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## Coding the Code: Applying ISO 19905-1:2016 as a software package for site-specific assessments

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### Abstract

Site-specific assessments of jack-up platforms have been covered by the ISO 19905-1 standard as of 2012. This standard, by merit of its carefully thought-out structure and unambiguous wording, allows for fairly straightforward application as a computer program. This paper presents part of the required enabling technology to do so and a program based upon it: Calypso.

The concepts that are introduced in the ISO standard are implemented as classes in an object-oriented program design. At every level, the standard disseminates how to build a model which is suitable for calculations based on the parametric properties of the platform and site. The software strictly maintains this distinction between the (never changing) parametric model and the (site-specific) load model. The program automatically generates the load model based on the parametric platform model and site-specific parameters. This way a user can perform the assessment by merely providing site-specific parameters without concern regarding the modeling details.

The key enabling techniques and principles that were used to create the Calypso program which are not covered in the standard, are covered in this paper. This includes the application of an object-oriented programming paradigm, linear algebra concepts such as the principal pivot transform, structural analysis concepts such as the area-moment matrix and details regarding the implementation of the P- $\Delta$  effect. A benchmark wave load calculation is presented to show some of the capabilities of the program.

### Introduction

Calypso is a computer program for performing a site-specific assessment (SSA) as specified in ISO 19905-1:2016 [ref 1], in this paper referred to as *the ISO standard* or *the standard* for short. Calypso implements the standard by default, but allows the user to deviate from the standard at every level. Because of its open structure, Calypso is a 'white box', a system where the inner components and logic are available for



inspection. Further details and guidance as well as a sample calculation are provided in ISO/TR 1905-2:2013 [ref 2] (*the ISO commentary or the commentary for short*).

The Calypso computer program rigorously maintains a distinction between:

- *the parametric model,*
- *the site data and the*
- *load model.*

*The parametric model* describes the platform. Any parameters that may change, such as leg extension or variable deck load, are excluded from this model. The parametric model includes a geometrical description of each leg (either truss leg or cylindrical), a geometrical description of the spudcans, a model of the hull and a model of the leg-to-hull interface. These models are implemented following the definitions of the ISO standard. Setting up the parametric model requires expertise, particularly the leg-to-hull interface model and the hull model. The parametric model is detailed in the next section.

*The site data* describe anything that is site-specific, such as metocean data, soil data, airgap and variable deck load. Providing the correct input requires some skill in the operation of jack-ups, but does not require engineering expertise. The site data is described in the final section of this paper, in which a case study is performed.

*The load model* is generated by Calypso based on the parametric platform model and the site-specific data. The default setting in Calypso is to follow the ISO standard. The user can specify where to deviate from the ISO standard, for instance by providing a user-specified marine growth thickness profile. The load model, among others, consists of a wind and wave load model and a structural model. Calypso performs calculations on the models and performs all checks prescribed by the ISO standard. Checks may be amended by the user in order to perform any checks specified by a classification society. The load model and generation thereof are described in the third section of this paper.

This distinction between parametric model, site data and load model allows for a further specialization within the jack-up industry for performing site-specific assessments. The parametric model should be created by a jack-up engineering expert, preferably the designer of the platform. The site data may be given by anyone skilled in operating a jack-up. The time-consuming task of creating load models and performing calculations is left to a fully automated computer program. This frees up time for the expert to look into those parts of the SSA that truly require an expert's effort, such as evaluating the risks.

This paper introduces the Calypso program. It is programmed in Python using the object-oriented paradigm. This allows the program to closely follow the modeling as proposed in the ISO standard. It comes with a browser-based user interface for input of the site parameters, for performing the calculations and for presentation of the output. For the modeling of the jack-up, the work for the experts, Calypso comes with a well-defined application programming interface (API). Calypso comes with strong built-in methods for visualization to allow for inspection of the model, e.g. Figure 1. All graphics shown in this paper are generated automatically by Calypso.

The ISO standard alone is not sufficient to create a computer program. A selection of the required enabling technology is described in this paper. These topics are specific implementation details that may be valuable tools for any engineer. These topics are: the area-moment matrix, the principal pivot transform and the secondary stiffness matrix to account for the P- $\Delta$  effect. Several methods are used to include the P- $\Delta$  effect in a benchmark calculation. It is concluded that the leg moment is captured correctly only if an iterative method, of one iteration, is used.

Benchmarking Calypso is an on-going process. The last section of this paper presents a benchmark study for wave load calculation based upon the sample calculation as worked out in the ISO commentary.

Future plans for Calypso focus on inclusion of a crane model, so that the user would be able to quickly verify crane operations. Due to the modular object-oriented layout of the program, it allows for future addition of seismic simulations and going-on / going-off location simulations.

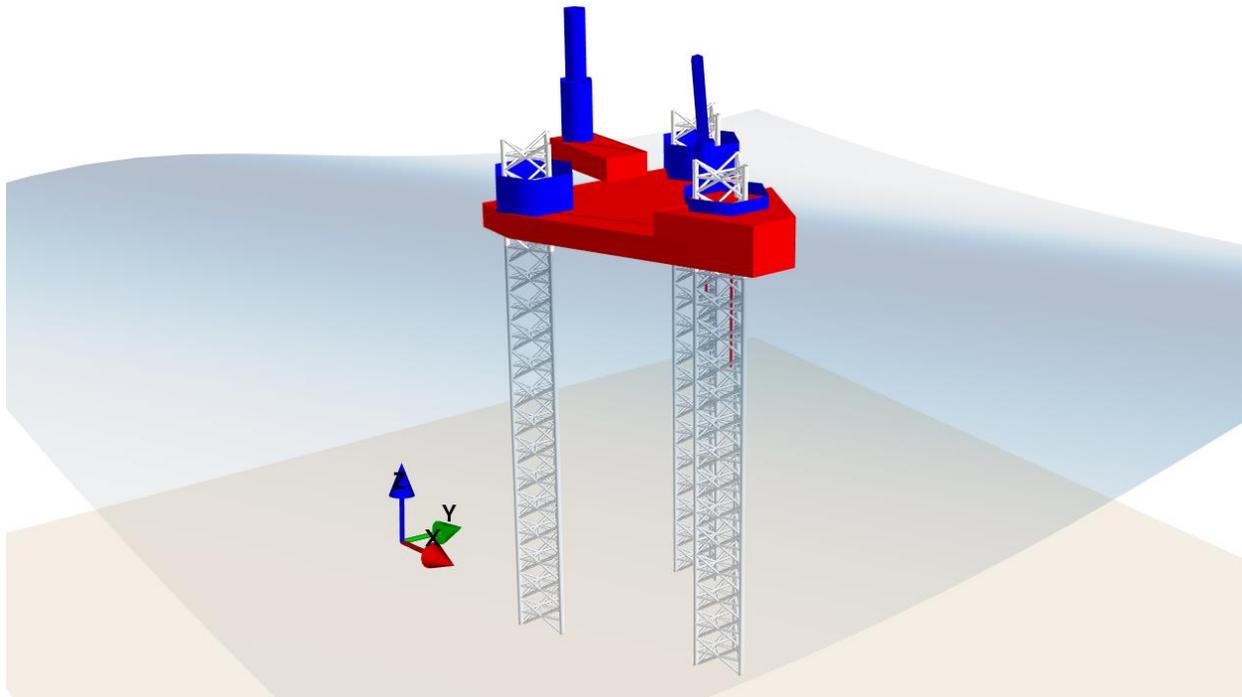


Figure 1 - Visualization of the Calypso jack-up model with the surface of a fifth order Stokes wave

## The parametric model

The parametric model is a description of the platform. It is used as a basis to generate the load model, which is used for calculations. The parametric model consists of separate models:

- Leg (including spudcan) model
- Hull model
- Leg-to-hull interface model

### The parametric leg model – modelling of the chord

A jack-up leg can be either a truss leg or a prismatic leg (cylindrical or square). Both can be modeled using Calypso. The truss type leg receives the most attention in the ISO standard and commentary, therefore it is highlighted in this paper as well.

Calypso allows the user to build up the cross section of the chord from basic shapes, such as rectangles and circular segments. The two chord types that get specific attention in the ISO standard, the opposed-rack split-tubular chord and the triangular chord member sections, are built into Calypso and can be defined by their shape parameters. Using one of these two standard chord shapes enables Calypso to automatically determine the hydrodynamic coefficients in addition to the weight, buoyancy, and stiffness parameters. Figure 2 shows the cross section of the chord as used in the sample calculation in the commentary.

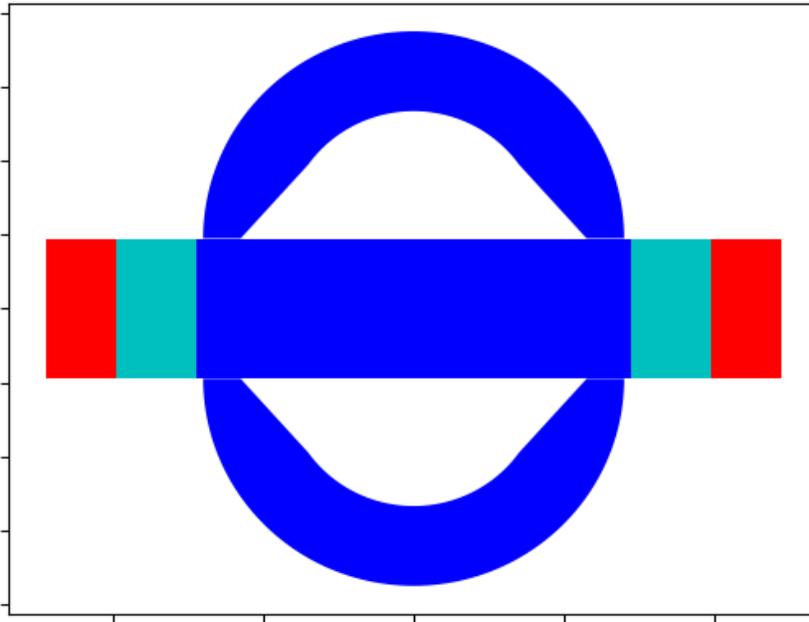


Figure 2 - Visualization of a split-tube opposed-rack chord based on a parametric model

### Selected topics (1) – the area-moment matrix

In order to combine basic shapes into a combined cross section, Calypso uses the area-moment matrix, which is an application of the parallel axis theorem. This method is most likely available in the public domain; however, the author has devised it himself and is not aware of any publications or of engineers using this tool in their work. The area-moment matrix stores the area, first moment of area and second moment of area of a cross section in a single  $A_{\text{moment}}$  matrix:

$$A_{\text{moment}} = \begin{bmatrix} A & S_x & S_y \\ S_x & I_{xx} & I_{xy} \\ S_y & I_{yx} & I_{yy} \end{bmatrix}$$



This matrix is symmetrical.  $A$  is the Area,  $S_x$  is the first moment of area integrated along the x-axis and  $I_{xx}$  is the second moment integrated along the x axis.  $I_{xx}$  is typically referred to as  $I_y$  in literature, the second moment integrated *about* the y axis.

Storing these values in this matrix form enables rotation and translation of the axis system without losing any of the relevant area data. The following matrix is used for translation:

$$T = \begin{bmatrix} 1 & -x & -y \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The negative  $x$  and  $y$  reflect the choice in Calypso to translate the origin of the axis system, not the location of the cross section within the axis system.

Now the translated area moment matrix becomes:

$$\hat{A}_{\text{moment}} = T^T A_{\text{moment}} T$$

The following matrix is used for rotation:

$$R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \alpha & -\sin \alpha \\ 0 & -\sin \alpha & \cos \alpha \end{bmatrix}$$

Again, the axis system is rotated, not the object. Now the rotated area moment matrix becomes:

$$\hat{A}_{\text{moment}} = R^T A_{\text{moment}} R$$

Any number of operations can be applied in series. If rotations only or translations only are performed, the order of the operations does not influence the final result. When combining rotations and translations, the order does influence the final result. Any number of cross sections, for which the axis systems are made to align, can be combined by adding the area-moment matrices.

### [The parametric leg model – modeling of the truss leg](#)

The parametric leg model for truss legs allows for several types of bracing, as defined in table 8.3-1 of the ISO standard. Type B is used for K-bracing and type C is used for X-bracing and split-X-bracing. The user merely has to provide cross sections for the bracing (including span breakers) and geometric information such as bay height and offsets.

The leg geometry defines the position and orientation of the chords. The leg is defined as a leg geometry, a stack of (different) bays, stacks of (different) chord sections and stacks of additional piping of which the position is part of the site data. The parametric model of the leg as presented in the commentary is visualized in Figure 3.

The spudcan, at the bottom of the leg, is defined as a set of truncated cones and cylinders. It has a user defined steel mass and stiffness. Modeling of a skirted spudcan can be done using a cylinder and user-provided weight of the soil plug.

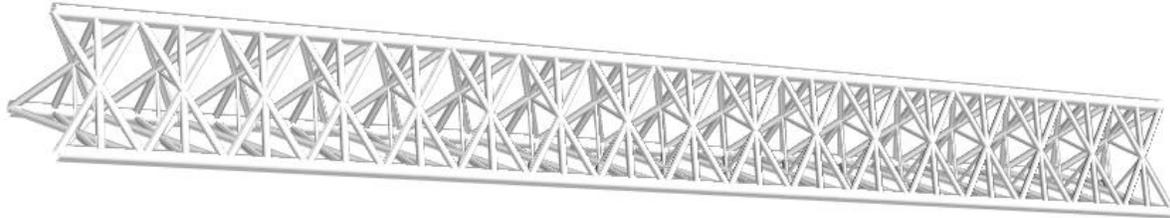


Figure 3 - Visualization of a leg based on a parametric leg model

### The parametric hull model

The ISO standard does not describe the modeling of the hull to the same level of detail as the modeling of the leg. Therefore, modeling the hull requires more expertise and effort from the user than modeling the leg. The model is a collection of geometric properties, indicating the depth of the hull, the leg locations, etc. Also, the shape of the hull and of any objects fixed to the hull are included for the benefit of the wind load model. A visualization of these blocks on a typical jack-up is presented in Figure 4.

Calypso comes with a standard, simple, rigid hull model which is used if no stiffness information about the hull is provided. The user may provide just the depth of the hull and thickness of the steel, based on which Calypso generates a simple grillage mutually connecting the legs and the center node. The user may also provide a self-defined grillage up to any level of detail. Finally, the user may provide a stiffness matrix connecting the guide nodes and center node, typically generated by an FEM model either by applying unit displacements or by generating a super-element.

The mass and rotational inertia may be assigned to the center node alone or distributed among any number of nodes in the hull model. The hull weight is defined directly by its mass. In case a grillage is defined, Calypso may include hull sagging if desired.

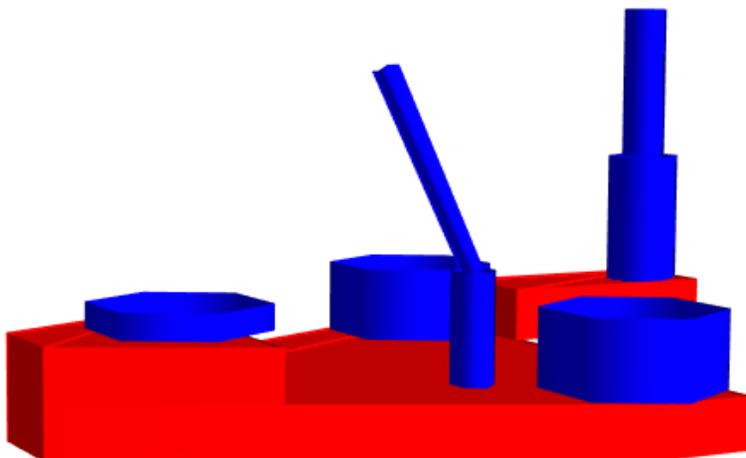


Figure 4 - Visualization of the hull shapes for the wind model



### The parametric leg-to-hull interface model

The leg-to-hull interface is incorporated parametrically according to section 8.5 of the ISO standard. It is used to generate an equivalent leg-to-hull interface stiffness and to perform strength checks on the leg as per section 12 of the ISO standard. Alternatively, the user may provide a leg-to-hull interface stiffness and location of the lower guide.

### The load model

The load model is used for calculations and is generated automatically by Calypso based upon the parametric model and the site-specific data. It consists of many separate but interrelated models, which are:

- The wind, wave and current load model of the legs
- The wind load model of the hull
- The structural (bar stool) model, with nodes, beams, links and hinges
- The weight model
- The mass model

### The wind, wave and current load model of the legs

The wind, wave and current load model consists of a stack of hydrodynamic properties for an equivalent leg as per section A.7.3.2.3 of the ISO standard. The user may specify a marine growth profile or use the default as per the ISO standard. The user may provide drag and inertia coefficients or use the default as detailed in the ISO standard section A.7.3.2. These values apply for both the wave/current load model and the wind load model. The inertia values are added to the node mass in the structural model as well.

The wind profile is based on user-specified site-specific conditions as is the wave model. Calypso will use the suggested wave model as per figure A.7.3.5 of the ISO standard unless specified otherwise by the user. The choice of regular wave models is between Airy, 5<sup>th</sup> order Stokes according to Fenton [ref 3], or the stream function according to Rienecker and Fenton [ref 4].

### The hull wind load model

The wind load on the hull is calculated as per section A.7.3.4 of the ISO standard based on the blocks as defined in the parametric hull model. The user may choose instead to provide a set of direction-dependent values for area and level of application of the wind force.

### The mass and weight model

The structural mass is known from the parametric leg and hull models. The user may have provided additional variable deck load and eccentricity in the site-specific parameters. The user may also overrule this definition and directly define elevated weight and eccentricity. The weight is determined based on the mass. For the submerged part of the leg, buoyancy is included based upon the parametric leg model.

### The structural model

The structural model represents the jack-up platform and its foundation as a bar stool model. Derived stiffness values are assigned to beams that connect nodes. All mass is lumped into these nodes. Nodes may be connected by beams, but also by springs, rigid links and hinges. Nodes have 6 degrees of freedom. It can be specified, per node, per degree of freedom, whether the force is input and the displacement is solved for or vice versa. This is done by performing a principal pivot transform on the global stiffness matrix. The P-Δ effect is included as a contribution to the stiffness matrix, dependent upon the internal axial forces.

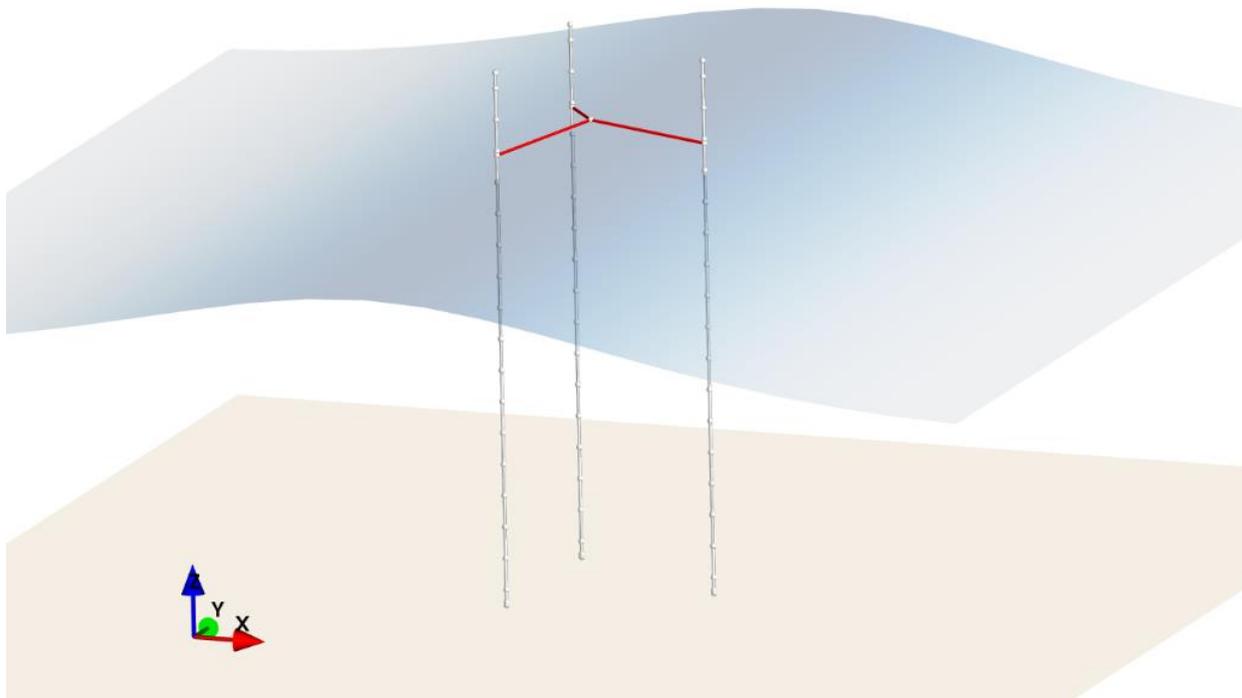


Figure 5 - Visualization of the structural model

### Selected topics (2) – the principal pivot transform

The principal pivot transform, e.g. as per Tsatsomeros [ref 5], is a transformation of a matrix that enables the exchange of selected entries on the right-hand side with the corresponding left-hand side. For instance, a stiffness matrix has the displacements on the left-hand side (LHS, the 'knowns') and has forces on the right-hand side, (RHS, 'the unknowns'), e.g.:

$$\begin{bmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ k_{31} & k_{32} & k_{33} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix} \text{ or } Ku = f$$

Where  $K$  is the stiffness matrix,  $u$  the displacement vector and  $f$  the force vector.



In practice, for some degrees of freedom of a structural model the displacement is known and for some degrees of freedom the force is known. This raises the need to exchange the LHS and RHS per degree of freedom, to arrange the matrix so that all knowns are on one side and the system can be solved.

The principal pivot transform (PPT) is a method to accomplish this. In Calypso the PPT is used for several purposes.

To hold the platform in place, each foundation element is connected to a node where all displacements are set to zero. For these nodes the displacements are known. In a typical calculation, an external force is applied to all the other nodes. For these nodes, the forces are known and the displacement is unknown. A PPT helps to create a system where all unknowns are on one side and the knowns are on the other side. Another use of the PPT in Calypso is when the user defines a displacement for a particular node rather than a force.

The PPT is also used in order to combine beams, for instance when there is a change of cross section of the chord within a bay. In this case a node is created at the discontinuity. No external forces are applied on this node, so the sum of the forces acting on the node should be zero. By exchanging the LHS for this node with the RHS, the zeros are on the LHS. Now the corresponding columns can be eliminated from the matrix. The displacements are on the RHS, but since the node is being eliminated, these are not of interest, and the corresponding rows can be eliminated from the matrix. Now the node has been eliminated, effectively combining the two beams into one.

The principal pivot transform is performed as follows. Firstly, the degrees of freedom to be switched are moved to the top of the force and displacement vectors. This requires row and column shifts of the matrix. Secondly, the matrix is partitioned in groups, grouping the degrees of freedom that need to be exchanged as such:

$$K = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix}, U = \begin{bmatrix} U_1 \\ U_2 \end{bmatrix}, F = \begin{bmatrix} F_1 \\ F_2 \end{bmatrix}$$

Where  $U_1$  and  $F_1$  are the parts of the displacement and force vectors that need to be exchanged respectively.

Now the transformed matrix is defined as:

$$\hat{K} = \begin{bmatrix} (K_{11})^{-1} & -(K_{11})^{-1}K_{12} \\ K_{21}(K_{11})^{-1} & K_{22} - K_{21}(K_{11})^{-1}K_{12} \end{bmatrix}, \text{ so that } \hat{K} \begin{bmatrix} F_1 \\ U_2 \end{bmatrix} = \begin{bmatrix} U_1 \\ F_2 \end{bmatrix}$$

Calypso applies this method silently. It enables the user to switch the known and unknowns for every degree of freedom at will, as long as the system is kinematically determined.

### [Selected topics \(3\) – the P-Δ effect](#)

The ISO standard, section A.8.8.6, differentiates between global P-Δ effects (effects on OTM) and local P-δ effects (effects on member forces). However, global P-Δ effects also influence the moment in the leg. This is a level in between global and local effects. Not every method accounts for this correctly.



The ISO standard distinguishes three different types of methods, being (iterative) large displacement methods, geometric stiffness methods and the (simple) negative spring method. The Calypso implementation of the P-Δ effect involves an addition to the stiffness matrix and can be applied iteratively or not. The negative spring method can be applied as well in Calypso, results of which are presented below.

Calypso amends the stiffness matrix of each of the beams in the leg by a (negative) stiffness matrix to account for the P-Δ effect. This stiffness matrix for the P-Δ effect as per Wilson [ref 6] is shown here for a simple 2D beam, with force and moment at either end:

$$\begin{bmatrix} F_i \\ M_i \\ F_j \\ M_j \end{bmatrix} = \frac{-P}{30L} \begin{bmatrix} 36 & 3L & -36 & 3L \\ 3L & 4L^2 & -3L & -L^2 \\ -36 & -3L & 36 & -3L \\ 3L & -L^2 & -3L & 4L^2 \end{bmatrix} \begin{bmatrix} u_i \\ \theta_i \\ u_j \\ \theta_j \end{bmatrix}$$

Where  $i$  and  $j$  are the two ends of the beam,  $F$  is the force,  $M$  is the moment,  $u$  is the displacement,  $\theta$  is the rotation and  $P$  is the compressive force. This matrix is valid for beams under tension or compression and shows that not only the horizontal displacement  $u$  but also rotation  $\theta$  leads to forces and moments. The minus sign before  $P$  indicates that this matrix is a stiffness reduction. The basic assumptions underlying this matrix are that the beam's deflection due to displacement is parabolic and deflection due to rotation is cubic.

In Calypso, the leg by default consists of one node per bay and therefore automatically includes the leg weight accurately into the P-Δ calculation as well.

The ISO standard states that for the negative spring method a stiffness of  $\frac{P}{L}$  should be used,  $P$  being the elevated weight plus leg weight above the guide and  $L$  being the distance between the center of gravity and the support point. This term is derived in the ISO commentary. This negative, earth-fixed spring should be applied at the hull node.

The ISO commentary derives that if a linear deflection is assumed (the leg being represented by a bar rather than a beam), that the stiffness reduction factor is  $\frac{P}{L}$ , which is the value that is recommended in the standard. It also derives the stiffness reduction factor for the case where the leg deflection is assumed to be sinusoidal. In this case the stiffness reduction is  $\frac{12P}{\pi^2 L} \cong 1.216 \frac{P}{L}$ . This value is close to the upper left value in the stiffness reduction matrix presented above, which is  $\frac{36P}{30L} = 1.2 \frac{P}{L}$ . The stiffness reduction matrix assumes a parabolic deflection due to force.

For a benchmark calculation, the leg model as introduced in the final section of this paper is used. The leg-to-hull interface and the foundation are modeled as simple rotational springs of 100 GNm/rad stiffness. Horizontal stiffness is infinite on both. A horizontal force of 17.67 MN is introduced at the hull, leading to 1.00 m excursion, not accounting for the P-Δ effect.



There are two built-in methods to apply the stiffness reduction matrix in Calypso. The simple method is to set the stiffness reduction only once, based on the weight alone. If the center of gravity is at the center of legs, this leads to the same stiffness reduction on all legs. The benefit of this method is that no further iterations are required. If one is interested in overall jack-up behavior alone, such as deck excursion and OTM, this method is sufficiently accurate.

If one is interested in the forces in the legs however, the second method account for the P- $\Delta$  effect is to apply the stiffness reduction matrix by iteration. Due to the excursion of the platform, the vertical force per leg may differ a lot, leading to different stiffness reductions per leg. The influence on the overall platform behavior is typically small, but the influence on the forces in the leg may be larger.

A comparison of the results of the different methods is presented in Table 1. It shows the deck excursion, representing overall platform behavior, and the foundation force and moment per leg, representing more local behavior. It can be seen that for deck excursion most methods work well. It can be concluded, in this case, that for the negative spring method, a factor of 1.2 yields better results. The horizontal foundation force for the negative spring is amended to account for the fictitious horizontal force introduced at the hull and presented in brackets.

For more local effects, it can be seen that the horizontal force at the foundation level is influenced by an iterative stiffness reduction. The leeward leg (1), with the largest vertical force, behaves more flexible due to the P- $\Delta$  effect and therefore some horizontal force is redistributed to the windward legs. The moment at the foundation seems to be unaffected, but the moment in the leg is affected by the difference in horizontal force at higher levels by about 4%.

It can be concluded, based on the above, that the P- $\Delta$  effect should be incorporated iteratively if the interest goes out to moments and forces in the leg. If interest only goes out to overall behavior such as deck excursion and OTM, any non-iterative method is sufficient as well. In case the negative spring method is used, the negative stiffness of  $1.216 \frac{P}{L}$  yields the closest results in this case.

## The site-specific assessment – a benchmark study

ISO/TR 19905-2, or *the commentary*, is a document that further explains how to use the ISO 19905-1 standard. An elaborate sample calculation makes up most of the document. This sample calculation is used to benchmark the wave load model in this section.

### Parametric leg model

The chord is an opposed-rack split-tube chord. Unfortunately, not all parameters are given in the commentary. The best fit was found using the parameters as presented in Table 2. The scale is tapered down to 50 mm at the rack and the locus of the scale is at the surface of the rack. A visualization of this chord is provided in Figure 2.

The bay height is 10.21 m. It is not clear what definition of vertical brace offset is used, but from the results it is apparent that the vertical distance between the nodes of two braces is 1.07 m. The chord distance is 16.15 m. The raw water risers are included in the parametric leg model but are only activated in the wave



load model as the position is dependent upon site-specific information. A visualization of the leg is presented in Figure 3.

Site-specific parameters are gathered from the ISO commentary and presented in Table 3. The values are entered into the Calypso Site data object without further modification. Calypso calculates the hydrodynamic parameters based on these site-specific parameters and the parametric leg model. The calculated values are compared to the values as presented in the sample calculation in the commentary in Table 4.

The wave is simulated as a 5<sup>th</sup> order Stokes wave, in combination with a kinematics reduction factor of 0.86 and a partial action factor of 1.15. The current blockage factor is automatically applied as per the ISO standard. This number varies between 0.90 and 0.94, which is different from the commentary that states a variation between 0.9 and 0.91 only.

The wave load on the spudcans is not detailed in the commentary and is included based on an equivalent large diameter cylinder in Calypso.

The wave forces as calculated automatically, i.e. without any interference of the user, in Calypso are compared to those in the commentary in Table 5. It can be seen that the results are very similar. Not too much value should be attached to the fact that the results are so close, as there must be many small differences in approach between Calypso and the software that generated the results in the commentary. However, the results do lead to the conclusion that the Calypso wave load module is successfully benchmarked against the ISO commentary.

## Conclusions

Calypso is a new tool that aims to automate time consuming tasks in performing SSAs. This way the engineering expert can focus on tasks that require expertise such as risk management. Also, Calypso opens up the opportunity to perform feasibility studies to those who are skilled but are not engineering experts. Once a parametric model of a jack-up has been created, only site-specific data are required to perform the analysis.

It is shown that the wave loads that are calculated automatically by Calypso, based merely upon parametric input and without interference of the user, matches well with the wave loads presented in the ISO commentary. Also, it is shown that the P- $\Delta$  effect is best implemented iteratively. If interest goes out to overall platform behavior only, such as for determining the DAF, a non-iterative method may also be employed.

Calypso is a software implementation of the ISO standard for performing site-specific assessments of jack-up platforms. The program makes available the insights from decades of experience that are covered by this standard to people who work with jack-ups on all sides of the offshore industry in an accessible way.



## References

- [1] ISO 19905-1:2016, Petroleum and natural gas industries – Site-specific assessment of mobile offshore units – Part 1: Jack-ups
- [2] ISO/TR 19905-2:2012, Petroleum and natural gas industries – Site-specific assessment of mobile offshore units – Part 2: Jack-ups commentary and detailed sample calculation
- [3] J.D. Fenton, *A Fifth-order Stokes theory for steady waves*, Journal of waterway, port, coastal and ocean engineering, vol. 111, Issue 2, 1985
- [4] M.M. Rienecker and J.D. Fenton, *A Fourier approximation for steady water waves*, Journal of Fluid Mechanics, vol. 104, 1981
- [5] M.J. Tsatsomeros, *Principal pivot transforms: properties and applications*, Linear Algebra and its applications 307, 2000
- [6] E.L. Wilson, *Three Dimensional Static and Dynamic Analysis of Structures*

## Tables

Table 1 - Results for different types of application of the P-Δ effect

	Leg	No p-Δ	Single stiffness reduction	Iterative stiffness reduction	Negative spring $\frac{P}{L}$	Negative spring $1.216 \frac{P}{L}$
Deck excursion [m]	[-]	1.00	1.10	1.10	1.08	1.10
Foundation vertical force [MN]	1	102	104	104	104	104
	2	67.2	66.0	66.0	66.2	66.0
	3	67.2	66.0	66.0	66.2	66.0
Foundation horizontal force [MN]	1	5.89	5.89	5.67	6.36 (5.89)	6.47 (5.89)
	2	5.89	5.89	6.00	6.36 (5.89)	6.47 (5.89)
	3	5.89	5.89	6.00	6.36 (5.89)	6.47 (5.89)
Foundation moment [MNm]	1	443	489	488	478	486
	2	443	489	489	478	486
	3	443	489	489	478	486

Table 2 - Chord parameters

Parameter	Value
Scale radius [m]	0.280
Scale thickness [m]	0.108
Offset from rack side [m]	0.00
Rack width [m]	0.19
Rack diameter [min, pitch, max] [m]	0.58, 0.79, 0.98

Table 3 – Site-specific parameters for test location 1 in sample calculation relevant for wave load calculation

Parameter	Value
Water depth LAT [m]	121.9
Water depth MSL [m]	122.5
Surge + tide [m]	2.44
Water depth SWL [m]	124.34
Airgap (w.r.t. LAT) [m]	20.9
Riser position (w.r.t. MSL)	-16.2
$V_{C_{surface}}$ [m/s]	1.49
$V_{C_{bottom}}$ [m/s]	0.82
$H_{max}$ [m]	26.8
$T_{ass}$ [s]	16.6
Penetration [m]	0.9
Support point	0.4

Table 4 - Comparison of hydrodynamic coefficients from the commentary and Calypso

	Heading [deg]	$CD_e \cdot D_e$		$CM_e \cdot A_e$	
		ISO TR	Calypso	ISO TR	Calypso
Lower section	0	6.59	6.58	6.34	6.35
	30	6.74	6.71		
	45	6.67	6.65		
	60	5.59	6.58		
Upper section – no caissons	0	6.20	6.19	5.59	5.62
	30	6.34	6.33		
	45	6.28	6.26		
	60	6.20	6.19		
Upper section – two caissons	0	7.17	7.16	6.25	6.28
	30	7.30	7.29		
	45	7.24	7.23		
	60	7.17	7.16		
Upper section – one caisson	0	6.69	6.68	5.92	5.95
	30	6.82	6.81		
	45	6.76	6.75		
	60	6.69	6.68		
Smooth section – no caissons	0	4.41	4.39	5.25	5.26
	30	4.56	4.54		
	45	4.50	4.48		
	60	4.41	4.39		
Smooth section – two caissons	0	5.00	4.99	5.90	5.93
	30	5.15	5.14		
	45	5.09	5.08		
	60	5.00	4.99		
Smooth section – one caisson	0	4.71	4.69	5.57	5.60
	30	4.86	4.84		
	45	4.79	4.78		
	60	4.71	4.69		

Table 5 – Comparison of wave loads from the commentary and Calypso

Direction	BS / OTM	ISO TR	Calypso (Stokes 5)	Ratio	Calypso (Stream)
60 deg	BS [MN]	20.2	20.3	1.00	20.3
	OTM [MNm]	1864	1864	1.00	1863
90 deg	BS [MN]	20.6	20.6	1.00	20.6
	OTM [MNm]	1898	1891	1.00	1890
120 deg	BS [MN]	20.0	20.0	1.00	20.0
	OTM [MNm]	1839	1836	1.00	1835