

# SeaFEM - Validation Case 14

Analysis of an offshore TLP structure



# SeaFEM

**Version**  
**15.1.0**



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## 1 Analysis of an offshore TLP wind structure

The present validation case deals with the seakeeping behavior of a real TLP platform supporting a 5 MW wind turbine. Actually, the characteristics of the TLP used herein correspond to that used by the NREL (National Renewable Energy Laboratory), and the final goal of the analysis is to compare the results obtained using SeaFEM against those reported by NREL. For more details, see reference [1].

The actual TLP structure under analysis has three major components: the wind turbine, the floating platform and the mooring system. In the present analysis, only the floating platform is physically modeled, while the mooring system and wind turbine effects are taken into account by using appropriate mass, damping and stiffness matrices.

The TLP structure properties introduced in the SeaFEM data tree read as follows:

### **Body data   ► group: name   ► body properties**

- Mass: 0.0
- XG: 0.0 m
- YG: 0.0 m
- ZG: 0.0 m
- Hidrostatics Type: Linear
- Radii of gyration R11: 1.0E-9 m
- Radii of gyration R22: 1.0E-9 m
- Radii of gyration R33: 1.0E-9 m

Note that the mass of the body is set to zero. This is so, because the actual values of the mass and inertia properties are specified by providing additional mass matrices that account for the mass and inertia properties of both, the floating platform and the wind turbine. Additional stiffness and damping matrices are provided as well to account for the restoration and damping effects of the wind turbine and mooring system. Note that a very small value is provided for the radii of gyration. This is because null values are not accepted by the solver, although the actual values have no effect if the mass is set to zero, since the corresponding inertia coefficients evaluate to zero as well ( $I_{ij} = R_{ij}^2 \cdot M$  being  $M$  equal zero). This emphasises the fact that the complete inertia properties of the system are casted into the additional mass matrices provided through the TCL extension script.

Finally, the center of gravity is set to (0,0,0) to enforce SeaFEM results to be referred to the origin of the global coordinate system. This is useful in the present case for the sake comparison, since NREL's results are also referred to the origin of such a global reference

system.

The various matrices provided to account for all the dynamic properties of the system are summarized in what follows:

- Mass matrix of the TLP platform. Reference point = (0.0, 0.0, 0.0)

8.6E+06	0.0	0.0	0.0	-349.16E+06	0.0
0.0	8.6E+06	0.0	349.16E+06	0.0	0.0
0.0	0.	8.6E+06	0.0	0.0	0.0
0.0	349.16E+06	0.0	14754.48E+06	0.0	0.0
-349.16E+06	0.0	0.0	0.0	14754.48E+06	0.0
0.0	0.0	0.0	0.0	0.0	361.4E+06

- Mass matrix of the wind turbine. Reference point = (0.0, 0.0, 0.0)

0.7E+06	0.0	0.0	0.0	44.3E+06	0.0
0.0	0.7E+06	0.0	-44.3E+06	0.0	6.60E+06
0.0	0.0	0.7E+06	0.0	-6.6E+06	0.0
0.0	-44.3E+06	0.0	3499E+06	0.0	0.0
44.3E+06	0.0	-6.6E+06	0.0	3560E+06	0.0
0.0	6.60E+06	0.0	-513.3E+06	0.0	101.2E+06

- Damping matrix due to the wind turbine. Reference point = (0.0, 0.0, 0.0)

0.04E+06	0.0	-0.01E+06	-0.25E+06	4.00E+06	0.08E+06
0.0	0.0	0.0	-0.11E+06	-0.18E+06	-0.05E+06
-0.01E+06	0.0	0.0	-0.04E+06	-0.92E+06	-0.33E+06
0.27E+06	-0.1E+06	0.0	16.17E+06	50.30E+06	13.88E+06
3.42E+06	0.06E+06	-1.00E+06	-23.92E+06	400.1E+06	59.01E+06
0.05E+06	-0.02E+06	0.22E+06	11.08E+06	-52.60E+06	101.2E+06

- Stiffness matrix of the wind turbine. Reference point = (0.0, 0.0, 0.0)

0.0	0.0	0.0	0.3E+06	0.2E+06	0.0
0.0	0.0	0.0	-0.1E+06	0.3E+06	-0.07E+06
0.0	0.0	0.0	-0.3E+06	-0.4E+06	0.0
0.0	0.0	0.0	8.5E+06	-22.4E+06	59.7E+06
0.0	0.0	0.0	26.8E+06	28.9E+06	-4.1E+06
0.0	0.0	0.0	-1.2E+06	1.1E+06	-4.8E+06

- Stiffness matrix due to the mooring system. Reference point = (0.0, 0.0, 0.0)

0.247E+06	0.0	1.53E+06	0.0	-7.26E+06	0.0
0.0	0.214E+06	0.0	6.27E+06	0.0	-0.511E+06
1.53E+06	0.0	70.4E+06	0.0	-44.6E+06	0.0
0.0	6.23E+06	0.0	15400E+06	0.0	-408E+06
-6.94E+06	0.0	-31.8E+06	0.0	15400E+06	0.0
0.0	0.0	0.0	-345E+06	0.0	94.7E+06

Note that, in the present case all the matrices have been referred to the origin of coordinates of the global reference system. Nevertheless, any arbitrary reference point could be used if necessary for each additional matrix. SeaFEM is responsible for the transformation of all such matrices in order to be referred to the point specified as the center of gravity of the body.

Finally, degrees of freedom of the floating structure must be activated as follows:

**Body data** ▶ **group: name** ▶ **degrees of freedom**

- Surge: activated
- Sway: restricted
- Heave: activated
- Roll: restricted
- Pitch: activated
- Yaw: restricted

The Body data section of the SeaFEM data tree also provides the option to apply external forces and moments to a given body. Use the following function for the Z-component of the external force, which is the force applied to the legs of the TLP structure tensioned in dynamic equilibrium.

**Body data** ▶ **group: name** ▶ **External loads** ▶ **External force Z:**

Mass\*g-vol\*density\*g

## Problem description

- Geometry and problem description

The geometry consists on a cylindrical floating platform of radius  $R=9.0$  m. and draft  $d=47.89$  m. The control volume has cylindrical shape with diameter  $D=1200$ m and height  $h = 200.0$  m.

- Simulation dimension = 3D
- Units system : Int. system (SI) - N,m,Pa
- Geometry units : m
- Gravity =  $9.80665 \text{ m/s}^2$
- Water density =  $1025 \text{ kg/m}^3$
- Analysis type: 1st order time domain
- Seakeeping analysis environment: Waves
- Seakeeping analysis type: Seakeeping
- Bathymetry: constant depth.
- Depth: 200.0 m.
- Waves absorption: Yes.
- X absorption reference: 0.0 m.
- Y absorption reference: 0.0 m.
- Absorption factor: 1.0
- Beach: 30.0 m.
- Sommerfeld radiation condition: Yes.

- Boundary conditions and seakeeping environment

- Wave spectrum: White noise.
- Amplitude: 1 m.

- Direction: 0.0 deg.
- Shortest period: 3 s.
- Longest period: 20 s.
- Number of waves periods: 40.
- Time data
  - Simulation time: 10000 s.
  - Time step: 0.0 s.
  - Output step: 0.5 s.
  - Start time recording: 350 s.
  - Initialization time: 300 s.
- Solver parameters
  - Processor unit: CPU+GPU (if available in the computer)
  - Solver: Deflated conjugate gradient
  - Preconditioner: Diagonal
  - Solver tolerance: 1.0E-7
  - Solver max. iterations: 1000
  - Free surface stability factor: 4
  - Dynamic solver max. iter.: 100
  - Dynamic solver relaxation: 1.0
  - Max. iter. time step: 20
  - Tolerance: 1.0e-4
  - Damping factor: 0.0
  - Alpha B-N: 0.0

## Mesh

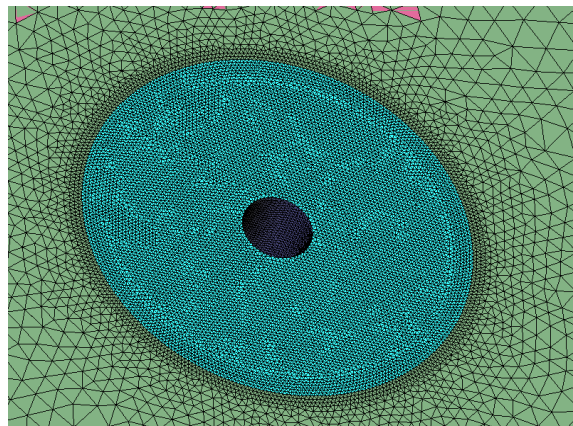
Mesh properties for the present analysis are summarized in the following table:

Mesh properties	
Min. element size	1
Max element size	40
Mesh size transition	0.1

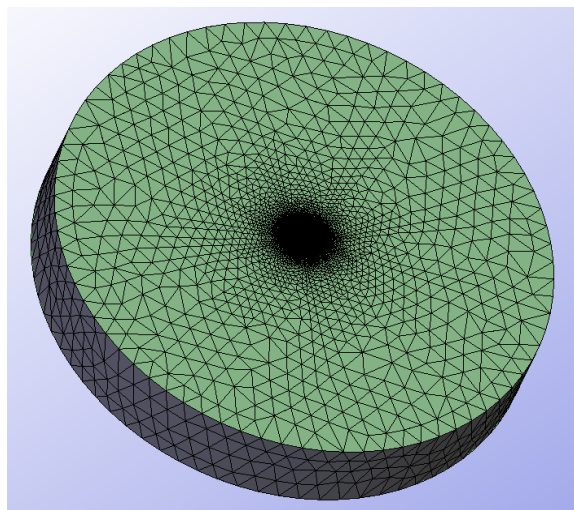


Number of elements	784.052
Number of nodes	135.321

The mesh finally obtained must be similar to that shown in the figure bellow. It can be appreciated how the mesh is gradually refined when approaching the body surface.



Detail of the mesh close the TLP structure



Global view of the computational mesh

## Results

After the meshing process the SeaFEM calculation can be started using the following option of the main menu.

**Calculate ► Calculate**

After finishing the calculation, load the postprocess module of SeaFEM

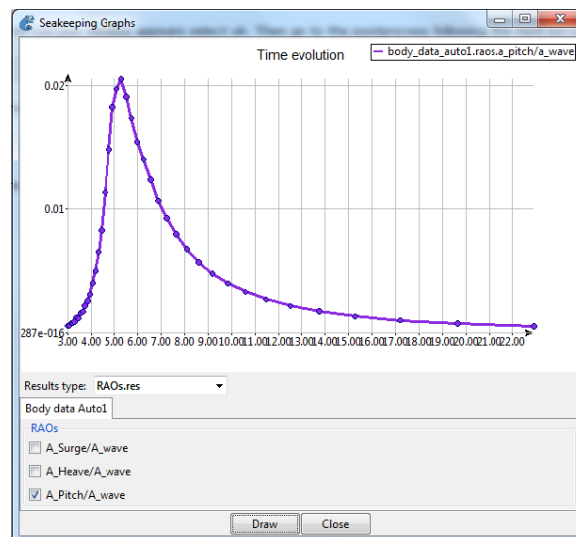
**Potsprocess ▶ Traditional post**

For the sake of comparison against the NREL results, proceed to represent the pitch RAO results of SeaFEM.

**View Results ▶ SeaFEM Graphs**

- Select the RAOs.res results file
- Select Pitch results option.

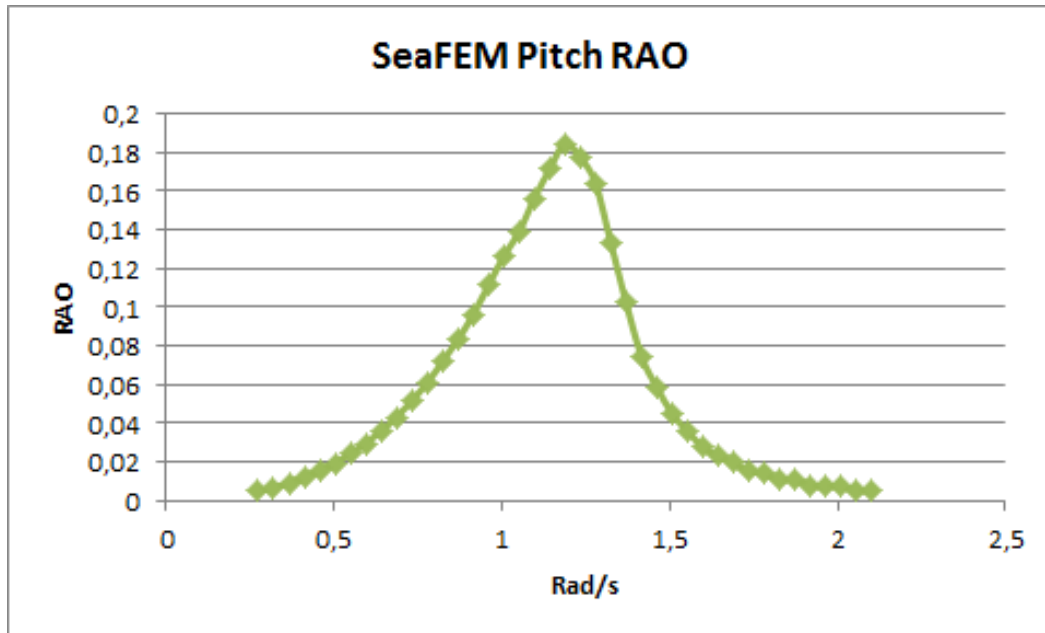
The graph obtained should look similar to that shown in the figure bellow.



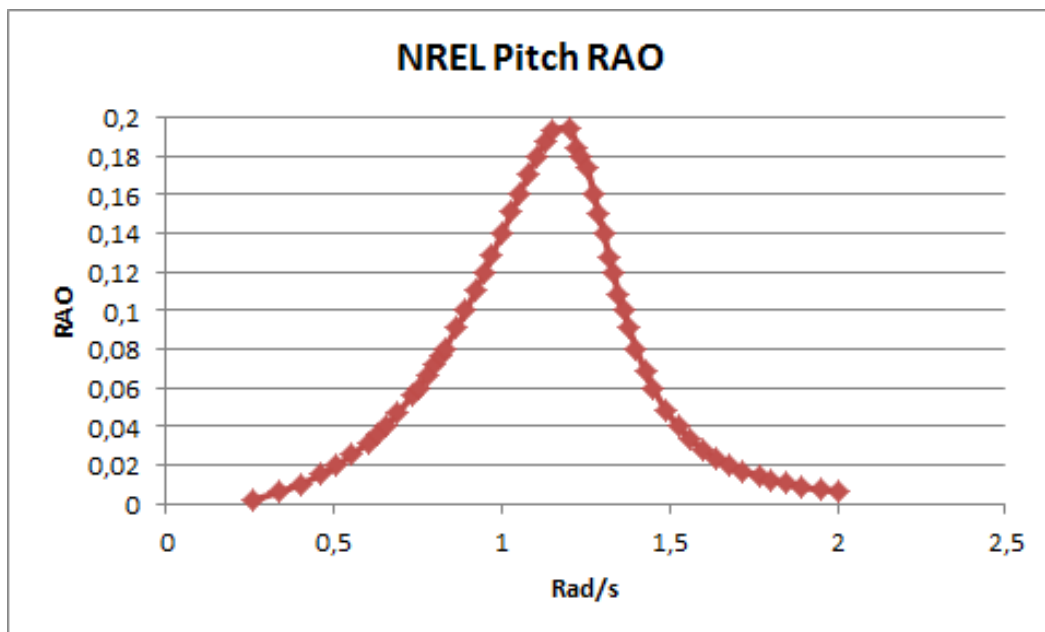
Pitch RAO results

Pitch RAOs results are reported in rad/m and are given as a function of time.

The Filename.RAOs.res file can be edited externally to obtain for instance the displacement at the end of the TLP structure. To this aim, we must simply multiply the Pitch RAOs results by the corresponding gyration radius (i.e. 9.0 m). This can be useful to compare the SeaFEM obtained results with some other results. It has been done in this case to compare the results obtained with SeaFEM calculus against the results reported in the NREL study. The following graphs represent the pitch RAO obtained using SeaFEM and the pitch RAO reported in the NREL study.



SeaFEM pitch RAO graph.



NREL pitch RAO graph.

As we can see the results are very similar in both studies, being the max RAO obtained in SeaFEM about 0,184592, and in the NREL case about 0,19413, hence resulting in a difference of about 0,0095382 (i.e. 0.05%).

## Appendix

This appendix is devoted to show the complete code of the TCL script used to specify the various matrices that account for the mas and inertia properties of the main components of the floating wind turbine, as well as the stiffness and damping effects due to the wind turbine and mooring system.

```
proc TdynTcl_InitiateProblem { } {

    TdynTcl_Add_Mass_Matrix 1 [list 0.0 0.0 0.0] [list \
        8.6E+06 0.0 0.0 0.0 -349.16E+06 0.0 \
        0.0 8.6E+06 0.0 349.16E+06 0.0 0.0 \
        0.0 0.0 8.6E+06 0.0 0.0 0.0 \
        0.0 349.16E+06 0.0 14754.48E+06 0.0 0.0 \
        -349.16E+06 0.0 0.0 0.0 14754.48E+06 0.0 \
        0.0 0.0 0.0 0.0 0.0 361.4E+06 ]

    TdynTcl_Add_Mass_Matrix 1 [list 0.0 0.0 0.0] [list \
        0.7E+06 0.0 0.0 0.0 44.3E+06 0.0 \
        0.0 0.7E+06 0.0 -44.3E+06 0.0 6.6E+06 \
        0.0 0.0 0.7E+06 0.0 -6.6E+06 0.0 \
        0.0 -44.3E+06 0.0 3499E+06 0.0 0.0 \
        44.3E+06 0.0 -6.60E+06 0.0 3560E+06 0.0 \
        0.0 6.60E+06 0.0 -513.3E+06 0.0 101.2E+06 ]

    TdynTcl_Add_Damping_Matrix 1 [list 0.0 0.0 0.0] [list \
        0.04E+06 0.0 -0.01E+06 -0.25E+06 4.00E+06 0.08E+06 \
        0.0 0.0 0.0 -0.11E+06 -0.18E+06 -0.05E+06 \
        -0.01E+06 0.0 0.0 -0.04E+06 -0.92E+06 -0.33E+06 \
        0.27E+06 -0.1E+06 0.0 16.17E+06 50.30E+06 13.88E+06 \
        3.42E+06 0.06E+06 -1.00E+06 -23.92E+06 400.1E+06 59.01E+06 \
        0.05E+06 -0.02E+06 0.22E+06 11.08E+06 -52.60E+06 101.2E+06]

    TdynTcl_Add_Stiffness_Matrix 1 [list 0.0 0.0 0.0] [list \
        0.0 0.0 0.0 0.3E+06 0.2E+06 0.0 \
```

```
0.0 0.0 0.0 -0.1E+06 0.3E+06 -0.07E+06 \
0.0 0.0 0.0 -0.3E+06 -0.4E+06 0.0 \
0.0 0.0 0.0 8.5E+06 -22.4E+06 59.7E+06 \
0.0 0.0 0.0 26.8E+06 28.9E+06 -4.1E+06 \
0.0 0.0 0.0 -1.2E+06 1.1E+06 -4.8E+06 ]
```

```
TdynTcl_Add_Stiffness_Matrix 1 [list 0.0 0.0 0.0] [list \
0.247E+06 0.0 1.53E+06 0.0 -7.26E+06 0.0 \
0.0 0.214E+06 0.0 6.27E+06 0.0 -0.511E+06 \
1.53E+06 0.0 70.4E+06 0.0 -44.6E+06 0.0 \
0.0 6.23E+06 0.0 15400E+06 0.0 -408E+06 \
-6.94E+06 0.0 -31.8E+06 0.0 15400E+06 0.0 \
0.0 0.0 0.0 -345E+06 0.0 94.7E+06 ]
```

```
TdynTcl_Message "TdynTcl_DefineBodyData finished!!!" notice
```

```
}
```

## Validation Summary

CompassFEM version	15.1.0
Tdyn solver version	15.1.0
RamSeries solver version	15.1.0
Benchmark status	Successfull
Last validation date	27/11/2018

## Bibliography

[1] Matha, D. Model development and loads analysis of an offshore wind turbine on a tension leg platform, with comparison to other floating turbine concepts. NREL/SR-500-45891 Subcontract Report, February 2010.

[2] Compass Ingeniería y Sistemas. SeaFEM Tutorials. Chap. 4 - TLP Tutorial. <http://www.compassis.com/compass/en/Soporte>.

[3] Compass Ingeniería y Sistemas. SeaFEM reference. Solver for seakeeping and maneuvering problems. <http://www.compassis.com/compass/en/Soporte>.

