AUTOMATED SITE-SPECIFIC ASSESSMENT OF JACK-UP PLATFORMS USING THE CALYPSO COMPUTER PROGRAM

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ABSTRACT

There is a growing demand for Site-Specific Assessments of jack-ups, due to a trend of including an SSA in tender proposals and of optimization of the variable deck load and required preload. In addition, and as a result, there is a growing interest among rig owners to perform SSAs in-house. The Calypso computer program was developed to fulfill this demand.
Calypso enables automated analysis of jack-ups. The core of the program is a full implementation of the ISO 19905-1 standard of 2016. The graphical user interface enables any skilled offshore engineer to perform a Site-Specific Assessment. The jack-up engineering expert may interface deeply with the program through the Application Programming Interface (API). This allows performing customized calculations and inspection of all steps of the calculation process.
This paper summarizes the implementation details of the program. In addition, the graphical user interface is presented. Furthermore, a novel method for simulation of the dynamic response of a jack-up platform using frequency domain methods is introduced.

Keywords: Jack-up analysis, SSA, push-over analysis, time-domain response simulation

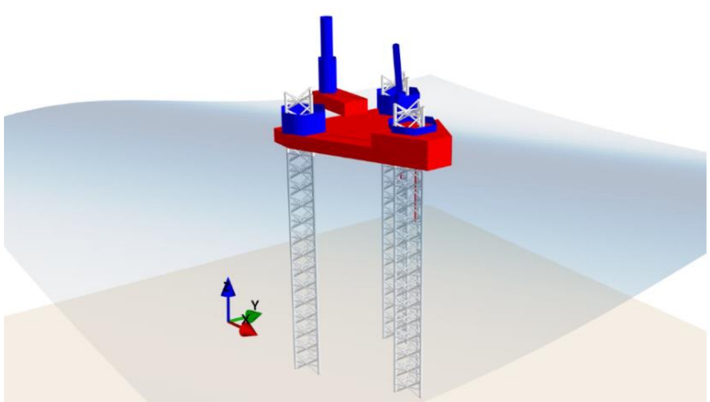

Figure 1 : Visualization of a jack-up in Calypso

INTRODUCTION

There is a growing demand from the industry, from drilling contractors, from wind-turbine installation contractors and from field operators to make Site-Specific Assessments of jack-ups an integral part of jack-up operations. SSAs could be used for determination of suitability for a prospect, for support of a tender, during the stay of the platform at the field to support variations such as in variable deck load. Currently, the SSA is typically used only for obtaining insurance and to comply with regulations. This is mainly due to the fact that rig owners have to rely on third parties to perform SSAs, which results in relatively long lead times and relatively high cost.

The Site-Specific Assessment of a jack-up is a complex undertaking. Expertise is required in structural analysis, structural dynamics and hydrodynamics. Furthermore, geotechnical skills are required as well as jack-up specific expertise such as for the modeling of the leg-to-hull interface. This makes performing SSAs the sole domain of jack-up engineering experts.

Calypso implements all this expertise in a computer program, accessible through a graphical user interface. It enables any skilled engineer, not necessarily a jack-up engineering expert, to perform a Site-Specific Assessment for any site using a predefined parametric model of the platform. A typical SSA can be performed in a matter of hours.

The core of the program is a full implementation of the ISO 19905-1 standard of 2016 [1] and of a number of referred documents. The purpose and benefit of this implementation of the ISO standard as a computer program is that the knowledge contained in the standard is made available to a large group of people. Currently, performing Site-Specific Assessments (SSAs) is the domain of jack-up engineering experts. Calypso opens up this domain to any skilled offshore engineer, tender specialist or estimator.

Calypso has an open, glass-box (as opposed to black-box) structure. This means that the jack-up engineering expert is able to interface with the program at a deep level. He can inspect the model and even use specific parts of the program to perform detailed analysis, such as push-over analysis and modal analysis.

The Calypso program was first presented in Hoogeveen [2] at the London jack-up conference of 2019. The focus of that paper is the inner workings of the program, some of the theoretical background, three implementation details and a validation case. Since the publication of that paper, a graphical user interface was developed as well as a novel method of simulation of dynamic and quasi-static platform response using a frequency domain approach. These are the key topics of this paper, along with a summary of the inner workings of the program.

SUMMARY OF THE IMPLEMENTATION

The ISO standard [1] explains how calculation models should be created based on the general arrangement and structural details of a jack-up platform, how the loading on these models should be calculated and how the suitability of the platform should be assessed based on the results. The Calypso program explicitly incorporates a distinction (see Figure 2) between:

- *the parametric platform model*,
- *the site data* and
- *the site-specific platform model.*

The *parametric platform model* is a never-changing description of the structural details of the platform. This comprises the hull shape, the legs, the footings and the leg-to-hull interface. The *site data* contains all information that is site-specific, such as metocean data and soil data. The *site-specific model* is automatically generated by the program based on the *parametric model* and the *site data* and contains all models that are required to assess the structural response and suitability of the platform for the site. More details about the implementation can be found in the next section and in Hoogeveen (2019) [2].

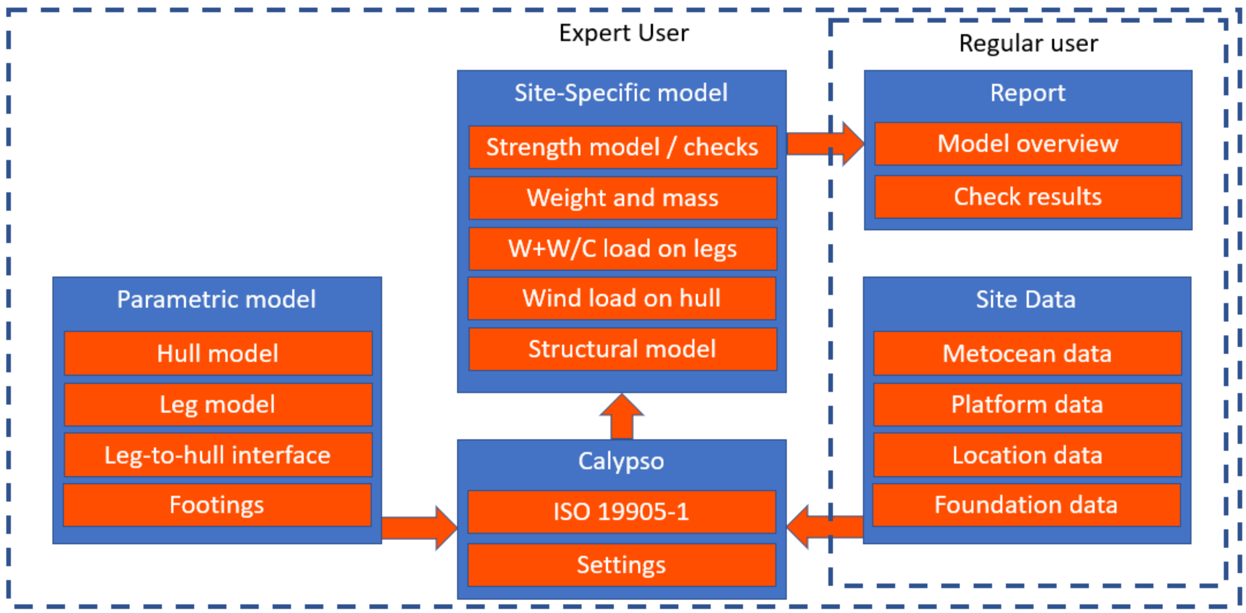

Figure 2 : Schematic overview of Calypso

IMPLEMENTATION DETAILS

The Calypso program is built up modularly and is made up of four groups of objects, that follow the distinction as presented in the previous section, see Figure 2. The expert user can interact directly with these objects through the well-documented Application Programming Interface (API), as presented in the following section.

The first group is called *the parametric model* and consists of all objects that make up the parametric model. This comprises the hull, the legs, the footings and the leg-to-hull interface. All details regarding the platform are stored in these objects. The required information can typically be found in detailed drawings of the platform. The level of detail that can be entered is high. For instance, the number of different sections that make up a leg is unlimited. The objects in the parametric model come with functionality to build the objects of the fourth group, *the site-specific model.*

The *parametric model* is to be created by an expert engineer. This is done once in the lifetime of a jack-up, or after the platform is improved such as with add-on footings (e.g. Jansen et al. [3]). Calypso could be used to determine the business case for such an improvement.

The second group of objects is called the s*ite data* and comprises all information regarding the site. These objects are the metocean data, platform data, location data and foundation data. The platform data is a set of parameters that pertain to the jack-up and is site-specific, such as variable deck load and the eccentricity box. The location data reflects parameters such as water depth. The foundation data can be one or multiple layers of soil. The penetration can be calculated by the program or given as a parameter if a penetration analysis was performed. These objects are mainly used to store data and come with limited functionality.

The *site data* can be entered by any skilled offshore engineer and does not require jack-up engineering expertise. The required data can typically be collected from a metocean report and a soil investigation report or a leg penetration analysis report if available.

The third group of objects is the calculating and reporting engine of *Calypso*. It takes the *parametric model* and the *site data* and generates the *site-specific model*, which is the fourth group of objects. After the site-specific model is created, the calculations are performed and a report is generated.

The fourth group is the *site-specific model* and contains a set of calculation models. These models are automatically generated based on the *parametric model* and the *site data.* This group consists of:

- The wind, wave and current load model of the legs
- The wind load model of the hull
- The structural (bar stool) model, containing nodes connected by structural elements (visualized in Figure 3)
- The weight/mass model
- The strength model

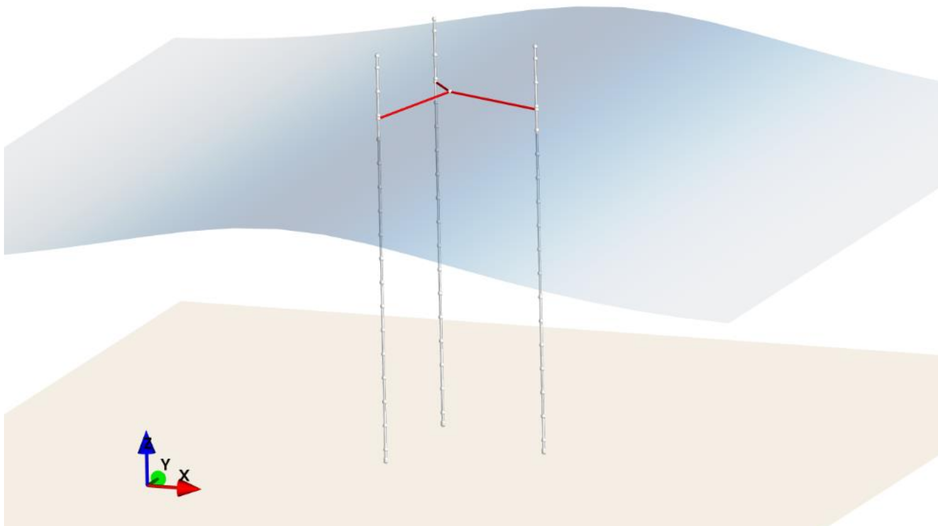

Figure 3 : Visualization of the structural model

THE USER INTERFACE

Calypso is made available as Software as a Service (SaaS). Users can login to a secured private area where they can access a browser-based interface and all of the user's jack-up models, site data and previous analyses. Typical calculations are run directly on the server, whereas batch runs involving time domain simulation can be run on a cluster for accelerated processing time. The program lay-out allows for parallelization and scalability, so that even large batches of calculations could be run swiftly. This section introduces different ways for a user to interact with Calypso as well as two examples of usage of the expert-user interface.

THE GRAPHICAL USER INTERFACE

The graphical user interface is intended to quickly perform a Site-Specific Assessment (SSA) according to ISO 19905-1 without requiring in-depth knowledge of jack-up engineering. It allows for selection of a pre-defined parametric jack-up model and for detailed specification of site data. All site data can be entered in a browser-based webform or as a spreadsheet. The main screens of the interface are presented in Appendix A.

A single calculation takes about 20 seconds to run on a single-core and generation of graphical output takes another 20 seconds if requested. After the calculation is done, the results are reported in a browser-based document, as a PDF file and in a database. A (blurred-out) example of the report of a recently performed SSA is included in the last figure in appendix A. The first section of the report summarizes the site data. The following sections summarize the results in an increasing level of detail.

THE EXPERT USER INTERFACE

The expert user interface allows the user to interface with Calypso directly through the Application Programming Interface (API). This requires jack-up engineering expertise as well as a basic understanding of the usage of an API. The API allows full control over all of the objects in Calypso. Some possible uses are listed in the following sections.

DIRECT USE OF THE STRUCTURAL MODEL

The structural model of Calypso is purpose-built and is mainly based upon Ghali et al. [4]. It is a miniature Finite Element Model, where the structure is made up of nodes that have a mass and are connected by elements. Each node has 6 Degrees of Freedom (DOFs). Nodes can be connected to other nodes through a stiffness matrix or by rigid elements. A stiffness matrix can be defined by a beam element, a spring element or direct input by the user. Rigid elements define one or more of the DOFs of one node (the slave node) as a function of the displacement of another node (the master node).

In typical use of Calypso, the structural model is automatically generated by the program. It can be visualized, see Figure 3, but other than that the regular user does not interface with it. The expert user may take the automatically generated structural model and add or modify any of the elements. For any node, the user may define the load and solve for its displacement, or define the displacement and solve for its load.

PUSH-OVER ANALYSIS

Calypso is suitable for a push-over analysis as described by HSE [5]. This type of analysis involves plastic deformation of structural components in a quasi-static approach. The environmental loading can be scaled up until failure is reached, where failure is defined as the collapse of the structure. Even severe plastic deformation could be deemed acceptable for an accidental case.

In typical use of Calypso, i.e. for an SSA, the foundation is modeled according to the ISO yield interaction envelope. This inherently non-linear model is included through an iterative engine. The stiffness matrix is updated every iteration until the solution has converged sufficiently. Any plastic element can be added by the expert-user in a similar fashion. A simple beam element can be extended by a yield function which basically caps the total loading. Similarly, the leg-to-hull interface can have a load-dependent stiffness to account for gaps and increasing contact area for increasing deformation.

DYNAMIC SIMULATION OF THE PLATFORM RESPONSE IN THE FREQUENCY DOMAIN

The ISO standard provides two methods to use time-domain simulation in an SSA. The first method is the deterministic two-stage approach. This approach is the default method of Calypso. Stage one is a time domain simulation of the structural response of a platform to irregular waves. The response of a dynamic model is compared to that of a quasi-static model in order to determine the Dynamic Amplification Factor (DAF). This DAF is then used in a quasi-static, non-linear design wave approach calculation, which makes up stage 2. This approach is pervasive in the ISO standard. For instance, the ISO yield interaction foundation model is suitable for a quasi-static design wave calculation only and should not be used in a dynamic simulation. ISO recommends, for dynamic simulations, to model the foundation as a rotational spring of constant stiffness.

The second method to use time-domain simulation according to the ISO standard is the stochastic one-stage approach. In this method, the SSA is based directly on the output of the time domain simulation, for instance a three-hour maximum. This method is mentioned in the ISO standard, but not detailed enough to be suitable for automated implementation. For instance, if a linear wave model is used for irregular wave simulation, such as implemented in most commercially available software, the wave forces may be severely underestimated as compared to the Stokes fifth order design wave approach.

The following describes the method of implementation of time domain simulation in Calypso, which the authors believe to be novel. The wave force on a jack-up platform is non-harmonic. The irregular wave elevation and kinematics are best described by second order Stokes theory, which is non-linear. The drag component of the wave force, which is governing for truss leg jack-ups, is quadratic with velocity and thus is non-linear as well. Therefore, the wave force on each node must be calculated in a time domain simulation. The result of this simulation is a force signal on each of the nodes.

The platform response due to dynamic excitation can be modeled as a *linear* process. In the case that the deterministic two-step approach is used, the purpose of the time domain simulation is to calculate the DAF. Therefore, interest goes out to overall platform behavior only, not to component loads. It is shown by Hoogeveen [2] that the Calypso implementation of the P-delta effect, which involves a negative contribution to the stiffness matrix, yields the same results as an iterative method for overall platform behavior, such as deck excursion, overturning moment and base shear.

A linear spring is typically used to model the foundation in dynamic simulations. All other components of the jack-up, including the leg-to-hull interface, are also modeled to behave linearly.

Based on the above, it can be stated that the jack-up can be modeled as behaving completely linear for dynamic simulations that are used to calculate the DAF. In matrix notation it can be stated that:

$$\boldsymbol{m\ddot{u}(t)} + \boldsymbol{c\dot{u}(t)} + \boldsymbol{ku(t)} = \boldsymbol{F(t)} \quad \textbf{(1)}$$

Where $\boldsymbol{F(t)}$ is a time trace of force on every node in every DOF, which was found through time-domain simulation of wave kinematics. This signal can be transformed to the frequency domain using the Discrete Fourier Transform (DFT), so that the force on every node is expressed as a set of complex amplitudes. Now equation **(1)** can be restated as:

$$\boldsymbol{m\ddot{u}(\omega)} + \boldsymbol{c\dot{u}(\omega)} + \boldsymbol{ku(\omega)} = \boldsymbol{F(\omega)} \quad \textbf{(2)}$$

Or, using $\boldsymbol{\ddot{u}(\omega)} = -\boldsymbol{\omega^2 u}$ and $\boldsymbol{\dot{u}(\omega)} = \boldsymbol{i\omega u}$,

$$(\boldsymbol{k} + \boldsymbol{ci\omega} - \boldsymbol{\omega^2 m})\, \boldsymbol{u(\omega)} = \boldsymbol{F(\omega)} \quad \textbf{(3)}$$

Equation **(3)** can be used to calculate the transfer function between complex nodal force excitation amplitudes and complex nodal response amplitudes. Using that relation, the dynamic platform response due to the wave force excitation can be calculated. Similarly, the quasi-static response can be calculated by taking only the stiffness into account and not damping and inertia. Using the Inverse Fourier Transform, the complex amplitudes of response can be converted back to the time domain. Further analysis, such as determination of the maximum response or most probable maximum response, can be done based on this signal.

This approach is efficient because the platform response is not integrated by a numerical solver but is being solved analytically. Moreover, more insight is provided to the (expert) user because the transfer functions are made available. These can aid in-depth research, such as on reinforcement / cancellation.

CONCLUSIONS

The Calypso computer program makes available all expertise contained in ISO 19905-1:2016 [1] to engineers who are not necessarily jack-up engineering experts. It allows for automated performance of Site-Specific Assessments (SSAs). Performing SSAs become so accessible and low-cost that SSAs may be performed in any phase of a project:

- Before the tender phase, to determine the suitability of a platform for a specific site.
- During the tender phase, to support the tender and instill trust.
- Before the execution phase, to perform the SSA and optimize the required preload or the allowable variable deck load.
- During the execution phase, if operation outside of the limits stated in the SSA is required. This could be due to unforeseen penetrations, imminent weather, operational decision making, etc. Calypso is fast and due to automation has an inherently high level of quality, making it a suitable tool for support of operations.
- For determination of the business case of a platform in a more general sense, as opposed to the design cases.

Because of the glass-box structure, Calypso allows those who are experts in the domain of jack-up engineering to perform an in-depth review of the performed calculations. Moreover, through the use of the well-documented API, the expert user has direct access to all components of Calypso.

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APPENDIX A – SCREENS OF THE GRAPHICAL USER INTERFACE OF CALYPSO

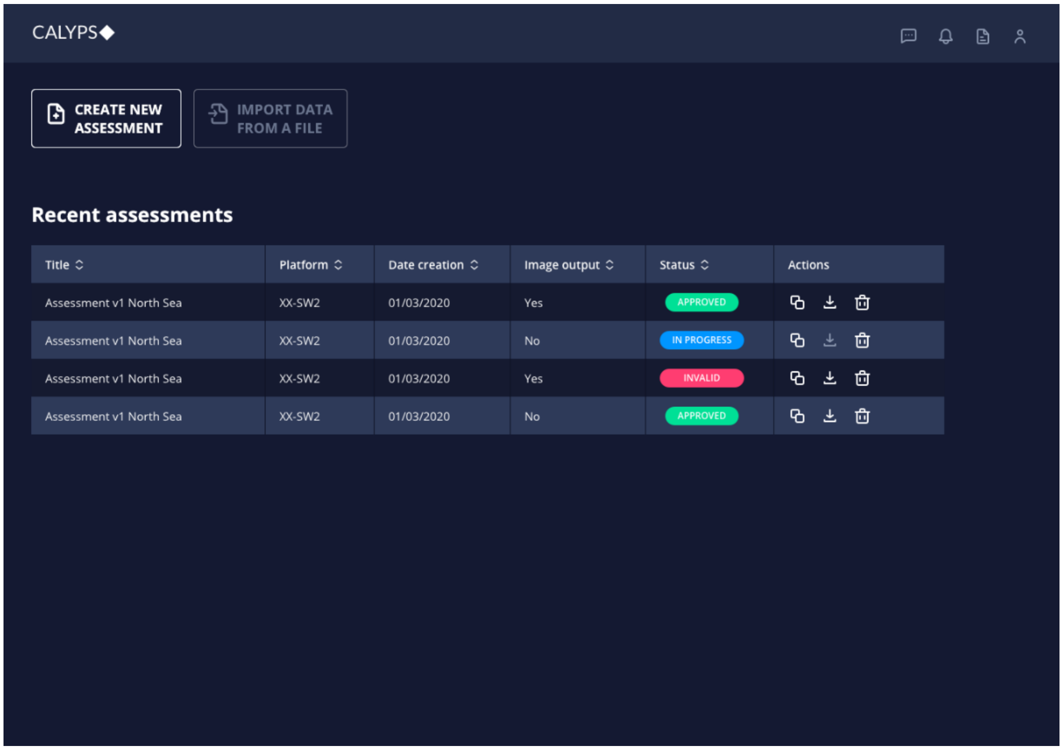

Figure 4 - Calypso Graphical User Interface – Dashboard

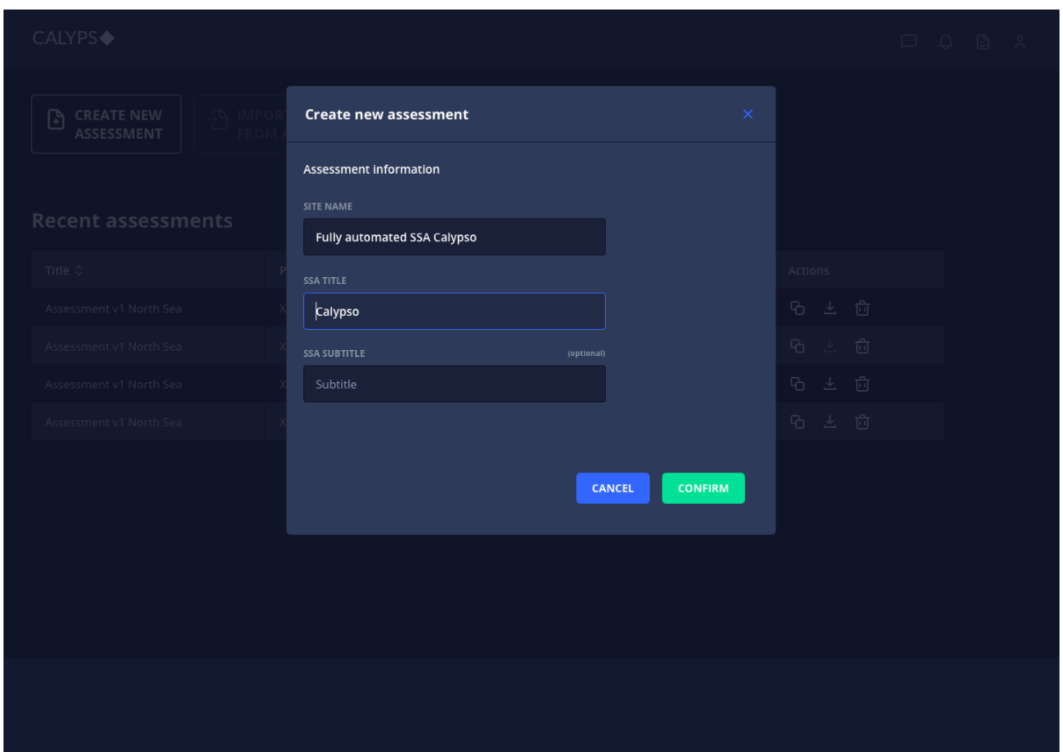

Figure 5 - Calypso Graphical User Interface - Create new SSA

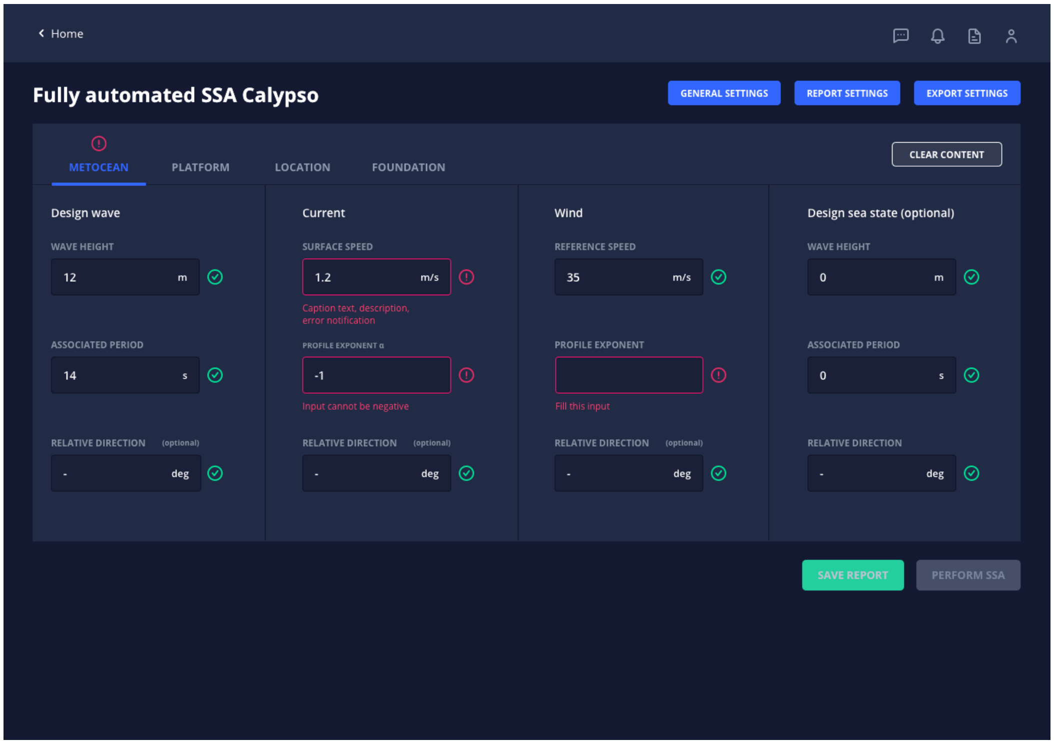

Figure 6 - - Calypso Graphical User Interface - Metocean tab

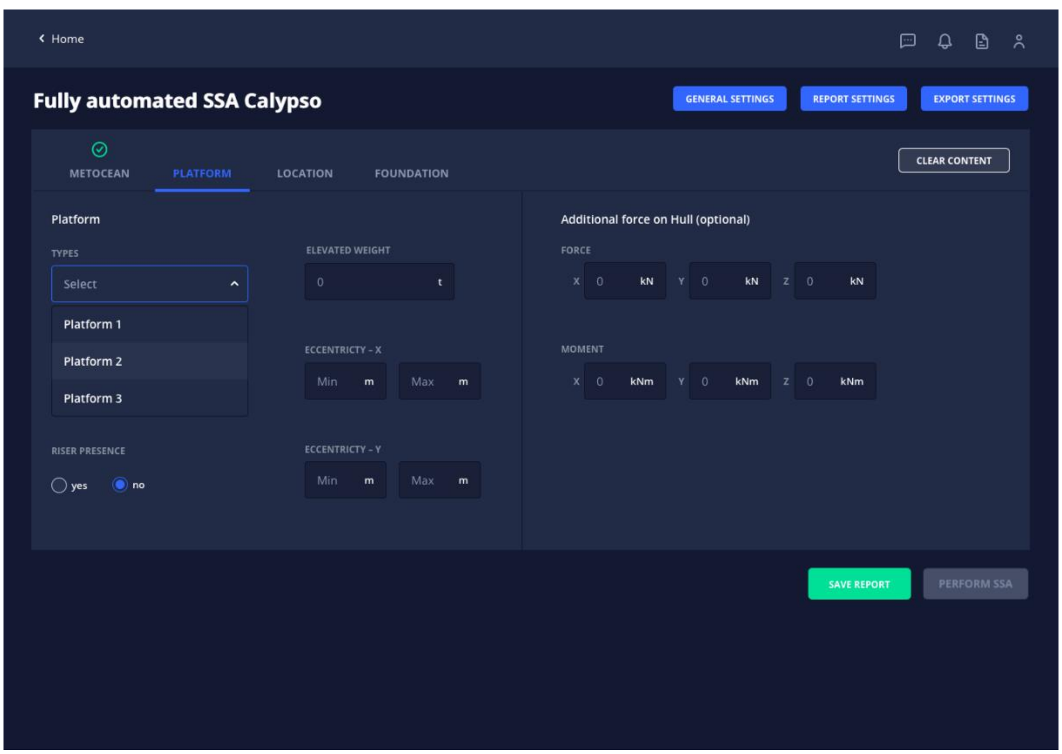

Figure 7 - Calypso Graphical User Interface - Platform tab

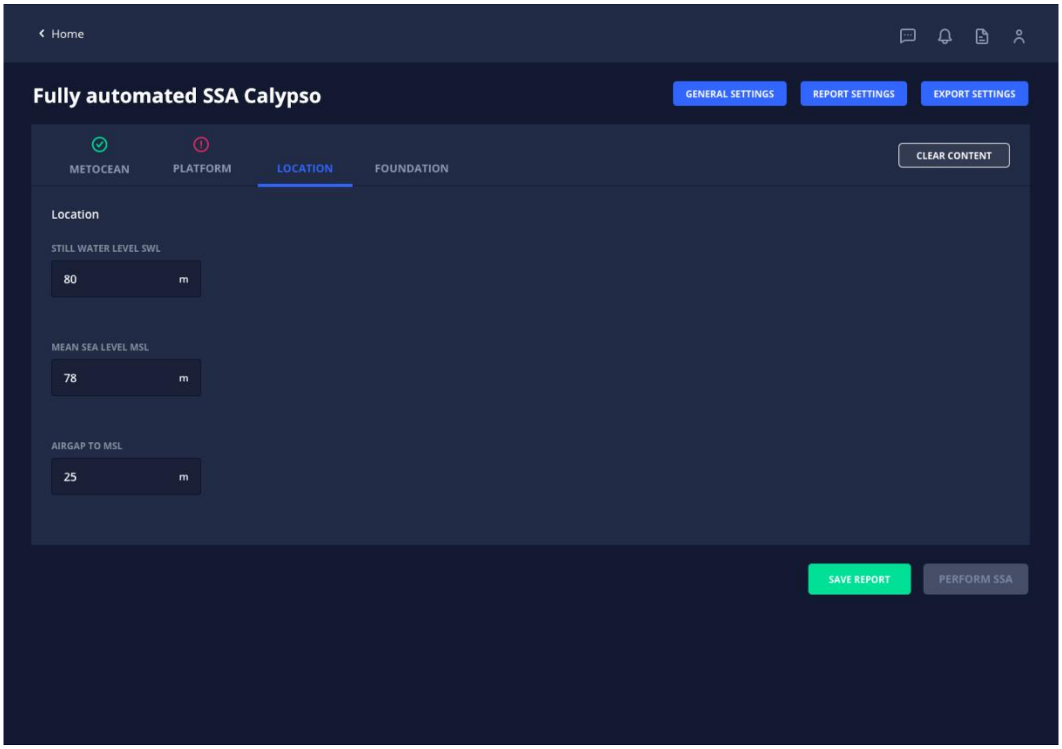

Figure 8 - Calypso Graphical User Interface - Location tab

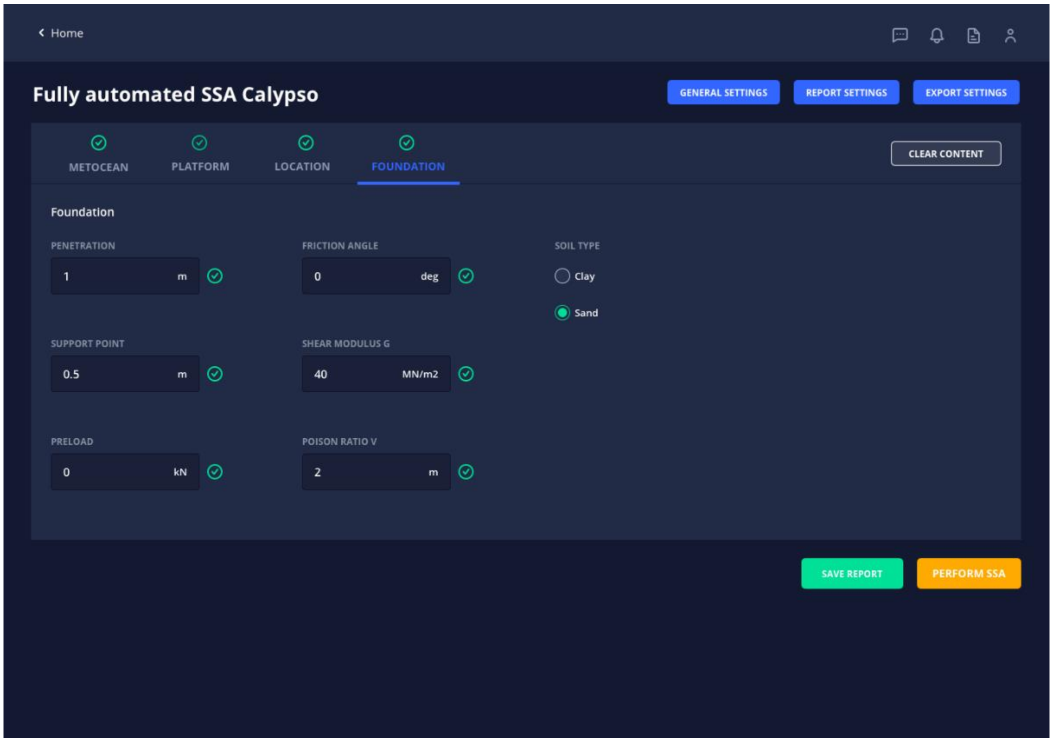

Figure 9 - Calypso Graphical User Interface - Foundation tab

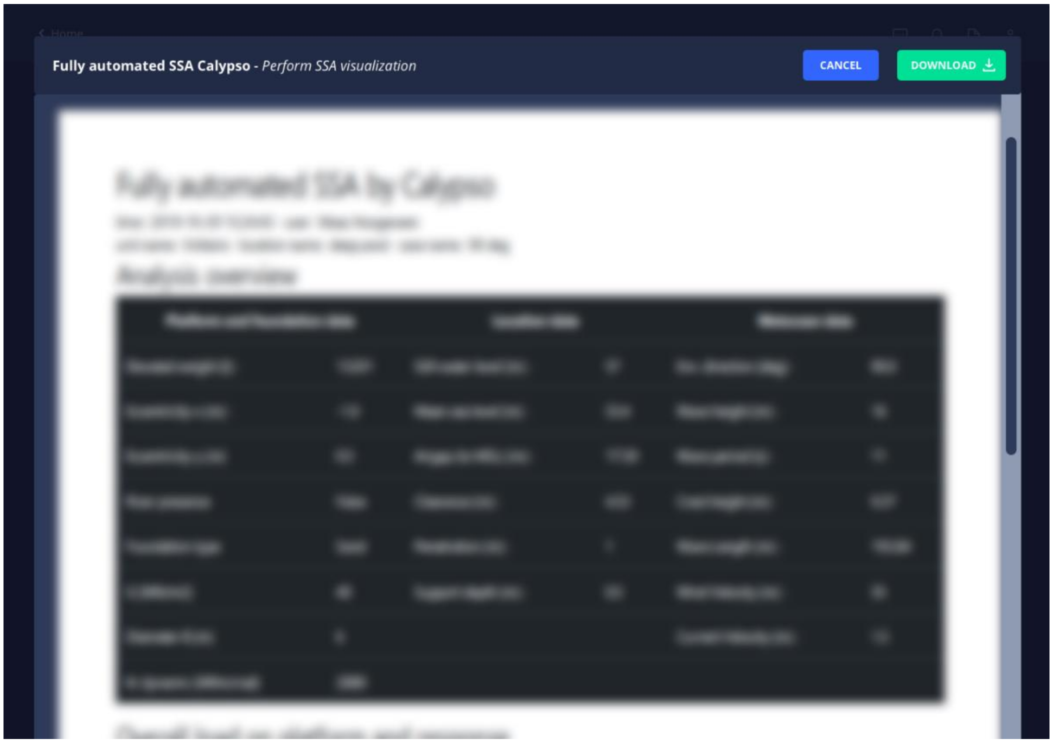

Figure 10 - Calypso Graphical User Interface - Example of report