Technische Universiteit Delft

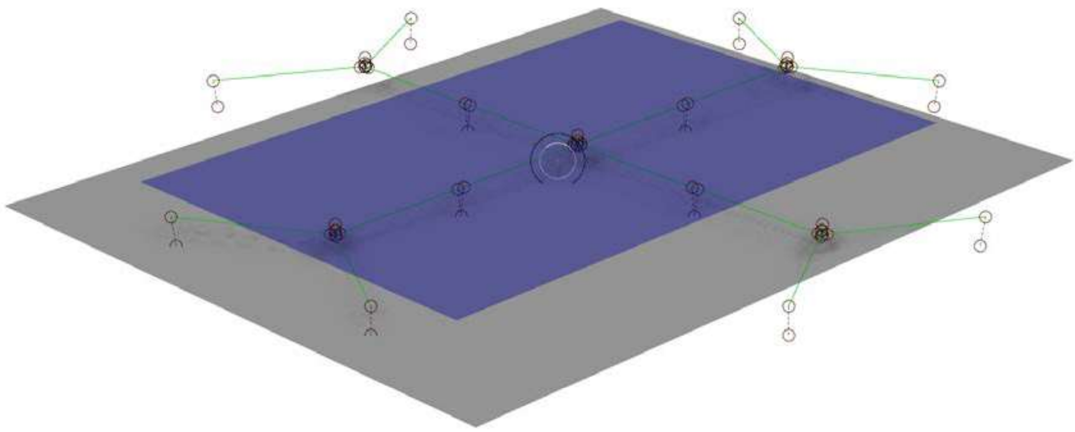
European Wind Energy Master
Offshore & Dredging Engineering

Mooring system design for wind farm in very deep water

Offshore floating wind turbines are one of the newest technologies in the renewable markets today. The world’s first floating wind farm, the Hywind Scotland Pilot Park, was commissioned in October 2017 and has been competitive with fixed bottom offshore wind turbines. There is a global push to make more renewable energy available, but less desire to have wind turbines cluttering the coastline. Floating wind turbines enable the developer to take advantage of unused offshore space, at depths where traditional fixed bottom structures are impractical and at locations that do not spoil the vista of the coastline.

This thesis project aims to develop a working mooring system at depth of 600 m in the Norwegian North Sea, and then investigates the possibility of shared anchors in a wind park with this mooring system. The DTU 10MW reference wind turbine atop a classic spar substructure is used. First, the mooring system at 320 m is tested under decay and environmental loads. Then a chain-polyester-chain mooring line with a bridle was developed for 600 m so that the surge offset is limited to<60 m for 3 load cases. A simplified model of the wind turbine was then developed for these three load cases. The simplified model was then used to create a wind farm arrangement with 5-6 turbines each. Each wind farm varied in layout and in the number of shared anchors.

It was found that while the mooring system designed passes the surge offset and natural frequency requirements, and the normal ULS safety class, it failed the high safety class in some cases. For shared anchors with multidirectional loads, the resultant force on the anchor is significantly less as long as the lines are distributed equally around the anchor point. The resultant force does not increase with two lines 120◦ apart. The footprint of a single turbine with the designed moorings larger than the footprint of the entire Hywind Scotland Farm, so suggestions are made for improvement and further work.



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Offshore & Dredging Engineering

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Numerical validation of experimental modal analysis of slip-joint connection in offshore wind turbine

To fulfil the increase in global demand of clean energy, the dimensions of offshore wind turbines are expected to increase with greater capacities and move further offshore in deep waters. For these conditions, the diameter of the monopile will have to increase beyond current manufacturing capacities. The slip joint connection can provide a means to construct monopiles out of smaller segments, thereby removing the limitations to its application.

A slip-joint consists of two inverted conical sections made of steel plates, placed one over the other. the upper conical section is connected to the transition piece and the lower conical section is connected to the monopile. It was found in preceding research related to the vibration assisted installation of the slip-joint, that the frequency of the vibratory force is the key to the successful installation of a slip-joint. The applied vibrations of specific resonance frequencies were found to be effective in the settlement of the slip-joint. A finite element (FE) model created in his work, failed to predict the exact resonance frequencies as observed in experimental modal analysis.

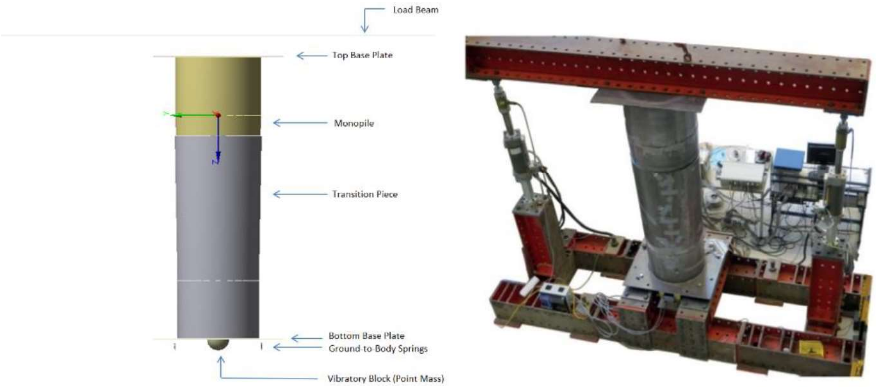

Figure 1: The FE model created (left) including components from experimental setup (right)

The main objective of this thesis was to replicate the results obtained by experimental modal analysis during dedicated lab experiments at TU Delft, by including the components from experimental setup in a FE model. These components include the top and the bottom baseplates which are connected to the monopile and transition piece respectively, the load beam on which the external static load is applied, and machine mounts connected to bottom base plate as shown in Figure 1. Further in this thesis, the FE model is modified in various ways to investigate the difference between the predicted and the observed natural frequencies of the setup. Factors like wall thickness of the cones, elasticity of the steel and stiffness of the machine mount which affect the global stiffness of the combined system are studied. As observed in the experiments that the monopile and the transition piece are not in perfect contact with each other due to the geometrical shape of the monopile, it has been tried to incorporate this observation in the FE model and see the impact of imperfect contact on the results of modal analysis. After investigating the effects of the above mentioned factors and modifications, the FE model was able to replicate the order of the modal shapes, but not the natural frequencies obtained by experimental modal analysis. Additionally, the stiffness near the contact region between upper and lower cone was found to be a key factor affecting the natural frequencies.

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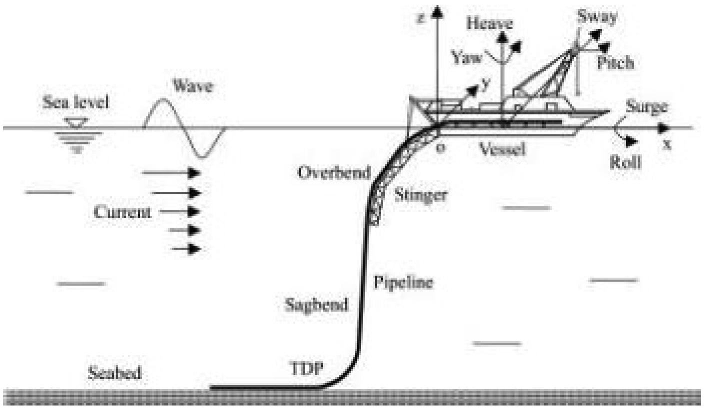
Offshore & Dredging Engineering

Technische Universiteit Delft

Vessel motion based assessment of pipeline integrity during installation

If weather conditions become rough, vessel motions with an increased amplitude are excited due to the presence of waves. The sagbend region of a suspended pipeline catenary may experience high loads due to these motions. When the loads become too high, the pipeline integrity cannot be guaranteed. In such cases, the pipeline is lowered to the seabed to prevent buckling and excessive damages to the pipeline. The pipelay operation is to be resumed later on when pipelay conditions have been improved. This process is called *Abandonment & Recovery* (A&R). It is essential to lay pipe as efficiently as possible to reduce the time spent offshore.
This study investigates the influence of the vessel motions with regard to pipeline integrity. This results in two objectives that are intertwined with one another. The first objective is to investigate the influence of vessel motions on the dynamic pipeline behaviour and integrity during installation operations. The second objective is to develop a method that will define a vessel motion based criteria for pipeline *Abandonment & Recovery* operations with respect to pipeline integrity.

Two methods are proposed to create ´statistical prediction´ curves to quickly assess the pipeline integrity. This requires the generation of multiple pipeline installation models during project preparation.
These methods are applied to various combinations of water depths and pipe properties. The dynamic behaviour of the pipeline is very sensitive to changes of these parameters. A shallow water and a deep water case are used for the analyses of the results and for the validation of the methods.
The pipeline integrity is assessed by predicting the maximum strain, the DNV buckling check and fatigue damage for a pipeline during installation based on stinger tip motions.



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Offshore & Dredging Engineering

Cost optimization of decommissioning offshore structures with the Pioneering Spirit using model order reduction and genetic algorithms

Over 450 oil platforms need to be removed from the North Sea in the next decade. Each of these platforms is custom designed for installation and service lifetime, but not for decommissioning. Allseas' Pioneering Spirit is the largest heavy lift vessel in the world, capable of lifting complete topsides in a single-lift operation. The vessel's lift system places up to eight lift points against the bottom of the platform and uses hydraulic cylinders to transfer the weight from the substructure to the vessel in a matter of seconds. But even with this vessel, removing an oil platform is technically challenging; the structural integrity needs to remain guaranteed, while minimizing the lift preparation cost as the structure will be scrapped. The goal of this thesis is to define a general approach that uses cost optimization for the platforms' lift preparation scope.

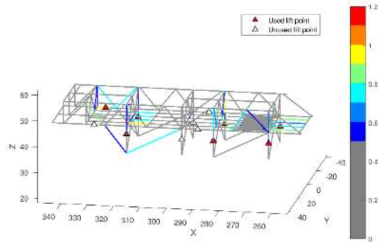
The costs of the platform's lift preparation scope consists mainly of two things; installation of lift points and reinforcement of the structure to avoid exceedance of their design resistance. In order to minimize the cost, the challenge is to find a lift configuration which minimizes the combined cost of the number, type and location of the lift points and the amount of reinforcement. A solution should not exceed constraints such as the allowable load per lift point, the number of lift points and the relative height difference between lift points. A lift configuration is statically undetermined, and the relative height difference between lift points is used to get different load distributions for the same configuration. In this way, forces are redistributed to strong points in the structure.

Detailed finite elements models are used to prove the structural integrity of a topsides during decommissioning. The number of degrees-of-freedom of such models is far too large for them to be used in an optimization algorithm. Model order reduction is used to condense the mass and stiffness matrix to the possible lift points, while keeping internal forces of interesting elements related to these points to check the structural integrity of a solution. The reduction allows for hundreds of lift configurations to be solved per minute.

The minimal costs for a lift configuration in the defined domain is found with the genetic algorithm. The optimization can include an excess amount of lift locations of different possible types. The location and load distribution over the lift points are used to define the cost function. The algorithm makes a selection that suits the constraints. The cost function gives the sum of the cost of the number and type of lift points and the number and type of structural failures.

This thesis presents a systematic approach for finding the optimal lift configuration for any offshore structure. The method is tested on a case study topsides by comparing the standard configuration with the optimized configuration. It is shown that by using the proposed method, the areas that need structural reinforcements are reduced from ten to zero and the amount of lift points is reduced from eight to seven, leading to a cost reduction of 27% on the offshore preparation scope.

The algorithm shows promising results for this topsides removal project. It is possible to include a new finite element model into the algorithm, which together with a generic cost function, makes sure the algorithm is conveniently applicable to other topsides removal projects.



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Offshore & Dredging Engineering

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Response of an Offshore Wind Turbine supported by a Non-Local Winkler Foundation: An Efficient 1-D Time-Domain Model accounting for the 3-D Frequency-Dependent Dynamic Soil Stiffness

With increasing evidence of human-induced accelerated climate change, the need of sustainable, non-polluting, energy sources becomes evident. Offshore wind generated electricity is currently one of the most promising sources of energy to create a sustainable global energy mix. The offshore wind industry has developed rapidly over the last years. The cumulative installed capacity shows an exponential growth. Monopiles remain the most popular substructure type of all installed substructures in Europe. This thesis focuses on calculation methods to evaluate the response of that foundation type.

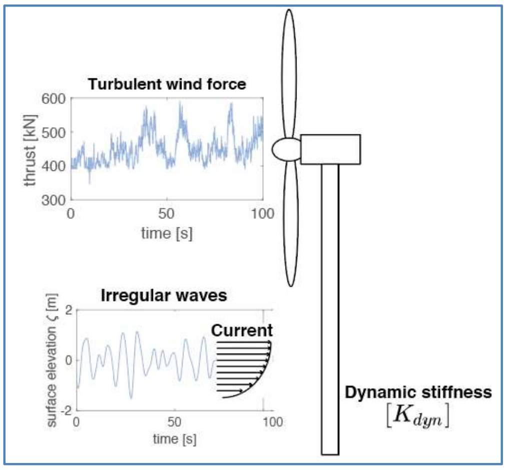
The interaction between a monopile and soil is called soil-structure interaction (SSI). In the offshore wind industry, SSI is commonly modelled as a 1D local Winkler foundation with local nonlinear elastic springs to represent the lateral soil stiffness. The stiffness is often based on semi-empirical relations between the lateral displacement of the pile and the soil pressure (p-y method). This approach neglects the interaction effects between different soil layers and there are uncertainties regarding the validity of applying this method to large diameter, rigidly behaving, monopiles.

In this thesis, a 3D linear-elastic (LE) finite element (FE) model is used to compute 1D global (non-local) complex-valued dynamic soil stiffness, which captures the coupled 3D reactions of soil to the pile. The frequency dependence of local and non-local linear-elastic lateral, rotational and coupling dynamic soil stiffness is analyzed for heterogeneous soil stratigraphy. The effect of different boundary conditions in the 3D model formulation to the frequency dependence of dynamic soil stiffness is analyzed.

The complex-valued-frequency dependent dynamic soil stiffness kernels are approximated by frequency independent coefficient matrices for added mass, damping and stiffness. The performance of the coefficient matrices in terms of representing the complex-valued dynamic soil stiffness is analyzed with cost functions. It was found that the dynamic soil stiffness can be approximated by frequency independent added mass, stiffness and damping coefficient matrices in the frequency range of interest for offshore wind.

A 1D Timoshenko beam model is developed in the frequency-domain and is discretized in space by Euler's central finite difference method. The added mass, stiffness and damping matrices, which represent the non-local Winkler foundation, are incorporated in the model. The SSI response of the 1D model to the dynamic loading is compared with the response of the 3D LE FE model in the frequency domain.

As a last step, a superstructure and turbine are integrated with the monopile SSI model and the total integrated model is transferred to the time domain. Time domain computations are performed for free vibrations, harmonic loading and realistic aero-/hydrodynamic loading scenarios. The transformation into the time domain is important since it allows the user to incorporated nonlinear wave and wind loading and air-turbine interaction effects that are considered to have a major impact on the resulting dynamic system response. The developed time-domain model is computationally very efficient in predicting the time-domain SSI response of an offshore wind turbine for varying loading scenarios.



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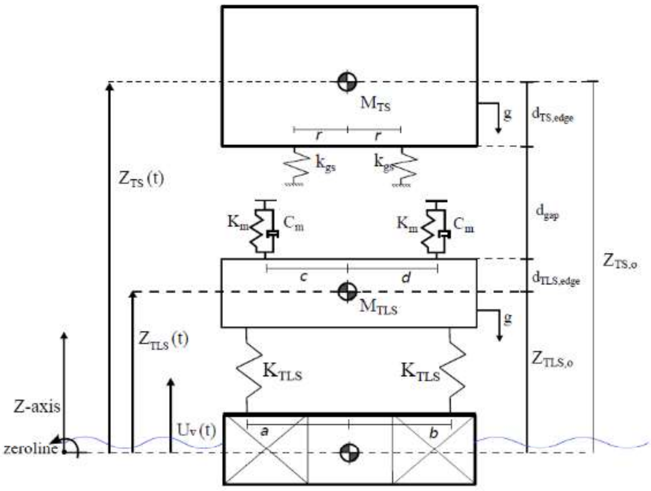
Offshore & Dredging Engineering

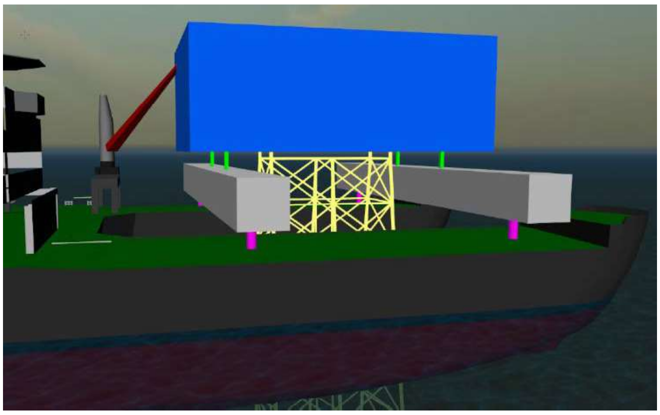
Technische Universiteit Delft

Modelling and Evaluating Impact Loads For Single Lift Operations by Decommissioning Vessels

Offshore production platforms in the North Sea must be decommissioned when production has ceased. A platform can be decommissioned using single lift with AMC (Active Motion Compensation) and transported to another desired location. However, the AMC is considered to be an expensive component. This thesis investigates a passive method of single lift to analyse further possible reduction in costs of decommissioning. A passive single lift involves no active motions compensation and the interaction between platform and vessel will cause uncontrollable impact. A time domain model was developed to evaluate the loads during the single lift procedure. Prescribed motions for the vessel were used as a conventional method, assuming no deviating responses after impact due to its dominant inertia capacity. The Pioneering Spirit was used as reference vessel. Environmental loading on the topside during a beam wave corresponding to an annual stochastic JONSWAP spectrum was used as representative condition. Multiple 1-, 2- and 3-Dimensional impact models with two vessel motions methods were built for modelling the motions of the vessel. The first was the prescribed motions method corresponding to a frequency domain stochastic response, lacking the account for coupling onto the vessel. The second method incorporated the coupled motions by use of the impulse response function (Cummins equation), to evaluate the motions after impact. A sensitivity analysis on the stiffness's within the system was performed which quantified the effects on the loads. A second analysis quantified the impact between the prescribed and coupled motions, their responses, and loads corresponding to the components within the system.

The results show that accounting for the pitch and heave motions in 3-D modelling, using the coupled motions method, resolves in the most accurate responses and a decrease in motion responses after impact. The coupled motions method is found to be a more appropriate method of modelling for the complete behaviour and loads of this type of impact problem, but more time consuming in solving. It showed a decrease of the mean forcing due to decreasing vertical motions after impact. An increase in mean zero-crossing frequency after impact and caused an increase in number of impacts. Finally the analyses showed that the substructure of the platform was the most critically loaded component.





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Offshore & Dredging Engineering

Design of a Feeder System for Offshore Wind Turbine Installation with an SSCV

With increasing demand for renewable energy, the offshore wind industry is ever growing. Wind turbine generators (WTGs) proceed to grow in numbers and in size, wind farms are located further offshore, in deeper waters, poorer soil conditions or in areas prone to earthquakes. These changes make it increasingly difficult to find capable and affordable jack-up vessels for transport and installation of WTGs. Installing with Thialf, one of Heerema's semisubmersible crane vessels (SSCVs), would mitigate most of the problems jack-ups have today and is thus regarded promising. However, Thialf is expensive and has a low sailing velocity. To optimize its installation up-time it will stay offshore for the project duration. A feeder system is required to supply it with WTG components, which are readily available at the marshalling yard. The objective of this research is to determine the critical activities in a feeder system for installation of WTGs with an SSCV, and to improve them so Heerema can make a competitive entrance to the WTG installation market.

Turbine manufacturers demand that WTG towers are positioned vertically at all times. A qualitative assessment for all components points to transport and offloading of the turbine towers to be critical activities. A comparative motion response analysis between a barge and a heavy transport vessel (HTV) shows that during transport, both solutions perform well in sea states higher than the intended installation sea state, thus making them suitable for the task. As offloading demands stricter limits than transport, vessel motions for that activity are too severe. The natural frequency of the vessel-tower system increases with each removed turbine, moving into governing wave frequency ranges for North Sea conditions. This phenomenon shows for both vessel types, from which it is concluded that a supply vessel will be selected based on project specific parameters, rather than motion response.

During preliminary developments within Heerema, tipping of the tower when its sea fastening is released and large swinging motions of the tower after lift-off were main problems found during offloading, to which improvements are necessary. Three concept solutions are assessed: one an alteration of the existing, single tower lift solution, two others making use of the SSCV's cranes with high capacity by respectively lifting a frame with 4 towers and two frames with 8 towers. For each concept, response limits are defined at relevant locations in the system. In-house software is used to determine the RAOs, from which the heading with the highest operability is computed. The offloading and installation activity sequence for wind farms of 48 and 96 turbines are defined, followed by a weather downtime assessment.

First simulations show waiting on weather (WoW) is governed by crew transfer from a crew supply vessel to the barge for mooring operations. This can be improved by using a crew basket, motion compensated gangway or HTV. Simulations with revised limits show that using a frame with 4 towers results in significantly lower WoW days and shortest net project times, making it the most promising concept. Shorter lifting exposure and reducing motion amplification by means of a low frequency system are drivers for the decrease in weather downtime. With a lower total project duration, costs are reduced substantially.

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Offshore & Dredging Engineering

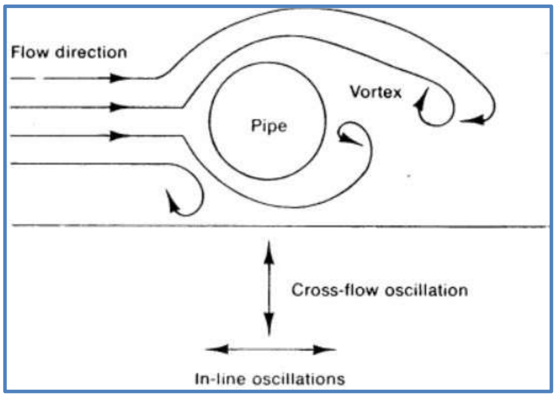
Technical feasibility assessment of hydrogen transport through existing offshore gas pipelines in the Dutch sector.

In the last century, the offshore industry has installed a network of offshore pipelines in the southern North Sea. Due to decreasing oil and gas extraction in the North Sea, many pipelines of this network are becoming redundant. A potential option for the reuse of these pipelines is the transport and storage of gaseous hydrogen, which is increasingly considered as an attractive energy carrier for a fossil fuel free economy. A Shell study has shown that offshore hydrogen production located at a renewable energy source, such as an offshore wind park, can economically compete with onshore hydrogen production that uses power cables to transport the energy to shore. The offshore hydrogen production case is based on newly built pipelines. If it is technically feasible to use existing pipelines, this can contribute to making the offshore hydrogen production case more attractive.

A transition from hydrocarbon transport to hydrogen transport through existing carbon steel gas pipelines changes the material behaviour of the pipeline, including a change in fatigue behaviour. Fatigue damage due to Vortex-induced vibrations (VIV) in offshore pipeline parts that are suspended above the seabed is a major challenge for oil and gas transportation in the southern North Sea. Therefore, it is of great importance to understand the change in fatigue behaviour due to the presence of gaseous hydrogen to assess the technical feasibility of hydrogen transport through the existing offshore pipelines.
A fatigue analysis for a specified existing gas pipeline of the NAM in the southern North Sea has been done according to DNV Free Spanning Assessment Methodology. For this analysis, the fatigue SN-curve for carbon steel material in a hydrogen environment is required. The SN-curve is approached based on available fatigue data for carbon steel material in hydrogen and severe sour environments. It shows that hydrogen has a significant influence on the fatigue behaviour of carbon steel material. The fatigue analysis outcomes show that adjustments to the pipeline are needed to avoid a significant increase in the risk of fatigue failure in critical pipeline sections. A remediation analysis has shown that rock dumping comes out as the cheapest option.

An existing time-domain numerical model that can determine the dynamic behaviour of a pipeline due to VIV is extended to perform fatigue damage calculations. The pipeline is modelled as a Euler-Bernoulli beam using the Finite Element Method. The model determines the VIV with a modal analysis in time-domain, which allows the model to include non-linear soil behaviour. The fatigue damage is determined for each pipeline element, which gives the fatigue damage distribution over the length of the pipeline. The time-domain numerical model is compared with the DNV Free Spanning Assessment Methodology and gives significantly higher fatigue lives. This suggests that the methodology that is used for the fatigue analysis is too conservative. However, there is still uncertainty about the influence of parameters predicting VIV. Further calibration of the model is required to ensure that the model outcomes correspond with target failure probabilities regarding industry standards.

The general conclusion of this research is that the specified existing offshore gas pipeline of the NAM is technically suitable for the transport of hydrogen if the adjustments are conducted. Compared to newly built pipelines, hydrogen transport through existing pipelines is an attractive option due to relatively low adjustments costs.



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Offshore & Dredging Engineering

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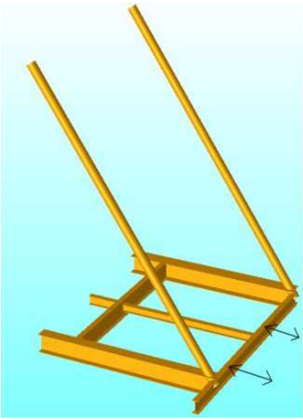
Defining a solid approach for designing a bridge landing against fatigue

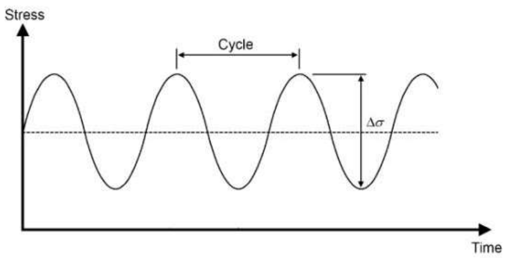
Offshore oil and gas projects usually require the presence of more than one facilities. These need to be connected with each other in order to enable the transfer of personnel. Hence, bridges are implemented, with their ends supported at extensions of the connected platforms, known as bridge landings. The bridge shall be able to follow the excitations that are imposed from the responses of the connected platforms. Thus, its one end should be pinned-supported and the other sliding-supported in order to be able to follow the continuously varying relative movement that is induced by the motion of the two platforms. As a result, friction is generated at the sliding supports of the bridge.

Similarly to any other structure, a bridge landing must be able to withstand the maximum operating loads and its configuration shall be checked against the different limit states. Although a jacket substructure is commonly analysed against the serviceability, ultimate and fatigue limit states, a bridge landing is usually checked against the first two. However, the generated friction induces varying stresses at the corresponding landing. Therefore, it is recommended to verify if the bridge landing is sensitive to fatigue.

This is the motivation behind this thesis, which intends to clarify the sensitivity of a bridge landing into the varying dynamic load of the generated friction. The analysis comprises examining three limit states (SLS, ULS, FLS) in order to highlight the governing one. The fatigue analysis was conducted using a simplified approach that enables to assess it in a straightforward way. This comprises the base case approach, through which assumptions are made regarding the wave and friction main characteristics.

After proving that fatigue is the governing state for such a design, a review of the base case approach was performed. This was achieved through examining the sensitivities of the friction coefficient and the directionality of the incoming waves. Although incorporating wave directionality in the approach does not appear to have a satisfactory impact on the results, a more accurate consideration of the friction coefficient seems a promising improvement. Finally, enhancement of structure is investigated in order to be sufficient against the fatigue requirements. This is achieved through examining four different options, the three of which were efficient.





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Offshore & Dredging Engineering

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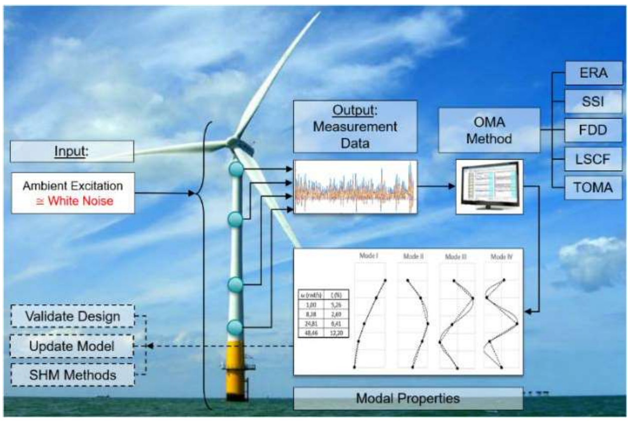
A benchmark study on operational modal analysis system identification algorithms for operating Offshore wind turbines

Recently, Offshore Wind Turbines (OWT) have attracted great attention in an effort to make a shift from fossil-based energy sources towards an enhanced sustainable and renewable energy production. In order to achieve the renewables targets and reduce the cost of wind energy, OWTs are consistently increasing in size. Therefore, research has targeted the optimization of OWT design. For many years, System Identification has played a central role in obtaining the actual modal properties of existing structures. Operational Modal Analysis (OMA) is a subset of these technique that applies on measurement data obtained from a structure loaded by ambient excitation. In the case of an OWT, such methods would be highly important in validating and/or updating the design and monitoring the structural health of the structure, which includes damage identification and fatigue damage estimation and would potentially lead into lifetime extension.

In practice, however, using OMA techniques on operating OWT is not a straightforward procedure. In fact, most of these techniques assume that the excitation is a white-noise process, which is not the case when waves and operational loads (e.g. rotational sampling) are present. Apart from that, the system itself is considered to be Linear Time-Invariant. Unfortunately, the modal properties of the system are highly affected by the varying rotational speed of the rotor and in general do violate the LTI assumptions. Given these challenges, the use-ability of existing methods need to be further investigated through application on OWTs under different operational conditions. Also, it is vital to asses and if possible eliminate the impact of the limitations related to loading on the identification.

Thus, a benchmark study of OMA algorithms has been performed on simulated data obtained from two models. The first model is a simplified OWT numerical model in Matlab, which can be used to validate the algorithms, and the second is the NREL 5-MW baseline offshore wind turbine in FAST that was used to simulate multiple different operational conditions. Using the simulated responses, at first, the Eigensystem Realization Algorithm (ERA) and the Natural Excitation Technique (NExT) were applied. Secondly, the widely used Stochastic Subspace Identification (SSI), has been included in this study. In Addition to these time domain techniques, the frequency-domain algorithms, Frequency Domain Decomposition (FDD) and the Least-Squares Complex Frequency-domain (LSCF) estimator were examined. In the end, Transmissibility-based Operational Modal Analysis (TOMA) was developed aiming in removing the influence of the external loading.
Through this study several parameters used in each algorithm as well as the robustness against harmonic excitation and measurement noise were investigated, providing the user with guidelines for each method. Then in the application on simulated data obtained from FAST, the results showed that all the algorithms were able to derive several stable modes, even when theoretically fundamental assumptions are violated. In general, the algorithms performed better for low wind speeds, while at high wind speeds the algorithms leaded in poorer identification (smaller number of stable modes). The greatest deviation compared to analytically obtained modal properties was observed in the damping ratios of the flapwise blade bending modes, where none of the algorithms was able to obtain such large damping ratios (>30%). However, most of them were still able to obtain two fore-aft tower modes and an accurate damping estimation. TOMA did remove the influence of external loading from the identification, but faced difficulties in obtaining blade modes. Finally, this benchmark study revealed the strengths and weaknesses of each technique when the core assumptions are violated.



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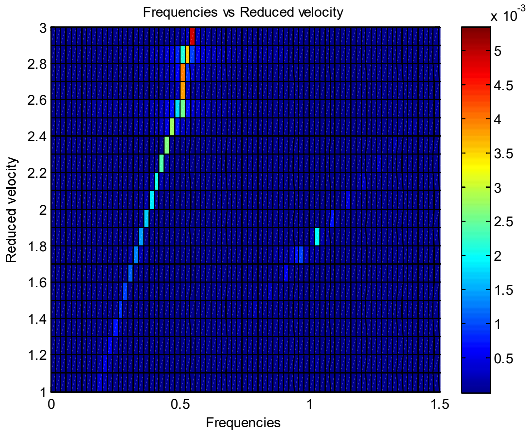
Offshore & Dredging Engineering

Modelling vortex-induced vibrations with a single wake oscillator coupled to both cross-flow and in-line motions

Vortex-induced vibration or as well-known as VIV is a phenomenon that has caught the attention of engineers along history. VIV is related to many engineering fields. In the offshore industry, it is of importance for risers that extract oil from the subsoil, and tethered anchors for floating units.

The main aim of the thesis is to model the VIV phenomenon through a new version of the wake oscillator model by Qu,2019. This modified model includes a new in-line coupling term that is introduced in the wake equation of motion. Apart from having a new in-line coupling term in the wake equation of motion, the model also includes a coupling term that relates the lift force with the fluctuating force in the in-line direction.



In order to analyze the performance of the modified wake oscillator model, it was required to understand the advantages and drawbacks of some models that were implemented before.

During the investigation, four main steps were followed:

1. The performance of the equation of The Van der Pol oscillator to model the VIV phenomenon was explored.

2. Analysis and identification of advantages and drawbacks on the wake oscillator model by Ogink and Metrikine,2010, the one without in-line coupling, were conducted. This wake oscillator model was used to model a rigid cylinder elastically supported in free oscillation experiments.

3. The modified wake oscillator model (Qu,2019) was used to model a rigid cylinder in free oscillation experiments and in forced in-line vibration experiments.

4. Performing a sensitivity analysis in the new model.

After analyzing the behavior of the new model, it was concluded that adding a coupling term in the wake equation of motion was helpful to improve the phenomenological modelling of coupled cross-flow and in-line vortex-induced vibrations of an elastically supported cylinder in fluid flow during free oscillation experiments. However, for the case of forced in-line vibration experiments, discrepancies between the model results and experimental measurements were observed. More in-depth study on the simulation of forced vibration experiments is recommended to further improve the wake oscillator model.

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Modelling the vortex induced vibrations of sea fastened wind turbine towers using a wake oscillator model

It is well known that for tall cylindrical structures under wind action, such as wind turbine towers, vortex induced vibrations (VIV) may occur. During the installation of offshore wind turbine towers there are different stages of transport where we might deal with VIV.

The main objective of this thesis is to explore the possibility of modeling the VIV of flexible cylindrical structures by means of an existing wake oscillator model. Sub objectives are to investigate the influence of the deck stiffness and vessel motions on the VIV. And also, the effectiveness of strakes as mitigation for VIV is investigated.

From the literature study it is found that an existing wake-oscillator model with acceleration coupling is a good way to model the VIV of a rigid cylinder that is free to vibrate in water. This wake oscillator model, which was tuned to the experiments in water, is then tuned to an experiment where the rigid cylinder was free to vibrate in air. These free vibration experiments were all done in the sub critical flow regime.
In the next step the model is extended to model the VIV of flexible cylindrical structures. In an attempt to validate, this model is used to simulate the cross-flow amplitude of a in situ chimney on whom measurements were done during VIV. Due to the size of the in situ chimney, the Reynolds number at which VIV occurred suggests that we are in the super critical flow regime. However, the measured Strouhal number had a frequent value of 0.21 which is common for the sub critical flow regime. From the simulations it was found that by making use of the force coefficients from the super critical regime good agreement is found between the simulated and measured crossflow amplitude, while adopting force coefficients from the sub critical regime, the model significantly over predicted the response.

Finally, the model is applied in a case study with a wind turbine tower. A total of four cases are investigated. From this case study it was found that a stiff deck will result in VIV at higher windspeeds, but will also increase the loads. The VIV of the tower is hardly influenced by the vessel motion since the frequencies of the two are far apart. According to the model, covering the top one third of the tower with strakes significantly reduce the VIV, but with a penalty of increased in-line bending load on the deck.

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Flexible floating island

Nowadays, fears over rising sea levels due to global warming have prompted many countries with lands below sea level to find solutions to ensure the safety of nation and citizen. Furthermore, the development and utilization of marine resources have always been a topic of interest. Due to these necessities, the concept of flexible floating islands that can be used for fish farm, energy islands and residence has emerged. The flexible floating island consists of many smaller identical triangles connected by springs. This design is convenient for installation, disassembly, and diversification of functions.

The main objective of this thesis is to investigate and analyze the forces acting on and motions of the flexible floating islands due to the interaction with regular waves; a numerical model is an excellent way to complete that mission.

The floating islands in waves that are constrained with mooring lines have translational and rotational motions under the combined effect of hydrodynamic, hydrostatic, gravitational and mooring forces. The approach for solving the forces starts with linear potential theory, which means that uncompressed inviscid flow is assumed. After marking out the identical smaller panels on the wetted surfaces of each small triangle, the interface conditions between the triangle and the fluid are satisfied, thereby obtaining the source strength for each panel. With the expressions for the potentials, all the hydrodynamic coefficients including added mass, damping and wave exciting forces can be evaluated.

Finally, the response of islands can be evaluated by using the equations of motions of the island in the time domain and converting them to the frequency domain. Two models are created in this thesis, a single island model and a two-island model, the former focuses on learning the methods for solving the hydromechanics coefficients, and the latter focuses on the hydrodynamic interaction between the two islands.

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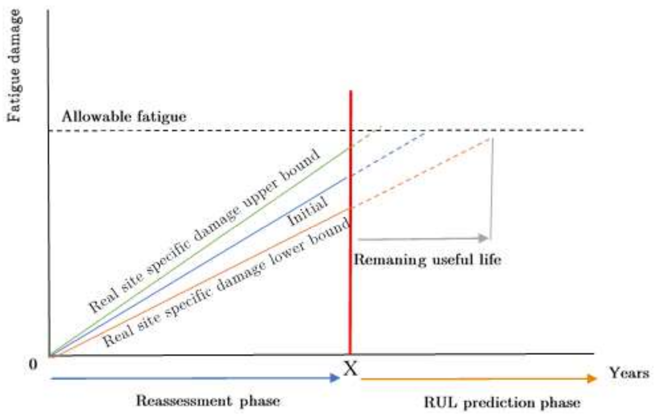
Fatigue assessment of existing offshore wind turbine support structure for lifetime extention

Wind energy has become an important topic nowadays and has made a remarkable growth during the last decades, especially in Europe. Offshore wind turbines (OWTs), together with their support structures, are designed for an operational period of 20 years. The first generation of these offshore wind turbines has already reached or is approaching their designed lifetime of 20 years. Depending on the legislation and the governmental subsidies, a decision needs to be made about their future. One option is to keep the OWTs in operation after exceeding the design lifetime while the safety levels are not compromised. Operating after the design life, which is called lifetime extension has become more and more interesting in the current market conditions. To find out whether the safety levels, which are determined by the design standards are not compromised when the lifetime is extended, the OWT support structures should be reassessed when the end of design life is insight. Reassessing the support structure can take out the uncertainties of the parameters that are monitored and can make lifetime extension possible.

The objective of this study is to propose a framework for reassessing existing OWT support structures for lifetime extension since there is not a clear detailed methodology describing the assessment and extension which can be applied for OWT support structures. Because of the complexity of the problem and the limited time, only the governing limit state is studied which is the fatigue limit state. The proposed framework consists of two phases. The first phase is the reassessment phase in which the available documentation and measurements of the (operational) history are taken into account to determine the fatigue damage with more certainty from the installation of the OWT till the point when the reassessment takes place. The second phase is the remaining useful lifetime (RUL) prediction phase, which aims at determining the remaining operational lifetime of an OWT without exceeding the safety limits. For both phases, different methods can be used that can be classified in deterministic methods and probabilistic methods. An overview of the proposed framework is presented in the figure below.

Finally, the suggested framework is demonstrated in a simplified case study. First, the fatigue lifetime of the simplified structure is calculated with wave conditions of the Gemini wind farm; This calculated lifetime resembles the initial design lifetime and serves as a comparative measure for the following reassessment and RUL prediction phases. Then the simplified structure is reassessed with updated data, using a deterministic method. Subsequently, the RUL is predicted by using probabilistic fatigue calculations whereby different uncertainty distributions are taken into account. From this case study, it can be concluded that the proposed framework is applicable for different amounts and types of measurement data as well as assessment methods. The deterministic reassessment shows different outcomes of fatigue life of the structure even with a small change in the input parameters. The probabilistic fatigue calculations used for the RUL are computational more complicated but very promising since site-specific uncertainty distributions replace the generalized partial safety factors. The suggestion is, therefore, to use probabilistic models to achieve a longer lifetime for the OWT support structure without compromising the safety levels.



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Offshore & Dredging Engineering

Numerical Modelling of Interconnected Floating Solar Energy Platforms

Land scarcity is increasing and therefore one of the main challenges for renewable energy in the future is ‘physical space’. While renewables need a lot of space compared to conventional energy sources, and the competition for space is already increasing (food production, housing etc.), leading to higher land costs and opposition. Public resistance to new highly visible windfarms and onshore solar farms is hardening. Large land-based solar farms compete with agricultural use and can have negative effects on the ecosystem, by covering the soil from the solar light. A solution to the stated problems is by placing renewable energy production at sea, among which offshore floating solar energy.

One of the main challenges in offshore floating solar is the continuous wave-induced motion of floaters, and the forces that arise at the most critical points. Dynamically modelling multiple floaters in waves becomes very computationally and time intensive when the number of floaters increases. This research focused on creating and comparing a linear and a non-linear model that calculates motions of multiple floaters under first order wave forces. The aim is to perform these calculations with open-source software only.

The dynamic forces on the floaters are obtained by evaluating the radiation, diffraction and wave excitation potential in the open-source Boundary-Element-Method-Solver NEMOH and showed good resemblance with commercial software packages AQWA and DIFFRAC. The modelling of the motions is performed in time (linear and non-linear RK4-integration-scheme) and frequency domain (linear). The implementation of the dynamic forces in both cases showed to be the most critical for the behavior of the floaters. Especially the determination of the hydrodynamic coefficients: Infinite added mass and retardation function for the time domain simulation are key in getting the same result for the linear time domain and frequency domain. Suppressing non-realistic values of gap resonance between multiple floating bodies increases the efficiency of time-domain simulations. Small differences between the motions of the floaters can cause significant differences in the forcing, therefor it is rather advisable to perform the comparison between the linear and non-linear case in time domain.

A comparison of different wave directions and conditions showed that the results of the linear model are of the same order of magnitude as the non-linear model. For the determination of motions and forcing under first order wave forces this shows that both cases are similar. Nevertheless, other non-linear effects can be added in a follow-up study.

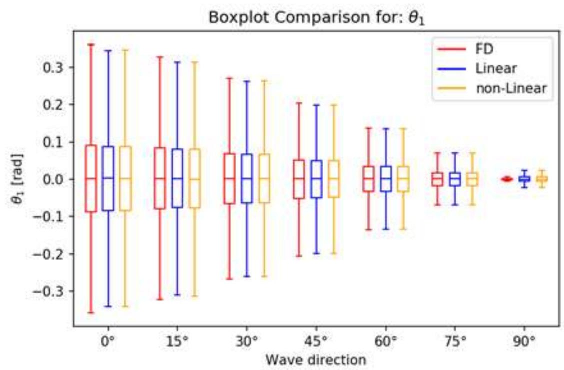

Figure 1: Motion in pitch of one of the floaters for different wave directions.

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Offshore & Dredging Engineering

Analysis of a Wind Driven Reverse Osmosis Desalination System: Experimental Study Using a Pressure Exchanger Energy Recovery Device

With a fast growing world population, the lack of fresh water is one of the world's biggest future concerns. Water stress can lead to conflicts, holds back economic growth and has a major impact on human health. Nowadays, more and more countries that lack fresh water sources are using the saline water from the oceans and desalinate it to produce fresh water. The most common way to do this is by the means of Reverse Osmosis (RO). However, one of the biggest negative aspects of desalination is its high energy consumption, mostly provided by fossil fuels. Therefore, a more sustainable solution using renewable energy sources to power a RO system is necessary

Delft Offshore Turbine (DOT) is currently developing a hydraulic drive train wind turbine that converts the aerodynamic power captured from the wind into hydraulic power. With a positive displacement pump, a high pressure water stream is created for centralised electricity production using a spear valve and a Pelton wheel. Using this hydraulic turbine for the purpose of fresh water production with RO can be a well fitted combination. Using wind as an energy source for desalination purposes, however, creates some major challenges, one of which is dealing with the inconsistency of wind. For varying wind speeds, a hydraulic wind turbine is controlled by regulating system pressure hence the pump torque with the spear valve. With a Seawater Reverse Osmosis (SWRO) system with ERD, it is researched how to regulate the flows and pressures for a stable operation.

In this thesis, the combination of the hydraulic wind turbine with a Reverse Osmosis system with an Pressure Exchanger Energy Recovery Device (ERD) is being analysed in more detail. For this, a numerical model is used to determine the systems' behaviour and an experimental test setup is designed and constructed to validate the model results. The aim of this thesis is to compare the desalination system performance with a stand-alone system without an ERD, to determine the influence of varying ERD settings on the systems' pressure for potential system pressure and torque controllability, and to investigate how the RO system with an ERD affects the wind turbines stability.

The analysis shows a large positive influence on the amount of produced permeate when using an ERD in the RO system. In addition, the power consumption of the RO process can be reduced by up to 80%. A varying input provided by the high pressure pump, for example as a results of varying wind speeds, does not seem to (negatively) affect the efficiency of permeate production. By varying the ERDs' rotational speed, the feed pressure at the membranes inlet hence the pressure at the high pressure pump can be slightly influenced. However, this limited influence is not enough to effectively affect and control the high pressure pumps' torque.
On top of that, for the wind turbine to operate in a stable operating region, it seems that the use of an ERD affects the system in such a way that water production can only be realised at fairly high wind speeds. To optimally make use of the hydraulic wind turbine and operate at the highest possible aerodynamic efficiency, a combination of electricity production at low wind speeds and water production with an ERD when wind speeds are sufficient, can be interesting. For this, future research is required.

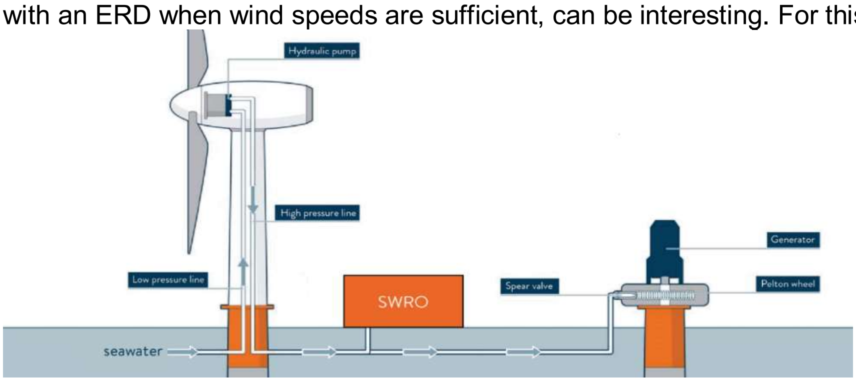

Figure 1: Visualisation of the DOT hydraulic wind turbine with a SWRO system.

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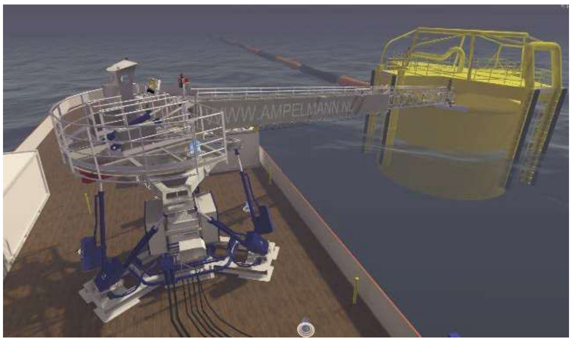
Offshore & Dredging Engineering

Technische Universiteit Delft

Determine the impact on the workability affected by dynamic interaction of an Ampelmann system connected to a CALM buoy

The diversity of offshore structures is increasing nowadays, as more and more offshore structures are floating. To study the opportunity for Ampelmann to expand to the floating market it is necessary to see if working with floating structures requires a new way of operating. A potential market for Ampelmann is transferring maintenance personnel to catenary anchored leg moored (CALM) buoys. These on- and offloading buoys for tankers are stationed relatively close to shore and are connected to an onshore storage facility.



The current method of connecting the Ampelmann system to an offshore structure is done by applying a constant force on the target structure to keep the gangway connected. There is a dynamic interaction between the Ampelmann system and the floating structure, which potentially can influence the motions of the floating structure and the workability of the Ampelmann system.

The current method of calculating the workability is based on a kinematic approach where dynamic interaction is not included. The effect of the dynamic interaction between the Ampelmann system and the CALM buoy has been studied by a numeric, coupled, time-domain model. Using this model the response of the coupled system will be compared with and without the dynamic interaction of the gangway forces acting on the buoy.

An analytical approach is used to perform a sensitivity study of the parameters exerting the total damping forces on the CALM buoy. This study showed that the hydrodynamical damping of the buoy is the governing factor. According to diffraction data of the buoy, the hydrodynamical damping can vary significantly in the frequency spectrum. For low- and high-frequency waves the hydrodynamical damping of the buoy is much lower than in the mid-frequency spectrum. The damping forces caused by the gangway are of bigger impact when the hydrodynamic damping of the buoy is low. This is used to create a case-study for regular, low-frequency waves to study the influence of the gangway damping forces on the motions of the buoy. This case study is used in the numerical model of aNySIM, and in a numerical model based on the analytical approach in Python. Both showed that the amplitudes of the motions of the buoy are reduced by the damping forces of the gangway.

A workability study has been performed by creating time series of the dynamic interaction using the 3D aNySIM model and then comparing it to the operational limits using a MATLAB model. The operational percentage and statistics of each sea state results in the total workability. The workability obtained with a dynamic approach is improved by 1% compared to the workability obtained with a kinematic approach.

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Offshore & Dredging Engineering

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Coupled Dynamics of a dual lift operation

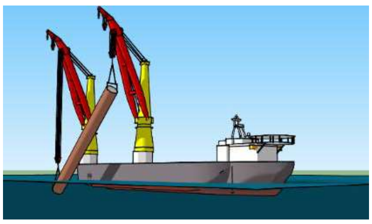
Offshore wind farms are moving to deeper waters, implying that larger substructures will need to be installed. The monopile is the leading substructure nowadays and this structure could be promising for use in deeper waters as well. Generally, jack-up vessels are used for the installation of the substructures and turbines. However, the jacking up and down of these vessels is time-consuming and limiting with regard to the water depth. A solution to tackle these two drawbacks, is to conduct the installation with a floating vessel. However, this brings along other challenges due to the hydrodynamics of the floating vessel. Therefore, this thesis focuses on the installation of XXL Monopiles with a monohull vessel. An XXL Monopile is a monopile with approximately a length of 120m and a diameter of 10m.

Boskalis is expanding its position on the offshore installation market and has recently added a new heavy lift vessel to its fleet. This vessel is the Bokalift 1 which is a monohull vessel equipped with a crane of 3000 tons lift capacity. To strengthen their position on the installation market, Boskalis is thinking about a new kind of heavy lift vessel which will be an extended version of the Bokalift 1: a Bokalift 2. This vessel will be a monohull vessel as well but possibly equipped with two cranes. The idea is to use this vessel for the installation of XXL monopiles with the use of both cranes. Boskalis wants to understand the dynamic behavior of the lifted object and vessel during this kind of operation and to know whether the installation with this kind of vessel is feasible or not. This will be assessed by determining the Eigenmodes and corresponding natural frequencies of the system, including the dynamic coupling between the lifted object and the vessel.

The installation of the XXL monopile with a Bokalift 2 is a novel operation. The phase of interest during this installation is the upending of the monopile, which will be executed partly through the splash zone. Using a simplified model, the modes and corresponding natural frequencies are determined for the lifted object in air (no vessel included). This is done with a modal analysis. With a more complete model made in OrcaFlex, these modes and frequencies are verified. The model is expended by including the vessel and subsequently a modal analysis is done. Since the submerged part of the monopile during the upending cannot be seen as a slender structure, the Morison equation is not applicable. To run the time domain simulations with the correct hydrodynamics included, the model is improved using a diffraction software AQWA. With this improved model, the dynamic coupling between the monopile and vessel is determined and it can be concluded that there is a strong coupling between the monopile's yaw motion and the vessel's roll motion.

Since an XXL monopile is being considered, it was decided to take a look at the piston mode. This is a phenomenon where the water inside the monopile moves up and down. The water column in the monopile will be excited by the waves and this results in a harmonic moving water plug inside the monopile. Since the monopiles are becoming bigger, the water volume is becoming bigger as well and might be of great concern. In previous studies this piston mode has been investigated, but never been applied in a complete model. In this preliminary study, this phenomenon is modeled in OrcaFlex and implemented into the monopile installation model. From the comparison between a model with and without the piston mode it is concluded that, generally, the piston mode will result in larger responses. However, the approximation of the piston mode phenomena is done by making several assumptions. The coupling between the water in and outside is not considered for example and, therefore, further research is required to gain more knowledge on the effects of the piston mode.

The current thesis provides more insight into the behavior of the lift and vessel dynamics. Based on these results, it is known to which motions attention need to be paid. Also, the coupling between the monopile and vessel is established and could be reduced by the use of tugger lines. A novel way of modeling the piston mode is developed and the effect of the piston mode is resolved to be increasing the motions of the system.



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Offshore & Dredging Engineering

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Limiting mechanisms for the torque density of wind turbine drivetrains

As wind turbines continue to increase in size, so do the loads acting on the drivetrain. To handle the higher loads the mass of the drivetrain needs to increase. A better understanding of this mass increase can result in lighter drivetrain design and provide an insight in which drivetrain design has the lowest mass potential for large rotor diameters. In this thesis the limiting mechanisms, mass and torque density of three offshore wind turbine drivetrains are investigated for an increasing rotor diameter. The limiting mechanisms in this thesis provide a theoretical limit to the minimum required mass of a drivetrain for increased loading. Through an extensive literature study the limiting mechanisms are found and three scaling models are developed to calculate the torque density of the drivetrains. The drivetrains that are being considered in this thesis are the drivetrain with gearbox and high-speed generator, the direct drivetrain and the hydraulic drivetrain. The following research questions are answered in this thesis:

- What are the limiting mechanisms of the three investigated drivetrain types?
- What are the achievable torque densities of the three investigated drivetrain configurations for increasing rotor diameters?

For the drivetrain with gearbox and high-speed generator, a planetary gearbox with two planetary stages and one parallel stage has been selected (see Figure 1). In this setup, a high speed permanent magnet generator is included in the design. For the direct drivetrain configuration, the radial flux permanent magnet synchronous generator (RFPMSG) has been selected. For the hydraulic drivetrain, an internal radial piston pump is used to pressurize hydraulic fluid.

Two limiting mechanisms are found for the drivetrain with gearbox and high-speed generator: Tooth flank stress (**1.72 GPa)** and Root bending stress (**0.24 GPa)**. The Tooth flank stress is found to be governed by the Hertzian contact strength while the root bending stress is governed by the flexural strength. Two limiting mechanisms for the RFPMSG are found for the airgap flux density (**1 T)** and the current loading (**30 - 200 kA/m)** in the generator windings. The airgap flux density is limited by the saturation of the stator teeth material in the generator whereas the current loading is limited by the heat dissipation of the windings and stator laminations. For the hydraulic pump, the limiting mechanism is found at the interaction of the camring and the cam roller.
As for the gearbox, the maximum stress that is allowed at this point is determined by the Hertzian contact strength of the material and is again found to be (**1.72 GPa)**. Using the limiting mechanisms of the three drivetrain configurations, scaling models for the mass and torque density of the three drivetrains have been developed.

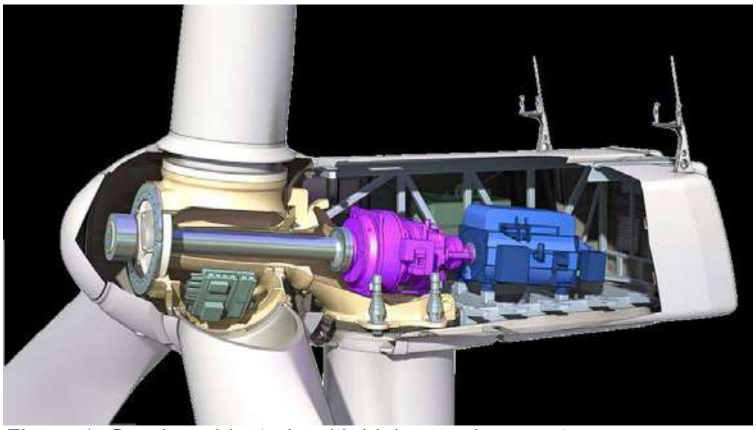

Figure 1: Gearbox drivetrain with high speed generator

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Offshore & Dredging Engineering

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Wind turbine driv-trains condition monitoring through SCADA data on farm level

The offshore wind industry has grown rapidly over the last decade and drivetrains are increasing in size to reduce the cost of energy. These turbines are operating in a harsh environment. Adopting a preventive maintenance strategy is important to achieve an as high as possible availability of the farm and reduce the cost of maintenance. A well performing condition monitoring system that utilizes SCADA data from the wind farm can enable this strategy without the need in additional cost in hardware.

This master thesis focusses on the development of a framework that can be utilized for this task. This framework can process raw operational SCADA data collected at the Egmond aan Zee offshore wind farm to create a clean dataset to train supervised machine learning models on. This work provides an insight in the correlation between different SCADA signals using a mathematical approach and from a understanding of the system integration of drivetrain components. Bearing temperatures are modelled using a data driven approach to describe the temperatures under healthy conditions. Several models are evaluated for this task and it was concluded that a decision tree supervised machine learning regression model resulted in the lowest error between predicted and measured values. Anomalies are detected and tracked with a normal behaviour model and a Sherward and CUSUM control chart that are applied on the residual error between modelled and measured temperature signals.

4 anomalies could be identified in the gearbox bearing using the developed framework. Abnormal behaviour of the drivetrain could be identified as early as 1 month before the turbine was taken out of productions. This highlights that temperature based condition monitoring that utilises SCADA data can be used for early detection of faults by combining the accuracy of supervised machine learning methods with different fault detection methods like the CUSUM control chart.

This work also investigates the relation between experienced wake of a wind turbine and the influence on the drivetrain component temperatures. The wake conditions at Egmond aan Zee, modelled with an Ishahara wake model, and the component temperature measurements from the SCADA data are used for this analysis. The bearing temperature distributions under different operational and wake conditions can be compared by clustering over the wind speed and the velocity deficit or turbulence intensity at turbine level. It is concluded from this work that no change in component temperature can be observed from a data perspective where one hourly mean SCADA data is utilized.

The effects of asymmetric wake conditions opposed to wake experienced over the entire rotor is analysed by comparing the temperature distributions under these conditions in a cluster where the turbine is partially waked. A small shift towards higher component temperatures can observed on a limited amount of data for turbines under asymmetric loading conditions.

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Offshore & Dredging Engineering

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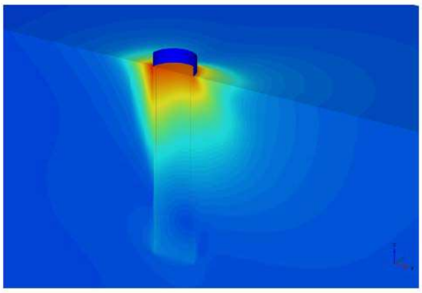
Lateral bearing capacity of GBM Vibro-drill installed monopiles

Offshore wind turbines are commonly supported by monopile foundations. Impact hammering is the conventional method for installing offshore monopiles but has several disadvantages. Time-consuming installation procedures, high noise emissions and steel fatigue due to the high impact are problems resulting from this installation procedure. GBM Works is a start-up that is currently developing the Vibro-drill: a new method for installing monopiles, aiming to solve the stated problems associated with the hammering method. The Vibro-drill is mounted at the bottom of monopile and uses vibrating elements that simultaneously jet water, aiming to reduce the soil resistance. As a result, the monopile can penetrate the soil to target depth under its own weight.
The monopile foundation is designed to support an offshore wind turbine throughout its lifetime of about 25 years. As the wind turbine is primarily subjected to lateral loads, one of the major design requirements is the stability of the pile in terms of lateral bearing capacity. Hammered piles have shown to provide sufficient lateral bearing capacity and this method has been used world-wide to install monopile foundations. Because the Vibro-drill machine is a unique and new concept, there is insufficient knowledge about the installation effects. Therefore, the lateral bearing capacity of a Vibro-drill installed pile is yet unknown.
Before this new method can enter the offshore wind market, it needs to be researched and demonstrated that this new method provides sufficient bearing capacity for an offshore wind turbine. To that end, this thesis contains a study regarding the possible soil effects and resulting bearing capacity of Vibro-drill installed monopiles.

Predictions of the monopile response were done with a finite element model in Plaxis 3D. The numerical model was verified based on data from monopile tests in Cuxhaven from 2014. During these full-scale field tests, three pile pairs were installed in dense sand by vibro-driving and hammering. The effect of the methods was quantified by lateral load tests on both piles. The input parameters for the Plaxis model were derived from CPT measurements using empirical relations based on relative density recommended for monopile design. The FEM predictions show a fit with the field-measurements during initial loading where after the curves start to deviate. The differences between the FEM prediction and the field measurements are discussed, expected is that they are caused by creep effects that occur in the field.

As no soil effects as result from Vibro-drill installation have yet been measured, a worst-case approach was taken to identify the risks concerning the lateral bearing capacity. A hypothetic soil disturbance as result of Vibro-drill installation was generated based on studies regarding soil effect due to existing vibrating and jetting methods. Different worst-case scenarios of possible soil effects were sketched to study the resulting pile reaction due to a horizontal applied load. This was done by comparing the monopile response of a hammered and vibro-drill installed pile and increasing the pile size of the Vibro-drilled pile iteratively until a similar reaction to the hammered pile was obtained. In this way, the effect of a Vibro-drill installation was quantified in terms of additional pile material. For the studied scenarios, an additional proportion ranging from 17% to 29% of the embedded pile material was required to compensate for the softer pile reaction. Also, a study on the effect of pile size has shown that for larger piles, a lower proportion of additional pile material is required to compensate for a possible softer pile response resulting from Vibro-drill installation.



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Offshore & Dredging Engineering

Technische Universiteit Delft

Modelling of submerged oscillating water columns with mass transfer for wave energy extraction

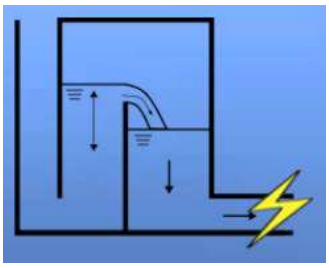
In the past decades, the global demand for energy has increased. The aim to reduces has led to an increase in the production of renewable energy sources, such as wind and solar energy. However, there are more major energy resources available in the oceans, such as wave and tidal power. The estimated potential global energy resource in waves is around 2 Terra Watt. Over the years, many different technologies have been developed to harvest this high-density energy source. Yet, the harsh weather conditions are challenging the survival of the energy converters.

A potential device that avoids the risk of high environmental impacts and has a reduced vulnerability is the Neptune: The Neptune is a fully submerged wave energy converter. Inside the structure, a weir and internal air pocket separate two water columns. One column acts as an oscillating water column to pressures of the incident waves. During its oscillations, the inner free surface level exceeds the weir and spills water into the second column. This column acts as a reservoir, and the overflow water is drawn off through an exit pipe, including a turbine. From the net flow through the columns, energy can be extracted. This design has the advantage of being fully submerged and has a single moving part, namely the turbine.

The objective of this thesis is to form a more scientific base concerning this device. A numerical model is made to predict the dynamic behaviour of the system. The equations of motion of the water columns are derived from the equations of conservation of mass and momentum. The excitation forces are obtained from the linear wave theory for regular undisturbed waves. The hydrodynamic coefficients are determined from associated literature. The dynamics of the internal air pressure is derived from the conservation of mass and the pressure density relation for an adiabatic and reversible thermodynamic process. The pressure oscillation of the air chamber is coupled to the flow of the columns. The mass transfer between the columns is assumed instantaneous and modelled for the different conditions of the free surface displacement with respect to the weir level. The weir discharge is included in the expressions for the convective acceleration and momentum associated with the change of mass in the columns. An impact pressure is derived for the falling water from the weir on the column. The response of the turbine was modelled assuming a linear relationship between the flow through the turbine and the regression relation of stationary hydraulic turbines.

Using the developed model, the time series of the response is obtained by solving the non-linear differential equations in the Matlab ODE45 solver. The model is solved for a full-scale structure with a natural period of 8.5 seconds. The results are found for different periods of regular incident waves and various weir levels. From the results, an increase of resonance periods was identified, caused by the transfer of potential energy from the resonating column to the other column. Due to the weir discharge, a uni-directional flow is obtained in the second column. The uni-directional flow is desired for the extraction of energy.

Furthermore, an increase in the mean displacement in the first column is found, caused by the damping in the second column. The increased of damping, from pressure losses or the turbine, resulted in a decrease of weir discharge. An optimal turbine diameter was found to be dependent on the relation between the dynamic flow and the damping induced by the turbine. This relation also results in a maximum power take-off efficiency of 7 to 12% depending on the weir level and the incident wave height. These are low efficiencies compared to other wave energy converters. It is likely caused by the inefficient energy transfer between the columns. Further research and optimizations are required to assess the feasibility of this wave energy converter.



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Offshore & Dredging Engineering

Technische Universiteit Delft

Simulating Bending Failure of Ice using Smoothed Particle Hydrodynamics

The offshore industry is a conservative industry, sticking to rigid best-practices and reluctant to try new techniques. A promising new technique that hasn't found much adoption in the offshore industry is SPH. This thesis aims to improve the reach and use of SPH within the offshore industry. With an abundance of world's unexplored hydrocarbons located in the Arctic Region, 18%, ice-structure interactions (ISI) are set to increase. Modelling these ISI requires complex dynamics and SPH can model these ISI dynamics without extra treatment.
SPH works by interpolation of a set of neighbouring particles using a weighing function, see Figure 1. The particle being interpolated is shown in red, the neighbouring particles in black, and the kernel (weighing) function in green.

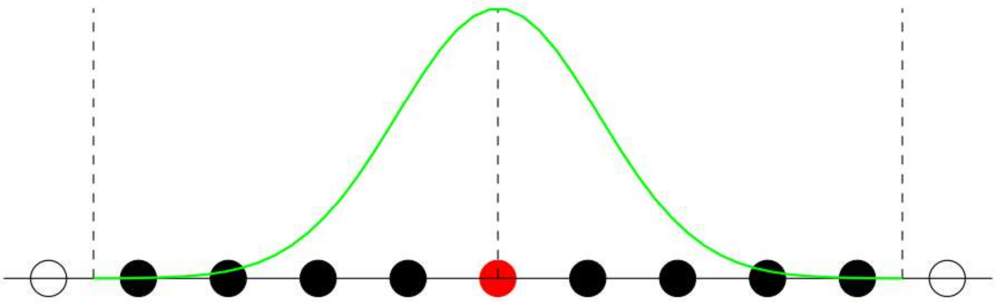

Figure 1: 1D SPH

This modelling technique offers many advantages over conventional rules-of-thumb, Finite Element Modelling (FEM), and Finite Volume (FV) methods. SPH is a particle based method, thus, uniquely suited for problems with large displacements, or discontinuities.
However, in the standard, weakly-compressible (WCSPH) method spurious pressure fluctuations and particle clustering can occur. By implementing the plethora of correction methods and equations present in literature, such as kernel corrections, incompressible variants, or density corrections, these drawbacks can be circumvented and a robust framework can be formed.

An implementation of WCSPH that focuses on adaptability and flexibility is presented in this work. The flexibility of the implementation allows future researchers to focus on the core of their research, only changing the equations they are interested in, instead of implementing all the required equations for a full SPH simulation. A validation study of the implementation has shown that it matches closely with existing implementations and real-world results.

The mathematical model developed in Keijdener, Hendrikse, and Metrikine (2018) and Keijdener and Metrikine (2014) is implemented in the proposed WCSPH implementation. Comparing the results shows close agreement for the breaking length and its dependence on the ice velocity. However, significant differences are present in the time until failure. Despite this discrepancy, this work shows the possibility of combining solid mechanics with SPH, and validates the integration method, solver, and SPH model.

In the future I expect the use of SPH to grow in all industries, the offshore industry included. SPH is an extremely promising technique with many advantages over conventional techniques. As shown by the comparison with Keijdener, Hendrikse, and Metrikine (2018), SPH can approximate dynamics without extra treatment and is, therefore, a valuable tool for the offshore industry.

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Offshore & Dredging Engineering

Combined earthquake & wave action on offshore wind turbine monopile foundation

The offshore wind industry has been extended over the last years in areas of active seismicity, such as East Asia, where the design of offshore wind turbines becomes significantly challenging, because not only the aerodynamic and hydrodynamic loads act on the offshore structures, but also earthquake is a big threat.

The present master thesis deals with the dynamic analysis of the response of an offshore wind turbine monopile due to the application of hydrodynamic and earthquake loads. The interest is focused on the understanding of the dynamic properties contributing to the dissipation of energy experienced by the structure. More specifically, the sources of damping are investigated, emphasizing on the hydrodynamic and the soil damping. A numerical approach for the estimation of the hydrodynamic viscous damping is presented based on the calculation of the drag coefficient C_D and its dependency on the Reynolds number, the Keulegan-Carpenter number and the surface roughness.
Furthermore, the soil radiation damping is studied by including the interaction of the soil with the structure. The supporting soil is modelled around the monopile with frequency-dependent springs and dampers. The estimation of the soil coefficients is accomplished by integrating in the model of the structure, an advanced soil model developed by Dr. J. De Oliveira Barbosa.

The analysis of the response of the structure is executed by examining three load cases for the hydro-dynamic and earthquake loads. The overall outcome reveals that a noticeable amount of energy is dissipated because of the presence of the soil radiation damping, coming also to the conclusion that the soil-structure interaction should be considered as frequency-dependent during earthquake. Despite the fact that the approach for the estimation of the hydrodynamic viscous damping constitutes a more precise method, its participation for the specific tested cases is limited to the total amount of damping.

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Offshore & Dredging Engineering

Monopile upending workability and techniques

To respond to the growing offshore industry Jumbo Maritime has designed a new vessel to expand its offshore fleet: The Stella Synergy. The vessel will be able to install monopiles for the offshore wind and oil and gas industry. The main objective of this thesis is: Making a model that is able to predict the motions of the vessel as well as the forces induced by the monopile on the vessel during the monopile installation process. First the most suitable upending technique has been chosen for the Stella Synergy. The upending of a monopile can be seen in figure 1. The different techniques are analysed in a multi criteria analysis. Upending with the gripper turned out to be the best choice. The gripper design has been chosen the same way. The two rotating arm gripper and linear four arm gripper score highest but have almost the same score, therefor one of these two grippers is advised.

The hydrodynamic parameters of the vessel are obtained using AQWA, then a model of the vessel is made in Matlab to decide on the best location for the gripper with the least severe motions. The calculated RAOs are compared with the measured RAOs by Marin and are almost similar. When the crane hoisting curve is taken into account only two possible upending locations remain: x = 42m and x = 70m. Both locations are on the starboard side of the vessel. At the location x = 70m the motions are far less severe, so the dynamic forces will be less high. A disadvantage of this location is that only monopiles up to 100 m can be placed into the gripper without coming to close to the secondary crane.

The forces on the crane and gripper during upending and the workability of upending have been examined using a model in Matlab, the upending process is split up in six phases. Because the monopile is partly under water during four of the six phases the wave forces, added mass and damping that act on the monopile are calculated using AQWA. The viscous damping is calculated using the drag coefficient of a cylinder. The dynamic forces are the biggest during phase 3, where the monopile is only submerged with a small part far away from the vessel. The static forces during phase 1 to 5 are really low, therefor the workability of upending in phase six is computed, the workability is 34.3%. The workability of the vessel while it is hoisting a monopile from a barge onto the gripper is investigated using a ten degree of freedom model. The natural frequencies of the model are calculated and compared with the RAO plots. The total workability for a hoisting cable length of 64m is 29.9% and for 80m is 27.9%. Increasing the offlead angle from one to two degrees will increase the workability to 44.0% for 80m and 36.7% for 64m. It is advised to look into increasing the maximum offlead angle of the crane.

Figure 1: The upending of a monopile

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European Wind Energy Master
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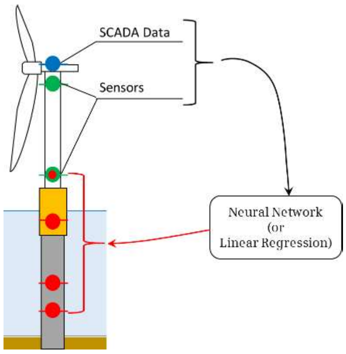
Fatigue Assessment of Offshore Wind Turbines using Measurements of Individual Turbines and Machine Learning Techniques

Fatigue is often a governing design factor for offshore wind turbines. Since the design of offshore wind turbines includes conservatism, the actual accumulated fatigue damage can be lower than what the turbine is designed for. In this case, the operator can make a decision on life time extension of existing wind turbines. Therefore, it is important to estimate the actual accumulated fatigue damage to support decision making on life time extension, and for optimization of support structure design. However, fatigue critical locations are located near mudline where it is unfeasible to install strain gauges to measure the accumulated fatigue damage.

The first purpose of this thesis is to investigate if data-driven approaches (linear regression and feed forward neural network) can be applied to estimate the accumulated fatigue damage both in individual turbines and farm-wide. The second purpose is to determine the minimum number of sensors and quantity of data required for accurate estimation.



Towards this goal, real measurement data of two offshore turbines in the same wind farm have been used. Specifically, the data-driven approaches have been applied with real measurement data from the SCADA systems, measurements at the top and bottom of the tower, and data from a wave measurement system. This data was used to estimate the accumulated fatigue damage at multiple locations (tower bottom, transition piece and two levels on the monopile) in the form of damage equivalent loads. Throughout the study, 10 min statistical properties of the measurement data have been used as input to the learning algorithms. One remark is that the estimation has not been performed for the fatigue critical location near mudline itself, but it is expected that estimation with these approaches can be expanded to the fatigue critical location if accurate response estimation at multiple locations on the support structure is possible.

The results of this thesis show that the data-driven approaches can give accurate estimates damage equivalent loads on individual turbine level at multiple locations on the support structure when moment or inclination signals at tower bottom is used.

For farm-wide level estimation as well, it has been proven that the data-driven approaches can give quite accurate estimates the damage equivalent load. However, it should be noted that the turbines used in this study have similar dynamic properties. Therefore, the farm-wide level estimation with the data-driven approaches should be further investigated in the future.

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European Wind Energy Master
Offshore & Dredging Engineering

Substructure models for dynamic analysis of floating wind turbines and the effect of hull flexibility

While pursuing large size wind turbines with a steel-efficient floater, a traditional rigid body assumption for the floater might not be valid anymore. However, up to date, the flexibility of the hull still cannot be efficiently included into state-of-art aero-servo-elastic-hydro simulation tools. As a result, it is necessary to identify the significance of the effect of hull flexibility.

The effect of hull flexibility has just been studied in recent years. There were work focused on the influence on substructural internal load, global responses and dynamics of the system. However, it was found that little has been done from a tower design point of view. It was then further found that the design of a tower on a floating foundation has also seldom documented. In order to fill the knowledge gap, two research questions are accordingly defined: What is the difference in tower design with a floating foundation and What is the effect of hull flexibility on tower design?

To answer the first research question, a FEM model with rigid hull is built based on four different floating concepts which are designed for large size wind turbines. Structural analysis is then implemented and the 1st tower bending natural frequency is compared between a fixed foundation and a floating foundation. For the second research question, a FEM model with flexible hull is built based on a spar-buoy concept. The rigid hull model and flexible hull model are compared by implementing structural analysis and fatigue damage analysis under waves load.

From the implemented analysis, it was found that the 1st tower bending natural frequency will significantly increase (except for TLP) if the foundation changed from a fixed foundation to a floating foundation, which leads to the difficulty of a soft-stiff tower design for floating wind turbines. Furthermore, it was found that the extra flexibility from the hull can lead to decrease in the 1st tower bending natural frequency and the magnitude of the decrease can depend on the design of the tower. For a stiff-stiff tower design, the decrease is significant, meaning there will be a high uncertainty in the 1st tower bending natural frequency if hull flexibility is not considered.

Therefore, it is concluded that for a large size wind turbine, inclusion of hull flexibility is necessary when evaluating the dynamic properties of the tower and is certainly important for dynamic response analysis.

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Offshore & Dredging Engineering

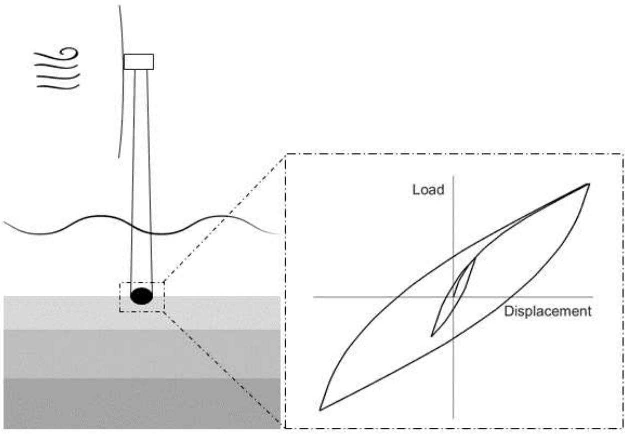
Technische Universiteit Delft

The Macro-Element Method for Integrated Analyses of Offshore Wind Turbines

Offshore wind energy is considered a necessary renewable energy resource, that may stimulate the transition from fossil fuels. Following the successful development in Western Europe, offshore wind is quickly gaining momentum in the Asia-Pacific region. At variance with North Sea-based offshore wind turbines, structures installed in the Asia-Pacific region are prevalently exposed to typhoons, giving rise to severe wind speeds and, consequently, extreme waves. Such conditions have become design driving for support structures.

Considering that the response of the support structure due to these extreme waves is dependent on soil stiffness, a state-of-the-art foundation model accounting for non-linear, hysteretic soil-monopile behaviour is included in integrated time-domain analyses. Besides considering load-dependent hysteretic damping, the foundation model accounts accurately for the unloading-reloading stiffness. This multi-directional macro-element model has been primarily developed and verified for fatigue limit state analyses. In this thesis, the results of additional 3D finite element verification analyses are presented to identify potential model limitations under ultimate limit state conditions. With regard to different geotechnical and loading scenarios, it is observed that the macro-element model satisfactory predicts load-dependent stiffness and damping, even for the extreme load levels relevant to the Asia-Pacific region.

To capture the offshore wind turbine dynamic response to extreme loading, time-domain analyses are performed with two foundation models: 1) the current industry standard based on non-linear elastic API *p-y* curves, and 2) the non-linear elasto-plastic macro-element model calibrated against the API *p-y* curves and also load-displacement curves from 3D finite element analyses.
From the models calibrated against the API standard, the effect of accounting for the load-dependent stiffness and damping on the response at interface for extreme load cases is determined. A reduction of the moment at interface level is observed, due to an improved soil stiffness and damping estimation. Further, as the API *p-y* curves do not account for the correct initial stiffness, the response at interface level is additionally evaluated with the macro-element model calibrated to 3D finite element analyses. The results show a further decrease of the response, that may be attributed to the (initial) stiffer response of the monopile at mudline from 3D finite element analyses.



One of the recommendations is to numerically evaluate the contribution of hysteretic damping with regards to the system damping. Therefore, the validity of the often-used linear damping estimation strategy is investigated for the non-linear system. The interference term in the response at mudline has shown to cause a phase difference, with respect to similar response that does not account for the interference term. The applicability of the logarithmic decrement method that is currently used for system damping estimation is therefore questioned. To evaluate this further, it is suggested to perform additional studies that account for a more adequate representation of the response spectrum.

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Offshore & Dredging Engineering

Seismic analysis of cranes on jack-ups

GustoMSC, an NOV company, is a market leader in the design of offshore wind installation jackups. Offshore wind turbine installation has been situated mainly in the North Sea, which is not very seismically active. As a consequence, wind turbine installation jackups have been designed and analysed for low seismic excitations. The offshore wind industry is expanding to East Asia, where it finds itself in seismically active regions where seismic excitations are significantly higher. Therefore, operators are requesting GustoMSC to supply input for risk analyses of their jackups and its crane. GustoMSC requires a tool to conduct ultimate limit state analyses of a jackup and its crane under seismic conditions. This tool has been created and applied in this work.

The main challenge of this thesis is related to the estimation of the probability of exceedance of a predefined structural limit of a crane on a jackup given a set of seismic ground motions. To tackle this challenge, suitable models of the jackup and crane substructure are developed and verified. With use of a data package, containing two months worth of wind turbine installation data, a Monte Carlo analysis is conducted to determine the probability of exceedance of the structural limit in a 50-year period.
When constructing the jackup model, the mass and stiffness distribution of the jackup is important for an accurate response, a slight eccentricity in the mass of the jackup leads to a very different response. A tool has been created which ensures the mass distribution and eccentricity are incorporated to the degree of accuracy required.

To determine the probability of exceedance of the structural limit in a 50-year period, the seismic analysis tool has been used to conduct a Monte Carlo analysis. Using data from a previous wind park installation operation and ISO 1990XX standards and Eurocode 8, probability distributions have been created for the boom angle, slewing angle, hook load, earthquake timetrace, angle of incidence of excitation and probability of occurrence of the earthquake. By including all relevant variables, the work in this thesis has determined the probability of exceedance of the structural limit for a 50-year period to be 7.7%.

The tools and method created in this thesis allows for the probability of exceedance of the structural limit due to seismic excitation to be determined. Creation of this tool allows GustoMSC to consider high seismic excitations in future designs.

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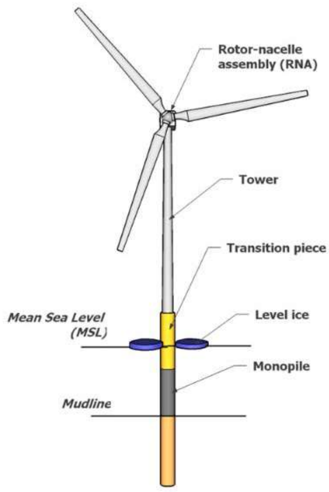
Offshore & Dredging Engineering

Mitigation of ice-induced vibrations of offshore wind turbines by Control Idling



Offshore wind farms are being developed at locations with moderate ice conditions such as the Baltic Sea, where drifting sea ice upon interacting with offshore structures could lead to the development of a phenomenon known as Ice-induced vibrations (IIV). These vibrations are especially severe when the turbine is idling. Current mitigation measures consist of an expensive solution of ice cones, which are only favourable when ice occurs seasonally.
The main objective of this study is to investigate numerically a novel approach to mitigate the ice-induced vibrations of offshore wind turbines by means of control idling.

Three regimes of IIV are generally distinguished, viz. intermittent crushing (ICR), frequency lock-in (FLI), and continuous brittle crushing (CBR). Among these regimes, the ICR and FLI can cause significant vibrations in the offshore structure. Preceding the ice action, the rotor aerodynamics during the parked condition shows that for the wind speeds below the cut-in wind speed of the rotor, the turbine operates in the unsteady aerodynamics termed as dynamic inflow.

The comparative analysis is made between the two cases: one with the ice action only, and, the other with the combined effect of ice and wind, where the rotational rotor speeds chosen are 3.0rpm, 6.9rpm and 12.1rpm. In the ice-action case, it is found that the structural response frequency during the ICR and FLI is around the first and the second natural frequency of the structure, respectively. In the case of ice and wind, it is found that the unsteady BEM method has certain limitations, especially in the ICR regime. Furthermore, the aerodynamic damping has no notable effect on the range of IIV regimes for the rotor speed of 6.9rpm and 12.1rpm. However, it does have a significant effect for the rotor speed of 3.0rpm. The quantitative comparison of fatigue damage between the two cases showcases that for the majority of ice-sheet velocities during ICR and FLI, the damage is found to be greater in the ice and wind case. Based on the results, it is concluded that the rotor aerodynamics does help in damping the vibrations in the ICR regime, but in the FLI regime, it has no significant impact when specific ice-drift speeds are considered.

It can also be confirmed that by the careful selection of the rotational rotor speed, the range of IIV regime can be influenced. However, to draw the general conclusion, the analysis needs to be conducted for varied ranges of rotor speeds. Also, the present framework of the aerodynamic model needs to be improved to capture the vortex-ring flow state to predict the rotor aerodynamics accurately for all the ice-sheet velocities.

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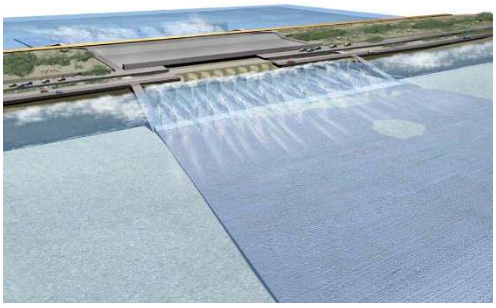
The consideration of constrained flow solutions for the purpose of implementing a tidal power ploant in the Brouwersdam reconnecting Lake Grevelingen and the North Sea

After the construction of the Grevelingendam (1965) and Brouwersdam (1971) the water quality in Lake Grevelingen deteriorated in the course of the years. This caused a decline of ecological parameters influencing surrounding flora and fauna. Amongst others, Rijkswaterstaat and the provinces of Zeeland and South-Holland established a plan to reconnect Lake Grevelingen with the North Sea again to infuse oxygen enriched water into Lake Grevelingen and create increase the quality of the local ecology. This plan will be executed by installing culverts in the Brouwersdam, thereby restoring the connection between the two water bodies. As part of an integrated approach, Rijkswaterstaat intends to develop the hydraulic structure to a tidal power plant and implement turbines to not only generate power, but also perform water management measures as installation of these devices are able to influence and control the discharge through the culverts.

From the literature study can be concluded that implementing constrained flow devices, wherein the entire mass flow is guided through the turbine, offers a solid solution for the posed problem. In order to broaden the insight in the behaviour of the water level, which has its influence on the local flora and fauna, in Lake Grevelingen due to the construction of the tidal barrage, three hydraulic models are set up wherein input water level data from the North Sea is used to simulated the tidal action in the lake. The considered cases include a configuration wherein *11* of the *18* culverts measuring *8* m by *8* m are equipped with unidirectional turbines. The remaining culverts are left unequipped. Thereafter, two culvert configurations wherein each culvert is equipped with respectively a unidirectional and bidirectional turbine are considered. By simulating the water level variation in the lake, one can also estimate the generated power and the energy output of the considered models. Besides, to provide a larger view on the possibilities, a multivariable analysis of the three cases is carried out wherein power generation and water



management requirements are considered. Herein varying the cross-sectional area of the culverts and their number. For the first considered case, also the number of empty culverts is varied. From these analyses, one can conclude that installing bidirectional turbines increases the controllability of the flow

which is desired. Moreover, implementing unequipped culverts in the array will diminish the controllability and is in terms of water management not desired. Finally, full time turbine modulation, wherein the turbines are not generating the optimal amount of power over the full scope of the tidal range for the purpose of water management is preferred over intermittent turbine modulation, wherein turbine modulation only occurs when the water level surpass certain water levels.
Nevertheless, to fully satisfy the posed requirements, additional turbine modulation should be executed as the monthly averaged and maximum tidal range standards are not fully met.

From the analyses, a bidirectional culvert configuration existing of *24* culverts measuring *9* m by *9* m is preferred. To investigate if this configuration is economically feasible, a cost estimate is established after which the Net Present Value, Internal Rate of Return, Payback Period and Levelised Cost of energy are determined.

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Offshore & Dredging Engineering

Power efficiency of the gyroscopic-pendulum Wave Energy Converter

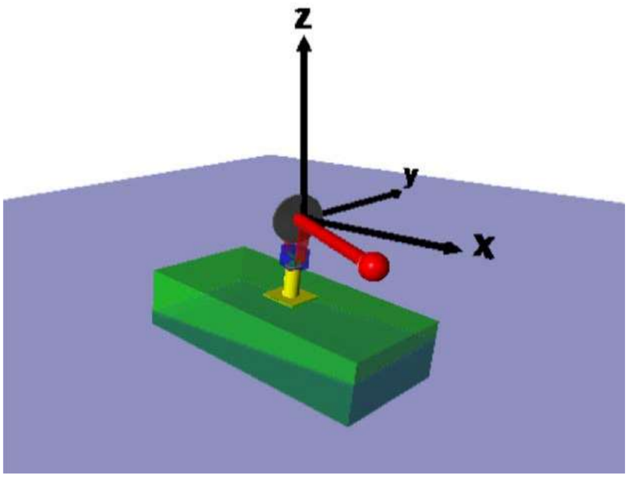
The oceans, which cover nearly 70% of the earth's surface, can be considered as an inexhaustible energy source for renewable electricity due to its size and predictability. One way to capture ocean energy is by harnessing the energy produced by waves at sea, by means of devices called wave energy converters (WECs).

Delft University of Technology is developing a new floating WEC concept called the "gyroscopic-pendulum (gp)". This concept is a modification of the so called "classical vertical axis pendulum (cp)", which is capable of producing mechanical power harvested from the rotations of the pendulum around the vertical axis.

The new concept is proposed by adding a flywheel with the aim to enhance the rotations of the pendulum about the vertical axis. The enhancement comes from gyroscopic precession which is created due to a change in the angular moment of the spinning flywheel caused by the torque originating from the weight of the pendulum.

This thesis starts with a general introduction about wave power followed by the mathematical and numerical model of the gyroscopic-pendulum. Numerical simulations are performed in which the gp and the cp are both imposed with the same harmonic roll motion, while the gp system also receives some power input to rotate the disk. The main objective is to find out in which ranges of amplitude and frequency of imposed motions, the gyroscopic-pendulum results in an improvement of the power efficiency compared to the classical vertical axis pendulum.

The results obtained from tests performed in the simulated conditions, shows us that the gyroscopic-pendulum has a significantly higher efficiency compared to the classical vertical axis pendulum when the frequency of the imposed roll motion is in the range of 1.4 to 1.75 rad/s and the amplitude is the range of 0.6 to 0.95 m.



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Radial Piston Pumps: Performance and Efficiency

The modeling method for the performance of positive displacement pumps of hydraulic pumps is based on collecting operational data of the pump for its operational envelope and using equations with empirical fitting parameters and fit these equations to the data. This way values for the fitting parameters are obtained, with which the equations can be used as model for the operating performance of this specific pump. By implementing this modelling method no information about the contribution of each component present in the pump to the performance losses is obtained. A model which analyzes each component and estimates its contribution to the total power losses would be beneficial in the design of pumps. Therefore the answers to the following research questions are sought after in this work:

- What are the components critical to performance within hydraulic pumps?
- To what accuracy can a component-wise, analytical model for pump performance be created?
- How sensitive to certain parameters used in the equations is the model?
- What are the possibilities of implementing this model into pump design?

After the pump system was analyzed and the internal interactions found, the components which effect pump performance the most were identified. These include bearings, rollers, seals, springs, valves and leakage flow which is dependent on gap size, piston movement and viscosity of the hydraulic fluid. For these components analytical equations are presented which are incorporated in the model.
The accuracy of the model is tested by comparing its results to test data of an experimental camring driven radial piston pump. The model predicts leakage flow to an average difference of 3% relative to the data, but outliers up to 49% for high pressures and -35% for low pressures are observed. Input torque is predicted to an average difference of -19% relative to the data. This difference is mainly caused by the inaccuracy of the predictions below 30 bar operating condition, where outliers up to -61% are observed. These results are compared to an empiric modelling method and are found to be more accurate for leakage flow for the entire operational envelope, yet on average less accurate for input torque.
The sensitivity of the model to certain parameters is tested. The parameters investigated are the rolling resistance coefficient of rollers and bearings, bearing lubricant viscosity, hydraulic fluid temperature, piston-cylinder alignment and the corresponding forces resisting piston motion and the assumption of laminar leakage flow.
To show the possibilities of the model in pump design the rollers and appurtenant bearings present in the pump are replaced with hydrostatic bearings. The design is discussed and a hydrostatic bearing with an orifice restrictor is designed of which implementation will approximate the total efficiency of the pump with rollers. The Reynolds number of the flow necessary is found to be too high for capillary restrictors. To approximate the same total efficiency for each operating condition the average bearing flow is found to be 0.0016 L/s, which corresponds to an average fluid film height of 12 μm. The orifice restrictor diameter which allows this flow is found to equal 0.24 mm.
This work shows the possibilities of such a model, yet there is plenty room for improvement of the accuracy of the predictions made. Recommendations to this end are given in the conclusion and recommendations of the report.

Therefore, it is concluded that for a large size wind turbine, inclusion of hull flexibility is necessary when evaluating the dynamic properties of the tower and is certainly important for dynamic response analysis.

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Offshore & Dredging Engineering

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Alternative cable laying – a conceptual design fora n offshore power cable lay system on non-cable lay vessels

In this thesis, an alternative cable lay system was designed that can be used on existing non-cable lay vessels. This design is conceptualized and analyzed for a specific market, following the steps in the engineering design process. The technical and economic analysis investigates the feasibility and competitiveness of the new cable lay system.

Nowadays, cables are installed over a chute at the aft of a vessel. This makes the operation very sensitive to motions, inducing high cable loads that result in limited workability. Also, load carrying capacity is limited for existing cable lay vessels within the Boskalis fleet, making the application of joints a necessity in offshore export power cable installation.

The design focusses on the international offshore export power cable installation market (both AC and DC), including interconnectors, from shore to substation or shore to shore. This market was selected because of the limited load-carrying capacity of current cable lay vessels, the internationally growing offshore wind market and the relatively low market share of Boskalis in this segment. New concepts were generated and evaluated using multi-criteria analysis, scoring them on technical and economic criteria determined for the selected market.

The concept that has been selected for further development focuses on export power cable laying through a moonpool. A Dockwise semi-submersible heavy transport vessel is targeted for this design because it is being converted into a fall pipe vessel already. This conversion includes the installation of a moonpool, opening up the possibility to make the selected vessel a multi-purpose vessel. Making use of static stability software, the maximum load-carrying capacity of this vessel has been determined. From this analysis, it can be concluded that the maximum cable load that can be carried by the selected vessel is 9.000 tonnes of cable equivalent, which is approximately 110 km of currently installed export cable length. Conventional cable lay vessels from Boskalis have load carrying capacity up to 5.000 tonnes. Additionally, a deck-layout with the crucial parts of the cable lay system is designed, taking into account all necessary alterations regarding the conversion of the vessel.

The main technical challenge for the newly designed system is the second end cable pull-in. With limited space in the moonpool and vertical laying of the cable, the conventional pull-in method cannot be used here. Three solutions have been developed, based on a deployment quadrant or bight lay down. Two of these are already proven in the field, making the concept technically feasible.

A model has been made to evaluate both conventional cable lay and cable lay through a moonpool. Using dynamic time-domain analysis, operational limits have been determined for both methods, keeping the catenary shape of the cable constant. This analysis concludes that cable laying through a moonpool indeed increases the workability for the selected vessel. No concrete increase can be seen for moonpool cable laying with a conventional cable lay vessel. This is due to its sensitivity to roll motions, for which the distance towards the center of gravity is equal in both concepts. For the selected vessel, cable laying over a chute is not possible for the chosen catenary shape and sea states because the maximum allowable curvature is exceeded. This is due to the large arm for pitch motions, from the center of gravity to the chute at the aft of the vessel. Cable laying through a moonpool, however, is possible up to 2 meters significant wave height. The limiting factor for all simulations that were done is the maximum allowable curvature.

To investigate the competitiveness of the newly designed cable lay concept, an economic analysis is done. Several recently acquired project cases are introduced to compare project costs for both concepts. This analysis concludes that the newly designed cable lay concept is in average conditions 21 to 40 \% more expensive for all cases than the conventional way of cable laying. For cable installation during wintertime, the newly designed cable lay system is only 6.5 to 27\% more expensive than the conventional cable lay system.

This illustrates that the newly designed cable lay system is technically feasible but not competitive with conventional methods at the moment according to this analysis. However, the costs and installation time of joints with the conventional methods are not taken into account here due to limited available data. Therefore, the new cable lay concept still has the potential to be competitive for the selected market. Further research must be done to substantiate this.

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Offshore & Dredging Engineering

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Workability increase using tugger control

For the offshore market an increase in renewable projects can be observed. The technological innovations are continuously decreasing the costs of renewable projects. Especially offshore wind is getting more cost effective, and is receiving a lot of attention. However, with the growth of the sector, new challenges arise. Water depths are increasing, soil parameters worsening and greater distances from shore need to be overcome. Whereas prices of installation are under pressure. This drives the market towards larger and more innovative installation vessels. A trend can be observed towards monohull craning vessels which combine a large crane with a large storage space on deck. During lifting the monohull vessel experiences large motions of the lifting configuration at even small wave loading. The large motions are mainly the result of resonance within the system, which results in large crane forces. It is these forces which decreases the vessels work-ability. Applying damping to the system is a way to counter the resonance. The tugger winches can be used to apply damping to the lifting configuration.

The aim of the thesis is to investigate the potential damping effect of a tugger damping system for the Bokalift 1 during a jacket lifting operation. With special emphasis on the effect of different control systems of the tugger winches. Two different models are used in the thesis to research the effects of tugger damping on the dynamic behavior of the lifting configuration. Namely, a simple 2D matlab model, and a more extensive 3D Orcaflex model.

The Orcaflexmodel is build for researching the effects of tugger damping and different control systems. Comparing the responses of the model to airy waves loading. To have control in both longitudinal and transverse direction boomwinches on the crane are used, in combination with deckwinches. Which are located on both ends of the deck. The hydro static properties of the model are calculated with the program GHs. The hydro dynamic properties are calculated with the help of the AQWA.

The matlab model is used to enable quick research on the effects of tugger damping and different control systems. The model is based on a 5 degree of freedom (DOF) mass-spring-damper-system. The equations of motion (EOM) are derived using the lagrange formalism with help of the program Maplesoft. The model is validated with help of proven software Orcaflex.

Seven different control systems are made and tested in the matlabmodel. The control systems are examined in two different simulations. Firstly the roll motion is studied when the model is subjected to wave loading. Secondly the damping capabilities for the lifting configuration with initial displacement are tested. The first analysis shows the PID controller has the highest roll motion reduction of the jacket. Linear control system scores higher than quadratic. The results from the second analysis shows that stepwise controller takes the shortest to fully damp the lifting configuration.

Following on the results of the 2D model analysis the 3D model will further inspect the effect of tugger winches for the linear, quadratic, and PID controller. A model analysis shows there are 4 important modes within the wave excitation range. The combination of these modes results in the highest crane forces at a wave period of 5.5s. The linear and quadratic control system are once again compared, only now in the 3d model. The assessment shows the linear model as more efficient in reducing the crane tip forces. Lastly the linear and PID control systems are compared towards each other and a modelwithout tugger damping. Based on the results, the linear control system increases the total forces on the crane. Where as the PID reduces all forces.

It is shown that tugger damping does not necessarily decrease forces acting on the crane tip for head on waves. From the tested control system the PID controller reduces the forces most effectively and efficiently. However the effect of the PID controller depends on the loading wave frequency and for which it is tuned.

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Offshore & Dredging Engineering

Technische Universiteit Delft

Corrosion in Underwater Offshore Slip Joints

In order to connect a monopile to a transition piece of an offshore wind turbine efficiently, a new connection method called the Slip Joint is being developed. The Slip Joint is made out of a conical section at the top of the monopile foundation and a conical section at the bottom of the transition piece which are slid over each other to form a connection. Van Oord is currently getting the Slip Joint connection certified by DNVGL, requiring that the structural integrity must suffice during the total lifetime. Offshore with harsh salty conditions, corrosion important to be aware of. The interface between the cones of the Slip Joint creates a local environment with crevices that has a unknown corrosion behavior. Because it is necessary to know the corrosion behavior within the Slip Joint, the following research question has been formulated: What corrosion behavior can be expected in offshore submerged Slip Joint crevices?

Because research towards steel crevices of large geometries was not carried out before, a test method had to be developed. This required multiple innovative methods, and thus trial tests to confirm the feasibility of the test method. Chosen is to use specimens with multiple crevice geometries and test them during a 60 days immersion test. In total 260 steel plates and 37 different crevice geometries have been studied on their corrosion behavior. To monitor the corrosion behavior during the test period, open current potentials have been measured. After the test period the specimens were cleaned and weight losses have been measured. With the weight loss measurement, the corrosion rate of each specimen has been calculated. Additionally to testing the corrosion behavior in crevices, the usability of Impressed Cathodic Corrosion Protection on a crevice is tested by applying a current on the specimens using a potentiostat.

The data of the tests show that the test was carried out in a consistent manner and that the test method gives reproducible results. The test indicate that local corrosion attack in the crevices of the Slip Joint can occur and that the corrosion behavior is correlated with the crevice geometry. A model has been formulated which can be used to estimate corrosion rates in crevices for design purposes.

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Offshore & Dredging Engineering

Sitting up system: a novel concept for large integrated offshore wind turbine installation

It is expected by the EWEA that in the North Sea only the wind energy capacity will increase to 45 GW. In 2015 the capacity was only 5.2 GW. Offshore contractors should be capable of installing lots of turbines and just that is a problem. As turbines increase in size installation vessels need significant upgrades. Therefore, most contractors look for cheaper and better solution for installing these large offshore wind turbines. The Sitting Up System or SUS is a new concept designed by Marine Innovators B.V. and installs fully assembled wind turbines with their foundation. It decreases offshore installation time and decreases operational cost significantly.

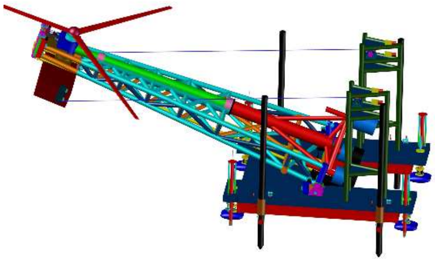
The SUS is designed to transport and upend wind turbines to a vertical position while anchored to the seabed. For now, the SUS is a concept and has multiple design possibilities, using either a hydraulic or a buoyant lifting system. Analysis on these lifting methods and their operational functionality resulted in a buoyant type lifting system. The SUS 3: 'Buoyant upend 2' concept consists of latticed structure and two buoyant modules. The large module is sunk to anchor the SUS and the small buoyancy module is pulled along the lattice to create an upending moment.

Using the software Matlab the upending motion of SUS 3 is modelled as a rigid body to find limiting wave conditions. The model uses second order stokes theorem and Jonswap to simulate waves on the structure. Loads on the structure are calculated using the Morison equation. Two DOFs are considered as the SUS can rotate around a hinge at the seabed and move the buoyancy module.

In the simulation a wind turbine of 200 meters height is upended in 30 minutes, while operating at 40 meters water depth. The first phase of the upending wave loads is most critical. The criteria for the SUS to operate depends on the acceleration of the top tower assemble of the wind turbine, these cannot exceed 0.1 g. In this case the limiting sea state is a H_s of 1 m with a T_p of 4.5 s, leading to a workability of about 16 percent. During the beginning stages of upending the natural frequency of the system operates around 10 seconds. This is critical as waves oscillate near this frequency. Though the simulation does not account for radiation or diffraction, the performance in later stages of upending gives a better result. Here, it can operate with a H_s of 2.5 meters resulting in a workability of 75 percent.

The SUS 3 is anchored with spudcans during upending and shear loads are most significant. These spudcans can experience a shear load of 24 MN, when considering a H_s of 3.5 with a T_p of 8.5. Therefore, anchoring method should be designed such that it can comprehend these shear loads more efficiently.

The work done by the winches pulling the buoyancy module is 13 percent more than the potential energy gained after upending with no waves. When waves are applied, energy is gained due to the uplifting force of waves. As the structure is lifted, resistance of pulling the buoyancy module decreases and can move more efficiently. Considering a H_s of 1.5 m and a T_p of 5.5 s will results in an energy gain of 5 percent. Therefore, this method is quite efficient in upending wind turbines offshore.



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Offshore & Dredging Engineering

Technische Universiteit Delft

Sitting up system: a novel concept for large integrated offshore wind turbine installation

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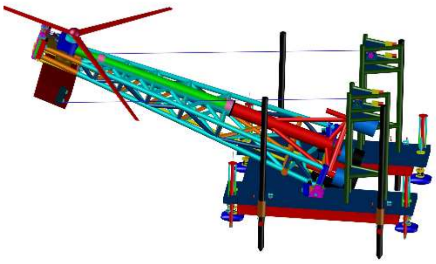

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Offshore & Dredging Engineering

Technische Universiteit Delft

Floating Jack Installation, A parametrized motion prediction model for jacket installation

In contrary to a one-off jacket installation where a contractor can wait for favourable weather conditions, the installation of support structures for offshore wind turbines is of repetitive nature. This repetitive nature leads to a need for a better understanding of the behaviour during installation of various jacket geometries. This need brings the research objective of this thesis to "Development a parametrized motion prediction model for jacket installation.".

A 2D numerical model of a jacket type support structure installation in the side-lead direction has been developed in Python with two ways of calculating the forcing. Both of these methods rely on the Morison equations. The first calculation method uses bins along the length of all jacket members. Current, waves and the jacket's motions result into a flow perpendicular to the member center lines. This flow is used to determine the drag and inertia loads exerted by the water. The second method uses an equivalent stick model. This is a cylinder with a varying diameter over its height, representing the jacket structure. Strictly horizontal water particle velocities and accelerations due to current, waves and structural movements are used. This, in combination with the reduced number of bins leads to a reduction in computational cost.
To find the characteristics of the system a sensitivity study is performed. Based on environmental and operational measurements taken from five jacket installations, the input for simulations were set in the goal of reproducing the measured response. The environmental and vessel measurements did not satisfy the level of accuracy needed, leading to a mismatch in results. In most cases the jacket structure design for a project is a given, meaning that jacket weight and location of center of gravity are set. These properties have a big impact on the dynamic system, nevertheless, the rest of the system still gives opportunities for increasing the workable limits. Two effective examples of this is the weight of the jacket lifting tool and crane height.

A stick model implementation of the hydrodynamic forcing gives results comparable to the member evaluation implementation. The natural frequencies from the FFT taken of the free vibrations match well. However, a small difference in damping is observed. The equivalent stick model provides good results for quick estimations at low computational cost.

The response of three jacket designs is studied using a base case jacket for reference. Implementing a slender design with smaller member diameters results in lower jacket inclinations for comparable sea states. This comparison also holds as the significant wave height is increased. A coarser jacket design with bigger member diameters results into a higher response amplitude. However, the difference in response between the base case jacket and the coarse design fades as the significant wave height increases. The third considered design has suction buckets with a large diameter. These buckets make the system very susceptible to wave loading when lowered through the upper layer of the water column where the highest water particle velocities and accelerations are present.

Concluding from the analyses, predicting the jacket motions during the installation phase with the numerical model with the equivalent stick implementation is most effective. The results are suitable for quick estimations. The numerical model with implementation of the member evaluation is preferred if more detailed results are needed.

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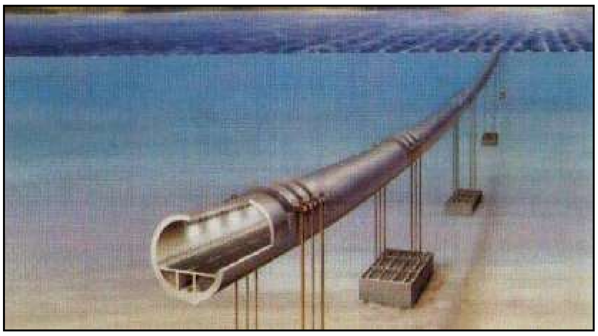
Offshore & Dredging Engineering

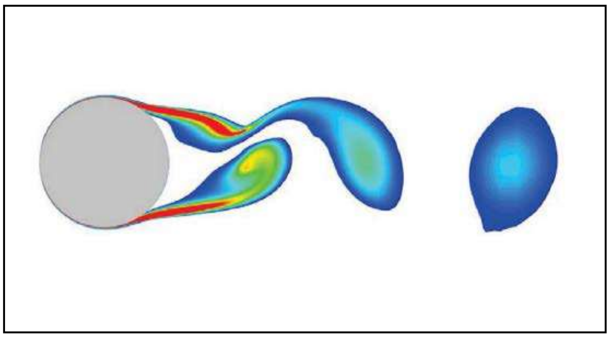
Structural response of a submerged floating tunnel induced by current flow

A submerged floating tunnel (SFT) is a concept that has been investigated quite thoroughly in the past, but has never been built till now. A tube is placed underwater, around 20-50m depth, anchored to the seafloor or restrained with pontoons in order to avoid water traffic and wave forces at the surface, as well as high water pressures in larger depths.

It is well known that when a cylindrical structure is put inside a fluid flow, periodic motions are induced on the body, created by their interaction. These motions are called Vortex Induced Vibrations (VIV's) and in the offshore industry are mainly caused by currents. Significant forces can arise due to VIV's, which can endanger the structural integrity of the SFT.



Hogsfjord project



Fjeld,2013

The objective of the present Master thesis is to numerically investigate the static and dynamic load effects acting on a tether-stabilized SFT. Focus has been put on capturing the Vortex-Induced Vibrations generated on the structure, when interacting with a current flow. The primary goal is to identify, analyze and evaluate the risks that are considered likely to initiate hazardous events or hazardous conditions in a high risk structure, such as the SFT, and propose measures or design principles/constraints to avoid the identified risks.

A 3D model of the structure has been developed, for this reason. The significance of VIVs is captured, governed by the unsupported free-span length of the tube, as well as the possibility of a progressive failure when one tether unexpectedly fails.

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Offshore & Dredging Engineering

Experimental setup of the dry test for a gyroscopic-pendulum wave energy converter

Oceans account for 71% of the earth's surface, marine resources and energy are abundant. Therefore, making full use of marine energy is a good choice for humans to solve the energy crisis. One way to capture ocean energy is converting wave energy to electrical energy, by means of devices called wave energy converters (WECs).

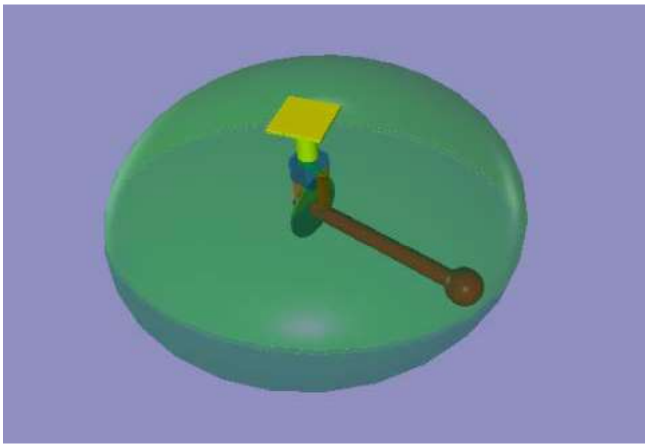
This project introduces a new type of wave energy converter named "Gyroscopic-Pendulum Wave Energy Converter (GP WEC)". Compared to the classical vertical axis pendulum WEC, a flywheel is added in the system. In combination with the floater motions it creates a gyroscopic effect on the pendulum causing it to rotate, a power take-off device is connected directly to the rotating pendulum shaft in order to harvest the wave energy and generate electrical energy.

To investigate whether this new type of WEC will generate more energy than the classical one, this thesis proposes a dry test setup for the gyroscopic pendulum allowing for systematically investigating the gyroscopic effect on its power output.

This thesis starts from the design of the GP WEC dry experiment and then provides the clear definition of all the components of equipment, along with the applicable scaling laws of all the components and parameters. Also, the requirements as to limits of the equipment are studied with a parameter study.

Using the results of the parameter study a numerical model of the GP WEC is used to simulate the dry-tests. Based on these simulations the range and number of parameters that will be tested in the future experiment are confirmed, and test matrices defined. Some interesting observations from the numerical simulations are further studied looking into the time domain response.

This thesis concludes with the definition of a test setup for dry experiments to be executed at TU Delft in a follow-up study, test matrices for investigating the gyroscopic effect on the power output are defined, and simulation results are presented which can be used for later validation of the physical model.



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Offshore & Dredging Engineering

Developing a two-dimenisional penetration model for the GBM Vibro-drill

The energy transition results in large offshore windfarms being installed. The most common support structure for a wind turbine at sea is a monopile. These are currently installed by large hydraulic hammers. However, hammering produces a lot of underwater noise which harms marine life. Therefore the industry is looking for new installation methods that are more environment-friendly. GBM-works aims to be the first to implement such a new installation technique called the Vibro-drill. They introduce a revolutionary new design which is to replace the hammering technique. Vibrations, jetting and liquefaction are used to reduce the soil resistance. This reduction is so powerful that the monopile sinks into the ground under its own weight without producing the harmful underwater noise.

Before each monopile is installed an analysis is made of the factors determining the chance of a successful installation. This process is called a penetration prediction. For the industry to accept the Vibro-drill installation method, penetration predictions are required to prove the applicability of the new technique. The radical changes in the installation process used by this technique make it impossible to use current penetration prediction methods. This means that a new prediction method needs to be developed that takes into account the specific features of the Vibro-drill.

This thesis aims to address this problem by way of providing building blocks for the development of a fully-fledged penetration prediction model that is applicable to the Vibro-drill method. To this end, this thesis will focus on delivering a two dimensional soil model in penetrated by a pile.

The two-dimensional approach which is the basis of this thesis, has of course its limitations as only a part of the pile and soil are included in the model. The assumed point symmetry over the centreline of the monopile leads to only a slice of the pile being modelled.
The soil is captured using a lattice model. A well-known practice for modelling soil in a two-dimensional way. The properties of the lattice are determined using Cone Penetration Test data. As a result the model represents different layers of soil along the depth. The model uses a rigid pile to penetrate the soil. The penetration of the pile causes a reaction force in the soil. This force is used to calculate the friction forces. The reaction force and the friction force are the basis for calculating the penetration speed of the pile. From this it follows that the penetration speed and final installation depth depend on the different soil layers within the soil model.
A first step towards validation is made. The pile/lattice interaction is verified and the results are compared to real life test data. A sensitivity analysis is performed to evaluate the dependence of the lattice size and resolution on the penetration speed of the pile. Subsequently the penetration predictions of the model in its current form are analysed. The results are compared to the real-life outcome of tests with the Vibro-drill.

From this first attempt to validation the conclusion can be drawn that the two-dimensional model, as developed in this thesis, could be a suitable basis for further work on a viable penetration prediction method for the Vibro-drill technique. Finally, recommendations are made for further enhancing the model with a view to its eventual implementation as a fully functional penetration prediction model for the Vibro-drill.

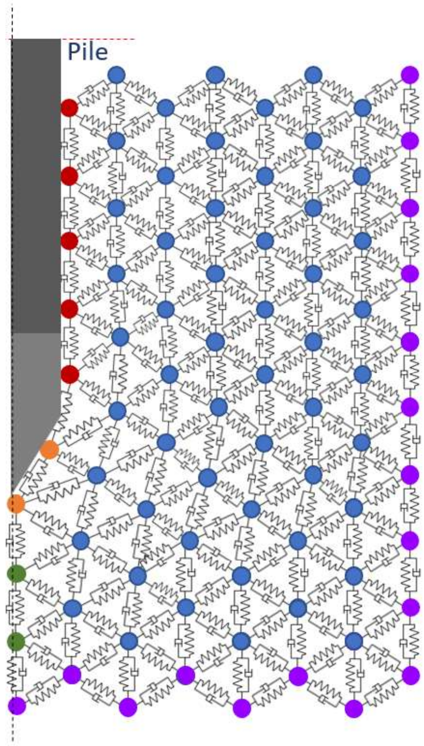

Figure 1: A visual presentation of the pile penetration model

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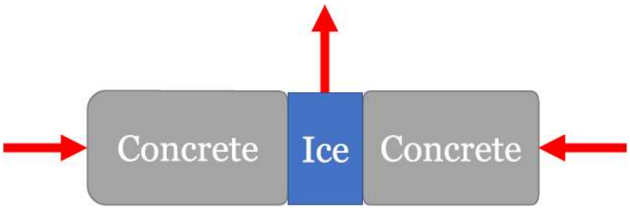
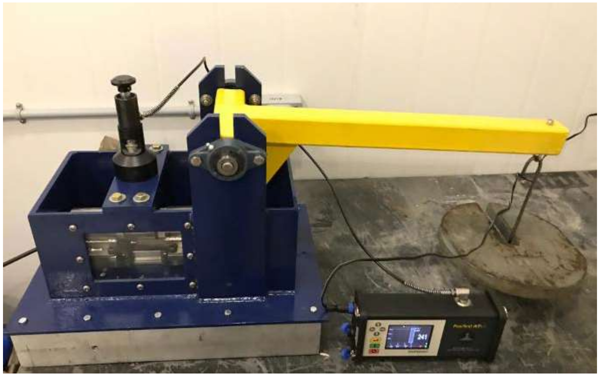
Offshore & Dredging Engineering

Technische Universiteit Delft

Ice-concrete bond analysis

In regions which experience arctic conditions, structures like offshore wind turbines, oil-platforms, light houses, piers and bridges suffer from abrasion by moving ice sheets. This results in challenging maintenance and repair works. At the ice-structure interface, several mechanisms exist which are responsible for the wear of concrete such as: freeze-thaw cycles, chemical effects of sea water, and mechanical loading of concrete. The main cause of concrete abrasion is however thought to be the flow of ice floes together with a layer of crushed ice, which is partly controlled by friction and adhesion between the two interfaces. Adhesion is thought to be the main component of the static friction and is, under certain circumstances, also directly responsible for concrete abrasion. It is yet not well known to what degree ice adhesion contributes to concrete abrasion, and how extrinsic parameters such as: pressure, hold time and submergence relate to the ice-concrete bond strength. This research aims to better understand the physical phenomena happening at the ice-concrete interface by shearing an adhesive ice-concrete bond to get a better understanding of the role of ice adhesion in concrete abrasion processes.





To achieve this goal, a double shear apparatus has been designed and ice-concrete shear tests have been performed in a thermal laboratory. The apparatus was designed to be relatively simple compared to conventional soil shearing machines. The design allowed for the ability of submergence, accurate and sustained application of normal load, improved implementation of standardisation procedures, and easy portability. The temperature during the test was remained relatively constant at around - 9° for dry the ice-concrete adhesion test, and around 0° C for submerged tests. The influence of hold time, varying from very short (6 seconds) to overnight, and pressure (51, 316 and 682 kPa) on the force required to break the ice-concrete bond has been investigated following a series of five test sequences. In sequence 1, the applied pressure was remained when shearing the ice. In test sequence 2, the shearing was initiated immediately after removing the applied pressure for a certain amount of time. In sequence 3, the time between removing the pressure and pulling out has been varied. In sequence 4, different materials have been used to clamp in the ice and sequence 5 investigated the influence of submergence.
The results show a positive influence of holding time on the force required to perform the shearing and although a higher normal load results in a higher shearing force, it is unclear what the result is of a higher normal load on the adhesive force. This result holds for both the remained and released pressure tests. The bond strength also appeared to increase when waiting after removing the applied load. Submergence showed to have a negative influence of the bond strength compared to the dry tests. When using a different surface as the concrete specimen, a pure paste surface showed to give the highest bond strength and a pure sandstone surface resulted in the lowest bond strength. The results of using a cut-concrete surface, as used in all other tests, were in between the pure paste and sandstone surfaces.

It is concluded from the experiments in this research, that mechanical theory seems to be the main mechanism of the ice-concrete bond. The failure type of the ice-concrete bond is dependent on holding time and pressure. Visual observations show an increase of ice stuck to the concrete surface for both higher normal loads and longer holding times.

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European Wind Energy Master
Offshore & Dredging Engineering

Impact of seabed scour on the dynamics of bottom-founded offshore wind turbines with large diameter monopiles

The offshore wind industry is growing rapidly, and pushing into greater depths and extreme environmental conditions. The monopile is widely used as foundations for these turbines. The constant dynamic loading of the wind turbine by the environment makes it important to study the dynamic response of the turbine for both natural frequency design (within soft-stiff range) and fatigue applications.

Scour is an important factor influencing the dynamic properties of a turbine. Experimental evidence exists to suggest that scour can have significant impact on the resonance frequencies of the turbine. It is thus important to study the extent and nature of this impact. The scour design according to standard codes of practice shows no difference between local and global scour. Capturing this deviation from the standard codes could be very valuable in further optimizing the design of foundation in what is already a very cost sensitive offshore wind industry.

The thesis aims to use the capabilities of 3D FE modelling to simulate the effects of scour on the dynamics of a structure. A 3D soil model with the benefit of refined descriptions of soil-structure interfaces and HM coupling is used to model the soil, while the structure itself is modelled as a Timoshenko beam.
The aim of this study is to introduce scour into the above soil model and study the impact with emphasis on soil structure interaction during modelling.
With an advanced soil FEM model and realistic environmental loading, it is expected that the impacts produced by scour will be quite close to reality. The specific questions that are intended to be answered at the end of this study are:

- Whether scour has an impact on the resonant frequency of a turbine
- How the impact (if any) differs for local scour and global scour under different depths
- Whether non-linear soil is important for these examinations
- Whether scour has an impact on the damping of the OWT in non linear soil

The above questions are examined in the context of non-linear soil, for a large diameter monopile - both under operational and cut-off loading

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Offshore & Dredging Engineering

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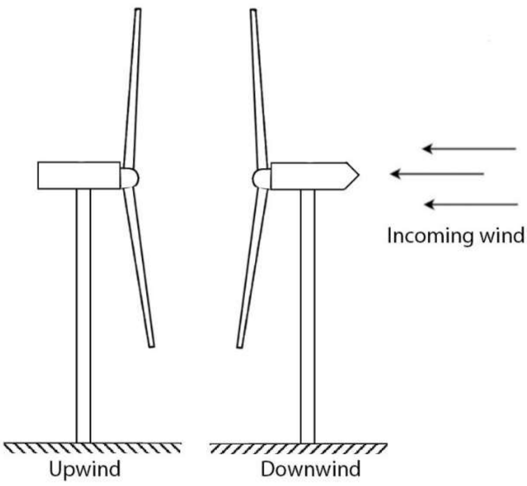
The dynamic response of a wind turbine blade to downwind tower shadow

The quest for affordable renewable energy causes the need for bigger and more efficient wind turbines. To counter the problem of possible collisions between the growing turbine blades and the tower support structure, downwind turbines might be a solution. For this configuration blade flexibility no longer forms a problem and besides that passive yaw systems can be applied. However, the fatigue lifetime of the turbine components might significantly decrease due to tower shadow effects.



This thesis aims to decrease the uncertainty in the difference between downwind turbines and the conventional upwind turbines. An aeroelastic blade model is constructed using a finite element model of the NREL 5MW turbine blade. This model is subsequently converted to a downwind model including a wake behind the tower structure that temporarily slows down the inflowing wind on the blade when the blade is in the tower shadow area. This wake description follows from a literature review and should be valid for the flow conditions around the turbine. History dependency of the aerodynamic forces on the blades is included in the model using the Küssner function.

A comparison in tower wake effects is done using simulations of upwind and downwind turbine blades which result in the blade motions caused by the tower shadow disturbance. From these motions also the root moments are deduced over time as well as the angle of attack variations for the different blade elements. A comparison with other software confirms the order of magnitude of the blade position in equilibrium and a check for dynamic stall issues is done to show the possible influence on the blade lift after the tower shadow disturbance. The root moment variations are used as a fatigue indicator using rainflow analysis.

Concluding from this, wind velocities near cut-out speed for downwind turbines cause the biggest wake effects. The static blade deflections and root moments are highest for rated wind speed at upwind turbines. Compared to upwind turbines, the downwind turbines are prone to higher wake effects and therefore increased fatigue damage. The overturning root moment and flapwise deflection variations for downwind turbine blade have shown to be up to 88 % and 100 % higher compared to those for upwind turbines respectively.

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Offshore & Dredging Engineering

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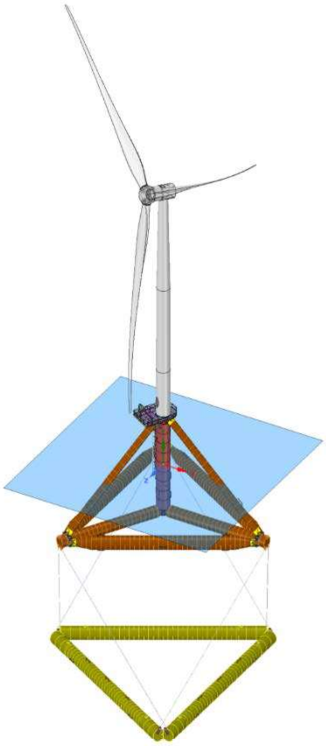
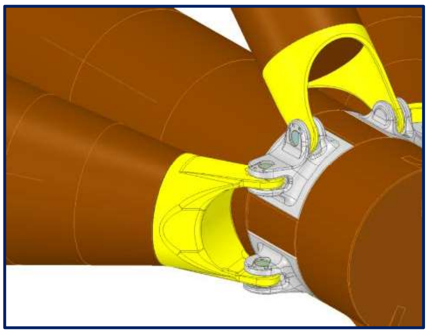
Fatigue strength assessment of the pinned connectiion in the TetraSpar concept

In a world with an increasing population and level of welfare, there is a large demand for more and cleaner sources of energy. Floating wind turbines have great potential to meet a significant part of this demand. They are however not yet commercially available, because of huge technical and economic challenges. Most of the concepts that are currently developed focus on technical feasibility.

The TetraSpar concept is designed with a focus on both technical and economic challenges. One of the main advantages of the concept is the type of connection, with which the steel tubular members are connected. This connection allows for industrialization of the fabrication and assembly process, which is potentially a huge competitive advantage. However, there are major concerns about the fatigue strength. The variable nature of the environmental loads, and the dynamic behavior of a floating structure result in continuously varying internal forces, which could cause significant fatigue damage.





Hence, the fatigue strength of the pinned connection is assessed in the research project presented in this thesis. The fatigue strength is quantified by an estimated fatigue lifetime, which is the expected time to failure of the most critical point in the connection. The lifetime is estimated based on the yearly accumulated fatigue damage. A computer model of the structure has been constructed, with which time signals of the internal forces in the structure are calculated, based on the environmental loads.

The pinned connection was not included in this model, so internal forces in the steel tubular members have been translated manually to forces in the pinned connection. The connection was decomposed in its basic components and nine potential critical locations have been identified. Stress concentrations are expected at these locations, which make them sensitive to fatigue. The internal forces were combined with the dimensions of the components, so that nominal stresses could be calculated. The hotspot stress at the potential critical locations was estimated with stress concentration factors (SCFs), which are found in literature. Relationships between the internal force and the hotspot stresses are derived in this way, and time signals of the hotspot stresses are obtained. Most of the identified locations could be assessed with hand calculations, except for two locations. They are analyzed with finite element software (ANSYS). The time signals of the hotspot stresses have been used to calculate the expected fatigue damage with the Palmgren-Miner rule. The damage is calculated for all wave directions and based on real wave statistics.

Results have shown that there are five locations in the design that have an expected fatigue life time of less than 100 years. Three of them have an expected lifetime of less than 60 years, which is the absolute minimum according to the standard for floating offshore wind turbines. Although results are expected to be conservative, one of the recommendations is to do a more detailed stress analysis on the critical locations in the pinned connections.

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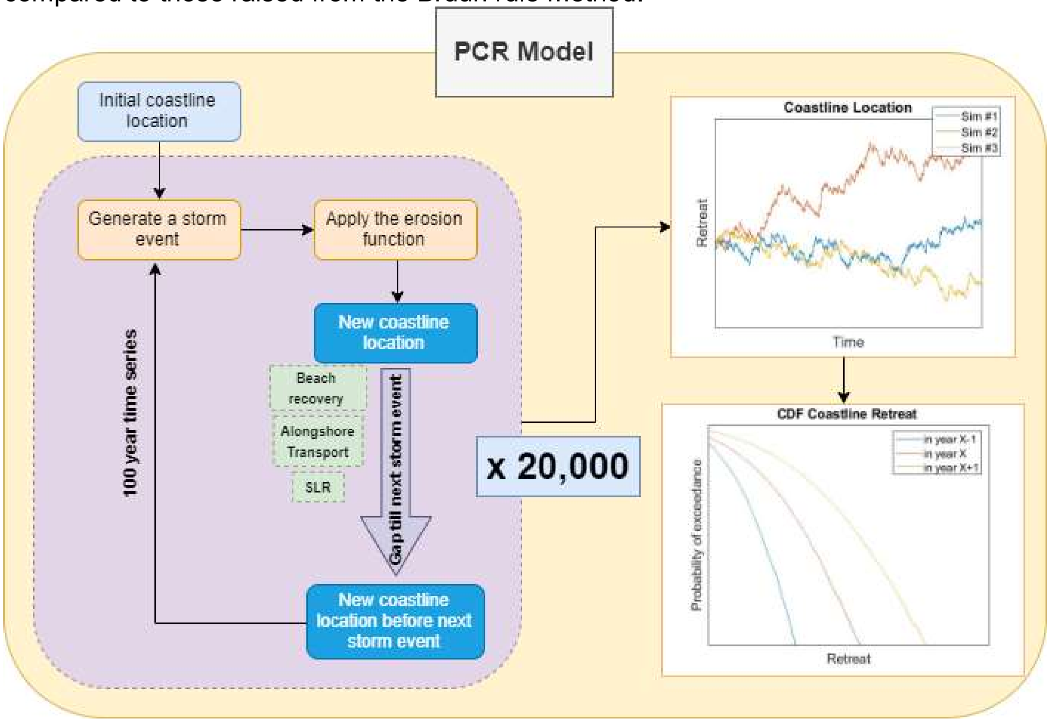
Estimating future coastline changes along Holland coast, under different sea level rise scenarios, using a probabilistic approach

Due to climate change and sea level rise (SLR) the coastal zones are getting exposed to increasing risks like coastal recession, putting in risk human lives and billions of dollars worth of coastal infrastructure. Low lying countries like the Netherlands are considered more vulnerable to the effects of sea level rise. Large parts of the Dutch coast have been eroding for centuries and nourishments schemes of approximately 12 million m^3 have been implemented annually in order to maintain the coastline as it was in 1990. However, the future dune erosion will further increase due to the impacts of climate change and hence the adaptation strategies should be in line with the accelerated sea level rise and the possible effects that may bring.

The most commonly used method to assess sea level rise impacts on shorelines is the Bruun rule. However, nowadays the coastal zone management requires a stochastic approach to estimate coastal retreat. Bruun rule's deterministic nature cannot align with the risk-based framework of coastal zone management. This necessity initiated the development of a process-based model, the Probabilistic Coastline Recession (PCR) model, estimating the future coastal recessions in a probabilistic approach.

In this research, the PCR framework was applied at eleven locations along the Holland coast, in the Netherlands, under three different SLR scenarios. The availability of coastal profile data (from 1965 until now) and coastline position data (from 1843 till 1980) made the Holland coast an ideal location to explore and extend the applicability of the PCR framework. The most relevant assumptions for this coast were identified and explored. The recovery rate of the dune was a weak point of the PCR model and Holland coast was an interesting area to be tested. Three approaches of calibrating the *natural* recovery rate of the dunes were followed. In addition, the alongshore sediment transport which was assumed negligible to the previous case-studies, in this work it was integrated into the PCR model. Projected recessions on the period 2020-2100 have been made using the updated PCR model for the SLR scenarios RCP4.5, RCP8.5 and Deltascenario, based on the most landward position of the coastline in each year. Finally, the results were compared to those raised from the Bruun rule method.



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Offshore & Dredging Engineering

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Structural Performance of a 10MW Turbine in Offshore Hurricane Wind Conditions - A Case Study for the Gulf of Mexico

Offshore wind farms are being deployed in ever more challenging conditions. Relatively unexplored are wind farms deployed in hurricane-prone regions. That is exactly the challenge that Mexican government faces as they want to expand their renewable energy resources by developing offshore wind in the Gulf of Mexico. The increased variability in wind resources, due to a combination of a reduced energy-yield design wind speed and increased hurricane structural design wind speed, pushes the overall design challenge of the turbines. Of key importance is the limited knowledge on how hurricane wind affect structures, particularly OWT's.

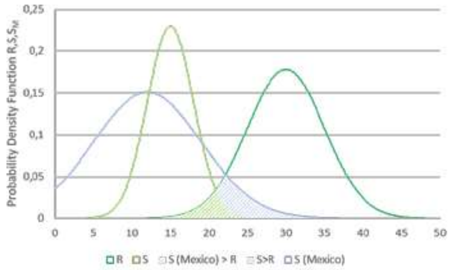
This study aims to identify how main characteristics of hurricane winds differ from models of regular extreme winds used in engineering simulations, to more accurately quantify hurricane winds loads and response effects on a 10MW turbine and to assess, albeit in a simplified manner, the structural ULS and SLS performance of the turbine under these extreme conditions.

The most important distinction found between hurricane winds and regular extreme winds is the turbulence spectrum: Yu [18] found turbulence energy is shifted towards the lower frequencies for hurricanes while Li [16] found that turbulence energy is shifted towards the higher frequencies. Both agreed that, although disagreeing on the turbulence spectra, that these wind parameters are likely storm-dependent and/or location-dependent. In this study, hurricane parameters are incorporated into a wind generation model adopted from Cheynet [2] and altered to incorporate the hurricane spectra. The wind model is limited to the 1D longitudinal case due to limited available information on other wind components for the hurricane winds. To quantify the loads and response effects due to the different spectra, a numerical approach is considered, using a finite-element blade model developed by Pim van der Male [21] applying the DTU's 10MW reference turbine's structural and simplified aerodynamic properties.

Within the boundaries of the inaccuracies present in the numerical input adn simulations, it was found that both the Yu and Li hurricane spectra show an increased load effect on the turbine blade, the response effect being equally large for both and roughly 20% larger compared to the Kaimal cases. This difference is proven to be predominantly due to the selection of the surface roughness length for hurricane conditions which was found to be larger by both Yu and Li studies [16, 18] for hurricane conditions. The difference due to the spectral change is negligible since the turbulent energy is nearly equal around the natural frequency of the considered 10MW blade thus not giving rise to significant changes in a dynamically amplified response. Selection of accurate hurricane wind parameters such as roughness length are thus equally important as the identified difference in turbulence spectra as they also result in significant changes of about 20% in the final results. Blade orientation has a considerable effect on reducing the response of a single blade if oriented downward. Averaging the thrust forces over all three blades however, effectively negates this advantage.

Structural performance was assessed through failure probabilities of the blade given the results of the aforementioned simulations. It was found that the hurricane wind simulations resulted in the largest failure probabilities, showing a non-linear increase in failure probabilities for larger wind speeds. Bending is the governing failure mode of the blade as these failure probabilities are considerably larger compared to the shear failure probabilities for wind speeds exceeding 50 year return period conditions.

Verifying the blade model response, it was found that the initially assumed three modeshapes were insufficient to accurately described the blade deformations. The model was therefore also not able to capture the correct internal root shear forces and root bending moments affecting the final results presented.



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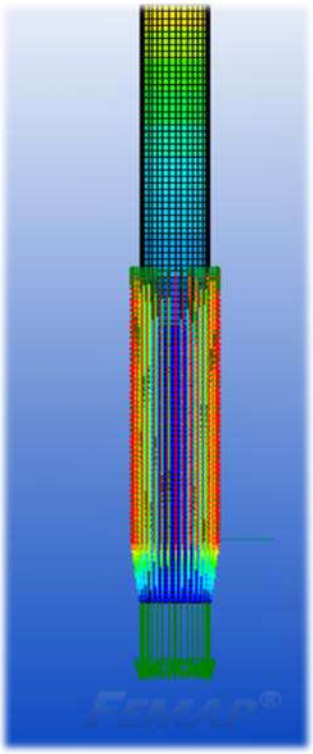
Offshore & Dredging Engineering

Development of an effective pile-soil reactin model to research the optimization of vibratory driving of monopile foundation pile with the GBM Vibrodrill system

As the offshore wind industry grows, the demand for larger wind turbines and foundations increases. The most common foundation type for a wind turbine is a monopile which is currently installed by large hydraulic hammers. This installation method generates a lot of underwater noise which may harm marine life. To solve this problem and its unwanted consequences, GBM aims to implement a new silent installation technique. By applying fluidization, jetting and by inducing vibrations by harmonically exciting the bottom of the pile, both the dynamic tip resistance and the shaft resistance are reduced so that the monopile can penetrate the soil. These techniques are aimed to produce less harmful underwater noise than conventional hammering.

Little is known about the penetration performance of a pile which is harmonically excited at the bottom. This thesis aims to provide more insight on the penetration performance when exciting a pile at the tip.
A literature study is performed on existing pile penetration models. From this study it is concluded that, currently, there are no available penetration models capable of describing the penetration performance of the pile when exciting the system at the bottom with varying harmonic excitations. Therefore, the aim of this thesis is to develop a new penetration model. The purpose of this model is to describe the penetration performance at different harmonic force parameters. The developed model is based on finite elements by using the FEMAP software. The pile is represented by shell elements. The interaction between the pile and the soil is modeled using multiple spring-damper-slider elements which are spread along the pile surface. The slider elements allow the relative motion between the pile and the surrounding soil. The different soil-structure interaction elements are uncoupled and the sliding resistance is assumed linearly elastic, perfectly plastic. Energy radiation due to elastic waves is captured by simple dashpot elements.



The developed model is used to analyze the effect of certain parameters on the penetration of the pile. This is done by changing the amplitude, the frequency or the direction of the harmonic force for a specific set of soil parameters. For each variation, the model calculates the pile displacement at a certain depth from which the penetration speed is determined. This penetration speed is then compared to the other results to determine the effect of each chosen parameter. Also, the location of excitation is analyzed. The model is used to analyze a pile which is excited from the top or at the bottom.

From the results it is concluded that an increase in the amplitude and the frequency of the excitation has a positive effect on the penetration speed. The dependence of the direction of the vibration on the pile penetration is complex. Therefore, a clear correlation between the two could not be obtained within the time framework of this research. Finally, it is concluded that exciting the pile from the top results in a faster penetration speed compared to a pile which is excited at the bottom.

This research provides is a first step towards understanding of the Vibro-drill system performance. As this is an investigation which is still in progress there are some recommendations for further research on this topic. One important recommendation is to improve the soil reaction in the model to a coupled system where it is now uncoupled. Furthermore field tests can be performed providing more knowledge on the effects of the soil and to validate the model.

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Offshore & Dredging Engineering

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Single lift blade alignment for large offshore wind turbines

In 2022 the first 12 MW offshore wind turbines are expected to be installed. Due to the continuous upscaling of wind turbine generators new problems are expected to arise during the installation of the turbines. Especially the workability of the installation of larger wind turbine blades, which are already causing problems during the installation of 8.4 MW turbine blades, are questioned by Van Oord. This research focuses on the alignment process of the blade with the hub, which is considered to be the limiting factor in installing wind turbine blades. The ultimate goal is to reduce single blade installation times by facilitating the alignment process
.

To investigate how different environmental conditions influence the dynamic behavior of the blade in the alignment process, a numerical model is developed. The motions of the blade, forces in the taglines and aerodynamic forces on the blade are evaluated for different environmental conditions during 30-minute simulations in the time domain. Wind velocity, turbulence intensity and the angle of the incoming wind relative to the blade are environmental parameters that influence the motion of the blade. Results for a 8.4 MW reference turbine blade are compared to a 12 MW turbine blade and conclusions are made concerning the installation workability for larger turbine blades.

Results show that the displacement of the blade root is caused by the rotation of the blade and installation tool around its x- and z-axis. The response spectrum of the blade root motions contains a significant amount of energy at the lower frequency part of the spectrum. In this part the first and second natural frequency of the system occur, which correspond to the rotations that are the main causes of the blade root displacement. The effect of wind speed, turbulence and incoming wind angle on the response of the blade is significant. Furthermore simulations are conducted for different rotation angles of the blade in the blade installation tool, which can result in large reduction, around 50%, of blade root motions. The responses of larger turbine blades (length 107 metre) increase compared to a smaller turbine blade (length 80 metre). Workability is expected to decrease due to the increase in blade root motions.

Based on the results of the analysis, several improvements are proposed for decreasing the blade root motions using the existing tagline set up. Using a different angle of the blade in the installation tool and increasing the tagline tension both decrease blade root motions. A solution using an extra tagline is proposed and discussed to show how the current setup could be improved.

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Offshore & Dredging Engineering

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Design optimisation of an adjustable Pre-Piling-Template for offshore wind-turbine installations

The demand for a substantial increase in renewable energy causes the need for more and bigger wind turbines. To counter the problem of available space, windfarms will move into deeper water. The challenge of deeper water in combination with higher turbines, require new developments in the wind industry. The often used monopiles make way for a new jacket-founded windturbine. Installation of these type of structures opens a market for a so called Pre-Piling Template.
This thesis aims to analyze the adjustability of the Pre-Piling Template for windturbine installation based on quasi-static calculations.

First a number of conceptual designs of a versatile adjustable Pre-Pilling Template are made. A wide variety of configurations is configured. The complicated part of the design is that the Pre-Piling Template must be viable for a three-legged and four-legged configurations with several centre-to-centre distances. Thereby, it should be possible to convert the entire system on deck of a vessel during given offshore conditions. From eleven concepts a selection of two alternatives has been made, based on listed criteria by the client: Robustness, Adjustability, Financial costs and Safety.

For two selected cross-centre alternatives a global structural analysis is performed under environmental loading. One cross-centre is a composed cross centre, with which a three- and four-legged configuration can be installed with the same cross-centre mid-frame of the PPT. The other alternative consist of two separate mid-frames, one for a three- and one for a four-legged configuration. To speed up the installation process, primarily all the piles to be installed will be stabbed into the Pre-Piling Template. After all piles have been stabbed into the frame, the hammering procedure will start. When all piles are stabbed significant forces arises from wind and especially hydrodynamic actions. The static deformations of the template induced during the multiple installation steps can cause overall displacements of the centre of each particular sleeve.

The added value of a Pre-Piling Template is the installation speed versus the required accuracy of the pile installation. A high installation speed only makes sense if piles can be installed within the required tolerances. Therefore the deformations of the frame and the corresponding displacements are governing. To determine the displacements, a 3D-model is constructed and a rotational and translational spring is implemented to model the soil-structure interaction. To consider this soil-structure interaction, a model by A.B. Cammaert et al (2011) is used to determine the required stiffnesses. The model is modelled using Matrix Frame software, with which the final displacements, at the height of the mid-frame, have been determined.

A detailed analysis of the static internal forces is worked out based on a bolted flange-flange connection. Checks are done conform Det Norske Veritas (2010) and based on a ULS-driven design. Two potential connection configurations are worked out; an alternative with less but more heavy bolts of M64, as well as an alternative with substantial more smaller bolts of M36.

Finally, several optimisations are identified to speed up the installation time of assembling and disassembling the adjustable Pre-Piling Template. Recommendations are made in cooperation with Breman Machinery and will result, in consultation with installation experts that are well known with the barge of the client, to a final design.

A clear conclusion, about the PPT-design, can not be made because the installation is site specific. If a project includes two different configurations, a three- and four-legged foundation design, a composed mid-frame that is viable for both configurations is recommended. For this composed mid-frame variant the operation to adjust the frame to another footprint can be done more efficient with a higher safety level on deck of the vessel.

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