Chapter 22

ON THE EFFECT OF AN OFFSHORE BREAKWATER ON THE MAINTENANCE OF A HARBOR CONSTRUCTED ON A SANDY BEACH

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INTRODUCTION

In this paper the author describes an experimental attempt to prevent the rapid blocking of a harbor entrance caused by littoral drift in the summer period. This work was conducted at "Seppu", a fishing harbor constructed on a sandy beach in Hokkaido, Japan. This investigation was originally sponsored by the Harbor Section of the Hokkaido Prefectural Office. One of the top priority objectives, at that time, was to determine the efficiency of two jetties constructed on the updrift side for the purpose of countering the sand drift. Detailed observations including preliminary model experiments, were made from 1961 to 1963 on the general aspects (ie condition and phenomena) of the coast in question. Meteorological data were also compiled together with investigations as set forth by the government.

Based on the above, the author finally suggested the utilization of natural forces ie waves, offshore currents etc, by constructing an offshore breakwater to curb the blockage of the harbor mouth.

This idea was shown to be adequate at least qualitatively by model experiment with the exception of the troublesome time scale problem. These findings, however, have not been adopted as yet for actual improvement of the harbor at present.

DESCRIPTION OF THE PROTOTYPE

GENERAL DESCRIPTION

The Hidaka coast, where the above mentioned fishing harbor is located, faces the Pacific Ocean, and its 160 km shoreline is a continuation of gently curved arcs from Point Erimo to Tomakomai harbor, stretching in a south-easterly direction. The general view of the Hidaka coast is shown in Fig.1.

Many rivers from the Hidaka mountains flow into the ocean transporting large quantities of sand and gravel. Moreover eroded cliffs and beaches can be seen in many places along the coast. Accordingly it may be surmised that a large amount of sand is drifting in the vicinity of the shore line extending over many miles of this coast. A rough survey of the coast reveals a general trend of deposits of sand exclusively on the south-eastern side of the water-front structures, for example, jetties or breakwaters, which project at right angles to the coast line. On the other hand it was noted that the north-western side of these structures were more or less eroded. The directions of river mouth are angled in most cases in a westerly direction by littoral current. However, in a few exceptional cases an alternation of river mouths by summer and by winter, according to their geological condition was seen.

Moreover, observations revealed that the complicated problems resulting from the drifting sand occured more frequently along the coast line to the west of Shizunai than along the coast line to the east. Some examples of the difficulties due to drifting sand will be given on the fishing harbors "Seppu", "Atsuga", "Mitsuishi", and "Higashishizunai", and various other sites along the coast line between these fishing harbors.

In Seppu harbor the south-east breakwater was constructed by steps over a period of 10 years adding 20 or 40 meters at a time due to governmental reasons. Immediately after the construction of the first section, progression of the south-eastern beach was observed reaching the head of the construction by the end of the summer period with a retreat of coresponding lengths in the winter period. This was repeated until the final construction of the breakwater in 1963. It was noted that the progression of the sand in the windward of the break-water became practical solid ground approximately 1 meter above sea level. This results in a rapid blocking in some cases of the harbor entrance channel, which is reopened in winter, and this was repeated each successive year for each addition of the breakwater construction. On the north western beach adjacent to the harbor, the situation was entirely different. In other words a gradual receding of the coast was noted. In addition during the corresponding summer months there were no sand deposits even in the recess between the groins. Thus, the base of revetment is washed directly by waves approaching obliquely to the coast. At a distance of 500 meters along the coast to the west of the base of the north-west breakwater no sand deposits even in updrift recesses of the groins were seen. Thus, with increase of the random loss of the groins by scouring, the revetments protected by the groins gave way to severe scouring which eventually resulted in the breaking up of the revetments.

A similar state of affairs was seen in the Atsuga harbor. (Fig.1.) Here also the progression of the beach on the south-eastern side, and the recession on the north-western side was observed. Approximately 1 km to the west of this harbor, a large number of groins, consisting of wooden piles and stone rubble were destroyed after the construction of the harbor.

As a result, with the loss of the revetments, the Hidaka railroad running parallel to the coast, became exposed to the direct washing over by waves. According to the inhabitants of this area, this direct exposure to wave damage was not seen before the construction of the harbor.

Next, in regard to the mouth of the Niikappu river, a few miles south-east of Seppu, while a slight swerving to the west was seen, this change did not go any further. This may be attributed to the protective effect of a point of land consisting of hard rocks jutting out into the sea.

Over some distance of the western beach extending to the downdrift side of these projected rocks, a remarkable erosion can be seen at present. There is a place eroded violently, also between Shizunai and Niikappu. At this place there remains an old sand dune of approximately 10 m height, and several hundred meters in length, half of which has already been eroded on the seaside. Thus the railroad and highway formerly passing by the dune was transfered to a more stable location.

Concerning the fishing harbor Higashishizunai which is located 10 km to the east of Shizunai, it is a well known fact that this harbor was once buried almost completely by sand immediately after its completion. Since this incidence, plans for a new harbor were carefully investigated to avoid such conditions and as a result at present the harbor has a new outer breakwater built some distance on the seaside of the previous breakwater. Since then the condition of the harbor has improved considerably. However, the beach to the south of the breakwater of this harbor began to recede, especially in the winter as in the previous case.

Now as an additional situation the Monbetsu river mouth lying close to the west breakwater, began to show a tendency of changing its direction towards the east. This tendency seems to depend largely upon the appearance of the new outer breakwater.

At the Mitsuishi fishing harbor, at present while no annoying problems concerning drifting sand on the harbor itself have been observed, on the western beach adjacent to the west breakwater an increasing recession of the coast line has manifested itself especially in recent years. As a means of prevention solid revetments and permeable groins are now under construction. Although the direction of the mouth of the

Mitsuishi river located close to the harbor is westward in summer season, in winter it turns eastward towards the Erimo point. On the shoreface immediately outside of the south breakwater a considerable amount of sand is deposited in summer. Extending over the entire length of the Hidaka coast waves sweeping in during the winter have a more serious effect upon the coastal erosion than those in summer. The summer waves generally have a longer period or smaller steepness than those in the winter.

The above mentioned facts seem to provide us with some important suggestions in surveying the data already prepared, on the wind, the waves the offshore current and the drifting sand of the Hidaka coast.

WIND, WAVES, AND CURRENT

Wind The windrose shown in Fig.2. is the result of observations performed by the Construction Office of the Seppu harbor in 1961 and 1962. The frequency distribution of the wind direction is also shown in Table 1. A more detailed analysis of the data shows that the directions from ESE to S are most frequent in the summer and in contrast those from W to NNW are dominant in the winter. These tendencies of the wind direction coincides with those of the waves washing the coast of Seppu harbor. Since the coast line of the Hidaka runs in a SE direction the general trend of winds are at oblique angles along the entire coast line. The shoreline is at an angle of 40 to 60 degrees to the direction of the summer wind which sweeps in from the south-eastern seaside. In winter, the shoreline is at an angle of 0 to 30 degrees to the wind from the west.

Waves The observation of waves at Seppu was commenced in 1961 and has been continued ever since. The apparatus used here for the purpose is rather simple and inexpensive. It is an ordinary transit type provided with a handle connected to the horizontal axis and some other transmission mechanisms for recording. The observer of the transit follows the vertical movement of a buoy set beforehand at an adequate position in the sea, and then the recording pen, attached to the end of an arm connected to the horizontal axis at a right angle, runs on a paper rolled on drum, which gives a scaled wave motion. The observation is usually done twice a day throughout the year, at 9:00 in the morning and at 3:00 in the afternoon. By this method, however, it is practically impossible to make observations at night or on snowy or heavy rain days. There were a considerable number of days in which the observations were impossible because the offshore buoy was often washed away in rough weather.

An interesting feature of the incident waves on this coast was noted by reviewing the general tendency of waves

TABLE 1. --WIND DIRECTION (FEB., 1961, to MARCH, 1962)

Wind Direction	S	SE	SW	SSE	SSW	N	NE	NW	NNE	NNW	W	WNW	WSW	E	ESE	ENE	Total
The number of Times	27	54	14	44	7	9	7	47	5	6	61	33	24	11	26	2	377
Frequency (%)	7	14	3	11	1	2	1	12	1	1	16	8	6	2	6	0.5	

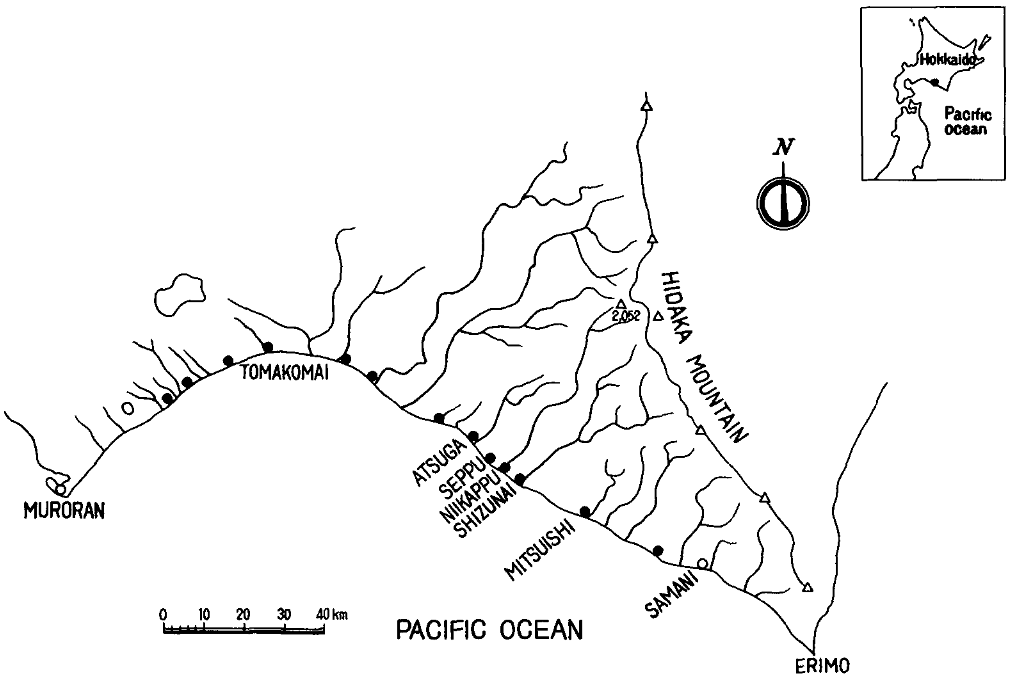


FIG. 1 --LOCATION MAP OF HIDAKA COAST

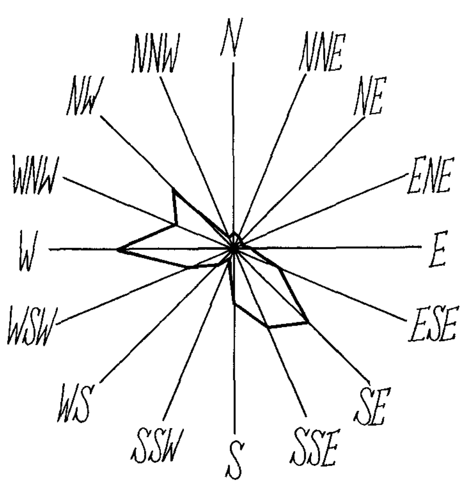


FIG 2

coming to this harbor as a whole and by further more careful observations on details by season and by month.

The diagram shown in Fig.3. is a histogram of wave height and wave period accumulated as a significant wave for the total number of observations from February 1961 to March 1962. From this figure, it can be seen that the most frequent height of the incident waves was from 50 to 60 cm and their most frequent period was 3 seconds throughout a given year. As far as the present data of observation is concerned, the maximum value for wave height and wave period were 310 cm and 8 seconds respectively, and the frequency of occurence of the wave height above 100 cm was 36 % and that of the wave period above 5 seconds was 17 %. Furthermore from April to October, the occurence frequency of the wave period longer than 5 seconds is higher than that from November to the following March.

With regard to the wave height, we do not know at present whether a similar tendency exists or not. However within the limit of the present available data it may probably be said that the occurence frequency of the wave height above 100 cm is higher in both September and October than in others.

With regard to the direction of incident waves which have an important effect on the movement of the drifting sand, those from W to WNW were quite frequent in winter.

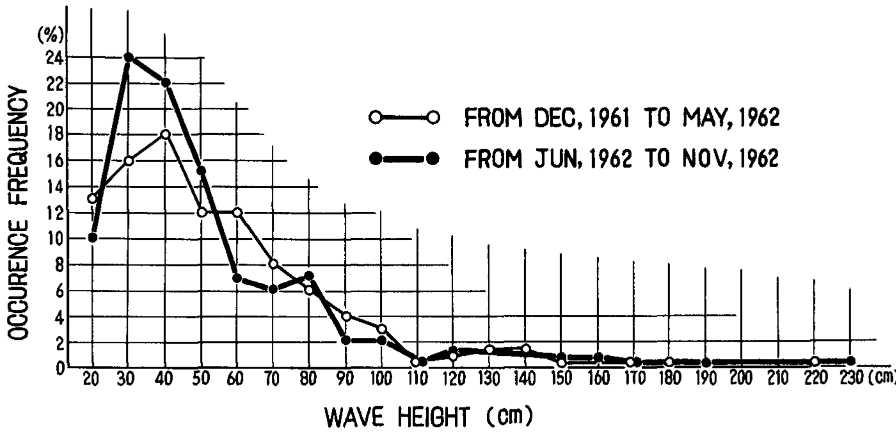
<u>Current</u> It is a well known fact that the direction of the incident waves is closely related to that of littoral current, which has also been proved on the Seppu coast. In Fig.4. and Fig.5. the frequency diagrams on the direction of the incident waves and that of the littoral current are shown respectively. It can clearly be seen that a very close correlation exists between them. Some current meters, including a autorecording type, were used for the field observations of offshore currents. As a supplement to these instruments, a simple method of current observation has been used by floating an anchored painted board which shows the direction of current.

CHANGES ON THE BEACH LINE AND ON THE PROFILE OF THE SEA BED ALONG THE COAST

Though the rough outline on the coastal changes occuring in various places along the Hidaka coast was as mentioned above, further detailed information on the changes of the beach line and sea bed in the vicinity of the Seppu are required prior to model experiments for the Seppu investigation.

As mentioned before the present water-front lay approximately 150 m to the seaward in the summer of 1962

FIG. 3. --FREQUENCY DISTRIBUTION ON WAVE HEIGHT



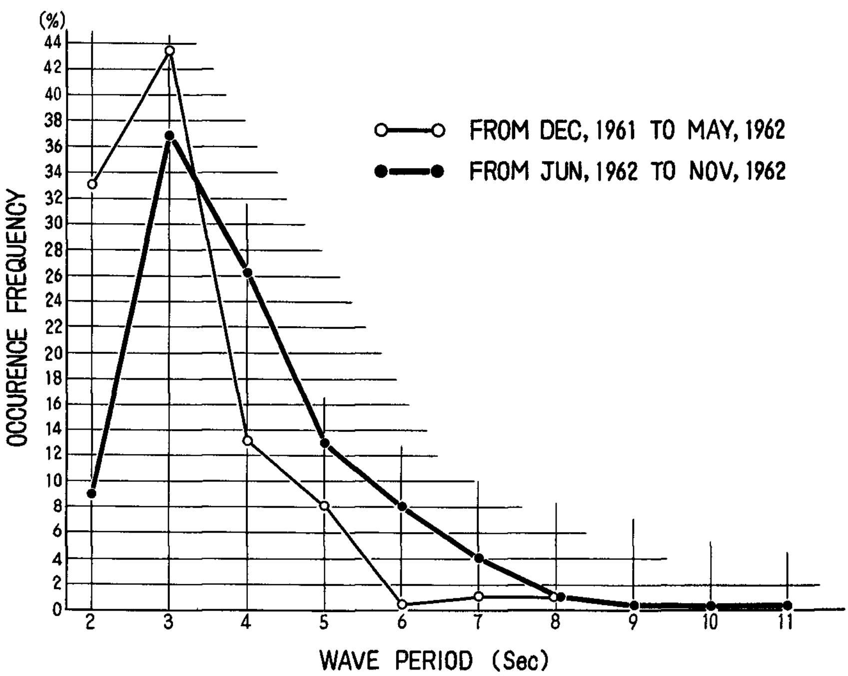


FIG 4. --FREQUENCY DISTRIBUTION ON WAVE PERIOD

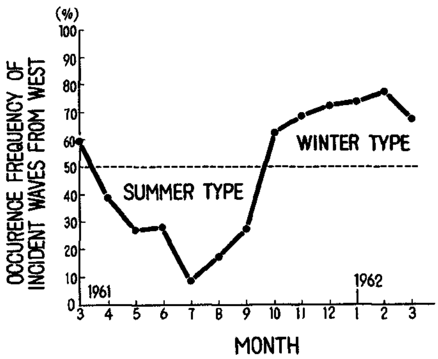


FIG. 5. --FREQUENCY DISTRIBUTION ON DIRECTION OF INCIDENT WAVES

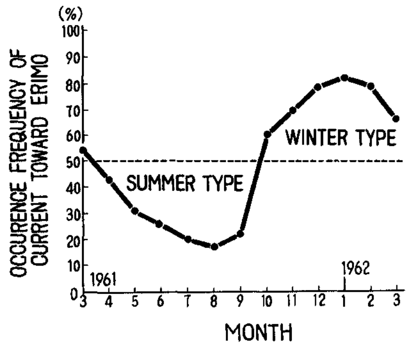


FIG 6 --FREQUENCY DISTRIBUTION ON DIRECTION LITTORAL CURRENT

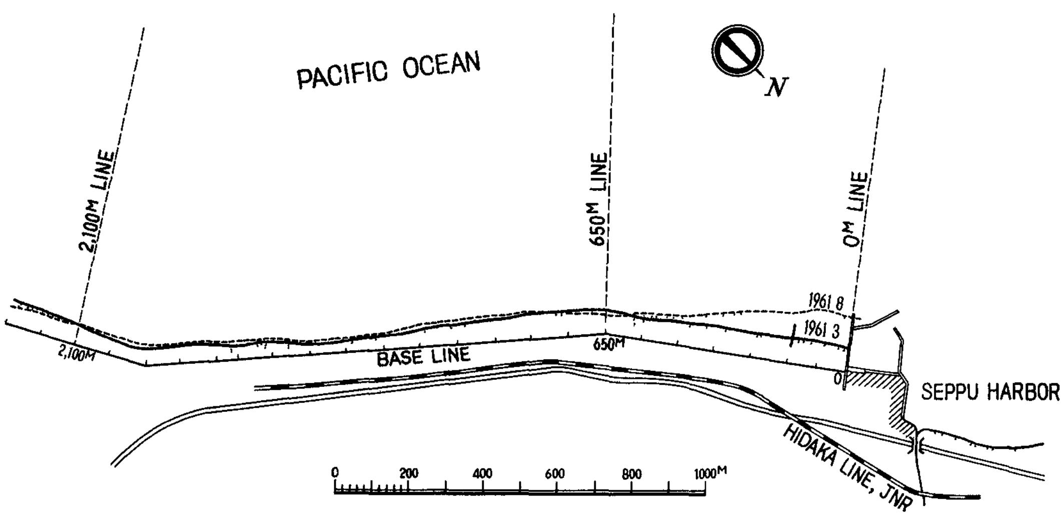


FIG 7 --LOCATION MAP NEAR HARBOR "SEPPU" as compared to that of 1948, which is the year prior to the construction of the breakwater. The water-front showed a recession of 50 to 80 m usually in winter. The total amount of this recession is, however, decreasing gradually in accordance with the two added jetties, one of which extends from the joint where the south breakwater first turns and another is placed about 150 m apart along the coast to the east side of the breakwater. The two jetties are approximately 40 meters in length and both project at right angles to the coast line. This fact is clearly shown in Fig.8, in which the results of monthly observations are plotted regarding the progression or recession of the beach. In each diagram the distance from the base line to the water-front is plotted in the ordinate and the time is plotted in the abscissa.

In Fig.8, "a", "b", "c", "d",....show respectively the position on the shoreline at 150 meter intervals in a south-easterly direction. Fig."a" shows the position of the water-front at a point close to the south breakwater in the manner as above. Figures "a",...."d" indicate the maximal and minimal line of progression and recession of the shore line during August~September and January~February. It was noted that in accordance with the progressive distance from the harbor as in "e", "f",...the difference between the two decrease.

Now at greater distances from the harbor beyond the 2000 m point the time of the progression and recession show a complete reverse with the maximal recession seen from August to October and the maximal progression seen from February to March. Fig.9. represents the profile of the sea bed at points "0", "650", "2100". As may be seen, similar phenomena as indicated above are apparent. As a result of sounding, it was shown that at depths over 6.0 m no changes were seen on the sea bed. This site is 700 m off shore. As may be seen in this Figure, no sand bars were present which is a special feature of this coast.

From the above findings, the following may be surmised: ie (1) along the gently curving waterline between the south breakwater of Seppu harbor to the Niikappu river mouth a large amount of sand shifts towards the harbor in summer and during the winter this shift reverses its direction. (2) This migrating sand mainly consists of bed load drift which moves along the water line. This may be seen in the size distribution which clearly shows the difference in size of sand particles at the sea bed at a depth over 5.0 m as compared against that along the beach line.

In short, every year in summer during the typhoon season the swells (or waves of long period) sweep in along the coast and cause a massive migration of the comparatively large grained sand which makes up the beach line. This shifting sand moves out to the mouth of the harbor. After the blocking the mouth, at times part of this sand is known to reach the northern beach. It may also be surmised that the smaller sized sand grains are carried off shore composing a suspended drift

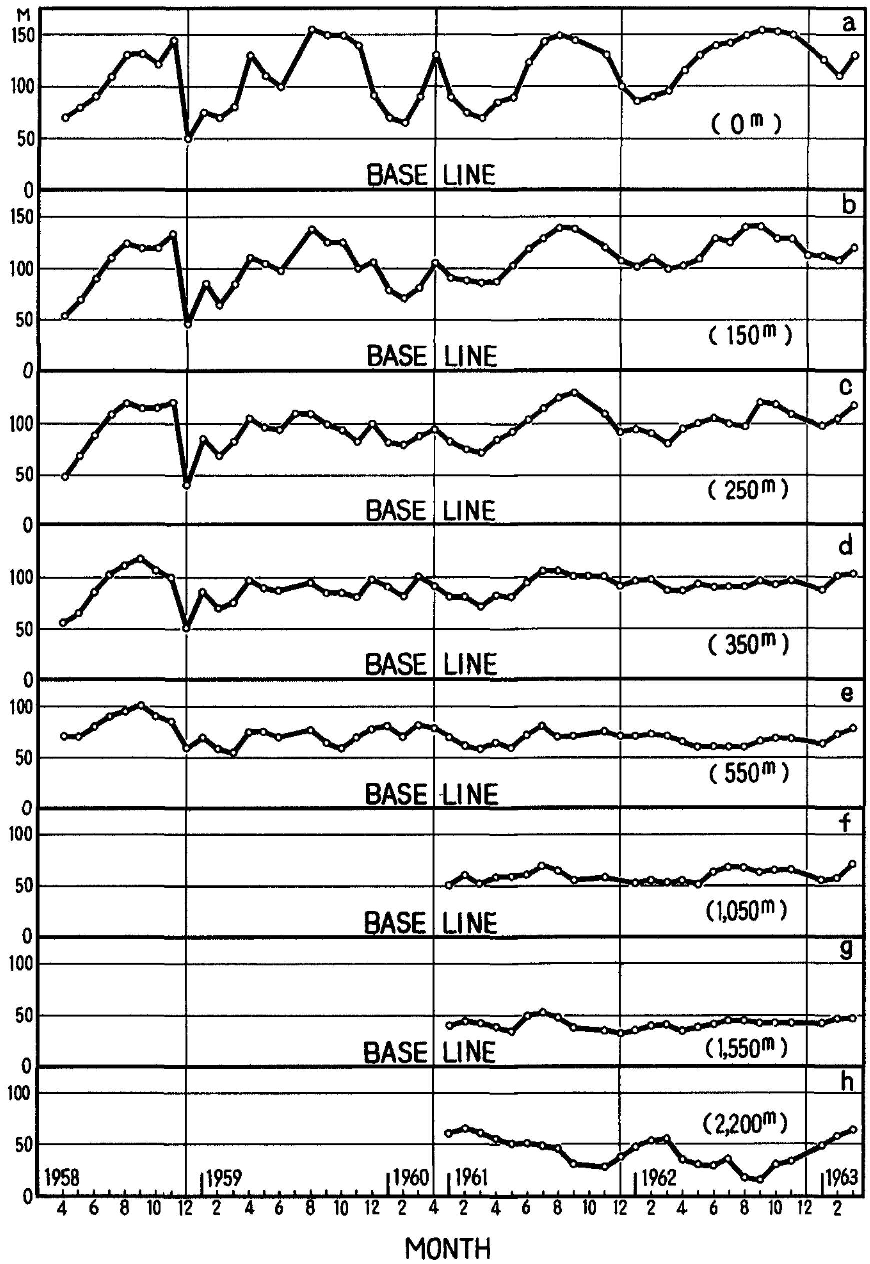


FIG. 8.--CHANGES OF BEACH LINE ON SOUTHEASTERN SIDE OF HARBOR "SEPPU"

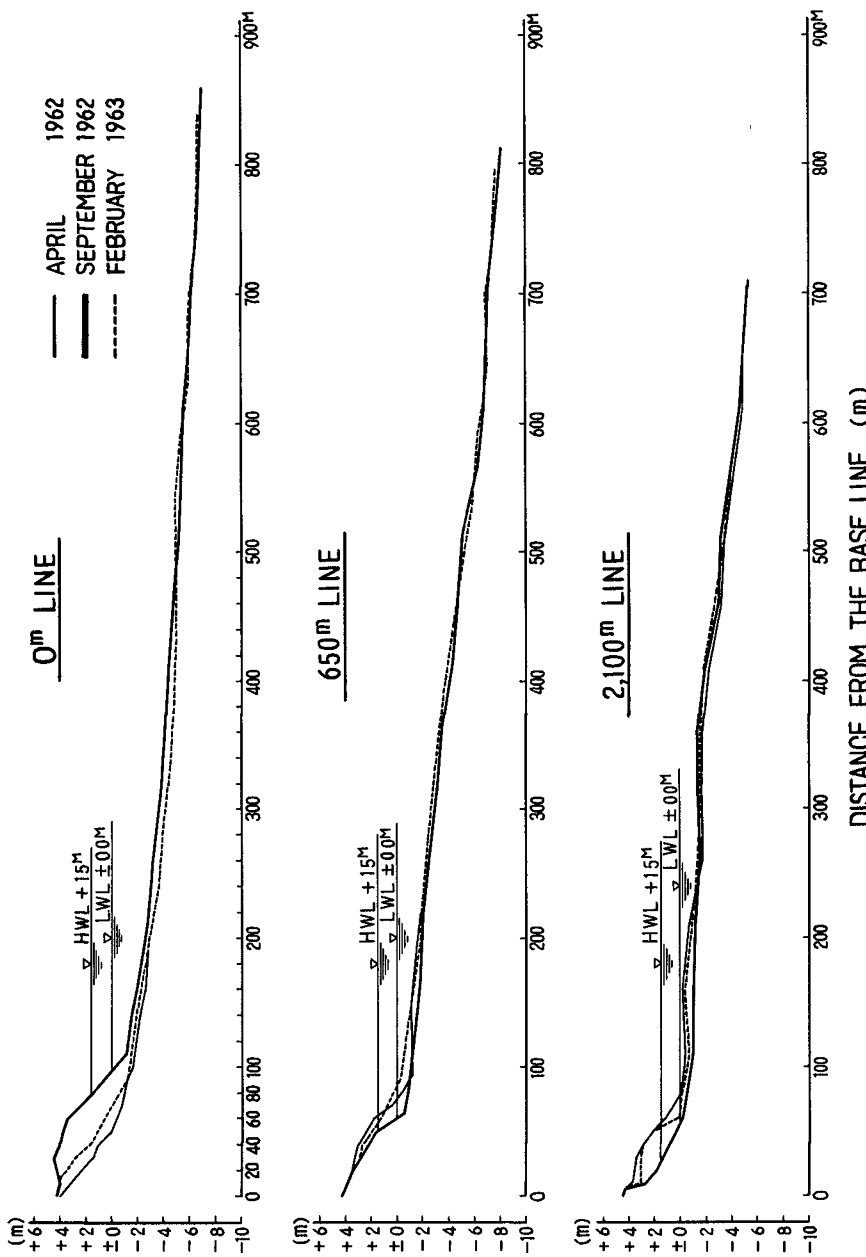


FIG. 9. --PROFILE OF SEA BED NEAR "SEPPU"

and may be carried across the front of the harbor entrance to the west.

However, a complete investigation concerning this has not been carried out. Nevertheless, it may be considered that no significant difference in volume between the amount of sand newly deposited along the entire sloping coast line between Seppu and the Niikappu river mouth, and the sand carried west past the harbor mouth exists. Therefore, it may be said that the blocking of the harbor mouth in summer is caused by a rapid shift of the sand deposited during the short period over the entire length of this section which results in the accumulation of sand on the south-eastern side of the harbor.

Summarizing the above, the following may be said.
(1) The beach line to the south-east of the harbor, when viewed for the entire year, shows an approximately orderly progression and recession.
(2) No remarkable sand bars are seen on the entire bed of the sea in the off shore areas in front of the harbor.
Further, it was observed that the sorting coefficient of the sand at depths over 5.0 m was small and even, showing a remarkable difference as compared against the beach line sand. Still further, in regard to the sand blocking the Seppu harbor, the size was large and generally the size was the same.

THE DRIFTING SAND

In the case of this model experiment no dynamical similarity between the motion of sand particles in the model and in the prototype exists, because the same kind of natural sand as in prototype was used for the movable bed materials. Now, as well known, sand movement on a coast may be divided into the so-called beach drift and suspended drift. However, in such a small scale model as described in the later part of this paper, it is impossible to observe the motion of the suspended drift itself in the model. In spite of this, a satisfactory similarity, at least qualitatively, with regard to the motion of the bed load drift may be expected.

From this point of view, the mean diameter and the sorting coefficient were chosen as the index, which shows the difference between these two types mentioned above. Thus, from the results of sieve analysis on numerous samples collected at various points on the beaches and shorefaces extending around Seppu, it was suggested that a large quantity of drifting sand in the form of beach drift or bed load drift contributed in blocking the harbor mouth. This may be said at least within the extent of the present work.

MODEL EXPERIMENTS

The initial purpose of the present model experiments was in determining experimentally the extent of the effect of the two proposed jetties on the prevention of harbor blockage. The jetties were proposed by the Harbor Section of the Hokkaido Prefectural Office. The dimension of the model basin was 7m x 12m. The depth of the tank was 0.4 m with a movable bed constructed on a 1/100 scale. The prototype represented by this model covers an area of 1060m x 670m. The sea sand used in the movable bed has a mean diameter of 0.4 mm and a specific gravity of 2.7. Since this is an experiment concerning the shifting of sand on the sea bed, as the law of similarity Reynold's law should be applied, however in the present work the calculation made on the wave heights and periods in the model experiment were based on Froude's law. The time scale will be dealt with in a later series of work. In other words, the size of sand used in the present model had no direct relationship with the prototype, and the movement of the sand was caused by the scoring force of the waves.

As for the current pattern since Froude's law was applied in the construction of the model the path of sand migration insofar as the beach drift is concerned, shows a similarity. Here the author considered the fact that the sand of the water line moves by the scoring force of waves on the sea bed, eventually resulting in erosion of the shore or accumulation of sand. However, he decided to ignore the complicated mechanism of the above, and endeavored to reproduce the outward appearance of the end result of the above as seen in the prototype. This was because, he considered that it would be sufficient to achieve the purpose of the preliminary experiment. Further, as seen in the description of the prototype, as a result of sand sampling and observations on shore line changes it was determined that the drift phenomena in the vicinity of Seppu harbor were almost invariably related with beach drift. Thus, in the model experiments qualitatively it was considered sufficient to observe the beach drift alone which greatly simplified the work.

In regard to the incident direction of the waves in the model, the direction was based on data previously described. Namely, the summer waves were from a SSW direction and the winter waves were from a westerly direction and the height and wave period, as described under waves, it was shown that wave heights of 50$\sim$60 cm and wave periods of 3$\sim$4 sec. had the highest frequency of occurence. However, at the actual site during August and September when the shore line rapidly advances and the harbor mouth is blocked, wave heights of 1.5$\sim$2.0 m with periods of 7$\sim$10 seconds show the highest frequency of occurence under the influence of typhoons. Now in view of the fact that during this period, the highest number of no observation days is seen, the accuracy of the data on long wave periods and wave heights may be lacking. This was taken into consideration and the experimental wave heights were set at 2.3 cm with a wave period of 1.0 second in 1/100 scale model. Naturally, comparative studies were made on the most frequent wave heights and periods.

The experiments were conducted as follows. The proposed jetties were placed in their positions in the model. Thereupon, as an initial step, waves from a SSW direction were sent in continuously over a long period and at given intervals, the changes of the beach line and the profile of the sea bed were observed. Thus, in the final stages the experiments were continued until the beach line advanced to the head of the breakwater and blocked up the entrance of the harbor. The time required for the above was used as the criteria for the purpose of comparing the phenomena as seen in the model experiments. As mentioned previously, the above has no similarity with the actual time of the prototype. An example of the experiment is given in Fig.10.

Next, experimentally, following the experimental on the proposed jetties, a plan for an offshore breakwater in parallel to the sea shore, it is well known that on the inland side a tombolo appears. In this particular case wave diffraction is seen at both ends of the offshore breakwater, and the resulting waves are reflected by the south breakwater. This results in a current between the offshore breakwater and the south breakwater which flows in the opposite direction to the normal current of this coast. As a result, the sand drift to the west is strongly inhibited, and a tombolo forms at the east end of the offshore breakwater. One example of this experiment is given in Fig.11.

By this method an extensive sand jetty reaching out to the offshore breakwater is formed by the strength of the waves. This results in a considerable delaying of the arrival of the sand pile to the mouth of the harbor. The location of the offshore breakwater together with its length was varied within reason.

While some difference was seen in the results, in all cases, insofar as the experiments using the same model are concerned, the time required for the tombolo to form was twice as long as that of the time lapse for the harbor mouth to be blocked by sand in the presence of the proposed jetties as set forth in the original plans.

In order to determine still further the effect of this offshore breakwater, the same model was reproduced in 1/50 scale in a 20m x 15m tank. The results of this large scale model experiments are shown in Fig.12....Fig.16. While the scale of this second model is twice as large as that of the first model, the sand composing the movable bed in the second case was the same size as the first.

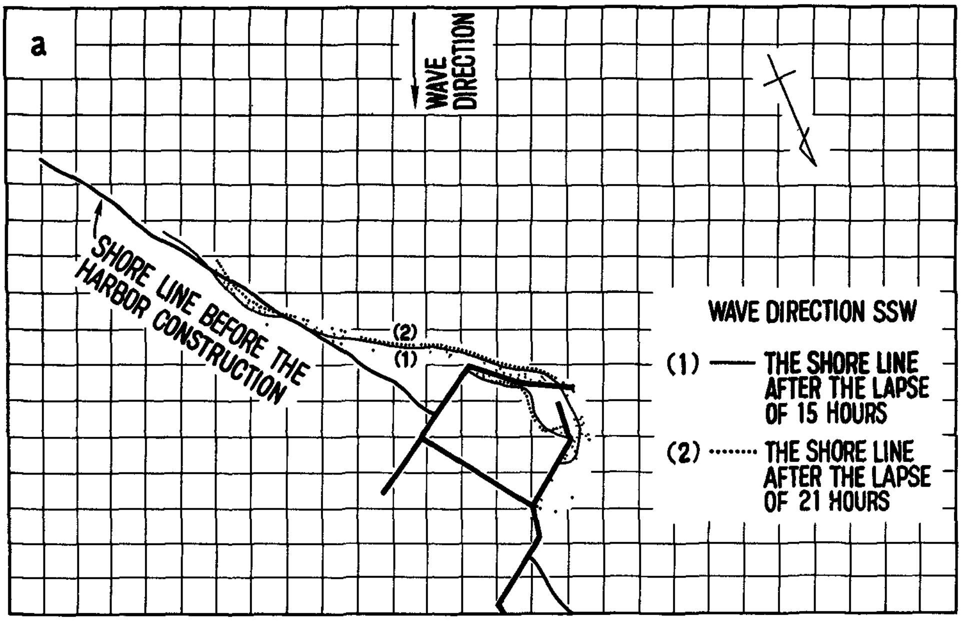


FIG. 10.--RESULTS OF EXPERIMENT IN THE CASE OF JETTIES

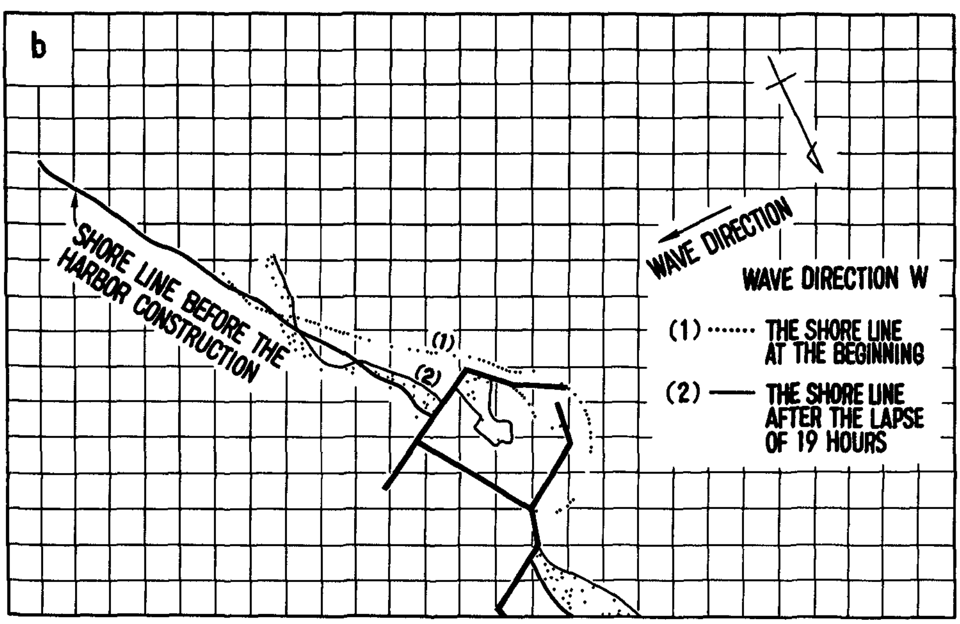
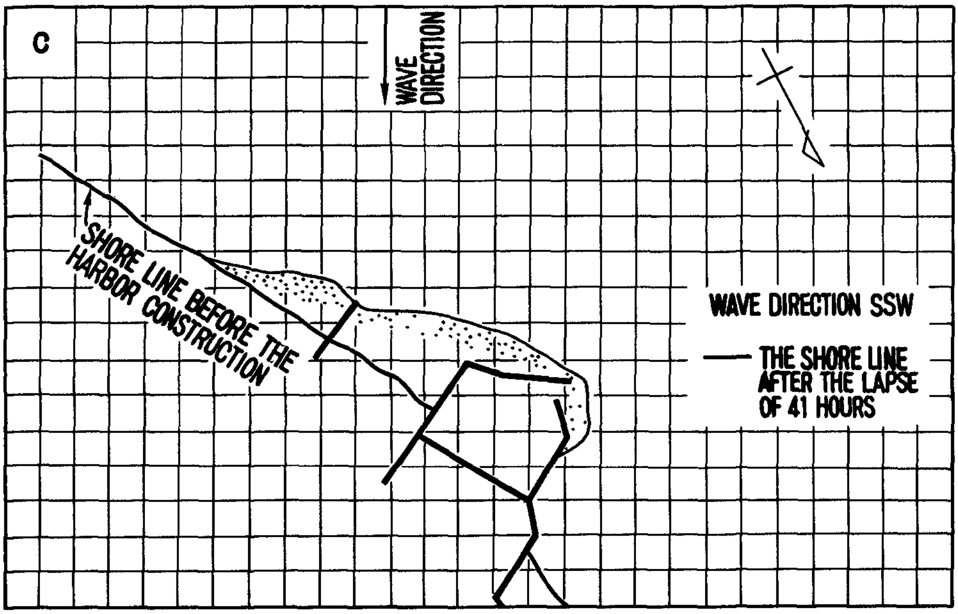


FIG. 10.--CONTINUED



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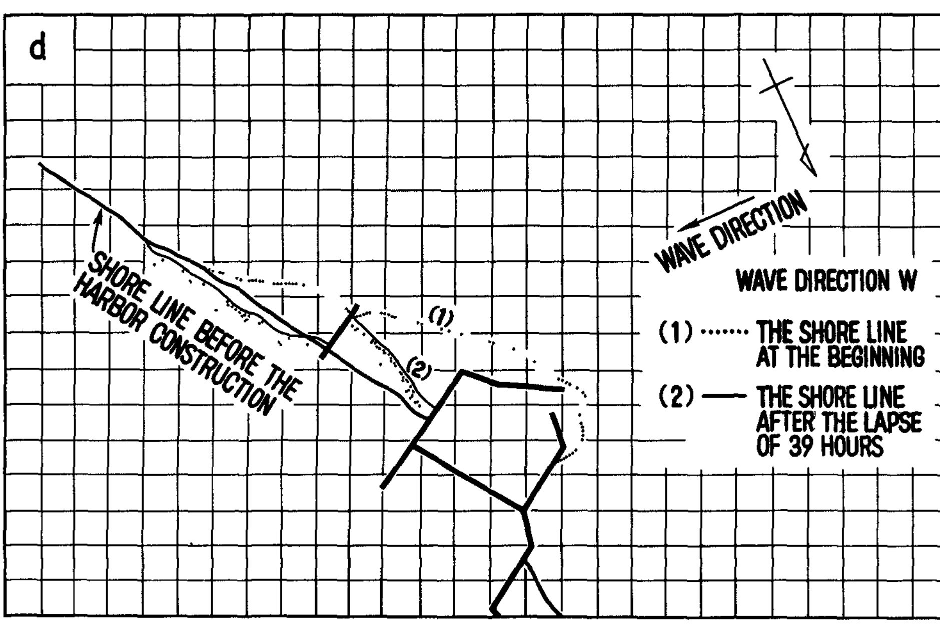

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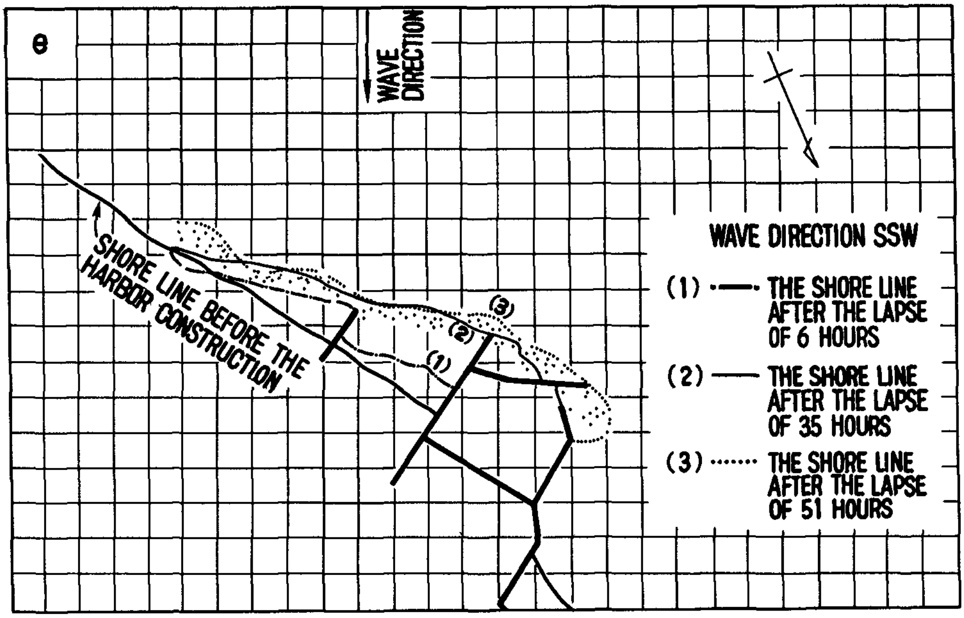
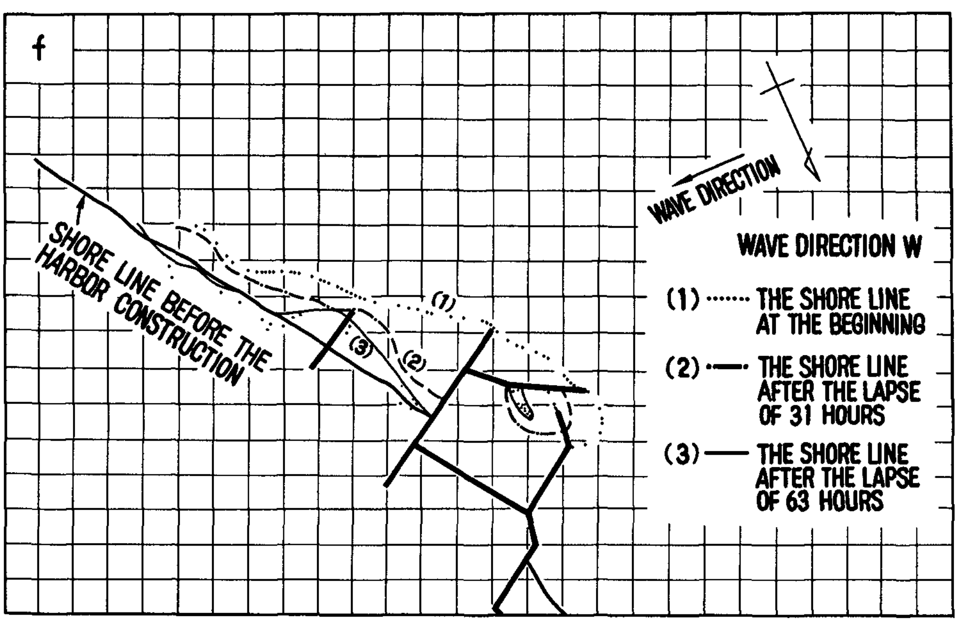


FIG. 10. --CONTINUED



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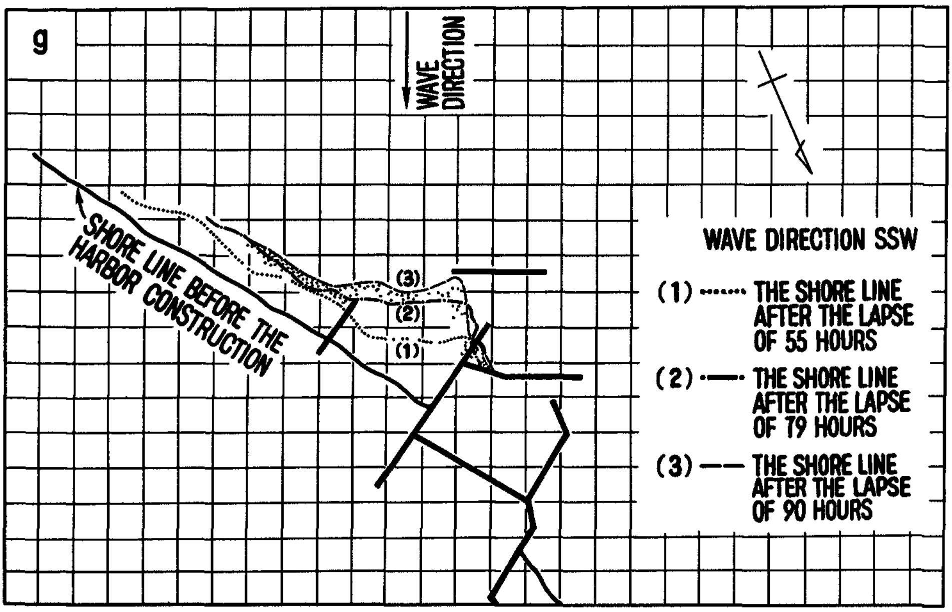


FIG. 11. --RESULTS OF MODEL EXPERIMENT IN THE CASE OF OFFSHORE BREAKWATER (SCALE 1/50)

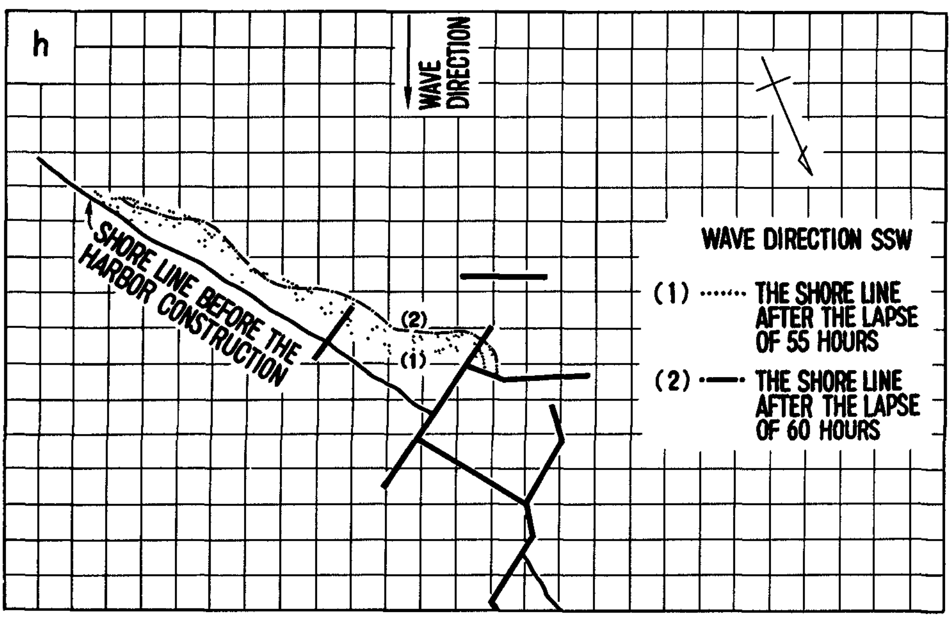


FIG. 11. CONTINUED

FIG 12 --RESULTS OF MODEL EXPERIMENT IN THE CASE OF OFFSHORE BREAKWATER (SCALE 1/100)

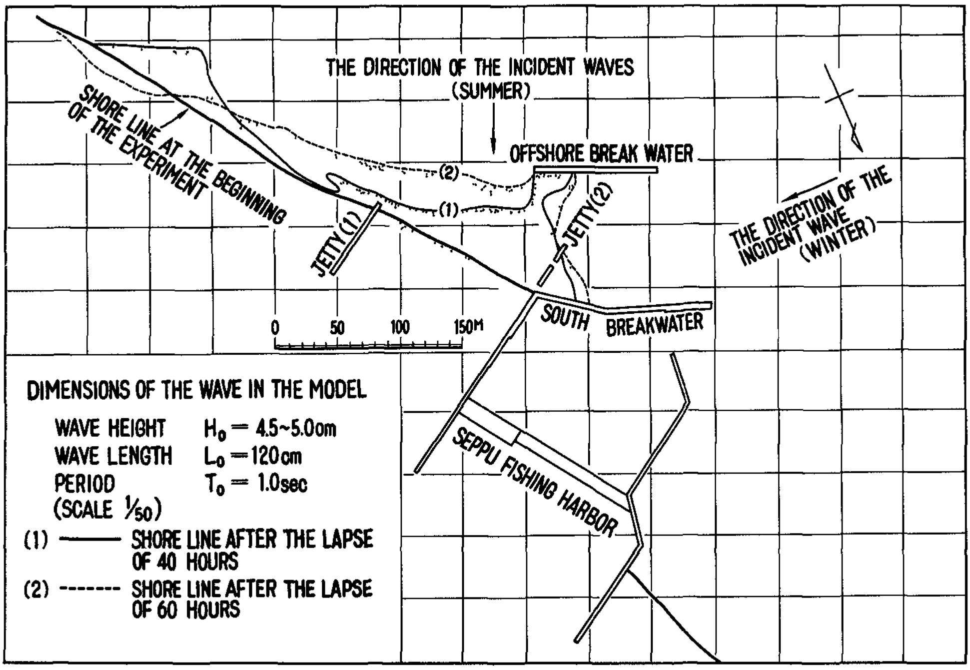


FIG 13 --RESULTS OF MODEL EXPERIMENT IN THE CASE OF OFFSHORE BREAKWATER (SCALE 1/100)

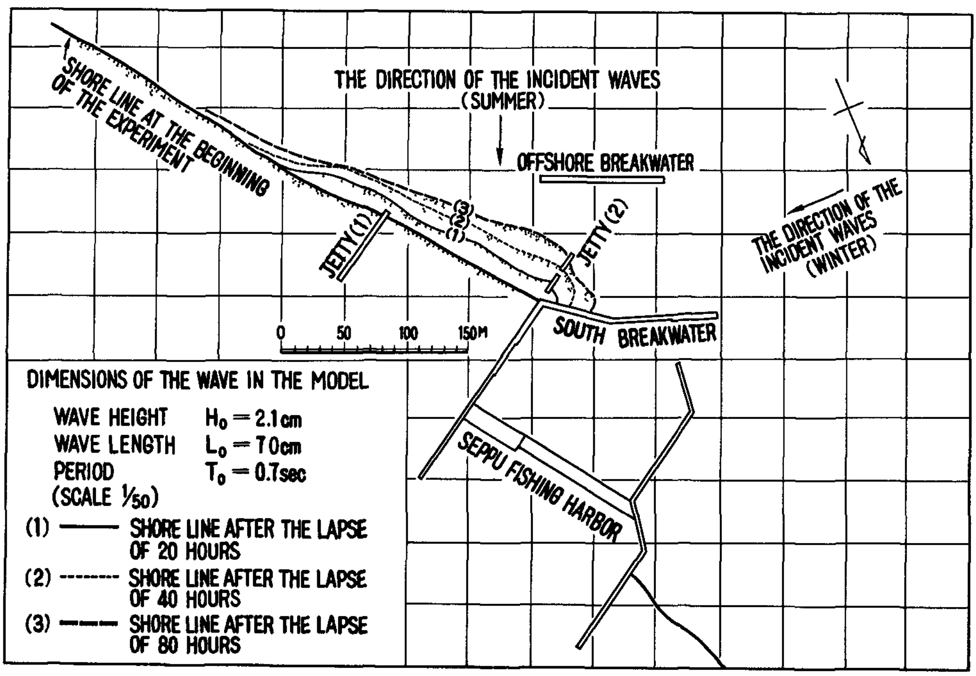


FIG 14 --RESULTS OF MODEL EXPERIMENT IN THE CASE OF OFFSHORE BREAKWATER (SCALE 1/100)

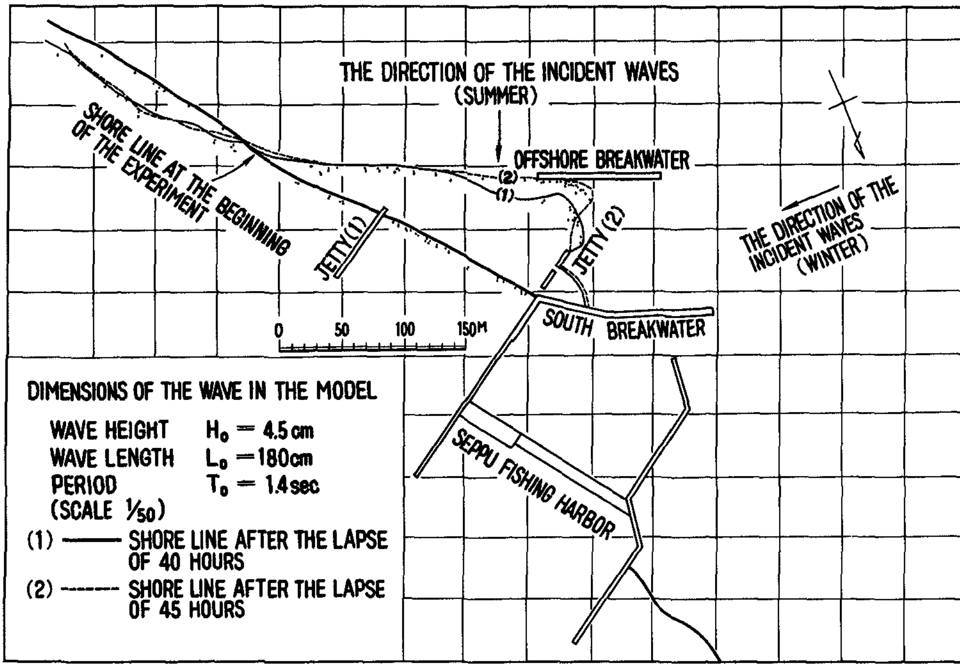


FIG 15 --RESULTS OF MODEL EXPERIMENT IN THE CASE OF OFFSHORE BREAKWATER (SCALE 1/100)

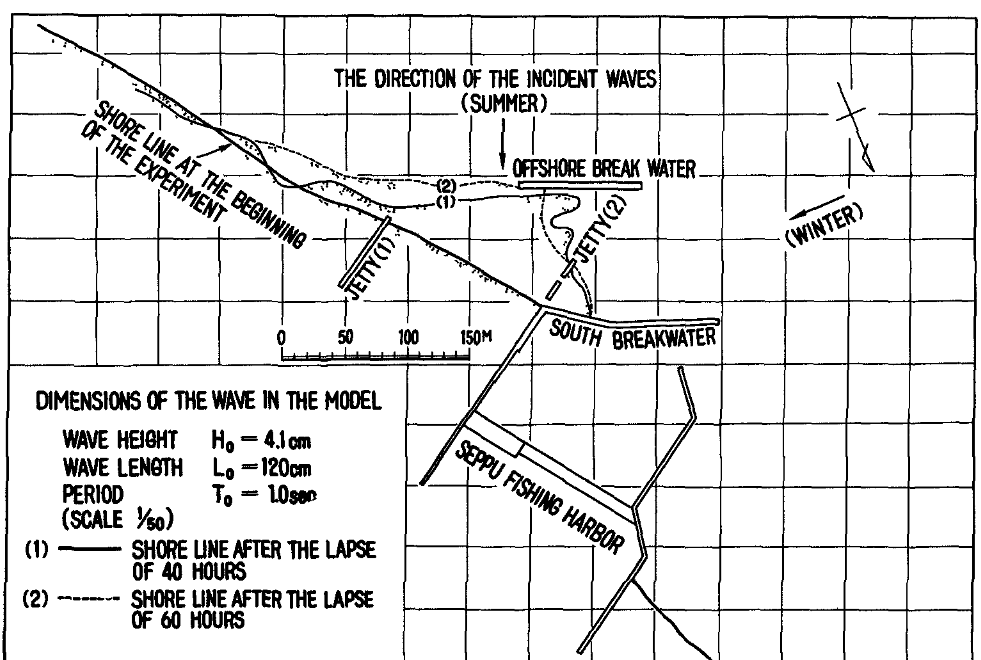
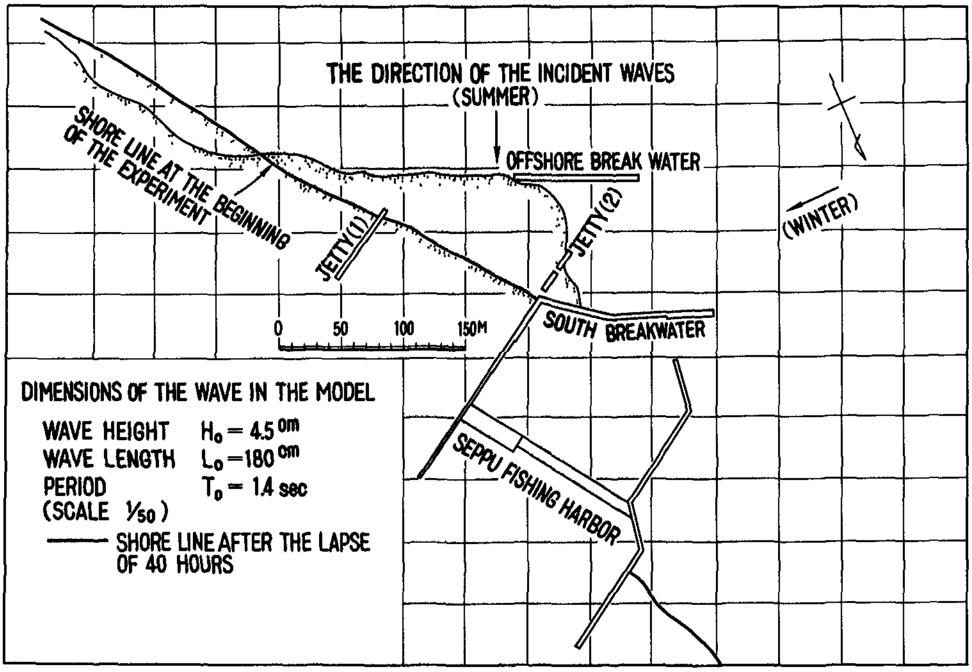


FIG. 16 --RESULTS OF EXPERIMENT IN THE CASE OF OFFSHORE BREAKWATER



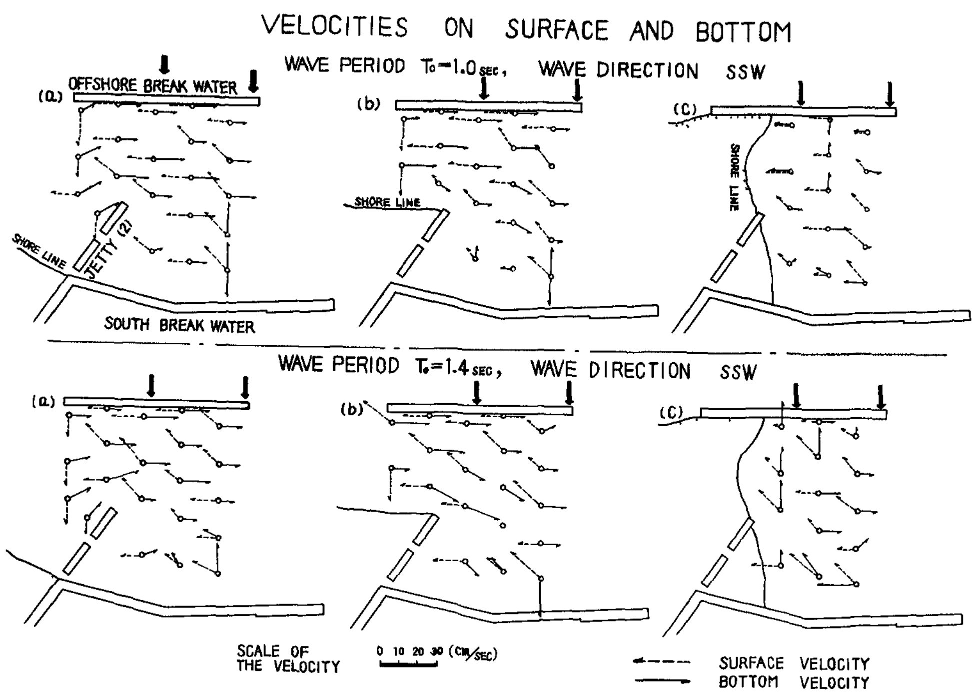


FIG 17 --VELOCITIES MEASURED ON MODEL

Therefore the time standard differed from that in the first model experiment.

As may be seen in Fig.17, in the area between the offshore breakwater and the south breakwater, the direction of the localized currents seen on the sea bed and on the surface change in accordance with the development of the tombolo. Moreover, in all cases the above mentioned currents move in such a way as to prevent the infiltration of the drift sand into this area.

CONCLUSION

Since, all effective methods for the prevention of sand blocking of Seppu harbor, are of such a nature that the balance of summer and winter waves must be taken into consideration, it is imperative that any instalation which may inhibit, even to the slightest extent, the recession of the south-eastern shoreline of the harbor caused by westerly waves in winter must be strictly avoided unless of course the advantages of such an instalation are outstanding in a positive direction.

From this point of view, it may be said that the original plans for the prevention of sand drift along the water line, are in all cases, direct means of preventing sand migration by jetties, while the proposal of an offshore breakwater has its aim on the indirect effects of diffraction and reflection by which it is proposed to inhibit the migration of the sand.

In the case of this particular coast the direction of this offshore breakwater, approximately coincides with the outstanding westerly wave direction in the winter months, and as a result it hardly inhibits the recession of the south-east shore line.

In short it seems obvious that a direct assault on the natural forces would merely result in a tremendous expenditure. Thus, in the case of a small fishing harbor such as Seppu, from a financial point of view alone, methods which directly oppose the natural elements should be avoided, and such forces should rather be diverted and put good use.

As mentioned before the original jetties were aimed at directly blocking the waterline sand drift. In this case, by diverting the direction of the coast current caused by breaking waves in an offshore direction, the migration of the sand along the shore line is swept seawards and the jetties serve as sand accumulation pockets until the sand pile advances to the head of the jetty. However, the effectiveness of this direct blocking jetty method is seen only when the absolute volume of shore line drift sand is small, or when the grade of the sea bed is steep .

Now in the case of Seppu where the drift sand volume from a single direction is extremely large, and moreover since the sea bed slopes gently away, the sand deposit rapidly reaches the head of the jetty and instead of being swept seawards, the deposit creeps around the jetty and advances.

In place of the above jetty method, by constructing an offshore breakwater in an appropriate position, it would become possible to make the sand deposit pocket much larger and to delay the time of the sand arriving at the harbor mouth at least until the beginning of the recession of the south-east shore line by winter waves.

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