PREFACE.

The Pacific coasts of Japan have from time to time been invaded by destructive sea waves, the so-called '*tsunamis*.' Our history abounds with the records of terrible catastrophes wrought by '*tsunamis*,' which were frequently associated with great earthquakes originating in the bed of the neighbouring ocean. The damage to life was sometimes counted by many thousands, villages were swept away in a moment, and sometimes large extents of coast lines were buried under the water. Before inquiring into the means of mitigating the damages associated with the horrible inflow of the waters of the ocean, it has in the first place been necessary to discover the nature of excitement of these waves, and afterwards to search after the necessary appliances for alleviating the effects of these catastrophes. It was with this object in view that the secondary oscillations of the oceanic tide had to be studied, for solving the problem touching the mode of excitement of the destructive sea waves.

One of the most destructive sea waves of recent years was that of Sanriku, by which the coasts of Rikuzen, Rikuchū, and Mutsu bordering on the Pacific Ocean suffered serious damage.

By examining the mareograms during the disturbances, Prof. Omori was led to the conclusion that the bays or inlets oscillate like fluid pendulums with periods peculiar to their own. What is the mode of excitement and how the period could be calculated remained still unknown.

One recognises at once a close resemblance of these oscillations to the seiches observed in lakes. An interview with Mr. E. Sarasin during the Physical Congress at Paris in 1900, and subsequent visit to Genève where the limnimeter is constantly recording the motion of the lake, led me to suggest to the Earthquake Investigation Committee the desirability of investigating the same subject in Japanese lakes, and search after any effect which may be associated with earthquakes. The proposal was at once taken up and limnological work was begun in 1901, in Lakes Biwa and Hakone with Sarasin's limnimeter. Although slight earthquakes have been encountered during the excursions, no special signs in the oscillation either before or after the shock were experienced.

The Bay of Ôsaka being of elliptic form, and connected with the sea at both extremities by narrow necks, partakes the character of a large lake; the question whether motion of the nature of the seiches is to be traced as secondary oscillations of tides was studied in 1902, by Drs. Nakamura, Honda, and Yoshida with the assistance of two other students. In the records of tide gauges at several stations were found superposed on the principal tidal curve small undulations of constant periods, which were approximately given by the wellknown Merian's formula. In 1903, observations were made on the coasts of Tosa, Kii Tôtômi, Shimôsa and Rikuchu which are open to the Pacific Ocean. From these diagrams, it was found that on open coasts the secondary oscillations are inconspicuous, but in bays and inlets which open into the Pacific, they are significantly indicated by the remarkable see-saw motions.

In the mean time, it appeared to me that Green's investigation concerning the motion of waves in a variable canal of rectangular section of small depth can be extended to that of non-rectangular section, and made to meet the cases of seiches. With a slight modification, the investigation can be extended to a wave motion in a canal, whose line of symmetry is not necessarily straight. When the mean line is curved, the wave will also participate in its course in nearly the same curvature. The amplitude of oscillation is always affected by a factor $(\text{breadth})^{-\frac{1}{2}} \times (\text{depth})^{-\frac{1}{4}}$, showing how the height of the wave is changed by the contour of the boundary and the depth of water. The presence of the said factor shows that the effect of a narrow basin is more conspicuous than its shallowness, inasmuch as the elevation varies as the inverse square root of the breadth, while the depth affects it inversely as the fourth root. As a good illustration of the presence of this factor, we may cite the extraordinary elevation of the destructive waves, when the inlet gradually tapers like a wedge. The profile of the wave is however difficult of calculation. On the coasts bordering on the ocean, the term affecting the height is only the depth, so that the effect is not so ominous as in bays and inlets; consequently on calm days, the secondary oscillations are not so pronounced. In fact, cases have often been observed in which the boats far out at sea did not in the least encounter the swell of the waves, although these caused great disaster on the shore. These considerations led me to the conclusion that the mode of vibration of destructive sea waves is of the nature of oscillations in a canal of variable depth and breadth. If the vibration is stationary, and the length between the node and loop l, then the period is $4\int_0^l \frac{ds}{\sqrt{gh}}$, where h is the depth, g the acceleration due to gravity and s the length measured along the median line. Further it appeared to me that stationary waves may be produced between the Kuroshiwo and the shore, but when the water here is once disturbed, we may expect most promiscuous groups of waves to be propagated from the disturbance; these waves will be swallowed by the bays and estuaries lying in their way, especially when the periods of oscillation are in close agreement.

Sir G. H. Darwin,* in his wellknown lectures on "Tides" delivered in 1897 speaks of the tides in Venice:—

"Every visitor to Venice must, however, have seen, or may we say smelt, the tides, which at springs have a range of some four feet. The considerable range of tide at Venice appears to indicate that the Adriatic acts as a resonator for the tidal oscillation, in the same way that a hollow vessel tuned to a particular note, picks out and resonates loudly when that note is sounded."

Later investigation in 1904, 1905 and 1906, which were mostly undertaken by Drs. Honda and Terada, assisted by several graduates of the university, in nearly all the bays bordering on the Pacific Ocean and the Japan sea, revealed the truth of the acoustical analogy first propounded by the great authority on the tides.

Led by this consideration, Dr. Terada treated the problem of the secondary oscillations by bringing in the theory of resonators in close contact with the vibration of bays and estuaries. As an outcome of the discussion, a mouth correction must be added to the period calculated according to Merian's formula, as is wellknown in the theory of organ pipes. Still more interesting is the mutual influence of the dumb-bell shaped bays, bearing close resemblance to the acoustical resonators

* Tides, p. 168–169, First Edition.

communicating through a narrow channel. This is beautifully illustrated in the oscillations of some bays, fulfilling the stated condition.

When the volume of water in the bay and consequently the depth and the breadth change, it is necessary to add a small correction. This question was discussed by Dr. Isitani.

In limnological work, Sarasin's limnimeter is universally recognised as a trustworthy and convenient instrument, and was used in some of our lake surveys. In observations of secondary oscillations, the large range of the tidal fluctuation prevented the use of the instrument. The tide gauge in its usual form is too cumbrous as a portable instrument, and the great damping through communicating tubes annihilates waves of secondary oscillations of short periods, so that they are mostly lost on the record. This defect was first modified by Dr. Nakamura by balancing the pressure by means of a mercury column, and greatly reducing the range of the tidal fluctuation without in the least interfering with damping, which it was necessary to keep suitably small in order that the secondary oscillations may not be lost to view. This was further improved by Dr. Honda, who greatly simplified the apparatus, and changed it to a neat portable form. In most of the present investigations, Dr. Honda's instrument was used.

The records obtained either by the tide gauge or with Dr. Honda's instrument all present semidiurnal fluctuations, and on it the undulations to be investigated appear in serrated form. For the exact study of the phenomena, it is sometimes necessary to eliminate the tidal undulation. This was effected by means of Dr. Terada's tidal rectifier, by which only the secondary oscillations were brought to view. When the bay responds to waves of different periods, so that they are mingled together, this procedure was the easiest step for analysing the different components.

Dr. Endrös, in his elegant research on the seiches in one of the Bavarian lakes, made use of a model for studying the periods of oscillation. The same method was followed by Drs. Honda, Terada, and Isitani in a slightly different manner. The models of bays having the contour lines and the magnified depths of those already studied were placed in a water tank, so that the water in the model came to the level mark, and waves were then excited in the tank. When the period of the wave was in harmony with that of the model bay, the water in the model responded to the exciting wave with extreme ease, and continued vibrating for some time even after the subsidence of the exciting wave. Not only was Dr. Endrös's experiment extended in this direction, but the courses of the stream lines in the model were closely studied by Dr. Honda. By an ingenious device of sprinkling the surface of water with fine aluminium powder, and photographing the surface by a camera with the optical axis vertical, the trace of dust particles was observed; these photographs proved distinctly that the surface of the water was oscillating and showed at a glance the mode of response to the external source of excitement. This graphical representation is more practical than that deduced from mathematical calculation, which is next to impossible on account of the variable depth and the irregular contour. Thus in delineating the oscillations proper to bays, the study with models, when a hydrographical chart can be obtained, is generally sufficient to determine the nature of oscillations and their periods. It seldom happened that the periods which can not be detected with the model were ever observed. We are now in a position to infer from the study of models how the bay oscillates without entering intó the actual registration of the secondary oscillations.

The contour lines of equal depths in different bays were drawn by Dr. Isitani, who also undertook the laborious task of integrating and determining the volume of the bay; after suitably choosing the median line, he also calculated the periods. They generally agree quite closely with the observed values.

The problem which still remains unsolved is how the waves of different periods are generated in the surrounding ocean and especially on the Pacific side. They may be due to local variations of atmospheric pressure, earthquakes, and such allied causes. The following hint may also not be out of place as to the cause of these waves on the Pacific coast. By far the greater part of the destructive sea waves, which from time to time have devastated our coast, seem to have had their origin on the waves originating off the eastern coasts of Japan. The existence of a sort of standing waves with the land on one side and on the other the ocean current running nearly parallel to the shore is quite imaginable. Along the east coast of Rikuchū and the southern part of Hokkaidô, the gulf of Tosa and the adjacent districts, the course of the current is nearly parallel to the line of equal depth. In such cases, the presence of standing waves with the land and the current as the boundaries is a matter beyond dispute. The current will not behave exactly like a solid shore, but on account of its high speed, it will partake the nature of a quasi-elastic solid, making the waves rebound. It resembles a liquid jet in the ocean; it will oscillate with periods peculiar to itself; it will thereby be capable of transmitting vibration to the bounding waters; it will be set in forced vibrations by earthquakes and other causes. In fact, the behaviour of the current resembles a piece of india-rubber band, several hundred miles wide, stretched nearly parallel to the coast on the Pacific side. It therefore appears to me that the existence of Kuroshiwo is extremely favourable to the generation of exciting waves, which spread devastation along the sea coast.

Thus a portion of my proposals to the Earthquake Investigation Committee has been happily brought to a close by the indefatigable zeal of several investigators, who not only prosecuted the observations, but improved the apparatus, deduced corrections to observations, compared the observed with the calculated periods, and solved the important question as to the mode of excitement of oscillations proper to bays and estuaries. It fell to my lot only to guide the method and fix the places of observation, and it is on account of this responsibility that I have allowed myself to add these words as a preface.

Finally I must not omit to state that my best thanks are due to Dr. B. Mano, the President of the Earthquake Investigation Committee, for allotting during several years a part of the fund granted to the committee for continuing the present research, and the kindly interest with which he has watched the results.

H. NAGAOKA.

Member of the Earthquake
Investigation Committee.

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