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TIME TRACE WINDOW BASED APPROACH FOR SCR STRENGTH ANALYSIS IN ULTRA DEEPWATER OF GULF OF MEXICO

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ABSTRACT

For a steel catenary riser (SCR) in the ultra deep water of the Gulf of Mexico (GOM), the areas of major concern from a dynamic stress response point of view are the sagbend region near the touchdown and the region below the hang-off at the SCR top where local bending must be accommodated. Usually global strength (stress/strain/buckling) analysis focuses primarily on the sagbend region, while more detailed analysis associated with design of the riser hang-off assembly concentrates on the SCR top region.

The global strength design of the SCR is controlled by dynamic response in the sagbend region, which is primarily driven by the host vessel motions. Vessel motions are in turn induced by metocean conditions such as hurricanes and winter storms. Given the random nature of the ocean waves, to obtain statistically sound results, random wave simulations involving multiple (usually ten (10)) three (3) hour realizations have been a well accepted practice by the offshore industry. Just as waves in an extreme or survival storm event are randomly distributed, stress (and strain) response events are randomly distributed as well. For a comprehensive design, there will be far more than one sea state to be analyzed with each sea state undergoing multiple three (3) hour simulations. In addition, the design often progresses iteratively, i.e., there will be several cycles of analyses to be performed before the final design can be concluded. Therefore, the overall computational resources in terms of time and data storage are quite significant. This paper presents the methodology that significantly reduces the computer simulation time without compromising the analysis accuracy for the strength analysis of the SCR. The paper uses the example of a SCR in the ultra deepwater of the GOM attached to a DeepDraft Semi™ designed by SBM Atlantia Inc.

The methodology builds on time traces of the host vessel motions, and the correlation between the vessel/porch motion and the SCR sagbend response. Generally the maximum riser sagbend stress occurs when the wave pushes the vessel, then the riser porch toward its touchdown point (slack position). One vessel/porch motion characteristic - the downward speed at the riser porch dominates the SCR sagbend response. By screening the downward speeds at the riser porch under slack condition, the time at which the sagbend response (stress/strain/buckling) peaks is identified. A time trace window containing the peak time and with band width of about 200 seconds is located and the SCR global dynamic analysis is performed based on this time trace window. In some scenarios, up to five (5) windows associated with the top five (5) downward speeds at the riser porch for one realization are needed to capture the peak stress response in the SCR sagbend.

INTRODUCTION

With offshore developments expanding to ultra deepwater, riser systems are becoming more challenging and more complicated. Numerical simulation based on finite element analysis (FEA) is playing increasingly bigger roles in the riser system designs and design verifications, and new simulation tools/methodologies are highly demanded to improve the simulation efficiencies.

The SCR strength analysis in the ultra deepwater of the GOM using random wave approach is very time consuming. The strength design of the SCR is controlled by the dynamic response in the sagbend region. In order to reduce the computer simulation time, a screening methodology to identify the peak stress events in the sagbend region is crucial. One approach used in industry practice is to identify the largest expected wave in a sea state and simplify it with an equivalent regular wave train imposed on the host vessel at a specified vessel offset. However, fixed phasing of the calculated vessel motion components in a regular wave train generates a bending stress in the sagbend which may be more conservative than that occurring in a random wave train under the same wave height.

An alternative approach would be to identify "windows" of time in a time trace of host vessel motion in a random sea state where a peak bending stress might be expected to occur, and perform the dynamic analysis based on the time trace window identified. The agent used to identify the time trace window shall be easily available and has strong correlation to the SCR sagbend response. By screening the motion characteristics at the riser porch under riser slack condition at a time the SCR sagbend stress peaks, it is observed that there exists strong correlation between the porch downward speed and the stress in the sagbend region. The higher downward speed at the porch is corresponding to the greater stress in the sagbend. Therefore the porch downward speed is used to identify the time at which the sagbend stress may peak.

VESSEL AND VESSEL MOTION DATA

To demonstrate the validity of the methodology and illustrate how to use it, the paper uses an 18" oil export SCR as an example. The SCR is hung off from a DeepDraft Semi™ designed by SBM Atlantia Inc. The semi design offers the advantages of a SCR friendly hull design, and inshore topside-to-hull integration. As show in figure 1, the platform north is oriented 45 degrees counter clockwise from the grid north. Two (2) SCR layout scenarios are evaluated in this paper:

- Scenario 1 - The SCR departs the semi north face in line with the platform north, and the platform north heading environment condition pushes the riser porch toward the riser touchdown.
- Scenario 2 - The SCR departs the semi north face 30° west from the platform north, and the platform northwest heading environment condition pushes the riser porch toward the riser touchdown.

The riser porch downward speed results from a combination of the vessel heave, roll and pitch motions. In Scenario 1, the vessel roll is dominant and vessel pitch is negligible. In Scenario 2, the vessel roll and pitch are equivalent in magnitude.

The six (6) degrees of freedom vessel motion time traces in the 100 year hurricane event and intact moorings were generated by SBM Atlantia Inc. The time traces include both mean, first order, and second order motions. Since the hurricane wave peak period is close to the semi heave, pitch and roll natural periods, special attention should be paid to model the vessel damping and compute second order wave forces.

Table 1 shows the environment parameters for the 100 year hurricane with intact mooring system. The environment condition is for central GOM based on the recent API Bulletin 2INT-MET (May 2007), reflecting increased extreme conditions post Ivan and Katrina. Based on the platform orientation, a 10% reduction in signification wave height was taken for the wave travelling toward the platform northwest direction. For the platform north heading wave, ten (10) realizations with each realization lasting three (3) hours were provided. For the platform northwest heading wave, nine (9) realizations with each realization lasting three (3) hours were provided. It should be noted that for each of the realization, the exact wavelet phases were also recorded and used in the SCR analysis in order to compute the wave loading directly acting on the SCR correctly.

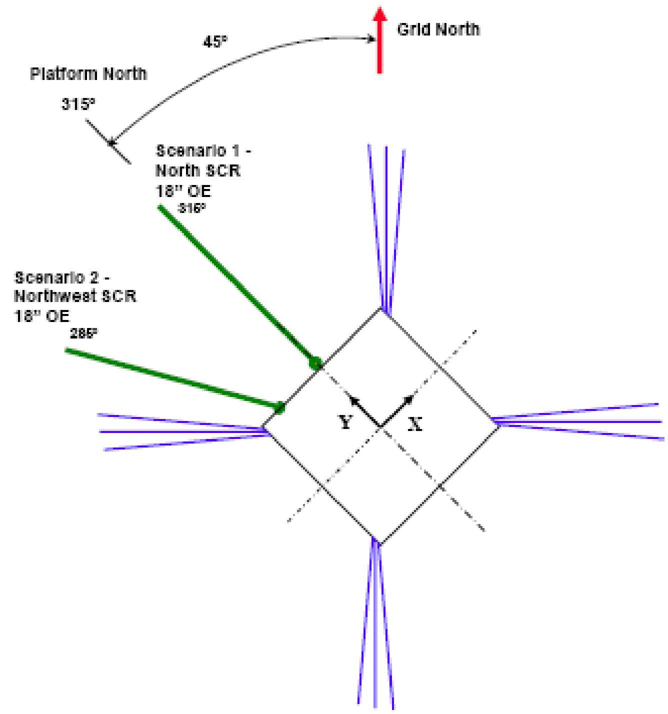


Figure 1. Schematic of SCR Layout

Table 1. 100 Year Wave Hurricane Data

Environment Parameters	Platform North Heading	Platform Northwest Heading	Description
Wind, V_w (ft/s)	149.6	149.6	*1-hr mean at 10 m*
Wave, H_s (ft)	51.8	46.62	*For extreme wave*
Wave, T_p (s)	15.4	15.4	*Spectral peak period*
Current, V_c (ft/s)	5.93	5.93	*Surface speed*
Current, V_c (ft/s)	4.43	4.43	*Speed at mid-profile*
Zero V_c Depth (ft)	331	331	*0-speed depth.*

SCR CONFIGURATION

The 18" oil export SCR is terminated at the DeepDraft Semi™ through a flexible joint assembly hung off in the riser porch. Table 2 presents the key characteristics of the assumed oil export SCR.

It should be noted that this paper is to present a methodology that helps design other than to present a design itself. The SCR layout, environment and SCR configuration data presented are based on the best available information without losing generality.

Table 2. SCR Key Design Parameters

Parameter	Value
Steel Pipe Grade	X70
Outer Diameter (inch)	18
Wall Thickness (inch)	1.125
Departure Angle (deg)	14
Strake Length (ft)	8,600
Suspended Length (ft)	10,180
Horizontal Distance to TDP (ft)	5,360
Water Depth at TDP (ft)	8,000

ANALYSIS AND RESULTS

CORRELATION OF THE MAXIMUM SAGBEND STRESS TO THE MAXIMUM PORCH DOWNWARD SPEED

In order to explore the correlations of the sagbend peak stress to the porch downward speed, multiple three (3) hour duration time domain riser dynamic simulations are performed. For Scenario 1, as shown in Table 3, five (5) individual maximum von Mises stresses in the sagbend out of 10 realizations are located in the time trace windows around the time at which the first (1^{st}) maximum porch downward speed occurs respectively. Four (4) are associated with the time trace windows around the time at which the second (2^{nd}) maximum porch downward speed occurs respectively. One (1) is associated with the time trace window around the time at which the fourth (4^{th}) maximum porch downward speed occurs respectively. So for Scenario 1, the maximum sagbend stress from each realization can be found in the top four (4) time trace windows associated with the maximum porch downward speeds.

For Scenario 2, as shown in Table 4, seven (7) individual maximum von Mises stresses in the sagbends out of 9 realizations are located in the time trace windows around the time at which the first (1^{st}) maximum porch downward speed occurs respectively. Two (2) are associated with the time trace windows around the time at which the second (2^{nd}) maximum porch downward speed occurs respectively. So for Scenario 2, the maximum sagbend stress from each realization can be found in the top two (2) time trace windows associated with the maximum porch downward speeds.

The analysis validated the strong correlation of the maximum sagbend stress to the maximum porch downward speed.

To further illustrate the correlation, Figure 2 (a) shows the time history of the porch downward speed in Realization 6 of the scenario 1 in the event of the 100 year hurricane heading platform north. Figure 2 (b) shows the time history of the maximum von Mises stress in the SCR sagbend region in Realization 6 of the scenario 1 in the same event. The correlation of the maximum sagbend von Mises stress to the maximum porch downward speed is obvious.

Figure 3 (a) shows the time history of the porch downward speed in Realization 6 of the scenario 2 in the event of the 100 year hurricane heading platform northwest. Figure 3 (b) shows the time history of the maximum von Mises stress in the SCR sagbend region in Realization 6 of the scenario 2 in the same event. Again, the correlation of the maximum sagbend von Mises stress to the maximum porch downward speed is obvious.

TIME TRACE WINDOW BASED APPROACH

After the peak time associated with the peak of the sagbend von Mises stress is identified, a 200 second time trace window that contains the peak time can be selected. The starting and ending time of the window is recommended be such defined that the peak time is located at the 150 second of the window. This is to position the peak time far enough from the start of the time trace window. In other words, there are at least 100 seconds specifically arranged for the vessel to transit from the initial position to the targeted position. The length of the time trace window and the transition time will be discussed later.

Figure 4 compares the von Mises stress time histories obtained from the 200 second time trace window and three (3) hour time trace data for Realization 6 of Scenario 1. Two results match very well after the build up/transition period.

Figure 5 compares the von Mises stress time histories obtained from the 200 second time trace window and three (3) hour time trace data for Realization 6 of Scenario 2. Two results match very well after the build up/transition period.

TIME TRACE WINDOW WIDTH AND BUILD UP TIME

The width of the time trace window depends on two needs: [1] coverage of the peak time; [2] enough build up/transition time.

The peak porch downward speed may not necessarily occur at the same moment as the peak sagbend stress. There may be a phase difference of a few seconds, since it takes time for the motion at the riser porch to propagate to the touchdown point along the riser. To assure the window coverage, 10 seconds before and after the porch peak time is recommended. This requires a minimum window width of 20 seconds. In the practice, people may be interested in the riser response history for a period longer than 20 seconds. So it is recommended to expand the window width from 20 seconds to 100 seconds with the porch peak time at the center of the window.

In the window based approach, a build up/transition period to allow the vessel to transit from the initial position to the targeted position and from the initial static status to the targeted dynamic status. Numerically, this build up/transition process is to damp out the historical effect due to “false” start time.

Table 5 and figure 6 show the time trace window based results with different build up time for the realization 6 of Scenario 2. After the build up time reaches 80 seconds, the percentage difference between the window based result and the three hour simulation result drops down below 1%.

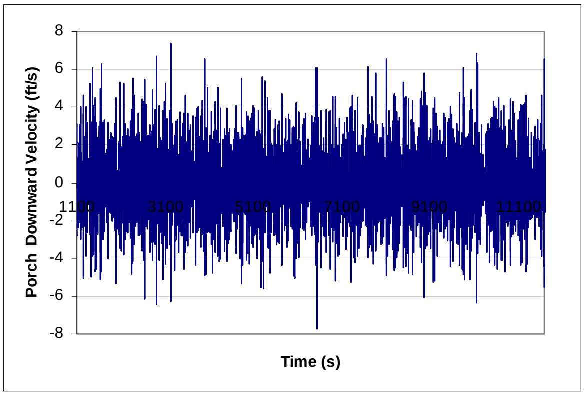
The length of build up time is associated with the memory effect of the vessel motion and length of the wave period. Usually the higher the sea state (thus the longer the wave period), the longer the build up time would be. In practice, a build up time of 100 seconds should cover almost all sea states.

Table 3. Scenario 1 SCR Sagbend von Mises Stress Correlation to Riser Porch Downward Speed

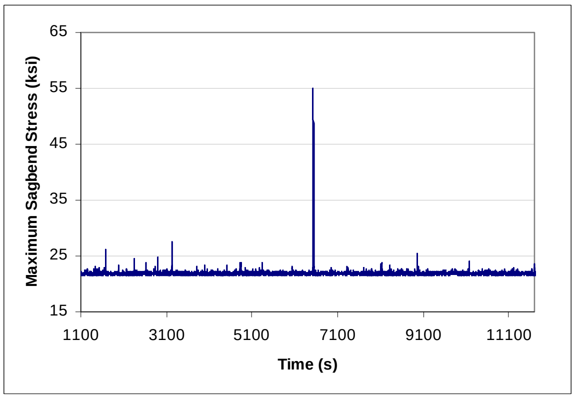
	Realization 1		Realization 2		Realization 3		Realization 4		Realization 5		Realization 6		Realization 7		Realization 8		Realization 9		Realization 10	
	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity
Unit	s	ft/s	s	ft/s	s	ft/s	s	ft/s	s	ft/s	s	ft/s	s	ft/s	s	ft/s	s	ft/s	s	ft/s
Window 1	7343.8	-6.40	7231.8	-6.06	8199.0	-7.29	5530.8	-7.37	2821.8	-6.35	6536.2	-7.70	7522.8	-7.33	11597.4	-6.27	8853.8	-7.07	4125.2	-6.97
Window 2	9187.8	-6.35	3920.2	-6.00	3752.4	-6.73	3803.0	-6.62	5712.6	-6.31	2904.6	-6.42	4494.4	-6.19	8344.0	-6.05	9442.6	-6.30	8539.4	-6.80
Window 3	11525.0	-6.14	9282.8	-5.69	9672.6	-5.72	3700.2	-5.84	3180.0	-6.09	10167.4	-6.33	2186.0	-5.87	10024.8	-6.03	2349.2	-5.91	3473.0	-6.72
Window 4	3713.8	-6.10	10942.6	-5.56	6231.4	-5.61	3373.0	-5.78	6882.2	-5.72	3220.8	-6.26	5264.4	-5.74	1671.2	-5.94	6143.6	-5.73	10781.6	-6.36
Window 5	9052.2	-6.04	1785.2	-5.48	11128.4	-5.38	9419.8	-5.57	9833.0	-5.63	2632.6	-6.14	5713.0	-5.54	9698.4	-5.86	5861.2	-5.67	8870.8	-6.15
	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress
Unit	s	ksi	s	ksi	s	ksi	s	ksi	s	ksi	s	ksi	s	ksi	s	ksi	s	ksi	s	ksi
	9165.0	25.86	3920.2	25.87	8199.0	31.74	5531.0	30.12	6894.4	25.18	6536.6	55.05	4494.2	24.94	11597.2	42.19	9442.2	28.42	4124.8	26.55

Table 4. Scenario 2 SCR Sagbend von Mises Stress Correlation to Riser Porch Downward Speed

	Realization 1		Realization 2		Realization 3		Realization 4		Realization 5		Realization 6		Realization 7		Realization 8		Realization 9	
	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity
Unit	s	ft/s	s	ft/s	s	ft/s	s	ft/s	s	ft/s	s	ft/s	s	ft/s	s	ft/s	s	ft/s
Window 1	3713.8	-6.40	3920.2	-6.06	8199.2	-7.29	5530.8	-7.37	2821.6	-6.35	6536.2	-7.70	7523.0	-7.33	11597.4	-6.27	8854.0	-7.07
Window 2	7343.6	-6.35	7231.8	-6.00	3752.4	-6.73	3803.2	-6.62	6882.4	-6.31	2632.6	-6.42	4494.6	-6.19	1671.2	-6.05	9442.8	-6.30
Window 3	11525.2	-6.14	9282.6	-5.69	6231.4	-5.72	3700.2	-5.84	3180.0	-6.09	3220.8	-6.33	5264.4	-5.87	10024.8	-6.03	2388.2	-5.91
Window 4	10447.8	-6.10	9965.0	-5.56	11128.6	-5.61	3373.0	-5.78	5712.8	-5.72	2904.6	-6.26	5713.2	-5.74	8343.8	-5.94	6785.0	-5.73
Window 5	9052.0	-6.04	10942.6	-5.48	6020.2	-5.38	9668.0	-5.57	9303.2	-5.63	10167.6	-6.14	2186.0	-5.54	2107.2	-5.86	6143.0	-5.67
	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress	Time	Sagbend Stress
Unit	s	ksi	s	ksi	s	ksi	s	ksi	s	ksi	s	ksi	s	ksi	s	ksi	s	ksi
	3713.6	24.95	7231.6	23.69	8199.2	27.75	5531.0	29.00	2821.6	23.83	6536.6	42.06	4494.6	23.43	11597.4	29.50	8853.8	26.25



(a) Porch Downward Speed in Realization 6



(b) Maximum Sagbend von Mises Stress in Realization 6

Figure 2. Scenario 1 Sagbend Maximum von Mises Stress Correlation to Porch Downward Speed with 100 Year Platform North Heading Hurricane

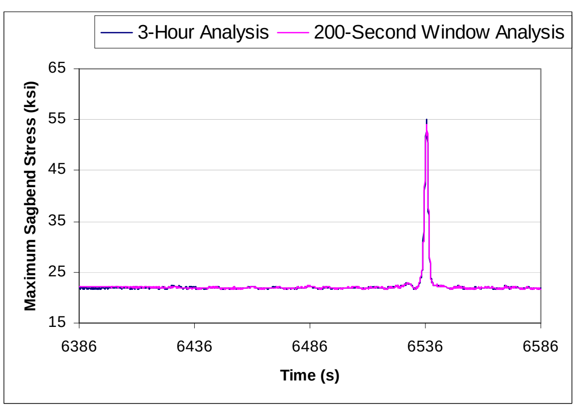
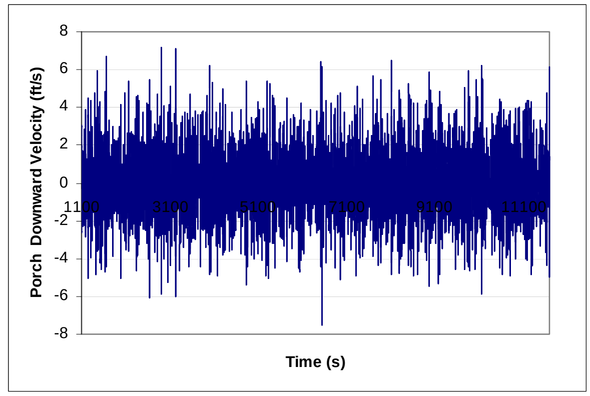
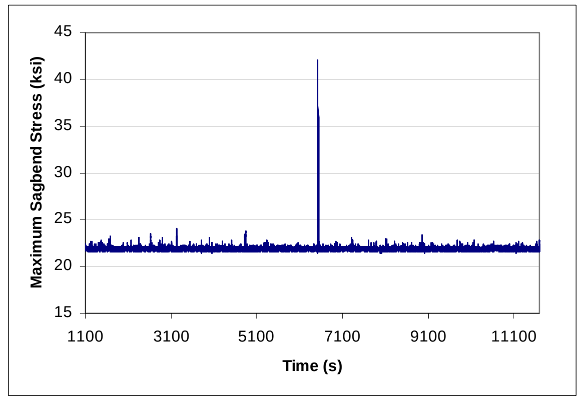


Figure 4. Results Comparison – 200 Second Window vs. 3 Hour Simulation with 100 Year Platform North Heading Hurricane for Realization 6 of Scenario 1



(a) Porch Downward Velocity at Realization 6



(b) Maximum Sagbend von Mises Stress in Realization 6

Figure 3. Scenario 2 Sagbend Maximum von Mises Stress Correlation to Porch Downward Speed with 100 Year Platform Northwest Heading Hurricane

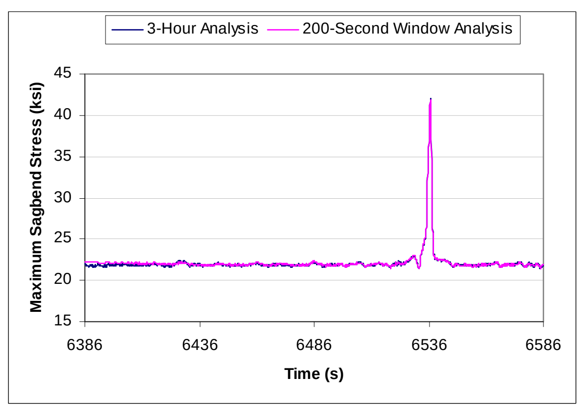


Figure 5. Results Comparison – 200 Second Window vs. 3 Hour Simulation with 100 Year Platform Northwest Heading Hurricane for Realization 6 of Scenario 2

Table 5. Sensitivity Study to Build up Time for Realization 6 of Scenario 2

Build up Time	Maximum Sagbend Stress from Three Hour	Maximum Sagbend Stress from Window	Percentage Change from Three Hour Simulation
(s)	(ksi)	(ksi)	
20	42.06	47.18	12.18%
30	42.06	45.13	7.31%
40	42.06	44.27	5.26%
50	42.06	43.61	3.69%
60	42.06	43.32	3.00%
70	42.06	42.53	1.11%
75	42.06	42.71	1.54%
80	42.06	42.26	0.47%
90	42.06	42.14	0.18%
100	42.06	41.99	-0.17%

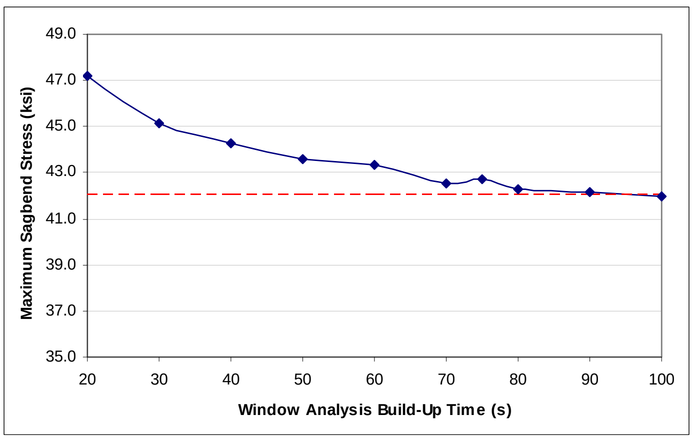


Figure 6. Sensitivity Study to Build up Time for Realization 6 of Scenario 2

DISCUSSIONS

TIME TRACE DATA

The vessel time trace data can be generated using commercial and/or in-house software through different approaches. One approach to produce the vessel motion data is to utilize the first-order vessel response amplitude operators (RAOs) along with the user specified second-order vessel motion using riser specialty software such as Flexcom and Orcaflex. The other more accurate approach is to use coupled time-domain software to simulate vessel motion. For semi floating production unit (FPU) in the deepwater, the latter approach is more reliable in the SCR analysis as the riser touch down response is very sensitive. With the time trace data ready, the porch downward speeds can be obtained applying the rigid body principles using the riser specialty software or spreadsheets.

APPLICATION CONDITIONS

The screening methodology proposed to screen the occurrence time for the peak SCR sagbend stress is applicable to the SCR hang-off to the DeepDraft Semi^{TM} or semi with application in the deep/ultra deep water of the GoM. Though the validity to the other type of vessels such as Spar, TLP and FPSO in the GoM and other regions of the world is not yet explored, the proposed window based approach should be in principle applicable. In addition, when SCR is in its slack position, the correlation is stronger.

However, the window based approach may underestimate the structure strain if plastic deformation has occurred before the time trace window is assessed unless this precondition/previous plastic deformation is captured/modeled in the analysis.

For the window based approach, we believe it is applicable to any type of the vessel and any region of the water in the world.

OTHER APPLICATION

So far the application of the proposed window based approach targets the SCR strength analysis only. For the wave induced SCR fatigue analysis, usually the wave scatter diagram was condensed to a large number of representative sea states such as 100. Usually the vessel motion time history includes over 100 sea states with each sea state containing three (3) hours of first order wave and slow drift motion data provided by vessel designer/maintainer or generated by the users.

To reduce computer resources, our experience and sensitivity study shows that sixty (60) minute window chosen for each time history file of the corresponding sea state can generate wave fatigue analysis results within 10% difference to those obtained from three (3) hour simulations. The starting and ending time of each sea state shall be the same. It is recommended that windows start at 60 minutes and end at 120 minutes.

It should be mentioned that random seed for each fatigue sea state shall be varying to avoid the biased results.

IDENTIFICATION OF PEAK TIME USING OTHER METHODS

There exist many other methods to identify the occurrence time for the maximum sagbend stress. For example, the offshore design often progresses iteratively, i.e., there will be several rounds of analyses to be performed before the final design will be concluded. After initial round of analysis utilizing three (3) hour simulation, the time associated with the maximum sagbend stress or other interested parameters are identified. For the following rounds of the analysis, the window containing the time identified can be used for the strength analysis unless the vessel motion data is regenerated or significant changes to the riser design compared to what it was in the previous three (3) hour simulation are made.

CONCLUSIONS

The paper presents the methodology that significantly reduces the computer simulation time without compromising the analysis accuracy for the strength analysis of the SCR attached to the DeepDraft Semi™ in the deep/ultra deepwater of the GOM.

The methodology builds on time traces of the host vessel motions, and the correlation between the vessel/porch motion and the SCR sagbend response. Generally the maximum riser sagbend stress occurs when the wave pushes the vessel, then the riser porch toward its touchdown point (slack position). One vessel/porch motion characteristics - the downward speed at the riser porch dominates the SCR sagbend response. By screening the downward speeds at the riser porch under slack condition, the time at which the sagbend response (stress/strain/buckling) peaks is identified. A time trace window with length of 200 seconds and peak time located at 150 seconds is selected. The dynamic analysis based on the time trace window will capture the maximum sagbend stress and saves the computer time up to 95% of the three (3) hour simulation.

There exist other methods to determine the stress peak time, and with the stress peak time ready the following window based approach will be the same. The window based approach is especially important for the very complicated riser system such as pipe-in-pipe SCR, where the more time consuming general purpose software such as ABAQUS is required.

ACKNOWLEDGEMENTS

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REFERENCES

American Petroleum Institute, "Interim Guidance on Hurricane Conditions in the Gulf of Mexico", API BUL 2INT-MET, May 2007.

American Petroleum Institute, "Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs), API RP 2RD, 1st Edition, June 1998. Reaffirmed, May 2006.