IMPACT WAVE FORCES ON VERTICAL AND HORIZONTAL PLATE

by

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INTRODUCTION

The hydrodynamic impact problem is a very difficult problem because the physics of what actually happens during the instant of impact are not understood. Despite of fact that a large number of references exist on the subject, many questions are left unanswered.

The object of this research is to investigate the problems of hydrodynamic impact associated with the water waves impacting on the vertical and horizontal plates. Of particular interest are the impact forces, their relation to the incident wave parameters and scale effect problems.

VERTICAL WALL BREAKWATER

Consider first the case of the vertical plate which can simulates easily the breakwater wall. The prediction of shock-pressures exerted by breaking waves is the most important thing to be known for the design of breakwaters. However due to great difficulties in the experiments, very little information is available in regard to the practical data of the shock pressures on the prototype objects. On the other hand, during the recent decades a large number of model investigations of shock pressures have been undertaken. They indicate that the configurations of breaking waves at breakwaters vary in a wide range depending upon the type of breakwaters, the characteristics of breakwaters, the characteristics of incident waves, the ratio of the depth of water in the front of the breakwater to the height of the incident wave.

In the previous research undertaken for example, by Nagai [7], Mitsuyasu [6], Hayasi [3], Rundgren [9], Richert [8], Loginov [5] and others, the shock pressures at particular points of the vertical wall were considered. The results of these investigations give a very ambiguous picture of the problem; often they are contradictory and have been presented in a different way. Thus, it is extremely difficult to compare the results by different authors. The value of pressure depends very strongly on the position of the air cushion. Moreover, the considered wave is usually disturbed by the preciding wave, so it

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loses part of its energy before it reaches the wall. These factors are, to some extent, a random factors.

In order to predict the effective forces on the vertical wall and to avoid the influence of the air cushion configuration on the impact forces, in the present study, the total force on the breakwater wall will be considered. The vertical plate with two degrees of freedom (horizontal displacement and rotation around the horizontal axis) simulates the breakwater wall (Fig.1). The wave breaking is forced by the composite-type bottom on which the test wall is situated. The displacements of the two points are measured simultaneously by the Phillips' capacitive sensors. The deflection of the supporting rings is in the elastic range, therefore the forces at the two measuring points are related to the displacements by Hooke's law.

Numerous experiments indicate that, if for certain wave height, the breaking wave front is approximately plane and if it creates a very thin air cushion, the pressure peak reaches a maximum value. If the wave height is only slightly smaller, the wave front will be sloping backwards. On the other hand, if the wave height is larger, the air cushion will be thicker and the wave breakes further from the wall. Threrefore, for a given wave period and a given depths h_1 and h_2, it is only one wave height that is associated with the max. force.

The first series of experiments were carried out in the wave tank being 10 m long and 25 cm width for three various wave periods. For each period, the wave height corresponding max. force was chosen.

As was mentioned above, the max. impact forces may be treated as a random variables. In order to obtain a set of data which is sufficient for statistical analysis, the experiments were repeated many times.

Since the extension of model shock pressure into prototype scale is of particular interest for engineers, various model scales were also considered. Taken as a prototype was the breakwater on 6 m water depth subjected to the wave dimensions being 2,5 m height and 5-6 s period. Laboratory tests were conducted in the five scales 1/20, 1/30, 1/40 and 1/50. It means, that considering the scale 1/20 as a reference scale, we obtain a set of experiments in the scales 1/1, 1/1.5, 1/2 and 1/2.5.

In the various scales, the corresponding wave parameters and water depths were calculated in accordance with the Froude's law. At the same time, the mechanical device for the impact force measurement has not been changed.

From the numerous laboratory tests we found that

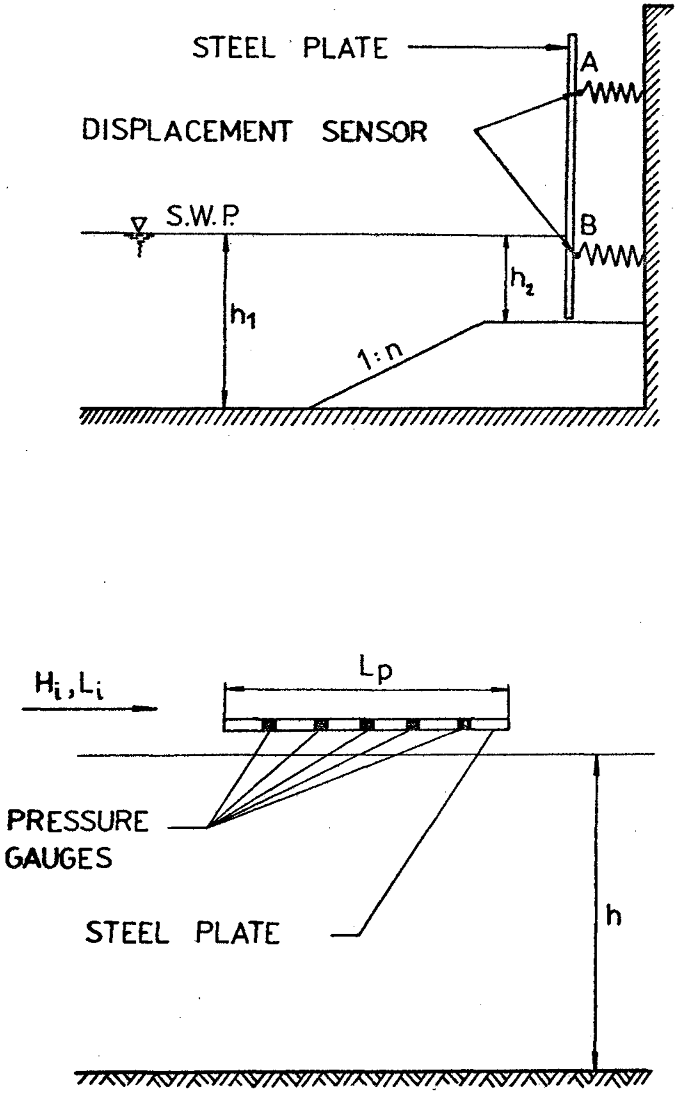

Fig.1 Vertical and horizontal plates.

probability density functions $f\left(\frac{R_1}{\bar{R}_1}\right)$ and $f\left(\frac{R_2}{\bar{R}_2}\right)$ ($\bar{R}$ -mean value of the impact force R) are of the Weibull type

$$\left.\begin{array}{ll} f(x) = ab\cdot x^{b-1}\exp\left(-ax^{b}\right) & \text{for } x > 0 \\ f(x) = 0 & \text{for } x \leqslant 0 \end{array}\right\} \qquad (1)$$

$$\text{where: } x = \frac{R_1}{\bar{R}_1} \quad \text{or} \quad x = \frac{R_2}{\bar{R}_2}$$

From Eq.1, it immediately follows that the probability distribution function F(x) takes the form

$$F(x) = 1 - \exp\left(-ax^{b}\right) \qquad (2)$$

Taking the derivative of Eq.2 gives

$$Y = \ln a + bX \qquad (3)$$

$$\text{where: } Y = \ln\left\{-\ln\left[1 - F(x)\right]\right\}, \quad X = \ln\{x\} \qquad (4)$$

Thus, the representation of the Eq.3 in the logarythmic scale is the straight line. In the Fig.2, the theoretical formula (3) is checked against the experimental data for the impact force R and various model scales. The agreement is quite satisfactory. However, for various scales the distribution parameters a and b takes a different values. When the parameters a and b are found from the Fig.2, the corresponding probability density functions can be easily calculated (see Fig.3).

The wave forces were measured in two points of the vertical plate. One supporting ring was approximately situated at the SWL (for wave force R_1 - point B), the other was above SWL (for wave force R_2 - point A). Fig.4 shows the example of the correlation between the force R_1 and R_2. In each calculated cases the correlation coefficient was greater than 0.8.

As the mechanical measuring device was not scaled, it is difficult to say how much wave momentum is associated with the pulse and how much is dissipated by the mechanical and hydrodynamic dumping.

In order to give the answer on that question we considered the very simple model. In the first place, by way of experimental verification we found that the horizontal motion of the plate predominates over the rotation motion; in the record it is only one frequency that is visible. So we can state that the two degrees of freedom system is approximately equal to the two systems having one degree of freedom (Fig.5). The unknown characteristics of the measuring systems are defined by the special calibration tests.

The equation of motion of any single-degree-of-freedom system can be reduced to the equation of motion of a simple spring-mass system with damping

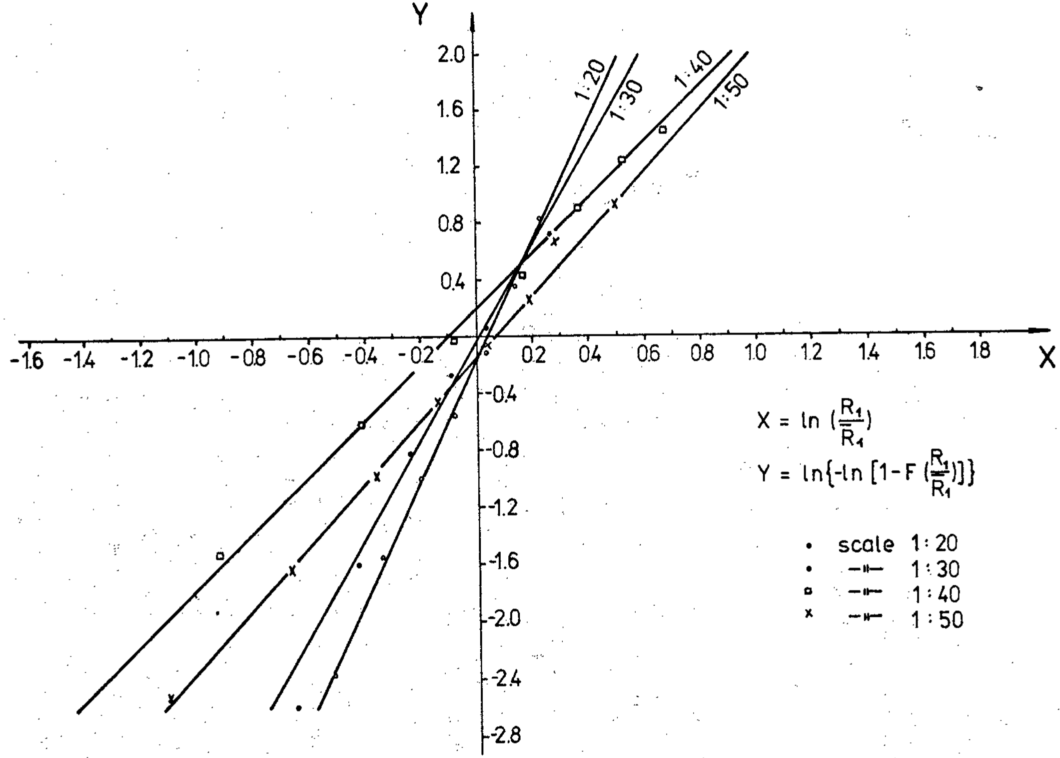

Fig.2 Probability distribution for max. forces in the logarythmic scales.

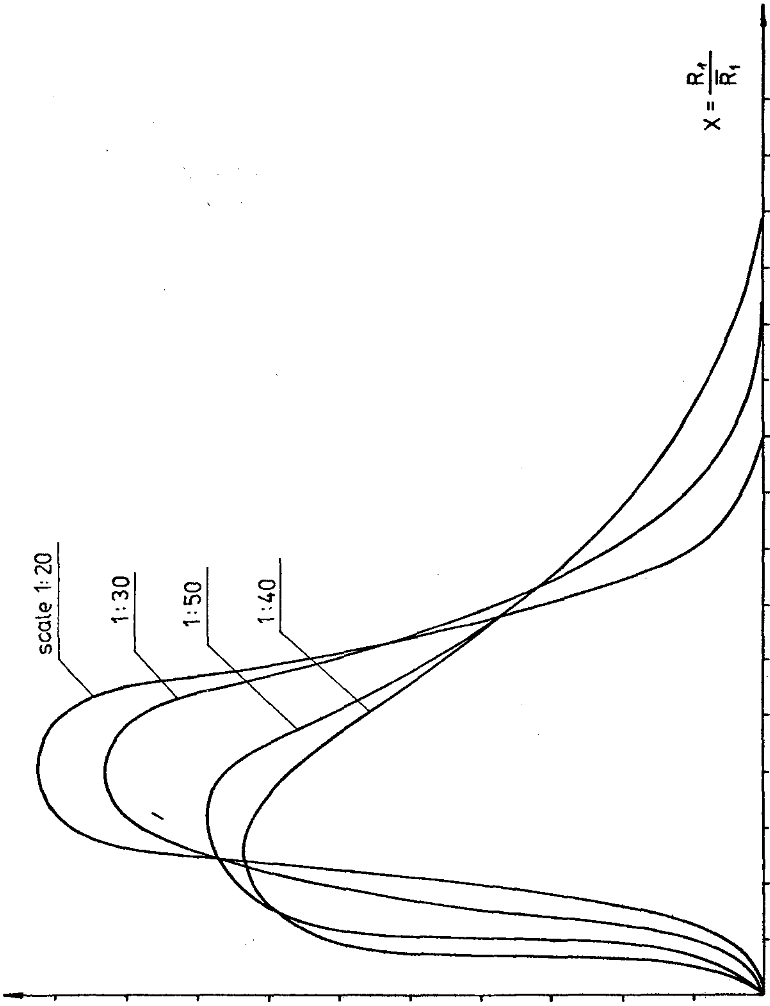

Fig.3 Probability density functions for max. forces.

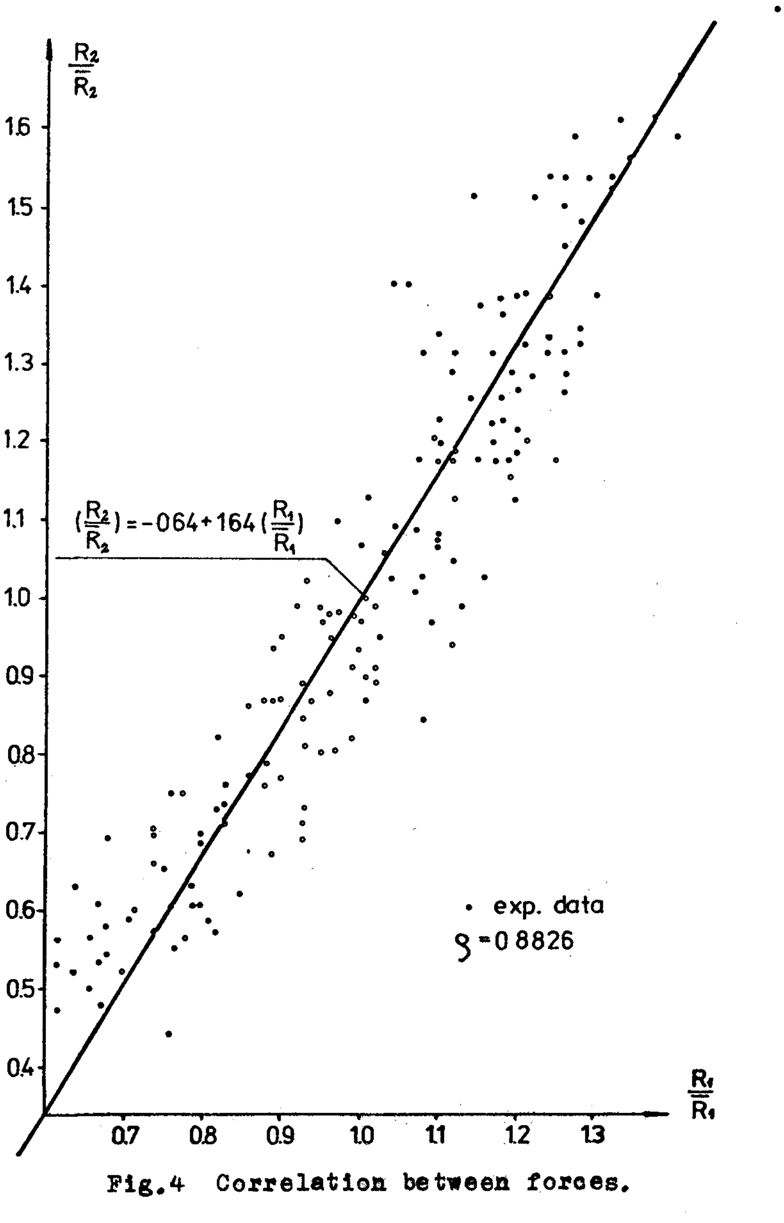

Fig.4 Correlation between forces.

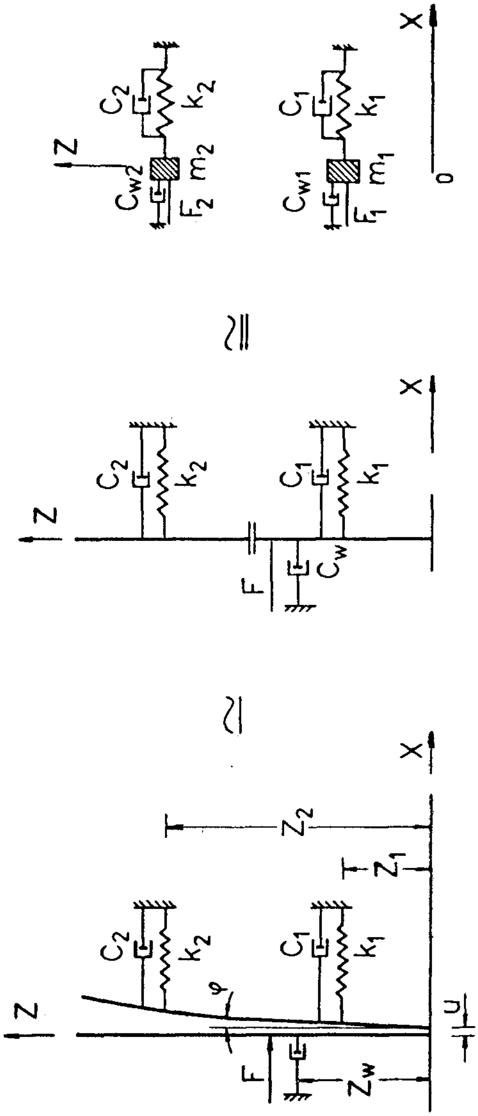

Fig.5 Equivalance of the measuring systems.

$$(m + m_a)\frac{d^2u}{dt^2} + (C + C_a)\frac{du}{dt} + k \cdot u = P(t) \tag{5}$$

in which: u - displacement of the plate,
m - mass of the vibrating part of system,
m_a - added mass of the water participating in vibration,
C - mechanical dumping,
C_a - hydrodynamic dumping,
k - stiffness of the system,
P - impact force.

As we know displacement u, the impact force P (t) is given by the Volterra type integral equation

$$u(t) = \frac{1}{(m+m_a)\cdot\omega} \cdot \int_0^t P(\tau) \cdot e^{-h(t-\tau)} \sin\omega(t-\tau)\,d\tau \tag{6}$$

From numerical solution of the Eq.6 follows that, the rise time of the impact force is less than or equal to 1/4 of the natural period of the measuring system $T_\eta \approx 0.003 \div 0.005$ s . Moreover, only ~40% of the wave momentum is associated with the plate displacement; almost 60% of the momentum is dissipated due to mechanical and hydrodynamic dumping and added mass generation. It means, that the real maximum impact force is about 2.5 times greater than the force calculated simply from the displacement u by Hooke's law.

We consider now the problem of the force scalling. Usually, for the gravity wave phenomena, we use the Froude law of similarity. Thus for the mean wave force we have

$$\frac{\overline{R}_p}{\overline{R}_\lambda} = \lambda^3 \tag{7}$$

in which: $\overline{R}_p$ - mean wave force for prototype,
$\overline{R}_\lambda$ - mean wave force in the scale 1:λ.

At present we assume that in model experiments (scale 1:λ) we obtain the wave force which is equal to $\overline{R}_M$. When no scale effect, the following relation becomes

$$\overline{R}_M \equiv \overline{R}_\lambda \tag{8}$$

When it is not that case, we define the scale effect coefficient in the form

$$\eta_\lambda = \frac{\overline{R}_\lambda}{\overline{R}_M} \tag{9}$$

thus

$$\overline{R}_p = \overline{R}_\lambda \cdot \lambda^3 = \overline{R}_M \cdot \lambda^3 \cdot \eta_\lambda \tag{10}$$

Applying the above definition of the scale effect coefficient to the mean maximum forces we obtain the distribution of the η value as shown in Fig.6. It should be noted that the experiments in the scale 1:20 serve as a reference experiments. If we reduce model scale twice (from 1:1

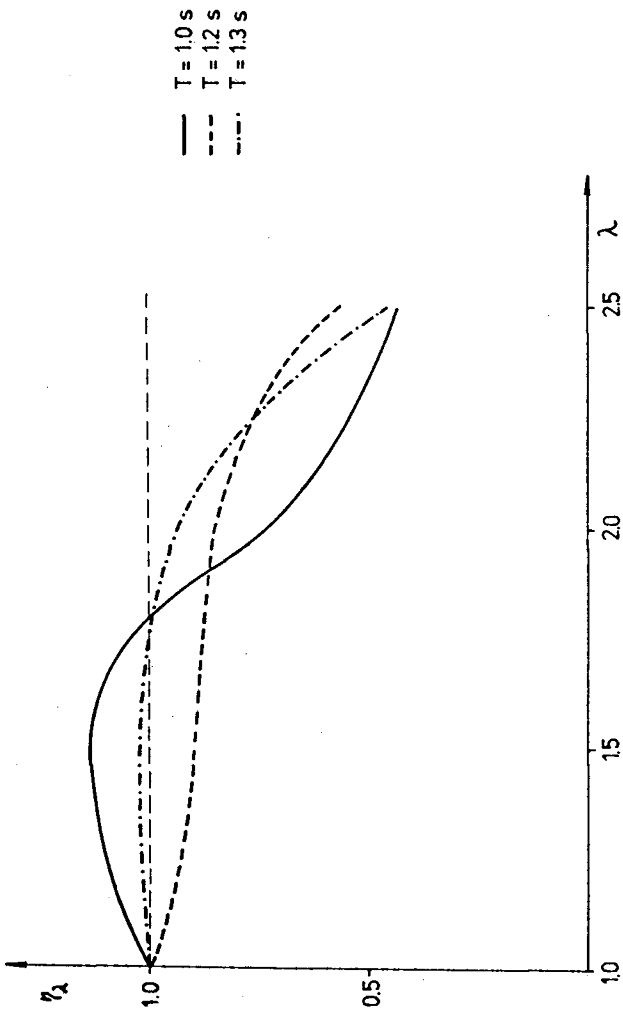

Fig.6 Scale effects coefficient for mean max. impact force.

to 1:2), the mean impact force at the model decreases less than it follows from Froude law for period T=1s. It means that $\overline{R}_M > \overline{R}_\lambda = \frac{1}{8}\overline{R}_P$ or $\overline{R}_M/\overline{R}_P > 1/2^3 = \frac{1}{8}$
Therefore, the prediction of the prototype forces basing on the model test (in this case) overestimates the real force. Thus, the scale effect coefficient $\eta_\lambda < 1$ has to be included (see Fig.6).

The scale effect concept can be extended to the maximum impact force with arbitrary probability of occurrence. From the calculations (not indicated here) follows that the relatively high scale effects may be expected for very low and very high probabilities.

The work reported in this part of paper is the first phase of a project intended to develop insight into breaking wave forces acting on breakwaters and the more efforts are needed towards better understanding of these sophisticated phenomena. First of all, the amount of the air content in the breaking wave is still not good defined. However, the air in the water influences strongly on the added mass vibrated with the plate.

HORIZONTAL PLATE IN THE SPLASH ZONE

An important class of forces for which there is not a large extensive history of study are the impact forces that act on horizontal members in so called "splash zone" [1,2,4,10]. The splash zone is a region wherein the particular horizontal members of the maritime structure are not usually considered to have continuous contact with the waves, but which are located at a height relative to the mean water surface, so that only occasional contact with the water will occur. The nature of the forces that occur during such contacts is essentially impulsive.

In order to provide some knowledge of the pressure distribution on the underside of horizontal members a laboratory study was made. The particular problem considered here is treated by the impact force measurements for a horizontal rigid plate, assuming that the wave system propagates in a direction of longitudinal axis of the plate. A illustration of the situation being analyzed is shown in Fig.7 for the progressive wave and in Fig.8 for the standing wave; the height of the plate (1 m length) above the mean water level is equal to S, H is the incident wave height and h is the water depth. The six electro-kinetic type pressure gauges are installed along the plate axis. The working frequency band for the pressure gauges is equal to 10^{-2} – 10^{4} Hz.

The records taken from the experiments illustrate the impulsive character of pressure. Sometimes due to disturbances underneath the platform, the peak pressure

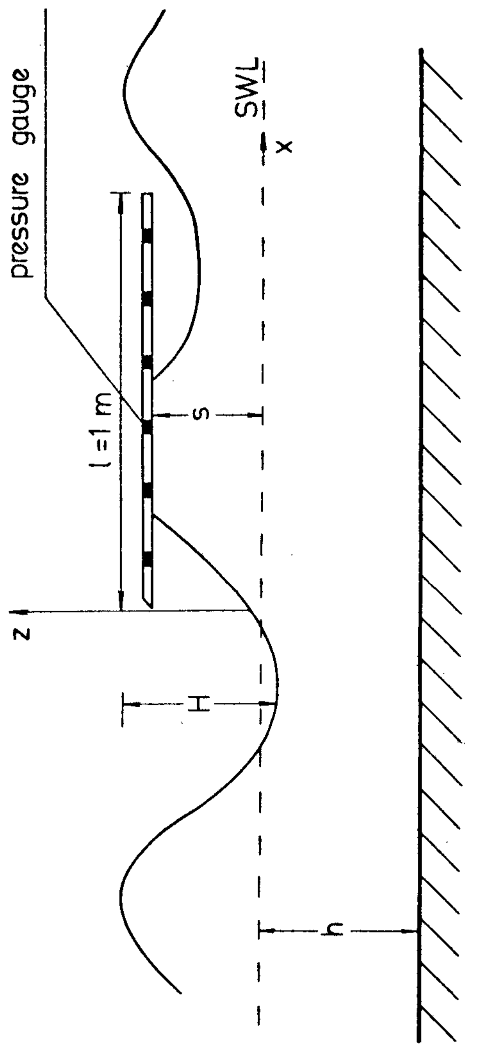

Fig.7 Definition scetch for progressive waves.

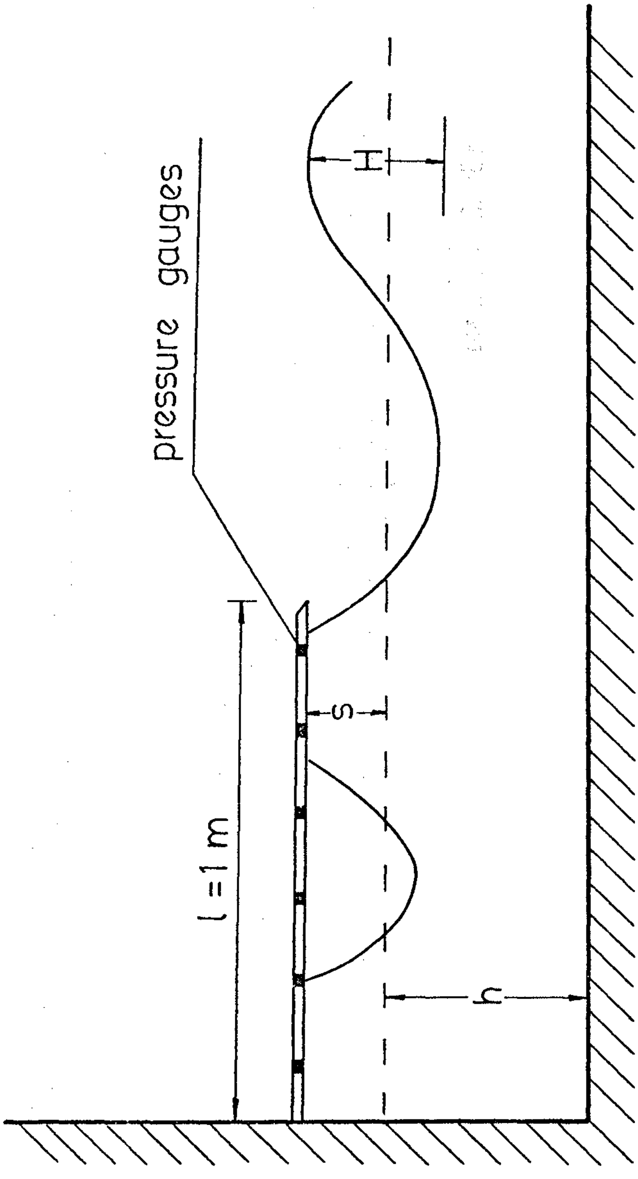

Fig.8 Definition scetch for standing waves.

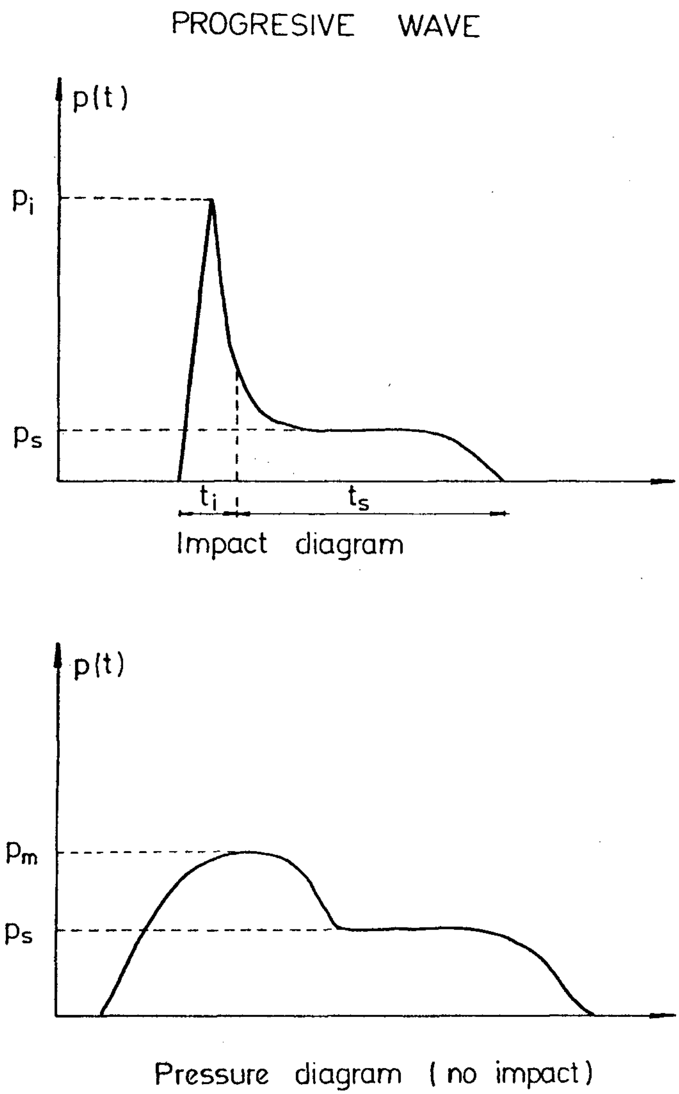

Fig.9 Notations for the impact pressures progressive waves

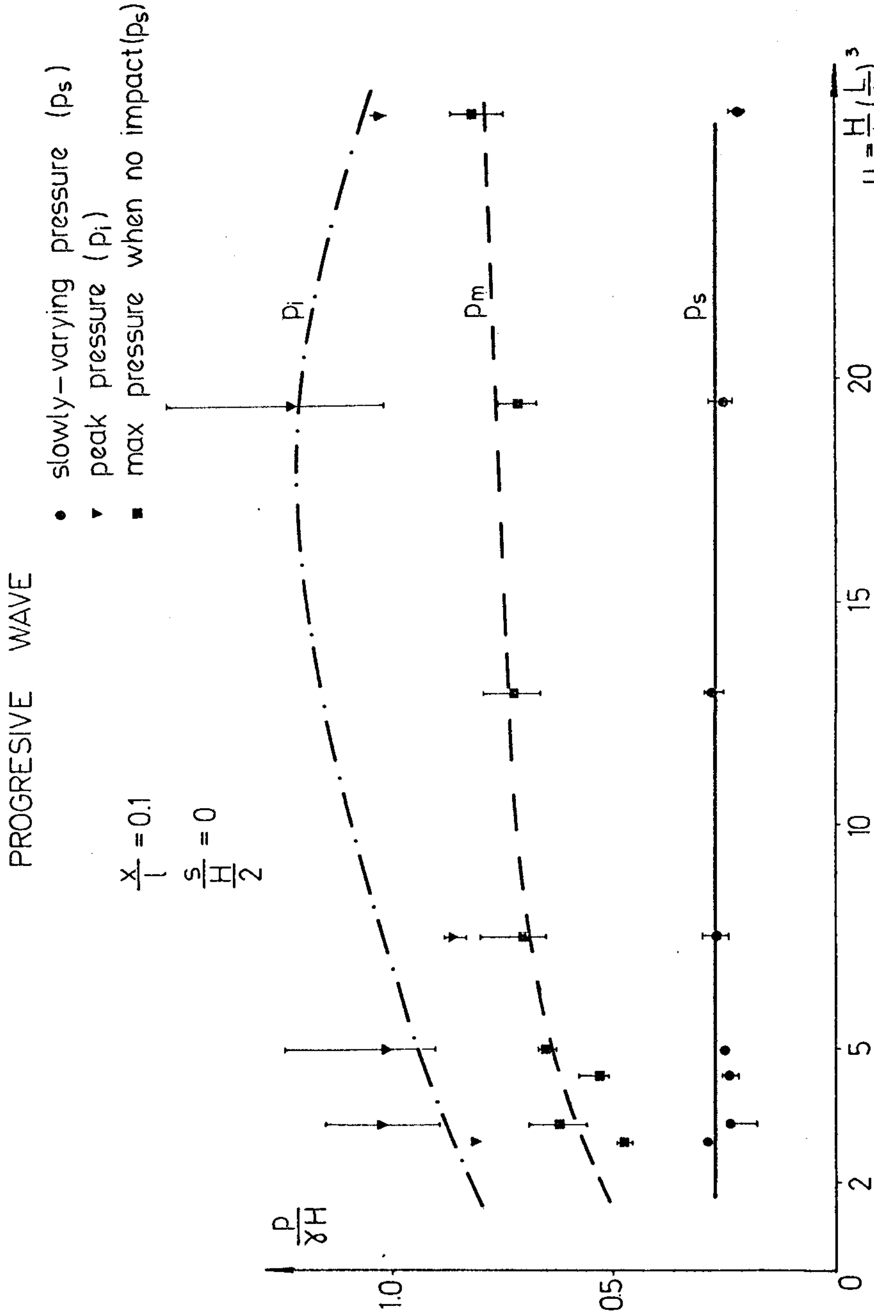

Fig. 10. Impact pressure as a function of Ursell's number

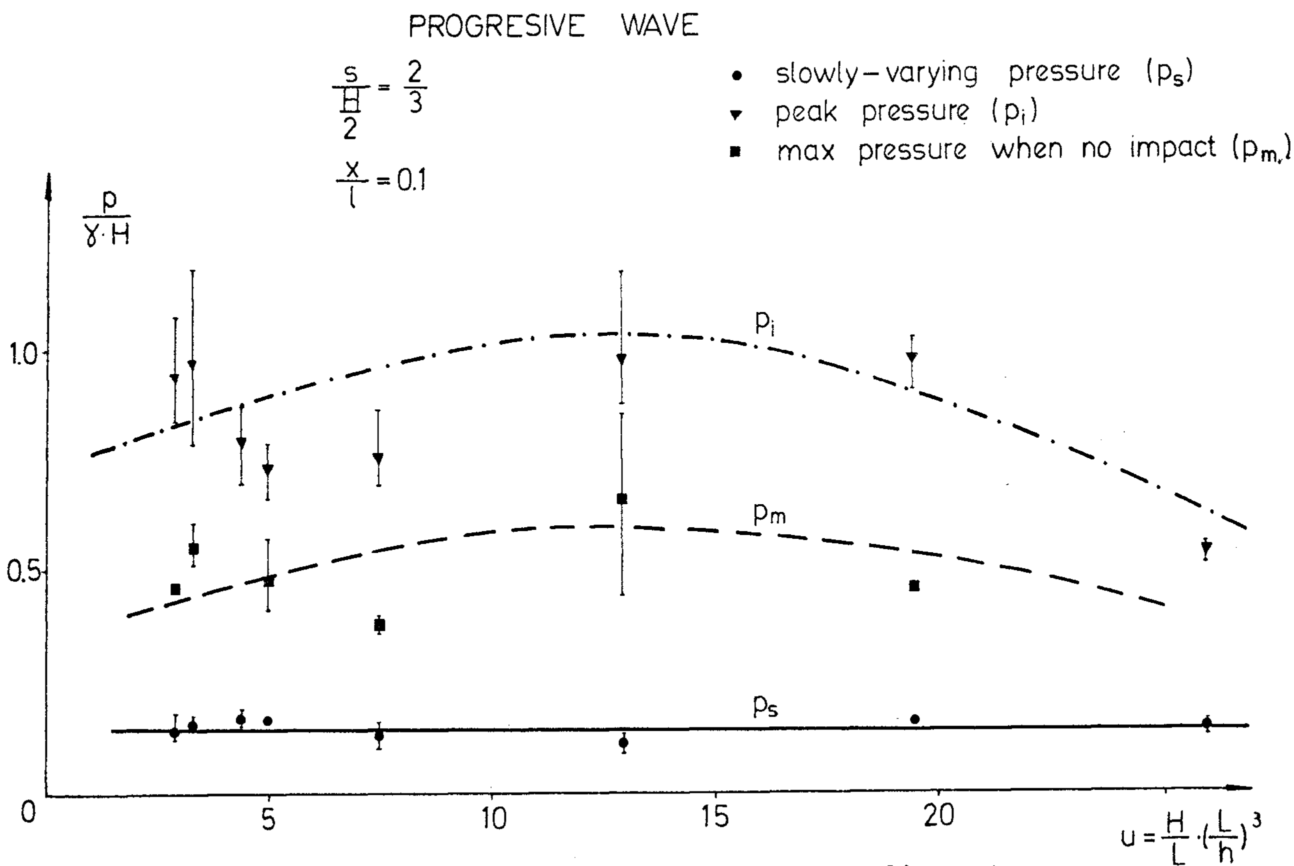

Fig.11 Impact pressure as a function of Ursell's number

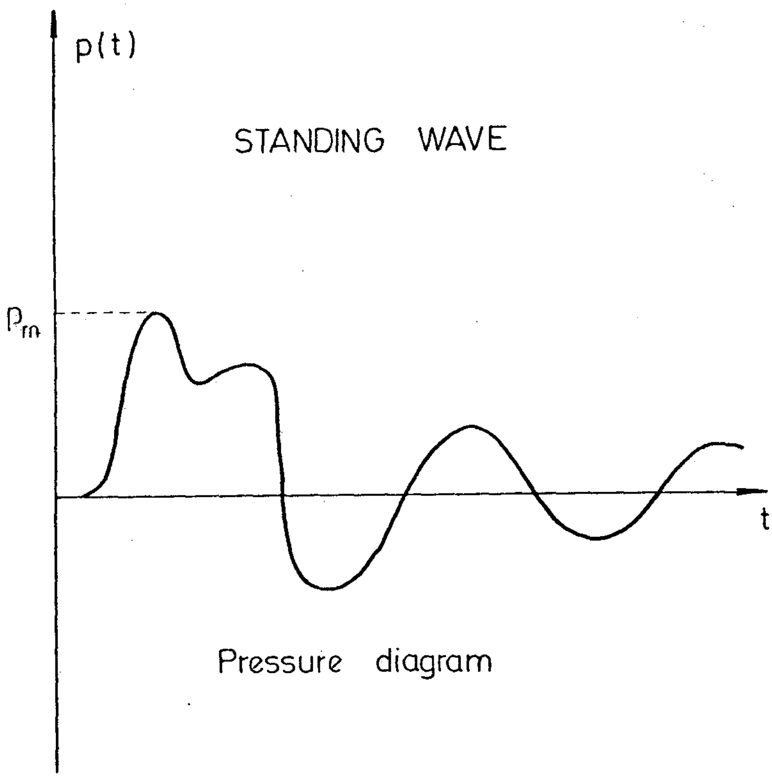

Fig.12 Notation for the impact pressures standing waves .

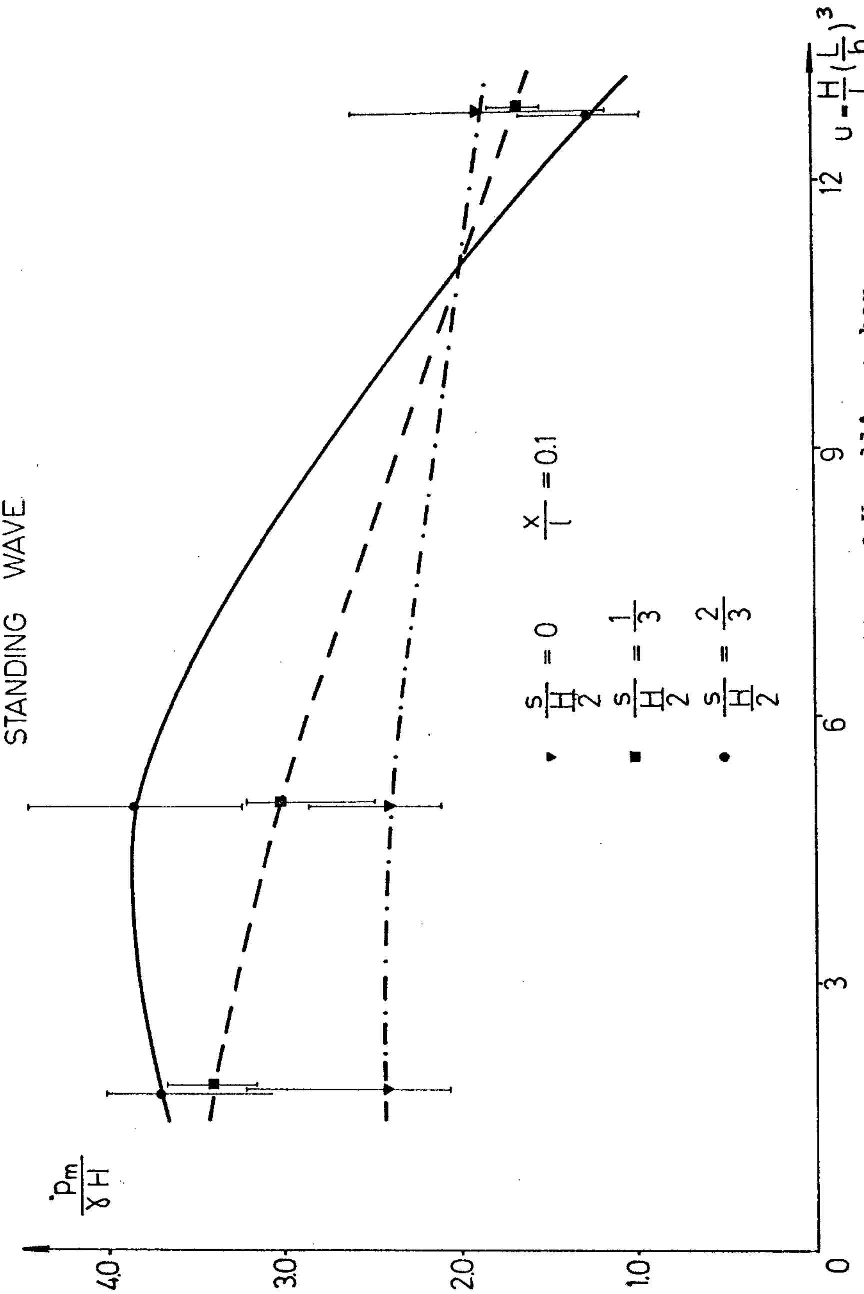

Fig.13 Impact pressure as a function of Ursell's number.

is not so clearly pronounced. In order to classify the impacts induced by the progressive waves we use the notations given in Fig.9, in which p_i - peak pressure, p_s - slowly varying pressure and p_m - maximum pressure when no impact occurs.

The incident wave were Stokes' waves $2 \leqslant \frac{L}{h} \leqslant 8$ (L - wave length, h - water depth).

In Figs.10 and 11 the normalized wave induced pressure is plotted against the Ursell's number

$U = \frac{H}{L}\left(\frac{L}{h}\right)^3$ for nondimensional clearance $S/\frac{H}{2} = 0, \frac{1}{3}, \frac{2}{3}$

(S - clearance between the bottom of the horizontal plate and the still water level).

The data points are the results of the averaging of numerous experiments. Moreover, the standard deviation from the mean value is also indicated. The slowly-varying pressure p_s is almost constant in the considered range of Ursell's number. The highest value p_s is obtain when the plate is at the still water level ($S=0$).

The maximum pressure p_m (when no impact) is slowly-varying function of Ursell's number with max. value at $U \sim 10 \div 15$. The same tendency for the peak pressure p_i is observed. In Figs.10 and 11 the best fittings of the experimental data are indicated by the solid and dashed lines.

When the standing waves are considered, it is hardly to distinguish the various types of pressure.

According to Fig.12 the analysis of the experimental data is restricted to the maximum pressure value p_m. The example of the result is given in Fig.13. The pressure p_m is also the slowly varying function of the Ursell's number.

CONCLUSIONS

With respect to measurement of the impact forces at the vertical wall due to breaking wave it was found that the maximum force can be treated as a random variable with the probability distribution of the Weibull type. The amount of the air entraped into breaking wave produce some inconsistency with Froude scalling law. Thus, the statistical concept of the scale effects was introduced.

The preliminary study of the wave impact on the horizontal plate sugests that the peak pressure and the slowly-varying part of pressure are functions of the Ursell's number.

It should be pointed out that the more efforts are needed to better describing of these complicated phenomena.

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