# ON THE STUDY OF A PNEUMATIC BREAKWATER VII

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# ON THE STUDY OF A PNEUMATIC BREAKWATER VII

## The Full Size Tests under Natural Conditions during the 7th Typhoon (1959) etc., & the Pernanent Installations at Tsurumi Shipyard, Yokohama, Japan.

by

Michinori KURIHARA and Yōichi AWAYA

**Abstract**

In order to protect a ship moored at the fitting-out quay from the severe wave conditions during the period of typhoon and of seasonal wind in spring, Tsurumi Shipyard, Nippon Steel Tube Co. came to adopted the pneumatic breakwater in 1956.

Many preliminary researches were undertaken on the wave character in the shipyard basin and especially on the perforated pipe of ladder type as a device for the shallowness of water near the quay.

The test installation was set in August 1957 at the east side of the fitting quay. Many experiments on the bubble jet and the induced surface current were done. But about a year had passed in vain without any chance to test its wave reducing performance for strong winds to April 1958.

Since that time we had been favoured several times with strong winds. We could obtain the wave records of the wave reducing tests and the records proved that the pneumatic breakwater was very effective.

Based upon these tests, it was planned to build the permanent installations both at the east and the west side of the fitting-out quay and they were completed in Feb. and July 1959 respectively.

They were used several times during the seasonal wind and the times of typhoon frequently visiting Kanto district in this year and the wave records were obtained. Every time the effectiveness of the pneumatic breakwaters was ascertained.

In this report we give the results of some tests except the most significant one conducted during the 11th Typhoon (1958).

### Test Installation

1. Full scale experiments of a pneumatic breakwater have been conducted several times since April, 1959 under a temporary setting of the test installation at the east fitting-out quay of Tsurumi Shipyard, Nippon Steel Pipe Co.

This report gives information on the results of some experiments except the most significant one conducted at the period of the 11th Typhoon, already reported on the Bulletin of Research Institute for Applied Mechanics No. 12 which will be refered as Report V in the following.

*Experiment No. 1.* April 21st, 1959, 10–12 A.M. It blew strong seasonal wind of SW since the early morning. The sea was rough. As the wave recorder on the open sea side was out of order, only the other one on the protected zone was used both for the original and the reduced waves.

Continuous variation was observed in the wind and the waves, and markedly calmed down at the end of the observation.

In order to see the time variation of wave character, the wave records through the whole period were subdivided into 7 parts, admitting the number of waves about 100 that correspond to 5 minutes in time.
They are arranged as follows:

Table 1

| Record | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Time | 10.17 | 11.16 | 11.23 | 11.29 | 11.38 | 11.43 | 11.48 |
| Number of signif. waves | 40 | 33 | 33 | 33 | 33 | 28 | 33 |
| Air consumption, $m^3$/min. | 0 | 46 | 57 | 57 | 57 | 57 | 0 |
| Mean period, sec | 3.45 | 3.43 | 3.37 | 3.46 | 3.58 | 3.14 | 3.37 |
| Mean height, cm | 66 | 57 | 57 | 56 | 47 | 37 | 45 |
| Water depth, m | 6.5 | 6.7 | 6.7 | 6.7 | 6.8 | 6.8 | 6.8 |

Air valve was somewhat squeesed between E–F and was stopped between F–G. However, to avoid overestimation of the efficiency of the breakwater F and G are treated to correspond to the air supply 57 $m^3$/min and O respectively.

The test run A is by time so apart from the other ones that it can not be compared with the others. Fig. 1 shows the time variation of wave height.

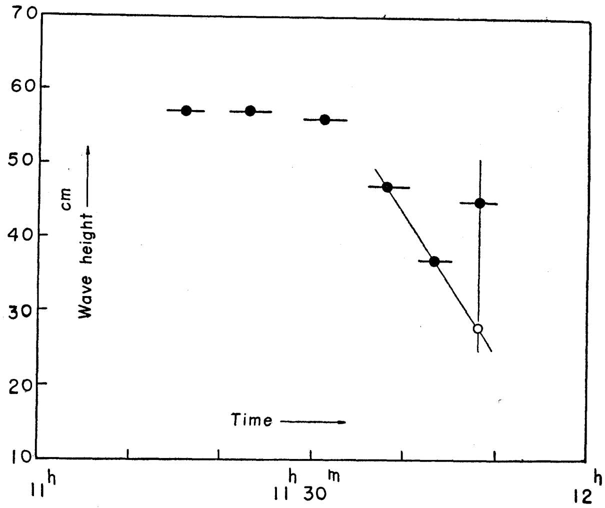


Fig. 1. Wave reduction test. Exp. 1. (Test installation)

The figure shows that the wave height decreases markedly at the end of the period. Being nothing any adequate record of the reduced wave to compare with the original wave G, it was obtained from the E and F by extrapolation. Thus we obtain the following result for the significant waves:

| | Wave height cm | Reduction ratio |
|---|---|---|
| Original wave | 45 | $=\dfrac{\text{Reduced w.h.}}{\text{Original w.h.}}=0.62$ |
| Reduced wave | 28 | |

Mean period (E, F, G) $=3.36$ sec ($\lambda=17.6$ m),
Air consumption $=56\ \mathrm{m^3/min}$,
Water depth $=6.8$ m, Pipe A. ……(1.1)

*Experiment No. 2.* July 8, 1959, 4–5 P.M. Wind velocity $=5$–$7$ m/sec, water depth $=8.1$ m, air consumption $=33.7\ \mathrm{m^3/min}$. Records of the original and the reduced waves were obtained during 16.10–16.20 and 16.25–16.35 respectively. In order to make the comparison more accurately, merely the ending part of the original and the opening part of the reduced wave record, each of which was last and first 5 minutes, were selected.

Selecting significant waves, the comparison gives the following result:

| | Period sec | Wave height cm | Reduction ratio |
|---|---|---|---|
| Original wave | 2.87 | 41 | $=\dfrac{\text{Reduced w.h.}}{\text{Original w.h.}}=0.54$ |
| Reduced wave | 2.91 | 22 | |

Mean period $=2.89$ sec ($\lambda=13.1$ m),
Air consumption $=33.7\ \mathrm{m^3/min}$,
Water depth $=8.1$ m, Pipe B. …(1.2)

*Correction to the wave depression due to the following current.* Velocity of the surface current ($U_{\max}$, m/sec) at the point 6 m away from the perforated pipe is given as

$$U_{\max}=0.72\ \sqrt[3]{Q'/20} \qquad \cdots(1.3)$$

where $Q'$ denotes the total amount of air ($\mathrm{m^3/min}$) supplied to the pipe.

The wave recorder was fastened to the quay wall, 28 m behind the perforated pipe. The velocity $U$ in its vicinity reduced to 58 % of $U_{\max}$ as mentioned in paragraph 10, Report V.

If the propagation velocity and the wave length in deep water are denoted by $c$ and $\lambda$ respectively, the rate of the wave depression $r_1$ caused by the following current may be approximately considered as a function of $\delta=4U/c$ and $m_0=\lambda/2\pi H$, in which $H$ denotes the water depth. The theoretical results are shown in Report V. Estimating $r_1$ from Fig. 9b) of Report V, we have the following results for the corrected reduction retio $r'$.

Table 2

| Experiment No. | $Q'$ $\mathrm{m^3/min}$ | $U$ m/sec | $c$ m/sec | $\lambda$ m | $\delta$ | $m_0$ | $r_1$ | $r'$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 56 | 0.59 | 5.24 | 17.6 | 0.45 | 0.346 | 0.936 | 0.66 |
| 2 | 33.7 | 0.50 | 4.52 | 13.1 | 0.44 | 0.307 | 0.934 | 0.58 |

*Correction to the increment of wave height due to the diffraction.*[1] As men-

1) The correction was necessiated since the bow was located 20 m behind the perforated pipe.

tioned in Report V, the wave direction inclined about 30° to the quay wall and the end of the pneumatic breakwater may be considered as placed at 27 m, $L$, from the quay, though the end of the perforated pipe being 25 m away. In estimating the diffraction from the end of the breakwater, special regard should be paid to the reflection at the quay wall. Fig. 10a), b) in Report V illustrate the results of calculations when $2L/\lambda=2$ and $2L/\lambda=3$ under those conditions.

Using those results, the diffraction coefficient $r_2$ at the point of the wave recorder (28 m behind the perforated pipe) was estimated by extrapolation[1] and then the real reduction ratio $r_0$ was deduced from $r'$ given in Table 2.[2] That is as follows:

| Experiment | $2L/\lambda$ | $r_2$ | $r_0$ | |
|---|---|---|---|---|
| 1 | 3.07 | 0.51 | 0.49 | (1.4) |
| 2 | 4.12 | 0.49 | 0.38 | |

In correcting the data we neglected the effect of the diffracted waves entering into the protected zone through the opening between the quay and the bubble jet in order to avoid the over-estimation of $r_0$.

Now summerizing the wave reduction performance of the pneumatic breakwater so far obtained:

Table 3

| Exper. | Air consump. $Q$,1/sec·m | Depth $H$,m | Effective depth[3] $H_e$,m | $\xi$ $10^{-4}$ | Period $T$, sec | Wave length m | Reduction ratio[4] $r_0$ | $\lambda/H_e$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 41.3 | 6.8 | 8.25 | 5.58 | 3.36 | 17.6 | 0.49 | 2.13 |
| 2 | 24.4 | 8.1 | 9.87 | 2.42 | 2.89 | 13.1 | 0.39 | 1.33 |

Plotting the values of $\lambda/H_e$, $\xi$ and $r_0$ into Fig. 5 "the relation between $\xi$ and the wave-length-depth ratio"[5], we see that they agree closely with the theoretical relation.

## Permanent Installation at the East Side

2. *Design of the permanent installation.* Through a number of the tests, at ordinary time and at the extraordinary time of the 11th Typhoon, the effectiveness of the pneumatic breakwater was proved to be very much to the purpose. So that it was planned to build a permanent installation based upon these tests.

The perforated pipe was a ladder type made of steel pipes, the length of which being 25 m. A couple of the main pipes was 4 inches in diameter. And between them were welded 25 cross-pipes with one meter interval. Each of them measures 3 inches in diameter, 2 m in length, on which bored 245 holes, 1.6 mm

1) We used an approximate formula $r_2=\text{const.}\ (2L/\lambda)^n$ for the extrapolation.
2) In calculation we used the relation $r_0=\sqrt{\dfrac{(r')^2-(r_2)^2}{1-(r_2)^2}}$ .
3) Effective depth is given by $H_e=1.25\times(H-0.2)$, where $H_e$, $H$ are measured in m.
4) The reduction ratio means the ratio of the reduced wave height to the original wave height.
5) See page 22, Fig. 11, Report of the symposium on a pneumatic breakwater (April, 1958, Nagasaki).

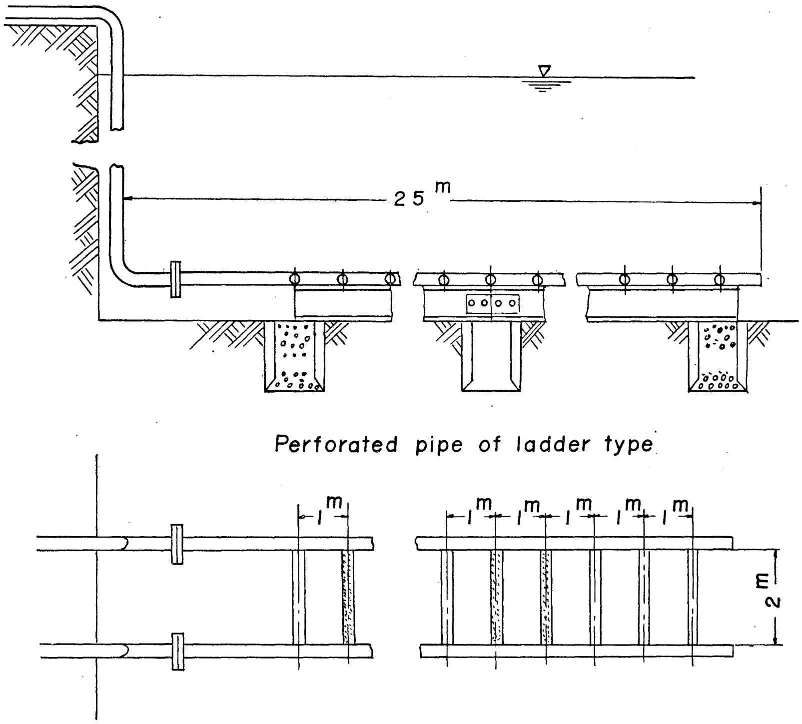


Fig. 2. Permanent installation at the east iside of the fitting-out quay.

in diameter.[1)]

The pipes were galvanized thickly to protect them from erosion.[2)] It was also intended that the maximum air consumption was 100 $m^3$/min for a head loss at the hole was 5 m in water column, with the assumption of contraction coefficient $=0.37$.

The wave reduction performance was assumed to be nearly the same with that at the time when the wind reached its highest velocity at the 11th Typhoon. That is, wave reduction was expected to be 83% (70% in energy) for the waves of the period 5.2 sec (length=42 m) in the water between the quay and the ship[3)]. Attenuation due to the following current was of course included in it.

---

1) At first the holes were bored in 1.8 diameter and after the galvanization they were finished in 1.6 mm diameter.

2) The holes being obstructed by mud, air supply has been repeated every day. As the result of it there has been nothing wrong since the construction, 17 months before.

3) According to Bretschneider's relation on the wind waves, $c/H=0.076(gF/U^2)^{0.28}$, $H/L=0.67(gF/U^2)^{-0.065}$ for $10^2 \lesssim gF/U^2 \lesssim 4\times10^3$, where $c$, $L$ and $H$ denote the propagation velocity, the length and the height of the waves and $U$, $F$ also the wind velocity and the fetch respectively. So that we have $H \propto U$ for a given fetch.

Therefore the reduction ratio of the wave height being 83% means that the wind force, too, decreases in 83%. For instance, during the storm 25 m/sec of mean wind force may be considered to be weakened to 21 m/sec, merely concerning to the activity of the waves.

3. *Full size test during the 7th Typhoon.* Since the permanent installation was completed in Feb. 1959, it was used several times during the seasonal wind in spring and at the times of typhoon frequently visiting Kantō district. Every time the effectiveness of the breakwater was ascertained. It was a great fortune that at the 7th Typhoon the wave record of reduction test was taken by the staff of the shipyard.

The Typhoon struck the Suruga Bay in the early morning of Aug. 14 and went past by the Kantō district. The test of wave reduction was carried out over an hour from 8 o'clock in the morning at the end of the storm, so that the waves were not so rough. The atmospheric pressure and the wind velocity varied as follows:

| | | | | | |
|---|---|---|---|---|---|
| Time | 8.00 | 8.12 | 8.20 | 8.30 | 9.00 |
| Atm. pressure | 996.2 | 997.4 | 997.9 | 998.0 | 998.0 |
| Wind direction | S | S | SSW | SSW | S |
| Wind vel. m/sec | 18 | 12 | 10 | 9 | 15 |

The mean depth of water was estimated at 7.33 m. At the fitting-out quay was moored a 45000 ton oil tanker, the hull of which was 4 m apart from the quay wall and the bow was 10 m behind the perforated pipe along the water line. The wave meter was attached to the quay 28 m behind the perforated pipe and gave the record of wave profile within the V-region between the hull and the quay. Supply of air was increased every few minutes till its maximum was reached, and then

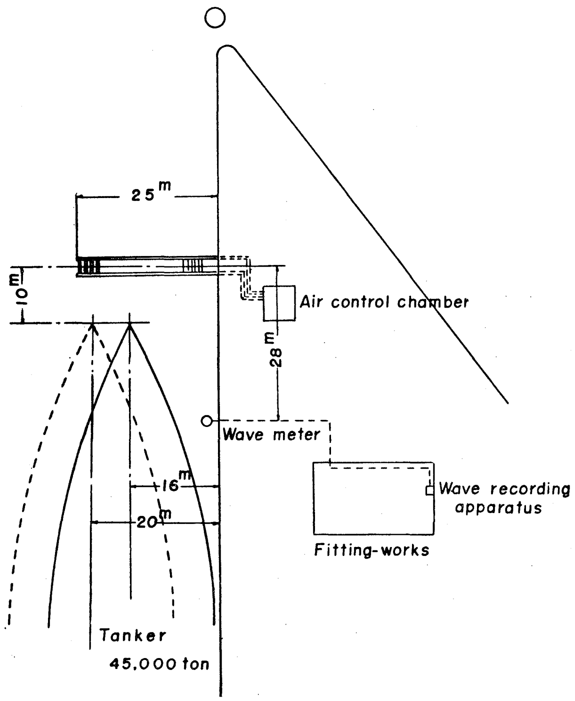


Fig. 3. East side of the quay.

it was decreased gradually, as shown in the following table:

| | | | | | | |
|---|---|---|---|---|---|---|
| Time[1] | 8.05 | 8.10 | 8.12 | 8.14 | 8.16 | 8.18 |
| Air consumption $m^3/min$ | 0 | 28 | 30 | 33 | 39 | 46 |
| Time | 8.20 | 8.26 | 8.28 | 8.30 | 8.32 | 8.40 |
| Air consumption $m^3/min$ | 39 | 28 | 26 | 24 | 0 | 0 |

At the beginning and ending of the air supply it takes about 4 or 5 minutes to develop fully or to disappear completely for the bubble jet and the horizontal current. Similarly it is also difficult to consider that the developed flow pattern could not attain its steady state when air supply was changed unless it takes about 3 minutes. Therefore the wave record is not so good to estimate the efficiency, since the change of air supply was so rapid that the corresponding steady state could not be achieved. Considering these facts the wave record was divided into 3 parts so as to contain the waves as many as possible in each part. Then we may regard the mean values of the measured quantities in each part as more reliable.

| Part | I | II | III |
|---|---|---|---|
| Time | 8.05–8.12 | 8.13–8.20 | 8.32–8.40 |
| Mean air supply $m^3/min$ | 0 | 35 | 0 |

In the above table the mean air consumption means the cube of the mean cubic root of air consumptions, since it is the velocity of the horizontal current that is directly effective for the wave reduction.

The mean property of the significant waves selected from these data I, II, III are computated as follows:

| | I (original) | II (reduced) | III (original) |
|---|---|---|---|
| Mean time | 8.08 | 8.16 | 8.36 |
| Mean air consumption $m^3/min$ | 0 | 35 | 0 |
| Mean period sec | 4.65 | 4.29 | 4.03 |
| Mean height m | 1.15 | 1.03 | 1.00 |
| | Mean depth=7.33 m. | | |

………(3.1)

It can be seen from the above table that, in the first place, the mean height of the reduced wave II is not so low, comparing with that of the original wave I. In the second the former is, on the contrary, larger than that of the original wave III. Finally the period markedly decreases from I to II, II to III.

The first two facts are largely due to the decrease of the wind velocity at the end of the storm, and that is closely related with the last fact. The wave

1) Time means the time at which the air supply was changed.

meter makes a record of the waves within the V-region between the ship and the quay. Those waves, widely different from the ones outside the V-region, have the characteristics stated in the paragraph 7, Report V. That is, when their wave lengths are less than about 25 m, they turn into the waves with transverse components, while more than about 25 m, they becomes like the progressive waves without nodes. Therefore if the wave period becomes over 4 sec, the mean wave height, deduced from the wave record, will be to decrease.

As shown in the table of page 52 in Report V, Record C at the 11th Typhoon in 1958, shows this phenomenon. The wave height decrease in spite of the increase of the wind velocity from $C_3$ to $C_4$. That is caused by the transformation from the waves with transverse components to the progressive wave without nodes. Then let us suppose that the waves with transverse components at $C_3$ gradually change to that without nodes at $C_4$.

How much might the wave height increase, developing into the wave with transverse components? The next method may be applied to know the proportion.

In order to increase the reliability of the measurements, 4 records were grouped in two, $C_2$, $C_3$ and $C_4$, $C_5$ and averaged respectively. The former was assumed to be the wave with transverse components and the latter to be the wave without nodes.

| | | $(C_2, C_3)$ | $(C_4, C_5)$ |
|---|---|---|---|
| Time | | 6.27 | 7.23 |
| Reduced wave | Period, sec | 4.14 | 4.99 |
| | Height, cm | 150 | 165 |

For the same wave pattern the wave height in the V-region was assumed to be proportional to that outside the V-region. Perhaps, the sudden increase of the wind velocity at 6.20–7.20 brought the greater increase in the wave height than in the wave period. But to simplify the treatment and to avoid overestimation, stee-

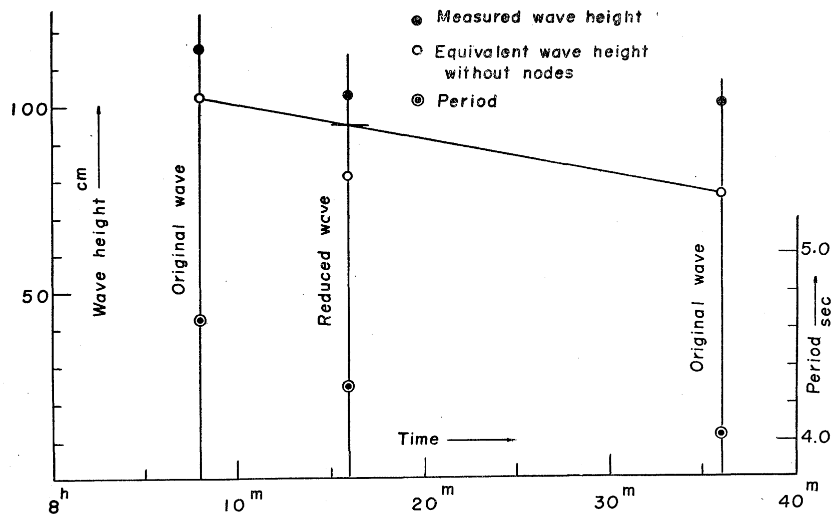


Fig. 4 a). Wave reduction test of the permanent installation during the 7th Typhoon (1959).

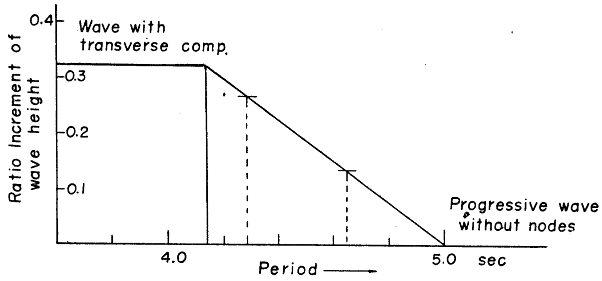


Fig. 4 b).

pness of the outside wave was assumed to be constant. So that the wave height become $165\times(4.14/4.99)^2=114$ cm when ($C_2$, $C_3$) was supposed to be without nodes. Therefore the ratio of the increment of the wave height becomes $(150-114)/114=0.32$, which was caused by the transformation of the wave without nodes into one with transverse components.

Then we could assume Fig. 4b) showing the change of the ratio of the increment of the wave height.

Now, turn to the observed value (3.1). According to Fig. 4b) the wave pattern within the V-region can be transformed to that of without nodes. Thus we obtain the following result for the equivalent wave height corresponding to (3.1) (see Fig. 4a)) :

| | I (original) | II (reduced) | III (original) |
|---|---|---|---|
| Time | 8.08 | 8.16 | 8.36 |
| Period, sec | 4.65 | 4.29 | 4.03 |
| Height, cm | 102 | 81 (95) | 76 |

Interporating from I and III we obtain 95 cm as the wave height of the original wave corresponding to the reduced wave II. Therefore the wave reduction performance becomes as follow:

$$\left.\begin{array}{l}\text{Period}=4.29\text{ sec, air consumption}=35\text{ m}^3/\text{min,}\\ \text{water depth}=7.33\text{ m, reduction ratio}=0.85.\end{array}\right\}\quad\cdots(3.2)$$

As before, the reduction ratio must be corrected for the attenuation ($r_1$) due to the following current. As the velocity distribution of the horizontal current due to the new perforated pipe is not yet measured, we suppose it has the same distribution as that due to the test pipe. Then current velocity near the wave meter may be assumed to be 58% of the maximum.

Putting $Q'=35$ m$^3$/min in (1.3), we have $U_{max}=0.81$ m/sec. Then it becomes $U=0.50$ m/sec, while it gives $c=6.69$ m/sec, $\delta=4U/c=0.30$ and $m_0=\lambda/2\pi H=0.62$. Thus we have $r_1=0.94$ from Fig. 9a) in Report V. The bow being situated 10 m behind the perforated pipe, the diffracted wave at the both ends of the pipe is not significant. Neglecting it to avoid overestimation, we have the true reduction ratio $r_0=0.90$. The result is summerized as follows:

Table 4

| Air consumption $Q$, l/sec·m | Depth $H$, m | Eff. depth $H_e$, m | $\xi$ $10^{-4}$ | Period sec | Wave length $\lambda$, m | Reduction ratio, $r_0$ | $\lambda/H_e$ |
|---|---|---|---|---|---|---|---|
| 25[1] | 7.33 | 8.90 | 3.0 | 4.29 | 28.7 | 0.90 | 3.2 |

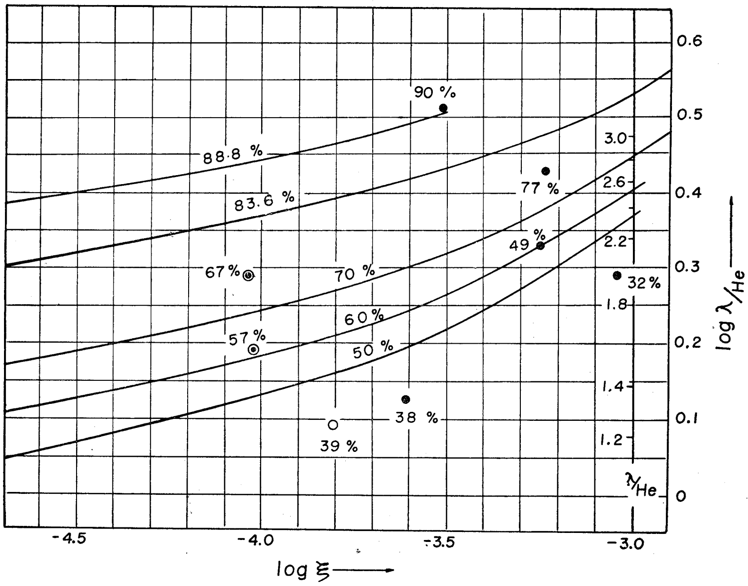


Fig. 5. The relation between $\xi$ and the wave-length-depth ratio.
○: The Iwojima island. ◉: The Hajima island.
●: Tsurumi Shipyard.

The above result with those of all the other full size tests conducted so far in Japan are plotted in Fig. 5 "Relation between $\xi$ and the wave-length-depth-ratio". The figure shows that the agreement between the observations and the theory is satisfactory.

### Permanent Installation at the West Side

4. In the port of Tsurumi Shipyard the east side of the quay is used for fitting out a large ship, while the west side, connected to the port by the cannal as illustrated in Fig. 6, is used for equipping a small ship. During storm the small ship of hundreds tons moored rolls heavily and occasionally suffers serious damage. As our purpose was realized at the east side it was also planned to set a pneumatic breakwater at the west side in order to protect small ships, and then it was completed July, 1959.

A number of typhoons had visited that year and then the installation was employed every time. Though quantitative data could not be obtained for want of

1) The length of the perforated pipe being 25 m, the air supply per meter is gives by dividing the total air supply by 23 m, because there is nothing of perforation on the double of cross pipes by the quay.

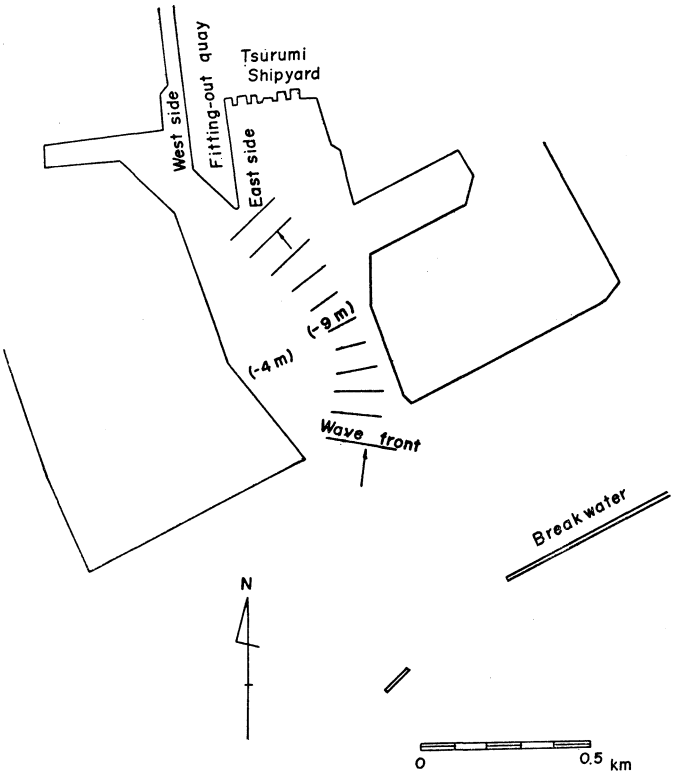


Fig. 6. The port of Tsurumi Shipyard.

wave recorder, its effect was greatly appreciated. That is, the waves of long period almost passed over the breakwater, but the main components (of comparatively short period) that play a great role for the pitching and rolling motion of a ship recieved considerable damping and depression. So that the oscillations were remarkably lessened.

Those experiences taught us that the pneumatic breakwater was very effective for the protection of a ship moored at the pier and it would be practicable even from the economical view point.

5. The waves in the vicinity of the west quay enter by the port through the canal that is comparatively shallow ($-2$ m$\sim-5$ m). In their course the waves are to reduce their height considerably. That tendency might become more pronounced in the components with long period. So that, judging from the the experience of the 11th Typhoon (1958) the mean period may be lower than 5 second even in the stormy period. On the other hand the components that exert a great effect on the oscillation of a ship are considered to have the wave length of the same order as that of the ship. Thus the wave of 4 second (wave length 25 m) was made an object of our plan.

The waves propagate parallel to the fitting out quay. So that fairly good effect might be achieved if the pneumatic breakwater is constructed following the east quay.

A ship was moored 3 or 4 m apart from the quay. If the perforated pipe of ladder type having the length enough to reach the outside of the hull (about 10 m) were set perpendicularly to the quay wall, the ship were to have been moored in the horizontal current induced by the breakwater. Moreover the horizontal current flows backward with no appreciable diminution of its velocity because of the ship itself becoming a guide-vane. Therefore it may well be said in the sense of diminishing the oscillatory motion of a ship that the wave attenuation effect of the following current has a role as important as the wave damping effect proper to the pneumatic breakwater.

The allowable maximum air consumption was estimated as 40 $m^3$/min. The depth is about 5 m below the standard sea level which is shallower than that at the east quay.

Following the example of the 11th Typhoon, suppose the increase of water level be 2.3 m, the water depth during Typhoon may be estimated 7.3 m. If the increment of the effective depth by use of the ladder type may be supposed 25% as in the case of the east quay, we have an effective water depth 9.1 m. Air consumption per unit length of the perforated pipe is $Q=40/10=4\ m^2/min$, then we have $\xi\,(=Q/g^{1/2}H_e^{3/2})=7.68\times10^{-4}$.

By use of Fig. 5, we can obtain with this value of $\xi$ the performance curve of our installation for wave damping as shown in Fig. 7.

Now we should find the velocity of the surface current in order to estimate the attenuation of wave height due to the following current.

If the bow is moored as near to the pipe as possible so as to the ship itself being a sort of guide-vane as stated before, the surface velocity may attain nearly

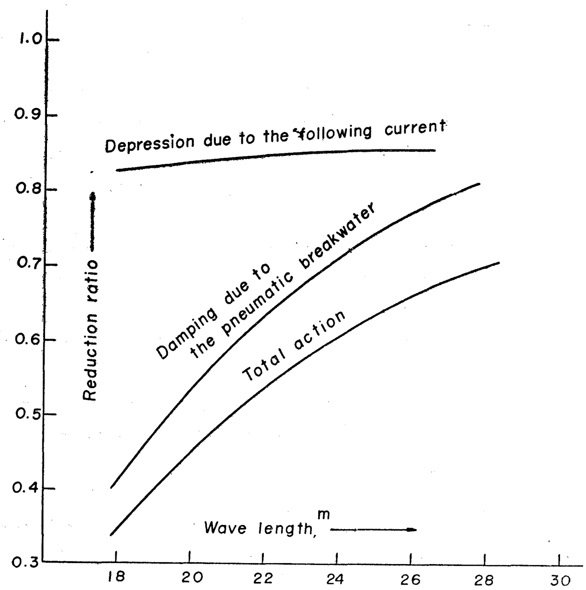


Fig. 7. Characteristic curve of wave reduction for the permanent installation at the west side.

its maximum for the front of the ship. Thus we have $U=1.20\,\mathrm{m/sec}$ by (1.3). Then we can obtain the depression of wave height due to the following current from Fig. 9a) in Report V. The result is shown also in Fig. 7.

The resultant decrement of wave height is obtained by multiplying the reduction ratios above obtained for the two kinds of actions of our installation. The result of calculation is also given in Fig. 7.

Damage caused by the oscillatory motion of a ship due to waves may be assumed to be proportional to the energy of waves, namely, the mean square of wave height. Therefore, if the mean wave height will be decreased to 70%, the damage will markedly lessen. As seen in Fig. 7 the waves having length less than 28 m may satisfy this condition. We are much satisfied with those effects of a pneumatic breakwater.

6. *Design of the perforated pipe* The perforated pipe was designed so as not to make an appreciable change in the discharge distribution along the pipe, even in the case of maximum air supply $40\,\mathrm{m^3/min}$. Two main pipes are of steel, 3 inches in diameter. The interval of them are 1.5 m taken similarity to that at the east side. The cross pipes are also of steel, 2 ½ inches in diameter, the pitch of which is 0.75 m.

The area of the air holes was determined so as to admit a pressure drop of 5 m in water column by ejection at the maximum discharge.

For one cross pipe we have, assuming vena contraction coefficient=0.37,

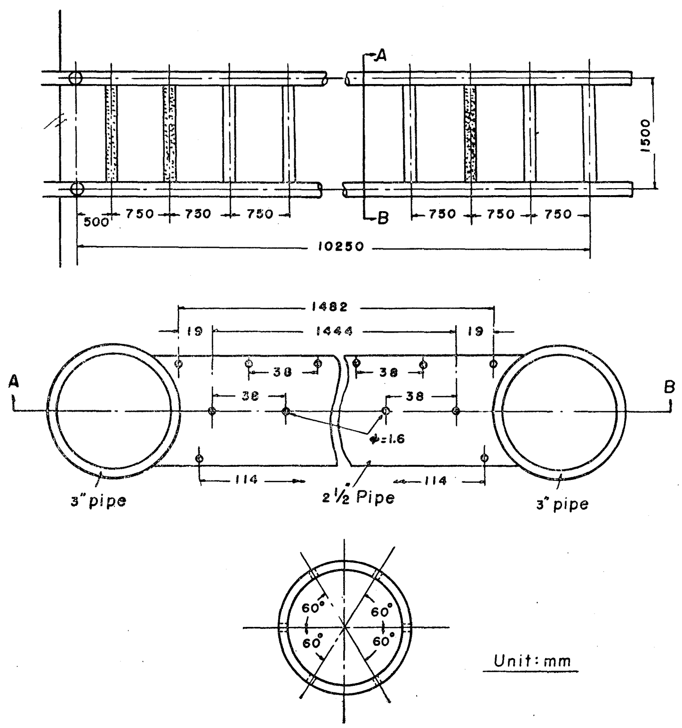


Fig. 8. Permanent installation at the west side of the fitting-out quay.

the total effective area of the holes = 1.37 cm$^2$,
the total area of the holes = 3.69 cm$^2$,
the diameter of the hole = 1.6 mm,
the number of the holes = 184.

Fig. 8 illustrate the perforated pipe and the arrangement of the air holes.

Galvanization was applied for protection of the pipe from erosion like the east side. Namely much care has been expended upon the perforation that at first a gimlet of 1.8 mm in diameter was used for boring and then that of 1.6 mm was applied for finishing touches after galvanization.

All the other equipments under the water were galvanized thickly to protect them from erosion. There have been nothing wrong on the discharge of air since the construction of the installation, the east one being in February and the other one in July of 1959.

7. *Air compressor* Two of the reciprocating air compressors were employed part-timely for the breakwaters, which were equipped for the other proper works of the shipyard.

The specification of the compressor is: capacity = 75 m$^3$/min, out put pressure = 7 kg/cm$^2$, axial horse power = 500.

Because of their high pressure those reciprocating compressors are not adequate for supplying the air to the pneumatic breakwater, but economically serve to our experiments because of them being already set up in the shipyard.

In the present electric power transmission of Japan, however, the electric current is apt to be cut off in the midst of typhoon when the pneumatic breakwater is driven by necessity. Therefore it is needed to depend on the independent electric power plant or to furnish with the compressed air not to depend on the electric power transmission.

Recently Sigmo-Reteau free piston gas producer of 1000 h.p. has begun to be produced in Tsurumi shipyard. So it is planned to send gas directly into the perforated pipe that is obtained from the gas producer. The work will be executed in the near future.

The specification of the gas producer is as follows:

GS 34 1000 HP turbine gas producer:
Diesel cycinder; diameter = 340 mm,
Compressor cylinder; diameter = 900 mm, stroke = 370~470 mm,
Gas pressure = about 3.1 kg/cm$^2$, Max. temperature = about 450°C,
Gas supply = 4 kg/sec.

In this case two kinds of energy losses are unavoidable. At first the high temperature gas is cooled down to the normal temperature without to be utilized its heat energy and secondly, in the course of the bubble jet, the soluble constituents are lost into water. But the latter loss is not so significant because of nitrogen gas being the main constituent of the gas.

Thus the gas producer can only supply about 180 m$^3$/min of effective gas at the normal condition. However this amount of gas is sufficient for our purpose.

Now, from the stand point of energy efficiency of the installation, it is desirable the gas producer to be used to drive a system of gas turbine and rotary air compressor. On the other hand, it may be a serious economical loss to employ the gas producer solely for the pneumatic breakwater. Thus, if the turbine is made to operate a power plant at ordinary time and to drive the compressor for the pneumatic breakwater part-timely in case of necessity, the economical difficulty will be greatly lightened.

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