6. *Experimental Investigation on Prevention of Damage of Tunami.**

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In Bureau of Public Works, Department of Home Affairs, when they consider the prevention of damages from future tunamis have undertaken a model experiment as a means of preliminary investigation. The experiment is now being carried out in Research Office of Public Works, and the author here tries to explain some results heretofore obtained which include the change of the height of the wave in a smooth sloped channel, also in a channel with a baffle wall of different heights and with a wall representing a break-water, the effect of the wheeling of the wave and some others.

Here the results are only described, full discussion of the result being expected after it will be finished.

From the results it is clearly understood that it is the predominant factor to control the force which acts on the structures that where the breaking of the wave takes place and what is the distance to the structures from the site of breaking.

Near the site of breaking the destructive power of the wave seems enormously larger than the other sites.

Arrangement for Experiment.

The experiment was mainly carried out in a tank made of board which has the length 10·6 m, the width 1·23 m and the depth 0·60 m. (Fig. 1).

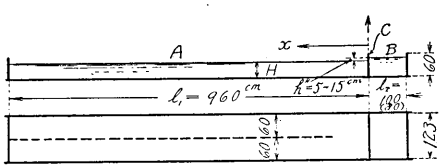

Fig. 1. Water tank for the experiment.

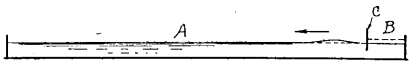

Fig. 2. A long wave is generated in the tank.

* Communicated by N. Mononobe.

The water level in the compertment B (the width of which is normally 100 cm sometimes 80 or 200 cm) is initially higher than that of A normally by 10 cm (sometimes 5 or 15 cm) and by pulling up the bulkhead board C (Fig. 1 and 2) a long solitary wave was generated in the compartment A. The winding velocity of the board C was 20 cm/sec.

Inside of the tank were painted white and at the distances 10, 20 or 40 cm. vertical scales were marked to facilitate the observation as may be seen in the photographs of the Plates. Thus the readings were taken sometimes from direct observations, sometimes from instantaneous photographs, mainly taken with a shutter of 1/100 sec., and sometimes from cinematographs with 16 mm. film and with the max. operating speed 64 frames per sec. or 1/100 sec. for one exposure.

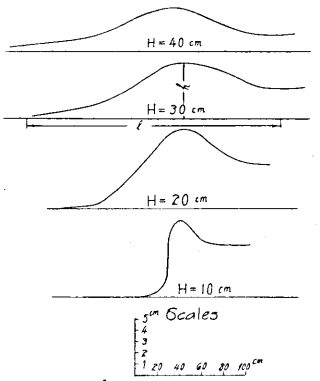

Fig. 3. Waves generated at the depths $H=40$, 30, 20 and 10 cm.

The Wave.

Examples of the waves in the experiment are shown in Fig. 3. These are the shapes of the waves at a distance $x=2{\cdot}25$ m. from the board C (Fig. 1) and which is generated under $l_2=80$ cm, $h''=15$ cm. at the depths $H=$ 40, 30, 20, and 10 cm. From the figure we read the heights and the lengths of the waves as follows

H(cm)	h(cm)	l(cm)	l/h
40	3·9	250	65·9
30	5·0	230	46·0
20	7·1	180	25·7
10	7·1	85	12·1

The propagation velocities of the wave observed at the crest in a series of experiments are shown in the following table.

The record of Sanriku tunami on March 3, 1933, shows[1] that the height is nearly 3·5 m. and the length of the wave is nearly 17 km. at

1) Haruo MATUO, "Estimation of Energy of Tunami and Protection of Coasts," *loc. cit.*, pp. 55-64.

Depth H(cm)	Initial head h''(cm)	Height of the wave h(cm)	Propergation vel. (cm/sec.)		
			Measured	Calculated by $\sqrt{gH}$	Calculated by $\sqrt{g\left(H+\frac{h}{2}\right)}$
40	15	3·9	168·5	198·0	203·0
30	15	5·0	154·5	171·5	178·5
20	15	7·1	145·0	140·0	152·5
10	15	7·1	129·0	99·0	115·5

the month of the bays if we assume the mean depth at the month 60 m. and the period of oscillation 11·5 min. Comparing the scales with that of the experiment the ratios are roughly in the order of 1/7000 for the length and 1/100 for the heights.

Experiment on Slopes.

Effect of the base slope upon the wave was first observed on 2 kinds of slopes i. e. 1/20 and 1/40, as shown in Fig. 4.

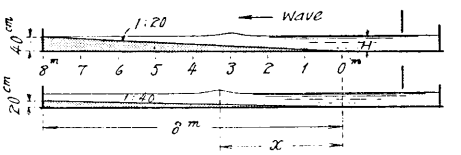

Fig. 4. Arrangement of the slopes 1/20 and 1/40 on which the experiment was carried out.

Observations were made upon the following subjects and the results are shown in Fig. 6 and 7.

1. The chang of the height of the wave during the propergation on the slopes, the loci of the crest of the wave being shown in the figures by broken lines denoted by h (See also Figs. 20—25 in the Plates).

2. The sites where " breaking " of the wave takes place, denoted by B on the h curves in the figures. (also Fig. 21).

3. The max. height the water reaches when it runs up against the vertical wall set at different sites as shown in Fig. 5. These are shown by full lines denoted by h' in the figures.

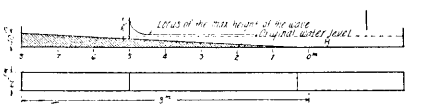

Fig. 5. Arrangement for the measurement of h'.

4. The displacement of small floating waxes, originally set at the corresponding sites of the figure, during the first oscillation of the wave. These are shown as d in the figure. In this experiment the time during

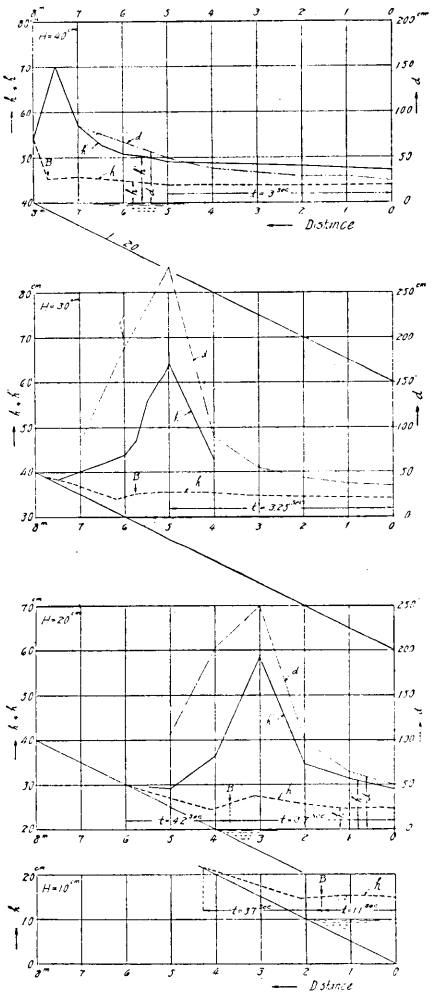

Fig. 6. Results of the experiment on the slope 1/20.

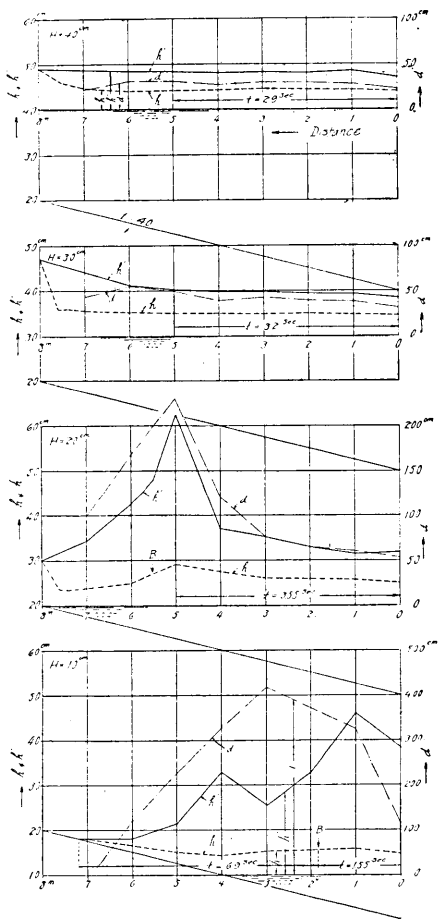

Fig. 7. Results of the experiment on the slope 1/40.

in which h= the locus of the crest of the wave, B indicates where the breaking takes place. h'= the max. height which the water reaches at the vertical wall of the corresponding sites. d= total displacement of a small floating wax, originally placed at the corresponding sites of the figure, during one oscillation of the wave, the direction being equal to the direction of propagation of the wave. H= original depth of water in the tank (Fig. 5)

the displacement was observed, but as the observation was made by usual 0·2 sec. stop watches and moreover as the instant of the beginning and the end of the motion was ambiguous some errors of observations may be expected.

Depth H	The time of one oscillation observed	
	on 1/20 slope	on 1/40 slope
40 cm.	2·1 sec. at $x=0$ m. and $x=7$ mm.	2·0 sec. at $x=0$ m.
30	2·2 „ „	2·6 „ „
20	2·7 „ „	2·5 „ „
10	4·1 „ „	4·1 „ „

According to the figures it is obvious that the height of the wave increases with the decrease of the depth and by detailed analysis it is understood that the rate of increase is somewhat greater on 1/40 slope than on 1/20 slope, this latter approximately following Green's law.[2)]

Breaking of the wave takes place at the depth $H \fallingdotseq 2h$ on 1/20 slope and at $H \fallingdotseq h$ on 1/40 slope.

The height h' may be taken as a measure of the kinetic energy at the site. For the experiment of larger depth in which breaking does not take place such as the case when $H=$ 40 cm and 30 cm on 1/40 slope, the values h' at different sites differ but little. On the contrary when breaking takes place, h' is conspicurouly large near the site of breaking and this indicates that the kinetic energy is here especially large. The ratio $h'_{max.}/h_0'$ is approximately 4·3 for 1/20 slope, and 3·6 for 1/40 slope, in which $h'_{max.}$ and h_0 denotes the max. value of h' and h' at $x=0$ respectively.

In another pair of experiments on the slopes 1/4 and 1/8, the max. height h' at the end of the slope was observed (Fig. 8 also Fig. 26 and 27 in the Plate), and the ratio h'/h_0 was as follows, in which h_0 is the height of the wave at the head of the channel.

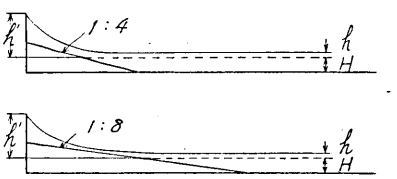

Fig. 8. Arrangement of the slopes 1/4 and 1/8 on which the experiment was carried out.

For this experiment mean values of each 4 observations were taken.

2) According to Green's law the height h_x of a wave at a depth H_x is expressed $h_x \infty h_0 \left(\frac{H_0}{H_x}\right)^{\frac{1}{4}}$ in which h_0 is the height of the wave at the depth H_0.

Depth H	Height of the wave at $x=0$ m h_0	Value of h'/h_0	
		on the slope 1/8	on the slope 1/4
40 cm.	6·4 cm.	2·13	2·00
30	7·8	4·62	2·66
20	10·8	3·20	3·64
10	6·9	2·23	3·23

According to the table the value h'/h_0 is, at the depth of 30 cm, conspicuously larger on 1/8 slope than 1/4. As may be seen from the experiments on the slopes of 1/20 and 1/40, the waves seems liable to break at larger depth for the slope 1/40 than 1/20. The steeper is the slope the more non-liable-to-break becomes the wave. Therefore the wave which does not break at the end on the slope of 1/4 at the depth $H=30$ cm., is observed to break just before the end wall on the slope of 1/8, thus h' for the case becoming very large for the latter. At the depth $H=40$ cm breaking does not take place for both slopes, thus both values of h' being moderate. For the depth $H=20$ cm and 10 cm breaking takes place half way up the slope and, as may be expected, the water runs up higher for 1/4 than 1/8.

To see the effect of the base conditions, wire mesh which is made of 0·1 cm wire with the spacing of 1·0 cm was attached on the sloped base and the same experiment was carried out, and the results were as follows,

H	h_0	h'/h_0	
		slope 1/8	slope 1/4
30 cm	7·6 cm	5·53	2·48
20	10·1	2·84	3·89
10	5·6	2·47	3·12

The results are compared with that of the preceeding ones and we would conclude that the effect of the conditions of the base is rather small.

Experiment on Breakwater.

Baffle Walls. On the slope 1/40 vertical baffle walls of different heights were fixed perpendicular to the direction of propagation of the wave and the change of the wave along the channel was observed at

the depths $H=20$ cm and 10 cm. The height η of the top level above the still water level was $\eta=0$, 2·5, 5, 7·5 and 10 cm, therefore the total height of the wall becoming the sum of H_n and η, in which H_n is the depth of the still water at the site of the wall. For the depth of $H=$ 20 cm (Fig. 4) the site of the baffle wall was selected at $x=3$, 5 or 7 m. and the max. height h_s to which the wave runs up high at the vertical end wall at $x=8$ m was observed and the relations of h_s/h'_s to η are shown in Fig. 9, in which h_s' is the hight at $x=8$ m when there is no wall in the channel.

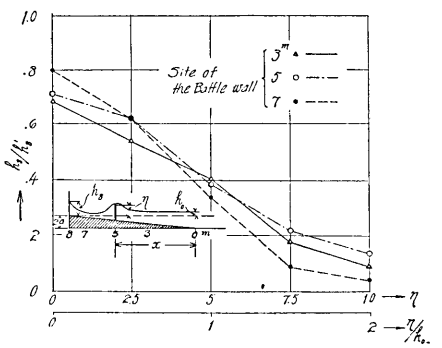

Fig. 9. Observations with baffle walls on the slope 1/40 with the depth of water $H=20$ cm, in which $h_0=5{\cdot}0$ cm and $h_s'=8{\cdot}7$ cm. with various values of η (cm)

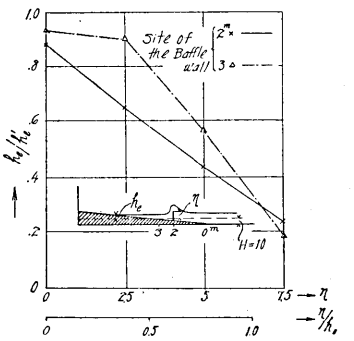

Fig. 10. Do. with the depth $H=10$ cm. $h_0=6{\cdot}5$ cm and $h_e'=8{\cdot}7$ cm.

Another result at the depth $H=10$ cm is shown in Fig. 10 also Fig.

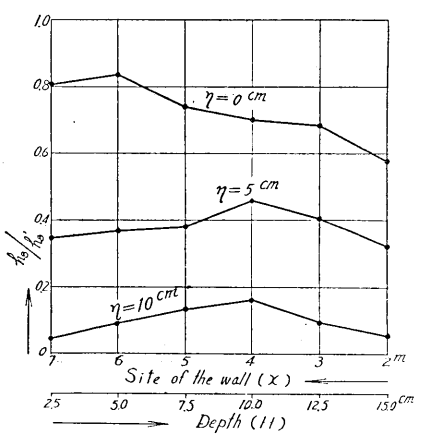

Fig. 11. Effect of the site of the baffle wall when $\eta=0$, 5 and 10 cm on the slope 1/40 and with the depth $H=20$ cm.

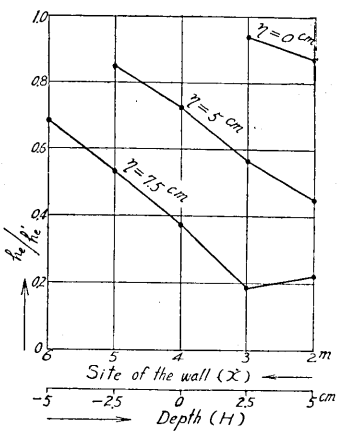

Fig. 12. Do. with the depth $H=10$ cm.

28, 29, 30 and 31. Here the end of the wave does not reach to $x=8$ m, being half way up the slope, therefore the ratios of the height h_e, as shown in the figure, to h_e' which is observed when no wall exists are taken.

In the above experiment when $H=20$ cm, the effect of the site is rather small, so long as η is const., as may be seen from Fig. 11.

From this and from Fig. 9 we may conclude that the nearer to the coast is the vertical baffle wall, the more efficient it becomes, so far as the total height of the wall is constant. This however seems not hold true for the experiment at the depth $H=10$ cm (Fig. 12), but we must remember that for the depth "breaking" takes place at the site $x=1{\cdot}8$ m. when no wall exists and that the observations are made after $x=2$ m. According to Fig. 12 the site of the wall has much effect on the value h_e which may be said after breaking of shorter waves.

Experiment on Breakwater Having a Cut in the Centre. In a channel having a breadth of 60 cm and on the slope 1/20 or 1/40 the vertical wall having the height of 60 cm and a centre cut of breadth b (Fig. 13) was elected at $x=4$ m, observations were made under $b=1{\cdot}5$, 3, 6, 12, 18, 24, 30 and 45 cm.

The readings of the max. height of water were taken at the fore-side edge A in Fig. 13 and at the end of the channel which is at 4 m. distance from the wall.

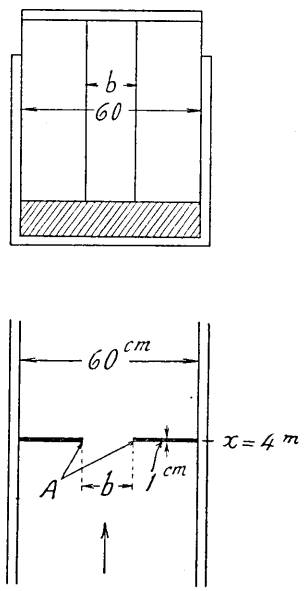

Fig. 13. Vertical wall having a cut in the centre.

The walls were at the middle of the slope and the depths of still water at the site were as follows,

Depth of water H at $x=0$ m.	Depth at the wall	
	slope 1/20	slope 1/40
40 cm	20 cm	30 cm
30	10	20
20	0	10
10	−10	0

According to Fig. 14 and 15 which show the relations of h_8/h_8' to b/B, the curves of the mean values is convex upward showing that the effect of b is conspicuous for smaller values.

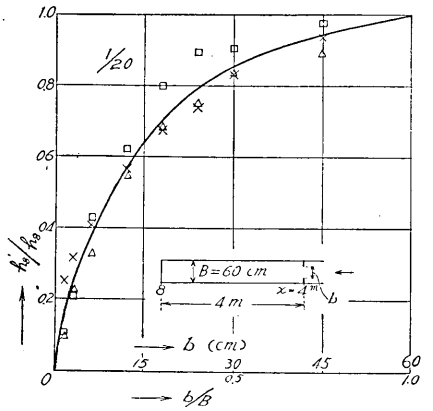

Fig. 14. The relation between h_8/h_8' and b/B for the slope 1/20,

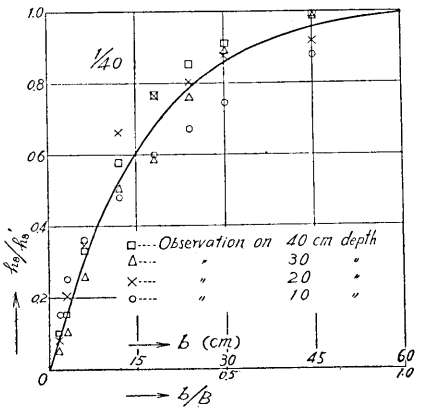

Fig. 15. Do. for the slope 1/40,

in which h_8 is the height at $x=8$ m with the wall and h'_8 without the wall.

Effect of the distance of the wall to the end wall was observed, and a result at the depth $H=40$ cm on the slope 1/40 was as follows,

Site of the end wall, breakwater being at $x=4$ m.	$x=8$ m	7	6	5
h/h'	0·60	0·59	0·61	0·64

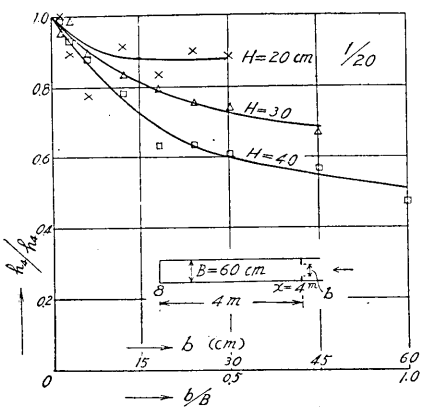

Fig. 16. The relation between h_4/h'_4 and b/B for the slope 1/20,

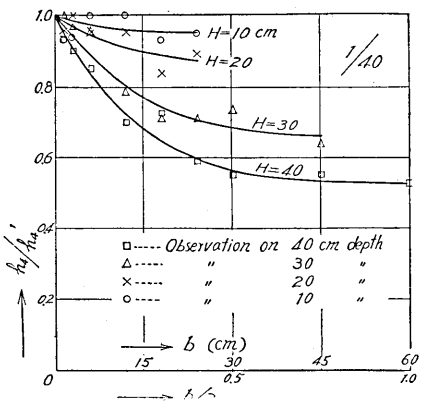

Fig. 17. Do. for the slope 1/40,

in which h_4 is the height at $x=4$ m at .1 of the wall and h'_4 the height of the wave at $x=4$ m when no wall exists in the channel.

in which h is the height at the corresponding site and h' is that when no wall exists. From this it is obvious that the effect of the distance from the wall is negligible.

Results of observations at A (Fig. 13) are shown in Fig. 16 and 17.

Under sloped vertical walls as shown in Fig. 18, experiments were carried out under $b=12$ cm and $l'=0$, 25, 50 and 100 cm and results at the depths $H=40$ and 10 cm on the slope 1/40 were as follows,

		$l'=0$ ($\theta=90°$)	25 cm (43°50′)	50 cm (25°40′)	100 cm (13°30′)
h_8/h'_8	$H=40$ cm	0·58	0·30	0·33	0·31
	$H=10$ cm	0·63	0·57	0·62	0·67

From the result we would conclude that in the bay the effect of the slope of the wall is rather small.

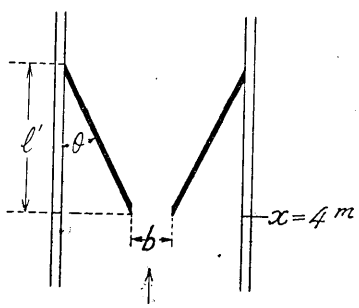

Fig. 18. Arrangement for the experiment with sloped vertical walls.

Effect of the Wheeling of the Wave.

According to the investigation[3] on the disaster of the great Sanriku tunami on March 3, 1933, the height of the wave in a bay opening direct on the ocean for the epicentre is conspicuously larger than in oblique one. To see the effect of the "wheeling" of the tunami, the experiment was done in a straight channel having a branch as shown at the left hand under corner of Fig. 19. The wave which was generated in the same manner as the previous experiments and which comes from the direction indicated by the arrow runs up high against the direct end A and the other branch end B, the angle which is subtended between the two directions being θ. The ratio h/h_0, i. e. the ratio of the height at B to A, was plotted for various values of θ. Heretofore the experiment was done for $\theta=45°$, 90° and 135°, in the channel having uniform depth $H=40$, 30, 20 and 10 cm, and under $l_2=80$ cm, $h''=15$ cm. (Fig. 1)

Results of experiments with two kinds of breadth of the main channel, i. e. 60 cm and 30 cm, the breadth of the branch channel re-

3) H. MATUO, "Estimation of Energy of Tunami and Protection of Coasts," *loc. cit.*, pp. 55-64.

maining the same for both experiments, show that the difference between the two is not perceived and in Fig. 19 they are equally treated.

The conditions of water at its max. height in the branches are shown in Fig. 32, 33, and 34 in the Plate. Fig. 35 is that at the direct end.

For the sake of the deficiency of the data of experiments, especially for smaller values of θ, definite result is not obtained so far as yet, but we would apply tentatively the formulas

$$h=h_0e^{-\frac{\sqrt{\theta}}{25}} \quad \text{or} \quad h=h_0\theta^{-\frac{\theta}{250}}.$$

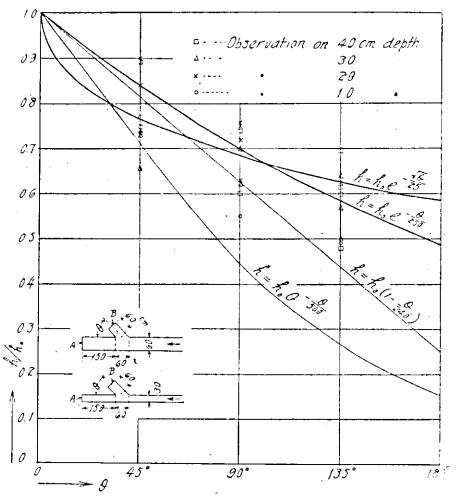

Fig. 19. Results of observations on the wheeling of the wave.
h_0= the height at A, h= the height at B.

Dr. Hiroi[4] has introduced the following formulas for the wheeling for the surface wave

$$h=h_0\left(1-\frac{\theta}{240}\right) \quad \text{or} \quad h=h_0\theta^{-\frac{\theta}{500}},$$

from the measurement on the sea at the breakwater of Otaru, Hokkaidô. These formulas seem not hold true, as may be seen from the figure, for a long wave as the tunami, the loss of the energy for a long wave being expected smaller than the usual surface wave.

Other Experiments.

The experiment of the effect of the convergency of the shape of the bay is now going on and the experiments on topographical models of important towns in the coast of Sanriku are also contemplated.

Remarks

The results above mentioned are of model experiments and it must be remembered that they cannot be applied directly for the design of structures so far as yet the law of similitude is not considered.

4) Harbour Construction, 1 (1924), 39, (in Japanese).

6. 津浪の災害輕減に關する模型試驗

內務省土木試驗所 松 尾 春 雄

內務省土木局に於ては今般の三陸大津浪の直後災害復舊豫算を計上して復舊工事を施したのであるが，將來の津浪の被害輕減の爲には積局的に災害防止設備を施す要ある事を認め，三陸地方に對しては之を計畫中である．然るに如何なる地點に如何なる構造物を設くれば最も有效であるか，又その强度を何程にすべきか等に關する研究が不十分である爲に，此等に關する試驗を行ふ事となり，目下內務省土木試驗所に於て研究中である．

玆にはこれ迄に行はれた試驗の中

1. 一定の底面勾配を有する水路中を長波が傳はる場合の波形の變化．
2. 上述の水路中に種々の高さの阻壁を波の進行方向に直角に立てた場合の波形の變化．
3. 防波堤內に於ける波形の變化．
4. 波の傳播方向の轉換に依る波高の變化．

等に就て述べたものである．玆には主として試驗の結果のみを述べ結果に對する檢討は試驗完了後にする事として玆には差控へた．

これ迄の試驗の中最も顯著な結果は，海中に築造された築港用の防波堤の如き構造物は津浪に對しては效果が尠く，陸上に築かれた防浪堤が割合に效果が多い事，津浪は波が碎ける附近に於て非常に大なる破壞力を有する事，及構造物の此の線よりの距離が之に對する津浪の破壞力を決定するに主要な要素であるといふ事である．

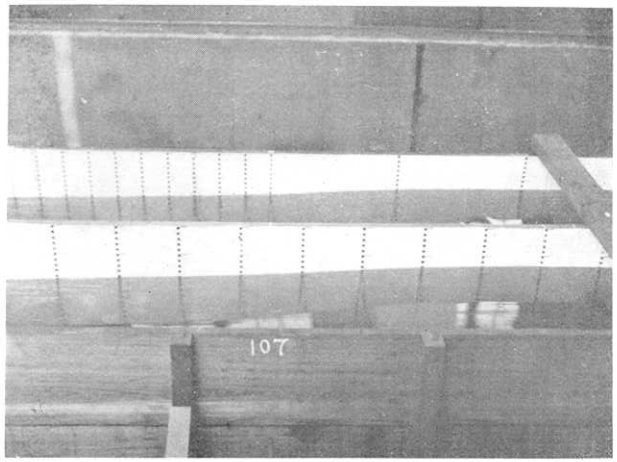

Fig. 20. The wave on the slope 1/20 (further side) and 1/40 (nearer side) for the depth $H=40$ cm and at the distance $x \fallingdotseq 1.8$ m (Fig. 4)

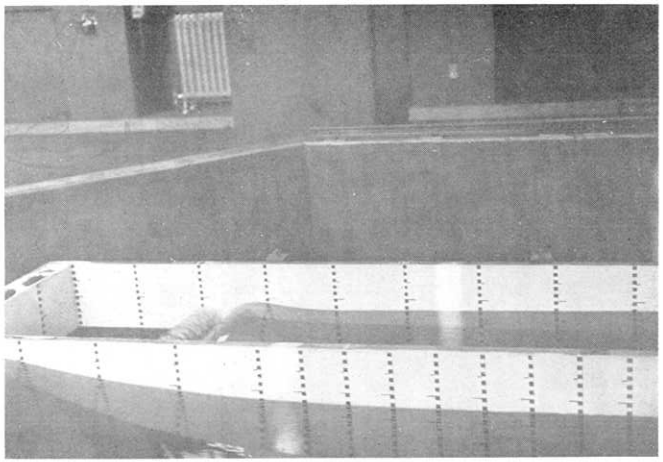

Fig. 21. Do. $x \fallingdotseq 7.5$ m.

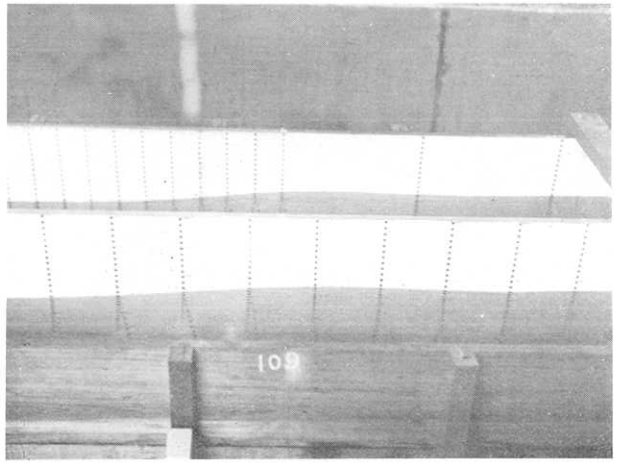

Fig. 22. Do. $H=30$ cm, $x \fallingdotseq 1.8$ m.

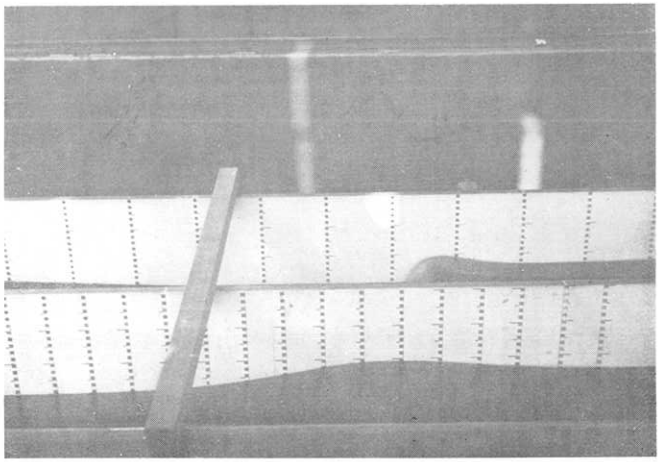

Fig. 23. Do. $H=30$ cm, $x \fallingdotseq 6.4$ m.

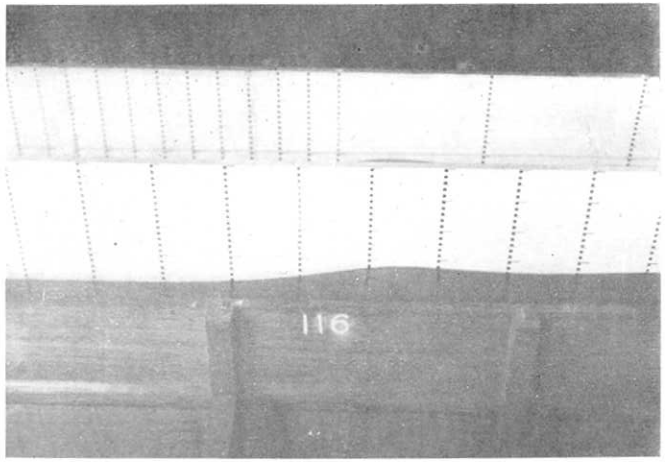

Fig. 24. The wave on the slope 1/40 for $H=20$cm, $x \doteqdot 2.8$ m.

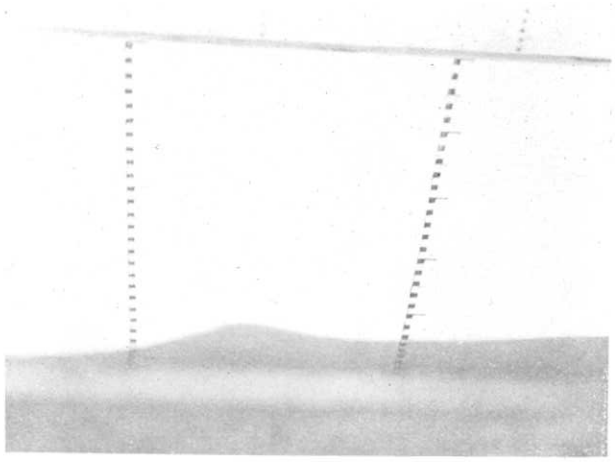

Fig. 25. Do $H=10$ cm, $x \doteqdot 0.55$ m.

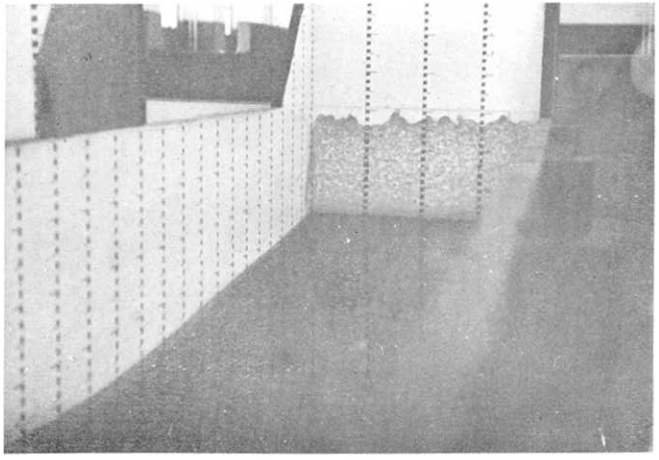

Fig. 26. Experiment on the slope 1/8. An instantaneous snap when the water splashed against the end wall of the slope. $l_2=80$ cm. $h''=15$cm, $H=20$ cm and $h_0=9.0$ cm (Fig. 1 and Fig. 8).

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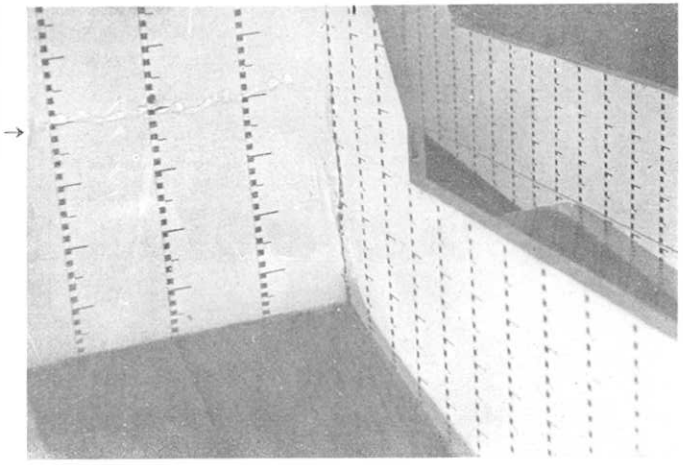

Fig. 27. Experiment on the slope of 1/4. At the height marked with the arrow the upper end of the water can be perceived. The experimental data are equal to Fig. 26.

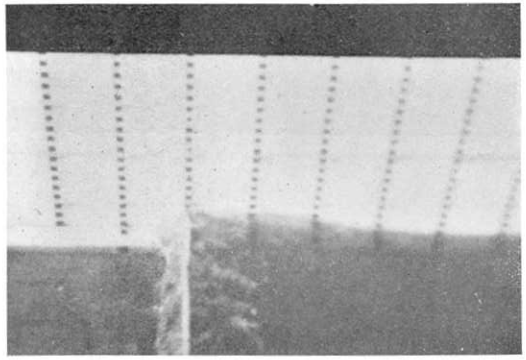

Fig. 28. Experiment of the baffle wall on the slope 1/40 and at the depth $H=10$ cm and with $\eta=7.5$ cm. The photograph is taken at the instant when the crest of the wave reached the wall. The site of the wall $x=3.0$ cm, hence $H_3+\eta=10$ cm.

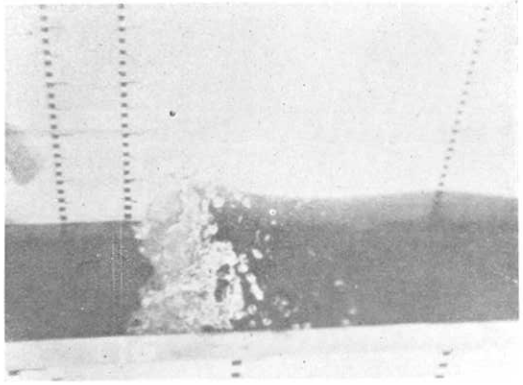

Fig. 29. Do. $x=2.0$m, $H_2+\eta=12.5$cm. Breaking of the wave takes place at $x=1.8$ m when no wall exists in the channel.

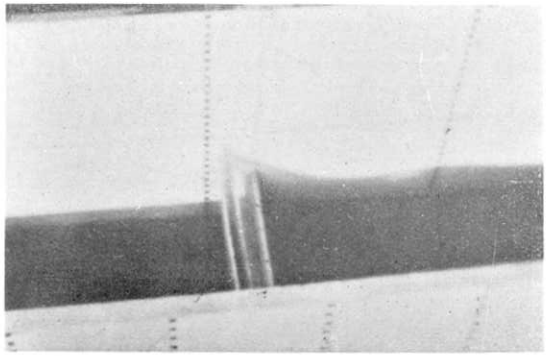

Fig. 30. Do. $x=1.0$m, $H_1+\eta=15.0$ cm

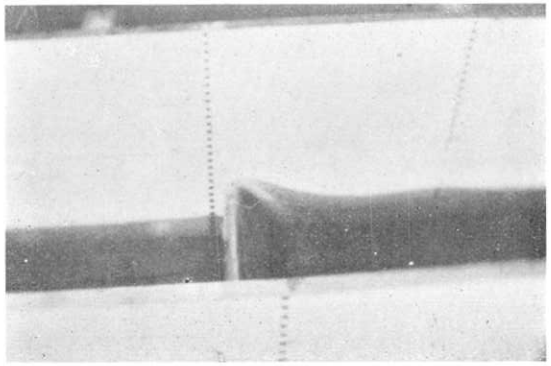

Fig. 31. Do. $x=0$m, $H_0+\eta=17.5$ cm

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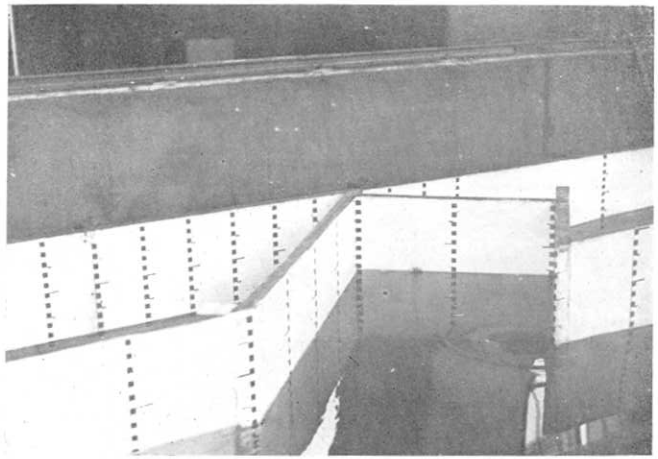

Fig. 32. Experiment of the effect of the wheeling of the wave. The condition of water at its max. at the end of the branch, when $H=40$cm and $\theta=45°$.

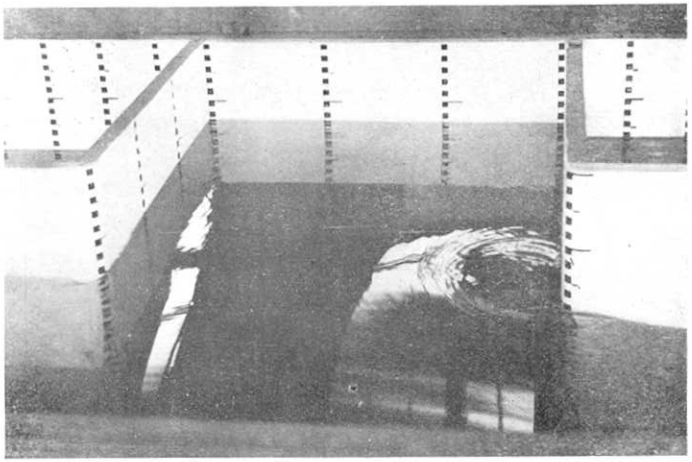

Fig. 33. Do. $H=40$ m, $\theta=90°$.

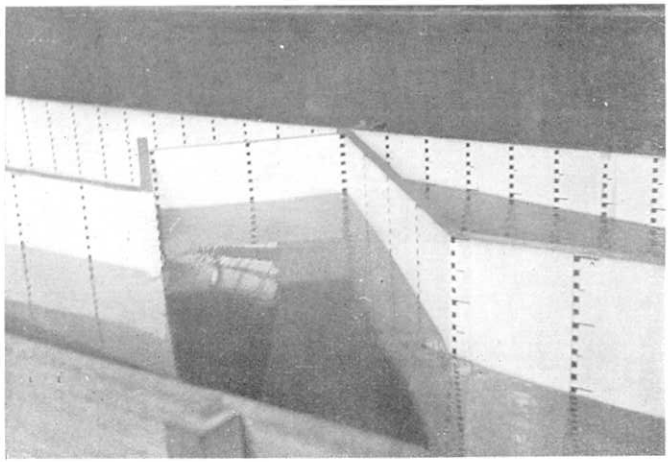

Fig. 34. Do. $H=40$cm, $\theta=135°$

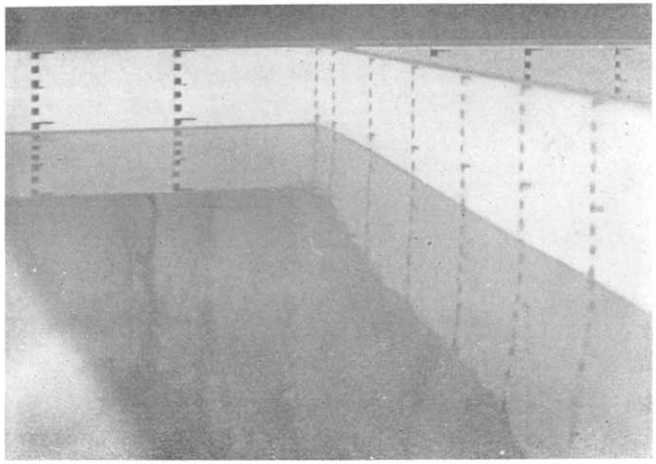

Fig. 35. Do. The condition of water at its max. at the end of the main channel when $H=40$ cm.

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