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# Simulation of Static and Dynamic Behaviour of The Wave Energy Collector in Real Sea

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## Abstract:

*The pneumatic wave energy collector is a component of the wave power plant and its purpose is to transform the wave mechanical energy into electrical energy. The purpose of this paper is to show the outcome of our research concerning determining the distribution of wave pressure in the collector structure.*

*In a first part of our work we will present the Goda method to determine the pulsating wave loads. The basis of the Goda model is an assumed linear quasi-static and dynamic pressure distribution over the height and width of the caisson. With the concern of verifying the structure's resistance when hit by the waves in the Black Sea, we constructed the collector structure in Design Modeler (CAD model); the structure had been meshed and it had been determined displacement, strain and stress for the loads calculated.*

*In the second part a set of dynamic analyses had been conducted to determine the structure behaviour to harmonic loads. A modal analysis is conducted to determine natural frequencies and modal shapes. The analysis is made using Ansys Workbench 12.01.*

**Key words:** *wave energy collector, Goda method, static structural analysis, modal analysis.*

## Introduction

The pneumatic wave energy collector is a component of the electrical micro-plant (see Fig.1) and its purpose is to transform the wave mechanical energy into electrical energy; the wave hits the structure, the water seep in a chamber specially designed and compresses the air in the chamber [1]; the air moves a turbine coupling an electrical generator. Afterwards the process is reversed when water is exiting the chamber.

The chamber has two openings; the first is under the water surface and permits water to seep in; the later permits air circulation and it's placed above the water surface.

The process is based on water level variations in and outside the collector; these variations dictate the way pressure and volume of air vary through the collector.

The structure will be mounted in the Black Sea, where the multiannual wave system, as it was empirical measured and recorded on the SW coast, is characterized by:

| | |
| --- | --- |
| - the maximum significant height | 8.2 m |
| - the average multiannual significant height | 1.03 m |
| - the maximum average period | 9.8 s |

- the average multiannual period 3.9 s

Computations have been made using the average significant wave for the Romanian coast which has the following values:

- the average of maximum height 1.6 m
- the average wave period 4.58 s

The problem of fluid-structure interaction is relevant to possible violent slamming loads on walls. It is known that the impact loads are highly localized both in time and in space. The shape of the wave front just before the impact defines the impact type.

Four types of impact can be distinguished: 'Wagner-type impact', 'Steep wave impact', 'Bagnold-type impact' and 'Aerated fluid impact'. [2]

Wagner-type impact can be detected when the wave front is inclined from the wall. The second impact type corresponds to the case where the wave front is almost vertical before the impact and can be modelled as a hydraulic jump. In Bagnold-type impact the wave profile is inclined toward the wall, the wave is almost breaking and its upper part contacts the wall before the wave overturning with trapping an air cavity. The fourth case corresponds to spilling breaker when the wave breaks before arriving at the wall and the fluid is mixed with air around the impact region. Wagner-type impact and Bagnold-type impact are two detailed types of breaking waves. [3]

This paper describes the simulated behaviour of the collector for the static and dynamic loads induced by waves. First we will determine the loads on the structure using the height and wave period of the average significant wave for the Romanian coast. In case of pulsating wave loads we can use the model proposed by Goda. These loads were applied on the structure, along with the gravitational load of the superstructure. Afterwards, if needed, the shape would be optimized and the simulations run again to confirm changes.

Secondly, the optimized shape is subject to a modal analysis and results are shown and compared with the modal analysis of the original shape.

The modal analysis estimates the natural vibration frequencies of the given structure and can plot the modal shapes. These are compulsory before running any vibration analysis.

Furthermore, we applied a pre-stress modal analysis in order to determine the way that frequencies shift and the new modal shapes.

The CAD structure was designed in Design Modeller and the analyses were conducted in Ansys Workbench.

## Static structural analysis

Wave propagation on the surf zone is influenced by a complex pressure distribution, wind generated currents, water level variations and the existing coastal structures.

At present there are various numerical models to transform surf zone waves [4], [5], useful in practical engineering applications and research. The models are very different using different algorithms, input data and user control on the model.

Once the wave height and wave period in front of the structure are known, a model is needed to transform wave heights into loads on the structure. In case of pulsating loads, the model proposed by Goda can be used [5]. The basis of the Goda model is an assumed pressure distribution over the height and width of the caisson.

According to Goda this method is applicable to either breaking or non-breaking wave conditions. The superposition of quasi-static and dynamic pressure on the structure has a trapezoid distribution both under and above the water surface.

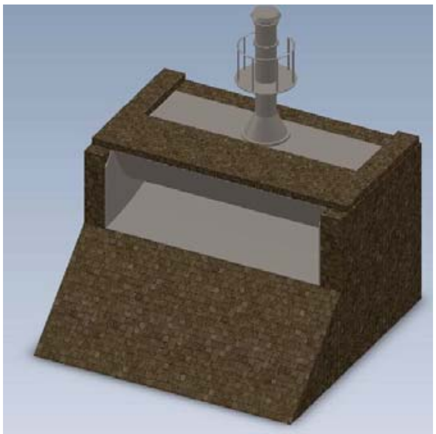


**Fig.1.** Hydro-pneumatic wave energy collector

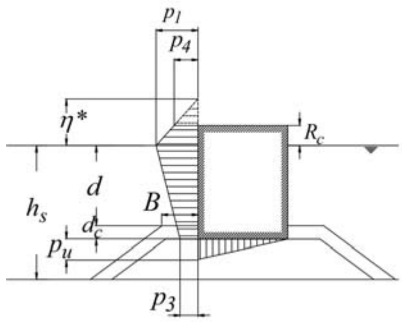



**Fig.2.** Pressure distribution according to Goda

Theoretical wave height $\eta^*$ and distribution pressures $p_1$, $p_3$, $p_4$, $p_u$ are determined with the following formulae:

$$\eta^* = 0{,}75 \cdot (1 + \cos\beta) \cdot \lambda_1 \cdot H_{max}, \tag{1}$$

$$p_1 = 0{,}5 \cdot (1 + \cos\beta) \cdot (\lambda_1 \cdot \alpha_1 + \lambda_2 \cdot \alpha^* \cdot \cos^2\beta) \cdot \rho \cdot g \cdot H_{max}, \tag{2}$$

$$p_3 = \alpha_3 \cdot p_1, \tag{3}$$

$$p_4 = \alpha_4 \cdot p_1, \tag{4}$$

$$p_u = 0{,}5 \cdot (1 + \cos\beta) \cdot \lambda_3 \cdot \alpha_1 \cdot \alpha_3 \cdot \rho \cdot g \cdot H_{max} \tag{5}$$

In which:

$H$: incident wave height in front of the structure;

$\beta$: angle of incidence of the wave attack with respect to a line perpendicular to the structure;

$\rho$: water density;

$g$: gravity;

$\alpha_1$, $\alpha_2$, $\alpha_3$, $\alpha_4$: multiplication factors dependent on the wave conditions and the water depth (see below);

$\lambda_1$, $\lambda_2$, $\lambda_3$: multiplication factors dependent on the geometry of the structure.

The α-factors are given by:

$$\alpha_1 = 0.6 + 0.5 \cdot \left( \frac{4\pi \cdot h_s / L}{\sinh\left(4\pi \cdot h_s / L\right)} \right)^2$$

$$\alpha_2 = \min\left( \frac{\left(1 - d/h\right) \cdot \left(H/d\right)^2}{3}, \frac{2 \cdot d}{H} \right)$$

$$\alpha_3 = 1 - \left( \frac{d + d_c}{h} \right) \cdot \left( 1 - \frac{1}{\cosh\left(2\pi h / L\right)} \right)$$

$$\alpha_4 = 1 - \frac{R_c^*}{\eta^*}$$

In which:

$h_s$: water depth in front of the structure;
$L$: wave length;
$d$: depth in front of the structure;
$d_c$: height over which the structure protrudes in the rubble foundation
$R_c^*$ : $min(R_c, \eta^*)$

With notations given in Fig.2, dimensions for the structure are the following:

$h=4m$, $h'=2.5m$, $d=1.5m$, $d_c = 1m$, $R_c = 1m$, $B=6m$, $l=5m$, $tg\theta = 1/100$, $\beta = 15^o$.

To simulate the collector structure it is interesting to observe three situations: two loads using the average wave in the Black Sea and the third load using the maximum (highest) wave in the last 50 years which occurred in 1981($H_{max} = 22{,}08m$, $T_{max} = 8{,}3s$, $L_{max} = 100m$).

The computed pressure loads for the three cases are presented in the table below:

***Table 1:*** Multiplication factors and pressures using Goda model

| Load situation | $\eta^*$ [m] | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | $\alpha_4$ | $p_1$ [kPa] | $p_3$ [kPa] | $p_4$ [kPa] |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Load 1 | 2,50 | 0,68 | 0,267 | 0,7 | 0,6 | 15,61 | 10,92 | 9,36 |
| Load 2 | 3,98 | 0,75 | 0,673 | 0,634 | 0,748 | 36,77 | 23,31 | 27,53 |
| Load 3 | 32,44 | 0,95 | 0,136 | 0,918 | 0,969 | 234 | 214,81 | 226,74 |

Besides the wave load, the structure is loaded with concrete on the structure as shown in Fig.4 *($p=25\ kN/m^2$).*

Limit conditions on the structure:

- superior side is free;
- lateral sides are frictionless support type;
- inferior side is fixed support.

In the first scenario we will go for the first load situation and see the results.

The mesh was created under the sweep method and has 72551 nodes and 11430 elements (see Fig.3). The load defined on the structure consists in the fixed support, the wave load and the gravitational loads generated by the concrete and the superstructure (on the top of the collector).

The material used is a structural steel, with the following properties:

***Table 2:*** Material Data

| | |
|---|---|
| Density | 7850 kg m^-3 |
| Compressive Yield Strength | 2.5e+008 Pa |
| Tensile Yield Strength | 2.5e+008 Pa |
| Tensile Ultimate Strength | 4.6e+008 Pa |
| Young's Modulus | 2.e+011 Pa |
| Poisson's Ratio | 0.3 |

Results from this case are given in the following pictures:

Looking at Fig.5 one can see that maximum total deformation reaches 1.11 metres and there is no need to continue with the next cases. Thus we will have to make an optimization of the structure. In order to lower the stress (Fig.6) we created 2 frames positioned such as to divide the front face in three equal pieces. The structure was re-evaluated with the same load distribution (Fig.7). The material is the same, but the mesh has 60860 nodes and 26719 elements. In Fig.8 are represented the results for the second loading situation; the stress plots are omitted as the obtained values are negligible.

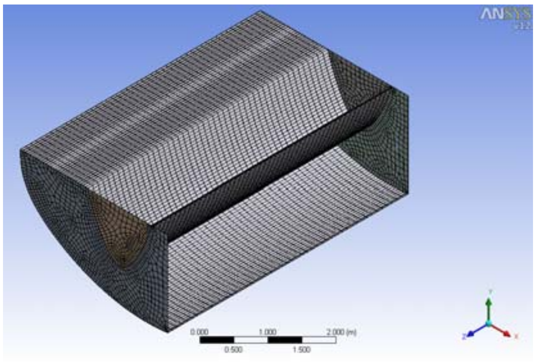


**Fig.3.** Sweep method mesh

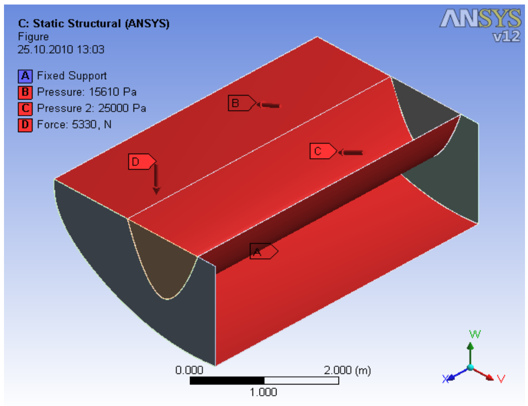



**Fig.4.** Load distribution on the structure

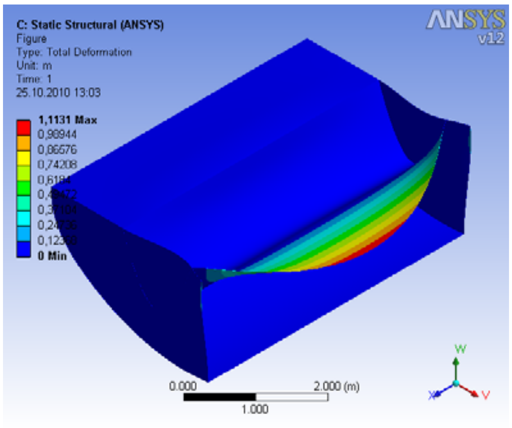



**Fig.5.** Total Deformation (Load1)

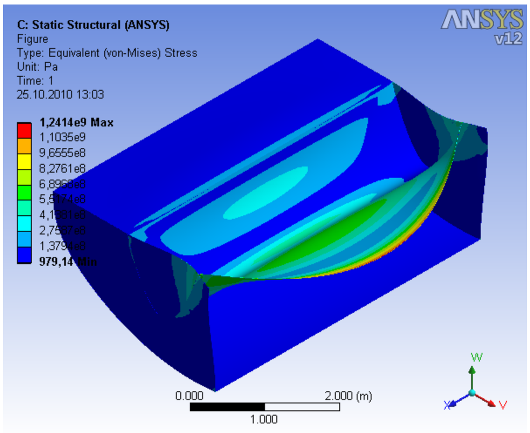
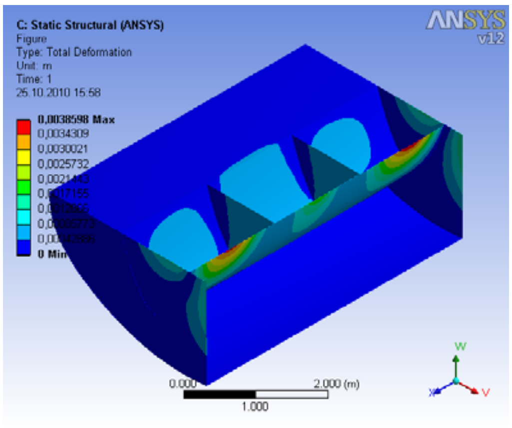



**Fig.6.** Equivalent Stress (Load1)



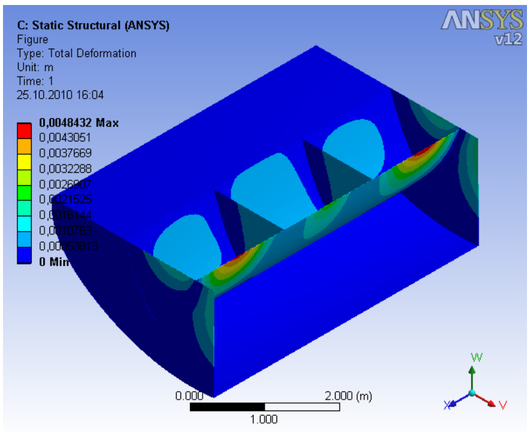




**Fig.7.** Deformation for optimized structure (Load1) **Fig.8.** Deformation for optimized structure (Load2)

We can see the improvement of the behaviour after the optimization: before the frames were added total displacement reached a maximum of 1.11 metres and afterwards only 3.8 mm for the same load distribution.

## Linear dynamic vibration simulation

The study of structural dynamics is critical for understanding and evaluating the performance of the energy collector. Usually, vibration analysis begins with a modal analysis that estimates the natural vibration frequencies and shape modes of the given structure. The frequencies of the structure can be determined from an unloaded state or from a loaded structure, as loads may shift the frequencies.

In this paper we will present the results obtained from the modal analysis conducted on the optimized shape of the collector using. The analysis is with pre-stress as the structure is permanently loaded by the concrete weight which is identical with that from static structural analysis.

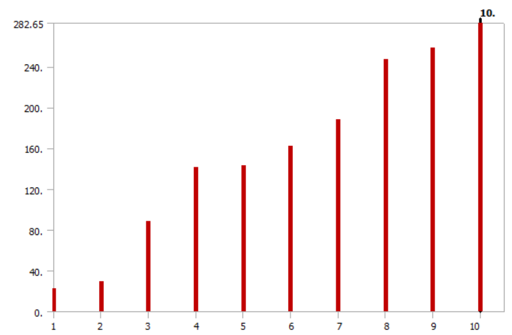
On the collector it was added the superstructure which contains the turbine. Once the model changed, the mesh was updated and it has 66967 nodes and 27060 elements

We determined the first ten natural frequencies and shape modes. The results are represented bellow.

The simulation was conducted using the Modal Analysis from Ansys Workbench.

***Table 3:*** First ten natural frequencies and their representation

| Mode | Frequency [Hz] |
|---|---|
| 1. | 22.631 |
| 2. | 29.132 |
| 3. | 88.762 |
| 4. | 141.23 |
| 5. | 143.42 |
| 6. | 162.17 |
| 7. | 188.39 |
| 8. | 247.29 |
| 9. | 258.5 |
| 10. | 282.65 |




It can easily be noticed that the first ten natural frequencies are well over the wave frequencies, which do not pass 1-2 Hz. Therefore the structure will never be found in resonance with waves.

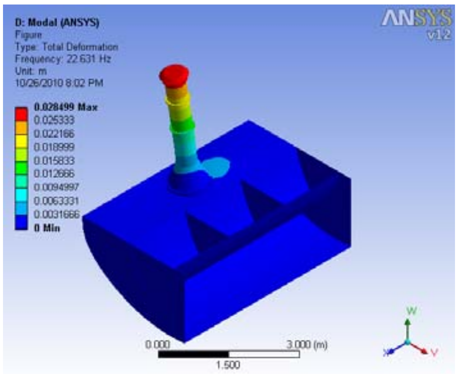



**Fig.9.** Mode 1

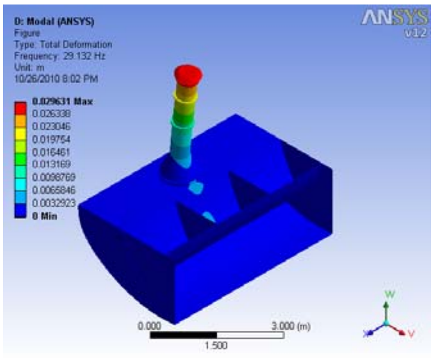



**Fig.10.** Mode 2

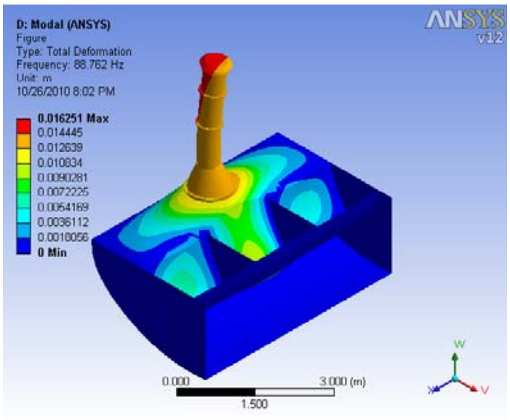



**Fig.11.** Mode 3

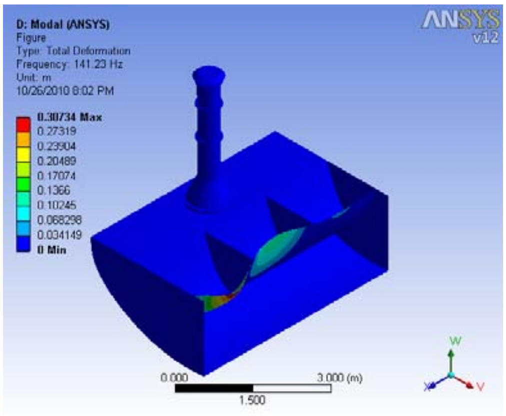



**Fig.12.** Mode 4

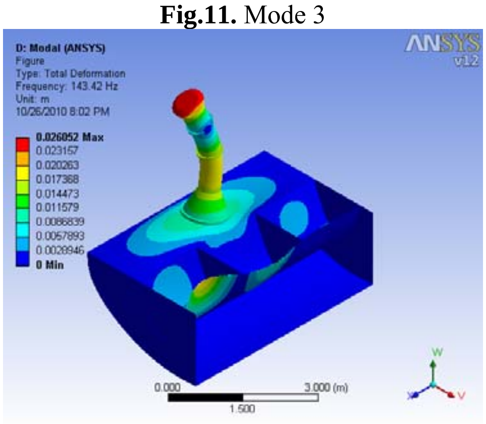



**Fig.13.** Mode 5

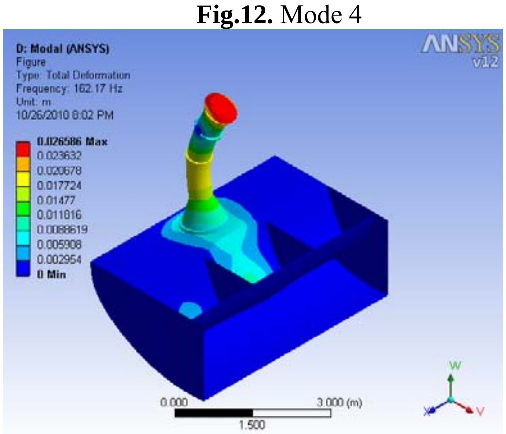



**Fig.14.** Mode 6

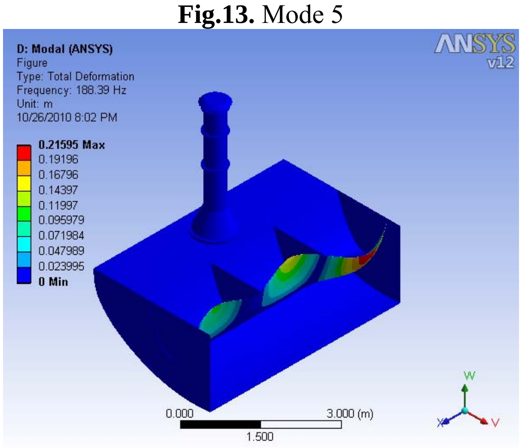



**Fig.15.** Mode 7

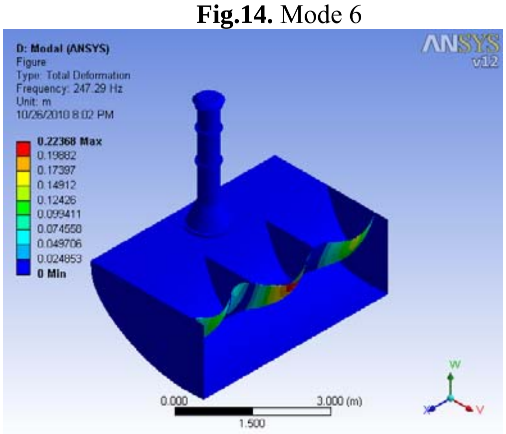



**Fig.16.** Mode 8

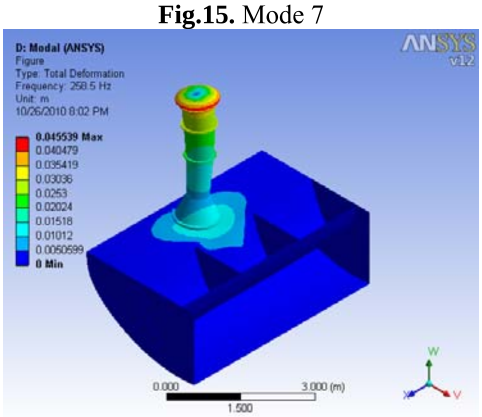



**Fig.17.** Mode 9

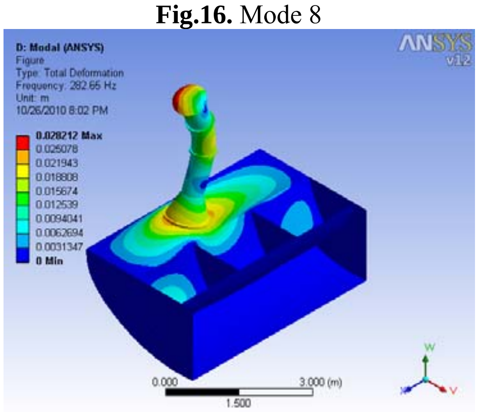



**Fig.18.** Mode 10

## Conclusions

In the conditions of wave characteristics in the Black Sea, stress and displacement states are acceptable from the view of elastic resistance and exploiting conditions.

The water level influence on stress and displacement is insignificant, but it influences more the hydraulic regime of the pneumatic chamber and collector's efficiency.

The most affected area is the superior part of the chamber where there is a large quantity of concrete which affects stress and displacement; this can be seen comparing stress and displacement in load 1 with those from load 2; stress and displacement on the inferior and lateral sides of the structure are minor due to construction.

On the other hand from modal analysis we learned that first ten natural frequencies are well over the wave frequencies, which means that the structure is safe from resonance with waves.

The mode shapes describe the structure elements that are most affected by certain frequencies; and can be noticed that the less affected are the lateral sides; therefore collector's efficiency will not be reduced. Displacements are conventional, but the mode shapes give enough information about the most dangerous frequencies for the structure.

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# Simularea comportamentului static şi dinamic al captatorului de energie a valurilor în mare reală

## Rezumat

*În cadrul acestei lucrări sunt prezentate două aspecte ale studiului efectuat asupra unui captator de energie a valurilor. Captatorul face parte din microcentrala de captare a energiei valurilor având ca scop transformarea energiei mecanice în energie electrică.*
*În scopul de a determina distribuţia presiunilor din val asupra captatorului şi comportarea acestuia, am realizat o analiză statică structurală şi o analiză dinamică.*
*În prima parte, folosind datele multianuale ale înălţimii şi perioadei medii a valurilor, am făcut o estimare a presiunii valurilor folosind metoda numerică a lui Goda. Această metodă presupune că distribuţia presiunilor pe un perete este liniară şi are o formă trapezoidală, indiferent de tipul valului.*
*Analiza statică a fost realizată folosind softul Ansys(Workbench); după realizarea analizei se optimizează structura şi se refac calculele.*
*Cu structura modificată se realizează apoi o analiză modală pentru a vedea dacă frecvenţele naturale au valori apropiate de cele ale valurilor de impact.*