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DESIGN OF AN ELECTRICAL HYDRO-PNEUMATIC STATION POWERED BY WAVES WITH HYDRODINAMIC AND FINITE ELEMENT SOFTWARE

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ABSTRACT

To convert wave action into useful energy, a power plant must provide a way for waves to drive something, such as hydro-pneumatic station. This system traps waves in a partially submerged, artificial chamber with a hole in one wall above the water line. The hole leads to an air-driven turbine. As the crest of a wave enters the chamber, it raises the water level quickly, pushing the air above the wave through the hole and spinning the turbine's blades. The turbine is designed to turn the same way no matter which way the air flows through his, so the machine also runs as the retracting wave sucks air back into the chamber.

In the paper are presented numerical results of the simulation of the oscillatory wave motion and the oscillatory airflow through the chamber and numerical results obtained with a finite element software for design the parts of an electrical hydro-pneumatic station powered by wave.

Keywords: wave energy conversion, oscillating water column, hydrodynamic finite element code.

1. INTRODUCTION

Fossil fuels are not renewable over the span of human generations, and their use may be increasingly limited by environmental concerns over global warming and acid rain.

To meet the energy needs of a growing world population, engineers in coming decades will be challenged to economically generate power from solar energy sources and ocean waves.

Despite the fact that nearby 75% of the Earth's surface is covered with water, waves are a largely unexplored source of energy, compared with the progress that has been in harnessing the solar energy and the wind energy. Until recently the commercial use of wave power has been limited to small systems of tens to hundreds of watts aboard generate power.

Oscillating water column (OWC) method is considered as one of the best techniques to convert wave energy into electricity. OWC is economically viable design due to it's simple geometrical construction and also strong enough to withstand against the waves with different heights and different wave periods and directions. The common design consists of a rectangular chamber and a pyramidal top which is installed on the top of the chamber. A conical duct is erected on pyramidal top to reciprocally move the air from the chamber and into the chamber during the process of wave approach and wave leaves the chamber. A special turbine which is mounted on top of the duct is subjected to turn at one direction as the airflow moves bi-directional. A generator is connect to the turbine to produce electricity by rotating it's armature shaft which is coupled with the turbine shaft.

2. THEORY OF WAVE ENERGY

The total wave energy can be calculated as the sum of the kinetic and the potential energy. The potential energy can be calculated through the formula:

$$PE = m \cdot g \cdot \frac{y(x,t)}{2}, \text{ [J]} \qquad (1)$$

where:

- $m = w \cdot \rho \cdot y$, [kg],: wave mass;
- ρ: water density, [kg/m3];
- w: wave width, [m], assumed equal to the width of the chamber;
- $y = y(x,t) = a \cdot \sin(kx - \omega t)$, [m]: the wave equation, assuming sinusoidal waves;
- $a = h/2$, [m]: wave amplitude
- h: wave height
- $k = \frac{2\pi}{\lambda}$: wave number;
- λ, [m]: wave length;
- $\omega = \frac{2\pi}{T}$, [rad/sec]: wave frequency;
- T: wave period.

The potential energy can be written as:

$$PE = w \cdot \rho \cdot g \cdot \frac{y^2}{2} = w \cdot \rho \cdot g \cdot \frac{a^2}{2} \cdot \sin^2(kx - \omega t) \qquad (2)$$

To calculate the wave potential energy over one period, it assumes that the waves are only a function of x and are independent of time, thus: *y (x, t) = y (x)* and:

$dPE = 0{,}5 \cdot w \cdot \rho \cdot g \cdot a^2 \cdot \sin^2(kx - \omega t) \cdot dx$, and so:

$$PE = \int_0^\lambda dPE = \int_0^\lambda \frac{1}{2} \cdot w \cdot \rho \cdot g \cdot a^2 \cdot \sin^2(kx - \omega t) \cdot dx = \frac{1}{2} \cdot w \cdot \rho \cdot g \cdot a^2 \cdot \left[\frac{1}{2} \cdot x - \frac{1}{4} \cdot \sin 2(kx - \omega T) \right]_0^\lambda$$

Considering that $k = \frac{2\pi}{\lambda}$ and $\omega = \frac{2\pi}{T}$, it obtains: $PE = \frac{1}{4} \cdot w \cdot \rho \cdot g \cdot a^2 \cdot \lambda$.

The total kinetic energy over one period is equal to the total potential energy:

$$KE = \frac{1}{4} \cdot w \cdot \rho \cdot g \cdot a^2 \cdot \lambda \qquad (3)$$

Eventually, the total energy over one period will be:

$$E_W = PE + KE = \frac{1}{2} \cdot w \cdot \rho \cdot g \cdot a^2 \cdot \lambda \qquad (4)$$

Through the energy definition, it can also calculate other useful quantities, such as the energy density, the available wave power and its respective density.

Energy Density: $E_{WD} = \frac{E_W}{\lambda \cdot w} = \frac{1}{2} \cdot \rho \cdot g \cdot a^2$, [J/m2];

Power: $P_W = \frac{E_W}{T}$, [W];

Power Density: $P_{WD} = \frac{P_W}{\lambda \cdot w} = \frac{1}{2T} \cdot \rho \cdot g \cdot a^2$

In the case of deep water, the dispersion relation becomes:

$\omega^2 = \left(\frac{2\pi}{T}\right)^2 = \frac{2\pi}{\lambda} \cdot g$ and $\lambda = \frac{g}{2\pi} \cdot T^2 \cong 1.56T^2$.

By applying the formula: $\lambda = 1.56T^2$ in the relations for the energy and the power, it obtains:

$E_W = 0.78 \cdot w \cdot \rho \cdot g \cdot a^2 \cdot T^2$,[J], and $P_W = 0.78 \cdot w \cdot \rho \cdot g \cdot a^2 \cdot T$, [W]

Finally, if we use the wave height instead of the wave amplitude, it obtains:

$$E_W = 0.195 \cdot w \cdot \rho \cdot g \cdot h^2 \cdot T^2 \text{, [J], } E_{WD} = \frac{1}{8} \cdot \rho \cdot g \cdot h^2 \text{, [J/m2] , } P_{WD} = \frac{1}{8T} \cdot \rho \cdot g \cdot h^2 \text{,[W/m2],} \quad (5)$$

In the case of electrical hydro-pneumatic station powered by waves, in these formulae, T and h are used as parameters. The water density, ρ, and the gravity constant, g, are known. The wave width, w, can be considered to be equal to the chamber width.

Eventually, E_W , E_{WD} , P_W , P_{WD} can be easily calculated using the above formulas.

3. FINITE ELEMENT SIMULATION RESULTS AND CONCLUSIONS

The case set – up was made using a structured mesh, as the domain for simulation and has the following dimensions length 16 meters and width 6 meters. The mesh used has 41800 cells and 42498 nodes. The setup problem concerning the geometry and case set –up of the simulation is presented in figure 1.

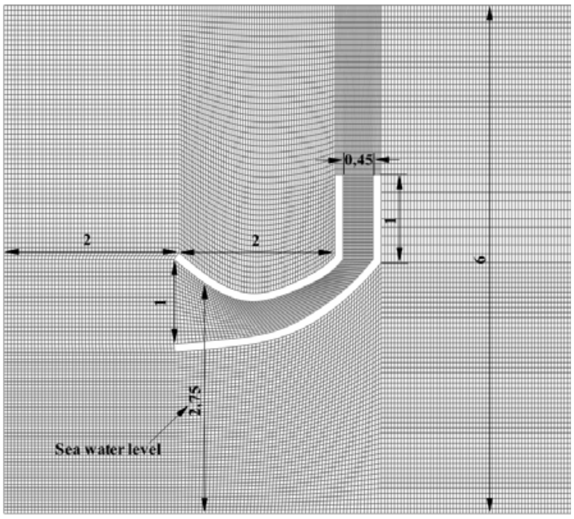

Figure 1. The finite elements mesh used in simulation, with some of the model dimensions in meters

For simulation was used a VOF model, and dynamic mesh. The time simulation used was of 12 seconds, with a variable time – step from 1e-6 seconds to 1e-4 seconds. In the following are presented some results from different time – steps.

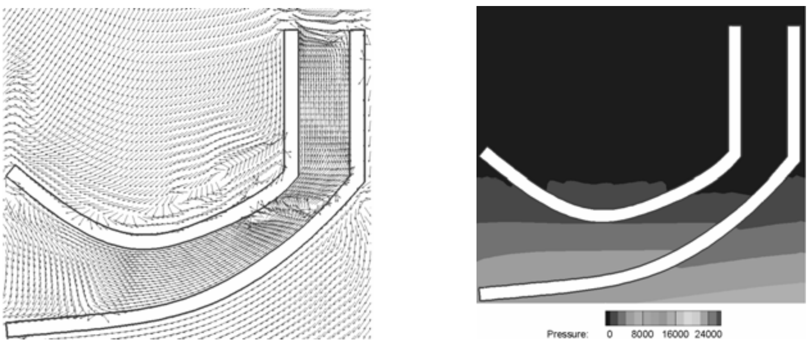

Figure 2. Velocity vectors(left) and pressure[Pa] contours (right) obtained using the dynamic mesh simulation at 2,691 time step

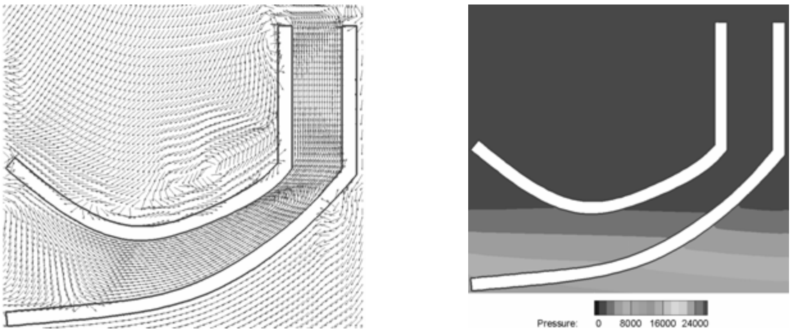

Figure 3. Velocity vectors field(left) and pressure[Pa] contours (right) obtained using the dynamic mesh simulation at 2,991 time step

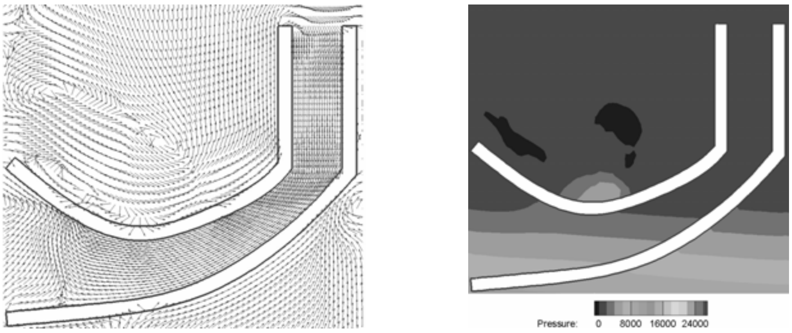

Figure 4. Velocity vectors field(left) and pressure[Pa] contours (right) obtained using the dynamic mesh simulation at 5,591 time step

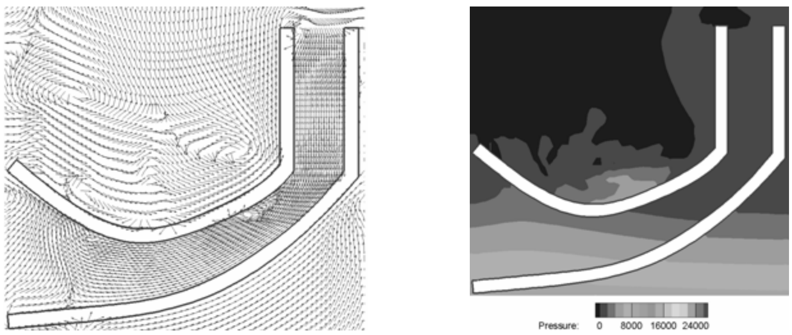

Figure 5. Velocity vectors field (left) and pressure[Pa] contours (right) obtained using the dynamic mesh simulation at 5,691 time step

As can be seen in fig.2 and fig.3, there is a decrease of pressure from step – time 2,691 to 2,991. Also the velocity vectors in the velocity vectors field are oriented toward the entrance. In the next presented time –steps (see fig.4 and fig. 5) can be seen a growth of the pressure from a step to another and the velocity vectors are oriented toward the output.
These results confirm the oscillation of column water and air with the needed velocities.

4. REFERENCES

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