CHAPTER 154

QUAY WALL WITH WAVE ABSORBER "IGLOO"

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ABSTRACT

This report summarizes the results of the research on a gravity type quay wall comprising several layers of concrete blocks with a special shape called "Igloo" as shown in Photograph–1.

INTRODUCTION

The recent trend for higher utilization of the basin in the ports and harbors by using the vertical wall as the facilities for berthing and cargo handling presents extreme difficulties for securing the calmness within the ports as the vertical wall would keep on reflecting the invading waves and increase the wave energy. Much research has been conducted on the vertical wave absorbing structure in Japan in recent years.

Research has proved that a vertical wave dissipating structure had an optimum wall depth which absorbs waves most effectively in accordance with the incident wave period.[1), 2)] This report is an artcle on the gravity type structure which is contrived to actual application with the best wave dissipating effect, and is made of concrete blocks.

Photograph–1

Our first step is to conduct a two dimensional model test look into the relationship between inci-

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dent wave period and dissipating effect, and then to conduct a three dimensional model test where we will investigate how the vertical wave dissipating structure calms the basin.

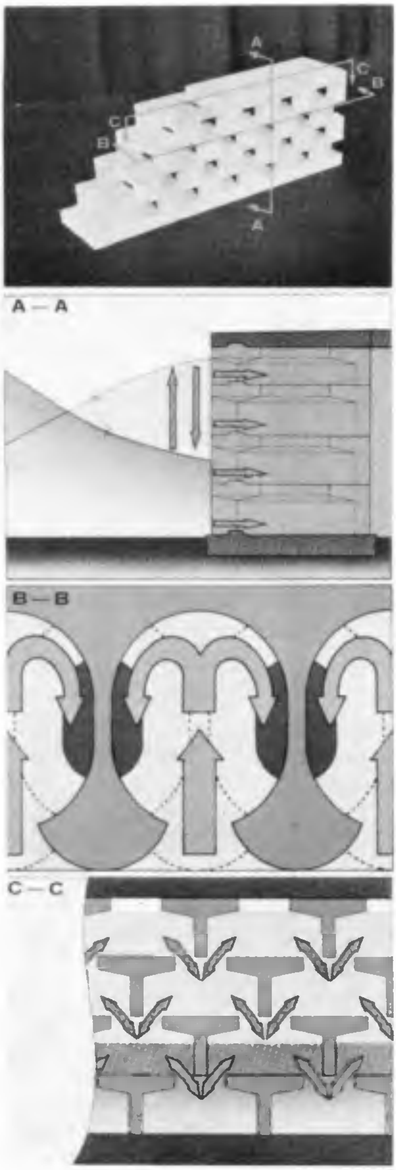
WAVE DISSIPATING PRINCIPLES OF IGLOO SYSTEM

The principles of the Igloo wave dissipating system are shown on the illustrations (Fig-1) and are summarized as follows:

The horizontal plate converts the vertical wave movement into the horizontal flow, then induces the water to enter the block which rotates the water inside cylindrical chambers and ruduces the energy through the friction with the wall surface through the forced diversion and merging of the flows.

Further in detail, the column shaped front wall lets the waves into the block smoothly, hardly reflecting the waves. The horizontal plate converts the vertical movement of the waves (the circular movement, to be more precise) into a horizontal flow. In physical terms, the potential wave energy is converted to kinetic energy. The converted water causes friction alongiside the wall surface in the block chambers and diverts and merges as it rotates, thus losing the energy. The loss ratio of water energy that flows in a void encountering resistance is the subject of studies in various universities. It has been found that the ratio is proportionate to 2nd or 3rd power of the velocity. That is, the more distance the water flows at a faster velocity, the more energy is lost.

Igloo system is contrived for the water to flow the longer distance at the faster speed. When the Igloos one piled together, the chambers formed by these blocks take a circular shape with a narrow entrance and a wider inside. Thus shaped blocks impart



Fig–1

faster velocity to the mass of water and induce the water into the chambers. The water advances directly into the innermost part of the chamber and then separates into two, and rotates alongside the walls. When the water rotates, the distance of the water flow increases. Even though the chamber space may be limited, the water revolves within the chambers at a high velocity and the energy thus lost is quite big.

As the phase between the water level in front of the seawall and that of the chambers is quite different, the water level in front of the seawall lowers, causing energy loss when the water is discharged from the chambers.

TWO DIMENSIONAL MODEL TEST

The model tests of this structure were carried out in the laboratory to investigate the hydraulic properties.

1. Test Facilities

Two dimensional wave channel with a wind tunnel owned by the Hydraulic Research Center of Nippon Tetrapod Co., Ltd. was used.

Dimensions of the channel:

Length 49.0m, Height 1.0m, Width 1.0m (50cmx2)

Wave generator

Flap type (hydraulic system, irregular waves)

Wave hight:	25 cm Max
Period:	0.6~3.0 sec
Blower:	Suction type, propeller system (Wind volume, 600 m^3/min.)

2. Test Model

We used a mortar-made 1:25 scale model of Igloo blocks and its specific weight was 2.3 ton/m^3, which is the same weight of actual Igloo blocks. The model is 15.2~26.0 cm in depth, 12 cm in width and 4.4~6.8 cm in height; their actual block size is 3.8~6.5 m in depth, 3.0 m in width and 1.1~1.7 m in height.

3. Test Method

(1) The wave measuring method:

The reflection coefficient is measured by the method provided by Healy, and the variation of the water level is checked by a volmetric wave meter. The change in the electric volume caused by the change in the water level is converted into an electric current, amplified by an amplifier and recorded by an oscillograph.

(2) Wave generation method:

Sinosoidal waves made by the function generator send the wave to the wave making control device, which generates regular waves with the required periods and heights.

4. Test Conditions

The cross section of the tests is shown in Fig–2. Test conditions are shown in Table–1.

5. Test Results

Non-dimensional factors affecting Igloo's wave dissipation include B/L: the ratio of wall depth against wave length, hc/H: the ratio of Igloo crown height above still water level against wave height, i: bottom slope, h/L: relative water depth, h/H: the ratio of wave height against water depth, H/L: wave steepness and others.

If the design conditions are limited to $h/H>2, 3<T<10$ sec, $0.3<H<2$ (m) in case of actual application, influence of non-dimensional factors such as h/L, H/L, and others are not so great. Out test condition is always set at i=1/30. The remaining non-dimensional factors such as B/L and hc/H will play an important role. Therefore we summarized the test results concerning reflection coefficient KR which is shown in Fig–3 (a)~(e) with B/L on the horizontal axis of cordinates and with hc/H as a parameter.

The following were made clear.

(1) In all tests, wave dissipating

Fig - 2. Test Cross Section

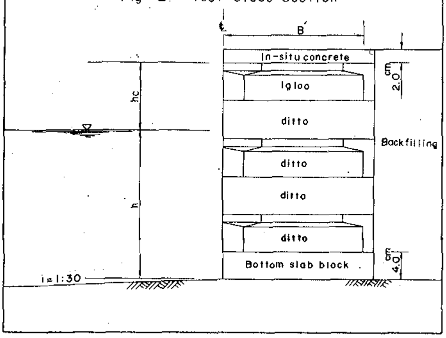


Table - I Test Conditions

B (B') (cm)	h (cm)	T (sec)	Lo (cm)	h/Lo	h/L	L (cm)	H (cm)	hc (cm)	B'/L	h/H	hc/H	H/L
15.2 (13.6)									0.039 ~0.164			
18.0 (16.4)									0.047 ~0.198			
22.0 (20.4)	16.0 ~ 22.0	0.8 ~ 2.4	100 ~ 900	0.018 ~0.220	0.055 ~0.242	83 ~349	2.0 ~ 6.0	2.0 ~ 8.0	0.058 ~0.246	2.67 ~11.0	0.5 ~4.0	0.006 ~0.072
26.0 (24.4)									0.070 ~0.294			
34.0 (32.4)									0.093 ~0.390			

List of Notation

- B: Igloo depth
- B : Effective depth of Igloo
- h: Water depth at the toe of the seawall
- T: Wave period
- Lo: Wave length in deep water
- L: Wave length of progressive waves at the toe of seawall
- H: Height of progressive waves at the toe of seawall
- hc: Distance from still water level to the crown height of Igloo (i.e, clearance)

effect gives the best result when $B/L=0.14\sim0.19$.

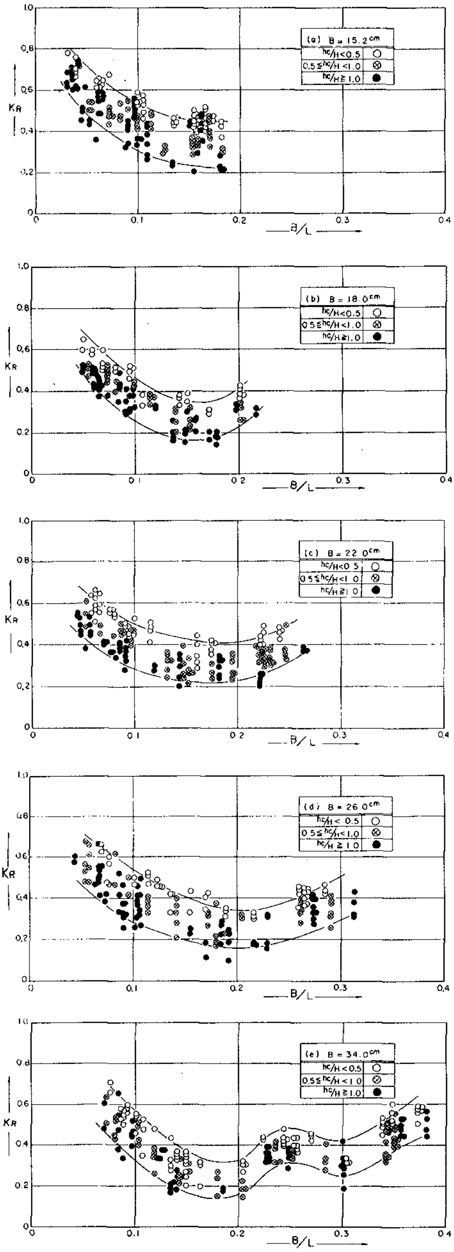
(2) Under the condition of $hc/H<0.5$, Igloo's performance is not satisfactory.

The above two conclusions are almost enough in designing Igloo system. Namely, in compliance with the local wave conditions, Igloo wall depth B will be set at $B/L=0.14\sim0.19$. The crown height of Igloo should be designed high enough to enable berthing and cargo handling. It is particularly important to set hc at $hc<\frac{1}{2}H$ for the designed wave height H.

It has been previously indicated that the reflection coefficient becomes minimized when B/L is given a certain value. This is worth noting and can be explained as follows:

The extreme example of long wave is shown in "Seiche", in that the longer the period, the bigger the reflection coefficient becomes. The water level asends and decends very slowly. The same can be said for the Igloo chambers where the water level that ascends and decends requires exactly the same length of time. Regardless of the shape of Igloo void, the waves reflect completely against the rear wall.

Conversely, if the incident wave period is too short, the reflection coefficient becomes larger. Such phenomenon can be explained as



Fig–3 Reflection Coefficient of Igloo

the responsive characteristics of water surface in the chambers. Depending upon the volume and shape of the Igloo void, the water in the void is composed of a responsive system with natural frequency. If water movement in front of Igloo system is considered as an external force and the frequency of this external force increases extremely, the Igloo system can hardly respond to the external force. In other words, despite the violent up-and-down motion of the waves in front of the Igloo system, the water in the void is almost tranquil. In this case, the waves reflect against the system as if it were a vertical wall.

Where there is a certain gap between the frequency of the external force and the natural frequency of the Igloo, the wave energy is most effectively reduced in the chambers. Also, the energy dissipates due to disturbances in front of the wall where two types of waves with different phases cause turbulence in order to keep the continuity of water surface. In our experiments, scattering waves with extremely short length were observed within the one wave length in front of the structures. We have to provide the theory behind this observation.

THREE DIMENSIONAL MODEL TEST

1. Reflection coefficient of incident waves from an oblique direction

Wave dissipating effect of incident waves from a right angle is obtained in the two dimensional test, but that from an oblique direction will be found in the three dimensional test. The measuring method of reflection coefficient for the incident waves from an oblique direction can be obtained by Hadly's theory. But due to the scattering waves against the wave dissipating structure, accurate measurement is difficult. Therefore, we use the indirect method to obtain reflection coefficient of incident waves from an oblique direction.

The calmness in the water basin using various types of center line structure is measured by changing boundary conditions (equivalent to reflection coefficients) through a computer's mathematical simulation method and the results will be compared with the hydraulic tests. The reflection coefficient is obtained from the boundary conditions where the two results coincide with one another. This is the exact opposite of the common method. Although some questions remain as to whether the given boundary conditions are accurate and yet reflection coefficient of the structure is correctly reflected. Considering the recent improvements made in the accuracy of the mathematical simulation method and the relative comparison with traditional vertical walls being the focal point of discussions, this method is considered to be reasonable.

2. Experimental Facilities

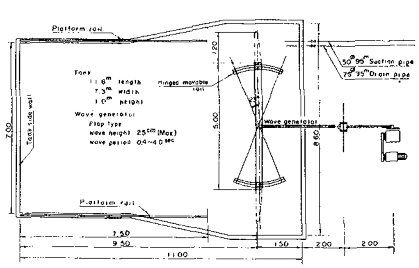
Three dimensional wave tank owned by Hydraulic Research Center of Nippon Tetrapod Co. was used. Fig–4 shows the tank dimensions and a wave generator.

3. Experimental method and conditions

Fig–5 shows one of the structure models. The water depth of the wave generator is 56 cm and that of the structure is 16 cm. And the slope is three to one. Small gravel and film wastes are placed around the side walls of the tank in order to avert reflection waves from the side walls.

The vertical wall model is made of mortar. The Igloo model is made of hard rubber 6 cm in width, 2.8 cm in height, 9.0 cm in depth, which is equivalent to 1:50 scale model. The regular waves in this experiment are 2.0 cm in height, 0.71 sec and 1.13 sec in period at the place where the water depth is 56 cm. Fig–6 shows the center line of the model and Table–2 shows test conditions.

Fig-4 Tank dimensions and a wave generator



The wave height in front of the structure are measured by a capacitance probe type wave meter placed under a movable platform across the tank. This meter reads wave height at the points distributed with 20 cm intervals length-wise and cross-wise.

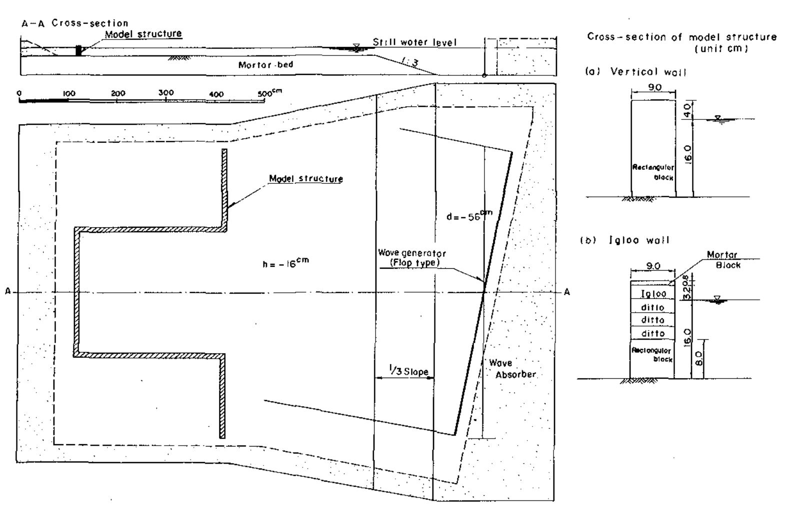
4. Results

Some cases are shown in Fig–7 through 9. Fig–7(a) (b) show the waves at a 45° angle on the center line of the structure. Vertical wall produced a net-like wave pattern in the basin because the crests of incident waves and reflected waves mix with one another. Amplitude at this point is two times that of incident wave height and more than two times at the wall. Those points of intersection run along the model front with the waves. Crests at even interval seem to run along the wall. Actual crest speed will be 5m/sec~10m/sec with waves of 10 sec in period at 45° angle. These waves cause overtopping, exert an unfavarable influence upon ships.

Igloo will absorb most of the crests of reflection waves. Crests of the incident waves run along the Igloo wall, when water level in the chambers rises shortly afterwards causing chain reaction in the adjacent chamber. Eddies and turbulences arisen will then diminish the wave energy. Photograph–2 shows the wave conditions of the Igloo wall.

Fig–8(a), (b) show an experiment concerning the waves on V-shaped center line. The effect of the Igloo wall will be more distinct than that of a straight center line. Vertical wall will produce the standing waves from the three direction such as incident waves and reflec-

Fig - 5 Test Model



ted waves from two different directions. In this experiment, wave amplitude is five times more than the incident wave height where amplitude is highest. Amplitude in the Igloo wall will be only twice that of the incident wave on the same spot. Photograph–3 shows the wave manners on the vertical wall and Igloo wall.

Photograph–4 shows the waves in the basin between the two wharfs. In the case of conventional vertical wall, a net-like wave pattern is seen in the basin. The pyramidal waves at the intersections of the net becomes several times higher than the incident waves. Excessive overtopping is observed at a quay wall. On the otherhand, in the case of Igloo wall, results of the test showed that waves in the basin presented the simular appearance to those of the incoming waves as though there were no structure.

Fig–9(a), (b) show the experiment of a port model. Vertical wall in the innermost part of the ports shows the same wave height as those of incident wave. But through the proper placement of a wave absorbing structure, reflection waves in the port decrease. Incoming waves from the open sea diffract into the port, but wave heights in the innermost part of the port becomes smaller.

Table - 2 Test Conditions

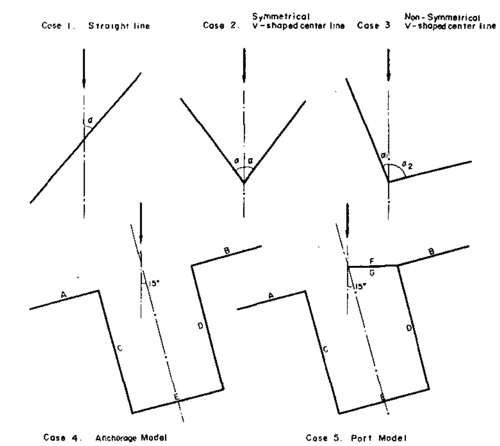
Case No	Center line shape	Center line angle	Type of wall	Incident wave period
1	Straight line	$\alpha = 30°$	(I)	0.71
				1.13
			(II)	0.71
				1.13
		$\alpha = 45°$	(I)	0.71
				1.13
			(II)	0.71
				1.13
		$\alpha = 60°$	(I)	0.71
				1.13
			(II)	0.71
				1.13
		$\alpha = 90°$	(I)	0.71
				1.13
			(II)	0.71
				1.13
2	Symmetrical V-shaped center line	$\alpha = 30°$	(I)	0.71
				1.13
			(II)	0.71
				1.13
		$\alpha = 45°$	(I)	0.71
				1.13
			(II)	0.71
				1.13
		$\alpha = 60°$	(I)	0.71
				1.13
			(II)	0.71
				1.13
3	Non-symmetrical V-shaped center line	$\alpha_1 = 60°$ $\alpha_2 = 30°$	(I)	0.71
				1.13
			(II)	0.71
				1.13
		$\alpha_1 = 75°$ $\alpha_2 = 15°$	(I)	0.71
				1.13
			(II)	0.71
				1.13
		$\alpha_1 = 75°$ $\alpha_2 = 45°$	(I)	0.71
				1.13
			(II)	0.71
				1.13
		$\alpha_1 = 90°$ $\alpha_2 = 30°$	(I)	0.71
				1.13
			(II)	0.71
				1.13
		$\alpha_1 = 90°$ $\alpha_2 = 60°$	(I)	0.71
				1.13
			(II)	0.71
				1.13

Case No.	Center line shape	Center line length(cm)	Type of wall	Incident wave period
4	Anchorage model	A = 175, B = 170, C = 310, D = 310, E = 225	A ~ E (I)	0.71
				1.13
			A ~ E (II)	0.71
				1.13
			A, B, D (I) C, E (II)	0.71
				1.13
5	Port model	A = 175, B = 170, C = 310, D = 310, E = 225, F = 110	A ~ G (I)	0.71
				1.13
			A ~ G (II)	0.71
				1.13
			A, B, D, F, G (I) C, E (II)	0.71
				1.13

Type of wall
(I) Conventional vertical wall
(II) Igloo wall

Tested Waves		Scale [L]	Scale [T]	Wave period T(sec)	Water depth h	Wave height H_0'	Deepwater wave length Lo	Nondimensional parameter h/L_0	Nondimensional parameter h/L	Wave length L(cm)
A-Wave	Model	1	1	0.71	16cm	2.0cm	78cm	0.205	0.229	70cm
	Proto	50	$\sqrt{50}$	5.0	8.0m	1.0m	35m			35m
B-Wave	Model	1	1	1.13	16cm	2.0cm	200cm	0.080	0.123	130cm
	Proto	50	$\sqrt{50}$	8.0	8.0m	1.0m	100m			65m

Fig - 6 Tested center line models



5. Comparison with a Mathematical Simulation Model

Wave height distribution of the basin can be obtained by the mathematical model using the same conditions as the physical model. Experimental results of each mathematical model using various boundary conditions with the same reflection coefficient as the structure can be compared with the experimental results of the physical model to find out the values of boundary conditions where two results coincide most closely. This is the method to identify the reflection coefficient of oblique incident waves. The mathematical model does not include the nonlinear wave effect, while the physical model does. So that amplitude of the mathematical model should be modified accordingly.

Tajbakhsh and Keller's three dimensional approximation formula shows the standing wave as follows:

$$\eta' = \left[1 + \frac{\varepsilon^2}{256} \left(9\omega_0^{-8} + 6\omega_0^{-4} - 15 + 8\omega_0^{4} \right) \right] \cos x$$

$$+ \frac{1}{8} \varepsilon \left(\omega_0^{-2} + 3\omega_0^{-6} \right) \cos 2x$$

$$+ \frac{3}{256} \varepsilon^2 \left(9\omega_0^{-12} + 6\omega_0^{-6} + 30\omega_0^{-4} - 16 + \omega_0^{-4} + 2\omega_0^{8} \right) \cos 3x$$

ε = ka

ω_0 = gk tank kh

k = $2\pi/L$

η' = $a^{-1}\,\eta$

a : amplitude of standing waves in deep water.

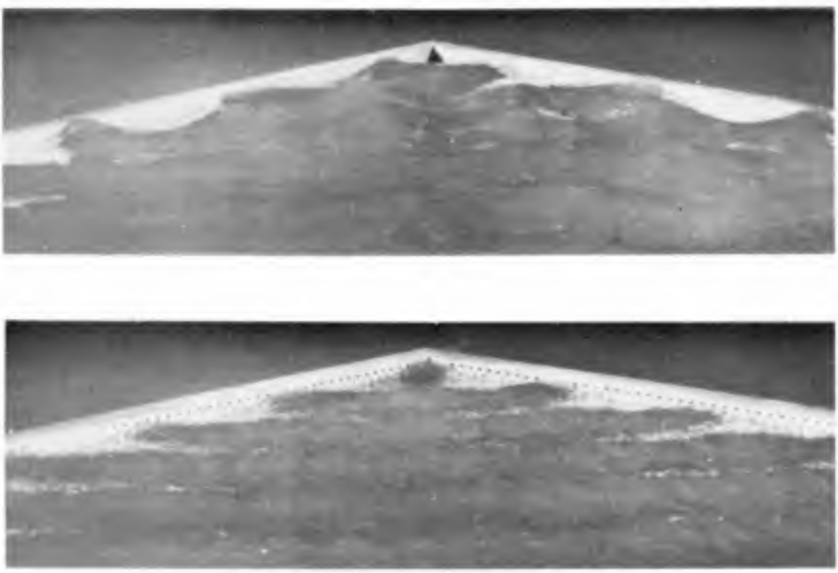
η : crest height at a certain water depth

Photograph–2

Fig-8(c), (d) show the experimental results of the mathematical model and they can be compared with those of the physical model. Given an incident wave angle of 45°, the values of the physical model coincided closely with those of the mathematical model in which boundary conditions are 30% of reflection coefficient.

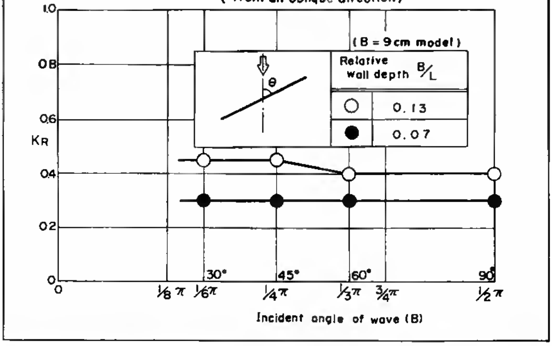
Fig-10 shows the reflection coefficients aquired by comparing the physical model with the mathematical model concerning many incident angles. The tests proved that reflection coefficient of Igloo hardly varied according to incident angles.

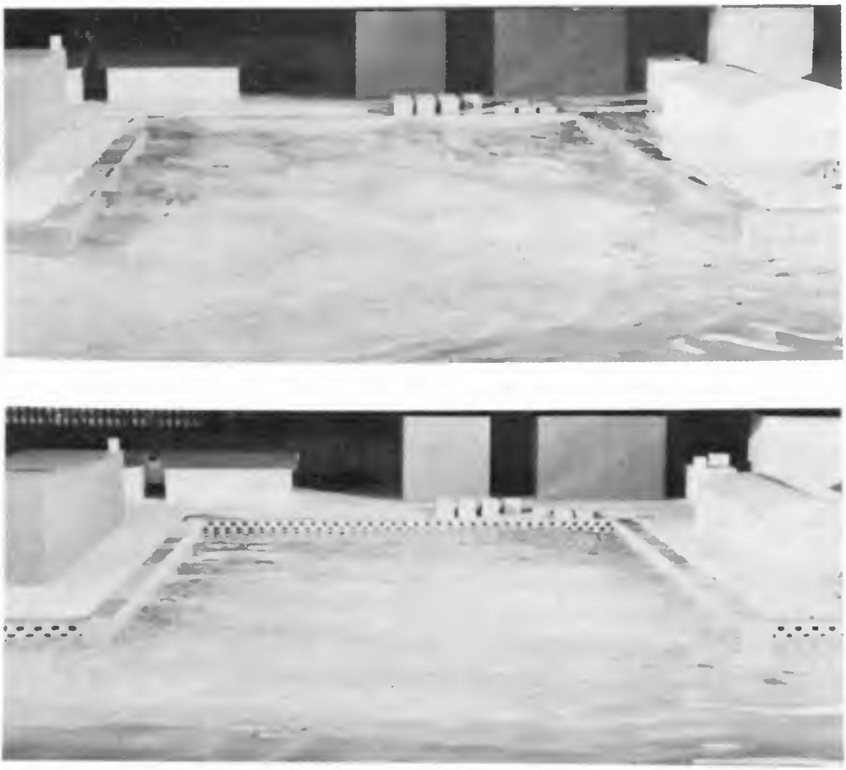
Fig-9(c), (d) show the mathematical model tests conducted under proper boundary conditions. These results coincide with one another so that the mathematical model is considered to be a useful method in estimating the wave height distributing in a port. It will be effectively used in the layout of a port including wave absorbing structures.



Photograph –3

Fig-10 Reflection coefficient of Igloo
(from an oblique direction)





Photograph–4

CONCLUSIONS

1. The wave dissipating characteristics of Igloo are shown in Fig–3. The best results are obtained at B/L=0.14∼0.19.

2. The reflection coefficient at B/L=0.14∼0.19 showing the minimum value can be explained in the responsive characteristics of Igloo system.

3. We confirmed by the three dimensional model test that Igloo helped improve calmness of a port.

4. Through the use of mathematical simulation model with the proper boundary conditions, the wave height distribution chart in the port was compared to that of the physical model. Then, we confirmed that the two results coincided with one another.

5. Fig–10 shows the summarized reflection coefficient values from the physical and mathematical model tests for oblique incident waves. The reflection coefficient of oblique incident waves does not vary according to the angle of incident waves.

ACKNOWLEDGEMENT

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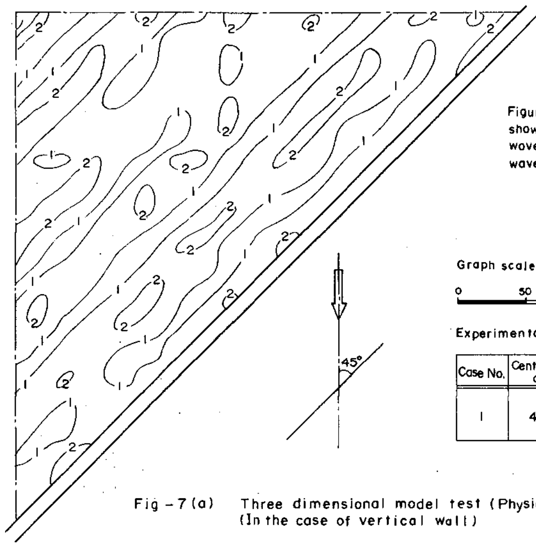
REFERENCES

(1) Yoshizo Nagao, Hisanori Kato, "Several experimental studies concerning vertical wall dissipating structure" (Papers presented to the 17th Conference of Coastal Engineering in Japan).

(2) Takeshi IJIMA, Yasuhiko EGUCHI and Akira KOBAYASHI, "Theory and Experiment on Permeable Breakwater and Quay Wall" Technical Report No.3 Coastal Engineering Department, Kyushu University, Fukuoka Japan, April 1971.



Figures in the graph show $^{H}/_{Ho}$, the ratio of measured wave height against deep water wave height.

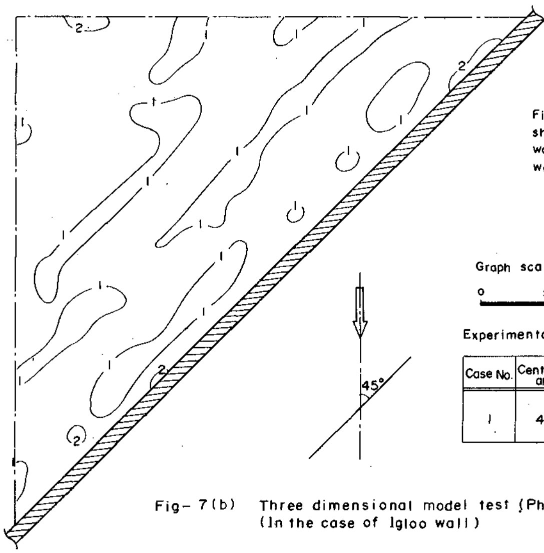
Graph scale

0 50 100 200cm

Experimental wave condition

Case No.	Center line angle		Wave period	Incident Wave height
1	45°	Model	T=0.71 sec	Ho=2.0 cm
		Proto	T=5.0 sec	Ho=1.0 m

Fig -7(a) Three dimensional model test (Physical model)
(In the case of vertical wall)



Figures in the graph show $^{H}/_{Ho}$, the ratio of measured wave height against deep water wave height.

Graph scale

0 50 100 200

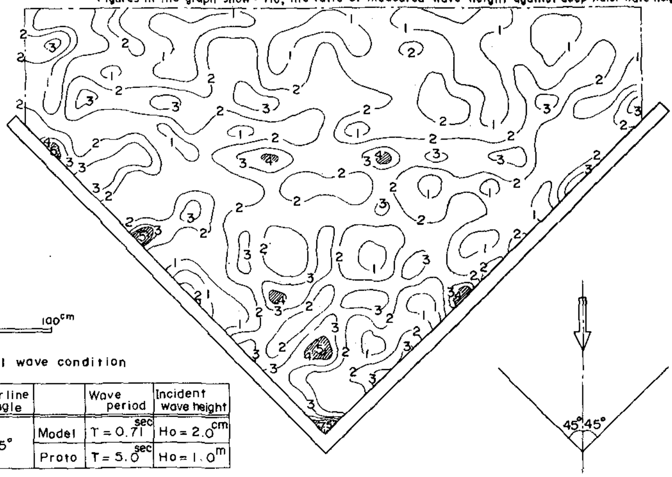
Experimental wave condition

Case No.	Center line angle		Wave period	Incident wave height
1	45°	Model	T=0.71 sec	Ho=2.0 cm
		Proto	T=5.0 sec	Ho=1.0 m

Fig- 7(b) Three dimensional model test (Physical model)
(In the case of Igloo wall)

Fig - 8 (a) Three dimensional model test (Physical model)
(In the case of vertical wall)

Figures in the graph show H/Ho, the ratio of measured wave height against deep water wave height.



Graph scale

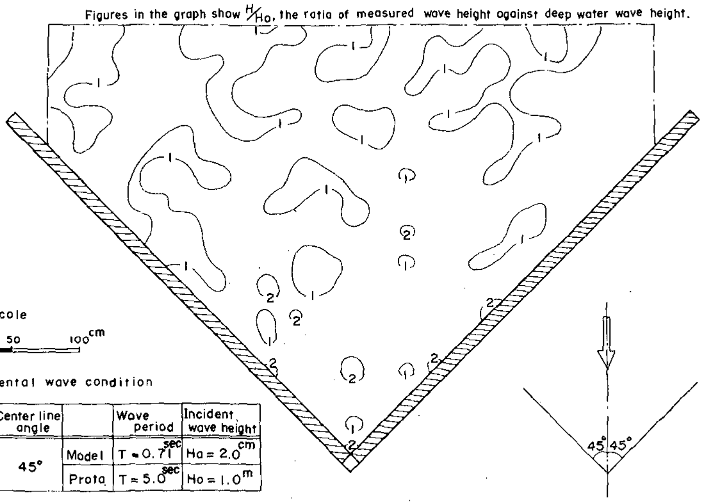
0 50 100 cm

Experimental wave condition

Case No.	Center line angle		Wave period	Incident wave height
2	45°	Model	$T = 0.71^{sec}$	$Ho = 2.0^{cm}$
		Proto	$T = 5.0^{sec}$	$Ho = 1.0^{m}$

Fig - 8 (b) Three dimensional model test (Physical model)
(In the case of Igloo model)

Figures in the graph show H/Ho, the ratio of measured wave height against deep water wave height.



Graph scale

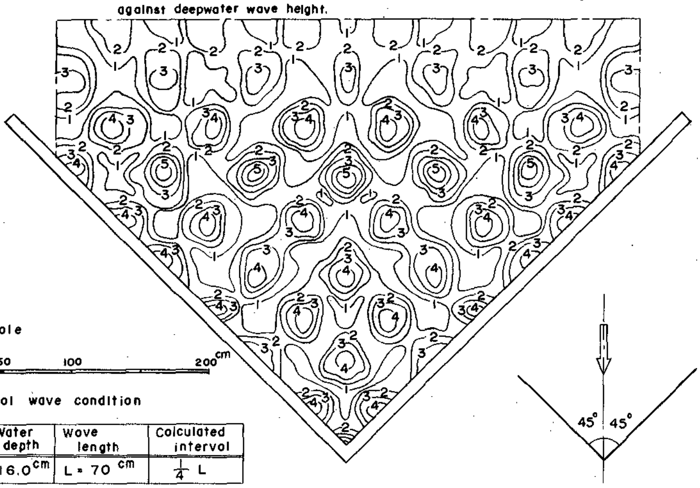
0 50 100 cm

Experimental wave condition

Case No.	Center line angle		Wave period	Incident wave height
2	45°	Model	$T = 0.71^{sec}$	$Ho = 2.0^{cm}$
		Proto	$T = 5.0^{sec}$	$Ho = 1.0^{m}$

Fig - 8 (c) Three dimensional model test (mathematical model)
In the case of vertical wall (KR = 0.9)

Figures in the graph show H/H_o, the ratio of calculated wave height against deepwater wave height.



Graph scale

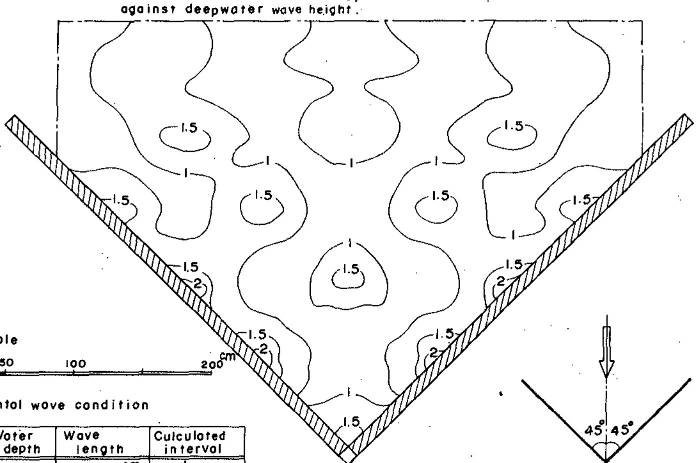
0 50 100 200 cm

Experimental wave condition

Case No.	Water depth	Wave length	Calculated interval
2'	16.0 cm	L = 70 cm	$\frac{1}{4}$ L

Fig - 8 (d) Three dimensional model test (mathematical model)
In the case of Igloo wall (K_R = 0.3)

Figures in the graph show H/H_o, the ratio of calculated wave height against deepwater wave height.



Graph scale

0 50 100 200 cm

Experimental wave condition

Case No.	Water depth	Wave length	Calculated interval
2'	16.0 cm	L = 70 cm	$\frac{1}{4}$ L

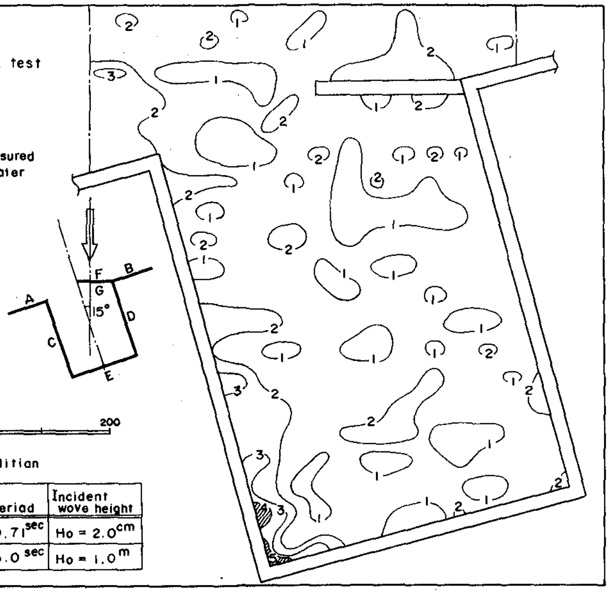


Fig – 9 (a)

Three dimensional model test (Physical model)

Figures in the graph show H/Ho, the ratio of measured wave height against deep water wave height.

A~G are all conventional vertical walls.

Experimental wave condition

Case No.		Wave period	Incident wave height
5	Model	T = 0.71 sec	Ho = 2.0 cm
	Proto	T = 5.0 sec	Ho = 1.0 m

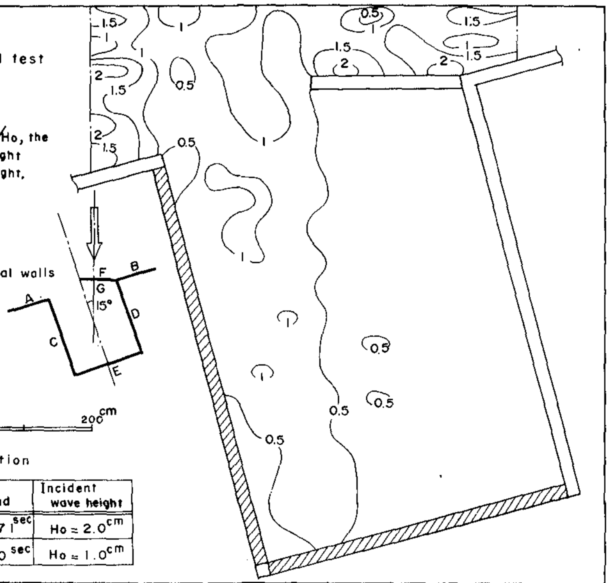


Fig – 9 (b)

Three dimensional model test (Physical model)

Figures in the graph show H/Ho, the ratio of measured wave height against deep water wave height.

A,B,O,F,G : Conventional vertical walls

C, E : Igloo walls

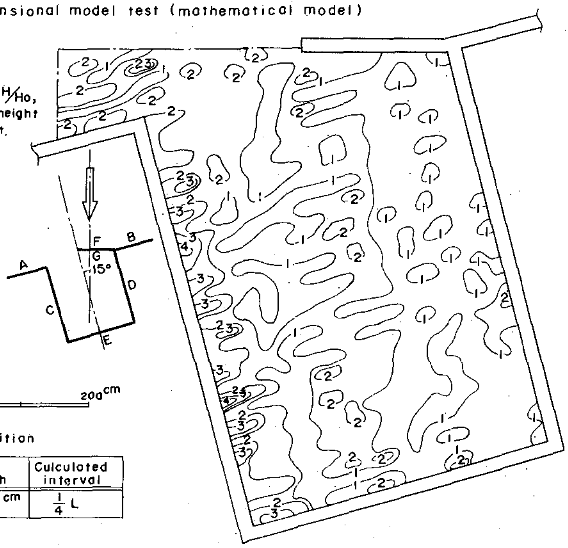
Experimental wave condition

Case No.		Wave period	Incident wave height
5	Model	T = 0.71 sec	Ho = 2.0 cm
	Proto	T = 5.0 sec	Ho = 1.0 cm

Fig – 9 (c) Three dimensional model test (mathematical model)

Figures in the graph show H/H_o, the ratio of calculated wave height against deepwater wave height.

Centerline A~G are all vertical walls. (K_R = 0.9)



Graph scale

0 50 100 200cm

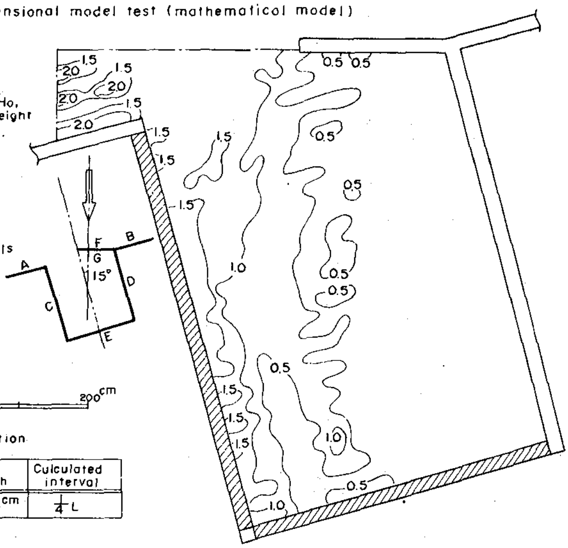
Experimental wave condition

Case No.	Water depth	Wave length	Calculated interval
5′	16.0cm	L = 70 cm	$\frac{1}{4}$ L

Fig – 9 (d) Three dimensional model test (mathematical model)

Figures in the graph show H/H_o, the ratio of calculated wave height against deepwater wave height.

Centerline A, B, D, F, G are vertical walls (K_R = 0.9) and centerline C, E are igloo walls (K_R = 0.3).



Graph scale

0 50 100 200cm

Experimental wave condition

Case No.	Water depth	Wave length	Calculated interval
5′	16.0cm	L = 70cm	$\frac{1}{4}$ L

APPLICATION

Igloo walls have been actually constructed and are going to be installed in several ports. Examples are given to show a standard type cross-section.

(a) As a revetment for a reclaimed land in a port (Fig-11)

Waves from the outer sea do not directly invate into the port. This wave dissipating structure is designed against the waves of short period and of high frequency as they are undesirable for navigation. Igloo wall was less expensive than the inclined armour block structures such as Tetrapod and Doloss.

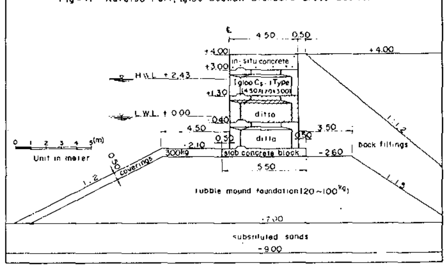


Fig-11 Karatsu Port, Igloo Seawall Standard Cross Section

(b) As a revetment for a pier (Fig-12)

Out of many sectional profiles of deep-water mooring facility, pier structure was selected. And Igloo was planned as revetment for the pier to keep calm the port.

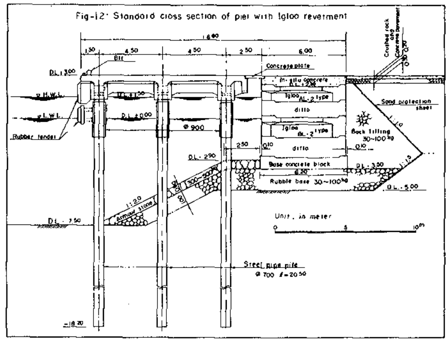


Fig-12· Standard cross section of pier with Igloo revetment

(c) Igloo wall on sheet piles (Fig-13)

We could use a dry method in constructing mooring facilities in a port which is expanded into the land. And Igloo wall was constructed on the sheet-piles as a quay wall because of its advantages in economics and construction work.

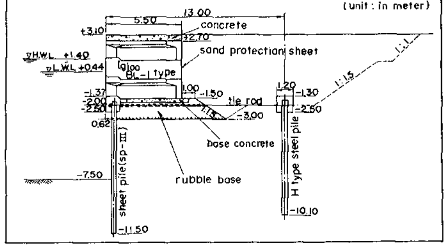


Fig-13 Shiogama Port, Vertical Wave Absorbing Wall Standard Cross Section (unit: in meter)

(d) Igloo wall in front of an existing quay wall (Fig-14)

The old sheet-piles quay wall was reconstructed by placing Igloo in front of the existing quay wall on the excavated ground making the water depth from 3 to 3.5m. This wall also helped calm the port. An extra safety measure was taken by providing a provisional sheet-pile in front of the existing sheet-pile wall during the construction period.

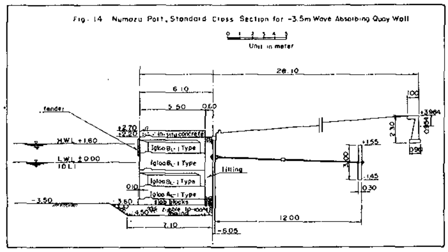
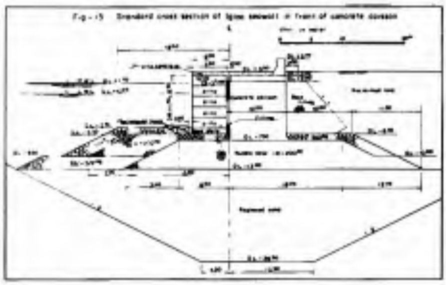


Fig-14 Numazu Port, Standard Cross Section for -3.5m Wave Absorbing Quay Wall

(e) As a revetment for a fishing area (Fig-15)

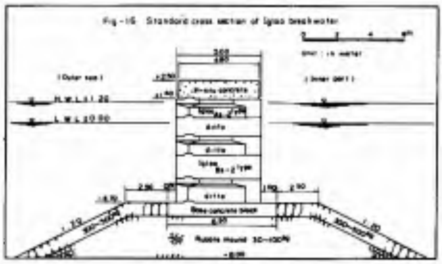
Igloo wall was planned in front of the existing breakwater made of concrete caisson with three fold objectives: preventing over-topping and reflection waves and providing a fishing area for the comunity people.

The Igloo wall seemed to become comfortable dwellings for small fish, as other type of wave absorbing structures such as Tetrapod and Doloss. But the latters are not suitable for fishing.



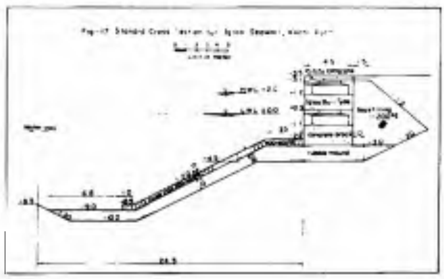
(f) As a wave absorber for bay with narrow entrance or for lake (Fig-16)

Igloo wall is planned as a wave absorbing breakwater because wind waves produced in the lake are less 1.5m in height and reflection waves from breakwater are harmful to fishing and fish culture.



(g) As a revetment for a waterway to prevent reflection waves (Fig-17)

As the port entrance is narrow and a number of ships pass this waterway, Igloo wall was constructed because it could dissipate invading waves from the outer sea as well as waves from navigating ships. The wall harmoniously matched with the aesthetics of nearby beach.



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