PHYSICAL MODEL FOR LABORATORY TESTING OF THE SUBMERGED WAVE ENERGY CAPTURING DEVICE

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The paper presents a physical model for testing the performances of a so called "submerged wave energy capturing device". This device is described in detail in a former paper and works on the basis of the pressure variations, induced at a given depth by the waves' free water level variations.

A reduced scale laboratory model of this device, having its original shape, would be practically impossible to be searched because of the great difficulties when changing the main determinant parameters (mass, elasticity, resistant force).

The paper presents a model whose shape was modified in order to obtain a much easier changing of those parameters, allowing an extended research of the required performances.

The paper explains in detail how the device was conceived and how it works and shows the possible practical applications.

This physical model was developed and tested in the Hydraulic Laboratory, belonging to the Department of Hydraulics and Environmental Protection of the Technical University for Civil Engineering in Bucharest.

The results and interpretation of some preliminary laboratory tests are also presented in the paper, the next step being a quantitative evaluation of the extracted wave's energy.

Keywords: wave energy, pressure variation, piston movement, oscillating system.

1. Introduction

The physical model presented in this article contains a patented practical idea, "*the submerged wave energy capturing device*", presented last year at the 8th Conference „DORIN PAVEL", held at the Bucharest Politehnica University (Tatu, 2014).

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The new solution presented in that paper has a completely different basis as compared with hundreds of existing proposals made all along the time and all over the world (Iulian,1994, Lazăr,1996 and many others), beingbased on the property of the waves to induce in the depth important pressure variations, having almost the same amplitude as the waves themselves.

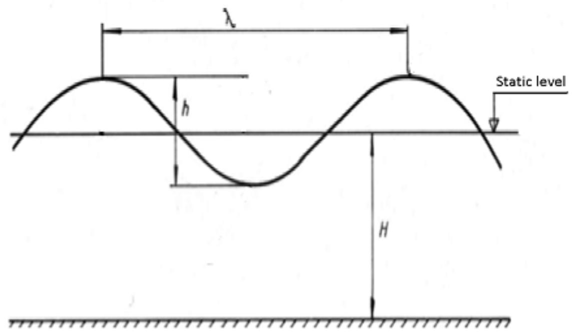

Fig. 1. Main wave's parameters.

A formula that is good enough for evaluating the pressure variation with the depth, validated by the theory but also by many experiments (Luca et al., 2002, Sorensen, 2006, Holthuijsen, 2007, Davidson-Arnott, 2010) is:

$$\Delta p_H = \pm \rho \cdot g \cdot \frac{\frac{h}{2}}{\mathrm{ch}\left(\frac{2 \cdot \pi \cdot H}{\lambda}\right)} \quad (1)$$

where (see also *figure 1*):

- Δp_H (*Pa*) is the pressure variation at the depth H (*m*);
- λ (*m*) is the wave's length;
- h (*m*) is the wave's height;
- ρ (*kg/m*^{3}) is the water density;

The amount of the pressure variation decrease is given by the hyperbolic cosine. As an order of magnitude, for λ=30 m, its dependence of the depth H is given in the table below.

Table 1.

H(m)	0	1	2	3	4	5
ch	1	1,022	1,089	1,204	1,372	1,6

The device, proposed also for an invention patent (Tatu, 2014), uses this property of the waves in a manner that allows getting many other advantages, as compared with the ones proposed before.

2.The device description

The device itself is extremely simple; it has the shape of a closed, watertight, empty box (filled with air) and has an elastic upper cover.

Figures 2 and 3 show two types of the device disposal, namely:

- in *figure 2* the cover itself is an elastic structure and the air inside is closed and contribute at the cover's elasticity;
- in *figure 3* the cover itself is inflexible and the air inside is maintained at the atmospheric pressure, througha pipe (*10*); its elasticity is assures only by a number of springs (*9*);

The box is set at a convenient depth and the variable pressure, acting on its cover, is producing, together with the reacting elastic force, a push-pull piston movement of the central rod (*4*), under a variable force, able to produce mechanical work, i.e. to convert the hydraulic energy of the waves into a mechanical one.

In the same time, the device is concentrating the low density energy of the waves (spread on the big entire surface of the box): the entire pressure force, exerted on the entire cover surface is concentrated in the central rod. This way, the wave's energy is converted into the mechanical one (and then in other kinds of energy) with a high efficiency.

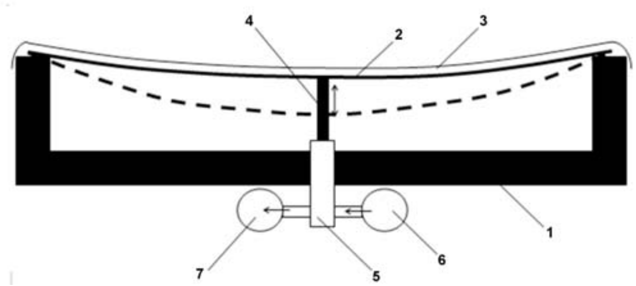

Fig. 2. Device disposal (1st type) (1 – box, 2 – elastic cover, 3 – waterproof foil, 4 – central rod and piston, 5 – cylinder, 6 – suction pipe, 7 – discharging pipe).

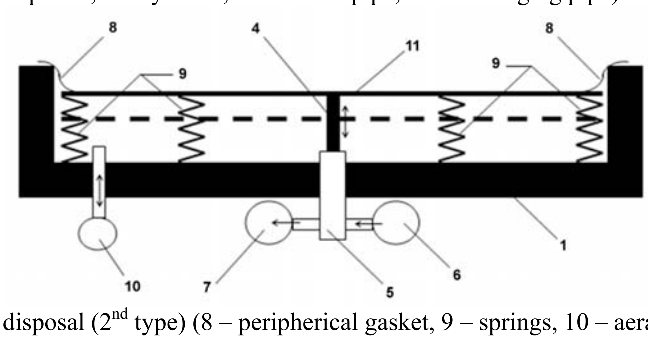

Fig. 3. Device disposal (2nd type) (8 – peripherical gasket, 9 – springs, 10 – aeration pipe, 11 – rigid moving cover).

The energy concentration is, just in fact, the main advantage of the proposed device, as compared with all those proposed before. It is an essential advantage, mainly for an industrial developing (in the past, just this low density of the waves' energy made the industrial application to be prohibited).

3. The physical model description

The performances of such a device depend, together with the waves' main parameters (*H, h, λ*), of the device's constructive characteristics themselves, such as:

- the elastic constant (*k*) of the elastic system (*9*), supporting the rigid moving cover (*11*) of the box (*1*);
- the mass (*m*) of the moving cover (*11*), i.e. it's *inertia*;
- the mass *m*, together with the elastic constant *k*, are defining the *own oscillation period* of the elastic system, a basic notion for an oscillating system $T = 2 \cdot \pi \cdot \sqrt{\frac{m}{k}}$;
- the resistant force (*Fr*) in the central rod.

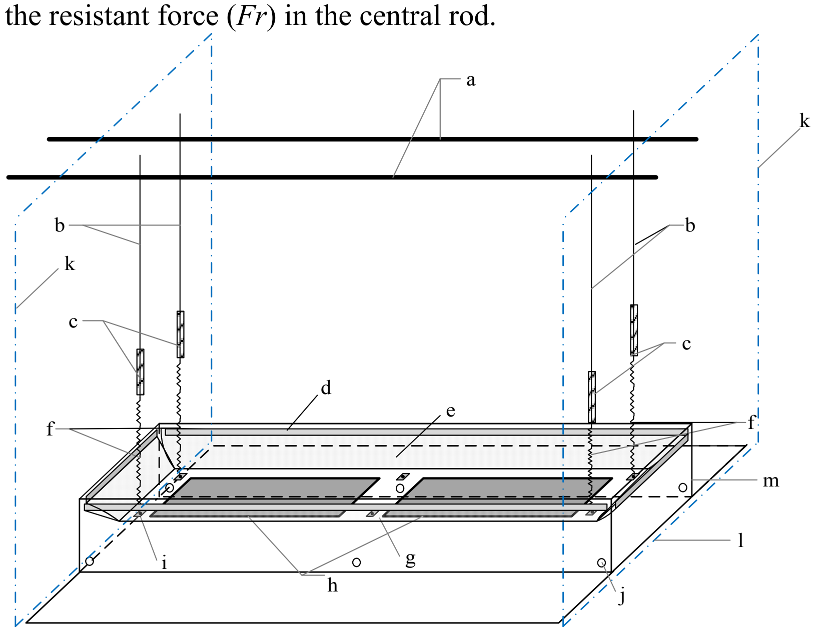

Fig. 4a. Physical model – 3D view.
a – transversal beam, b – tension rod, c – tightener, d – plastic foil grip, e – plastic foil, f – tension spring, g – moving cover, h – additional masses, i – spring hanger, j – orifice, k – channel wall, l – channel bottom, m – model box

To be studied in the wave channel of our laboratory, the physical model would have the possibility of an easily changing of all these parameters and the original shape of the device wouldn't allow it. Once the device sealed for enclosing the air inside, it would be very difficult to change the springs inside, the cover, the resistant force. Moreover, fixing the device on the bottom would represent a difficulty because of the great Archimedes floating force.

The physical model, specially conceived to allow easily changes of all those parameters is described below (*figures 4a, b, c and a* photoin *figure 5*).

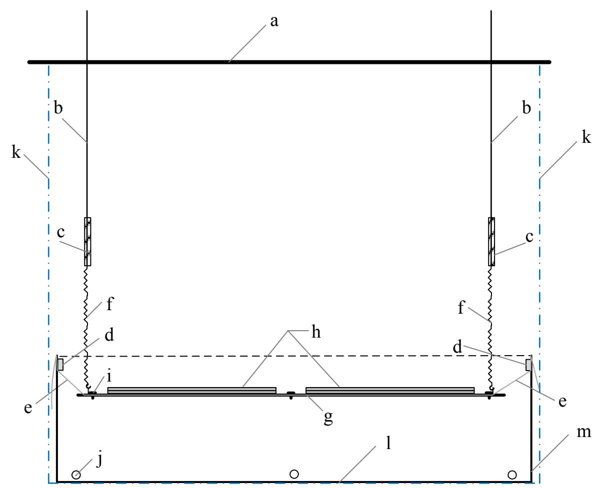

Fig. 4b. Physical model –cross section.

First of all, the entire elastic system, supporting the moving cover (*g*) is drawn out of the box, allowing changing the elastic constant *k* simply by replacing the springs, adding or removing them. No disassembling of the box is necessary.

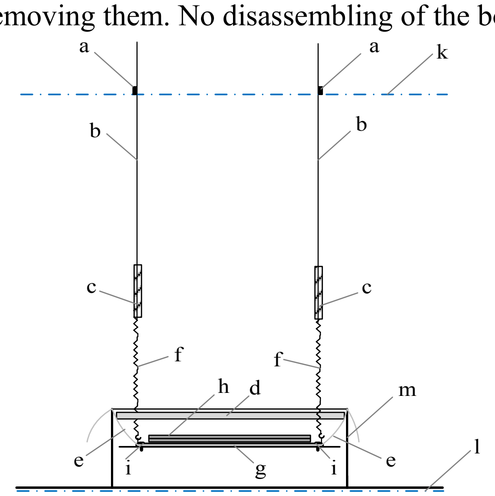

Fig. 4c. Physical model – longitudinal section.

Fig. 5. Physical model – photo.

Secondly, the mass *m* of the cover can be easily modified by setting additional masses (*h*) on the top of the cover.

Important advantages are due to the fact that the box is filled with water:

- there is no Archimedes floating force and then, no difficulties with setting it on the bottom of the channel;
- the plastic foil (*e*) must only separate the inside of the box of the outside one and it is not necessary to be completely tightened (not perfectly sealed).

The waves above the box are giving the cover a push-pull (oscillating) vertical movement, working as a piston for the water inside the box. The amplitude of this movement can be easily measured from the outside of the channel.

The orifices (*j*) on the both sides of the box allow the water in the box to be ejected out of the box or attracted inside it, in accordance with the piston movement of the cover. Attaching simple nozzles with different diameters to these orifices would generate different hydraulic resistances and, consequently, different resistant forces F_r.

4. Model designing

The main elements for dimensioning the model are shown in *figure 6*.

The water level is oscillating around the static level and the depth of the moving cover "*g*", corresponding to this level, is *H*. The height of the waves, between the maximum and the minimum level is *h*.

The upper face of the cover is supposed to a variable pressure between the limits $p = \gamma \cdot \left(H \pm \frac{h}{2} \right)$ while the lower one is supposed to a rather constant one, i.e. $p_0 = \gamma \cdot H$, grace to the damping effect of the small orifices "*j*".

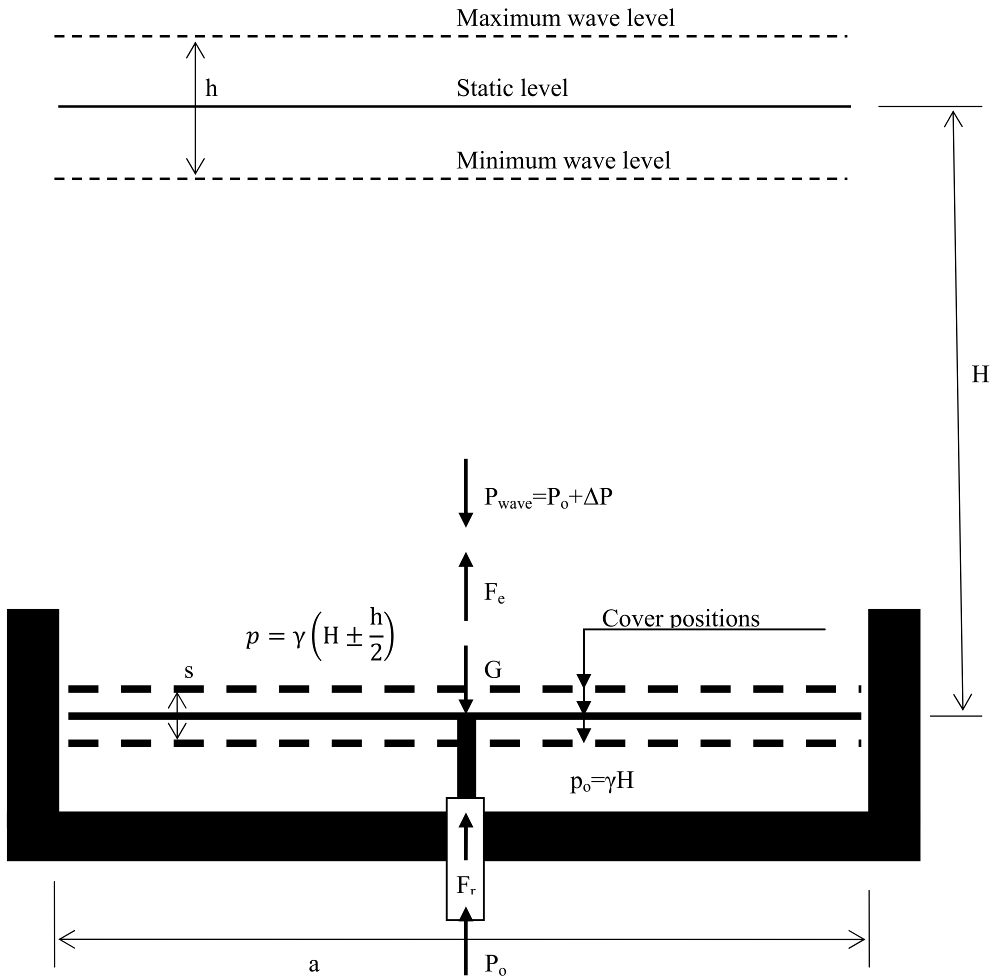

Fig. 6. Main parameters for the model designing.

The weight of the cover together with the additional masses *G* is tensioning the elastic springs, whose elastic constant is *k*, at an elongation *G/k* (the elastic force F_e is equal to *G*). So, the static (medium) position of the cover depends of the additional masses mounted on the cover. Using the tighteners *c*, this medium position can be preserved for different additional masses, in different test variants.

Considering *b* the other dimension (the width) of the box, the static pressure force, acting on the lower face of the cover (inside the box) is $P_0 = \gamma \cdot H \cdot a \cdot b$.

On the upper face of the cover, the pressure force is variable between the limits $P = P_0 \pm \Delta P$ where $\Delta P = \gamma \cdot \frac{h}{2} \cdot a \cdot b$.

So, the static pressure P_o is acting, with inverse senses, on the both sides of the cover. Considering no resistant force $(F_r=0)$, the resulting force remains the variable one $\pm \Delta P$, producing the cover displacement:

$$s = 2 \cdot \frac{\Delta P}{k} = \gamma \cdot \frac{h}{k} \cdot a \cdot b$$

The wave considered height was, in all variants, $h=0,2m$.

For the first variant of the model, its dimensions were: $a=1m$; $b=0,4m$.

Attending (without any resistant force) a cover displacement $s=8cm=0,08m$, the elastic hanging system would have the elastic constant

$$k = \gamma \cdot \frac{h}{s} \cdot a \cdot b = 10000 \, N/m$$

5. Some preliminary testing results and conclusions

Some preliminary measurementswere carried outin the Department of Hydraulics and Environmental Protection of the Technical University for Civil Engineering Bucharest.

In the Hydraulic Laboratory, there is a horizontal channel completely equipped for wave studies i.e. a wave generator at one end and a damping device at the other one. The width and height of the channel are*1 m*.

The water depth in the channel was set at*61cm*andthe waves had the characteristics presented in the following table:

As seen in the table, wave heights of about *20 cm* may be obtained at wave lengths of about *3 m*.

Table 2.

Wave characteristics in fixed slope channel.

Wave height h	Wave period T	Wave length λ
(cm)	(sec)	(m)
12	2,17	5,21
16,3	1,83	3,75
16,7	1,73	3,62

Wave height h	Wave period T	Wave length λ
(cm)	(sec)	(m)
17,4	1,59	3,54
18,5	1,55	3,15
18,8	1,49	3,09
19,4	1,47	2,93
22,6	1,39	2,82
23,8	1,35	2,59
24,2	1,29	2,49

The first dimension of the model box was equal with the channel width, i.e. $a=1m$.The second dimension of the box was chosen at the value $b=0,4m$, i.e. about *1/7,5* of the wave length

The cover was charged sequentially with two additional masses, *12 kg* and *16kg* respectively.

The main result of these first researches was a qualitative confirmation of the functioning principle of the device: the pressure variations transmitted in the depth by the waves do really produce the expected piston push-pull movement of the cover. For a resistant force whose value wasn't evaluated, the cover had mean displacements of $s=1,16cm$ and $s=1,48cm$ for the *12kg* and the *16kg* cover charging, respectively.

Another result, negative from a point of view but very instructive for the future, was that a parasite balancing ("see-saw") movement of the cover, around its mean line, was noticed. That's because the width of the box was too big as compared with the wave length ($b=0,4\ m=\lambda/7,5$) and the wave passage over the box had enough space to produce that movement. That is why, a new model is presently prepared with a width $b=0,2$ m i.e. $b=\lambda/15$, expecting to an important improvement of the cover movement.

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