Proper Oscillations of the Sea of Continental Shelf[1]

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Abstract

Even on the straight coast of an open sea, mareograms frequently indicate conspicuous oscillations on occasions of marine earthquakes or cyclonic storms, and the period of the oscillations is generally long, from several multiples of ten minutes up to two hours, especially a period of about one hour being the most frequent. Many investigators have taken notice of this phenomenon of which various explanations have been given. According to the writers' opinion, these oscillations are nothing but undulations of the sea of continental shelf. To confirm this view the writers measure the dimensions of the shelf seas on the charts of various parts of the Japanese coast and also of some foreign countries, and calculate the corresponding periods and show that the calculated periods agree fairly satisfactorily with the observed values.

I. Introduction

The general nature of sea-seiches, or secondary undulations in the sea, has been almost completely established by Messrs. Honda, Terada, Yoshida and Ishitani[2] and by many other investigators, and now the undulations are taken as tank-oscillations of some limited portion of sea such as a bay or an enclosed sea. Even on the *straight* coast of an *open sea*, however, mareograms frequently indicate conspicuous oscillations on occasions of marine earthquakes or of cyclonic storms, and in these oscillations we generally find a component of a long period attaining many tens of minutes to two hours, a period of about one hour being the most frequent. Since such long-period oscillations on open coasts cannot be attributed to ordinary bay-oscillations, a number of scientists have taken notice of this peculiar fact and attempted to explain it in several ways. Dr. Nagaoka[3] suggested the possible influence of an ocean current such as the Kurosiwo on the generation of long waves observed along the Pacific coast of Japan. On another occasion[4], he advanced an explanation based on the consideration of the free elastic vibration of the earth as a whole. Dr.

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[1] This paper was read at the Annual Meeting of the Physico-Mathematical Society of Japan on April 2, 1935. [2] Journ. Coll. Sci. Imp. Univ. Tokyo, **24**, 1 (1908).

[3] Tokyo Sugaku-Buturigakkwai Kizi, **1**, 126 (1902) [4] Ditto, **4**, 35 (1907).

Terada[1] emphasized the importance of this fact in his article in " Scientific Japan Past and Present " prepared in connection with the Third Pan-Pacific Scientific Congress, 1926. In another report[2], he suggested the vibration of sial block floating on sima material as excitation of water-undulations.

Thus there seem to be two lines of opinion as to the origin of such long periods of oscillation on free coasts. One attributes it to the vibrations of the earth crust transmitting to water, and the other seeks the origin in the sea-water itself such as the influence of ocean currents. The present writers consider these oscillations to be of hydrodynamical origin and ascribe them to the proper oscillations of the so-called " shelf sea " fringing the land. Hitherto, only land and sea of horizontal configuration have been paid attention as the scene of seiche-phenomena, so that it has been difficult to understand the nature of the long period undulations found on a straight coast having no irregularities such as bays or promontories. The writers believe, however, that an abrupt change of great magnitude in the vertical depth of a sea, as well as a discontinuous change in horizontal extent, may become a cause of undulations of a proper period. On the other hand, oceanography teaches us that there exist shallow seas less than 200 m in depth, called " seas of continental shelf ", making a step-like separation from the world ocean of 4000 m depth on average. Thus it is a very natural assumption that, in a shelf sea, proper oscillations may be generated by the action of a submarine earthquake or a cyclonic storm. The period for a shelf sea will of course be the same as for a bay, the line of discontinuous change in dimension always forming a nodal line in both cases.

With such ideas in mind, the writers measure the mean depths and breadths of the shelf seas along the coast of Japan and in several other regions of the world, and calculate the corresponding periods. Comparisons of the periods thus obtained with those actually observed on the mareograms constitute the present paper, and the satisfactory coincidence of the values seems to confirm our opinion. As to the generation and damping of the undulations in a shelf sea due to a cyclonic storm, one of the writers (T. N.) has touched on this problem in his paper[3] on a theory of meteorological tunamis and seiches.

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[1] Scientific Japan Past and Present, 284–285 (1926).

[2] Report Earthq. Invest. Com. (in Japanese), **100** B, 113 (1925).

[3] These Memoirs, A, **18**, 201 (1935).

2. Proper periods of the shelf seas

[A] *Japanese coast*:—In order to determine the mean depth and breadth of a shelf sea region, we draw several straight lines perpendicular to the coast at nearly equal distances from one another (Fig. 1), and measure the depths (H) along these lines using the charts[1]. With the obtained values we construct vertical sections of the sea bottom and from the sections the mean vertical section of the region.

Fig. 1

Map of Japan showing tidal station

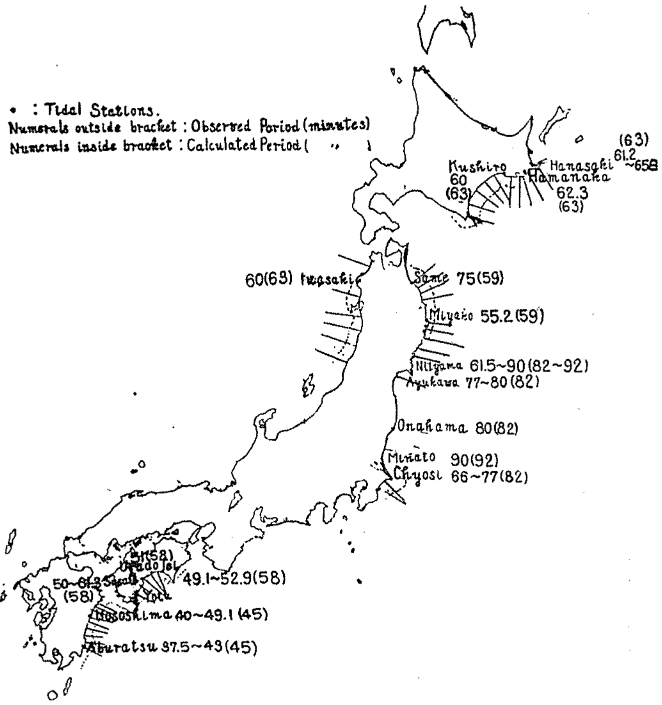

Fig. 2 shows such mean sections for six regions of the Japanese coast.

From these sectional diagrams, we measure the breadths (L) and the mean depths ($\bar{H}$) and calculate the corresponding period (T) by the formula, $T=4\int_0^L \frac{dL}{\sqrt{gH}}$ or $T=\frac{4L}{\sqrt{g\bar{H}}}$. No mouth-correction is needed, because the ratio of the depth to the breadth of the shelf

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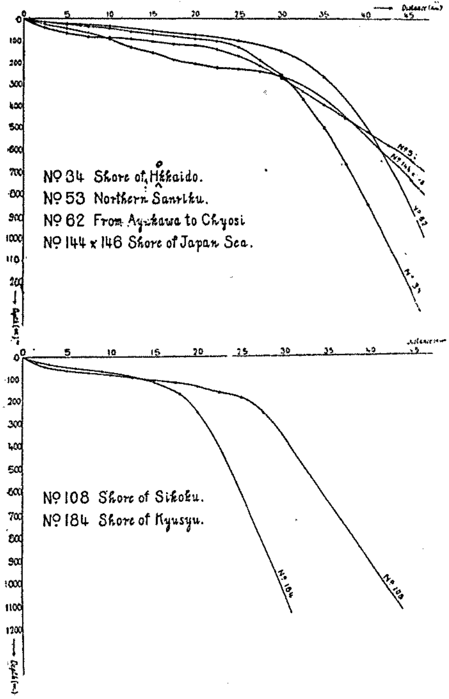
[1] Charts used are No. 34, 53, 62, 108, 184, 144, 146 issued by the Japanese Navy.

is exceedingly small. We take the observed periods from the Journal[1] of the College of Science, Imperial University of Tokyo, Reports[2] of the Imperial Earthquake Investigation Committee, and Bulletin[3] of the Earthquake Research Institute, Tokyo Imperial University. The observed stations are shown in Fig 1. In this map the lines perpendicular to the coasts are the lines along which we measure the depths, and the dotted lines show the margin of the continental shelfs. The observed and calculated periods are compared in Table 1, and their coincidence is generally very good.

Fig. 2

Mean sections of six shelf-sea regions



For the Sikoku Coast (Region No. 5) only, some explana-

Table 1. Periods along the Japanese coast

Region No.	Station No. Name	$\bar{H}$ (m)	L (km)	Period T (min.)	
				Calc.	Obs.
1.	1. Hanasaki 2. Hamanaka 3. Kusiro	57	22.5	63	62.3 61.2～65.6 60
2.	4. Iwasaki	103	30	63	60
3.	5. Same 6. Miyako	118	30	59	75 55.2
4.	7. Niiyama 8. Ayukawa 9. Onahama 10. Minato 11. Chyosi	60 or 65	30 or 35	82 or 92	61.5, 71.6, 90 60, 77, 80 80 90 60, 66, 67, 77,
5.	12. Tei 13. Urado 14. Susaki 15. Yotu	84 (300)	25 (50)	58 (85)	49.1～52.9 51, (73.9～77.5, 80) 50～54, 61.3 (76) (75.8)
6.	16. Hososima 17. Aburatu	88	20	45	40, 43.4～49.1 37.5～39.2, 43

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[1] **24** (1908).
[2] **34** (1909), Fig. 13, 16; **89**, 49 (1918); **100B**, 115 (1925).
[3] Supplementary Vol. **1** (1934).

tion will be necessary. The period of about 50 min. at Tei and Susaki may be said to agree with the calculated period 58 min., and to represent the oscillation period of the continental shelf in this region. On the other hand, the periods of about 80 min. observed at Urado, Susaki and Yotu differ from the period calculated for the shelf sea. If we assume, however, that the whole Sikoku Coast is a great bay having its mouth line through the Cape of Asizuri and Muroto, then we get 85 min. as the proper period of this bay with mouth correction. Thus the period of 80 min. is probably the oscillation period of the great bay which consists of the entire Sikoku Coast.

[B] *Foreign coasts*:—Naturally we have not many data at hand for foreign coasts, but can give a few examples of long period oscillations at certain open straight coasts of foreign countries, observed when tunamis have propagated there from a distant epicenter. These examples are shown in Table 2, in which the periods for the shelf seas are calculated in the same way as before stated, and the observed periods are taken from the Journal[1] of the College of Science and the Bulletin[2] of the Earthquake Research Institute, Tokyo Imperial University.

Table 2. Examples of foreign coasts

Station	$\overline{H}$ (m)	L (km)	Period T (min.)	
			Calc.	Obs.
Madras	40	25	84	87
Negapatam	60	50	137	90~120
Port Elizabeth	113	60	120	140
Coast of Peru	84	30	70	
Table Bay	145	60	106	105, 100~120
Vizagapatam	90	45	101	80~120

3. Nature of the long-period oscillations on open coasts

(a) The satisfactory coincidence of the periods calculated for the shelf seas and the actual periods observed seems to show that the principal oscillations of long period are undulations of the shelf sea; and thus we believe that the origin of the period should generally

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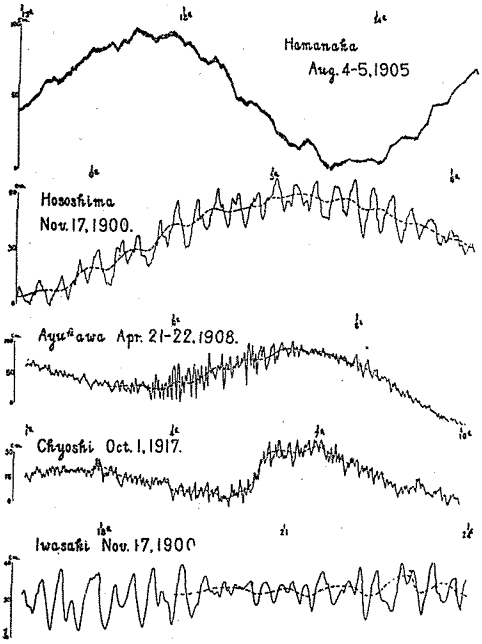
[1] op. cit. [2] op. cit.

be ascribed to the sea water itself, but is not attributable to the period of vibration of the earth crust.

(b) In support of our view we bring forward the fact that the conspicuous oscillations of these periods are observed not only on occasions of submarine earthquakes but also, frequently, during storms. Fig. 3 shows examples caused by storms and Fig. 4 examples caused by earthquakes.

Fig. 3

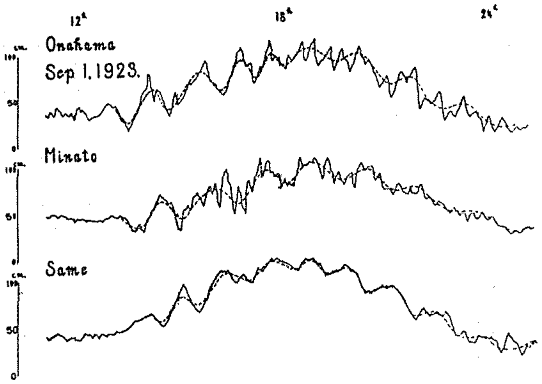
Examples of undulation caused by storms.



(c) In further support of our view, we point out the great difference between the damping of tunami caused by an earthquake and that generated by a storm. If the vibrations of the earth-crust be the direct source of the long period oscillations of water along the coast, the damping factor will be almost equal at the same place. On the contrary, if the origin is in the sea water, it is to be expected that the damping of the tunami will be smaller in an earthquake than in a storm, because, during a storm, the sea water will be far more disturbed and consequently the eddy viscosity is much greater than during a remote earthquake in calm weather.

Fig. 4

Examples of undulation caused by earthquakes.

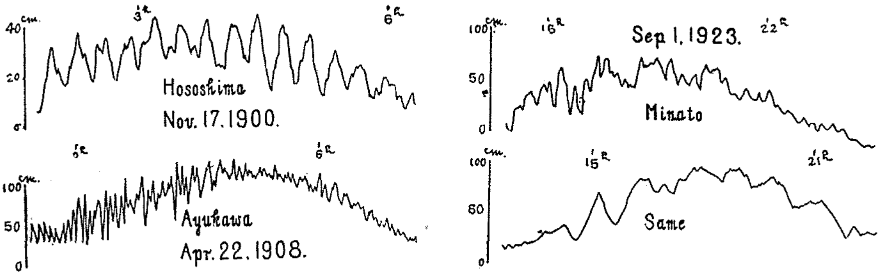


According to our theory[1] of tunami, the damping factor will be $e^{-\frac{1}{2}\nu\beta^2 t}$, where ν is the eddy viscosity, t the time and β a value such that $\beta\tan\beta H = f'/\nu$, f' being the coefficient of friction at the sea bottom. Now, Table 3 is a comparison of the actual damping factor or its index ($\frac{1}{2}\nu\beta^2$) in both cases of submarine earthquake and of cyclonic storm, and it shows evidently that the damping at the earthquake is smaller than at the storm. Several examples are shown in Fig. 5.

Table 3. Damping of the undulations

Damping in Earthquake.		Damping in Storm.	
Station	$\frac{1}{2}\nu\beta^2$	Station	$\frac{1}{2}\nu\beta^2$
Same	0.000089	Ayukawa	0.000157
Ayukawa	0.000076	Chyosi	0.000116
Onahama	0.000041	Hososima	0.000141
Minato	0.000041		
Chyosi	0.000065		
Urado	0.000058		
Hososima	0.000048		
Madras	0.000048		
Negapatam	0.000051		

Fig. 5 Comparison of damping of oscillations


in storm

in submarine earthquake

(d) Another subsidiary support is that, as seen before, the period of oscillation is not necessarily the same everywhere, but differs according to the locality of the coast, even for tunamis caused by one and the same earthquake and propagated from a very distant epicenter.

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[1] These Memoirs, A, **18**, 201 (1935).