Manufacturing and design of the offshore structure Froude scale model related to basin restrictions

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Abstract. Manufacturing steps for a modern three-column semi-submersible structure are delivered using CFD/CAE software and actual Froude scaled model testing. The three-column offshore is part of the Wind Float Project already realized as prototype for wind energy extraction in water depths more than 40 meters, and the actual model will not consider the wind turbine. The model will have heave plates for a smaller heave motion in order to compare it with the case without heave plates. The heave plates will be part of the Froude scale model. Using a smaller model will determine a smaller heave motion and this will affect predictions of the vertical movement of the three-column offshore structure in real sea. The Froude criterion is used for the time, speed and acceleration scale. The scale model is manufactured from steel and fiberglass and all parts are subjected to software analysis in order to get the smallest stress in connections inside the model. The model mass was restricted by scale dimensions and also the vertical position of centre gravity will be considered during the manufacturing and design process of the Froude scale offshore structure. All conditions must converge in model manufacturing and design in order to get the best results to compare with real sea states and heave motion data.

1. Introduction

The ship model basin was built between 1960 and 1965 and is currently the only basin equipped with Cusson appliances and equipment that can meet the requirements of a research basin. This basin gives the possibility for applied research to be done both on marine vessels, and on floating structures, so as to provide the naval field with new development concepts. This basin offers the University of Galati the opportunity to realize applied research not only for industry partners, but also for the young Romanian researchers in their doctoral program, whose potential will be exploited further on. The University of Galati in partnership with other institutions of research, development and innovation at European level can easily carry out their naval projects.

Experimental tests are a way of studying the behaviour of ships and semi-submersible offshore structures. Scaled models contribute to knowledge improvement in the field of naval hydrodynamics, thus, accepting the challenge to find the most modern design solutions.

Software evaluation of different hydrodynamic phenomena has developed a lot lately having better and better results. However, control and validation can only be done with experimental research, in a complex analysis, taking into account variables whose quantification is not easy to estimate. The possibility to study the behaviour of semi-submersible structures on the waves at the "Dunărea de Jos" University model requires adequate and well-trained personnel. Comprehensive studies are needed to
develop appropriate CFX simulations for the studied case. In Romania, studies validity can be checked only by using equipment and specialists from the "Dunărea de Jos" University.

The size of the basin, as well as the measurement equipment requirements will influence the model studied, that is the reason why only by using the similarity criteria can we validate numerical solutions from CFX solver. The experimental investigation of the performance of any model must take into account the possible interferences in the basin study and differences from not operating in open sea. The basin has a width of 4 m, a depth of 3 m and a length of 40 m and its measuring equipment can support a model with a maximum weight of 200 kg, that is why a Froude scaled model will face restrictions.

2. Scale model size calculation according to Froude criterion

The scale is limited by the measurement equipment limits for amplitude, and the maximum weight allowed. Due to the wide range of heave and pitch measurement the main restriction is the model’s weight. Based on the Froude criterion, \( F_{m} = F_{n} \), where \( F_{m} \) is for the model and \( F_{n} \) is for the natural scale structure, we will determine the scale by intersecting functions of the model mass according to scale \( f(x) = 3974000/x^3 \) and the constant function \( f(x) = 200 \). The calculated result is 26.44 and this corresponds to a model weight of 200 kg and this is the maximum value allowed by the measurement equipment of the University of Galati. We will choose a high value for the scale, 1:30, corresponding to a mass of 147 kg. All sizes and scales are presented in table 1. This scale is achieved by a geometric similarity between structure and designed model and all the other dimensions are proper to the test.

| Size                  | Structure               | Cylinder | Cylinder 1:30 | Semi-submersible | Semi-submersible Model 1:30 |
|-----------------------|-------------------------|----------|---------------|-------------------|-----------------------------|
| Column diameter [m]   | 10                      | 0.33     | 10            | 0.30              |
| Column height [m]     | 20                      | 0.66     | 20            | 0.66              |
| Heave plate diameter [m] | 20                    | 0.66     | 20            | 0.66              |
| Draft [m]             | 16                      | 0.53     | 16            | 0.53              |
| Weight[t]             | 1256                    | 0.046    | 3974          | 0.147             |
| VCG [m]               | 8.5                     | 0.28     | 8.5           | 0.28              |

Using Froude model we will establish the relation between model and the real semi-submersible structure. We will use the length scale as follows:

\[
k_l = \frac{L_n}{L_m} = 30
\]  

(1)

The speeds scale is determined from \( F_{r_m} = F_{r_n} \) and this is also \( \frac{v_n^2}{gL_n} = \frac{v_m^2}{gL_m} \).

And the result is (for our values):

\[
\frac{v_n^2}{v_m^2} = \frac{L_n}{L_m} = k_L = 5.47
\]  

(2)

Time scale will be determined from \( k_t = k_L/k_s \), and the result is (This value can be used for periods):

\[
k_t = \frac{t_n}{t_m} = \sqrt{k_L} = 5.47
\]  

(3)

The frequency scale is:
The mass scale is:

\[ k_f = \frac{f_n}{f_m} = \frac{1}{k_e} = \frac{1}{5.47} = 0.182. \]  

(4)

The acceleration scale is:

\[ k_a = \frac{\Delta_n}{\Delta_m} = k_e^3 = 30^3 \]  

(5)

2.1. Pre-analyzed model design

The semi-submersible structure with 3 columns materials will be chosen based on the rigorous analysis presented in Ansys CFX. A static structural analysis will be performed in each model case to get the best guidance in the implementation stages. Modern model manufacturing industry is based on steel models, fiberglass models, wooden models and plastic models. A model manufacture is a difficult job when the model has to respect some rules because it has to be geometrically similar to the original analyzed structure. We will present a successful way to pre-analyze (figure 1) the model in a coupled field analysis.

The pre-analyzed model in a coupled field analysis can use software and cost-free tools to evaluate the scale, the structure behavior in waves, and the dimensions required for any structural analysis. At any scale a Fluid-Structure interaction case with CFX and Static structural will be studied before building the model.

3. CFD/CAE numerical investigation

In accordance with the test plan, experimental tests will be carried out on semi-submersible model for wave directions 0, 60 and 90 degrees. To estimate the forces occurring on the 3D model of the semi-submersible with three columns we will use advanced Volume of Fraction simulation in ANSYS CFX. CFX software is able to simulate wave action on model from any angle with a parametric simulation where wave angle is the input parameter for analysis [1]. CFX analysis is able to determine model forces, moments and displacements in regular waves. CFX-Pre module can model input parameters of the analysis as required [2]. Based on the results of CFX-Post module we can view and measure the results for static mechanical analysis on the scale model. It will have to withstand forces and moments during experimental tests regardless of the direction of the wave. Graphical results are presented for simulated wave action on semi-submersible model (figure 2, CFX-Post results). At each step, we will evaluate values of forces and torque (figure 3) looking for the maximum values for ANSYS structural analysis.

\[ k_a = \frac{a_n}{a_m} = 1 \]

(6)
The study will be conducted to assess the vertical oscillation, pitch and depreciation amortization thanks to the plates with diameters of 1.5 to 2 times larger than the diameter of the column. The model is made of two different materials: steel and fiberglass. The connection is made by M8 stainless steel bolts in order to obtain a rigid model. Fiberglass columns and stainless steel reinforcements will be studied with 3D software from ANSYS Structural Static (figure 4.) with the gravity forces and buoyancy forces simulated in ANSYS CFX.

ANSYS structural static analysis for the scale model involves assessing the forces and pressures that occurs in basin testing. The CAD model should be tested on the maximum simulated load. For this analysis we will consider a fixed cylinder while the other two will have an applied pressure equal to the maximum hydrostatic pressure. The evaluation results will be included in the model pre-analysis until the size of the model will be able to support these loads. For this steps we use: mesh (figure 5), total deformation (figure 6), stress values (figure 7) and safety factor (figure 8).
Using this method of analysis software we are able to estimate the minimum diameter of the steel bars and the minimum fiberglass wall thickness for the vertical columns. Results indicated for the presented basin that bars with diameter of 30 mm and columns with 5 layers of fiberglass are enough to withstand the stress given by the basin tests.

4. Equations and mathematics

The model mass is limited to basin restrictions and the mass is decided also for easy handling during the test. To build the semi-submersible model to an appropriate scale according to the project requirements and basin restrictions, we will use approximately 40 m$^2$ of fiber glass and about 12 m of round steel pipe. This means that the final weight of the model developed will be about 30 kg. Fiber glass is a material used in boatbuilding, automotive and implementation of highly complex parts such as ship models and semi-submersible offshore structures. The most important properties [4] of glass fiber are: high tensile strength, heat resistance, chemical resistance, non-toxicity and non degrading bacteria and fungi. Fiber glass can be of several types and has variable percentage composition: SiO$_2$, Al$_2$O$_3$, Na$_2$O, CaO, MgO, B$_2$O$_3$, FeO$_3$ and PbO. These fibers come from suppliers in the form of rolls of material of different widths and are processed with the resin to fill the mold forms with various patterns. The glass fiber acquires a tensile strength of 60 MPa and an elongation at break of 1%.

The round steel 30mmX1.5 mm pipe is made of 304 L which gives it the property to be stainless steel because it has the composition of 18% chromium, 8% nickel, 0.03% carbon, 1% manganese, 0.045% phosphorus, and 0.03% sulfur. These pipes have a low carbon content which reduces the problems of precipitation of the bath of molten metal during welding. Therefore, this material lends itself well to the weld when using stainless steel electrodes.

Dimensional requirements are established according to the Froude scale. Model data for fiberglass wall thickness and stainless steel thickness are used in simulation of structural strength. Dimensions based on a schematic process design will lead to a well prepared model for basin test according to restrictions involved.

During construction, each layer of fiberglass is placed in a new direction to create a strong material after hardening. The connections between fiberglass and steel are based on screws in the pre-assembly
model (figure 11). During the model construction process dimensions are set to the precise value obtained from Froude scale (figure 12).

![Figure 11. Model pre-assembly fiber and steel.](image1)

![Figure 12. Final assembly of the model.](image2)

The semi-submersible model is build after CFD/CAE pre-analysis [5] and according to requirements of Hull Basin from University of Galati. It was already tested in the basin to assess heave and pitch motion in regular waves to determine RAO functions. To facilitate experimentation in the tank, the measuring equipment is mounted above center of gravity of the model deck surface with a wooden white deck. The wooden deck is used for placing measurement equipment above the centre of gravity on board the model during tests, and also for initial stability test.

The model for the WindFloat[6] semisubmersible was assembled by CirusPlast Constanta in December 2014, and the tests in the Hull Basin, in January 2015, were successful.

5. Conclusions
A concept for manufacturing models for three - column semi-submersible emerged from presented CFD/CAE software. The CFD analysis for wave action on the model, and for real scale structure is done with Ansys CFX. The three- column semi - submersible is analyzed with and without heave plates through CFX solver. The force and torque calculator will indicate the force acting on the Froude model and the values can be used in further static structural analysis. The model was tested successfully in the basin of the "Dunărea de Jos" University of Galati. All basin restrictions and technical suggestions will be modified according to the design in the pre-analysis. The response in regular waves depends on the model dimensions. A smaller model will determine a smaller output, and this will affect sensor readings for movements of model in basin tests. Through the use of ANSYS we will predict, before testing, if the scale model manufactured from steel and fiberglass will pass basin tests without technical difficulties. The result will be a rigid structure, able to face waves in basin tests, from all directions, according to the parametric simulation from CFX.

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