JACKUP GOING ON LOCATION ANALYSIS

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ABSTRACT

Instead of using the traditional wave height limit, often referred to as the 5-ft wave, it is possible to develop a more rational definition of operating limits for jackup units going on location through simulations of jackup leg touchdown on the seabed. This paper presents a recent development of analysis methods applied to jackup units going on location. In addition to the detailed analysis method involving the direct time-domain simulation of global motions and dynamics of the jackup whose legs are approaching and impacting the seabed, two simplified methods based on different simplification schemes are also studied. Verification of these simplified methods is carried out using a generic jackup design and representative soil conditions. Results show that both simplified methods perform reasonably well in predicting maximum vertical impact forces in comparison to the more sophisticated method.

KEY WORDS: Jackup Going On Location; Jackup Installation; Design Wave Method; Coupled Analysis.

INTRODUCTION

While the methods for assessing jackup units in elevated mode during operations are well established, a better understanding is still needed for the temporary modes, as it is in these temporary modes that the majority of productivity and property losses take place. The temporary mode explored in this paper is the so-called ‘jackup going on location’, also known as ‘jackup installation’ or ‘jackup emplacement', the operation that involves a floating jackup lowering its legs down to the seabed till the hull starts being elevated from the water.

Most jackup operating manuals provide only minimum guidance for the going on location operation often in the form of a single limiting wave height and allowable maximum pitch and roll motions. Attempts were made in the past to develop analysis methods that can better assist the jackup going on location operation. One of the early developments, as part of a joint industry project, was reported by Lai, et al. (1993) [1], Miller et al. (1993) [2], and Smith et al. (1994) [3]. The jackup going on location analysis was carried out using a 2-D finite element model (stick model), while the afloat jackup global motions were pre-calculated using a frequency domain hydrodynamic analysis program and then used as boundary conditions for the finite element analysis. The basic assumption is that the spudcan impact on the seabed does not affect the hydrodynamic responses of the afloat jackup.

Similar methods but with more refined structural models for the jackup going on location analysis were later studied by Matter, et al. (2005) [4], Chakrabarti (2012) [5] and Dong et al. (2013) [6]. A common assumption made in these studies is that, during the entire impact analysis, the spudcan is always in contact with the soil springs representing the seabed. This may be reasonable for the case of very soft soil, but is obviously not capable of simulating the rebound when the spudcan touches down on the stiff seabed.

Most recently, Daun and Olsson (2014) [7] explored the possibility of adapting the software originally developed for floating offshore structure global performance analysis to simulate the jackup leg touchdown on the seabed. Effects of clearance between the spudcan and the seabed were explicitly modeled. Rather than simulating the continuous lowering of the legs in each simulation run, the legs were assumed to be locked to the hull and a prescribed initial clearance between the spudcan and the seabed representing a single time instant of the jacking operation was applied in a simulation. In order to model the entire jacking operation for a given sea state, multiple initial clearances between the spudcan and the seafloor for the same realization of that sea state were analyzed in separate simulation runs.

It has been recognized that many factors can affect the loads and responses during jackup going on location. Four physical behaviors are considered critical in assessing the maximum responses resulting from jackup leg impact on the seabed. These are jackup global motions in random seas, the leg lowering process, transient impact of the spudcan on the seabed, and jackup structural dynamic responses. Recent advances in simulation software enable sophisticated simultaneous modeling of these behaviors in the time domain and, therefore, provide a more detailed simulation of the jackup leg touchdown process. While this method may not be practical for operational support or routine engineering design given the enormous extent of the associated computational efforts, it does provide a viable means of deriving verification data that can help in developing more efficient and less complex analysis methods that can still yield comparable results.

This paper presents a recent development of analysis methods applicable to jackup units going on location. In addition to the detailed analysis method, which involves the direct simulation of the aforementioned four critical behaviors, two simplified methods based on different simplification schemes are also studied in the present research. The first method follows the so-called design wave approach where a random sea is represented by a number of regular waves (i.e. design waves) derived to replicate the extremes of selected global motions that potentially could govern the impact responses due to the jackup leg touchdown. A jackup with a continuously lowering leg is simulated to each design wave in the time domain to calculate the maximum impact responses. The second method simplifies the leg lowering process to a number of discrete spudcan positions, each of which remains unchanged relative to the hull during the time domain simulation of the jackup in random seas. Verification of these two simplified methods is carried out using a generic jackup design and representative soil conditions. Results show that both simplified methods perform reasonably well in predicting maximum vertical impact forces in comparison to the more sophisticated method.

MODELING CONSIDERATIONS

One of the subjects often neglected in previous studies on the jackup going on location analysis is the process during which the jackup spudcan approaches the seabed and begins contacting the seabed intermittently. To start with the discussion without losing generality, consider a simple representation of the jackup going on location, as illustrated in FIGURE 1, using a single degree of freedom (SDOF) mass-clearance-springs system.

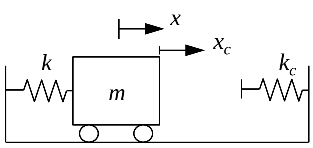

FIGURE 1. A Bilinear Free Oscillation System with Clearance (Butcher, 1999 [8])

Assuming linear spring stiffness and no damping, the analytical solution of the natural frequency, Ω, of this bilinear free oscillation system is determined by Equation (1), as derived by Butcher, 1999 [8]:

$$\Omega = 2\omega_-\omega_+\left[\omega_+\left(1+\frac{2}{\pi}\sin^{-1}\rho\right)+\omega_-\left(1-\frac{2}{\pi}\sin^{-1}\left(\frac{\rho}{\alpha\sqrt{1-\rho^2(1-1/\alpha^2)}}\right)\right)\right]^{-1} \tag{1}$$

where $\rho=x_c/x_0$ is the ratio of the clearance, x_c, to the initial displacement magnitude, x_0, and must lie in the interval [-1, 1] in order for contact/separation to occur; ω_- and ω_+, as given in Equation (2), are the natural frequencies of the mass-clearance-springs system before and after contact with the free spring; α is the ratio of ω_- to ω_+, representing the level of frequency separation; m is the mass and k is the linear stiffness of the spring attached to the mass; k_c is the linear stiffness of the free spring.

$$\omega_- = \sqrt{k/m}\,; \qquad \omega_+ = \sqrt{(k+k_c)/m}\,; \qquad \alpha = \omega_+/\omega_- = \sqrt{1+k_c/k} \tag{2}$$

Equation (1) shows that the natural frequency of the system under consideration depends on both the initial gap distance and the motion amplitude of the mass. When the initial clearance vanishes, i.e., $\rho=x_c/x_0=0$, the system natural period simplifies to the well-known bilinear frequency $2\omega_-\omega_+/(\omega_-+\omega_+)$. Another interesting observation is for the case of $\alpha \rightarrow \infty$ where the stiffness of the free spring (i.e. soil) is much greater than the stiffness of the spring attached to the mass, the limiting natural frequency of the system becomes $2\omega_-/(1+2/\pi\sin^{-1}\rho)$ for any initial clearance satisfying $\rho\in[-1, 1]$.

The implication of Equation (1) is that, for a jackup with its legs being continuously lowered toward the seabed during the installation, the natural period of the jackup-clearance-seabed system after an initial impact occurs will keep changing along with the varying spudcan-seabed clearance relative to the motions of the jackup (i.e. ρ). Given the importance of the natural period in determining the responses of the jackup during installation, Equation (1) suggests that the effect of spudcan-seabed clearance and the change of such clearance should be considered in the going on location analysis.

In addition to the spudcan-seabed clearance, there are other aspects that could affect the impact responses of the jackup during installation. These may include:

- The jackup is subjected to continuous excitation forces exerted by random environmental actions and holding tugs. The intermittent impact of spudcan on the seabed introduces additional impulsive excitation forces that will interact with those due to environmental actions and holding tugs through the transient responses of the jackup. The significance of such a coupling effect varies with the overall damping level and natural period of the jackup-clearance-seabed system as well as with the time interval of two consecutive impacts.

- Structural dynamics of the legs and leg-hull connections could affect the hull responses to the impact load exerted on the spudcan. In contrast to the analysis for elevated mode where attention is primarily given to structural responses, the jackup going on location analysis also concerns about the effect of impact-induced dynamics of the legs and leg-hull connections on the floating hull motions.

- Impact responses of the jackup hull may introduce additional changes to the water plane area when the equilibrium position is no longer on even keel and, as a result, the hydrostatic stiffness. They can also affect the application of the frequency-dependent added mass and hydrodynamic damping of the jackup hull.

- Nonlinearity of the spudcan-soil interaction and potential side sliding of the spudcan on the seabed may further alter impact responses. Assuming all other conditions are the same, stiffer seabed typically leads to higher impact loads on the spudcan.

A direct time-domain simulation approach, as described below, is developed to explicitly model most of these aspects to the extent that their interactions can be simulated at each time incremental step. Simplifications do apply, especially to the spudcan-soil interaction model, due mostly to the software limitations, although the developed simulation approach itself is intended for general applications. It is also noted that the effect of holding tug and current drag are currently not considered in the simulation.

In addition to this numerical intensive direct simulation approach, efforts are also made to develop simplified methods that can achieve an acceptable level of accuracy for much less computational cost. The results obtained from the direct simulation approach are used in this study as the reference data for verifying the suitability of simplified analysis methods. The vertical impact force on the leg-spudcan interface is chosen as a critical design parameter to present the developed analysis methods and verification results in this paper.

JACKUP MODEL FOR THE CASE STUDY

The jackup selected to demonstrate the direct simulation approach and the simplified analysis methods is adapted from BASS350 design, a moderate environment jackup comparable in capabilities to the B-Class, Super 116E, and Pacific 375 jackups. Major dimensions and relative mass properties of the jackup are depicted in FIGURE 2. The water depth assumed for the present study is 61 m (200 ft). FIGURE 3 shows the natural periods of the free-floating jackup whose legs are lowered to the depth where the spudcans are 2 m above the mudline in calm water. The leg lowering speed is set to be 0.01 m/s (2 ft/min).

Two homogeneous soil conditions are selected in the study, one represents very stiff soil with the undrained shear strength (S_u) of 450 kN/m^2 on the mudline and another is for very soft soil with S_u = 5 kN/m^2 on the mudline. For the results presented in this paper, linear soil model is applied; the soil spring stiffness is derived in terms of undrained shear strength of the soil.

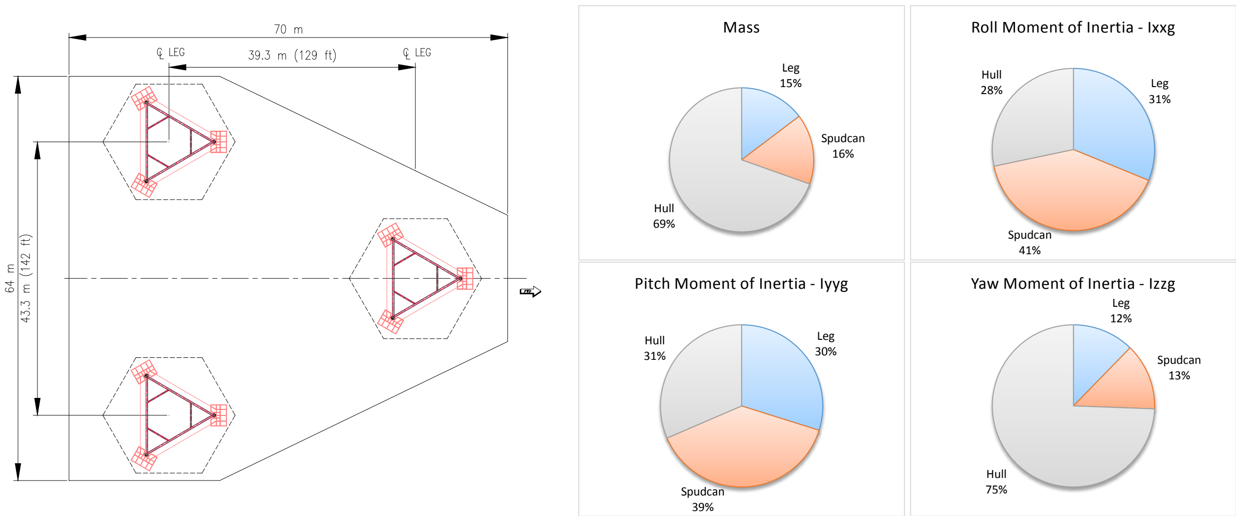

FIGURE 2. Major Dimensions and Mass Properties of the Case Study Jackup Model

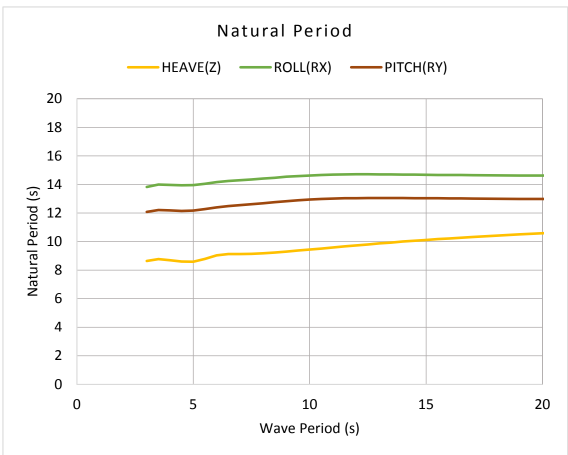

FIGURE 3. Natural Periods of the Jackup in Free-Floating Mode

The software used to simulate the jackup global motions, structural dynamic responses and impact on the seabed is OrcaFlex, a 3D nonlinear time-domain finite element program used mostly for global motion analysis for floating offshore structures, moorings and risers. The main jackup structural components, i.e. the hull, legs (hybrid models), spudcans, guides and pinions, are included in the analysis model, as illustrated in FIGURE 4. The jackup legs can be moved relative to the hull such that the spudcan elevation can be adjusted at each time step in the time-domain simulation of the leg touchdown on the seabed. The spudcan is modeled using a group of pipe elements, as shown in FIGURE 5. Collectively, the properties of these pipe elements are tuned to match the leg penetration curve determined in accordance with the recommended method in ISO 19905-1[9] for a given soil condition. The hydrodynamic coefficients required as inputs to OrcaFlex are calculated using ANSYS AQWA LINE, which is a frequency-domain diffraction-radiation hydrodynamic analysis program.

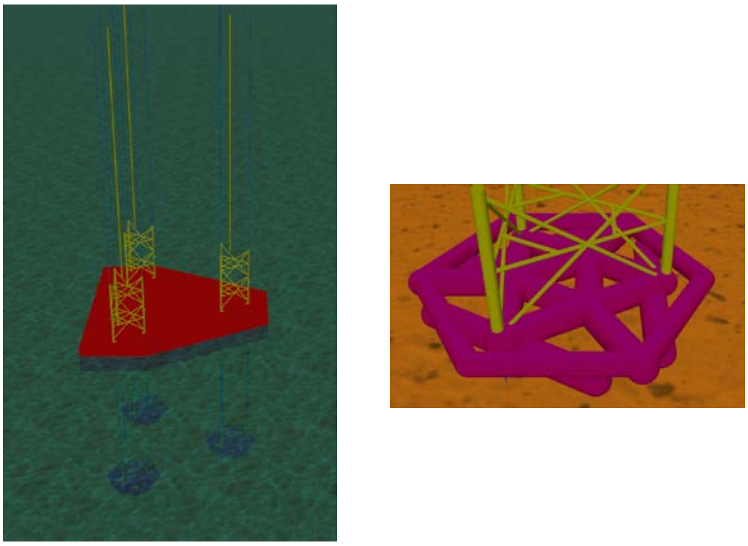

FIGURE 4. Jackup and Spudcan Models in OrcaFlex

DIRECT TIME-DOMAIN SIMULATION OF JACKUP GOING ON LOCATION

The direct time-domain simulation of jackup going on location involves detailed modeling of jackup's hydrodynamic responses in random seas, structural dynamics of legs and leg-hull connections, and transient impact on the seabed in a 'fully coupled' manner, meaning their interactions are taken into account at each incremental simulation time step. The jackup model as shown in FIGURE 4 is used in the direct time-domain simulation. In addition, the randomness of waves and jackup global responses as well as the randomness of the moment when the jackup legs start being lowered down are explicitly modeled. In so doing, the coupling effect of random wave induced global motions and the randomness of spudcan-seabed clearance can be modeled in the impact analysis.

The direct simulation starts with generating a 3-hour wave elevation time series for a given sea state and a selected random seed. To limit the calculation time, a 1-hour segment of wave elevation time series containing the maximum wave height is extracted as the input for the time-domain motions analysis in OrcaFlex. The initial elevation of the jackup legs are chosen to allow for a sufficient clearance to the seabed such that, if the legs were locked to the hull, no impact on the seabed would occur in the 1-hour simulation and the jackup would be in free floating mode. Since the jackup could start lowering its legs at any moment during that 1-hour time window, consecutive starting moments at an interval of 2 seconds are selected for the initiation of leg lowering. This results in 1800 simulation cases, each of which is associated with a distinct moment when the jackup switches from the locked-legs, free-floating mode to the process of lowering the legs till the legs settle on the seabed and their transient movements subside. Since jackup motions in free-floating mode are governed by the linear wave-frequency responses of the hull, it is not necessary to run the simulation of free floating motions for the entire time duration before a selected starting moment of leg lowering. Instead, only a short lead time sufficient to develop the hull motions is needed. This essentially leads to applying a sliding time window at 2-second interval to carve out segments of wave elevation time series as the inputs to the OrcaFlex simulations of leg touchdown.

An example of a 1-hour time series for a random sea state (H_s = 2 m, T_p = 10 s, PM spectrum) and a zoom-in plot of wave elevation history showing the starting moment of leg lowering at the local time scale t = 30 are presented in FIGURE 5. The third plot in FIGURE 5 depicts the resultant total vertical impact force recorded at the connection between the forward leg and its spudcan in the case of very stiff soil. The maximum impact force, as marked in the plot, represents an occurrence of extreme event. In the present study, there are 1800 records of such maximum impact force for a 1-hour realization of a random sea state.

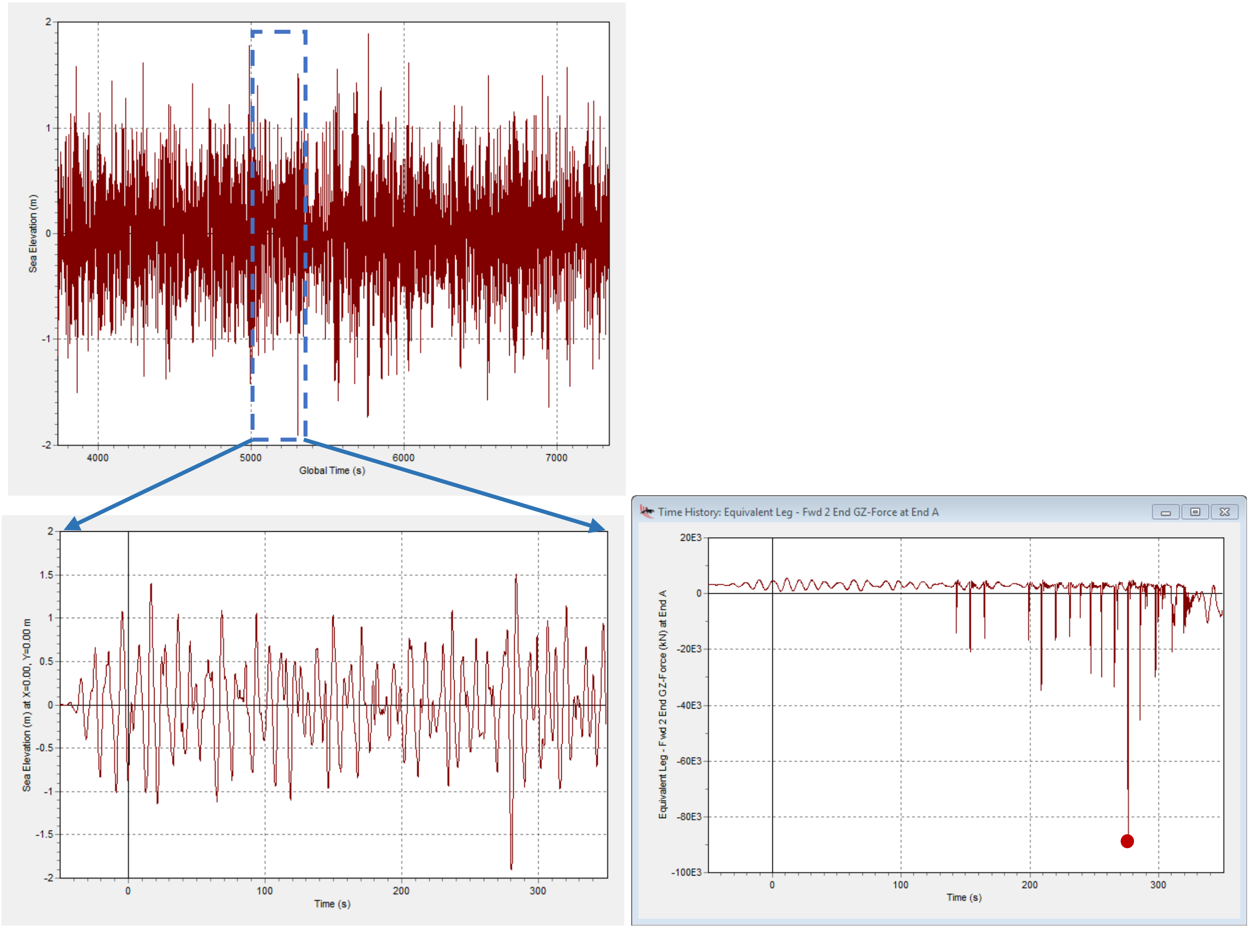

FIGURE 5. Example Wave Elevation and Vertical Impact Forces during Spudcan Touchdown on the Seabed (The jackup legs start being lowered down at the local time scale t = 30 at a constant speed of 0.01 m/s. The jackup is in free floating mode with locked legs prior to t = 30 s. The seabed has very stiff soil.)

FIGURE 6 depicts the normalized (by their mean value) zero-mean values of the maximum vertical impact forces for two realizations of the given sea state and for the seabed with very stiff and very soft soil conditions. It shows that the variation of normalized vertical impact force is greater in the soft soil case, although the associated mean value of the impact force is much lower in comparison to the stiff soil case. It further shows that the maximum impact forces obtained from the simulations associated with two adjacent starting moment of leg lowering at a 2-second interval could vary significantly, in particular for the soft soil case. This difference is not only caused by the leg lowering speed, which is fairly slow (0.01m/s), but more prominently the 6-DOF motions of the jackup hull that could lead to a very different initial elevation of the leg when it starts lowering down. Note that 2 seconds is 1/5 of peak wave period T_p = 10 s.

Note further that each data point in FIGURE 6 represents an occurrence of extreme event. The plots should not be interpreted as time series. Rather, each plot presents a collection of discrete independent extreme events that could occur for a realization of a given sea state in conjunction with various starting moment of leg lowering. The extreme value of the impact force associated with a specified statistic metric can be predicted using the records of these extreme events – for instance, each positive data point of zero-mean samples for a given sea state and a soil condition in FIGURE 6 may be considered as a maxima and used in determining the most probable maximum extreme value.

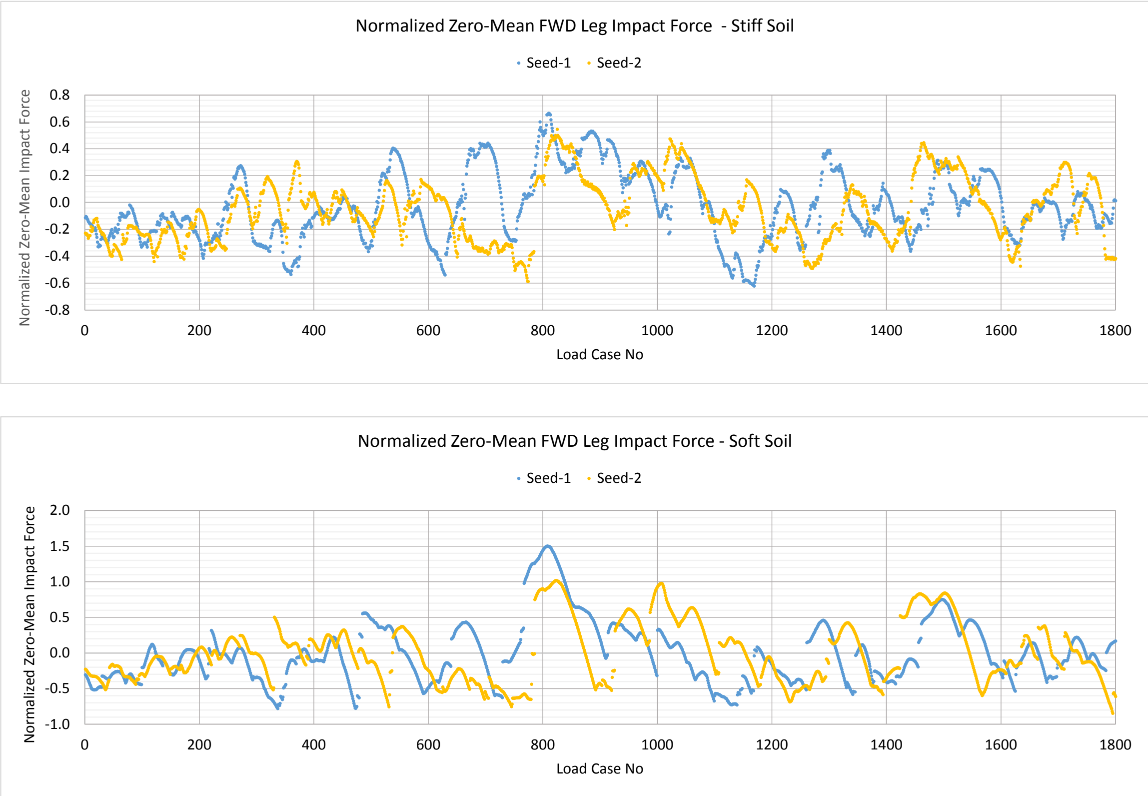

FIGURE 6. Normalized Zero-Mean Maximum Veridical Impact Forces at the Connection of the Forward Leg and the Spudcan

SIMPLIFIED METHODS

The direct time-domain simulation, as described above, allows for 'fully coupled' modeling of jackup going on location in a random sea and can explicitly simulate the interaction of sea state and leg lowering. The major drawback of this method, however, is high computational costs. Assume using a 1-hour segment of wave elevation time series screened from a 3-hour time history, the total number of time-domain leg touchdown simulations would be 1800 times the number of realizations of each random sea state times the number of sea states under consideration. This leads to a significant requirement of computing resources as well as efforts for data pre- and post-processing. As such, this method may not be practical for operational support or routine engineering design. However, given the level of details this method can model, it does provide a viable means of deriving reference data that can help in developing more efficient and less complex analysis methods that can still yield comparable results.

Two simplified methods are evaluated in the present study. The first one is inspired by the 'Design Wave' approach commonly used in the design of ships and floating offshore platforms [10]. Another is similar to the approach studied by Daun and Olsson (2014) [7], where the legs are locked to the hull at various prescribed elevations and remain unchanged in each time-domain simulation. Details of these two simplified methods are described in the following two sections.

SIMPLIFIED METHOD – DESIGN WAVE APPROACH

The basic concept of the design wave approach is to identify a number of individual regular waves, i.e. design waves, such that the specified critical responses of the jackup subjected to these design waves can match the related extreme responses of the jackup subjected to a given random wave. Once the design waves are defined, the jackup going on location analysis can be simplified to a deterministic regular wave analysis for each design wave. Normally the critical responses are those that are directly computable from the global motion analysis rather than the final target responses for checking against design or assessment criteria. It is essential that the selection of the critical responses be based on the understanding of correlations between global responses and a specified target response. It should be noted that, for different target responses, the correlated global critical responses could be different as well.

For the study presented in this paper, the target response is the vertical impact force at the leg-spudcan interface. The correlated global critical responses are found to be heave and pitch velocities at the jackup center of gravity as well as the velocities at the tip of the spudcan when the jackup is in free floating mode. Since these jackup global motions in free floating mode are governed by wave forces on the hull, the linear spectral analysis method should be adequate for calculating the magnitude of these motions. The design waves can then be determined using the procedure outlined in the ABS MODU Rules [10] and as summarized below:

- Calculate Response Amplitude Operators (RAOs) for each critical response. In the present study, the critical responses include heave and pitch velocities at the jackup center of gravity and the velocities at the tip of the spudcan.
- Select a random sea state and calculate the response spectrum of each critical response
- Calculate the maximum value for each critical response using the spectral analysis method. In the present study, the maximum value is chosen as the most probable extreme value derived from the response spectrum.
- Derive the design wave height curve as a function of wave period for each critical response by dividing the maximum response by the RAOs of the critical response
- Select design waves in terms of wave height, period and direction from the design wave height curves

An example of design wave curves is given in FIGURE 7 for the jackup in a sea state with H_s = 2 m, T_p = 10s and 180 degree wave heading. The two solid curves are for the horizontal and vertical velocity at the tip of the forward spudcan. The two dashed curves are for the heave and pitch velocity at the jackup center of gravity. The limiting wave curve has the wave height H_{max} =3.48 m. Also shown in the figure are the ranges of the pitch and heave natural periods of the jackup in free floating mode. Applying a regular wave defined by any point on a design wave curve associated with a specified critical response will generate the same maximum value of that critical response when the jackup is subjected to the actual random sea state used to derive the design wave curve. Since the regular waves defined using the points inside the area bounded by a design wave curve overpredicts the maximum value of the critical response, the design waves should be selected on the lowest envelope of all the design wave curves and the limiting wave curve. The periods of the selected design waves should cover the typical wave period range, while more attention needs to be paid to the ranges of pitch, heave and roll natural periods. Note that the spudcan-seabed clearance varying along with the leg movement could introduce additional changes to the natural periods.

After selecting design waves from the design wave curves, the jackup going on location analysis is performed using the same OrcaFlex model as shown in FIGURE 4. Since the wave conditions used in the simulation are no longer from the random waves but the individual deterministic regular waves defined by the selected design waves, the total number of simulations and simulation time can be greatly reduced. Typical vertical impact force time histories obtained using the design wave approach are shown in FIGURE 8, in which the effect of using two different phase angles of the design wave is also illustrated. The maximum impact forces can therefore be determined from the time histories calculated for all the selected design waves.

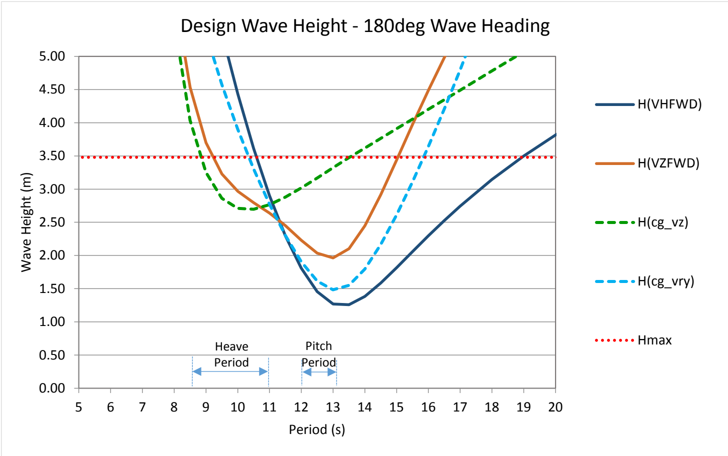

FIGURE 7. Design Wave Curves for the Jakcup (H_s = 2 m, T_p = 10 s, 180 deg Wave Heading)

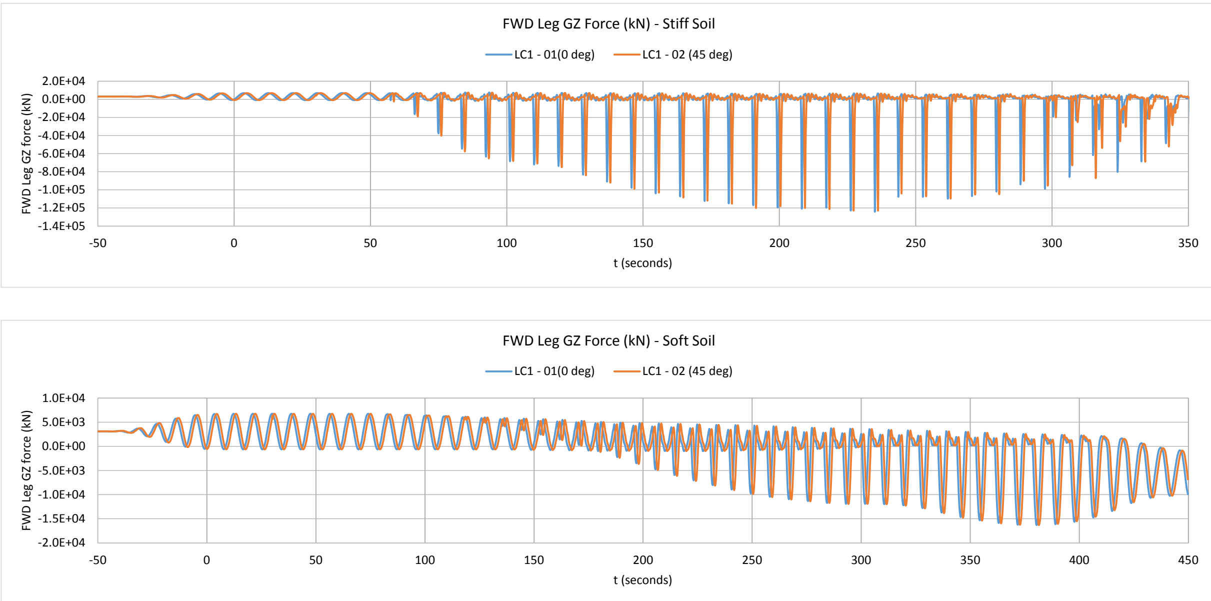

FIGURE 8. Typical Vertical Impact Forces at the Connection of the Forward Leg and Its Spudcan Calculated Using the Design Wave Approach (Two phase angles, 0 deg and 45 deg, of the design waves are considered.)

SIMPLIFIED METHOD – DISCRETE LEG ELEVATION APPROACH

Given that significant computational efforts required by the direct time-domain simulation are mostly inflicted by the need to address the coupling of two sources of randomness (random sea and random starting moment of leg lowering), one of the simplification schemes is to approximate the continuous leg lowering using multiple discrete leg elevations such that, for each time-domain simulation, the legs are locked to the hull while the randomness of sea state is explicitly modeled. Multiple simulations with different predefined discrete leg elevations are required for the same realization of a sea state. It is perceived that, with the selection of a sufficient number of discrete leg elevations and a long enough simulation of random wave induced global motions, the effect of changing spudcan-seabed clearance and its interaction with a random sea state can be suitably modeled. Recall that the direct time-domain simulation applies a sliding time window at a two-second interval to carve out segments of wave elevation time series as the inputs to the simulations of leg touchdown; the discrete leg elevation approach is schematically akin to applying a sliding observation window at each discrete leg elevation while all random sea states run through their courses.

Since the continuous leg lowering operation is approximated by multiple discrete leg elevations, the number of simulations is reduced to the number of discrete leg elevations times the number of realizations of each random sea state times the number of sea states under consideration. In addition, since the leg lowering does not need to be explicitly modeled, the OrcaFlex model in FIGURE 4 can be further simplified by removing the mechanism for moving the legs. The analysis model becomes similar to those used for site-specific assessment for jackups in elevated conditions; the main difference is the inclusion of the clearance between the spudcan and the seabed.

FIGURE 9 shows a typical three-hour (with additional ramp-up time) vertical impact force time history for the stiff soil case obtained using the discrete leg elevation approach. The extreme value of the impact force associated with a specified statistic metric can be predicted using these time histories calculated for each sea state.

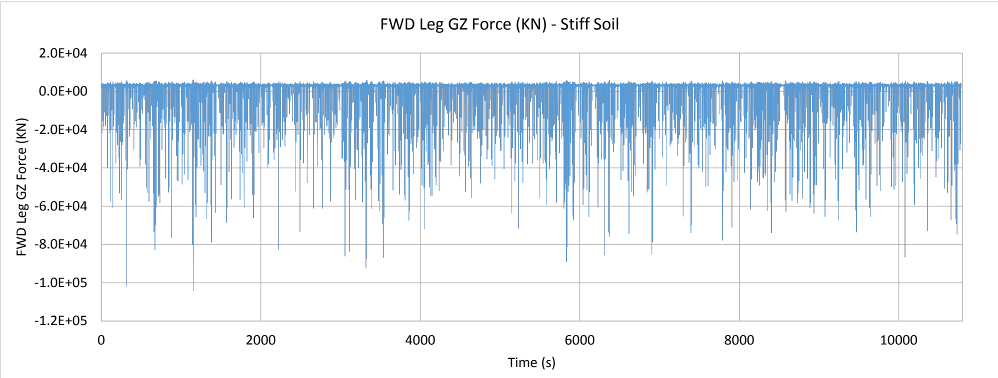

FIGURE 9. Typical Vertical Impact Forces Calculated Using the Discrete Leg Elevation Approach

COMPARISONS OF CASE STUDY RESULTS

The comparison between the direct time-domain simulation approach and the two simplified methods is carried out using the maximum vertical impact force measured at the forward leg-spudcan interface. The analysis model is shown in FIGURE 4. One sea state (H_s = 2 m, T_p = 10 s, PM spectrum) at 180 degree wave heading is applied when using the direct time-domain simulation method and the discrete leg elevation approach, while the design waves derived from this sea state are applied to the simulations using the design wave approach. For the direct time-domain simulation method, 2 random seeds for generating the wave crest elevation time series of the sea state are selected. A combination of 7 random seeds for the sea state and 5 discrete leg elevations are applied to the simulations using the discrete leg elevation approach. A total of 14 design waves are derived for using the design wave approach.

Comparative results for the very stiff and very soft soil cases are listed in TABLE 1 and TABLE 2, respectively, in which the maximum values of the vertical impact forces are derived using different methods. For each set of discrete occurrences of maximum vertical impact force calculated using the direct time-domain simulation method, the curve fitting for the three-parameter Weibull distribution is applied to the block data whose exceedance probability is below 20%. For the vertical impact force time histories calculated using the discrete leg elevation approach, the Weibull distribution curve fitting follows the recommended method in ISO 19905-1.

TABLE 1 shows that, for the very stiff soil case, the maximum values of the vertical impact forces obtained using two different random seeds have very small variations. The average of maximum values from using the discrete leg elevation approach are slightly smaller than those from the direct time-domain simulation methods, while in general the discrete leg elevation approach and the design wave approach give comparable results and show modest conservativeness.

For the very soft soil case, as shown in TABLE 2, the maximum values of the vertical impact forces appear much more sensitive to the change of random seed. The Weibull curve fitting could sometimes yield a relative low confidence level. See, for example, the case of Seed #1. Similar to the very stiff soil case, the average of maximum values from using the discrete leg elevation approach are slightly smaller than those from the direct time-domain simulation methods, while the discrete leg elevation approach and the design wave approach give comparable results and show modest conservativeness.

TABLE 1: Comparison of Vertical Impact Forces at the Leg-Spudcan Interface – Very Stiff Soil Case

Method of Deriving the Maximum Value	*Vertical Impact Force (MN)*			
	Direct Time-Domain Simulation Method		*Discrete Leg Elevation Approach*	*Design Wave Approach*
	Seed #1	*Seed #2*		
Maximum Value of All Sampling Point Sets	106	107	115	119
Average of Maximum Values of Individual Sampling Point Sets	106		103	--
MPM Values from Weibull Curve Fitting	109	109	--	--
Average of MPM Values from Weibull Curve Fitting	109		120	--

TABLE 2: Comparison of Vertical Impact Forces at the Leg-Spudcan Interface – Very Soft Soil Case

Method of Deriving the Maximum Value	*Vertical Impact Force (MN)*			
	Direct Time-Domain Simulation Method		*Discrete Leg Elevation Approach*	*Design Wave Approach*
	Seed #1	*Seed #2*		
Maximum Value of All Sampling Point Sets	17	15	19	18
Average of Maximum Values of Individual Sampling Point Sets	16		15	--
MPM Values from Weibull Curve Fitting	28*	16	--	--
Average of MPM Values from Weibull Curve Fitting	22*		17	--

Note:
Weibull curve fitting has relatively low confidence for the impact forces obtained using random seed #1 in the direct time-domain simulation

CONCLUDING REMARKS

This paper presents a recent development of analysis methods for jackup units going on location. The analysis model as shown in FIGURE 4 is used in implementing the direct time-domain simulation approach and the two simplified methods. The direct time-domain simulation involves fully-coupled modeling of jackup’s hydrodynamic responses in random seas, structural dynamics of legs and leg-hull connections, and transient impact of spudcan on the seabed. The first simplified method follows the concept of design wave approach where a random sea is represented by a number of regular waves derived to replicate the extremes of selected global responses that potentially could govern the critical impact responses due to the jackup leg touchdown. The second simplified method models the leg lowering process using multiple discrete leg elevations, each of which remains unchanged relative to the hull in the time domain simulation of the jackup in random seas. The main difference of the three approaches resides in how the randomness of sea state and starting moment of leg lowering is addressed in the analysis.

Among the three different approaches, the direct time-domain simulation is considered as a state-of-the-art modeling approach for the jackup going on location; the design wave approach is computationally most efficient because all the stochastic features are represented through purposefully selected deterministic design waves, while the discrete leg elevation approach offers a straightforward analysis method with a modest requirement of computational effort since only random waves need to be explicitly modeled in each simulation. Using the maximum vertical impact force at the leg-spudcan interface as an indicator, the two simplified methods appear to be able to produce the results that compare reasonably well with those from the direct time-domain simulation. Further verifications using other indicators, such as the pinion load, and sensitivity analyses with consideration of variations of jackup's main design and operational parameters are still required.

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