Mechanical behavior analysis of a submerged fixed point anchoring system for a hydroacoustic signature measuring sensor for divers and ships

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Abstract. The paper has as its main objectives the presentation and the analysis of the numerical analysis results for the study of a fixed point anchoring system for a hydroacoustic sensor when measuring the hydroacoustic signature of divers and ships in real sea conditions. The study of the mechanical behavior of this system has as main objectives the optimization of the shape and weight of the anchorage ballast for the metallic structure while considering the necessity to maintain the sensor in a fixed point and the analysis of the sensor movements and the influences on the measurements caused by the sea current streams. The study was focused on the 3D model of metallic structure design; numerical modeling of the water flow around the sensor anchoring structure using volume of fluid analysis and the analysis of the forces and displacements using FEM when needed for the study. In this paper we have used data for the sea motion dynamics and in particular the velocity of the sea current streams as determined by experimental measurements that have been conducted for the western area of the Black Sea.

1. Introduction
Diver and ship hydroacoustic signature is a high importance data which must be known for recognition. For this reason there is a need to create a database for these types of acoustic signatures. To measure these hydroacoustic signatures, it is needed to mount some sensors on the bottom of the sea. These sensors are mounted and pointed in fixed positions for measuring and must be kept in position, within some acceptable limits, until the measuring is finished. The sensor can be kept in fixed position using an anchoring system and appropriate anchorage ballast for it.
This study was focused on the volume of fluid (VOF) and FEM models [1, 2] optimization of a 3D model of a metallic structure design and its anchorage ballast. As mentioned, our two main objectives for the study were to analyze the mechanical behavior of the anchoring system and to find a proper shape and weight for the anchorage ballast while taking into account the movement limits for the measuring sensor.
To achieve these required goals, through the study, we considered some working hypothesis for the simplification of numerical model, such as: the bottom of the sea is perfectly horizontal, we study the fluid structure interaction (FSI) for the sea current streams by studying separately the flow around the ballast and around the metallic structure under the influence of the sea current streams at the measuring depth, we coupled the system of acting hydrodynamic forces on the metallic structure and...
different shapes of ballast in a FEM study [3, 4], when modeling the water flow around the metallic structure or around the ballast we have taken into account only the velocity of the sea current streams. The 3D metallic structure shape is a triangular pyramid, is presented in Figure 1 and was designed using Solidworks.

![Figure 1. 3D model of the studied metallic structure.](image)

Cylindrical and conical ballast 3D models are presented in Figure 2 and Figure 3.

![Figure 2. Cylindrical ballast 3D model.](image)  ![Figure 3. Conical ballast 3D model.](image)

This study was created in five steps as follows: 3D modeling of the ballast, 3D modeling of the metallic structure, 3D water flow on ballast modeling scenarios for sea current streams with speeds of 1 m/s, 1.2 m/s, 1.5 m/s and 2 m/s and assessment of the forces applied on it, 3D water flow on the
metallic structure modeling for sea current streams with speeds of 1 m/s, 1.2 m/s, 1.5 m/s and 2 m/s and assessment of the forces applied on it, 3D FEM simulation for displacements and forces in structure evaluation using 3D flow data and body characteristics for the metallic structure with ballast mounted.

2. Initial data and the study diagram

The study of the mechanical behavior of this system has as main objectives the optimization of the shape and weight of the metallic structure anchorage ballast while considering the necessity to keep the sensor in a fixed point and the analysis of the influence of sea current streams and sensor movements on the measurements.

To accomplish these objectives we conducted sixteen simulation scenarios for the water flow around the ballast for the cylindrical shape and the conical shape. These simulation scenarios used as variable parameters the water flow velocity and the inclination angle of the ballast cylinder shape generator and the height of this one. Figure 4 presents the parametric 3D shapes used for simulation and Table 1 presents the geometrical characteristics of the shape.

![Figure 4. 3D model of the studied ballast with parametric shape dimensions.](image)

| Dimensions | Configuration I | Configuration II | Configuration III | Configuration IV |
|------------|----------------|-----------------|------------------|-----------------|
| D          | 200 mm         | 200 mm          | 200 mm           | 200 mm          |
| H          | 300 mm         | 300 mm          | 300 mm           | 300 mm          |
| Theta      | 90 deg         | 88.33 deg       | 86.66 deg        | 85 deg          |

These configurations were used in different flows scenarios with sea current streams velocities of: 1 m/s, 1.2 m/s, 1.5 m/s and 2 m/s.

The metallic structure was designed as a 3D model and is presented in Figure 5. The flow around the metallic structure was analyzed for sea current streams velocities of: 1 m/s, 1.2 m/s, 1.5 m/s and 2 m/s.
m/s. The data obtained from the flow around the metallic structure is used as input data for the 3D FEM analysis in which forces and displacements were numerically calculated for the structure.

**Figure 5.** 3D model of the studied metallic structure with dimensions.

The schematic of the study organization and data flow between the studied problems is presented in Figure 6.

**Figure 6.** Present study organization and data changing between the studied problems

As can be seen in Figure 6 the study was conducted in four main steps: 3D modeling design, 3D flow simulation using the VOF method and the proper turbulence models [3, 4], forces and torques numerical determination for ballast configurations considered and the acting pressure on the metallic structure, 3D FEM simulation to evaluate the efforts and displacements in the sensor anchoring structure.

In the following section we present the results obtained for every step mentioned.
3. Numerical results
The numerical results obtained by simulations are presented as follows and the order of presentation is given by the study diagram presented in section 2, Figure 6.

3.1. Sea water flow simulation results around the ballast
The water flow simulation around the ballast was designed on four ballast configurations, for sea current streams with velocities of 1 m/s, 1.2 m/s, 1.5 m/s, 2 m/s.

The purpose of the 3D flow simulation around the ballast was to calculate the forces and moments for the center of gravity of each ballast configuration and choose the most appropriate from these for usage in the anchoring system configuration on the bottom of the sea when measuring divers and ships hydroacoustic signatures.

This shape of ballast chosen is presented in Figure 2, Figure 3 and Figure 4 and represents a configuration easy to make using simple and low cost machining techniques.

Once the forces and moments have been determined we decided which of the ballast bodies to use with the metallic structure to keep the measuring sensor in a fixed point on the bottom of the sea.

In Table 2, Table 3, Table 4 and Table 5 are presented the results obtained for torques and forces obtained for each ballast body configuration depending of the water flow scenario analyzed.

Table 2. Ballast body scenario simulation results for configuration I

| Parameter      | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|----------------|------------|------------|------------|------------|
| Sea current stream velocity | 1 m/s | 1.2 m/s | 1.5 m/s | 2 m/s |
| Theta          | 90 deg     |            |            |            |
| CG Total force | 15.299 N   | 22.025 N   | 34.313 N   | 60.827 N   |
| CG Fx force    | 14.703 N   | 21.160 N   | 32.992 N   | 58.448 N   |
| CG Fy force    | -4.229 N   | -6.110 N   | -9.430 N   | -16.812 N  |
| CG Fz force    | 0.014 N    | 0.065 N    | 0.065 N    | 1.037 N    |
| CG Mx torque   | -0.027 Nm  | -0.051 Nm  | -0.083 Nm  | -0.026 Nm  |
| CG My torque   | 0.001 Nm   | 0.000 Nm   | 0.000 Nm   | 0.002 Nm   |
| CG Mz torque   | -2.109 Nm  | -3.042 Nm  | -4.741 Nm  | -8.407 Nm  |
| Total mass     |            |            |            | 25.62 kg   |

Configuration I as we can see from data presented in Table 2 is not an acceptable solution. The total force acting on the ballast body in case of a sea current stream with a velocity of 2 m/s represents 24.20% of the total weight of the ballast which is not a solution for our sensor anchoring system. To this value we add the weight of the metallic structure and the weight of the ballast body. At the same time the total torque obtained is very high for the sensor and also creates a large displacement which can alter the measuring results for the hydroacoustic signature. The theta angle parameter of 90 degree generates a cylindrical shape for the ballast body, configuration I which is not that good from the point of the water flow characteristic and trajectory. In addition, the total mass of 25.62 kg is high when considering the total mass of the anchoring structure.

The results of Configuration II are presented in Table 3. From these we can see that the total force acting on the ballast in case of a sea current stream with a velocity of 2 m/s represents 22.83% from the total weight of the ballast which is not a solution for our sensor anchoring system.

The total weight of the ballast for this configuration is 23.48 kg and is high.
Table 3. Ballast body scenario simulation results for configuration II.

| Parameter          | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|--------------------|------------|------------|------------|------------|
| Sea current stream velocity | 1 m/s     | 1.2 m/s    | 1.5 m/s    | 2 m/s      |
| Theta              | 88.33 deg  |            |            |            |
| CG Total force     | 13.579 N   | 19.505 N   | 30.413 N   | 53.617 N   |
| CG Fx force        | 13.456 N   | 19.325 N   | 30.115 N   | 53.155 N   |
| CG Fy force        | -1.825 N   | -2.643 N   | -4.240 N   | -6.932 N   |
| CG Fz force        | -0.031 N   | -0.076 N   | 0.135 N    | -1.104 N   |
| CG Mx torque       | -0.001 Nm  | -0.008 Nm  | 0.003 Nm   | -0.133 Nm  |
| CG My torque       | 0.000 Nm   | 0.001 Nm   | 0.001 Nm   | -0.001 Nm  |
| CG Mz torque       | -1.980 Nm  | -2.845 Nm  | -4.423 Nm  | -7.810 Nm  |
| Total mass         | 23.48 kg   |            |            |            |

Total force which acting on this configuration is reduced with 7.21 N as against configuration I and total mass is reduced with 2.14 kg. As we can observe if we reduced the angle theta with 1.66 degree we can obtain a mass reduced with 2.14 kg in conditions of a material defined (aluminum alloy). Configuration’s III results are presented in Table 4. Total force obtained in this case is 50.935 N.

Table 4. Ballast body scenario simulation results for configuration III

| Parameter          | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|--------------------|------------|------------|------------|------------|
| Sea current stream velocity | 1 m/s     | 1.2 m/s    | 1.5 m/s    | 2 m/s      |
| Theta              | 86.66 deg  |            |            |            |
| CG Total force     | 12.866 N   | 18.487 N   | 28.861 N   | 50.935 N   |
| CG Fx force        | 12.824 N   | 18.427 N   | 28.770 N   | 50.795 N   |
| CG Fy force        | -0.982 N   | -1.412 N   | -2.177 N   | -3.521 N   |
| CG Fz force        | 0.335 N    | 0.443 N    | 0.709 N    | 1.363 N    |
| CG Mx torque       | 0.088 Nm   | 0.118 Nm   | 0.174 Nm   | 0.327 Nm   |
| CG My torque       | -0.001 Nm  | 0.000 Nm   | 0.002 Nm   | 0.004 Nm   |
| CG Mz torque       | -1.790 Nm  | -2.574 Nm  | -4.019 Nm  | -7.149 Nm  |
| Total mass         | 22.65 kg   |            |            |            |

Total force in this case is reduced with 9.892 N than configuration I. Total force in case of a sea stream velocity of 2 m/s represents 22.48 % from the total weight of the ballast which is still not a solution for our sensor anchoring system.

Configuration’s IV results are presented in Table 5. The total force obtained for this configuration is 46.612 N and total mass 19.53 kg. These are lower than the other three configurations. The difference in total force for this configuration compared with the first configuration is 13.215 N. Also we can observe that once we reduce the generator line angle, the mass of the ballast and the force acting on it decrease. Less force and less weight represent the solution we looked for and we considered this configuration of ballast to be the one needed for our anchoring system. For this configuration of ballast we have represented in Figure 7 and Figure 10 the flow trajectories and the pressure flow field.
Table 5. Ballast body scenario simulation results for configuration IV.

| Parameter       | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|-----------------|------------|------------|------------|------------|
| Sea current stream velocity | 1 m/s      | 1.2 m/s    | 1.5 m/s    | 2 m/s      |
| CG Total force  | 12.128 N   | 17.341 N   | 27.055 N   | 47.612 N   |
| CG Fx force     | 12.091 N   | 17.285 N   | 26.984 N   | 47.524 N   |
| CG Fy force     | -0.733 N   | -1.029 N   | -1.558 N   | -2.481 N   |
| CG Fz force     | 0.600 N    | 0.928 N    | -1.188 N   | -1.513 N   |
| CG Mx torque    | 0.073 Nm   | 0.116 Nm   | -0.115 Nm  | -0.112 Nm  |
| CG My torque    | 0.001 Nm   | 0.002 Nm   | -0.003 Nm  | -0.006 Nm  |
| CG Mz torque    | -1.634 Nm  | -2.342 Nm  | -3.649 Nm  | -6.475 Nm  |
| Theta           | 85 deg     |            |            |            |
| Total mass      | 19.53 kg   |            |            |            |

The following figures present results from the flow numerical simulation around configuration IV of the ballast body for two sea current streams with velocity values of 1 m/s and 2 m/s.

![Figure 7. Ballast configuration IV, flow trajectories, v = 1 m/s](image)
Figure 8. Ballast configuration IV, flow trajectories, $v = 2$ m/s

Figure 9. Ballast configuration IV, pressure gradients, $v = 1$ m/s
The flow around the ballast body is characterized by low turbulence; the differences in pressure are not so high from one stream velocity to another (Figure 9 and Figure 10). In the scenario with a sea current stream velocity of 2 m/s we can observe much more detachments of the flow around the ballast body and behind it (see Figure 7 and Figure 8). We also have a stream velocity increased by almost 50% from the free sea current stream velocity in both scenarios.

3.2. Sea water flow simulation results around the metallic structure

The simulation of the water flow around the metallic structure was made with the purpose to obtain data about the mechanical strains acting on the structure and which are caused by the sea current streams. The results obtained after the simulation of the mechanical strain on the metallic structure are presented in Figure 11 for the sea current stream velocity of 1 m/s and Figure 12 for the sea current stream velocity of 2 m/s. The flow around the metallic structure is not characterized by high turbulence and the mechanical strains on the metallic structure are low.
As we can see in Figure 11 and Figure 12 the influence of the flow is not large. The mechanical strains of the water flow on the metallic structure were loaded in the FEM simulation for force and stress evaluation on the anchoring structure.

The maximum value of the pressure on the metallic structure is of 201647.86 Pa and the minimum value is 201152.43 Pa. These values are used to evaluate, using FEM simulation, the efforts and displacements in the metallic structure.
3.3. 3D FEM simulation results

The FEM simulation is made on the metallic structure presented in Figure 5. The external loads used are: the weight of the structure, the weight of the ballast, the forces and torques acting on the ballast, the strain forces acting on the structure. As fixture the system was considered fixed in three points. The simulation was made for two scenarios: sea current streams of 1 m/s velocity and sea current streams of 2 m/s velocity. The results for the stress (von Mises) are presented in Figure 13 and Figure 14. Total displacements, and axes displacements are presented in Figure 15 and Figure 16.

Figure 13. Metallic structure’s stress distribution caused by the sea current stream flow with 1 m/s velocity

Figure 14. Metallic structure stress distribution caused by the sea current stream flow with 2 m/s velocity

The maximum value for the stress is with 50% less than the maximum admitted value for it. These values are obtained for the hardest conditions of sea current streams. Maximum value for stress in a sea current stream velocity of 1 m/s is 4.084 MPa, and for a sea current stream of 2 m/s velocity is about 13.822 MPa.
Figure 15. Metallic structure displacements caused by the sea current stream flow with 1 m/s velocity

Figure 16. Metallic structure displacements caused by the sea current stream flow with 2 m/s velocity

As we can see in Figure 15 and Figure 16 the maximum displacements is 1.032 mm in case of sea streams of velocity 2 m/s and is not affecting the measurement of the hydroacoustic signature.
4. Conclusions
This paper had as its main objectives the analysis of the numerical results concerning the study of an anchoring system for a measuring sensor in a fixed point for measuring the hydroacoustic signature for divers and ships in real sea conditions. The study of this system’s mechanical behavior had as main objectives the shape and weight optimization for the anchorage ballast of the metallic structure while considering the necessity to keep the sensor in a fixed point and the analysis of the sensor displacements influences on the measurements caused by the sea current streams. The study gave us the opportunity to choose from four different configurations of different shapes and weight for the ballast body. The variant proposed in configuration IV has been chosen, with a weight of 19.53 kg and the main geometrical characteristics presented in Table 1. For this ballast body configuration we have evaluated the forces and displacements in the anchoring structure caused by sea current streams of 1 m/s velocity and 2 m/s velocity. After the FEM analysis, we have found a maximum stress of 13.822 MPa which is less than 50% of the maximum acceptable stress. The maximum value of displacements was of 1.032 mm. This value of displacement does not have influences on the measurement sensor when measuring at a fixed point. In the end we think that the study achieved the goals required for it. As a future work, there is a need to determine the optimum material for the construction of the ballast body and for the metallic structure and also to study more carefully the hydroacoustic sensor directivity parameters diagram while considering at the same time the displacements found in the anchoring structure.

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