CHAPTER 192

PHYSICAL STUDY OF THE NATURE OF HIGH PEAK WAVE PRESSURES

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ABSTRACT

In order to investigate the generation mechanism of high peak wave pressures on vertical/steep walls two physical experiments are carried out on a specially constructed research apparatus. It is found from present experiments that the enclosed air volume as a physical medium under compression could not be a cause for the high peak short-period wave pressures. The wave breaking on a vertical wall is accompanied by cumulating of the wave energy and its redistribution on the smaller area of the wall and conditions for shock wave are created after the collision of the streams.

INTRODUCTION

During the breaking of a wave on vertical/steep walls or elements very short-period peak pressures have been recorded. There are experimental data which prove their importance about coastal and harbours works stability,(OUMERACI et al., 1992). But in the literature there are different and inconsistent physical hypotheses which should explain one and the same phenomenon - high peak pressure generating mechanism. These hypotheses have become a physical basis of different formulas for calculation of the wave loading on vertical walls or elements used in the designing and building of vertical structures. In this way insufficient study of the nature of high peak pressures has contributed to many failures of the vertical structures.

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The aims of this experimental study are: 1) to model breaking wave impact out of wave flume if we accept in advance that those basic assumptions of BAGNOLD, (1939) for the appearance of this type of high pressures are truth, namely a) the wave motion turns into translational motion; b) shortly before the impact the wave front is vertical and smooth; 2) to learn the quantitative effects of a entrapped air volume on the impact parameters.

PROCEDURE

The reasons to be investigated high peak pressures out of wave flume are: 1) the experiments carried out in a wave flume show that such kind of breaking wave impact, when the high peak short-period pressure appears, repeats very rarely even if there are the same wave parameters and the same geometry of the bottom at the approach of waves; 2) it is not possible to give in advance one exactly fixed air volume on the wall and to study its quantitative effect during breaking wave impact in a wave flume.

The experimental study is carried out on a specially constructed research apparatus, Fig. 1.

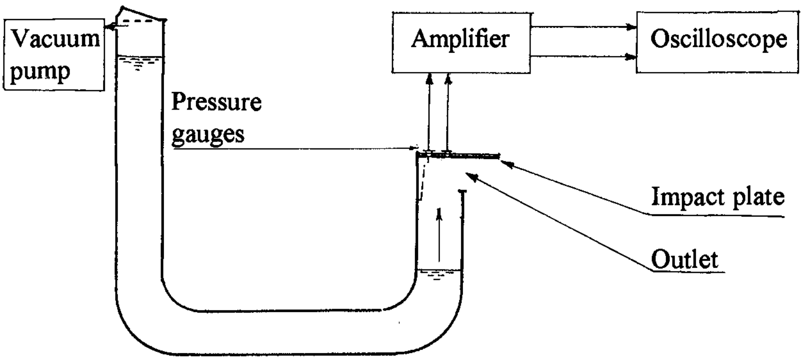

Fig. 1 Experimental set-up

One of the arms of "U"-shaped pipe is made of Plexiglas and has rectangular cross-section, which allows visual observation of the impact of the water column on a flat solid plate. Under the plate a water-air-outflow opening is left. Its dimensions are chosen in such a way that two requirements are met : 1) water column cross section remains the same until reaching the impact plate with velocity values from 0,8 to 1,5 m/s; 2) the spreading of a water hammer pressure is avoided.

The water column motion is a uniformly accelerated motion due to the head which is created beforehand by changing the pressure in one of the arms and instantly following equalising of that pressure. With this preliminary created head the water column velocity is regulated and it could reach the value of 1,5 m/s. At such velocity values in a wave flume, the high peak pressures at wave height of 6-10 cm has been registered, by SMIRNOFF, (1955) and RUNDGREN, (1958). The liquid mass taking part in the impact is 7,65 kg. The experiment is filmed by a high speed camera (4000 frames per second).

The research working program includes the following two physical experiments:

EXPERIMENT A: *Quantitative study of the entrapped air volume effect on the impact parameters: p, dp/dt and t, where p - hydrodynamic pressure; dp/dt - rate of pressure change; t - rise time.*

The air quantity is given preliminary. Under the impact plate in the side outlet plane a replaceable water-and airproof "threshold" is fixed. Its height D is given beforehand and varies from 0,06 H to 0,22 H , where H is the width of the water column, Fig.2.

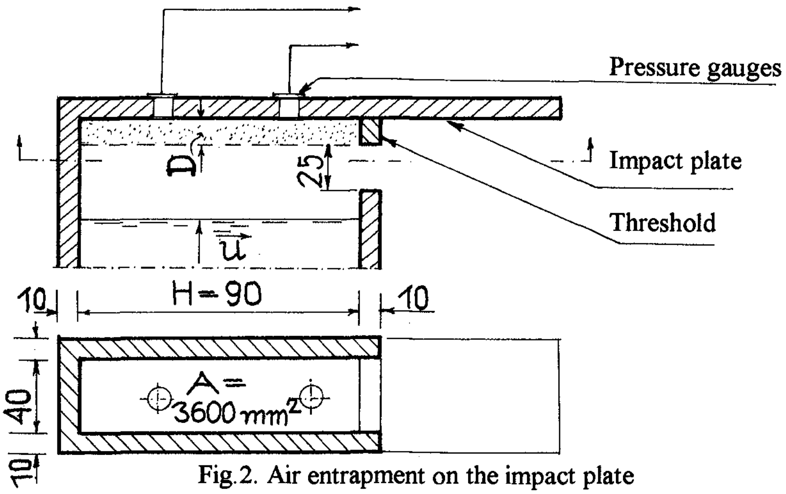

Fig.2. Air entrapment on the impact plate

In this way an air cushion with thickness equal to the threshold height and with a rectangular cross- section equal to that of the water column is created. The thickness of air cushion is as follows : D = 0,06 H ; D = 0,11 H ; D = 0,16 H ; D = 0,22 H. The pressures are measured in two locations by membrane resistor transducers (gauges) whose natural frequency is 2000 Hz and operating pressure range of up to 100 kN/m^2. The area of the membrane is 1 cm^2.

EXPERIMENT B: *Modelling of the wave front surface F motion during the breaking wave impact on a wall.*

The shape and velocity of the oncoming wave are known from the experiments in wave flume, (DENNY, 1951). By changing the geometry of the profile of the approach before the impact plate an analogous kinematic profile can be achieved. The pressures are measured in two locations before the entrapment of air cushion (G_1) and in the location of the air entrapment (G_2).

RESULTS

EXPERIMENT A

The recorded impact characteristics are shown in Fig.3.

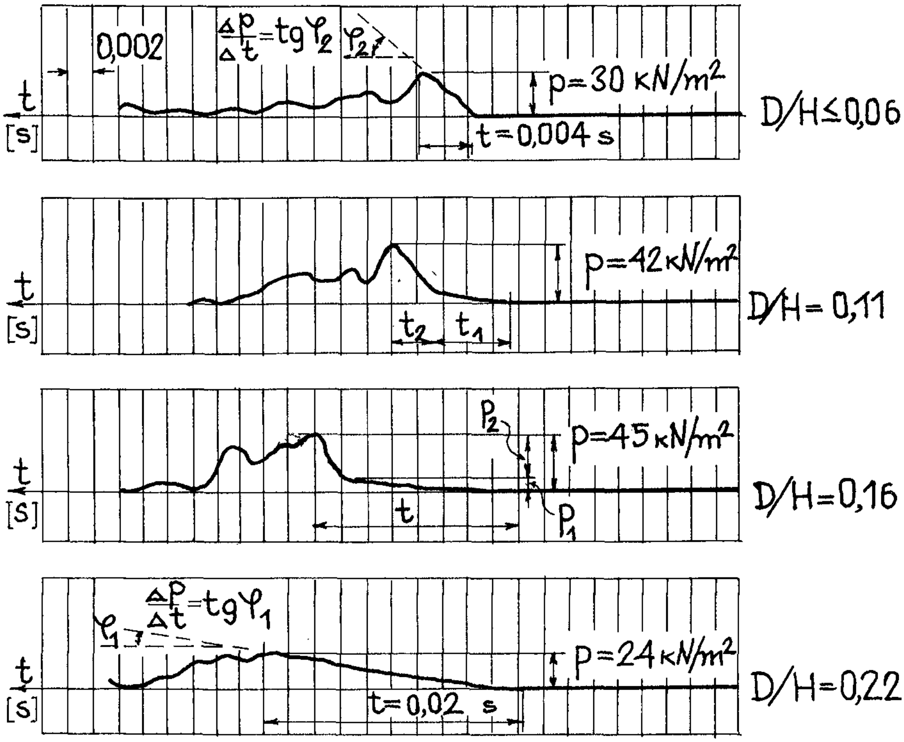

Fig.3. Effect of thickness of the entrapped air volume on impact parameters

The results could be divided in three different groups:

1. The effect of an air volume at D/H <= 0,06
2. The effect of an air volume at 0,06 < D/H < 0,22
3. The effect of an air volume at D/H >= 0,22

1. D/H <= 0,06. Compression of very thin air cushion.

During the impact the very thin air cushion is broken by the liquid to many small bubbles, which in practice do not reduce the kinetic energy of the water column. The pressure gauges do not catch the air compression of the small bubbles and register the impact pressure of the jets when the water gets in touch with the gauge membrane. Such insignificant small air quantities practically does not affect the character and the magnitude of the pressures.

2. 0.06 < D/H < 0,22. Compression of thin air cushion.

The rate of pressure change clearly shows two physical processes from which the maximum pressure value has been formed. The first part of the pressure is generated as a results from the air compression, but the second is indicated at the time of contact between the liquid and the impact plate. The rate of pressure change at the time of the contact of the liquid with plate is four times bigger than the one with the air compression. However, unlike the first case, during the compression of the continuous thin air cushion a loss of kinetic energy is almost not observed, Fig. 3. The resulting magnitude of the peak pressure in spite of the compression is increasing, Fig. 4

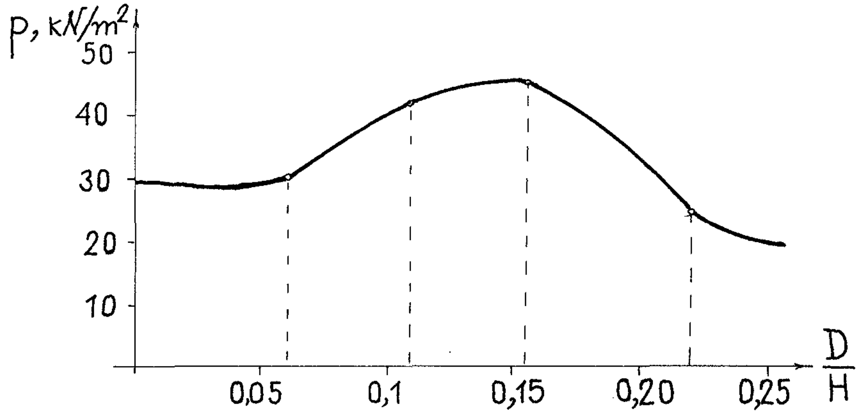

Fig. 4. Effect of dimensionless thickness (D/H) on magnitude of impact pressure

3. D/H >= 0,22. Compression of air cushion

At this thickness of the air cushion the pressure is due only to the air compression. Here the kinetic energy of running water is being reduced by the compression of the air cushion. The pressure magnitude is decreasing, Fig. 4. The rate of pressure change with air compression is nearly 4 times less of the same with a direct impact of the liquid.

From the experimental study described above the following conclusion about the quantity influence of the air volume could be made:

1). The pressure from the air compression is negligibly small with insignificant air volumes due to breaking of the air cushion into bubbles.

2). When the air cushion keeps continuous before it is broken, the pressure from the air compression is added to the pressure from direct liquid impact.

3). At bigger air volumes the water column does not reach the plate during the impact and the air cushion acts as a damper.

EXPERIMENT B

The research apparatus allows the motion of the wave front, which surface is designated here as F, to be simulated before and during the impact. By changing the geometry of the profile of approach before the impact plate and using a high speed camera a kinematical profile analogous to that of the wave front surface F motion in a flume (DENNY, 1951) is achieved, Fig. 5.

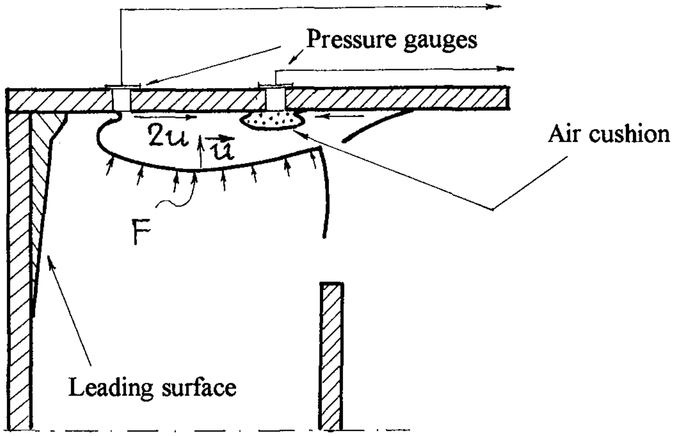

Fig. 5. Modelling of the wave front surface F motion

The Gauge 1 registers the pressure at the location where the water flow is deviated and accelerated upwards without air entrapment.

The Gauge 2 records the pressure where the air is entrapped, Fig. 6.

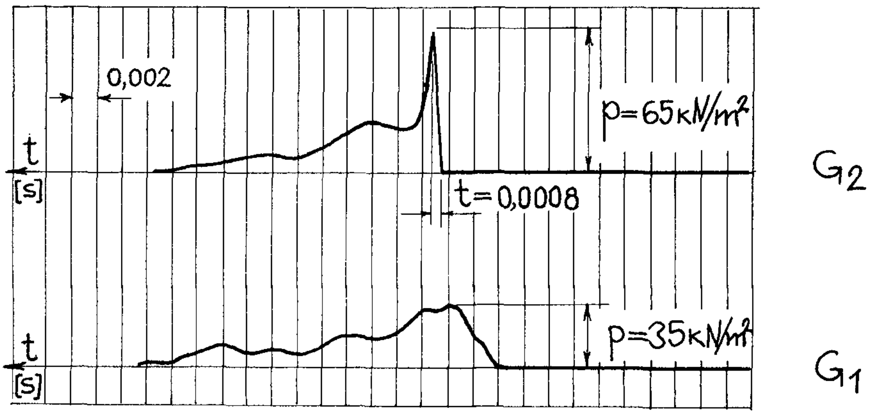

Fig. 6. Pressure-time records during the impact; G1: striking water column; G2: shock wave

The shape of the pressure curve obtained from Gauge 2 exactly repeats the records of high pressures in a wave flume made by numerous researchers (BAGNOLD, 1939; RUNDGREN, 1958; GODA & HARANAKA, 1967; PARTENSCKY, 1987; KIRGOZ, 1982; TAKAHASHI et al. 1994).

At the location of the entrapment of the air a counter stream appears and a free fluid issuing is strongly hampered. These conditions are of crucial importance for a shock wave to be created. It is confirmed from the record of Gauge 2 shown in Fig. 6 and after a comparison between the impact parameters from experiment A and experiment B, shown in Table 1.

Table 1. Comparison of impact parameters obtained from experiments A & B

Type of impact	u m/s	p kN/m^2	t s	dp/dt ($tg\varphi$) -
with air compression	1	24	0,02	0,14
water jet (column)	1	30	0,004	1
collision of streams and jets (shock wave)	1	65	0,0008	15

EXPLANATION OF THE GENERATION MECHANISM OF HIGH PEAK WAVE IMPACT PRESSURES

The physical experiments help to be established the following:

1. The enclosed air volume as a geometric space and a physical medium with density considerably smaller than that of water allows the focusing of the kinematical parameters vectors of the flowing liquid around the gas-liquid interface F.

2. The velocity values calculated using the data obtained with high speed camera are an experimental proof about the cumulative character of the wave flow rate during the breaking against the wall. The velocity of stream at the time of spilling on the plate is twice as much as the surface F velocity before its reaching the barrier. In physics the cumulative principle with water current motion is known, (LAVRENTIEV and SHABAT, 1977), (SLOBODETSKI and ASLAMAZOV, 1980). Its theoretical basis with waves breaking against a wall could be illustrated. If a water jet strikes a flat plate with velocity c, Fig. 7, the velocity values of both spilling jets on the plate are the same equal to c:

$$c_1 = c_2 = c \qquad (1)$$

and it is not dependent on the angle of attack θ .

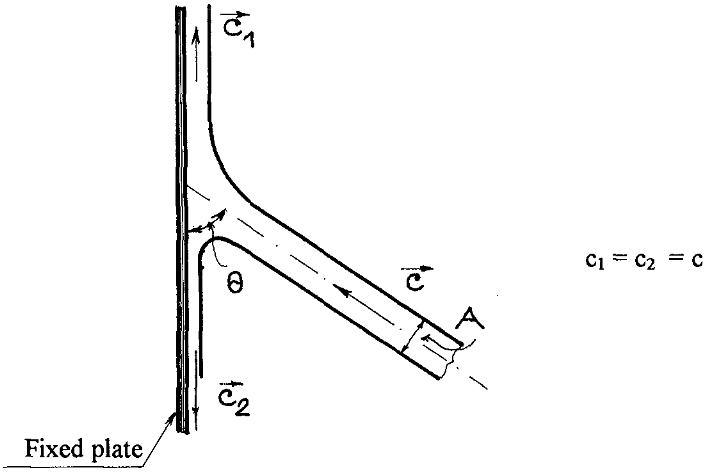

Fig. 7. Impact of a jet on a fixed flat plate

Now let examine this water mass of the wave which strikes the wall as it is shown in Fig. 8.

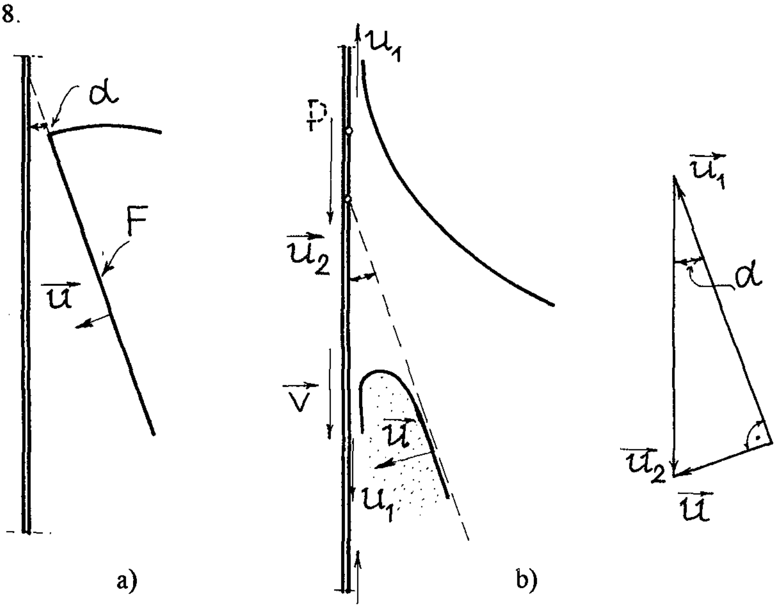

Fig. 8. Impact of a wave on a vertical wall

The velocity value of the front of wave respectively the water surface F before the impact ***u*** and the angle of attack between the wave front and the wall plane are known. Let find the stream velocity ***v*** with which it is spilling on the wall.

The velocity ***u*** could be shown by the vector equation

$$\vec{u}=\vec{u}_1+\vec{u}_2 \qquad (2)$$

where u_1 is the velocity component that is paralleled to the wave front and u_2 is the velocity of the cross point P of the wave front line and the wall line.
During the impact on the wall the velocity of the spilling stream is equal to the sum of both velocities

$$v = u_1 + u_2 \tag{3}$$

knowing that $c_1 = c_2 = c$.
The component velocities u_1 and u_2 could easily be found, ($u \perp u_1$).
Therefore $u_1 = u * \cot g\alpha$ and $u_2 = u/\sin\alpha$. Substituting these values in Eq. 3 gives

$$v = u \frac{1 + \cos\alpha}{\sin\alpha} \tag{4}$$

With small values of α, (such are made in practice) theoretically the velocity could reach values many times bigger than the velocity of the wave front before its contact with the wall. The same is the case considering the kinetic energy. The ratio of the energy per unit volume of such spilling stream on the wall $\rho v^2/2$ to the energy of moving water in the wave $\rho u^2/2$ is more than 1. When $\alpha = 10^0$, $v = 11u$,. $\rho v^2/\rho u^2 = 120$; at $\alpha = 2^0$, $v = 57u$, $\rho v^2/\rho u^2 = 3200$.

3. Due to the entrapped air space and the field of the velocities (as well as field of the accelerations) the wave energy is being distributed on a smaller area on the wall which is proved from both gauges indications. The cumulative character of the water stream motion on the wall contributes to the wave energy convergation. The stream which is moving vertically upward has started from the lower part of the wave. The counter stream is created by the impact of the wave crest. No matter the mass in the central part of wave (say in the form of striking jets) reaches the wall before or after the collision of these two streams. The possibility for spilling of water streams and jets disappears and after their collision a zone of high shock hydrodynamic pressure is created at the location of the entrapped air cushion.

CONCLUSIONS

1. The wave breaking on a vertical wall is accompanied by cumulation of the wave energy and its redistribution on the smaller area of the wall, and conditions for a shock wave are created at the collision of the streams and jets.
2. The closed air volume as a physical medium under compression could not be a cause for the high peak short-period wave pressures.

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REFERENCES

BAGNOLD, R.A.(1939). "Interim Report on Wave Pressure Research." Jour. of the Inst. of Civil Eng., Vol. 12. No. 7, pp. 202-226.
DENNY, D.K.(1951). "Further experiments on wave pressures." Jour. of the Inst. of Civil Eng., Vol.35, pp. 330-345.
GODA, Y. & HARANAKA, S.(1967). "An experiment on the shock pressure of breaking waves." Technical note of Port and Harbour Research Institute Ministry of Transport, Japan, No.32, pp. 3-18, (in Japanese). KIRKGOZ, M.S.(1982). "Shock pressure of breaking waves on vertical walls." J. WatWay, Port Coastal Ocean Div., ASCE 108, 81-95.
LAVRENTIEV, M.A. & SHABAT, B.V.(1977). Hydrodynamics problems and their mathematical models. Nauka Publishers, Moscow, 407 p.(in Russian).
OUMERACI,H., PARTENSCKY, H.W. & TAUTENHBAIN, E.(1992): "Breaking wave on vertical gravity structures." Pros. of the Second Int. Offshore and Polar Eng. Conf., San Francisco, USA, pp. 532-539.
PARTENSCKY, H.W.(1987). "Neue Bemessungskriterien für sennkrechte und geschuttete Weiienbrecher". Jahrbuch der Hafenbautechnischen Gesellschaft, Hamburg 42, 233-254.
RUNDGREN, L.(1958). "Water wave forces." Bull. No 54. Inst. of Hydraulics) Institute of Technology, Stockholm, Tekniska Hogskolan. 1-122.
SLOBODETSKI, I.S. & ASLAMAZOV, L.G.(1980). Problems on physics. Nauka Publishers, Moscow, 173p. (in Russian).
SMIRNOFF, G.N.(1955)."Pressure of breaking waves." Ph.D.- Thesis, Moscow Civil Engineering Institute, CIS, 138p, (in Russian).
TAKAHASHI, S., TANIMOTO, K., SHIMOSATO, K.(1994). "Dynamic response and sliding of breakwater caissons against impulsive breaking wave forces." Proc. of Int. Workshop on Wave Barriers in Deepwaters, Jan. 10-14, Port and Harbour Research Institute, Yokosuka, Japan, 362-399.