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EXPERIMENTAL STUDY OF A MULTI LEVEL OVERTOPPING WAVE POWER DEVICE

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ABSTRACT

Results of experimental investigations of a floating wave energy device called Power Pyramid is presented. The Power Pyramid utilizes reservoirs in multiple levels when capturing wave overtopping and converting it into electrical energy. The effect of capturing the overtopping in multiple levels, compared to only one level, has been evaluated experimentally. From the experimental results, and the performed optimizations based on these, it has been found that the efficiency of a wave power device of the overtopping type can be increased by as much as 76 % by using 5 levels instead of 1. However, using 5 levels introduces practical problems, and is most probably not economically feasible. It is concluded that it is reasonable to use 2 levels (maybe 3), which can increase the efficiency by 25 - 40 % compared to using a single level.

INTRODUCTION

Since H. Tornager and P. Dybdahl proposed the Power Pyramid in 1998 investigations of the hydraulic performance have taken place at the Hydraulics & Coastal Engineering Laboratory, Aalborg University.

The idea of the Power Pyramid concept is to capture overtopped water in reservoirs in multiple levels. Fig. 1 shows the Power Pyramid in action. Such a structure with reservoirs in multiple levels increase the amount of captured energy but introduces also several structural challenges.

Kofoed and Frigaard (2000) performed a preliminary experimental investigation of the Power Pyramid in various irregular wave conditions in a 1:15 length scale. This investigation showed that the effect of introducing reservoirs in multiple levels, increase the power production compared to a similar device with only one reservoir, see Fig. 2. The results shown in Fig. 2 corresponds to an increase in the overall efficiency (on a yearly basis, for a placement in the Danish part of the North Sea) of ~50 %.

Based on the preliminary investigations of the Power Pyramid a more extensive parametric study was formulated. The efficiency of the Power Pyramid for varying number of levels and various placements of levels are investigated. The main object of the present paper is to quantify the effect of reservoirs in multiple levels. A set of formulae describing the vertical distribution of overtopping is established. The optimal placements of the reservoirs for various types of configurations are found based on these formulae.

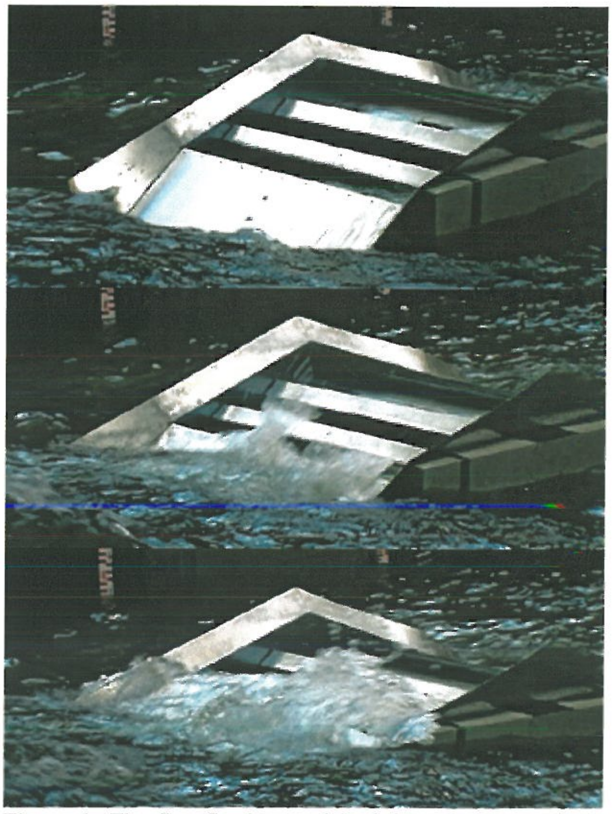

Figure 1: The first floating model of the Power Pyramid in action.

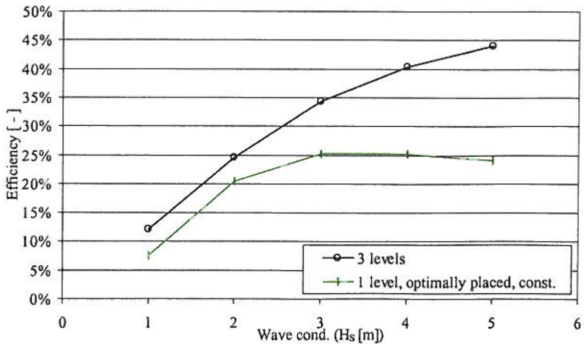

Figure 2: Comparison of efficiencies in various wave conditions for overtopping devices with 3 and 1 level, respectively.

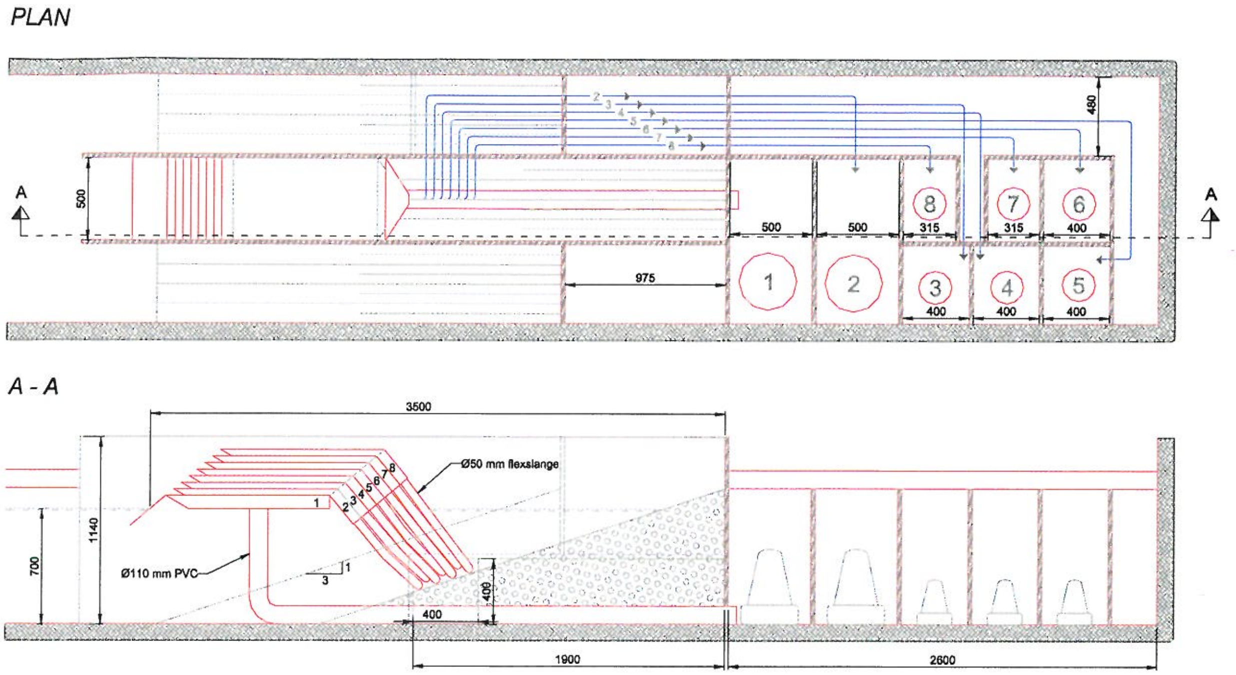

Figure 3: A sketch of the experimental setup in wave flume. Top: Plan view. Bottom: Cross sectional view. Measures are in mm, model scale.

MODEL TESTS

The tests focus on optimizing the geometrical layout of the front of the Power Pyramid. Therefore, a flexible model setup was designed and deployed in a wave flume at the Hydraulics & Coastal Engineering Laboratory, Aalborg University. The length scale in the model is 1:30.

Experimental setup

The model was build using a ramp with a limited draught, one fixed overtopping reservoir (the lowest one) and up to 7 reservoirs which relatively easily can be moved up, down, back and forth between the guiding walls. This enables easy testing of the several different geometrical setups. Each of the up to 8 reservoirs is connected to a larger tank. In Fig. 3 a sketch of the experimental setup is shown. Fig. 4 shows photos from the experimental setup. The size of each tank is determined from what level it is connected to - larger tanks to the lower levels, smaller tanks to the higher levels. Each of the 8 tanks is equipped with a pump – the larger tanks have larger pumps, smaller tanks have smaller pumps. The pumps have a capacity ranging from 0.5 - 35 l/s. Each of the tanks is also equipped with a level gauge connected to a PC. When the water level in a tank is reaching a maximum level the PC is sending a signal to a relay. The relay then starts the pump for a preset time and pumps the water back into the flume on the side of the tested structure as shown in Fig. 5. Since each of the pumps and level gauges is calibrated accurately it is possible to calculate the flow rate from each level to each tank. The time varying flow rate for each tank is recorded on the PC. However, in the following only the average flow rate for each tank is used.

Furthermore, the three wave gauges is placed between the guiding walls in front of the tested structure, see Fig. 5. The incident and reflected wave parameters are calculated using the method of Funke and Mansard, 1979, using these three wave gauges.

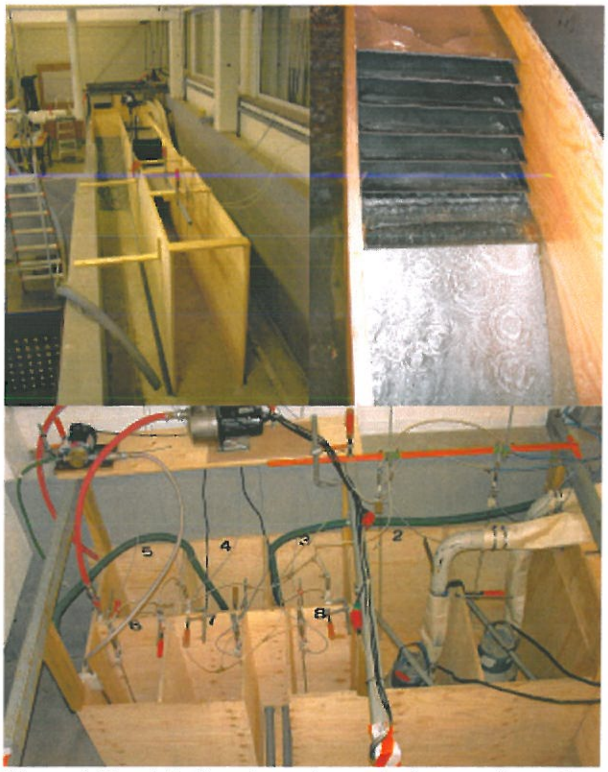

Figure 4: Top, left: Experimental setup in the wave flume. Top, right: Detail of the ramp and reservoirs placed in 8 levels, waves in action. Bottom: The overtopping water from each of the reservoirs is lead to separate tank equipped with pump and level gauge. The tanks are placed behind the tested structure in the flume.

Figure 5: Left: Wave gauges in front of the tested structure (note the limited draught of the ramp). Right: Pipes from the pumps emptying the tanks. Thus, the overtopping water is returned to the flume between guiding wall and sidewall of the flume.

Wave conditions

The tests are carried out using wave conditions typical for the Danish part of the North Sea. 5 wave conditions covering 88 % of the time is defined by The Secretariat of the Danish Wave Power Committee, 2000, These 5 conditions are given in terms of significant wave height H_S and wave peak period T_P, see Table 1. Furthermore, Table 1 also gives the probability of occurrence P_{occur} and the average wave power passing through a vertical cross section of the water column perpendicular to the wave direction P_{wave}.

Wave cond.	H_S [m]	T_P [s]	P_{occur} [%]	P_{wave} [kW/m]
1	1	5.6	46.8	2.4
2	2	7.0	22.6	11.9
3	3	8.4	10.8	32.2
4	4	9.8	5.1	66.7
5	5	11.2	2.4	119.1

Table 1: Wave conditions used in the performed model tests.

Wave conditions corresponding to $H_S < 1$ m occurs 11 % of the times, while $H_S > 5$ m occurs ~1 % of the time. These wave conditions are neglected when looking at the normal power production state.

Although an active wave absorption system is used, the target wave parameters have not in all cases been obtained exactly. The incident wave parameters found from reflection analysis of the wave measurements from the three wave gauges is used in the further analysis of the obtained data.

Tested geometries

The tests are performed using 8 reservoirs with an internal vertical distance $\Delta z = 1.35$ m (prototype scale). The ramp below the lowest reservoir is a linear slope with an inclination angle of 35°. Two different vertical distances from the lowest point of the ramp to the crest of the lowest reservoir is used, namely 9.00 and 12.00 m (note that the ramp is not extending to the seabed, as the results of the tests are to be used for a floating structure). Combining this with variations in the water depth d results in the combinations of the crest freeboards of the lowest reservoir, $R_{c,1}$, and draught of the ramp, d_r, given in Table 2. The term crest freeboard is used for the vertical distance from mean water level to the crest of the reservoir.

Series	d [m]	d_r [m]	$R_{c,1}$ [m]
A1	21.0	8.1	0.9
A2	20.4	7.8	1.5
A3	19.8	6.9	2.1
B	19.8	9.9	2.1

Table 2: Tested combinations of geometrical parameters.

The choice of geometries is based on the experience from Kofoed and Frigaard, 2000 and Kofoed, 2000.

RESULTS OF MODEL TESTS

Comparison with data from the literature

The results from the model tests are at first compared to existing results from the literature.

Van der Meer and Janssen, 1994, proposed an overtopping expression for non-breaking waves ($\xi_p > 2$) on straight, smooth and impermeable slopes. The expression has the form

$$Q = Ae^{-BR} \tag{1}$$

Q is the dimensionless overtopping rate defined as

$$Q = \frac{q}{\sqrt{gH_s^3}} \tag{2}$$

q is the overtopping rate [m^3/s/m], g is the gravity acceleration, R is the relative crest freeboard

$$R = \frac{R_c}{H_s} \tag{3}$$

ξ_p is the surf similarity parameter, corresponding to the wave peak period, defined as

$$\xi_p = \frac{\tan\alpha}{\sqrt{\frac{H_s}{L_p}}} \tag{4}$$

L_p is the wavelength corresponding to the wave peak period, A and B are constant coefficients found by best fit to be 0.2 and 2.6, respectively. Here, as in the rest of the paper, there is not distinguished between H_S and the spectral estimate of the significant wave height H_{m0}.

Kofoed, 2000, introduces two factors λ_s and λ_{dr} in eq. (2) in order to take low relative freeboard and limited draught into account. Eq. (2) is thus turned into

$$Q = \frac{q}{\lambda_{d_r}\lambda_s\sqrt{gH_s^3}} \tag{5}$$

where

$$\lambda_{d_r} = 1 - 0.4\frac{\sinh\left(2k_p d\left(1-\frac{d_r}{d}\right)\right) + 2k_p d\left(1-\frac{d_r}{d}\right)}{\sinh\left(2k_p d\right) + 2k_p d} \tag{6}$$

k_p is the wave number $2\pi/L_p$ and

$$\lambda_s = \begin{cases} 0.4\sin\left(\frac{2\pi}{3}R\right) + 0.6 & for \quad R < 0.75 \\ 1 & for \quad R \geq 0.75 \end{cases} \tag{7}$$

In the present study the situation is slightly different from the cases dealt with by Van der Meer and Janssen, 1994, and Kofoed, 2000. Overtopping was in these cases collected in only one level. Therefore, the overtopping rate q in (5) is set to the sum of the overtopping rates in each of the 8 levels q_n in order to be able to compare the results

$$q_{tot} = \sum_{n=1}^{8} q_n \tag{8}$$

Thus, it is assumed all overtopping is ending up in the lowest reservoir, i.e. the crest freeboard in eq. (3) is set to $R_{c,1}$.

The results from the performed tests are plotted in Fig. 6. It is seen from this graph that for low relative crest freeboards the agreement with Kofoed, 2000, is very good, while for higher relative crest freeboards the expression seems to overestimate the overtopping rate slightly. However, it should be kept in mind that the amount of overtopping at higher relative crest freeboards is very small which also means that larger scatter must be anticipated. So, all in all the measurements seems reasonable.

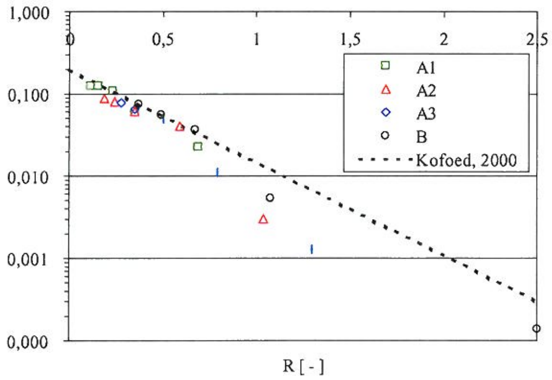

Figure 6: Dimensionless total overtopping (sum of all reservoirs) as a function of relative crest freeboard, compared to the expression given in Kofoed, 2000.

Vertical distribution of overtopping

The reason for performing tests with a relatively large number of reservoirs placed vertically close together is to gather information about the vertical distribution of the overtopping with a relatively good resolution. The goal is to establish an expression for the dimensionless derivative of the overtopping rate with respect to vertical distance, in the following named Q'. Inspired by the approach described above an expression for Q' is proposed

$$Q' = \frac{dq/dz}{\gamma_s \gamma_{d,r} \sqrt{g H_s}} = A e^{-B \frac{z}{H_s}} \tag{9}$$

z is the vertical distance to the mean water level.

In order to get estimates of Q' from the model tests, the following approximation is used

$$\frac{dq}{dz} \approx \frac{q_n}{\Delta z} \tag{10}$$

and $z = R_{c,n} + \Delta z/2$. n denotes the reservoir number, counted from bottom to top. In Fig. 7 Q' is plotted as a function of z/H_S.

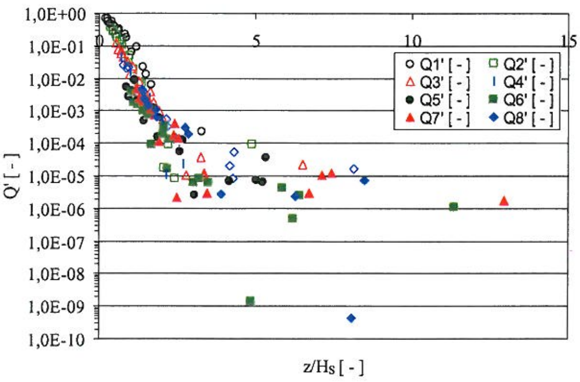

Figure 7: The dimensionless derivative of the overtopping rate with respect to vertical distance Q_n' plotted as a function of z/H_S.

From Fig. 7 it can be seen the data shows a clear trend for $z/H_S < 4$. For $z/H_S \geq 4$ a lot of scatter is present and the trend more or less disappears. However, the purpose of this study is to maximize the energy in the overtopping, and the overtopping rates (and thus also the energy contents) for $z/H_S \geq 4$ are very small. It is therefore considered fair (actually on the "safe side") to disregard the influence from data for $z/H_S \geq 4$ on a fitted expression for Q'. In Fig. 8 a zoom of Fig. 7 is shown, and a line representing a fitted expression for Q' is drawn as well.

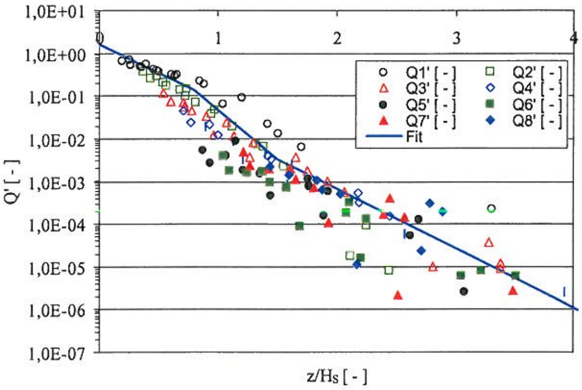

Figure 8: Zoom of Fig. 7. Data for $z/H_S \geq 4$ is truncated.

The line in Fig. 8 represents an expression for Q' based on eq. (9). However, the fitting coefficients A and B are not constant for all values of z/H_S but is given as piecewise linear functions of z/H_S by the expressions

$$A\left(\tfrac{z}{H_S}\right) = \begin{cases} 1.50 & \tfrac{z}{H_S} < 0.8 \\ -1.59\tfrac{z}{H_S} + 2.79 \quad \text{for} & 0.8 \leq \tfrac{z}{H_S} < 1.5 \\ 0.39 & 1.5 \leq \tfrac{z}{H_S} \end{cases} \tag{11}$$

$$B\left(\tfrac{z}{H_S}\right) = \begin{cases} 3.00 & \tfrac{z}{H_S} < 0.8 \\ 0.29\tfrac{z}{H_S} + 2.77 \quad \text{for} & 0.8 \leq \tfrac{z}{H_S} < 1.5 \\ 3.20 & 1.5 \leq \tfrac{z}{H_S} \end{cases} \tag{12}$$

Accepting this enables a numerical optimization of the vertical placement of the reservoirs.

OPTIMIZATION OF RESERVOIR CONFIGURATIONS

Now, for a given configuration of reservoirs an estimate of the power production of the Power Pyramid can be calculated using eq. (9). The procedure for this calculation is given in the following.

Calculation procedure

The overtopping rate for a single reservoir q_n can be found by integration of a reformulation of eq. (9)

$$dq/_{dz} = \gamma_s \gamma_{d_r} \sqrt{gH_s} A e^{-B\frac{z}{H_s}} \tag{13}$$

$$\begin{aligned} q_n(z_1, z_2) &= \int_{z_1}^{z_2} dq/_{dz}\, dz \\ &= \int_{z_1}^{z_2} \gamma_s \gamma_{d_r} \sqrt{gH_s} A e^{-B\frac{z}{H_s}} dz \\ &\approx \gamma_s \gamma_{d_r} \sqrt{gH_s^3} \frac{A}{B}\left(e^{-B\frac{z_1}{H_s}} - e^{-B\frac{z_2}{H_s}}\right) \end{aligned} \tag{14}$$

The content of power in the overtopping water for a single reservoir P_n [W/m] can be calculated using

$$P_n(z_1, z_2) = q_n(z_1, z_2) z_1 \rho_w g \tag{15}$$

ρ_w is the density of the seawater. For all reservoirs $z_1 = R_{c,n}$ and $z_2 = R_{c,n+1}$, except for the highest one. In this case $z_1 = R_{c,n}$ and z_2 is in principle infinite (set to a large value, say, the double of z_1).

The influence of the performance of turbine, it is anticipated to use for extraction of the power in the overtopping water, is paramount when dealing with wave energy devices of the overtopping type. The optimal vertical placement of reservoirs is most likely very dependent on the choice of turbines. However, it is not a part of the present study to find suitable turbines for the Power Pyramid. In order to roughly incorporate the influence of the turbine an idealized turbine characteristic has been assumed. An idealized turbine efficiency η_{turb} described by eq. (16) has been selected, Madsen and Frigaard, 2000. This choice is based on experience from a project regarding another wave power device of the overtopping type (Joule Craft project: JOR3-CT98-7027, *Low-Pressure Turbine and Control Equipment for Wave Energy Converters (Wave Dragon)*).

$$\eta_{turb}(z) = \begin{cases} \frac{z}{1.5} & for \quad 0 < z \le 1.5 \\ 1 & for \quad z > 1.5 \end{cases} \tag{16}$$

z is the pressure head [m]. Although the pressure head in reality will be dependent of the irregularity of the waves, the size of the reservoir (the area), the movement of the floating structure etc. it is set to $R_{c,n}$ in the following. This is the optimal, but not practically achievable, situation.

Thus, the total content of power in the overtopping water $P(H_S)$ for a single wave condition and a certain configuration of reservoirs can be calculated as the sum

$$P(H_S) = \sum_{n=1}^{no.of\ trays} P_n(R_{c,n}, R_{c,n+1}) \eta_{turb}(R_{c,n}) \tag{17}$$

As a measure of how well a certain configuration of reservoirs is working, an overall efficiency of the Power Pyramid η_{PP} is defined as

$$\eta_{PP} = \frac{\sum_{m=1}^{5} P^m P^m_{occur}}{\sum_{m=1}^{5} P^m_{wave} P^m_{occur}} \tag{18}$$

m indicates the wave condition referring to Table 1.

The presented procedure for calculation of η_{PP} is used to find optimal configurations of the Power Pyramid for varies numbers of reservoirs and various restraints on the minimum distance between the reservoirs Δz. A configuration is considered optimal when the maximum value of η_{PP} is found.

Results of optimization

Optimizations are performed for 1, 2, 3, 4 and 5 reservoirs. Furthermore, optimizations are performed with restraints on the minimum distance between the reservoirs, Δz, of 0.50, 0.75, 1.00, 1.25 and 1.50 m. In cases were the optimal configuration already meet the restraint on Δz, another optimization is superfluous and not carried out. The results of the optimizations are given in Table 2. P_{ave} in Table 2 is the average power production calculated as the summation above the fraction line in eq. (18). The fraction $\eta_{PP}^{opt.1} / \eta_{PP}^{current}$ in Table 2 expresses the improvement in the power production when comparing the current configuration to the configuration with one reservoir, optimally placed (conf. no. 1). For each of the optimizationss the optimal placement of the reservoirs are also given in terms of $R_{c,n}$. It is assumed that the crest of each reservoir is placed on the straight line defined by the overtopping ramp.

The results from Table 2 are also plotted in Fig. 9 and 10. From these it is seen that the efficiency η_{PP} is increased from 18.2 % to 31.9 % (a 75.7 % increase) by going from 1 to 5 reservoirs, if they are optimally placed. It can also be seen that introducing a restraint on Δz results in reductions in the efficiency.

So, if the goal is purely to get the maximal η_{PP}, one should obviously select to use as many reservoirs as possible. However, there are also practical and economical issues to be addressed. In the present study no detailed investigations of these issues are carried out. However, a configuration with 4 reservoirs with distance Δz = 1.0 m (conf. no. 14) seems to be close to the limit of what is practically and economically advisable. In this configuration the optimization results in crest level of the lowest reservoir $R_{c,1}$ = 0.50 m.

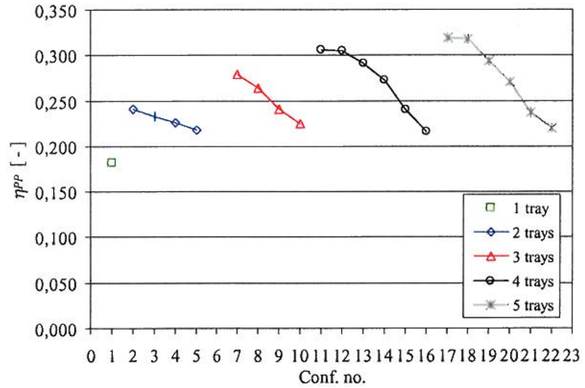

Figure 9: Results of optimization in terms of η_{PP} as function of configuration number. Based on Table 2.

Conf. no.	Configuration	No. of res.	$R_{c,1}$ [m]	$R_{c,2}$ [m]	$R_{c,3}$ [m]	$R_{c,4}$ [m]	$R_{c,5}$ [m]	P_{ave} [kW/m]	η_{PP} [-]	$\eta_{PP}^{opt.1} / \eta_{PP}^{current}$ [-]
1	Optimal	1	1.500					2.4601	0.182	-
2	Optimal	2	0.850	1.550				3.2526	0.240	1.322
3	min. Δz = 1,00 m	2	0.800	1.800				3.1416	0.232	1.277
4	min. Δz = 1,25 m	2	1.125	2.400				3.0513	0.225	1.240
5	min. Δz = 1,50 m	2	1.190	2.690				2.9422	0.217	1.196
6	Optimal	3	0.830	1.500	2.400			3.7924	0.280	1.542
7	min. Δz = 0.75 m	3	0.750	1.500	2.400			3.7756	0.279	1.535
8	min. Δz = 1.00 m	3	0.500	1.500	2.500			3.5629	0.263	1.448
9	min. Δz = 1.25 m	3	0.720	1.970	3.220			3.2594	0.241	1.325
10	min. Δz = 1.50 m	3	0.900	2.400	3.900			3.0267	0.224	1.230
11	Optimal	4	0.620	1.040	1.500	2.400		4.1458	0.306	1.685
12	min. Δz = 0.50 m	4	0.500	1.000	1.500	2.400		4.1214	0.304	1.675
13	min. Δz = 0.75 m	4	0.750	1.500	2.250	3.200		3.9484	0.292	1.605
14	min. Δz = 1.00 m	4	0.500	1.500	2.500	3.500		3.6853	0.272	1.498
15	min. Δz = 1.25 m	4	0.250	1.500	2.750	4.000		3.2599	0.241	1.325
16	min. Δz = 1.50 m	4	0.000	1.500	3.000	4.500		2.9279	0.216	1.190
17	Optimal	5	0.620	1.040	1.500	2.130	3.200	4.3235	0.319	1.757
18	min. Δz = 0.50 m	5	0.500	1.000	1.500	2.130	3.200	4.2991	0.317	1.748
19	min. Δz = 0.75 m	5	0.750	1.500	2.250	3.000	3.750	3.9706	0.293	1.614
20	min. Δz = 1.00 m	5	0.500	1.500	2.500	3.500	4.500	3.6580	0.270	1.487
21	min. Δz = 1.25 m	5	0.250	1.500	2.750	4.000	5.250	3.2133	0.237	1.306
22	min. Δz = 1.50 m	5	0.900	2.400	3.900	5.400	6.900	2.9667	0.219	1.206

Table 2: Results the optimization of the vertical placement of reservoirs in the Power Pyramid.

Conf. no.	Configuration	No. of res.	$R_{c,1}$ [m]	$R_{c,2}$ [m]	$R_{c,3}$ [m]	$R_{c,4}$ [m]	P_{ave} [kW/m]	η_{PP} [-]	$\eta_{PP}^{opt.14} / \eta_{PP}^{current}$ [-]
14	min. Δz = 1.00 m	4	**0.500**	1.500	2.500	3.500	3.6853	0.272	-
23	min. Δz = 1.00 m	4	**0.750**	1.750	2.750	3.750	3.5892	0.265	0.974
24	min. Δz = 1.00 m	4	**1.000**	2.000	3.000	4.000	3.4413	0.254	0.934
25	min. Δz = 1.00 m	4	**1.250**	2.250	3.250	4.250	3.2758	0.242	0.889
26	min. Δz = 1.00 m	4	**1.500**	2.500	3.500	4.500	3.0872	0.228	0.838

Table 3: Results of calculations of η_{PP} was also carried out for $R_{c,1}$ = 0.50, 0.75, 1.00, 1.25 and 1.50 m.

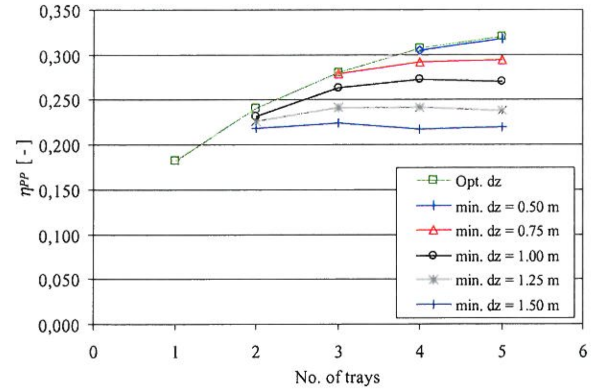

Figure 10: Results of optimization in terms of η_{PP} as function of number of reservoirs for various minimum Δz. Based on Table 2.

Calculations of η_{PP} is also carried out for $R_{c,1}$ = 0.50, 0.75, 1.00, 1.25 and 1.50 m in order to see the effect of increasing the crest level of the lowest reservoir (maintaining the same Δz = 1.00 m). The results of these calculations are given in Table 3 and Fig. 11.

$\eta_{PP}^{opt.14} / \eta_{PP}^{current}$ in Table 3 is the ratio between the efficiency for configuration number 14 and the current.

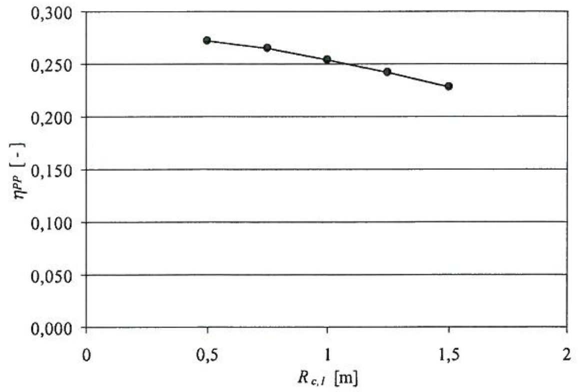

Figure 11: η_{PP} as function of the crest level of the lowest reservoir $R_{c,1}$ for 4 reservoirs with Δz = 1.0 m. Based on Table 2.

From Table 3 and Fig. 11 it can be seen that increasing $R_{c,1}$ from 0.50 to 1.50 m decrease η_{PP} with 14.2 %.

A comparison of configuration number 26 ($R_{c,1}$ = 1.50 m, 4 reservoirs, Δz = 1.0 m) and configuration number 1 ($R_{c,1}$ = 1.50 m, 1 reservoir) shows that introducing three extra reservoirs while maintaining the crest level of the lowest reservoir, results in an increase in η_{PP} of 25.5 %.

DISCUSSION

A number of issues are of great importance for the overall performance when designing a wave power device of the overtopping type. Some of the important ones are summarized below:

- Geometry of overtopping ramp.
- Configuration of reservoirs.
- Capacity of the reservoirs.
- Strategy for controlling the turbines.
- Characteristics of the turbines.
- The floating structure.

In the present study the focus is put on item number two. However, it is evident that there is heavy dependency between many of the mentioned issues. The dependency between the configuration of reservoirs and the characteristics of the turbines has already been touched upon. The question of capacity of the reservoirs is also closely connected to characteristics of the turbines and the strategy for controlling them. The goal when designing this part of the device is to avoid loosing some of the captured energy in the overtopping water by having a water level in the reservoirs significantly lower than the crest level. This is again in close connection with the design of the floating structure, as movements of the floating structure will entail the risk of spilling of water from the reservoirs. These questions have not been dealt with until now in the present study.

On top of all this come the economical and practical considerations. The following items can be mentioned as examples:

- The reservoirs should not be placed closer together than it is still possible for a person to access them.
- When selecting the number of reservoirs the increase in captured energy, by adding another reservoir, should be put in relation to the cost this addition.

A minimum Δz = 1.0 m could be a reasonable figure when considering the first item. If Δz = 1.0 m is assumed the increase in captured energy by adding reservoirs can be derived from Table 2. Going from 1 to 2 reservoirs (configuration number 1 and 3) results in an increase of 27.7 %, 2 to 3 (configuration number 3 and 8) gives 13.7 %, 3 to 4 (configuration number 8 and 14) gives 3.5 % and 4 to 5 (configuration number 14 and 20) gives -0.7 %. (The fact that this value is negative is an effect of the changing values of the A and B. In reality this just means that there is practically no effect of going from 4 to 5 reservoirs.)

It can be concluded from the figures mention above that it probably would be quite reasonable to use at least 2 reservoirs, maybe 3. But the increase in captured energy by going to 4 or 5 reservoirs are simply too small to pay what it will cost to build the necessary structures, extra turbines etc.

CONCLUSION

A series of model tests of a multi level overtopping wave power device have been carried out. The model was equipped with 8 reservoirs. A set of formulae was developed describing the vertical distribution of the overtopping. These formulae were utilized in an optimization of the vertical placement of the reservoirs. The optimizations were carried out assuming the number of reservoirs to be from 1 to 5, and the effect of applying restraints on the minimum vertical distance between two reservoirs was investigated. Furthermore, an investigation of the effect of changing the minimum crest freeboard for the reservoir, for a constant number of reservoirs and constant distance between them, was carried out. Some qualitative consideration regarding the design of an overtopping wave power device was also presented.

The conclusion of the presented work is that when designing an overtopping wave power device it seems reasonable to use 2 reservoirs (maybe 3, depending on cost). Doing so seems to increase the average power output of the device by 25 – 40 %, compared to a device with only one reservoir.

FURTHER WORK

So far only the effect of changing the vertical distance between the reservoirs, where the crests are moved up and down a straight line defined by the overtopping ramp was investigated. The effect of changing the horizontal placement of the reservoirs is currently being investigated using the same model setup. Tests of various designs of fronts on the each of the reservoirs are also being carried out in order to see if it is possible to achieve a higher energy output by these means.

Further investigations of the Power Pyramid by physical model tests using a floating model of the Power Pyramid in a multidirectional wave tank are currently being planned. Overtopping rates, as well as mooring forces and movements, will also be measured during these tests. A sketch of the anticipated principal layout of the floating model to be tested is shown in Fig. 12. The exact design of the model will not be decided until the model tests of the reservoir configurations is concluded.

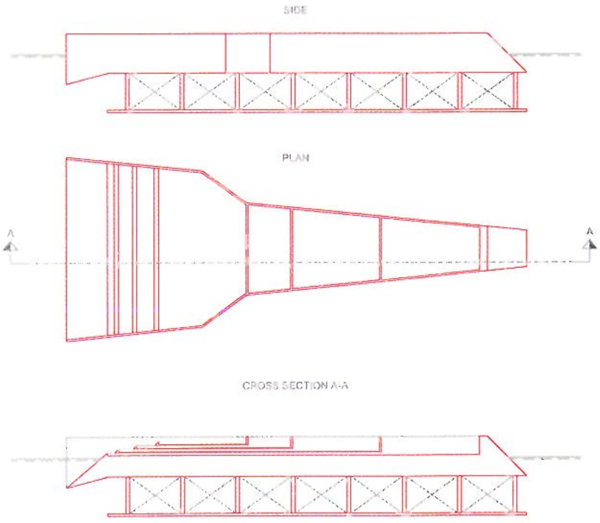

Figure 12: The anticipated principal layout of the floating model of the Power Pyramid to be tested.

Results from these investigations are expected to be available by the time of the congress and will presented if time allows it.

So far, it has been assumed that the Power Pyramid is floating at a certain level in all wave conditions, i.e. $R_{c,n}$ is constant once a reservoir configuration is selected. However, there is no doubt that an additional increase of the overall power production of the device can be obtained by adjusting the floating level of the Power Pyramid depending on the wave condition. I would be obvious to performed further investigation of this issue in the further development of the Power Pyramid.

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