks along the shore. The velocity histogram on the right hand side of Fig. 14 shows the occurrence number of the longshore current velocity picked up at intervals of ten meter distance along the shore line from the diagram shown in the lower portion of this figure. The mean velocities given from such histograms have been related directly to the deep water waves as follows.

In general, the longshore currents are related with the characteristics of breaking waves and the bottom slopes. But it is difficult to determine the angle of breaking line against the shore line because waves usually break at a slight angle to the shore line. However, when the contour lines of depth are nearly parallel to the shore line like this coast, the following consideration would be permissible.

The alongshore energy component entering the surf zone at the breaking line is $n_b C_b E_b \sin\alpha_b \cos\alpha_b dx$ per the length dx of the shore line, as shown in Fig. 15. On the other hand, there are the following relations between the deep water waves and the breaking waves when the contour lines of depth are parallel each other;

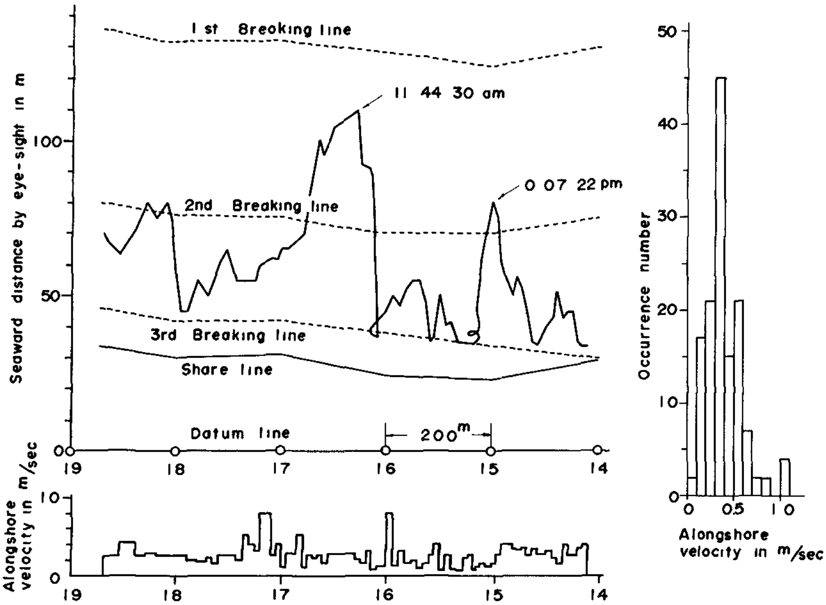


Fig. 14. An example of longshore current diagram.

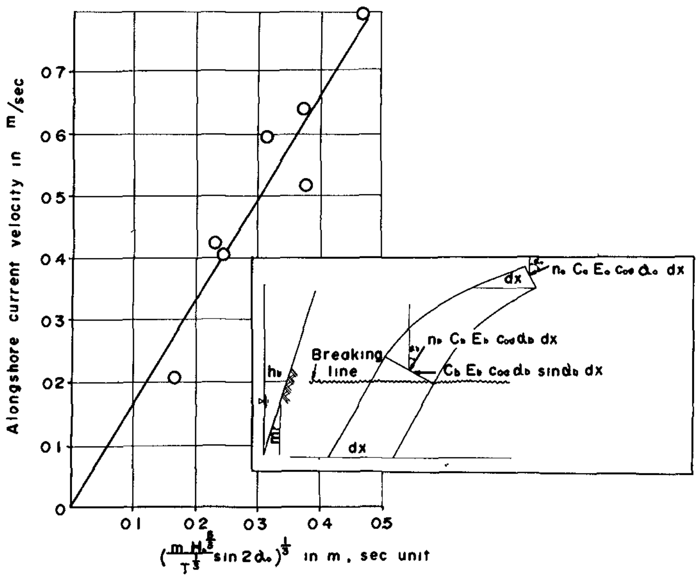


Fig. 15. Relation between longshore current velocities and characteristics of deep water waves.

$$\left.\begin{aligned} n_o C_o E_o \cos\alpha_o dx &= n_b C_b E_b \cos\alpha_b dx \\ C_o/C_b &= \sin\alpha_o / \sin\alpha_b \end{aligned}\right\} \qquad (1)$$

where n, C, E, and α are the ratio of group velocity against wave velocity, the wave velocity, the wave energy per unit area and the angle of wave crest against the shore line, respectively, and $_o$ and $_b$ are the suffixes for deep water waves and breaking waves, respectively.

Then,

$$\begin{aligned} n_b C_b E_b \sin\alpha_b \cos\alpha_b dx &= n_o C_o E_o \cos\alpha_o \sin\alpha_b dx \\ &= \tfrac{1}{2} C_o E_o \cos\alpha_o C_b/C_o \sin\alpha_o dx \\ &= \tfrac{1}{2} C_b E_o \cos\alpha_o \sin\alpha_o dx \end{aligned} \qquad (2)$$

If the velocity of alongshore current and the friction coefficent are respectively V and K in surf zone;

$$\tfrac{1}{2} s\, C_b E_o \sin\alpha_o \cos\alpha_o dx = K \rho V^3 dx\, h_b/m \qquad (3)$$

$$V = \frac{s}{K\rho} \frac{1}{2} \frac{m\, C_b E_o}{h_b} \sin\alpha_o \cos\alpha_o \qquad (4)$$

where s, ρ, h and m are the ratio of energy consumed to maintain the longshore current, the density of sea water, the water depth of breaking line and the mean bottom slope in the surf zone, respectively.

Using the relation of solitary wave theory as follows;

$$C_b = g\,(h + H)^{\frac{1}{2}}$$

$$H = 0.78\, h_b$$

$h_b = 0.448\ (T\, H_o/\, k_r)^{\frac{2}{3}}$ in the unit of m and sec, where k_r is the coefficent of refraction,

and $E = \frac{1}{8} g H_o^2$ in the equation (2),

$$V = \left(\frac{1}{2}\frac{s}{K\rho}\right)^{\frac{1}{3}} \left[\frac{(1.78\, g)^{\frac{1}{2}} g}{8 \times 2 \times 0.448^{\frac{1}{2}}}\right]^{\frac{1}{3}} k_r^{\frac{1}{9}} \left[\frac{m\, H_o^{\frac{5}{3}}}{T} \sin 2\alpha_o\right]^{\frac{1}{3}} \qquad (4)$$

If $k \doteqdot 1$,

$$V = K_o \left[\frac{m\, H_o^{\frac{5}{3}}}{T} \sin 2\alpha_o\right]^{\frac{1}{3}} \qquad (5)$$

where K_o is of dimension and should be determined by the data of measurement.

Fig. 15 shows the relation between the mean velocity of longshore current and the characteristics of deep water wave according to the equation (5) using the data obtained in the case that the deep water wave is 2.0-0.7 m in height and 9-10.5 sec in

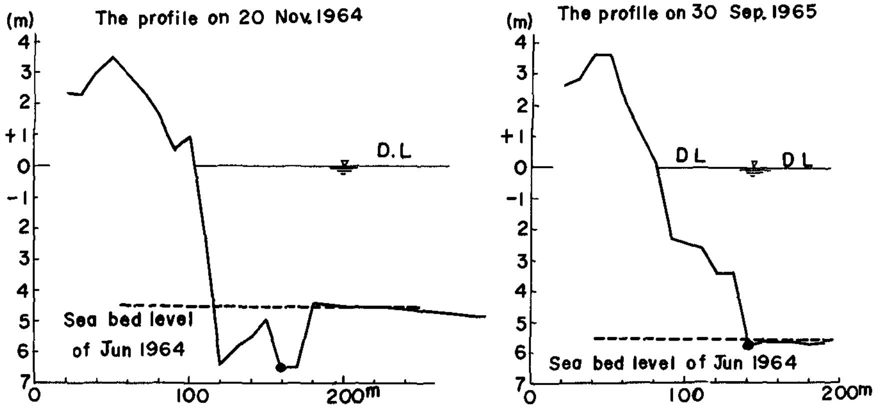
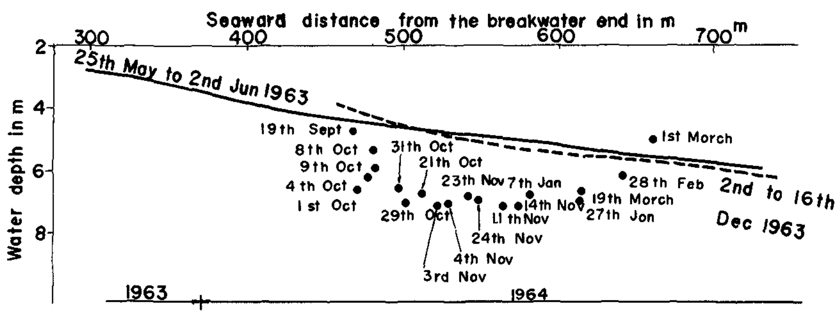


Fig. 16. Scoured hollows at the tip of breakwater.



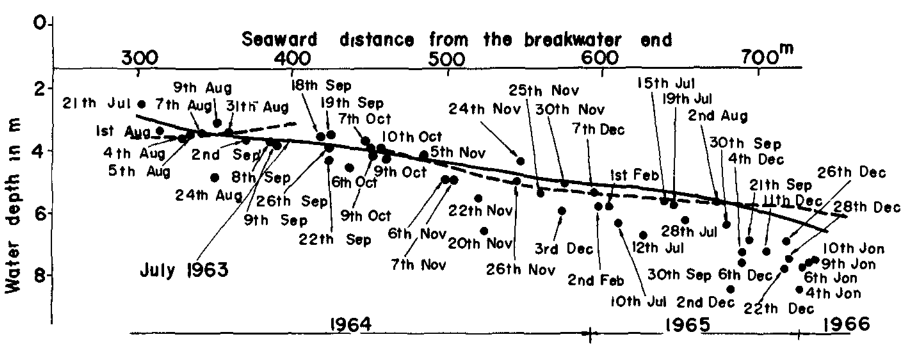


Fig. 17. Water depths of scoured hollows at the tips of the south and north breakwaters.

period. In this figure, K_0 would be assumed be 1.6 in the unit of m and sec.

INVESTIGATION OF SCOURING

Scouring around the coastal structure is also one of important problems in the harbor-works on sandy coast. Scouring depth at the tip of breakwater was sounded by a crane in process of construction-works. A sounding lead was hung from the 30 m arm of a crane.

Fig. 16 shows examples of the results of sounding by the above method and it also shows the profiles along the center line of the breakwater. (a) in this figure is the profile on 20 November after the maximum $H_{\frac{1}{3}}$ at 11 m depth was 3.0, 2.0, 1.2, and 1,1 m respectively on 16, 17, 18, and 19 November 1954. In this case, the scoured hollow is of W-figure in shape. (b) of the same figure is the profile after relatively smaller waves of less than 1 m in height continued. In this case, the scoured hollow is of V-figure in shape.

The water depths of these scoured hollows are shown in Fig. 17 by black dots against the distance measured from the landward end of the breakwater. In other words, the abscissa of each dot is nearly equal to the situation of the tip of breakwater at the time when each survey of scouring was done. In the case of the south breakwater, some dots situate above the bottom profile, which was surveyed at the time when the breakwater was not still so long. This fact seems to be attributed to the sand deposit in the vicinity of the breakwater.

Each scouring depth, that is, the ordinate difference between the bottom profile and each scouring dot in Fig. 17 has been plotted against the maximum significant wave height for 5 days before the surveying date of each scouring, as shown in Fig. 18. In this figure, the scouring depth does not exceed the significant wave height, except the case that the significant wave height is less than nearly one meter. The scattering of dots beyond $H_{\frac{1}{3}}$ for the case of waves of less than nearly one meter seems to be attributed to the fact that the hollow scoured by high waves can not be easily burried by the subsequent low waves.

It is doubtful how exactly Fig. 17 shows the scouring depth during the time when stormy waves are attacking the breakwater. Therefore, a self recording scouring-meter using a radioisotope shown in Fig. 19 has been tested northside the north breakwater. The detection pick-up consists of a Geiger-Muller tube and a radioisotope source of Cesium-137 of 25 millicuries, which is sheld with lead for the up and down direction, as shown in Fig. 20. The radiations emitted from the source are scattered by the materials around the pipe, of which some parts reach to the Geiger-Muller tube. The scattered radation caught by the Geiger-Muller tube is recoreded through a log-count rate-meter on the land.

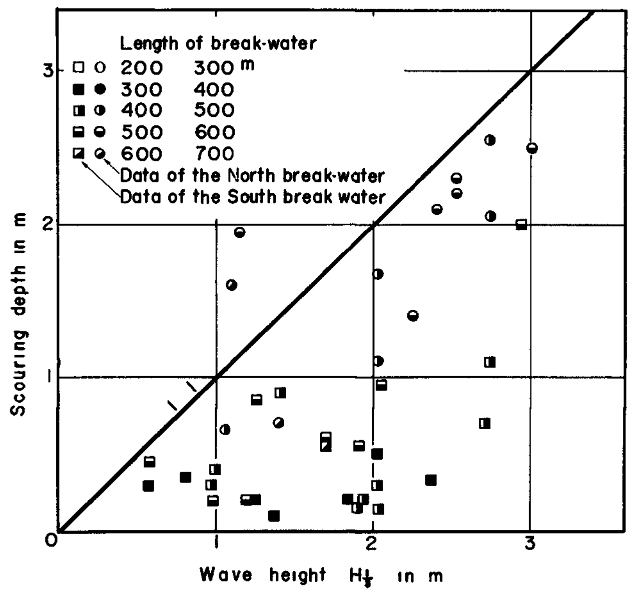


Fig. 18. Relation between wave height and scouting depth.

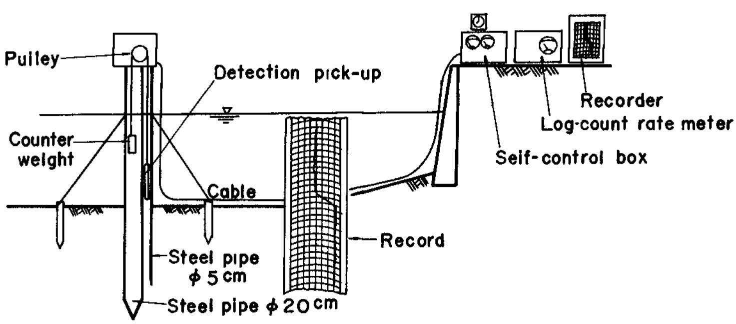


Fig. 19. Self-recording scouring meter.

The scattering rate of radation in sea water differs from that in bottom materials, so that the recording rate sharply changes at the sea bottom, as shown in Fig. 20. The pully is drived with an electro-motor in the top box of the pipes through the cable by the self control box on the land, so as to move the pick-up in the speed of 20 cm per minuts.

The above scouring-meter has been automatically driven each hour or every 12 hours. An example of records is shown in Fig. 21. This record would not show exactly the scouring at the toe of the breakwater, because the pipes of the scouring meter have been set 4 m depth of about 15 m apart from the breakwater and the scouring by the infuluence of the pipes themselves would seem to be contained in this record. But, from this figure, the depth of scouring seems to increase with the increase of wave height and decrease with the increase of wave period.

Two sounding-meter of the same type as the above-mentioned have been scheduled to be set beside the breakwaters in fall 1966. and an ultrasonic sounding-meter has been also scheduled to be tested in order to get the data which do not contain the influence of the pipe itself.

FUTURE CONSIDERATION

This field investigation will be continued until the completion of this harbor, although the main point and the method of the investigation change with the progress of the harbor-works. During the comming two years, the shoaling inside the breakwaters, the behavior of sand discharged on the shore outside the south breakwater and the scouring at the toe of the breakwater will be mainly investigated in order to get available data for the harbor-works.

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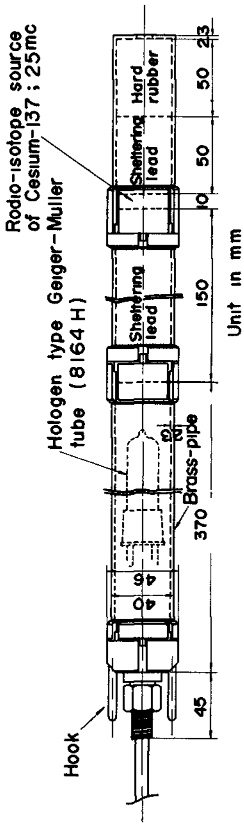

Fig. 20. Detection pick-up of the scouring meter.

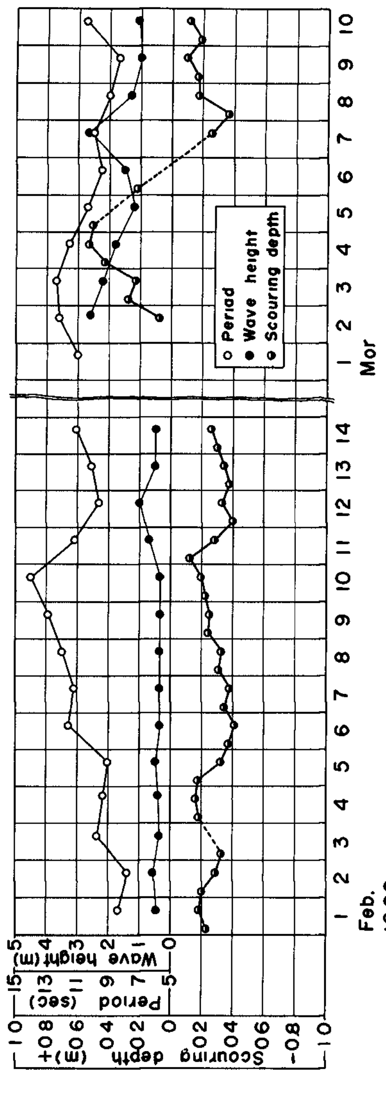

Fig. 21. A record of the scouring meter at 4 m depth beside the north breakwater.