8 A STUDY ON BEACH SEDIMENT AT ENO-SHIMA AND KAMAKURA

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Abstract

The paper presents the preliminary results of investigation on the movement of coastal sediment and its effects on beach erosion at Eno-Shima and Kamakura, summer resorts on the Pacific coast of Japan. This study constitutes a part of a series of extensive field survey program carried out by the authors and the engineers of the Hydrographic Office and the Transportation Technical Research Institute under auspices of the Kanagawa Prefectural Government over the period from September, 1956, to February, 1957.

One of the main difficulties encountered was the lack of records on the actual progress of erosion. No previous investigation had been made on winds, waves, littoral currents, variation of beach and nearshore profiles, except for recent geologic surveys by the Hydrographic Office [1 and 2]. As a result of the limited assigned period of investigation the influence of the summer, typhoon storms on the characteristics of beach sediment was left untouched. The eventual cause of erosion along these beaches could only be detected on the basis of more extensive, continued investigation.

Nevertheless some preliminary conclusions have been attained on the fundamental nature of the persisting erosion as affected by the characteristics of winds, waves, geographical situations, topographies, littoral currents, and consequent movement of beach sediment. A further investigation on littoral currents, waves, and beach profiles has been in progress on the same beaches since June, 1957.

1. Description of the area

1-1. Geography

The beaches of Eno-Shima and Kamakura extend roughly east and west in the north-eastern sector of the Sagami Bay (Figure 1). The bay opens on the Pacific Ocean, the fetch to the south partly restricted by the existence of the O-Shima lying approximately 30 miles apart from the beaches covered by our investigation.

The shoreline geographies sharply differ between the areas to the east and west of Eno-Shima. The characteristic of the shoreline to the west is a straight sand beach extending approximately 6 miles as far as the Sagami River. The shore consists of thick sand deposits, dotted with sand dunes near Eno-Shima West-side. The Sagami River, along with two other rivers located to the further west, is regarded as the principal source of beach sediment to this area. The outlets of the Sagami and Hikichi Rivers deviate toward east, signifying a predominant eastward migration of beach materials. The orientation of the Katase outlet should not be interpreted as contradicting this trend, for it had been shifting east and west until a jetty on the left bank has finally forced it to the present position. The general eastward migration of beach materials has also been supported by the results of a recent investigation of the Hydrographic Office [1] which show a progressive decrease in grain size toward east.

The migration of sand is, however, not likely to reach beyond Eno-Shima; it is intercepted by a tombolo connecting the island and the mainland. The sand may be slowed as it approaches the tombolo area and deposited on the sea floor or on the west slope of the tombolo, or pushed ashore by waves and winds to form dunes. The cross sections of the tombolo, Figure 2, diagramed from the recent surveys of the Hydrographic Office [2], demonstrates a probable accretion on the west slope.

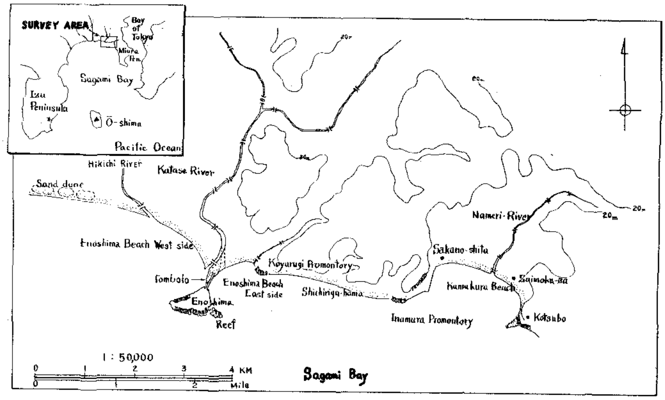


Figure 1 - Location of survey area.

The geography to the east of Eno-Shima, on the other hand, is distinguished by the irregular pattern of shoreline disposition and bottom contours. The beaches are separated into short segments by cliffed promontories at Koyurugi, Inamura and Kotsubo, barely exceeding a mile in length and 50 meters in width at low water level. This area is provided with several tributaries but they are too small to form a source of any appreciable amount of beach sediment. The direction of sand migration is unclear except for a portion of the Kamakura beach where a local, eastward movement seems to predominate as indicated by the deviation of the Nameri outlet toward east. A progressive decrease in grain size toward east has also been observed in this area. However, the migration of sand, if any, may be seriously interrupted by the existence of the promontories which are exposed to strong wave actions. They are fringed by wave-cut cliffs at the outer ends and subside into submerged rocky terraces down to the depths of approximately 10 meters. Not a strip of sand is found at the cliff base or on the rocky terraces close to it. It is therefore assumed that the beaches of Eno-Shima East-side and Kamakura are essentially isolated from adjacent beaches with scarce sand moving in or out.

1-2. Geology

The bottom topography of the Sagami Bay consists largely of five or six submerged terraces extending from the nearshore floor to the extreme edge of the continental shelf (Figure 3). A marked fault line runs at the depths of 15 meters between Eno-Shima and Kamakura. The submerged terraces are mostly covered by a thick layer of sand to the west of Eno-Shima, while to the east an exposed rocky terrace is found in front of each promontory, a spersely deposited sand bed resting in between forming a deeper, second terrace (Figure 4). According to the investigation of the Hydrographic Office [2 and 3] three succeeding terraces, down to the depths of 24 meters in front of Eno-Shima East-side, are subject to erosion except for the sand-covered first terrace located closest to the shore; in Kamakura area the terraces located in the depths of 15 to 50 meters are subject to accretion but those in the shallower floor either to accretion or erosion.

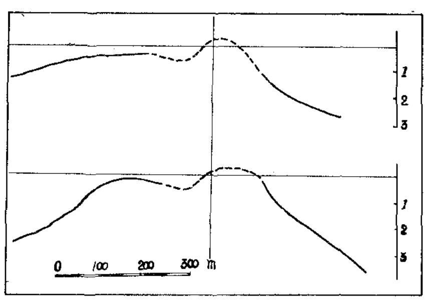


Figure 2 - Cross-sections of tombolo, Eno-Shima.

The complexity in the geologic structures of this area apparently reflects active endogenic deformations which have taken place in the past. It should be noted that the Sagami Bay area is traversed by the Fuji volcanic belt, and that repeated elevation or depression of the sea floor has resulted from a series of great earthquakes which assaulted the area in about 70-year cicle. A record shows that the great Kanto earthquake in 1919 caused an elevation as high as 2 meters throughout the Sagami Bay coast. A census among the villagers in the neighborhood of Kamakura reveals that no beach existed here until the Kanto earthquake of 1919 pushed the shoreline toward offshore.

In the light of sheer geological point of view one is strongly tempted to attribute the cause of the reported erosion to the unavoidable, natural process of earth movement. However, derivation of any eventual cause of erosion will have to be withheld until a comprehensive evaluation of all the possible effects of such unknown factors as winds, waves, littoral currents, or artificial establishments, is completed.

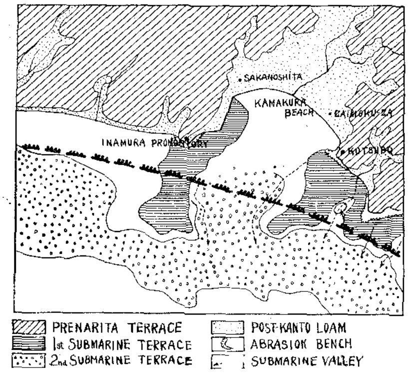


Figure 3 - Geological structure of Kamakura beach, by Tayama,R.

1-3. Winds, waves and tides

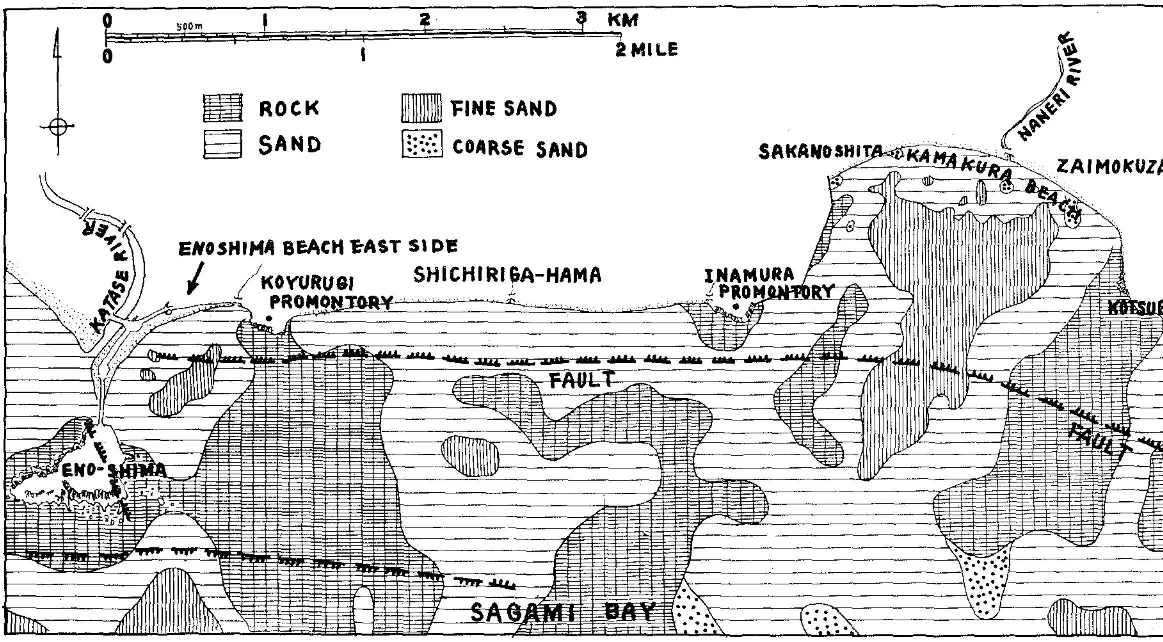


Figure 4 - Distribution of sand on the sea bottom near Eno-Shima and Kamakura; by Komukai, 1957.

The only data available were those of the Suka city situated at the estuary of the Sagami River. Figure 5 shows monthly averages of the frequency in wind directions expressed in per cent to the entire number observed, where "N" denotes the land wind from the N, NEN, and NWN directions and "S" the sea wind from S, SES, and SWS. The predominance of southerly wind during three months from June through August is presumably indicative of the influence of the typhoons passing the China sea and the northwest Pacific during this season. The data failed to give the maximum wind velocities caused by typhoons, as a re-

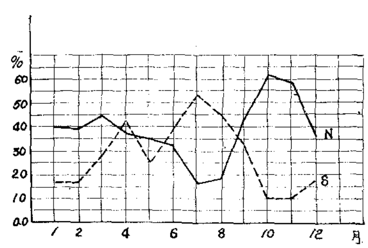


Figure 5 - Monthly average of predominant wind direction at Suka. (1950 - 1954)

sult preventing hindcast of characteristic waves from wind data. In order to estimate the wave characteristics in this area a reference was made to the results of T. Ijima (4) derived from the observations at the two Pacific ports of Naarai (Chiba Prefecture) and Onahama (Fukushima Prefecture):

> The predominant waves are generated by the typhoons and tropical atmospheric depressions of summer and fall seasons with the maximum wind velocities amounting to 40 to 60 meters per second. During winter and spring the wester or southwester prevails, influenced by seasonal atmospheric depressions traveling east, but their effect is smaller as compared with that of typhoons, with the maximum wind velocities remaining approximately 20 m/sec. Long-period swells would follow the fleeing typhoons or depressions but their energy spectra are highly variable as the fetches move. They are often overlapped by locally generated, short-period waves, resulting in irregular patterns of shallow-water waves. The moving fetches also affect the heights and periods of waves. The typhoons would send storm waves of 4 to 5 meters in height and 10 to 12 seconds in period accompanied by swells of 3 to 4 meters in height and 14 to 15 seconds in period. A swell of appreciable magnitude is seldom observed in winter and spring, but the waves of 2 to 3 meters in height and 6 to 10 seconds in period would prevail. Even in quiet weather the wave heights usually range from 0.4 to 0.5 meters and periods from 9 to 10 seconds.

The results of T. Ijima may not be applied to this area without considerable modification, but the general characteristics may agree, provided that local conditions should be taken into account because of the existence of O-Shima and the surrounding peninsulas.

No tidal record was taken in this area until a portable tide gage was installed in Eno-Shima at the onset of this investigation. The tidal ranges are supposed to be similar to those in the Bay of Tokyo, amounting to the average of 1.3 meters approximately. The diurnal inequality seems fairly marked. Other hydraulic characteristics, namely seich or wind set-up, may be regarded as practically negligible.

2. Method of investigation

The investigation consisted largely of sediment sampling and simultaneous observation of waves in the same area. Both wind and tide data were also taken starting from October, 1956. However, owing to frequent failures in gage, they did not prove to be of much value to the purpose of our investigation. The beaches of Shichiriga-Hama and Eno-Shima West-side were excluded from the area of investigation.

2-1. Sediment sampling

Three different samplers were used, classified as A-1, A-2 and B.

Sampler A-1 (Figure 6) consists of a total of 20 mesh-walled pipes, each 15 cm long and 1.8 cm in diameter. They are screwed in to a steel frame, five pipes in each of the four directions and on five different echelons. The mesh opening is 0.075 mm in diameter. Sampler A-1 is tied to a concrete block to add weight and sunk in waters of different

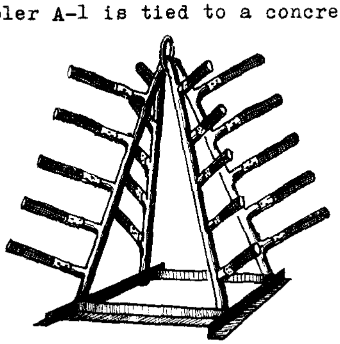


Figure 6 - Sampler A-1.

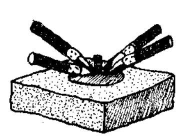


Figure 7 - Sampler A-2.

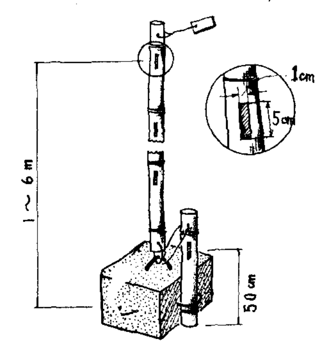


Figure 8 - Sampler B.

depths while carefully adjusting its orientation by a compass held on a boat. The quantity of sediment arrested by Sampler A-1 would tell the relative rate in the movement of suspended sediment with respect to the directions and heights above the sea floor. The heights of the open ends of the pipes on the lowest and highest echelons are 18 cm and 58 cm, respectively.

Sampler A-2 consists of four mesh-walled pipes attached in four directions to a rectangular concrete block. (Figure 7) The structure of the trapping pipe is similar to that of Sampler A-1 except for the length, 20 cm. This has been adapted to be used for arresting sediment in the surf zone where the sediment movement is expected to be far more active than outside the surf zone.

The open ends of the installed pipes were slightly directed upward to ensure that the arrested sediment may not be washed away and lost by disturbance caused either by waves or in the course of recovering operation.

Sampler B is a bamboo pole with a rectangular opening, 5 cm by 1 cm, at every other joint. The intact joints would add buoyancy to the pole to keep it upright in water or against wave action. This is capable of arresting suspended sediment in levels beyond approximately 50 cm above the sea floor up to the surface.

Each run of sediment sampling operation consisted of 3 or 4 equally separated lines either for Samples A-1 and A-2, or for B, named "Survey Line", drawn in the north-south direction. A survey line contained 4 or 5 samplers of the same type placed in 1-meter-depth intervals. Sampler A-1 was recovered in about a day or two; sampler A-2 in about a day or less; and sampler B was left in water for about a week. Three runs of sampling were performed both in Eno-Shima and Kamakura.

2-2. Observation of waves

The measurement of wave heights and periods was done by reading the positions of the crest and trough of the wave train on the scaled poles fixed in the known depths. The pole for the offshore waves is a thick bamboo pole anchored by concrete blocks to the depths of 8 to 10 meters. The pole for the nearshore waves is a long wooden staff rigidly attached to a concrete block and placed in the depth of 1.5 meters, approximately. The observation was made continuously for about 10 minutes of the heights and corresponding periods simultaneously at the offshore and nearshore zones. The poles were placed where the effect of refraction seemed least probable.

Every effort to determine the exact directions of wave orthogonals proved a failure, but a careful observation seemed to show that most waves enter the basins from south, and that waves break parallel to the shorelines.

3. Results of wave observation

3-1. Examination of wave records

An examination of the wave records is strongly affirmative of the general characteristics indicated by T. Ijima (4) . The predominant wave direction was likely to be from south, but local winds and bottom topographies complicated the patterns of the shallow-water waves.

Table 1 shows the maximum, mimimum and average values of the measured wave characteristics expressed in deep-water significant heights, periods and steepnesses. The effects of refraction have been eliminated from the results obtained in the nearshore zone, by comparing their deep-water values with those of the offshore measurement. Figure 9 shows a comparison of the significant wave heights with the average wave heights. Our values, shown by a solid line, are slightly lower than those commonly approved, but the agreement is satisfactory.

The data represent the ordinary wave characteristics prevailing in this area during late fall and winter; the wave heights range from 20 to 50 cm, occasionally reaching 70 cm,

Location of measurement	Date	H_0 min. max.	T_0 min. max.	δ_0 min. max.	Remarks
Eno-Shima	13 Sept.	32.0 41.4 @36.7	7.3 8.3 @7.8	0.003 0.005 @0.004	Gentle swell.
	12 thru. 15 Nov.	29.9 68.1 @ 11.6	4.8 8.6 @ 7.0	0.003 0.020 @ 0.008	Moderately high sea; sampling operation hind-ered.
	19 thru. 26 Dec.	28.3 57.7 @ 33.7	5.6 9.9 @ 7.4	0.003 0.007 @ 0.005	Gentle swell.
Kamakura	26 27 Oct.	22.4 33.0 @ 27.3	8.7 10.1 @ 9.2	0.002 0.003 @ 0.002	Gentle swell.
	8 Dec.	30.0 54.2 @ 42.0	5.2 7.2 @ 6.3	0.004 0.009 @ 0.007	Rough wind wave persisted from 4 to 9 Dec.; maximum wind velocities appr. 10 m/sec.
	28 Jan.	36.3 47.5 @ 42.1	7.2 8.2 @ 7.4	0.005 0.006 @ 0.005	Moderately high sea; sampling operation hind-ered.

Table 1 - Significant wave characteristics expressed in deep-water values; @ refers to the average.

the period from 5 to 10 seconds, and the steepness is 0.005 in average.

In order to obtain a more comprehensive view on local wind waves a theoretical assumption was made on the basis of the Sverdrup-Munk-Bretschneider method for a wind direction approx. south and the fetches to O-Shima and Izu peninsula 27 and 32 miles, respectively. The results are shown in Tables 2 and 3, which indicate that for wind velocities below 20 m/sec the wave heights would never exceed 4 meters. The lack of wind data, however, prevents a comparison of this assumption with the results of our observation.

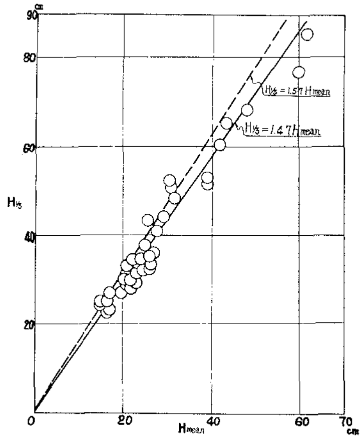


Figure 9 - Comparison of significant wave heights with average wave heights.

3-2. Alongshore distribution of breaker heights

In order to examine the distribution of breaker heights along the shore the refraction diagrams [5] have been constructed making use of the sea charts and the results of the recent survey by the Hydrographic Office [1]. The wave direction was assumed from south, in agreement with the observed predominant wave direction in this area. The assumed wave period was 10 seconds; this may correspond to a very low swell, or to a storm wave as high as 7 meters which could only be possible by a wind of 40 m/sec. It may represent the extreme case, but the refraction diagrams for the wave period of 8 seconds which stands for the familiar storm waves approximately 4 or 5 meters high (see Tables 2 and 3), did not show a virtual difference in the general pattern of refraction (Figures 10, 11, and 12).

The diagram for Eno-Shima East-side (Figure 11) shows remarkable divergence and convergence of waves along the beach, but the actual pattern is likely to be even more complicated because of the combined effects of diffraction and reflection by Eno-Shima and its surrounding sea walls. In rough sea the waves already break over the wide reefs jutting out of the east side of Eno-Shima, considerably reducing their heights further inshore.

The refraction pattern for Kamakura is more complicated due to confusing bottom contours.

u	F=50 km			F=60 km		
	H_F	T_F	t_m	H_F	T_F	t_m
m/sec	m	sec	hrs	m	sec	hrs
5	0.55	3.5	6.8	0.60	3.0	7.8
10	1.6	5.2	5.0	1.8	5.4	5.7
15	2.6	6.4	4.1	2.8	6.7	4.7
20	3.4	7.3	3.6	3.7	7.7	4.1
25	4.3	8.0	3.3	4.7	8.5	3.7
30	5.1	8.6	3.0	5.6	9.1	3.4
35	5.8	9.2	2.8	6.5	9.7	3.3
40	6.7	9.8	2.6	7.4	10.7	3.1

Table 2 - Theoretical assumption of waves for steady condition.

In general, however, a convergence at the Nameri outlet and Sakano-Shita is outstanding. At the west side of the basin a strong reflection is observed from the sea wall extending from Sakano-Shita to the Inamura Promontory (Sakano-Shita sea wall), and standing immediately in water, while the beach of Zaimokuza is relative calm.

Figures 13 and 14 show the distribution of breaker heights and depths derived from the refraction diagrams on assumptions that the wave energy loss by bottom friction is negligibly small, and that the formula of energy transmission based on the theory of small amplitude applies. The same pattern of breaker-height distribution was also observed in later surveys made in July, 1957, for swells of moderate height and wind direction from south (Figures 15 and 16). Waves tend to converge on the beach in front of Point 5 in Eno-Shima East-side, and on the Nameri outlet in Kamakura.

u \ t	2 hrs		3		4		5		6		7	
	H	T	H	T	H	T	H	T	H	T	H	T
m/s	m	sec	m	sec	m	sec	m	sec	m	sec	m	sec
5	0.4	2.3	0.5	2.8	0.5	3.0	0.6	3.2	0.6	3.4	0.6	3.5
10	0.9	3.8	1.2	4.3	1.4	4.7	1.7	5.2	-	-	-	-
15	1.6	4.7	2.1	5.7	2.5	6.3	-	-	-	-	-	-
20	2.2	5.7	3.0	6.7	3.7	7.6	-	-	-	-	-	-
25	3.0	6.5	4.0	7.7	-	-	-	-	-	-	-	-
30	3.8	7.3	5.1	8.6	-	-	-	-	-	-	-	-
35	4.5	8.0	6.1	8.9	-	-	-	-	-	-	-	-
40	5.3	8.5	7.1	9.4	-	-	-	-	-	-	-	-

Table 3 - Theoretical assumption of waves for unsteady condition.

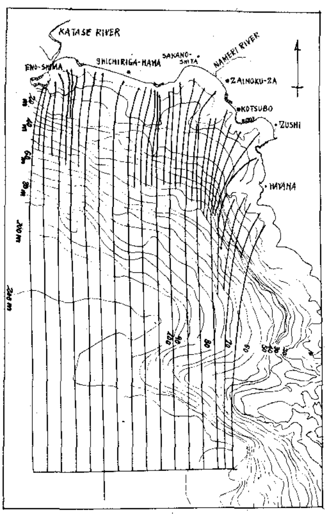


Figure 10 - Refraction in deep-water for assumed wave of 10 seconds from south.

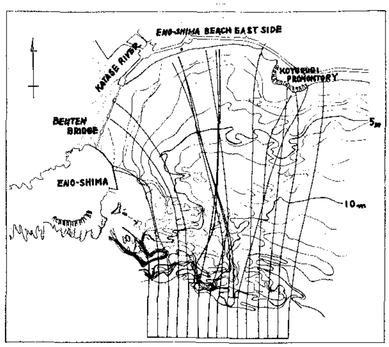


Figure 11 - Refraction in Eno-Shima for assumed wave of 10 seconds from south.

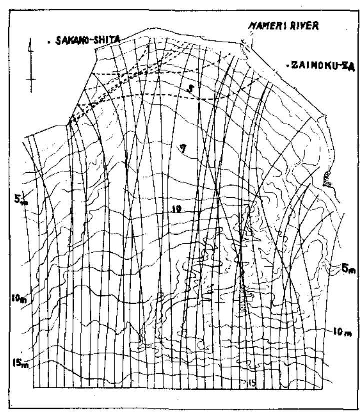


Figure 12 - Refraction in Kamakura for assumed wave of 10 seconds from south.

The principal effects of varying breaker heights along the shore are: The higher breakers cause stronger disturbance or scouring of bottom sediment in the surf zone; a larger amount of sand is thus set in suspension or made liable to transportation by littoral currents; the difference in alongshore water level inside the surf zone, caused by different rate of mass transport by breakers, may result in generation of littoral currents due to surface gradient and transport the sand away from where the breakers are higher.

3-3. Littoral currents

The nomograph presented by Inman and Quinn [6] has been employed to estimate pos-

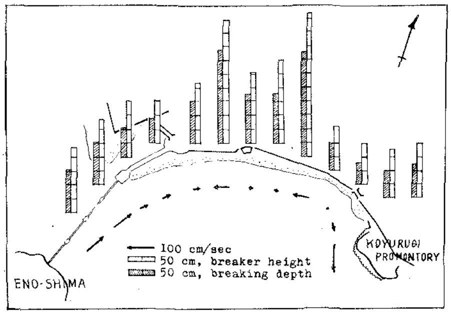


Figure 13 - Breaker-height distribution and resulting littoral currents by refraction diagram, Eno-Shima.

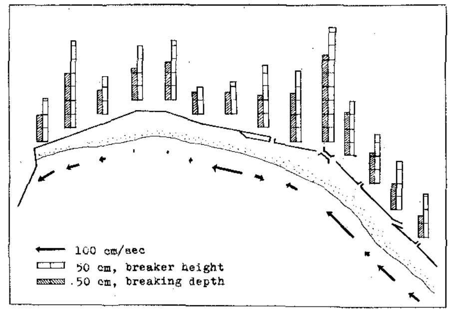


Figure 14 - Breaker-height distribution and resulting littoral currents by refraction diagram, Kamakura.

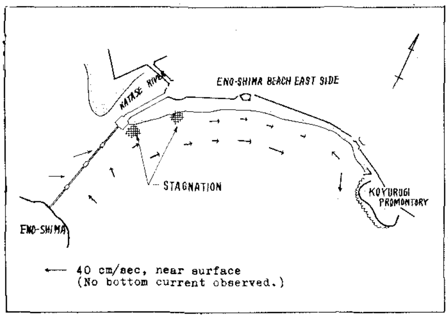


Figure 15 - Littoral currents observed at Eno-Shima, July, 1957.

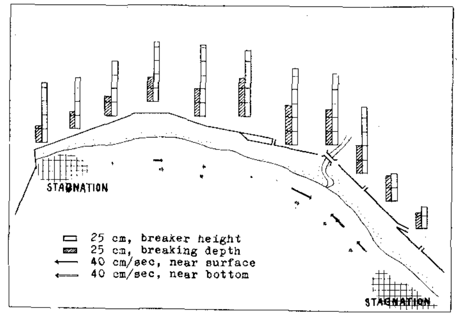


Figure 16 - Breaker-height distribution and littoral currents (surface and bottom) observed at Kamakura, July, 1957.

sible littoral currents along these shores. The results are given in Figures 13 and 14. Roughly the same trends were observed in our later studies on littoral currents made in July, 1957.

The rate and directions of the littoral currents are highly variable, subject to a slight change in wave and wind characteristics and also a consequent change in refraction and diffraction patterns. Our analysis has vastly simplified the conditions leaving only the predominant factors for theoretical consideration. It is therefore safe to maintain that our results on breaker-height distribution and littoral currents represent the substantial characteristics underlying actual complications which are often confused due to the effects of minor factors in field observation.

The results of the sediment sampling have provided an additional source of knowledge on littoral currents. The direction of sediment movement may be principally governed by littoral currents. Consequently, a comparison of the quantity of sediment arrested in different directions may indicate the predominant direction of littoral currents at that position for the period the sampling was continued. The results are given in Figures 17 and 18. The agreement is satisfactory in general.

4. Results of Sampling

Sampling operations were impossible at rough weather conditions. Therefore our results represent only the characteristics at ordinary weather conditions.

4-1. Horizontal movement of suspended sediment

An examination of samples obtained by Sample A-1 in all depths has revealed a definite relationship between the relative quantities of sediment arrested in the traps and their heights from the sea floor. Denoting the height of a trap from the sea floor by z, that of the highest echelon (58 cm) by z_0 , the quantity of sediment by m , and that of

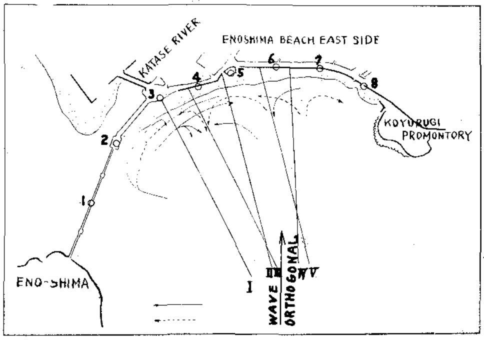


Figure 17 - Littoral currents estimated by refraction diagram (solid line) and sediment samples (dotted line), Eno-Shima.

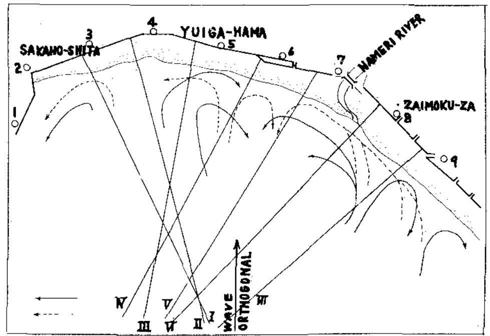


Figure 18 - Littoral currents estimated by refraction diagram (solid line) and sediment samples (dotted line), Kamakura.

the lowest echelon (18 cm) by m_0 , we obtain (Figure 19):

$$\frac{z}{z_0} = a \log \frac{m}{m_0} + b \qquad \text{............... (1)}$$

where a and b are presumably the constants depending upon wave characteristics, depths of samplers, grain sizes, specific gravities and fall velocities of suspended sediment. Determining the values of a and b from Figure 19, we obtain

for Eno-Shima East-side:

$$\frac{z}{z_0} = -0.41 \log \frac{m}{m_0} + 0.36 \qquad \text{....... (2)}$$

for Kamakura:

$$\frac{z}{z_0} = -0.37 \log \frac{m}{m_0} + 0.38 \qquad \text{....... (3)}$$

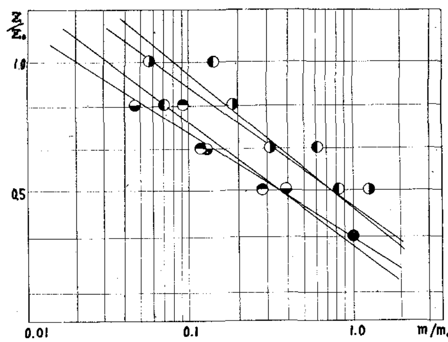


Figure 19 - Vertical distribution of suspended sediment in relation to height, for Sampler A-1.

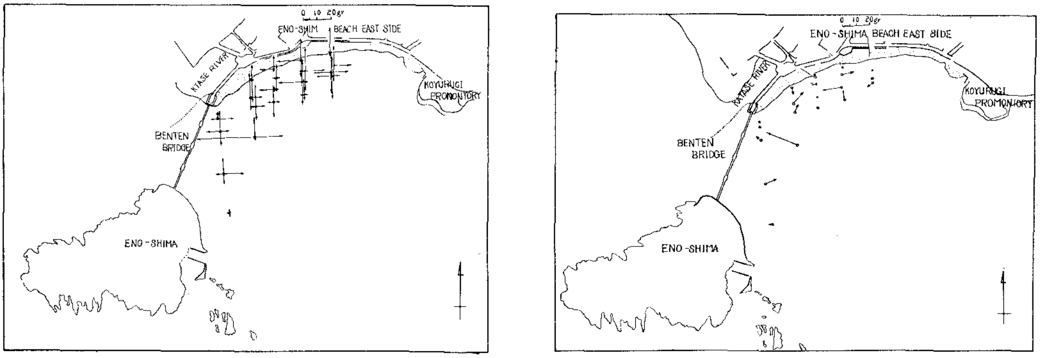
It is questionable, however, whether the lowest samples consist purely of suspended sediment or include a portion of the disturbed bed-load due to possible settlement of the sampling frame. Nevertheless, the relationships show a similar pattern of sediment distribution for each sampler, regardless of the depth and direction. Accordingly, the samples on the lowest echelon may be considered as representing the relative quantity of suspended sediment in the corresponding directions. It should also be noted that the values of a and b are only related to ordinary weather conditions.

Figures 20 (A) and (B) and 21 (A) and (B) show the examples of the distribution of the samples on the lowest echelon, m_0, obtained in unit sampling. Figures 20 (A) and 21 (A) show the net quantities in each trap, and Figures 20 (B) and 21 (B) the resultant quantities and their corresponding directions.

To summarize the results:

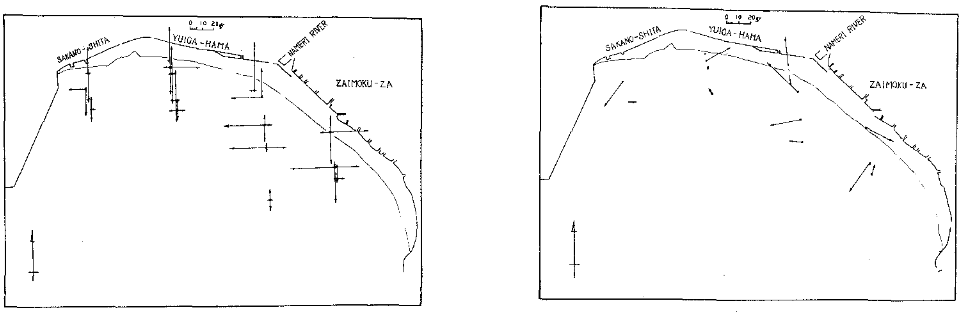
Eno-Shima East-side

1. A very active sand movement was found at the landward end of the tombolo, Point 3 and Point 5. The rest and further east of the beach did not show any remarkable movement of sand.
2. The resultant directions of samples for the survey line closest to Eno-Shima show



(A) (B)

Figure 20 - Horizontal distribution of suspended movement for Samplers A-1 and A-2, Eno-Shima.



(A) (B)

Figure 21 - Horizontal distribution of suspended movement for Samplers A-1 and A-2, Kamakura.

the existence of a current probably directed north-east as well as one likely to accelerate the growth of the tombolo.

3. This north-east current seems to turn east near Point 3, which, together with a westward current near Point 5, may possibly result in a rip current between the two points.

4. To the east of Point 5 some eastward currents were found at several points where convergence of waves seems relatively stronger, but in general the eastward current prevailed here.

The results have been diagramed in Figure 17, depicted by a solid line. The general trend is that the east slope of the tombolo is eroded by a current transporting the sediment to the north-east and then to the east beyond Point 3. The sediment transported thus may join the rip current here and finally settle in a deep floor in the basin. To the east of Point 5 the sediment would be carried east, but no sign of its deposition in the beach area is observed. It is assumed that the quantity of transported sediment may either be scarce or dispersed over a wide rocky floor around the Koyurugi Promontory and then gradually washed toward offshore or deposited inside the basin. The diagrams also show a strong sign of sand movement perpendicular to the shoreline. Consequently, a long spell of quiet weather may cause the shoreward migration of sediment from the offshore bottom thus creating a "nearshore circulation" inside the basin. On the other hand storm waves may cause a strong undertow which would erode beach materials and carry them into the greater depths in and out of the basin. The effects of the sea wall fringing the beach would be to strengthen the rate of scouring along the base by storm waves, but they have not been confirmed during our investigation.

Kamakura

1. A consistent seaward current was observed at the conjunction where the western end

of the beach and the Sakano-Shita sea wall meet. A strong scouring action of waves persists here.

2. A gentle wave action prevails along the eastern portion of the Zaimokuza beach, where sand movement is considerably obscure.

3. The beach between the Nameri outlet and Zaimokuza is presumably in equilibrium or subject to accretion. In the vicinity of the Nameri outlet where reflection from the Sakano-Shita sea wall and refraction by the bottom topographies cause a strong convergence of waves, the sediment movement is remarkably active but its predominant direction is unclear.

4. There is a possibility of the existence of a rip current near Point 5.

The shoreline of Kamakura is about 2,300 meters long and more exposed to the open sea than the beach of Eno-Shima East-side. Consequently the variation in wind and wave characteristics in the open sea is more important in affecting the pattern of littoral currents and, hence, sediment movement along the shore. Moreover, the waves reflected along the Sakano-Shita sea wall would accelerate the littoral currents toward east, resulting in a shift of the position of the rip current in the same direction. In the later survey on littoral currents a rip current was observed slightly east of the Nameri outlet. These facts may also account for the predominant eastward movement of beach sand at the Nameri outlet as signified by its orientation. The general pattern of sediment movement is regarded as primarily consisting of circulation inside the basin at ordinary weather conditions, or of resulting erosion of beach materials and their deposition in and out of the basin by storm waves. A persistent erosion was noticed at Sakano-Shita and Kotsubo.

Our investigation did not cover the depths beyond 5 meters. Sand movement around the promontories is, therefore, unclear.

4-2. Vertical distribution of suspended sediment

Figures 22 and 23 show the vertical distribution of suspended sediment measured by Sampler B continuously over a period of about a week. It should be noted that the manner of distribution differs with respect to their depths. The distribution in the depths greater

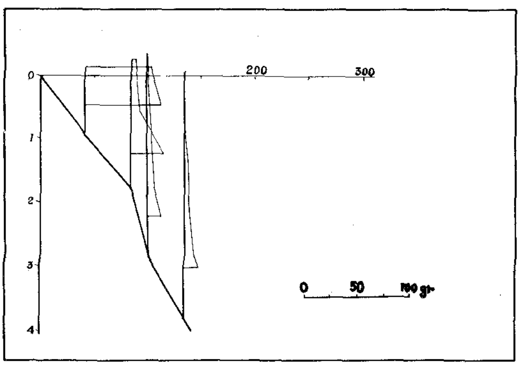


Figure 22 - Vertical distribution of suspended sediment for Sampler B, Eno-Shima.

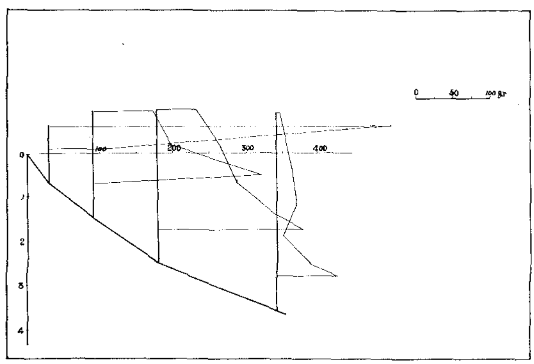


Figure 23 - Vertical distribution of suspended sediment for Sampler B, Kamakura.

than 4 meters and less than 2 meters are essentially the same. This can be explained by the fact that in the breaker zone, usually 2 meters deep at ordinary wave conditions, the breaking waves cause a uniform disturbance of water throughout the entire depth from surface to the bottom, while in water as deep as 4 meters or more, the disturbance by ordinary, gentle waves is only capable of keeping a small amount of fine sediment particles in suspension.

The diameters of sediment particles obtained in the surf zone, accordingly, densely scatter around 150 μ, and the average grain size in depths greater than 4 meters is 70 μ.

The distribution of sediment in the intermediate depths, from 2 to 4 meters, is, in general, similar to that of the river sediment. In the very shallow water, normally less than 1 meter, no definite rule was found to apply to the pattern of distribution.

The data also show that the sand movement is especially active in the central portion of the beach of Eno-Shima Eastside, i.e., between Points 3 and 5, and also between Points 2 and 3, and in the vicinity of the Nameri outlet.

4-3. Beach slope and profiles

The beach drift was sampled along the entire length of the shorelines. The location of sampling does not coincide with the "reference point" advocated by Bascom [7], but it was so selected as to roughly correspond to the mid-tide level of the shoreface. The average grain size of the beach drift show a definite relationship with respect to the foreshore slope, i.e., the coarser the grain size, the steeper the slope. (Figures 24 and 25). In Eno-Shima East-side the average grain size ranged from 150 μ to 550 μ, which correspond to the fore-

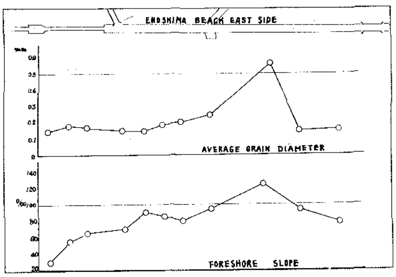


Figure 24 - Alongshore variation of foreshore slopes and corresponding grain size, Eno-Shima.

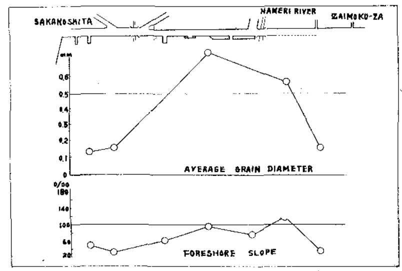


Figure 25 - Alongshore variation of foreshore slopes and corresponding grain size, Kamakura.

shore slopes ranging from 6/100 to 12/100, respectively. In Kamakura, the trend was a little obscure, but a steeper slope was almost invariably found where grains were coarse.

It should be added that the foreshore slope tends steeper from both ends of the beach toward Point 5 in Eno-Shima East-side, and toward the Nameri outlet in Kamakura. The similar variation of foreshore slopes was also noticed in our later observations in July and September, 1957, under similar wave conditions.

The bottom profiles have been drawn from the topographies surveyed by the Hydrographic Office during three months from October to December, 1956, [1] (Figures 26 and 27) The profiles at Points 3 and 5 show the existence of longshore bars. It is interesting to note that Point 5 is the position of maximum foreshore slope. This fact also supports our previous conclusion that the sand movement is most active at this portion of the beach. The profiles turn abruptly flatter at the depths of 4 to 5 meters where the submerged terrace ends nearshore. In Kamakura, however, only a faint sign of bar is found at Points 7 and 8. The bottom slops are outstandingly flatter.

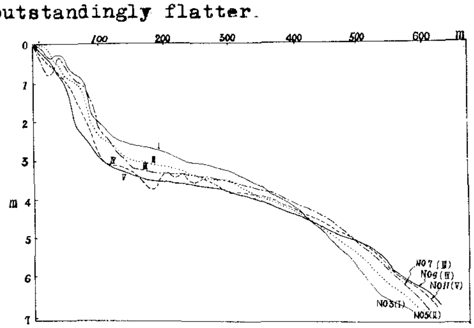


Figure 26 - Profiles perpendicular to shoreline. Eno-Shima (see Fig. 17).

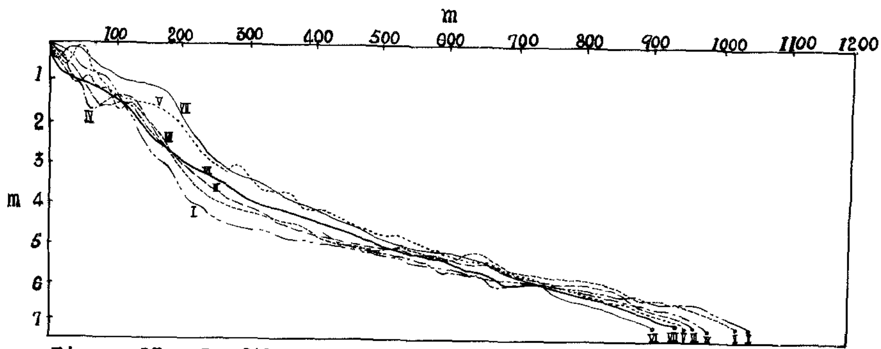


Figure 27 - Profiles perpendicular to shoreline at Kamakura (see Fig. 18).

5. Summary of investigation

1. The beaches of Eno-Shima and Kamakura are essentially isolated from the source of beach materials. The exact rate of sand movement around the promontories remain unclear, but in view of the geological structures of the adjacent sea bottom it would be safe to assert that their principal role is to hinder any sufficient amount of sand supply into these beaches.

2. The past record of earthquake shows that the erosion in progress on these beaches can be an unavoidable, natural process of earth movement.

3. The wind that most strongly affects the sediment movement in this area is the south wind prevailing during the summer, typhoon season from June through August. A further investigation is needed at rough weather conditions, especially during the typhoon season.

4. The predominant ordinary waves in this area are 20 to 50 cm in height and 6 to 10 seconds in period. They are strongly affected by the local conditions, namely the fetches inside the Sagami Bay, refraction and diffraction due to irregular bottom topographies, and reflection by artificial establishments. The convergence of waves is outstanding at the central portions of both beaches.

5. The alongshore sea walls at Eno-Shima East-side and Kamakura were recently expanded into the shore. Their effects on beach erosion would be to accelerate the scouring action of the storm waves at the base. This was not observed during our investigation, but considering the fact that there is no appreciable sand accumulation along the base of the walls despite intensive flight of beach sand in this area, such base scouring is presumed to exist. The principal effects of the sea walls along the east side of Eno-Shima and of the Sakano-Shita sea wall would be to send the reflected waves to the places where already the strongest wave convergence persists due to refraction. This may result in accelerated erosion there. Recent construction of an embanked approach to the Benten bridge at Eno-Shima seems to have finally barred the migration of beach materials over the tombolo area into Eno-Shima East-side.

6. The littoral currents form nearshore circulation inside the basins at ordinary wave conditions, but storm waves are expected to generate strong undertows and rip currents. They are overwhelmingly dependent on the surface gradient inside the surf zone which resulted from convergence of waves, and therefore also on wind and wave directions. However, the predominant wind is almost consistently from south and the locations of maximum wave convergence is accordingly fixed, i.e., at Point 5 on Eno-Shima East-side, and at the Nameri outlet in Kamakura. The littoral currents may also be affected by local winds that prevail from spring to fall.

7. The vertical distribution of relative sand movement from the sea floor to the level of about 60 cm shows a definite relationship common to all the depths in each basin.

The movement of suspended sediment between the sea floor and the level of 20 cm is most active at the locations of wave convergence.

The vertical distribution of suspended sediment from the sea floor to the surface is affected by the depth. In the depths greater than 4 meters fine suspended sediment distributes uniformly throughout the depth; in the depths from 4 to 2 meters the pattern of distribution resembles that of the river sediment, and in depths less than 1 meter relatively coarse grains distribute uniformly throughout the depth. No rule governing the vertical distribution was found in the depth of about 1 meter.

8. The horizontal movement of sediment is predominant in the direction perpendicular to the shoreline, and the alongshore movement is not so significant. Near Point 5 in Eno-Shima where wave convergence is intensive, the perpendicular movement of beach sediment is outstandingly active; even at relatively quiet weather conditions the beach materials are coarse, foreshore slope is steep and the alongshore bar persists. Consequently a long spell of storm waves may move the bar offshore, which may then extend in parallel to the shore resulting in a strengthened offshore migration of beach materials at the foreshore bottom. These materials may either be deposited in deep water or further out of the basin. The materials lost out of the basin would hardly be restored to the beach.

Acknowledgment

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