# L03 Semi-sub multibody analysis

## Introduction

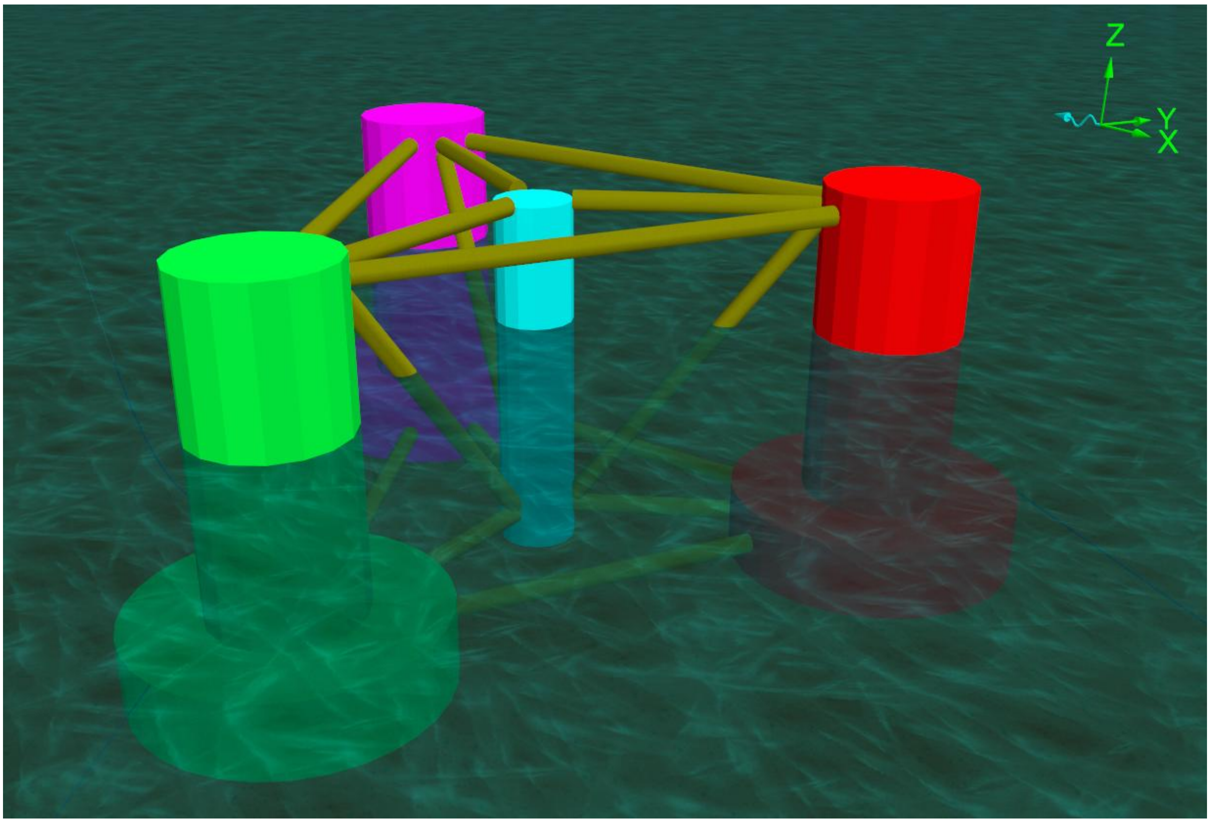
This example demonstrates how you might utilise the features available in OrcaWave and OrcaFlex to analyse the structural loads in the supporting members of a floating platform consisting of more than one buoyant body.

In this example we take a semi-submersible floating wind turbine platform and divide it into four floating bodies. We use OrcaWave to perform a multibody diffraction analysis of the distributed system. We then use OrcaFlex to perform a dynamic analysis with the pontoons and cross bracings explicitly modelled as line objects. Finally, we compare the multibody body vessel motions with those of an equivalent system modelled using a single vessel object, and briefly analyse the loads acting on the supporting members.

The platform chosen for this example closely resembles the OC4 platform, modelled as part of the L02 OC4 Semi-sub example. However, when dividing the platform into multiple bodies, some of the platform properties were not available and some simplifications have been made. Consequently, we do not consider this model to be totally equivalent to the model presented in example L02.

This example takes advantage of developments made in version 11.4 that improve the workflow when defining external stiffness for multibody models. **Therefore, this example and the process described are intended for use with OrcaWave and OrcaFlex version 11.4 onward.**

***Note:*** *If you use these models, or any part of them for your own analysis purposes, you must first satisfy yourself that they are correct and appropriate for the scenario being analysed.*



## Multibody approach

In order to analyse the loads acting in the supporting members of this floating platform, each of the four major columns must be capable of moving independently. To achieve this, each column will be represented in OrcaFlex by a vessel object, each with its own hydrostatic and hydrodynamic properties.

A multibody diffraction analysis has been used to gather the required vessel type information. Unlike a conventional diffraction analysis, we cannot simply treat the platform as a single rigid body. Instead, we will treat the platform as multiple separate buoyant bodies – all present in the same diffraction analysis – so that the influence of each neighbouring body is accounted for.

## OrcaWave diffraction analysis

### Mesh

When performing a multibody diffraction analysis, each individual body must reference a mesh file. In this case the three outer columns known here as the 'Aft offset column', 'Port offset column' and 'Stbd offset column' have identical geometry. Therefore, all three outer columns reference the same mesh file. We then translate each instance of the body mesh into the correct location by specifying the mesh position on the OrcaWave *Bodies* page. The 'Centre column' references a separate mesh file. The *Body* drop down box is used to navigate between the properties for each body when on the *Bodies* page.

The supporting cross members and pontoons have not been included in the mesh files. We assume Morisons equation is a more appropriate method for describing their contribution to the fluid loading on the platform.

In OrcaWave version 11.4, a new field was added to the *Bodies* page named *Hydrostatic stiffness method*. In this example we use the 'displacement' method which follows the default behaviour of the program in past releases. Under this configuration, each body mesh must be closed. This is true when working on single or multibody analyses. The other option is to use the 'sectional' *Hydrostatic stiffness method*. Whilst not considered in this example, the sectional method allows a user to define a multibody analysis using one or more open ended meshes. This feature allows users to isolate the loading on different regions of a hull, on the condition that all the meshes present in the multibody analysis come together to form one or more closed volumes.

In this example, the OrcaWave analysis has been configured to use the *control surface integration method* when calculating quadratic results. This method requires an additional mesh which, when combined with the body mesh, encloses a finite volume of water around the body. Since this is a multibody example, each body references its own control surface mesh and they have been defined so that they do not collide with the panels of another body.

Whilst preparing this example, a mesh sensitivity study was undertaken to ensure the body and control surface meshes were suitably refined to return converged vessel properties. For more information on working with meshes in OrcaWave, and the relationship between mesh refinement and results quality, see our document available on the papers and technical notes page of the Orcina website.

### Body connections

On the *Constraints* page, rigid connections have been defined between each outer column and the centre column. These connections are necessary to ensure the four bodies respond as a single rigid system. Note that the centre column has no connection defined to avoid a circular reference.

In reality these connections are not perfectly rigid because the connecting members will experience a degree of axial deformation, bending and torsion. OrcaWave is not capable of considering a semi rigid connection and so, for the time being, we assume these connections are rigid. Later we will model the system in OrcaFlex and these rigid connections between bodies will be replaced by line objects with structural properties.

### Mass and Inertia properties

The mass and inertia specified in an OrcaWave analysis should be representative of the entire floating system, including any significant mass and inertia representing the structure above the waterline. In this case we are interested in analysing the semi-sub when it is in a loaded condition with mass and inertia equivalent to that when the turbine rotor, nacelle and tower are installed along with ballast water. The mass of the mooring lines has not been included since their influence is small and will change depending on the environmental conditions and the model dynamics.

Since the four bodies are connected in OrcaWave, it is not strictly necessary to distribute the mass and/or inertia between the bodies at this stage. The connections are rigid and so the OrcaWave results will be consistent even if all the platform mass and inertia is assigned to a single body. However, an accurate distribution of the mass and inertia will be required in OrcaFlex if the loads passing through the supporting members are to be accurate. Consequently, we have chosen to distribute the mass and inertia in OrcaWave to remove the need to modify the imported vessel type data at a later stage. The centre column has been used to carry its own mass and inertia in addition to the extra mass and inertia of the turbine assembly, pontoons and cross bracings. The outer columns carry the mass and inertia of their own structure as well as that of the ballast water. These properties are specified on the OrcaWave *Inertia* page.

### External stiffness and damping

In order to make an accurate calculation of the displacement RAOs and any dependent results (mean drift load, QTFs, sea state RAOs), OrcaWave allows you to define external stiffness, external damping, Morison elements, constraints and connections. In this example, we are calculating mean drift loads and so the centre column stiffness matrix has been populated to represent the external stiffness provided by the platform mooring arrangement (see example L02 OC4 Semi-sub for an explanation of how to generate a mooring stiffness matrix). This stiffness will be replaced by line objects when modelling the system in OrcaFlex.

Furthermore, additional damping has been assigned to the system, as in example L02. Bearing in mind our goal is to assess the loads in the pontoons and cross bracings, technically you might expect to see the external damping distributed across all four bodies. However, without an obvious method for distributing the damping, this aspect of the model has been neglected and all the external damping has been assigned to the centre column.

### Setting up the diffraction analysis

For convenience, many of the same model settings have been carried through from example L02. For further information, see the same example for a description of:

- Calculation & output settings
- Environment settings
- Morison elements representing pontoons, cross bracing and columns
- Morison drag linearisation.

# OrcaFlex dynamic analysis

### Setting up the OrcaFlex model

When importing the OrcaWave results file to OrcaFlex, each body is assigned a new *vessel type*. Unlike a typical analysis, buoyancy properties and added mass & damping properties are stored under the *multibody group* data form. The connections between bodies – defined in OrcaWave – are also carried through to the vessel objects, but in this case the rigid connections have been replaced by line objects representing the pontoons and cross bracings. The line ends have been connected to the relevant vessel objects and the connection status of each vessel set to 'Free'.

The line objects have been defined so that they attract Morison drag. Consequently, the Morison elements which represent the pontoons and cross bracings – carried through from the OrcaWave analysis – have been removed. The Morison elements that represent the columns still exist and they have been distributed appropriately. This example does not include sea state RAOs, therefore the line objects are subjected to a fluid velocity derived from the undisturbed wave field.

Furthermore, please note that the Morison elements and line objects used in this example have been included to model viscous drag acting on the cross bracings, pontoons and columns. This approach aligns with that taken for example L02. OrcaWave and OrcaFlex are also capable of modelling added mass on Morison elements. These effects have been neglected throughout this example but could be included in your own analysis.

When building the OrcaWave model, the mass and inertia of the pontoons and cross bracings were lumped onto the centre column. Now that the support members have been modelled as line objects, the properties of the centre column must be updated. For convenience, we can use the *compound properties* report to calculate the mass, inertia and centre of mass of the pontoons and cross bracings. The *inertia compensation* feature available on the centre column data form is then used to remove the pontoon and cross bracing mass and inertia contributions. The centre column still includes mass and inertia contributions from the turbine assembly.

Corrections have also been made to the total displaced volume. OrcaWave estimates the displaced volume based on the body mesh. Each mesh contains many flat panels that result in a facetted geometry where the total displaced volume is often underestimated. The finer the mesh, the smaller any discrepancy. In this case, the centre column displaced volume has been increased so that the total displaced volume of the entire floater equals 13917m$^3$. The total displacement includes contributions from all four vessels as well as the submerged pontoons and cross bracings, with the system floating at the design draught. Finally, the mooring arrangement from example L02 example has been incorporated.

### Results – Platform response

In order to demonstrate that the single and multi-body analysis methods are both capable of representing the semi-sub platform, a comparison of the platform motions has been made. Figure 1 shows reasonable agreement in surge, sway and heave. More significant differences exist when comparing the rotational degrees of freedom.

A small change in the platform response is to be expected now that the cross bracings and pontoons are explicitly modelled in OrcaFlex. The cross bracings and pontoons are represented by line objects which have volume and OrcaFlex is able to estimate the change in displacement as the cross bracings and pontoons submerge and emerge from the water. In the single body model, the variation in cross bracing and pontoon buoyancy is neglected.

Further investigations demonstrated good agreement between the single and multibody analysis methods when running with a smaller wave height (see Figure 2).

Similarly, good agreement was observed when running a simplified linear frequency domain analysis. Note that at the time of writing, multibody groups are not compatible with the frequency domain solve type. Therefore, the frequency domain analysis was undertaken without added mass or damping and without the multibody group data. From this we can conclude the differences observed when comparing the single and multibody analysis methods under larger waves are most likely caused by non-linear effects that develop in the time domain simulations.

Unlike a diffraction analysis, where the wave height is infinitely small. OrcaFlex is capable of modelling waves of finite height. Furthermore, OrcaFlex calculates the response of a vessel object based on a dynamic reference frame. When a vessel object with calculated primary motion responds to the loads placed upon it, there may be a change in the incident wave direction and wave phasing. This can cause second or higher order effects to develop. These effects do not appear in a linear frequency domain analysis, and they are less significant when the wave height and platform motions are small. In this example, dividing the platform into four separate vessel objects appears to result in the development of subtly different non-linear effects.

**Results – Structural response**

Unlike example L02, where the platform consisted of a single rigid body vessel, we now have the ability to report the structural response of the cross bracings and pontoons. Without any data to compare the results to, we have focussed on demonstrating that the structural response is consistent when the incident wave direction is varied.

Figure 3 shows a comparison of effective tension time histories at nodes mid-way along the span of each cross brace. In each case the wave direction has been modified (60, 180 & 300 deg) and the centre of mass of the platform updated to account for reorientation of the turbine assembly. The results show very good agreement and demonstrate the platform experiences consistent loading when the wave direction changes. This is expected given the symmetrical distribution of the support members, and the fact the aerodynamics properties of the turbine assembly have been omitted.

Note that results have been logged at 1s intervals throughout to aid visual comparison in the various plots.

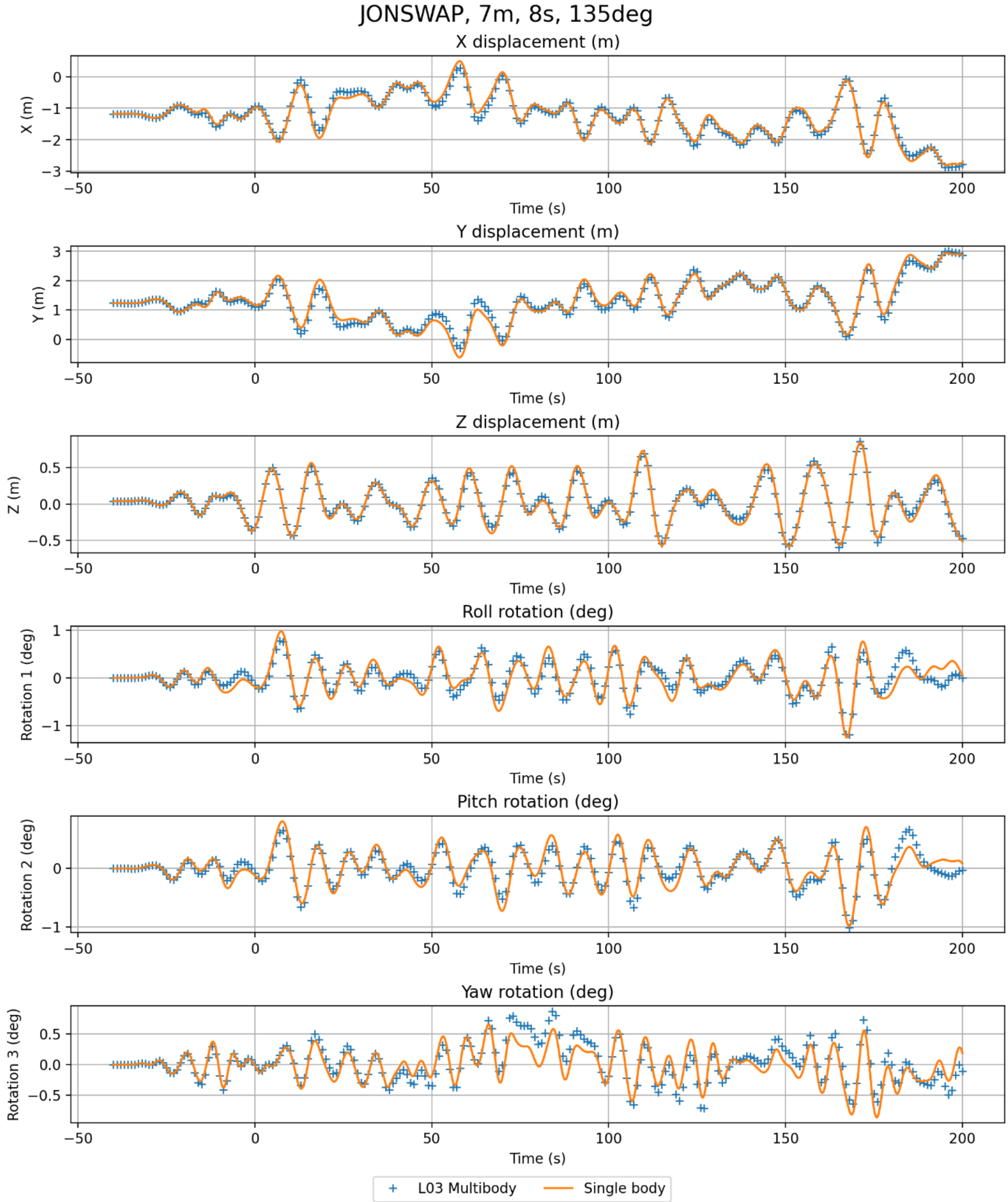



**Figure 1 – Time histories of surge, sway & heave displacement, roll, pitch & yaw rotation (7m Hs, 135 deg sea).**

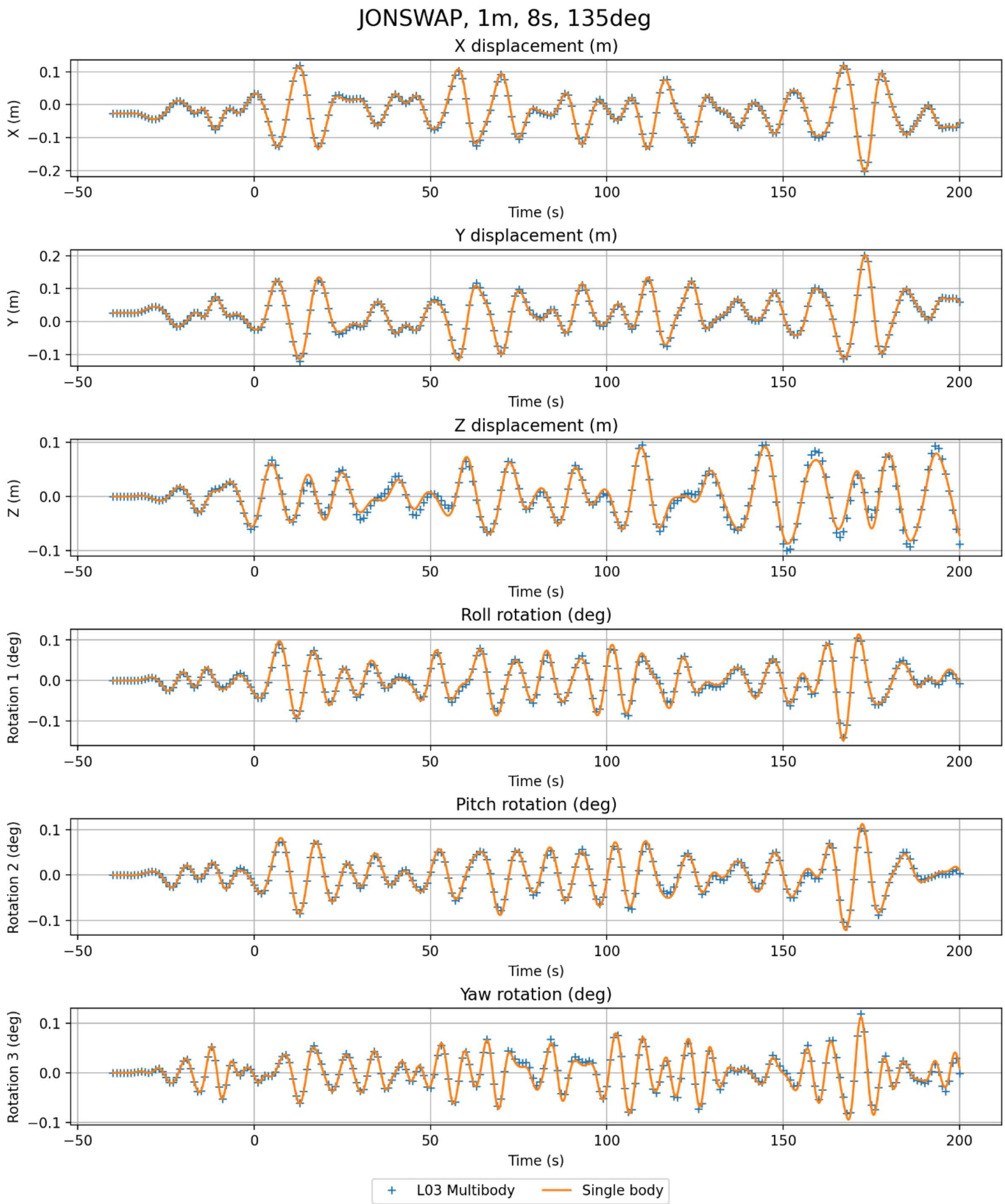



**Figure 2 – Time histories of surge, sway & heave displacement, roll, pitch & yaw rotation (1m Hs, 135 deg sea).**


**Figure 3 – A comparison of effective tension at the mid span of cross bracings 1, 2 & 3 when subject to an incident wave direction of 60, 180 & 300 deg respectively.**

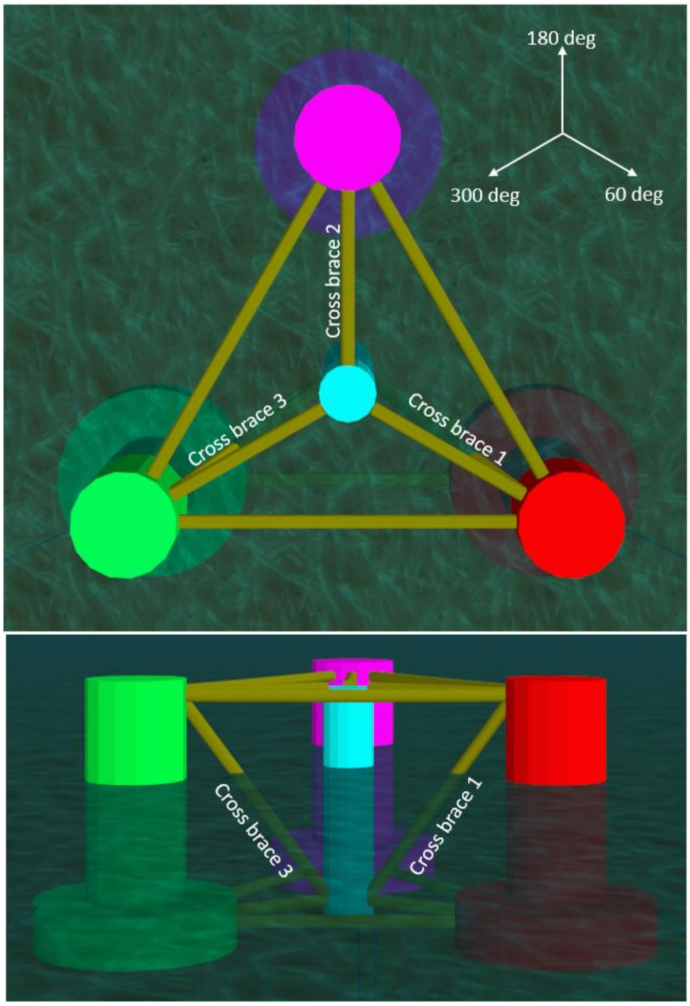



**Figure 4 – Labelled diagram identifying cross bracings and wave directions.**