CHAPTER 134

WAVE PRESSURES
ON LARGE CIRCULAR CYLINDRICAL STRUCTURE

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ABSTRACT

The field observations on wave pressures on large circular cylindrical structures are performed at the cooling water intake structure for Hamaoka nuclear power plant, which is located at the coast of Pacific Ocean. In this report, the results of the field observation on wave pressures are compared with the results of the calculation by small amplitude wave theory considering wave diffraction around the cylinder.

1. Introduction

There are many researches on wave forces on circular cylinder. If the diameter of circular cylinder is small in comparison with wave length, we can neglect the deformation of wave by cylinder and express wave forces as the sum of drag force and inertial force in accordance with Morison's formula. But if the diameter of circular cylinder is large, Morison's formula become invalid, and we must consider deformation of wave around the cylinder.

Wave forces on large circular cylinder are studied by Laird,[1] McCamy and Fuchs,[2] Bonnefille,[3] Nagai and others,[4] Chakrabatri,[5] Watanabe and Horikawa,[6] Yamaguchi and Tsuchiya[7] and so on. Most of these studies are theoretically or experimentally in the laboratory. Field observations on wave forces or pressures on large circular cylindrical structure are very rare.

Though it is not easy to measure all factors govering the phenomena in field observation, we can confirm the results of theoretical calculations and experiments in laboratory.

In this paper, the results of the field observations on wave pressures acting on large circular cylindrical structure are compared with the results of the calculation.

Observations were performed at the cooling water intake structure for Hamaoka nuclear power plant. It is sited at the coast of Pacific Ocean in Japan (See Fig. 1)

Cooling water intake structure is 600 m from shoreline. The water depth at this site is about 9 m and bottom slope is 1/100. The diameter of the structure is 16 m, and its height above the bottom is 11.2 m. (See Fig. 2)

Since the diameter of this structure is large, the inertial force is rather predominant than the drag force in all wave condition if we assume that $C_M = 2.0$ and $C_D = 1.0$. So it is possible to calculate the wave pressures on the structure by McCamy and Fuchs's formula.

Intake structure has six intakes, and there is a circular projection below the intakes, and there are fenders above the still water level. So it is not simple circular cylinder. And its height above the still water level is low in order to avoid breaking wave forces. But here it is assumed that the structure is circular cylinder, and the effect of wave overtopping is neglected. Thus we compared measured pressures with calculated pressures. Of course measured pressures are due to irregular waves, and calculated pressures are due to replaced regular waves.

2. Theory

(1) Wave pressures by small amplitude wave theory.

Wave pressures around the large circular cylinder is expressed as Eg. 1., if we consider the cylindrical co-ordinate shown in Fig. 3.[2]

$$\frac{P}{wH} = -\frac{1}{\pi^2 \left(\frac{D}{L}\right)} \frac{\cosh kh \left(1 + \frac{Z}{h}\right)}{\cosh kh} \cdot f\left(\theta, \frac{D}{L}\right) e^{i\sigma t} \quad \ldots\ldots(1)$$

$$f\left(\theta, \frac{D}{L}\right) = \frac{1}{H_0^{(2)'}\left(\frac{\pi D}{L}\right)} + 2\sum_{n=1}^{\infty} (i)^n \frac{\cos n\theta}{H_n^{(2)'}\left(\frac{\pi D}{L}\right)} \quad \ldots\ldots(2)$$

in which w is unit weight of water, p is wave pressure, H is height of progressive wave, L is wave length, k is wave number, σ is wave angular frequency, h is water depth, D is diameter of cylinder, $Hn^{(2)'}$ is derivative of Hankel function of the second kind of orders n, n is positive integer.

(2) Dimensional analysis of wave pressure on large circular cylinder.

It is known a priori that wave pressure acting on large circular cylinder depends on the next parameters, if the roughness of structure surface is neglected,

$$\frac{P}{wH} = f_1\left(\frac{D}{L}, \frac{h}{H}, \frac{H}{D}, \frac{\nu}{D\sqrt{gD}}, \frac{Z}{h}, \theta\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

in which ν is coefficient of kinetic viscosity, g is acceleration of gravity.

The fourth parameter on the right-hand side of Eg. 3 may be considered to represent the ratio of the Froude number to Reynolds number. It may be disregarded as it seems to be small.

Thus the dimensionless wave pressure acting on the side of circular cylinder could be written as

$$\frac{P}{wH} = f_2\left(\frac{L}{D}, \frac{h}{H}, \frac{H}{D}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

In analysis of the results of field observation, the effects of parameters in right-hand side of Eg. 4 on the value of P/wH are investigated.

3. Outline of observation

Field observations have been performed for about two years from September in 1972. (See Fig. 4)

Eight pressure gauges were attached to the side of intake structure shown in Fig. 5. Pressure gauges are strain-gauge type ones, and their range is from 0 to 2 kg/cm^2.

Wave gauge is set up in the offing. Its distance from the shoreline is 950 m, and water depth at the wave gauge site is about 13 m. Wave heights and pressures were often observed simultaneously, and about 170 data on the vertical and horizontal pressure distributions were recorded.

Each datum was recorded for twenty minutes and we obtained highest pressures, significant pressures and so on from the records for twenty minutes.

The analysis of the results of the observations is performed on the data that the highest wave height is more than 1 m. The range of the values of the highest wave height Hmax. wave period Tmax, water depth h, and dimensionless parameters shown in right-hand side in Eg. 4 are as follows:

Hmax	: 1.0 - 8.9 m	D/Lmax	: 0.11 - 0.34
Tmax	: 6.0 - 16.0 sec	h/Hmax	: 1.1 - 16
h	: 8.4 - 10.0 m	Hmax/D	: 0.06 - 0.56

in which Lmax is a wave length of highest wave as small amplitude wave.

4. Results

In order to compare the observed values with calculated values by Eg. 1, it is assumed that the highest pressure Pmax acting on the structure depend on the highest wave height, and the relations between dimensionless wave pressures and the dimensionless numbers shown in the right-hand side of Eg. 4 are investigated.

In obtaining above-mentioned dimensionless numbers from field data, we assume as follows :

a. The incident waves come shown in Figure 4. In other words, point No. 2 and 4 are at $\theta = 0$.

b. Progressive wave height at the site of intake structure equals to wave height obtained by wave gauge.

c. Water depth at the site equals to one obtained from the tide curve at the Omaezaki Harbour, where is 8 km from the power station.

(1) Relations between D/Lmax and Pmax/wHmax

Relations between D/Lmax and Pmax/wHmax are investigated from the field data at all pressure measured points. The relations at the point No. 2 and No. 4 are shown in Fig. 6. The curves in Fig. 6 are calculated from Eg. 1. Upper curve corresponds to the case of observed minimum water depth, and lower curve corresponds to the case of observed maximum water depth.

The results of comparison of observed dimensionless pressures with calculated ones are as follows:

a. Most of observed values are smaller than calculated ones at the deep part, but there are many observed values larger than calculated ones near the still water level.

b. In case of small values of D/Lmax, observed values of Pmax/wHmax are scattered above and below the calculated values. But in case of large values of D/Lmax, most of observed values of Pmax/wHmax are smaller than the calculated values.

(2) Relations between h/Hmax and Pmax/wHmax

Relations between h/Hmax and Pmax/wHmax in case of D/Lmax $\doteqdot$ 0.15 (0.14 - 0.16) and 0.20 (0.19 - 0.21) at the point No. 2 and No. 4 are shown in Fig. 7. In this figure, calculated values of Pmax/wHmax are shown as solid line.

In case of small values of h/Hmax, observed values of Pmax/wHmax are smaller than calculated values. This is due to nonlinearity of wave, as pointed out by Yamaguchi and Tsuchiya.[7]

In case of large values of h/Hmax, observed values are larger than calculated ones. This reason is not clear. But it is considered that the observational error is large if the wave height is small, and that the fenders near the still water level have influence to the observed wave pressures.

(3) Relations between Hmax/D and Pmax/wHmax

Relations between Hmax/D and Pmax/wHmax in case of D/Lmax $\doteqdot$ 0.15 and 0.20 at the point No. 2 and No. 4 are shown in Fig. 8. In this figure, calculated values of Pmax/wHmax are shown as solid line. The observed values of Pmax/wHmax become smaller, as the value of Hmax/D become larger, and in case of small values of Hmax/D, observed values of Pmax/wHmax are larger than calculated values.

(4) Vertical and horizontal distributions of wave pressures

In case of D/Lmax $\doteqdot$ 0.15 and 0.20, vertical distributions of observed and calculated wave pressures at $\theta = 0$ are shown in Fig. 9. Horizontal distributions of observed and calculated maximum wave pressures at the slightly lower points than still water level are shown in Fig. 10. As shown in these figures, the observed values coincide fairly well with the calculated values, or the formers are smaller than the latters in case of h/Hmax < 4.

Fig. 11 shows the horizontal distributions of observed and calculated wave pressures as maximum pressures occur at $\theta = 0$. In this figure the observed values are larger than calculated values at the rear side of structure. This reason is not clear. But it is perhaps due to the waves passing through the intakes.

(5) Applicable range of Eg. 1

From the applicable point of view, it is necessary to know the applicable range of Eg. 1. Comparing all field data with the results of theoretical calculation, the applicable range is investigated. Broken lines in Fig. 7 and 8 show the upper limit of observed values of Pmax/wHmax. Such limits are obtained at the another measuring points, and applicable range of Eg. 1 shown in Fig. 12 is obtained.

(6) Wave pressures on very large circular cylinder

Calculations of wave pressures on large circular cylinder by small amplitude wave theory are not so precise, as it is described already. Recently calculations of wave pressures by finite amplitude wave theory are presented, but these calculations are very complicated. So if we can use Eg. 1, it is very convinient.

The results of the calculation by Eg. 1 for the side of circular island, which has a very large diameter, are shown in Fig. 13.

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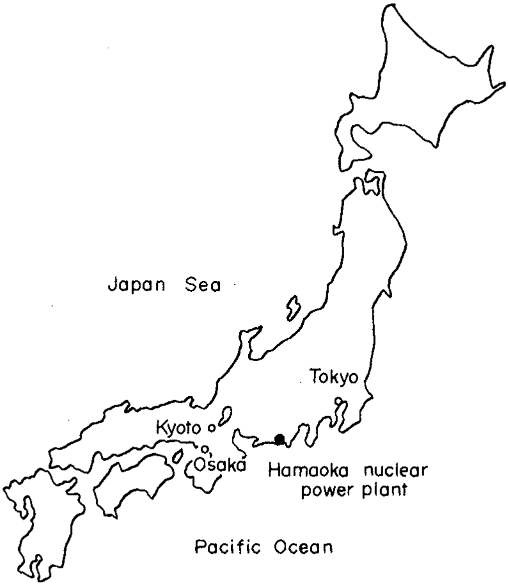

Figure 1. Location of Hamaoka nuclear power plant.

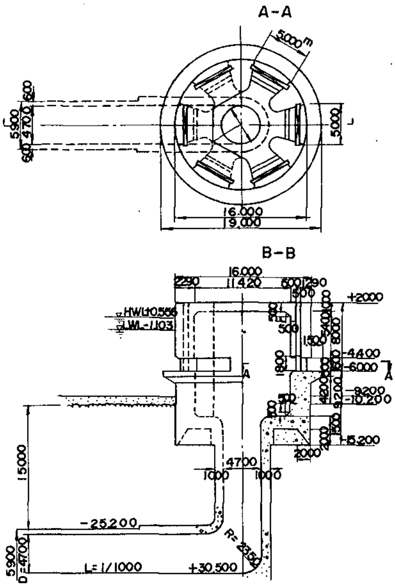

Figure 2. Intake structure of Hamaoka nuclear power plant

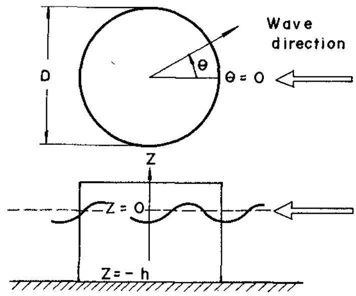

Figure 3. Cyrindrical Co-ordinate

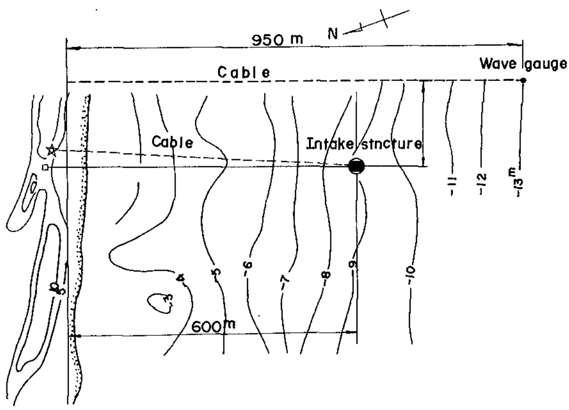

Figure 4 . Position of intake structure

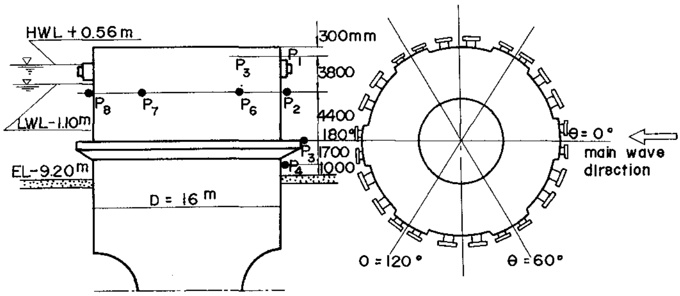

Figure 5 . Position of pressure gauges

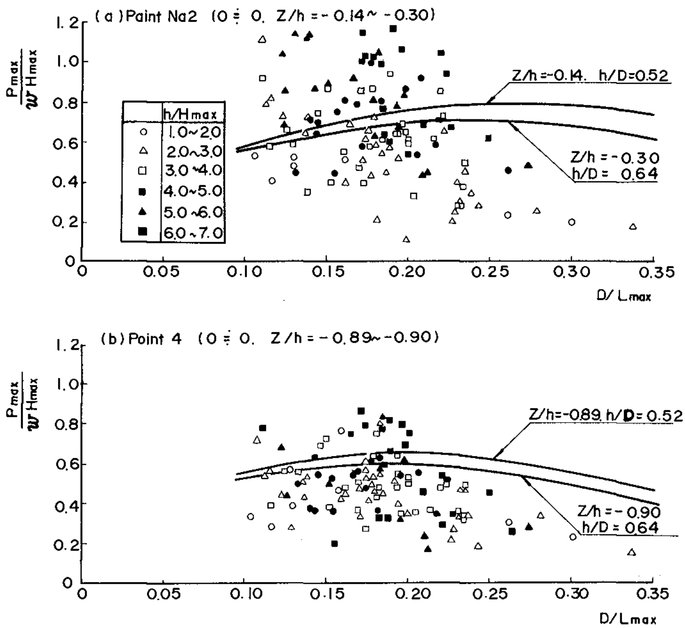

Figure 6. Relation between D/Lmax and Pmax/wHmax

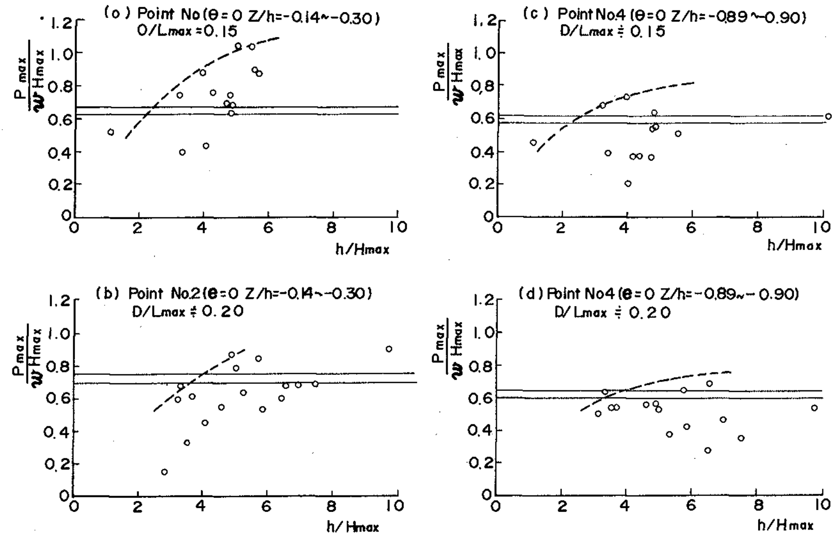

Figure. 7 Relation between h/Hmax and Pmax/wHmax

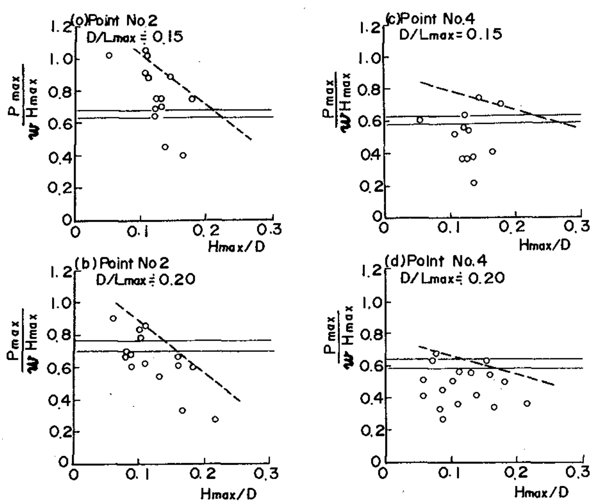

Figure 8. Relation between Hmax/D and Pmax/wHmax

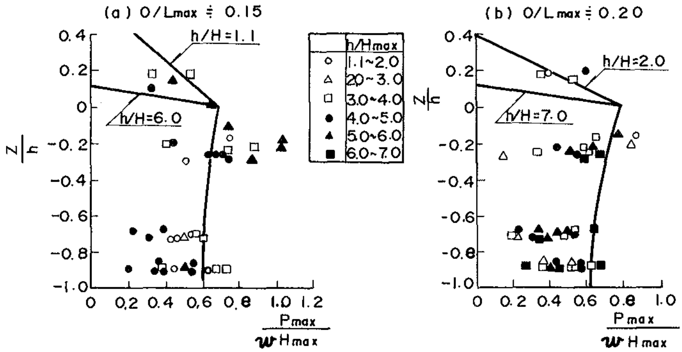

Figure 9. Vertical distribution of wave pressures

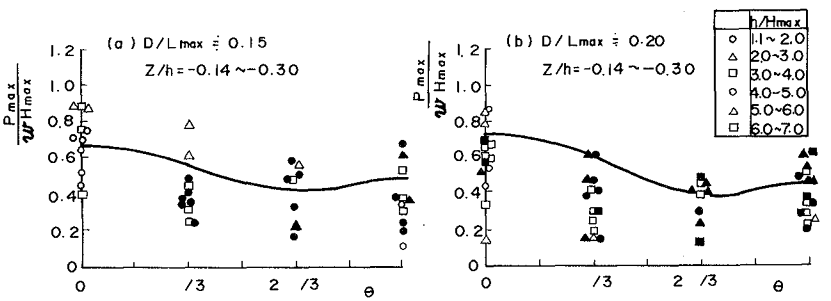

Figure.10. Horizontal distribution of wave pressures

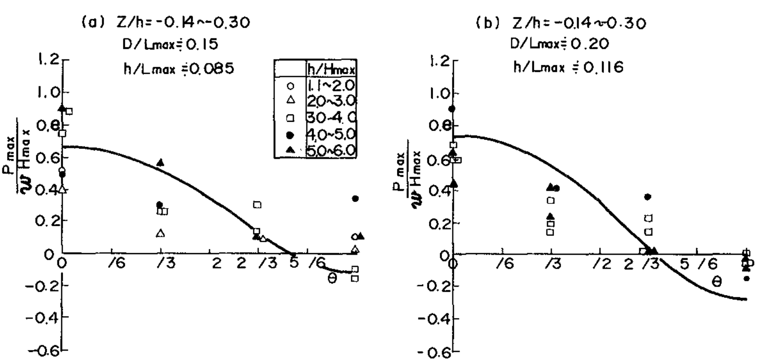

Figure 11. Horizontal distribution of wave pressures as maximum pressure occur at θ = 0

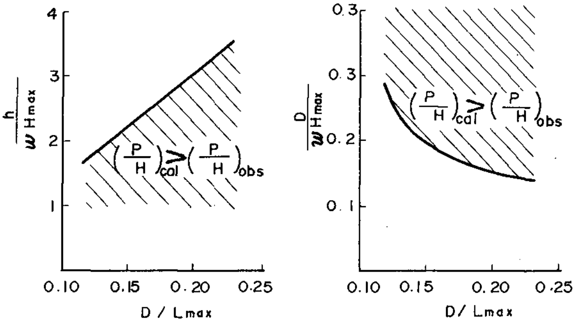

Figure 12 Applicable range of equation (1)

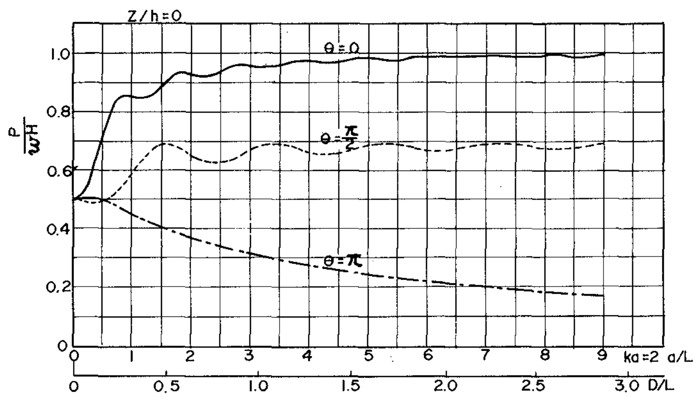

Figure 13 Relation between D/L and P/wH