Automatic analysis of floating offshore structures

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Abstract In the coming years offshore wind energy will be one of the most promising areas in the renewable power generation field. Achieving the optimum design of floating platforms requires a rigorous analysis chain to establish the response of the whole platform under different scenarios. With this aim, we have developed a software package that automatically analyzes the feasibility of a floating structure. The structure of the platform is defined according to a very general set of parameters, allowing us to consider a wide range of designs. The package calls some commercial applications and some codes developed by us, to complete the analysis process. Returned results include the hydrostatic equilibrium position, hydrodynamic pressure, RAOs (response-amplitude operators), material costs and static stresses.

1 Introduction

Offshore wind power is one of the most promising fields in renewable energy generation in the coming years. More than 90% of the worlds offshore wind power is currently installed in Europe. According to Global Wind Energy Council, offshore wind represents today about 2% of the global wind power installed capacity, and this figure will increase to 10% by 2020, with many ongoing projects mainly in Europe, United States, China and Japan.

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Offshore wind has a number of advantages compared to on land such as higher wind speeds and less turbulence, thus generating more energy from fewer turbines, and usually fewer environmental constraints. Offshore is particularly suitable for large scale developments near major demand centers represented by large coastal cities, avoiding the need for long transmission lines to bring the power to these demand centers, as is the usual case onshore.

The main areas for exploitation are however found far off the coast, in deep waters, where fixed supporting structures similar to the ones installed on land are no longer economical. These distant sites mean more difficult sea bottom operations and higher waves and thus floating platforms are more suitable in these conditions.

Floating platform designs were initially conceived for Oil&Gas industry operations. Therefore these designs were associated to huge safety factors due to implications to human safety and to the environment of the failure of such installations. But floating wind requirements are completely different and thus the major challenge for offshore wind development today is to continue to bring down costs, developing designs aimed at minimizing the capital expenditure and operating expenses while guaranteeing structural integrity and providing suitable operating conditions for the turbine.

For a formal optimization cycle to achieve the optimal design that minimizes the cost of produced energy (balancing the produced power and the expenses), it is first necessary to develop an analysis chain able to:

- Provide the response of the set platform-tower-turbine to different load scenarios (wind and waves spectra) in a fast and rigorous way.
- Robustly handle changes in design variables.

The response analysis of the whole set to different wave and wind scenarios is usually quite complex. The basis of floating structures optimization can be consulted in [3–5, 9]. Unfortunately these tools are not widely available for the companies working in this field. With this aim, we have developed a software package that automatically analyzes the feasibility of a floating structure. The structure of the platform is defined according to a very general set of parameters, allowing us to consider a wide range of designs. The package calls some commercial applications and some codes developed by us, to complete the analysis process. The main steps are:

- Generation of a CAD file of the floating structure.
- Material cost for the whole structure.
- Calculation of the hydrostatic equilibrium position, subject to moorings and wind force at the top of the tower.
- Calculation of hydrodynamic pressure and RAOs (response-amplitude operators) considering moorings and wave interaction.
- Structural analysis of the platform, using the previous calculations.

This analysis tool can be used into a multi-objective optimization strategy. This can help us find optimal designs depending on the placement of future exploitation fields.

Figure 1 shows a flowchart of the analyzer program. The rest of the paper is organized as follows: Section 2 describes how to encode geometry and to create a CAD model of the platform. Section 3 deals with the calculation of the equilibrium state. The numerical procedures to compute aerodynamic and hydrodynamic loads are described in Section 4. Section 5 details the structural study.

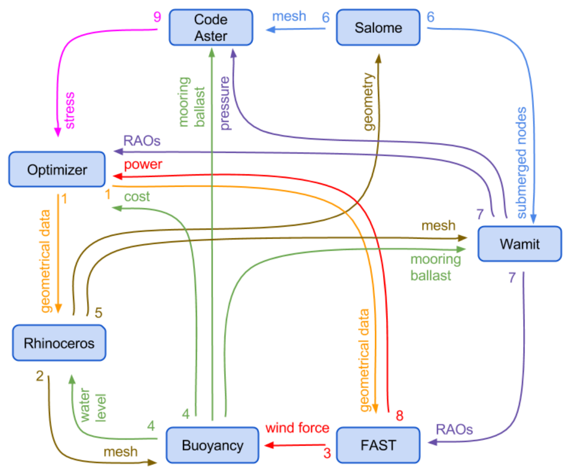

Fig. 1 Flow chart for the analizer program: 1) process geometry data, 2) mesh for the buoyancy program, 3) wind force 4) buoyancy program, 5) geometry in the equilibrium state, 6) conformal mesh for structural study, 7) RAOs and hydrostatic pressure, 8) power calculation and 9) structural study.

2 Geometry encoding

In order to consider a geometry encoding flexible enough to model a wide variety platform designs, we assume that platforms are mainly composed of empty bodies made of metal sheets, that is, their internal structures are neglected. We distinguish between three type of objects: pillars, connectors and towers.

- Pillars are bodies of cylindrical section that give the platform the ability to float. They can have a rectangular or elliptical base and their dimensions and position in the space are parametrized, as well as their lateral profile, thickness and anchor points. If they contain water acting as ballast, water height is also a parameter.
- Connectors have also cylindrical section; their geometry is parametrized in the same way than pillars. They can connect pillars or other connectors; contact points with the connected objects are also parameters.
- Towers are cylindrical objects on the top of some pillars; they are intended to hold wind generators.

The previous information is stored in a file keeping the structure of the three object types. Thus, it is very natural not only to change a specific parameter in the file, but also to remove or include a complete pillar, connector or tower. Such actions are among the first rules than an optimization algorithm based on grammatical evolution could need to implement (see [10]).

The first step in the analyzer program is to create a CAD model of the platform from the geometry encoding. To this end, a Python script was programmed to take advantage of the Python scripting for Rhinoceros [2]. The resulting geometry is composed of NURBS surfaces that can be exported in several formats. Figure 2 shows the resulting CAD file for the a semisubmersible platform designed by Mitsui Engineering & Shipbuilding Co. [6].

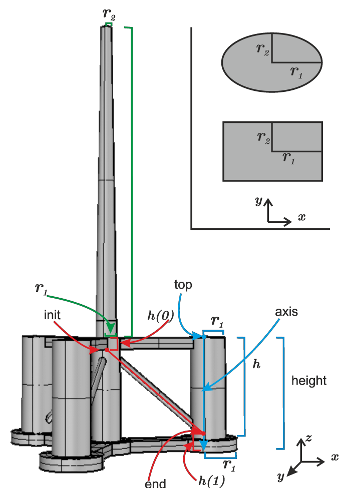

Fig. 2 Example of a semisubmersible platform designed by Mitsui Engineering & Shipbuilding Co. Some of the geometry parameters are detailed: pillars in blue, connectors in red and towers in green.

3 Buoyancy position

The hydrodynamic behavior of the platform is modelled with WAMIT [8], which assumes that the structure is given in the equilibrium state. We have implemented the calculation of such equilibrium state for a rigid body subjected to its weight, buoyancy forces, moorings, wind forces applied at the top of the tower and ballasts. We remark that the movement of a rigid body can be decomposed into the movement of the center of mass and the movement induced by the rotation respect to the center of mass. Besides, the total force applied to the body produces a change in the linear moment, whereas the total moment respect to the center of mass changes the angular moment of the body. When the body is balanced, both linear and angular moments are null as well as both the sum of forces and the sum of moments.

To find out the equilibrium state requires to solve a nonlinear system: the condition of the vertical alignment of the center of mass and the buoyancy center gives two equations; the balance between total forces and weight gives another one. Among all possible solutions, only those which are stable are relevant. A position is stable when the body recovers its position subjected to small perturbations. To calculate the stable positions, the time-dependent dynamic problem is solved, integrating the equations of the rigid body with frictional force in a time interval long enough.

We assume that moorings are composed of chains or cables that partially lay on the seabed. They are modeled with a nonlinear uni-element model based on catenary (see [11]). Both flexural rigidity and friction with seabed are neglected.

4 Hydrodynamic and aerodynamic modelling

The hydrodynamic interaction between surface waves and the platform has been computed using the software package WAMIT [8]. Its implemented model is based on a linear model where a potential representation is applied to the fluid velocity field. Once this potential is split taking into account the radiation and diffraction contributions, the hydrodynamic loads on the wetted body surface are computed. The numerical solution involves the discretization of an integral equation whose Green function satisfies the free-surface boundary condition. The high-order implementation of this numerical method, the so-called *panel method*, represents the surface body geometry by means of continuous B-splines. This geometric setting is accomplished since NURBS surfaces are approximated by B-splines when the original structure representation is exported from Rhinoceros.

These numerical simulations allow to evaluate physical quantities such as the total force and total moment acting on the rigid solid and also fluid fields (pressure, velocity, and free-surface elevation). However, only the RAOs and the hydrodynamic pressure computed by WAMIT are relevant for our analyzer. The six RAOs are transfer functions associated to each degree of freedom (DOF) of the platform motion. They depend on the heading angle and the frequency of the incident plane-wave excitations.

For the aerodynamic modelling, the software package FAST [7] has been used to compute forces and moments induced by wind at the top of the tower. Since only static wind loads have been considered, only the module Aerodyn was used. This computational code requires two kind of input data: those ones related to the platform dynamics (such as the turbine configuration, its weight, characteristics of its mechanical components, the tower dimensions, its vibration modes, etc.), and those data related to the aerodynamic setting, which include the physical parameters of air, wind speed and direction, airfoil profiles and blade configuration. This code has been used twice in the analysis process (see Fig. 1): Firstly, forces and moments are computed at the equilibrium position of the platform, which have been taken into account to determine the buoyancy position; Second, for each frequency considered, the aerodynamic forces and moments are computed and used as input data in the structural analysis performed by Code_Aster [1].

5 Structural study

The structural analysis is done using Code_Aster [1], a finite element code which includes a wide variety of mathematical models. Pillars are modeled as shells, while connectors and towers are modeled as beams with a shell transition at the end. Since Code_Aster can be executed through Python scripts, it is suitable to be integrated in the analyzer.

Mesh produced by Rhinoceros is not a conformal one; we created an appropriate mesh from the CAD file using SALOME. The forces and loads calculated through the process are provided to Code_Aster to define two problems:

- The dynamic problem considers time dependent forces and it is solved in the frequency domain. Its solution is added to the solution of the next problem.
- The static problem takes into account the hydrostatic pressure, moorings and the wind force. This is a pure Neumann problem because static forces are balanced and there are no fixed nodes. In order to remove rigid movements and to have a well posed problem, assembly matrices are modified and transferred to the external solver UMFPACK. The result is injected again in Code_Aster.

The resulting stress is processed to detect critical values in the structure (see Fig. 3).

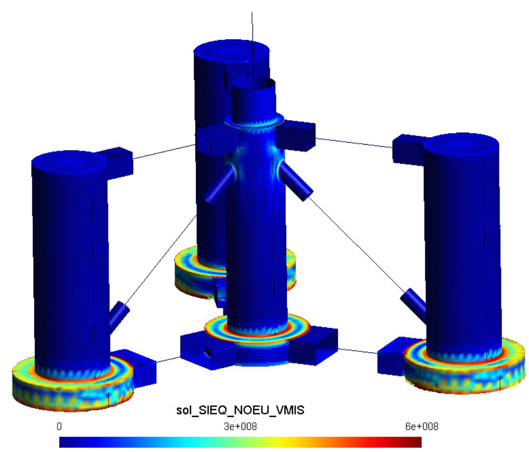

Fig. 3 Von Mises norm of the stress calculated with Code_Aster.

6 Conclusions

- The increasing development of offshore wind power requires tools to evaluate the validity of the platforms.

- An analyzer program is presented in this paper, being the result of a project conducted by the Repsol Technology Center.
- This program combines commercial and specifically developed software to calculate power, RAOs and stress for each structure.
- Inputs and outputs have been designed to easily integrate analyzer in an optimization code.

Acknowledgements Authors would like to thank the support of Repsol in this project and, in particular, the enthusiasm showed by Rosana Plaza Baonza and Jesús García San Luis. We want to recognize the work of Ibán Constenla Rozados in the early part of the project. Finally, we appreciate the opportunity given by the math-in network of presenting this paper in ECMI 2014.

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