L04 Sectional bodies

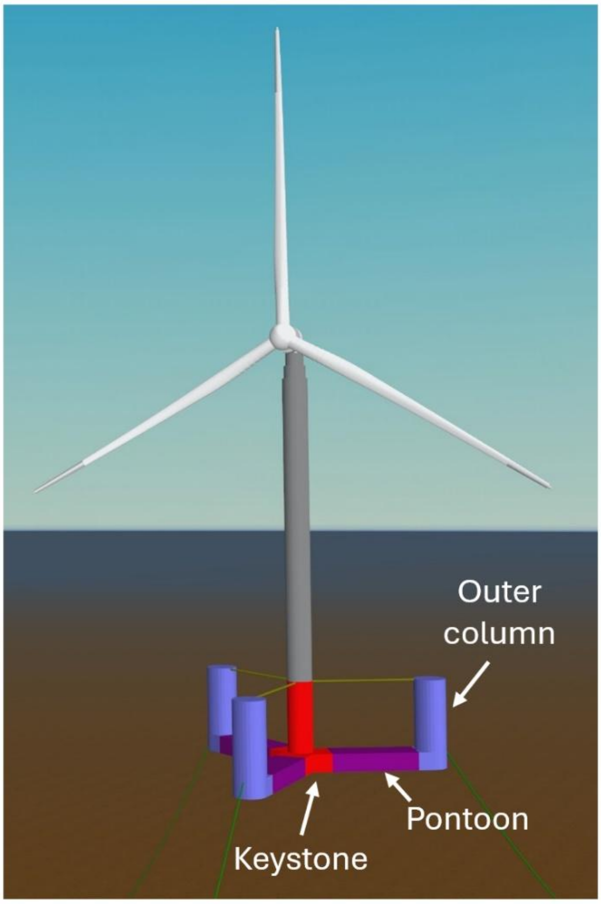
Introduction

OrcaFlex and OrcaWave have been capable of undertaking multibody analyses for some time. Prior to v11.4, we worked under the assumption that each diffraction body was a closed volume and users were able to model multiple hulls in close proximity. In example L03 we demonstrated this capability whilst modelling a semi sub platform. In v11.4 multibody functionality was enhanced to allow a diffraction system to be constructed from many sectional bodies. These sectional bodies must form one or more closed volumes when considered as a system, but each sectional body can be represented by an open mesh.

In this example we use OrcaWave to undertake a sectional body diffraction analysis of a semi submerged platform. Furthermore, we discuss how this approach can be used to introduce flexibility into a platform as well as understand the distribution of loads in the structure using OrcaFlex. We anticipate that the results reported by OrcaFlex could be used to inform a targeted analysis conducted with specialised structural analysis software.

Model properties

This example is based on the UMaine VolturnUS offshore wind platform as used in our K03 example. For details on the floater properties, see the K03 description document. The floater is modelled assuming the same loading condition as the K03 example with the turbine assembly fitted.



The floater has been divided into seven sectional bodies each holding a share of the mass and inertia of the whole floating assembly. Using the limited information available from example K03 and the VolturnUS reference document, we chose to divide the structural steel mass and inertia evenly between all seven sectional bodies. The fluid ballast was divided equally between the three pontoons and the fixed ballast divided equally between the three outer columns. The Keystone section in the centre carries the remaining mass and inertia, including that of the turbine assembly. Our approach to distributing the known mass and inertia was intended to produce a suitable OrcaFlex example. In practice, an accurate description of mass and inertia is very important to ensure the load distributed across the structure is representative of the real system.

Finally the diffraction analysis results are used to populate vessel type data for seven vessel objects in an OrcaFlex global analysis where the K03 turbine assembly is explicitly modelled.

OrcaWave diffraction analysis

A sectional body diffraction analysis builds upon the approach used for single body diffraction analysis. The principles discussed in our other diffraction examples still apply, however the diffraction results are now reported for multiple bodies, each representing a section of a hull as opposed to a complete floating body. Accompanying this description document we have included an OrcaWave results file and the associated mesh files.

Dividing a structure into multiple sectional bodies

Like the conventional multibody analysis discussed in example L03, the user must specify a mesh file for each body on the *Bodies* page. In this example we began with the same source mesh as example K03, however each mesh file included with this example now represents a subset of panels that we refer to as a sectional body. OrcaWave is not capable of dividing a mesh into sections, instead division of the body mesh into groups of mesh panels must take place beforehand. This could be achieved through manual manipulation of the mesh file, however for complex forms it is most easily accomplished in a meshing tool.

The number and extent of the sections used to describe a sectional multibody system is driven by the user and the application. A larger number of smaller sectional bodies will offer greater resolution when reporting the distribution of loads across the hull. In this sense, splitting the body into sections is analogous to discretising a line object into segments and increasing the number of nodes where loads act. However, a greater number of bodies will also demand more effort when building the model and longer run times during OrcaFlex analysis. In the extreme, consider a hull where each panel in the body mesh is represented by a different sectional body. This approach would provide results at a very fine resolution across the hull, however you will probably be able to reach the same conclusions more rapidly using much coarser discretisation.

If the purpose of the analysis is to investigate connection loads, it may be preferable to divide the structure into sections at known boundaries. In this example we have chosen to discretise the body into seven sections. The boundaries were positioned close to the interfaces between the outer columns, the pontoons and the central Keystone. OrcaWave will check to ensure that the sectional body meshes unite to form one or more closed hulls when truncated at the waterline. The panels from adjacent sections should unite leaving no gap or overlap at the interfaces.

As explained in our previous examples, diffraction analysis results are heavily dependent on the quality of the meshes used to describe the bodies. Mesh sensitivity studies are still important, however it may be more efficient to run a sensitivity study using a conventional single body diffraction analysis. Once you are confident that your mesh is good enough, you could consider dividing the mesh into several sections.

Hydrostatic stiffness method

Once the sectional body meshes have been specified, the user must change the *Hydrostatic stiffness method* specified on the *Bodies* page from 'Displacement' to 'Sectional'. This data item was introduced in v11.4 to support the sectional bodies feature. In previous versions of OrcaWave, all models used a method equivalent to the default selection of 'Displacement'. Choosing the 'Sectional' hydrostatic method indicates that the body mesh is open and that hydrostatic stiffness must be treated differently.

The influence of changing the hydrostatic method becomes apparent when you look at the hydrostatic results. We describe the hydrostatic properties of a displacement body using a symmetric 3x3 stiffness matrix that captures heave, roll and pitch degrees of freedom. For sectional bodies, there are now more non-zero terms in the full 6x6 hydrostatic stiffness matrix and the symmetry has been lost. Furthermore the hydrostatic results also include mean hydrostatic forces and moments. These forces and moments describe a static buoyancy acting in each degree of freedom. For a closed body, most of these loads are zero. However, when you consider a sectional body in isolation, the open nature of the mesh can lead to non-zero mean hydrostatic surge and sways loads acting on a sectional body, for example.

OrcaWave constraints

In this example we have seven sectional bodies that come together to represent one structure. Each OrcaWave body can, by default, move freely and so rigid connections have been specified on the *Constraints* page to force the system of bodies to move as one. Connections have been defined between each column and the respective pontoon and between each pontoon and the central Keystone. The order or precise chain of connections is not critical at this stage, although sensible choice of connections may save time when transitioning into OrcaFlex global analysis.

OrcaWave acknowledges the connections between bodies when calculating displacement RAO motion. This motion is then used during the calculation of other results such as mean drift loads, full QTFs, sea state RAOs and panel pressures.

An external stiffness matrix has also been defined. This stiffness matrix is a linear representation of the mooring stiffness acting on the system. Once again it is used to improve the calculation of the displacement RAOs, and results dependent on displacement RAOs. For more information on how to define a mooring stiffness matrix, see example L02.

Calculation & output preferences

Use of OrcaWave sectional body functionality leads to some limitations when setting the calculation & output preferences. For example, the 'Control surface integration' *quadratic load calculation method* is not compatible with the sectional bodies feature. That means users wanting to calculate mean drift loads or full QTFs are limited to the 'Pressure integration' or 'Momentum conservation' *quadratic load calculation methods*. Note the 'Momentum conservation' method is only capable of reporting loads in surge, sway and yaw for the ensemble of all bodies. Therefore, it is unlikely to be suitable for an analysis of sections. Nevertheless, it may be useful for comparing against aggregated loads from the pressure integration method for the purpose of assessing mesh convergence.

We have demonstrated how to calculate second order wave loads in previous diffraction examples. We have also demonstrated the effectiveness of different quadratic calculation methods in the Working with meshes technical note. In this example, second order loads have been neglected and OrcaWave has been configured to calculate first order results only, using the 'Potential formulation only' *diffraction solve type*. Strictly speaking, specification of OrcaWave constraint data (as discussed above) will only stand to influence the displacement RAOs in this analysis.

OrcaFlex global analysis

The OrcaWave diffraction data has been imported into OrcaFlex by dragging and dropping the OrcaWave results file onto the OrcaFlex window (see *L04 Sectional bodies.sim*). In doing so, each of the seven sectional bodies becomes a vessel object with its own vessel type data. This is a multibody model and so multibody group data are also populated.

Extended multibody group data

Multibody models store extended system data on the *multibody group* data form accessed via the *model browser*. On the *added mass & damping* page, we see that multibody models store extended matrices that describe the load on one body due to oscillation of another member of the group. On the *stiffness* page, we find the hydrostatic properties for each member of the multibody group. As discussed earlier, the hydrostatic properties of a sectional body must be considered differently. The selection of *stiffness method* ('Displacement'/'Sectional') made in OrcaWave is carried through to the OrcaFlex multibody group. For a sectional body, the hydrostatic data comprises non zero mean hydrostatic forces and moments and a larger 6x3 hydrostatic stiffness matrix.

Connections

As part of the diffraction analysis, we nominated rigid connections between each column, pontoon and the central Keystone. These connections are carried through to OrcaFlex during the import process. Direct connections between vessels can be useful, however there is scope to enhance the connection properties in OrcaFlex using other objects.

Vessel to vessel direct connection

When one vessel is connected directly to another, you have the opportunity to report connection loads. Similarly you can report time histories of the included effects acting on each vessel and summary results which break down different loading contributions at a particular point in time. However, those loads are reported at the vessel origin which may be located in an inconvenient position. Furthermore vessel connection loads summarise the total load applied to the vessel from all connected objects. One vessel may have several objects connected to it and so isolating the load at a particular junction can be challenging.

Connections using chains of constraints

To understand the loads at a particular location in the structure, constraint objects can be introduced into the chain of connections. Constraints can be placed at a precise location and used to connect one vessel to another. In doing so, constraints can be used to resolve the distributed load at a particular location. Constraints with double sided connections are particularly useful as you can set the in-frame and out-frame connections on a single data form. However it is important to note that the indirect method used to model double sided constraints is not compatible with modal analysis.

Constraints can also be configured to allow a degree of flexibility, although consideration should be given to whether this would produce motion consistent with the OrcaWave diffraction analysis. Summary results or time histories of the included effects can still be reported for each member of the multibody group to understand the different loading components and how they vary across the platform.

Connections using lines

Finally, in some cases line objects can be used to represent structural beams which tie the sectional multibody group together. This is an attractive option as line objects are able to deform introducing a degree of flexibility to the structure. Lines objects also have a very extensive list of results including the ability to report range graphs.

Having said that, the OrcaFlex line structural model has some limitations. These limitations should be considered before proceeding:

- The OrcaFlex line model assumes line objects are long, slender cylinders. The cylindrical assumption is important when OrcaFlex calculates the line volume, when modelling contact and when calculating stress results. Stress results are calculated assuming the line is a pipe made from homogenous material.
- Line objects are modelled according to Euler Bernoulli beam theory where shear deformation is neglected. For large cross section members, this simplification may not be acceptable.
- Vessel objects typically represent large scale structures with large mass and inertia. The structural members used to support these systems are very stiff. Such high stiffness lines can be challenging for the OrcaFlex solver to handle. This issue is compounded when attempting to model the beams with negligible mass. To overcome this issue, the structural member could be treated in the same way you might model the superstructure for a floating wind platform. The line would be assigned realistic mass properties, the inertia compensation feature could then be used to compensate for mass, inertia and hydrostatic stiffness effects. However care is still required to ensure no buoyancy is added to the system.

OrcaFlex model configuration

In this example we have used direct constraints to connect the seven members of the multibody group together. Constraints have been placed at the junction between each multibody group member so that the load can be monitored.

It is important to recognise that OrcaFlex does not have information regarding the detailed cross section of the structure or load path at the constraint location. Instead, the sectional body approach allows the user to distribute the load across a structure that otherwise would be considered whole. The constraint objects that connect the members of the multibody group offer an opportunity to resolve the distributed load at known locations.

Furthermore the constraints have been configured with two free rotational degrees of freedom to represent bending of each pontoon. A linear rotational stiffness has been applied to approximate the bending stiffness in each DOF.

The stiffness has been calculated assuming the pontoon is a thin-walled steel beam of rectangular cross section. The beam bending stiffness has then been converted to rotational stiffness with the appropriate units. The beam has non-isotropic bending stiffness. To accommodate these properties using OrcaFlex constraint objects, two constraints have been chained together. One free in *Ry* and one free in *Rz*. Chaining constraints in this way is satisfactory provided the magnitude of the rotations remains small. The following convention has been used when naming the constraint objects:

KS-FP Ry = The constraint located at the junction between the Keystone and the forward pontoon which is free to rotate about the constraint local y axis.

KS = Keystone	FP = Fore pontoon	PP = Port pontoon
SP = Starboard pontoon	FC = Fore column	PC = Port column
SC = Starboard column	Ry = Free to rotate about Ly	Rz = Free to rotate about Lz

Radial struts

In example K03, spar buoys were used to model the aerodynamic load experienced by the three radial struts that connect the keystone and the outer columns. In this example we continue to model the aerodynamic loading on the radial struts using Morisons equation, however we have replaced the rigid spar buoys with flexible line objects that complement the flexible floating structure.

The VolturnUS definition document provides limited information on the properties of the radial struts. For the purpose of this example, we have used arbitrary structural properties. The radial struts have been modelled so that they hold their own mass. Therefore corrections are required to ensure their mass and inertia are not double counted. OrcaFlex vessel objects have an inertia compensation feature to facilitate this correction. We introduce this feature in example L02. In this case, we have chosen to make a single correction to the Keystone compensating for the radial struts and the explicitly modelled turbine assembly. In practice, careful use of this feature is necessary otherwise the distribution of loads in the structure will be incorrect.

Modelling the radial struts with line objects also leads to a small change in the way that axial drag is calculated. Line objects are typically long slender structures. Axial drag is calculated at each node using a drag area equal to the surface area of the half segment either side of the node, ignoring the two end faces. In contrast spar buoys are often used to model cylinders that have larger diameter and limited span. The calculation of axial drag is made using a user specified drag area, often equal to the area of the end face. In example K03, the spar buoy drag coefficient was chosen with the corresponding reference area in mind. Therefore, a correction has been made to the axial drag coefficient so that the drag load experienced by the struts in this model is consistent.

Quadratic damping

In keeping with example K03, we have included quadratic other damping terms to approximate the hydrodynamic drag that acts on the platform. The damping terms are sourced from the viscous damping matrix presented in the VolturnUS platform definition document. This other damping has been applied to the Keystone only. Obviously in reality the drag load is distributed across the structure and it would be more appropriate to model drag on each member of the multibody group. This could be approximated by calibrating Morison elements or buoy object properties.

Comparing the single body and multibody response of the system

When building a multibody analysis, it is reassuring to verify that the system response in statics and dynamics is similar to that of a single body representation. In example L03, we presented a comparison of vessel motions when modelling a semi-sub platform as a single body and as a system of four vessels. While the results were not identical, a very similar response was observed, with the discrepancies diminishing as the wave height was reduced. It is known that OrcaFlex vessels subjected to first order loading are capable of experiencing non-linear effects in their calculated motion, effects that develop naturally in time domain analysis. So much so, we have methods to avoid any double counting of common second order loads when second order effects are included. When you discretise a floater into several vessels, those naturally occurring second order loads develop in a subtly different way. The same observations should be expected when working with systems of sectional vessels.

Reporting connection loads in statics

When running a static analysis on the system in still water, we can report constraint connection loads to interpret the influence of the distributed hydrostatic load on the platform. Opening the workspace *L04 Static workspace.wrk* will automatically show some connection loads of interest. To make this easier, all the constraint objects have been orientated so that the in-frame local x axis (Lx) points radially outwards. The in-frame Ly direction is perpendicular to this and Lz vertically upwards when the platform is in the reset condition.

In-frame connection Ly moment is the component of the total moment applied to the in-frame by the object it is connected to when measured about the constraint local y axis. Table 1 shows that the Ly moment reported at the constraint connecting the Keystone to each pontoon is positive. From this we can infer that the platform is experiencing a sagging condition. This is primarily driven by the net buoyant outer columns and the long lever arm between each column and the Keystone.

As the legs of the platform rotate, closing around the Keystone, they induce compression in the radial struts. Compression in the radial struts also results in a negative moment reported at the constraint connecting each pontoon to the respective column. See figure 2 where platform flexibility has been exaggerated by artificially reducing the constraint rotational stiffness.

Obviously, these findings are heavily influenced by our interpretation of the distribution of mass across the system. Similarly, the results are influenced by the flexibility of the platform modelled through constraint rotational stiffness and line structural properties.

Despite the geometric symmetry of the platform, the port and starboard loads reported in Table 1 are not consistent. This asymmetry is driven by the mass properties of the turbine assembly which induce non-zero platform pitch and roll angle in statics. This leads to variation in the hydrostatic stiffness experienced by members of the sectional multibody group used to construct the floater.

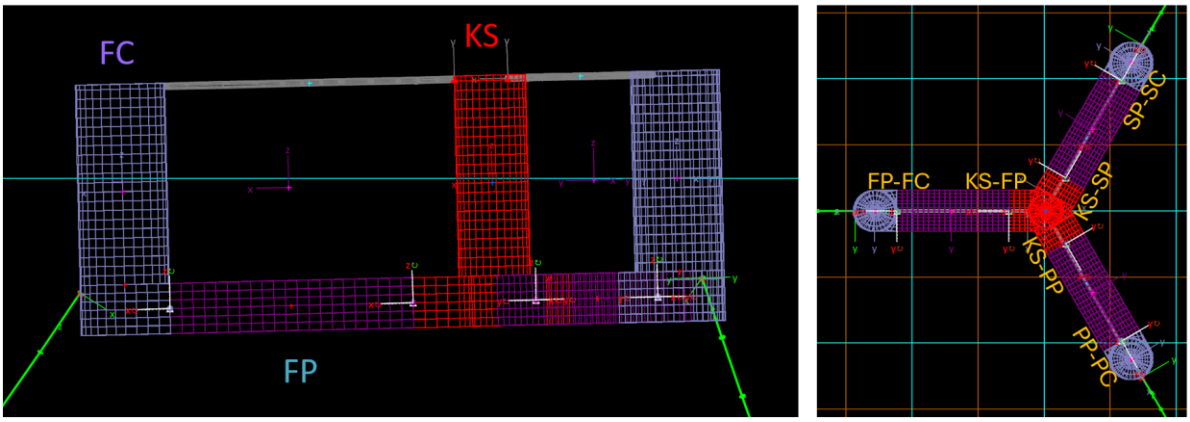


Figure 1 – Static analysis in still water.

Platform leg	Keystone Pontoon Ly moment (kNm)	Pontoon – Outer column Ly moment (kNm)	Radial strut Effective tension (kN)
Forward	162.9e3	-104.2e3	-6017.38
Port	115.3e3	-71.91e3	-4358.89
Starboard	114.5e3	-71.39e3	-4333.19

Table 1 – Positive Ly moment reported at constraint objects in statics.

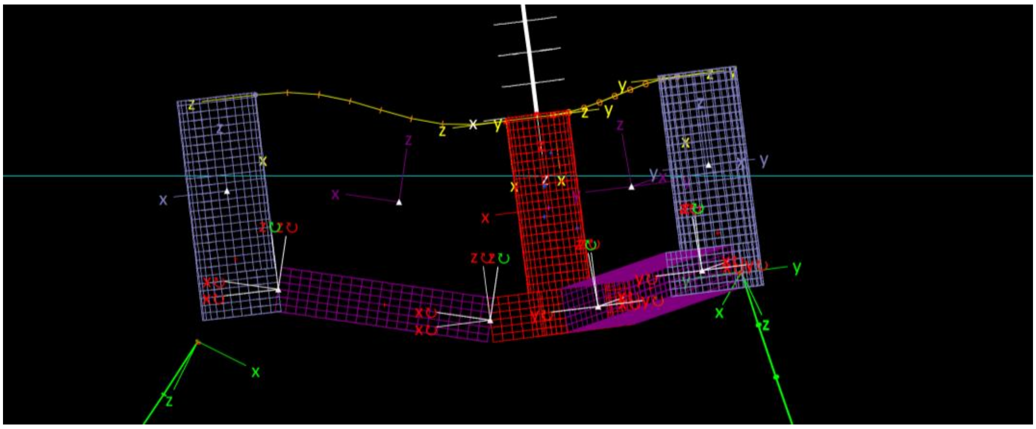


Figure 2 – Static analysis representing exaggerated platform flexibility.

Reporting structural loads in dynamics

Moving over to dynamics, the multibody group was subjected to waves and the system was free to respond leading to complex loading on the system. In this limited example we will inspect the compressive load in the *Fore strut* line object, which can be viewed by opening the workspace *L04 Dynamic workspace.wrk*.

Figure 3 is a range graph of effective tension in the *Fore strut*. It reports the minimum, maximum and mean effective tension experienced by the line object, reported at each mid segment and at the line ends over the whole simulation duration. Assuming the radial struts are thin-walled steel cylinders where the ends of the strut have en-castre boundary conditions, we can estimate the buckling load for the strut - of length 40.5m - to be:

$$P = \frac{4\pi^2 EI}{L^2} = 14609.2\text{kN}$$

Figure 3 shows that in this case, the peak compressive load is smaller than the estimated buckling load. Comparison across many load cases would allow a user to identify the most onerous conditions and could form the basis of a targeted analysis in specialised structural analysis software. This analysis could be enhanced further by releasing the turbine and subjecting the system to wind conditions. The influence of aerodynamic loading and a spinning rotor would then be transmitted from the turbine through the tower to the group of objects used to represent the platform.

OrcaFlex also uses Euler buckling theory to report a compression limit when reporting range graphs. The calculation is very similar to the estimate of buckling described above, however this limit represents the amount of compression a line segment can absorb before it would experience buckling, assuming the beam length is equal to the segment length and the segment boundary conditions are pinned. OrcaFlex undertakes the calculation to warn the user if the line segment is too long. The compression limit should not be confused with the load required to initiate buckling over the entire line object.

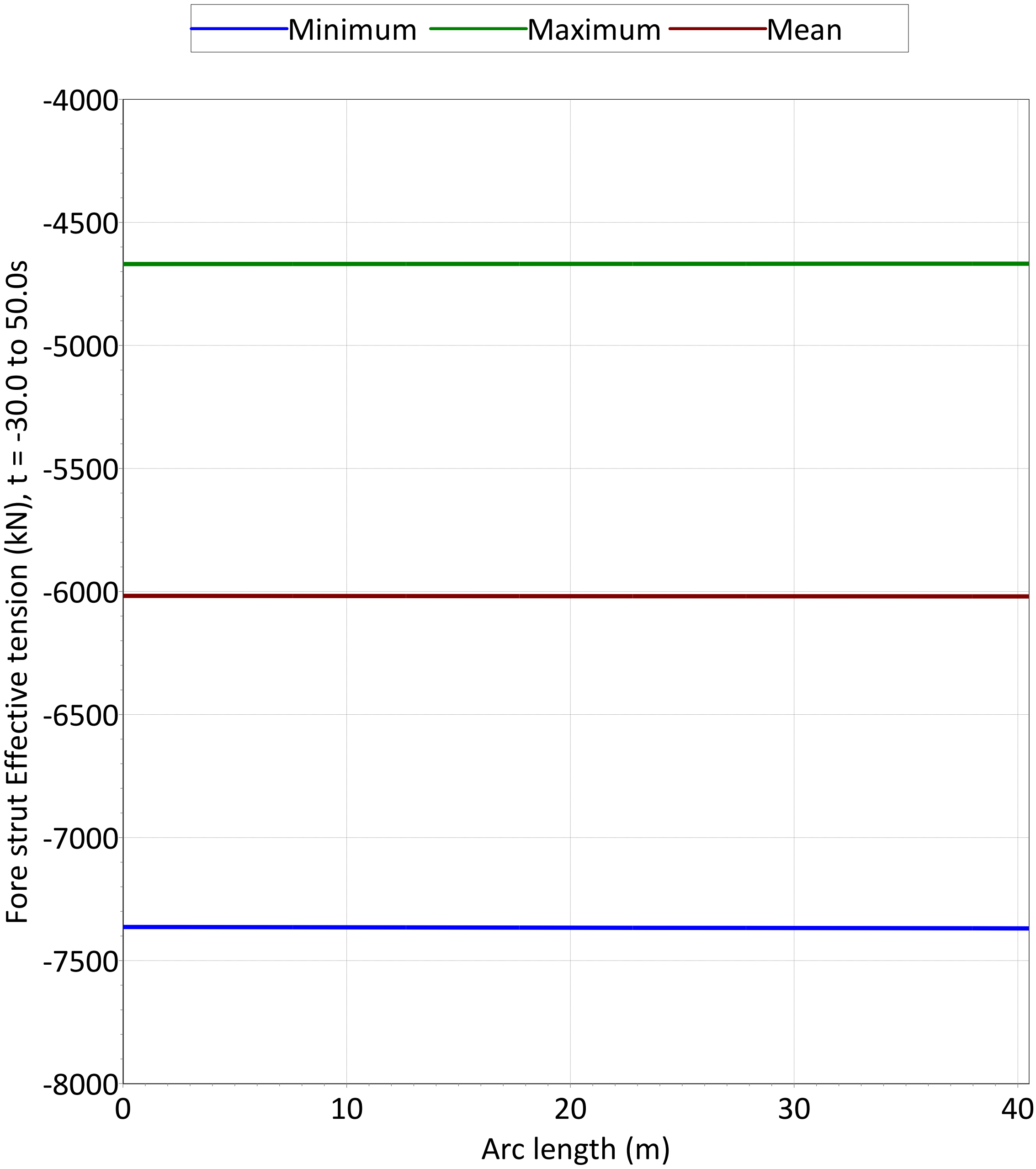


Figure 3 – Range graph of Effective tension in the Fore strut.