PITCH DAMPING RATIOS OF JACKUPS WITH VARYING DEPLOYED LEG LENGTHS

by
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ABSTRACT
While there is still no standard methodology for the analyses of jackups in the transition from afloat to elevated mode (often referred to as the Going on Location, Installation or Emplacement phase), it is envisioned that all such analyses will start with the free-floating response of the jackups. Given that most jackups have natural periods for roll/pitch that range from 8sec to 18sec range, and the fact that diffraction analysis does not capture viscous damping effects, all analyses become sensitive to the amount of "external damping" used in the response model.

This paper presents the results from a study that uses Smoothed Particle Hydrodynamics (SPH) to establish the effective pitch damping ratios of two jackups at their loadline drafts with legs at different deployed positions. The results from the SPH models are compared against those from Linear Diffraction Analyses to confirm the two methodologies produce comparable natural periods. Both the SPH and diffraction models focus on the hull and spudcans and ignore the truss part of the legs, as the truss members are too small to be properly accounted for in these models.

For each of the two jackup models, four Tip of Can (ToC) positions are considered. The results show that pitch damping ratios increase significantly as the ToC moves further and further below Hull Baseline (HBL), reaching values well in excess of 10%.

KEY WORDS: Jackups, Free-Floating, Going on Location, Damping, SPH.

INTRODUCTION AND BACKGROUND

The industry has recognized a need for improved capabilities of jackups during the transition phase for several years now, as conservative limitations have led to unnecessary delays in waiting on weather and higher costs. The transition phase refers to going from the afloat to the elevated mode and is often referred to as installation or emplacement of the jackup (commonly referred to as "going on location"). Typical solutions have centered around advanced analysis techniques to get a better understanding of the true capabilities of the jackup. These advanced analysis techniques have proven successful in reducing waiting on weather [Ref 1].

Uncertainties still exist within the advanced analysis techniques including quantifying the external damping for the jackup in the free-floating condition. Currently, potential flow theory is typically used for determining the response of the jackup. However potential flow does not capture the viscous damping effects. Proper definition of the amount of critical damping is necessary in defining the proper response of the jackup in numerical simulations as the roll/pitch natural periods for jackups typically fall within the excitation periods of the encountered waves.

Smoothed Particle Hydrodynamics (or "SPH") offers a tool for defining the critical damping values for a jackup. SPH is a flexible Lagrangian and mesh-less technique for computational fluid dynamics [Ref 2]. The Lagrangian reference frame of SPH makes it useful in solving problems with large deformations and distorted free surfaces. Specifically, the tool DualSPHysics [Ref 10] is used to perform the SPH analyses documented herein.

The DualSPHysics code originates from SPHysics, which is an open-source SPH model developed by researchers at various universities [Ref 7]. The default Dynamic Boundary Condition (DBC) method provided in DualSPHysics is utilized for modeling the floating body, in this case the jackup. The movement of the jackup is derived from the summation of force contributions from the fluid particles. By assuming that the jackup is a rigid body, the net force on each boundary particle is computed according to the sum of the contributions of all surrounding fluid particles according to the designated kernel function and smoothing length.

Bouscasse, Colagrossi, Marrone, & Antuono [Ref 3] presented successful validations of nonlinear water wave interaction with floating bodies in SPH compared to experimental data including the movement of those objects during the experiment (heave, surge and roll displacements). It was further shown that DualSPHysics was able to achieve close agreement with experimental results for the free decay tests of floating bodies. Verbrugghe, Devolder, Domínguez, Kortenhaus, & Troch [Ref 6] performed a simulation of a free decay test of a heaving cylinder lying on its side. Both the medium and fine particle density models by Verbugghe et al were shown to have strong agreement with the experimental data.

VESSEL PARTICULARS

Two Valaris jackups are utilized in this study, the VALARIS 109 (JU-109) and the VALARIS NORWAY (JU-292). The VALARIS 109 jackup is a medium-sized jackup with one of the most popular leg spacings in the industry (142ft X 129ft). The VALARIS NORWAY was selected for its much larger size and its somewhat unique spudcan shape. The dimensional particulars for each jackup are shown in Table 1 [Ref 12, 13].

Table 1 - Jackup Particulars

Parameter		**VALARIS 109**	**VALARIS NORWAY**
Length	ft	246	264
Breadth	ft	218	289
Hull Depth	ft	25	35
Transverse Leg Spacing	ft	142	206
Longitudinal Leg Spacing	ft	129	177
Leg Length	ft	486	568
Load Line Draft	ft	16	24

Analyses were carried out for the units having the legs with their Tip of Can (ToC) deployed to different lengths below the hull base line (HBL). For all cases, it was assumed that the units were freely floating at loadline draft, with the spudcans filled with water. As such, all cases have the same displacement (36,961k for the VALARIS 109 unit and 84,801k for the VALARIS NORWAY unit), but they do have different VCG and radius of gyration values depending on ToC, as given in Table 2. Table 2 also shows the water depth used (for both the SPH and diffraction analysis models).

The effects of the proximity of the ToC to the seabed on the damping is intentionally excluded from this study. Thus, an acceptable distance (minimum 80ft) between the ToC position and the seabed (or tank bottom) is maintained for all analyses to minimize these effects. A constant 328.1 (100m) water depth was used for all cases that had a ToC position under 200ft below HBL. For the cases with ToC even lower than 200ft below HBL, the water depth was increased in increments of 20 or 10m. As such, the other three water depths used are 393.7ft (120m), 459.3ft (140m) and 4592.1ft (150m).

Table 2 - Key Parameter Values by ToC Position for both Units

Parameter	VALARIS 109				VALARIS NORWAY			
ToC below HBL (ft)	55.0	155.0	255.0	355.0	72.0	180.0	289.0	397.0
VCG (ft ABL)	49.0	19.0	-11.0	-40.0	52.0	11.0	-30.0	-70.0
GML (ft)	190.0	213.0	235.0	257.0	154.0	186.0	218.0	250.0
R_{yy} (ft)*	120.0	112.0	129.0	163.0	143.0	147.0	178.0	224.0
Water Depth (ft)	328.1	328.1	393.7	459.3	328.1	328.1	393.7	492.1

* R_{yy} value about CG

DIFFRACTION ANALYSES

Prior to analyzing the units using the SPH approach, the units were analyzed using linear, frequency-domain diffraction analyses. The primary purpose for these analyses in the context of this paper is to identify the natural periods of the units for the cases considered. The second purpose for the diffraction analyses, which are based on potential theory and therefore ignore all viscous effects, is to establish the amount of added damping at the natural periods and show the sensitivity of the pitch response to the amount of "external" damping.

The diffraction analyses were carried out using WAMIT, a commercially available software package commonly used in the industry [Ref 11]. Figures 1 through 3 show representative models for the two units.

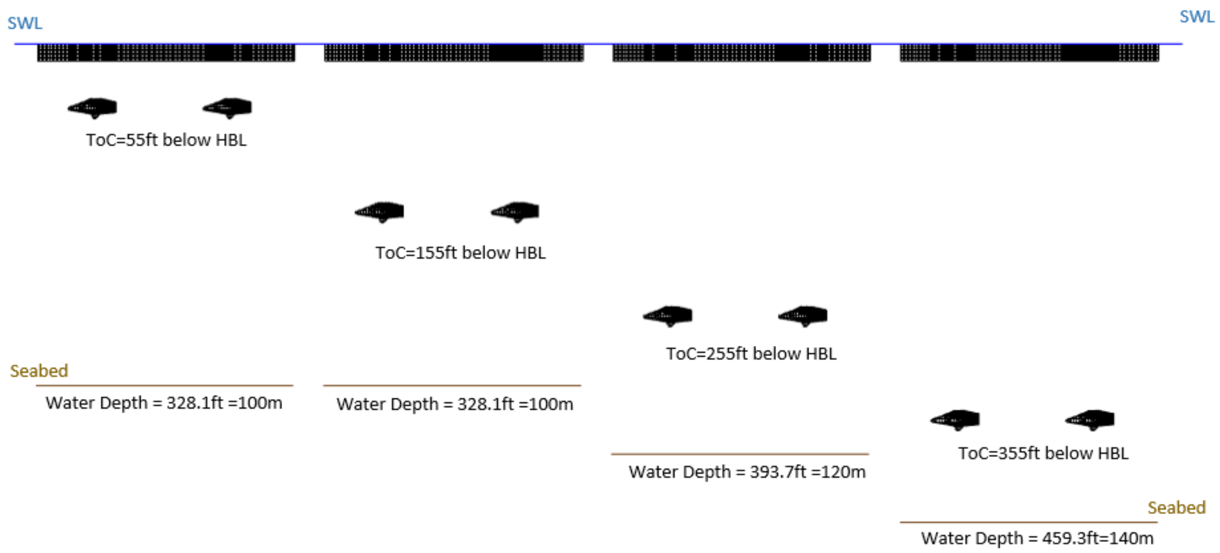

Figure 1 - Hydrodynamic Models for VALARIS 109 Showing ToC and Water Depth Values

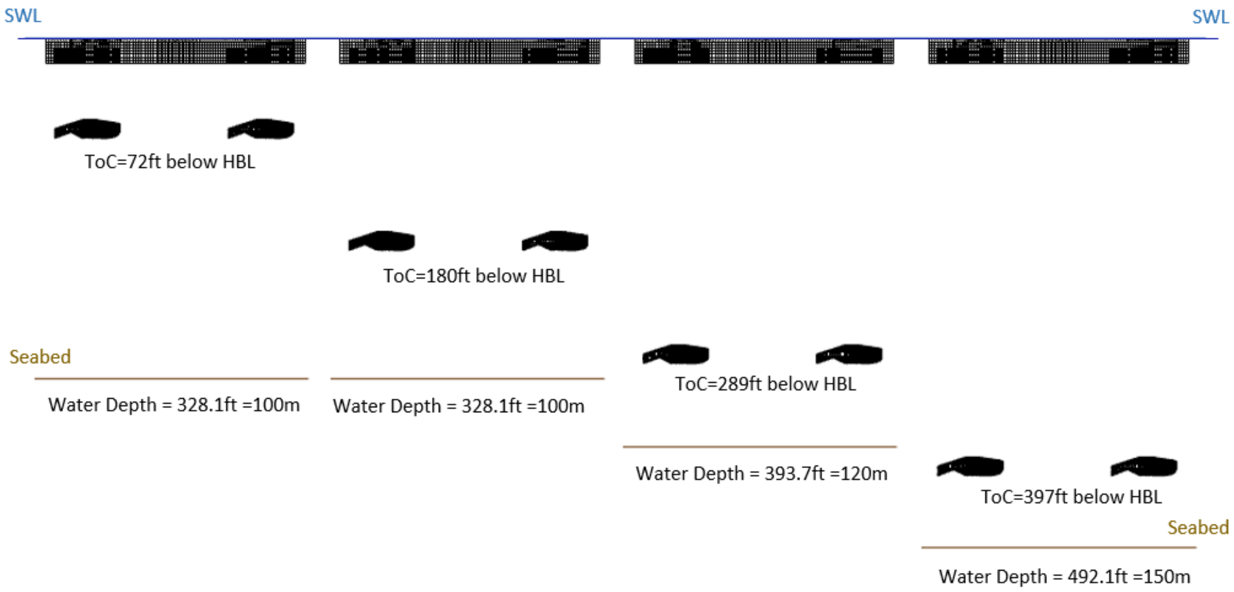

Figure 2 - Hydrodynamic Models for VALARIS NORWAY Showing ToC and Water Depth Values

As can be seen in Figures 1 through 3, the models used for the diffraction analyses ignore the truss part of the legs. This is common practice, as the leg components are not large enough to be significant diffraction components, especially for waves with periods greater than 10 sec.

Due to symmetry, half-models were used. As discussed, the diffraction models do not include the legs themselves, only the hull and spudcans. The models have their origin at the geometric center of the legs, at the SWL.

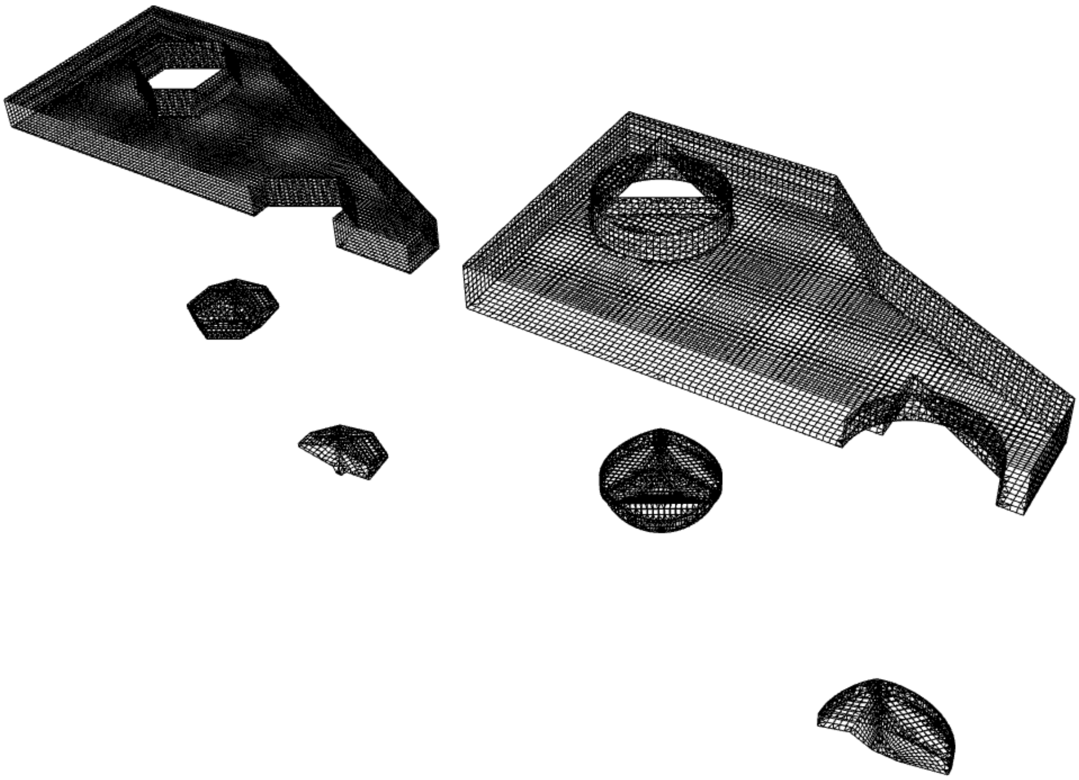

Figure 3 - Hydrodynamic Models of Both Units at Intermediate ToC Positions

The heave and pitch motion RAOs are shown in Figures 4 and 5 for the VALARIS 109 jackup and Figures 6 and 7 for the VALARIS NORWAY jackup, for all cases considered. These RAOs are for zero external damping (in all modes). From these motion RAO plots, several observations can be made, as outlined below.

1. Pitch response is sensitive to ToC position (since at different ToC positions, the VCG and Moment of Inertia values are noticeably different, producing pitch natural periods that differ by about 3 seconds).

2. Other than the effects of pitch resonance, Heave response is not sensitive to ToC position.

3. The Heave RAO plots show “bumps” or “spikes,” which correspond to the pitch natural periods. The heave natural period is not explicitly discernable in the RAO plots. This is because there is a large amount of heave added damping, even without accounting for viscous effects. For this reason, the focus of this study is only on pitch damping.

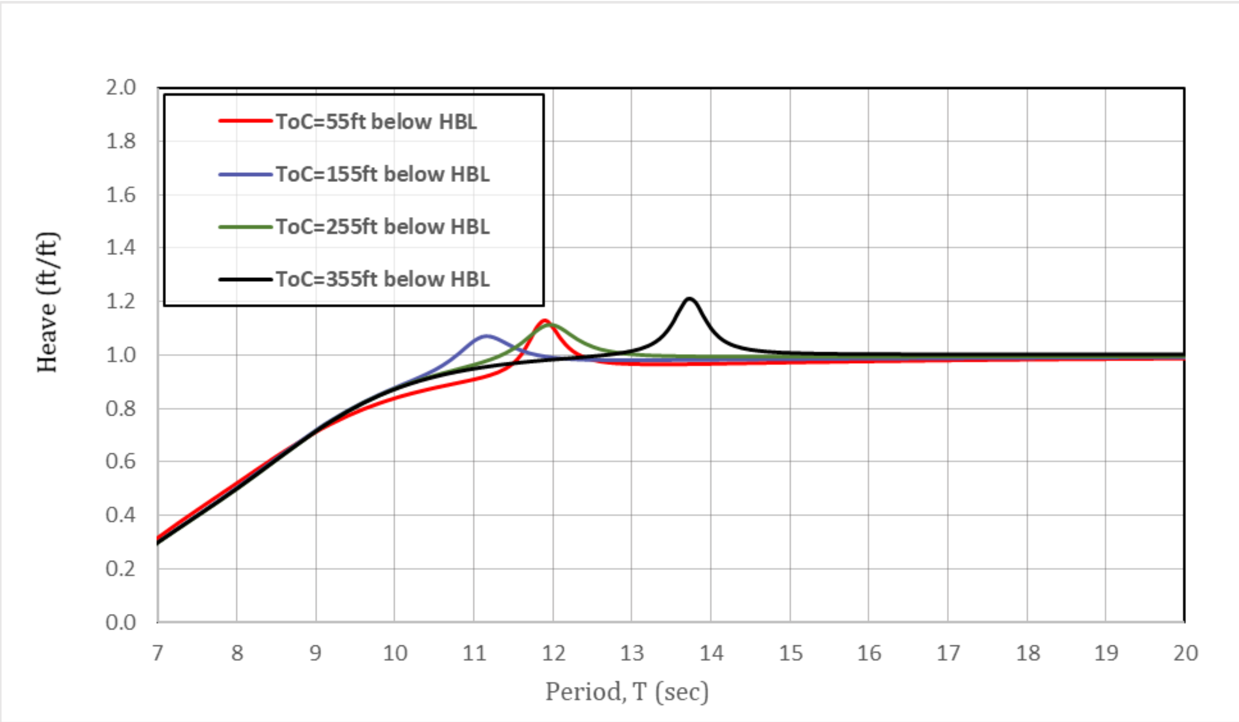

Figure 4 - Heave Motion RAOs for VALARIS 109 Unit (with Zero External Damping)

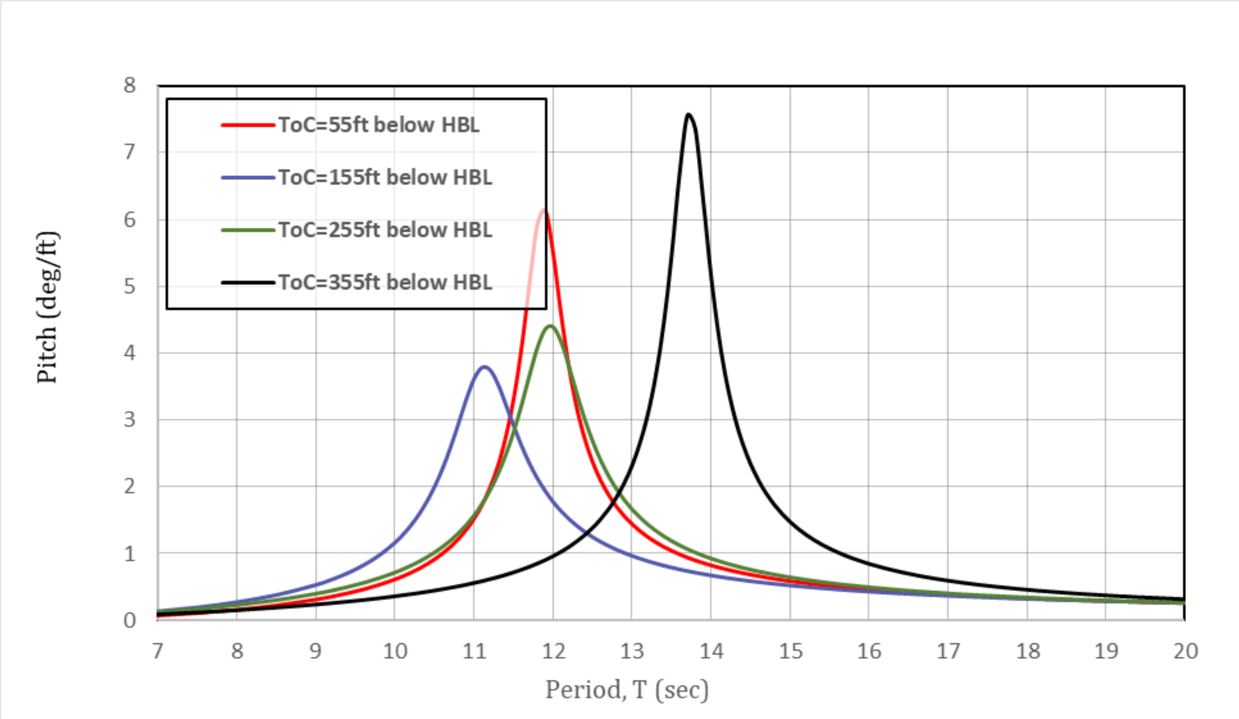

Figure 5 - Pitch Motion RAOs for VALARIS 109 Unit (with Zero External Damping)

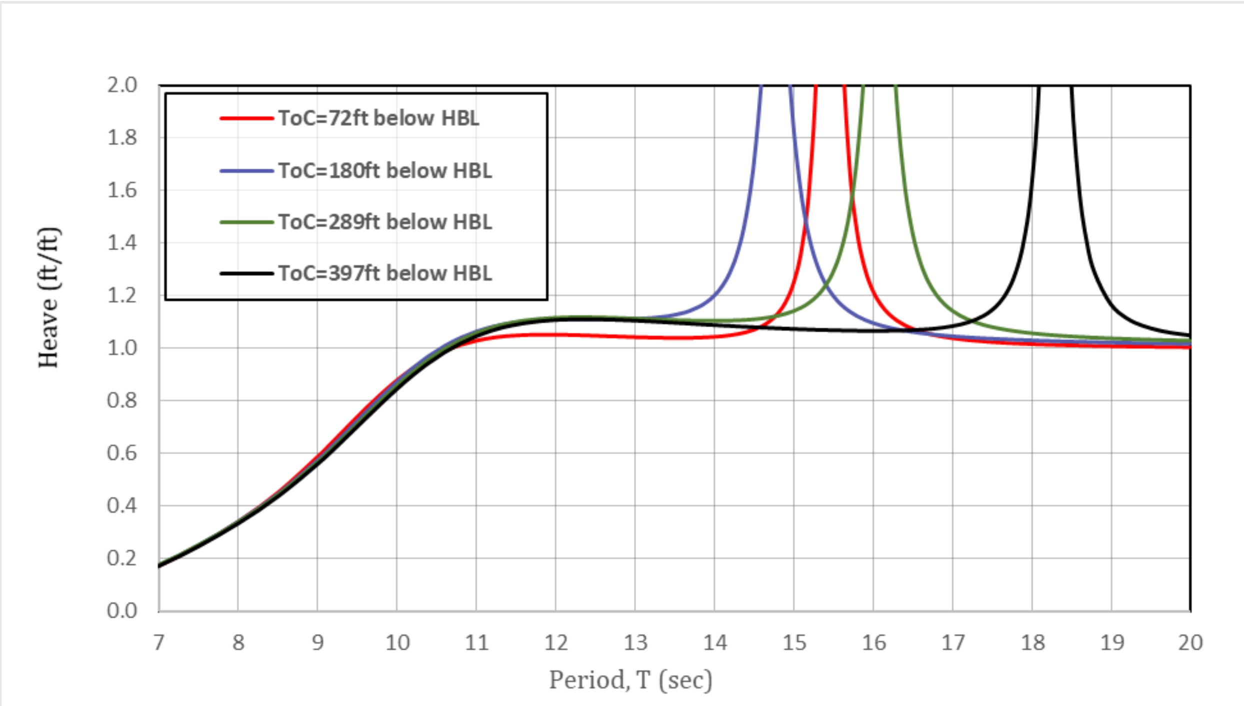

Figure 6 - Heave Motion RAOs for VALARIS NORWAY Unit (with Zero External Damping)

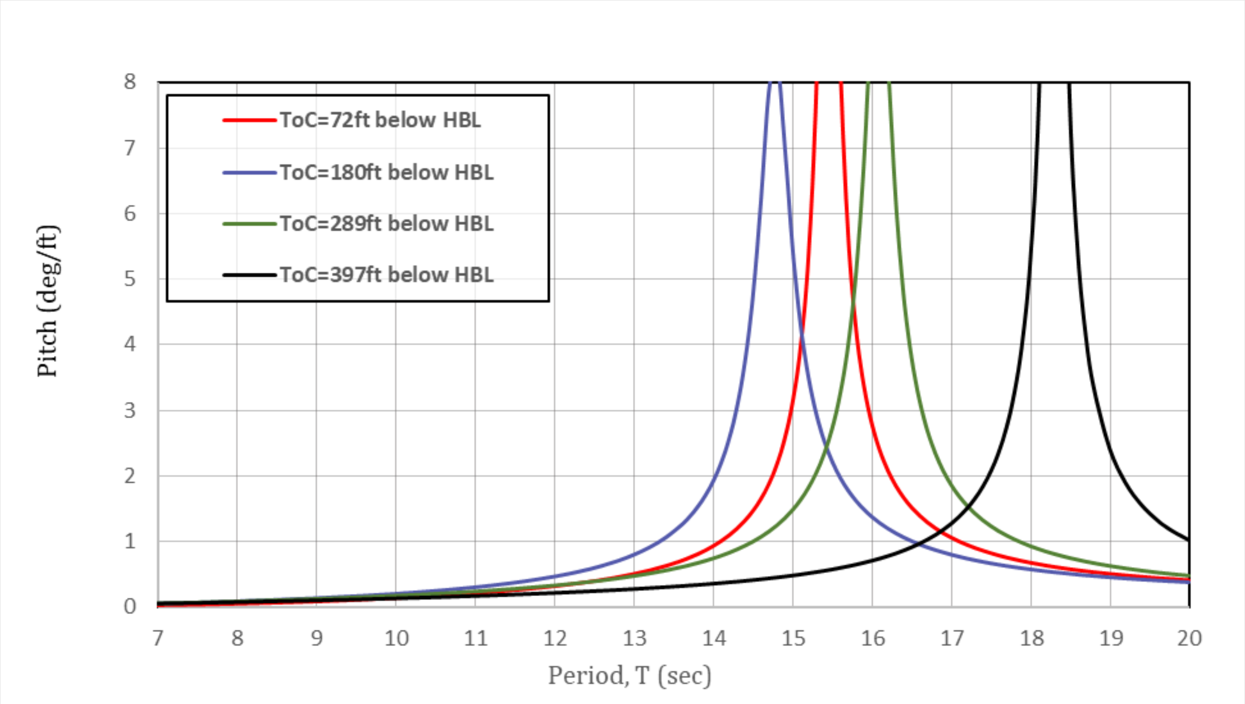

Figure 7 - Pitch Motion RAOs for VALARIS NORWAY Unit (with Zero External Damping)

SPH ANALYSES

Free decay simulations were run using the Windows GPU implementation of DualSPHysics v5.0.140 [Ref 10]. All simulations were run using full-scale models of the jackups, with a particle density of 2.6ft and unit weight of water of 64lb/ft^3. Tanks with sloping sides were utilized for the analyses to reduce wave reflection from the boundary. In all cases, the top basin dimensions are 1,312.3ft (400m) in width X 1,968.5ft (600m) in length. All models have an initial pitch rotational velocity of 0.1 rad/sec. Simulation time was 45 sec (sufficiently long to have at least two full oscillations). Figures 8 and 9 show SPH models for the two jackups for intermediate water depth cases. The models are shown with and without the fluid particles.

It is noted that the truss portions of the legs are not included in the SPH models. The reason for this is the relatively small size of the brace and chord members for these units when compared against the model's particle density of 2.6ft. Since the truss portion of the legs will introduce additional drag to the system, ignoring them is expected to produce conservative damping ratios.

Table 3 - SPH Model Particulars

Parameter	VALARIS 109				VALARIS NORWAY			
ToC below HBL (ft)	55.0	155.0	255.0	355.0	72.0	180.0	289.0	397.0
Water Depth (ft)	328.1	328.1	393.6	459.3	328.1	328.1	393.7	492.0
Basin Width – Bottom (ft)	656.2	656.2	656.2	656.2	656.2	656.2	656.2	853.0
Basin Length – Bottom (ft)	656.2	656.2	656.2	656.2	656.2	656.2	656.2	853.0
Basin Depth (ft)	426.5	426.5	492.1	557.7	426.5	426.5	492.1	590.6

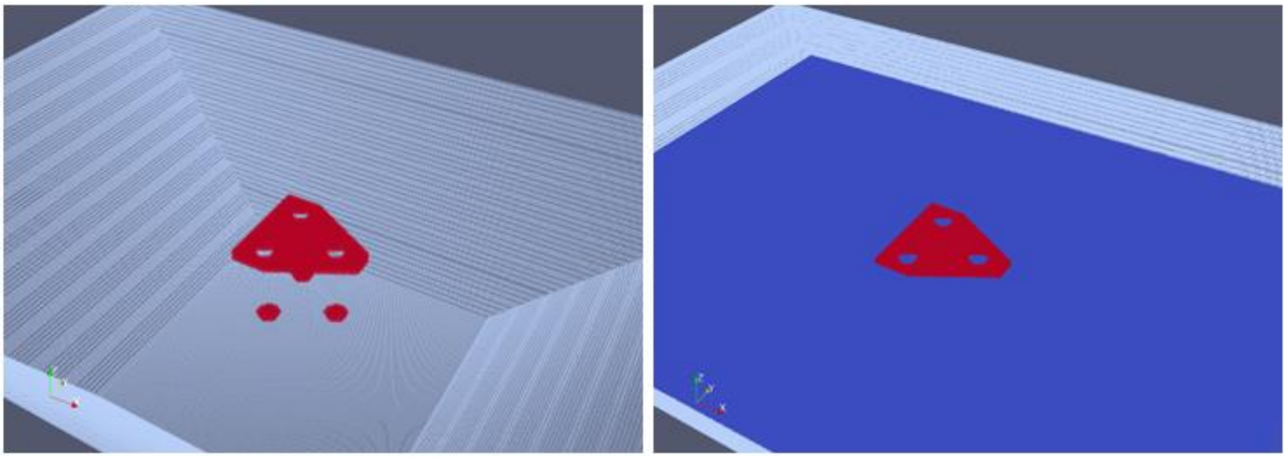

Figure 8 - SPH Models for VALARIS 109 Jackup with ToC = 155ft below HBL

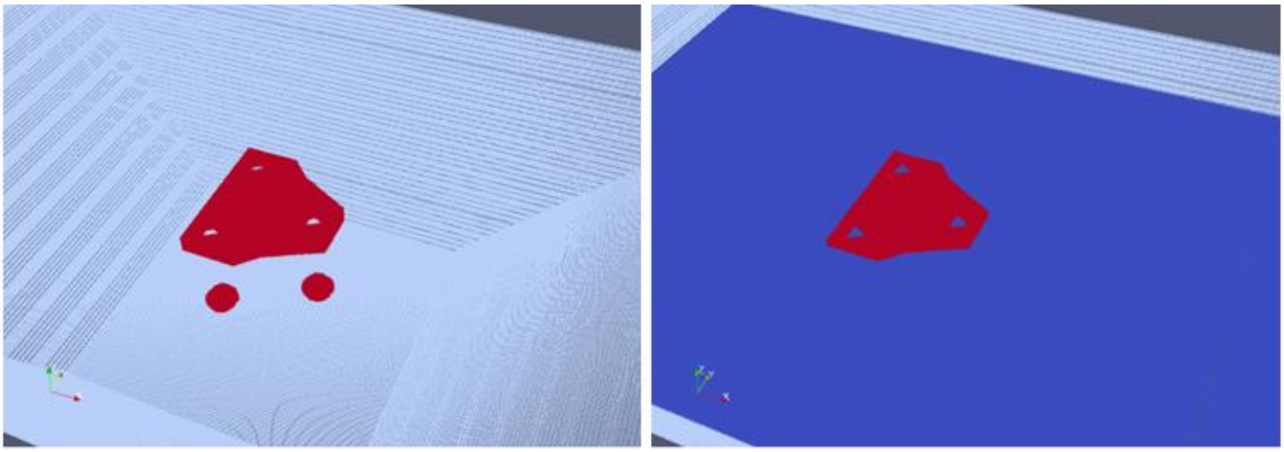

Figure 9 - SPH Models for VALARIS NORWAY Jackup with ToC = 180ft below HBL

The DualSPHysics models utilized the artificial viscosity approach proposed by Monaghan [Ref 2] and a density diffusion formulation proposed by Monteni and Colagrossi [Ref 5]. A value of 0.01 for the alpha coefficient in the artificial viscosity scheme has been shown to produce the best results in validation testing of wave flumes [Ref 8]. The diffusive term was set at δ=0.1, as recommended by DualSPHysics for most applications.

The critical damping value is estimated using the equations given by Clough [Ref 9] as shown below:

$$\theta = \theta_0 e^{-\xi\omega t} \qquad \text{Eqn (1)}$$

where, θ = Response Angle,
θ_o = Initial Rotation,
ξ = Damping Ratio,
ω = Damped Natural Circular Frequency and
t = Time

RESULTS OF SPH SIMULATIONS FOR PITCH DECAY TEST

The results of the pitch free decay tests for the VALARIS 109 and VALARIS NORWAY jackups are presented in this section. Figures 10 and 11 show the pitch oscillation time traces for all cases considered. From those time-traces, (damped) natural periods and damping ratio (ξ) values were determined. It is noted that the since the SPH simulations were carried out by introducing a rotational velocity instead of starting from a zero-velocity condition and a specified rotation, the time traces were shifted to resemble the form of Equation 1 before calculating the damped natural period and the damping ratio.

Plots of the fluid velocities for the free-decay simulation of the VALARIS 109 with a ToC of 55ft below HBL are shown in Figure 12. The plots are for the particles along a plane at centerline of the 3D model, and represent the troughs, peak, and zero-crossings of the first cycle.

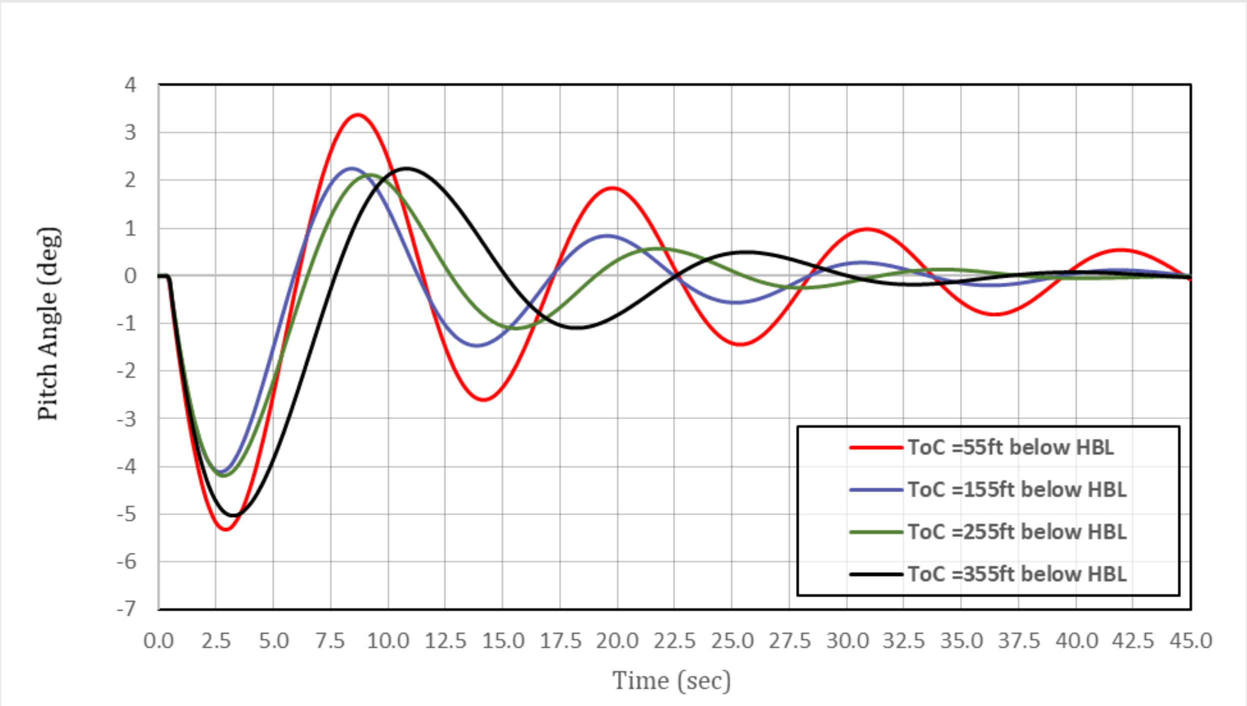

Figure 10 - Pitch Time Trace (Decay Test) for VALARIS 109 Unit

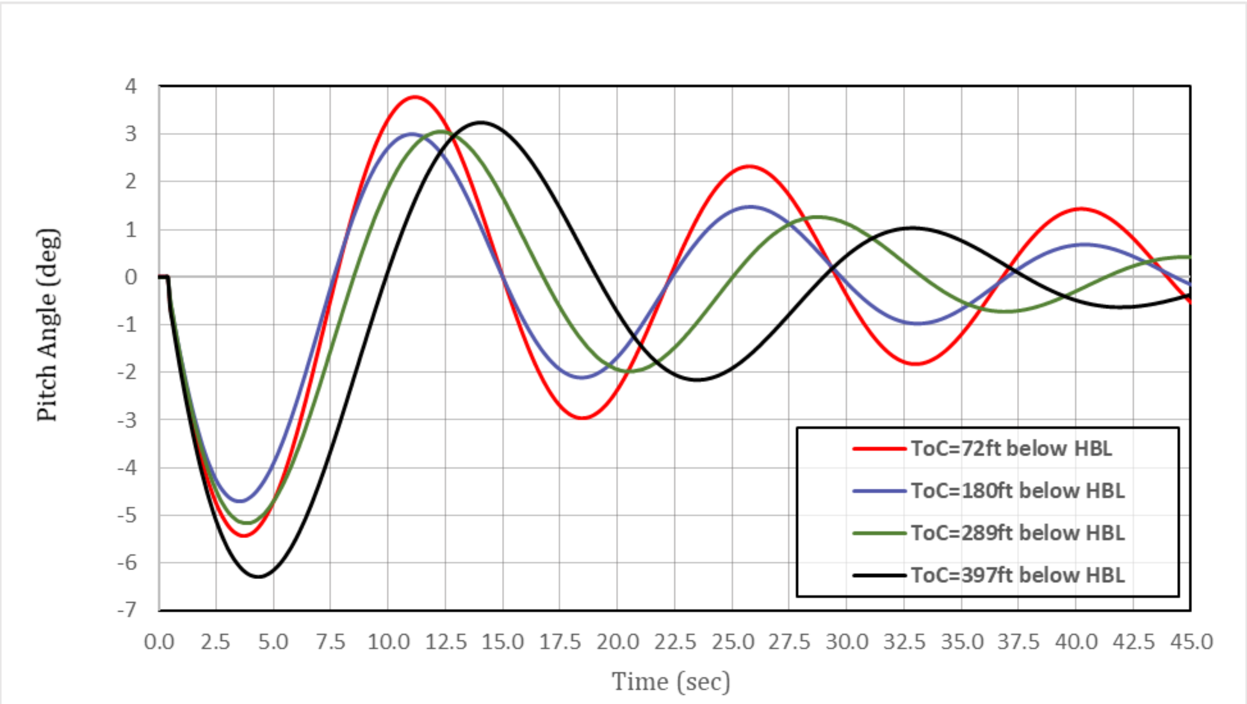

Figure 11 - Pitch Time Trace (Decay Test) for VALARIS NORWAY Unit

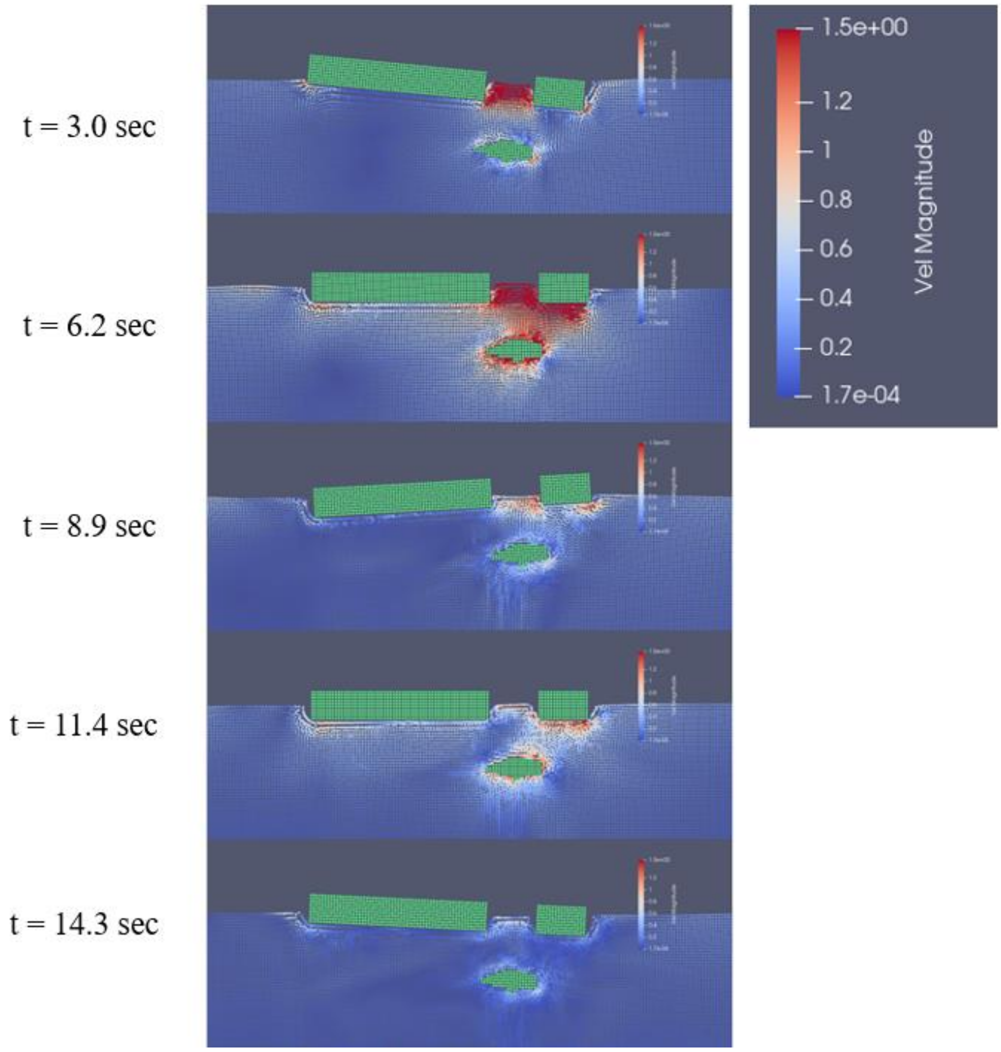

Figure 12 – Fluid Velocity (m/s) Plots at Centerline of VALARIS 109 Unit, ToC = 55ft below HBL

The natural period and calculated critical damping values are given in Table 4. For quick comparison, Table 4 also includes the Pitch Natural Periods and Added Damping Values from the diffraction analyses.

Table 4 - Pitch Natural Periods and Damping Ratios

Unit	ToC below HBL (ft)	Pitch Natural Period (sec)		Pitch Damping Ratio	
		SPH	Diffraction Analysis	SPH	Diffraction Analysis*
VALARIS 109	55	11.1	11.9	9.7%	3.6%
	155	11.2	11.1	15.8%	4.4%
	255	12.6	12.0	22.2%	2.8%
	355	14.7	13.7	26.4%	1.3%
VALARIS NORWAY	72	14.5	15.5	8.0%	2.1%
	180	14.6	14.8	12.3%	2.5%
	289	16.4	16.1	15.7%	1.6%
	397	18.8	18.3	18.3%	0.8%

*Note that these damping ratios may not be 100% applicable, as they reflect only the pitch-induced-pitch added damping component, as obtained from the Radiation Analysis modeling which reports these values about the origin (at the center of the legs, at the SWL, not the CG). Also, since there are slight differences in the natural periods from the SPH modelling and the Diffraction Analysis modelling, the critical damping values, which are calculated as $C_{cr} = 2k/\omega$, where k is the pitch rotational stiffness and ω is the pitch natural frequency, are slightly different. These differences are relatively small, though.

The damping ratios plotted by ToC position are shown in Figure 13 for both jackups. Figure 13 indicates that the total damping ratios for pitch for both jackup units, as determined from the SPH analyses, increase almost linearly with ToC position.

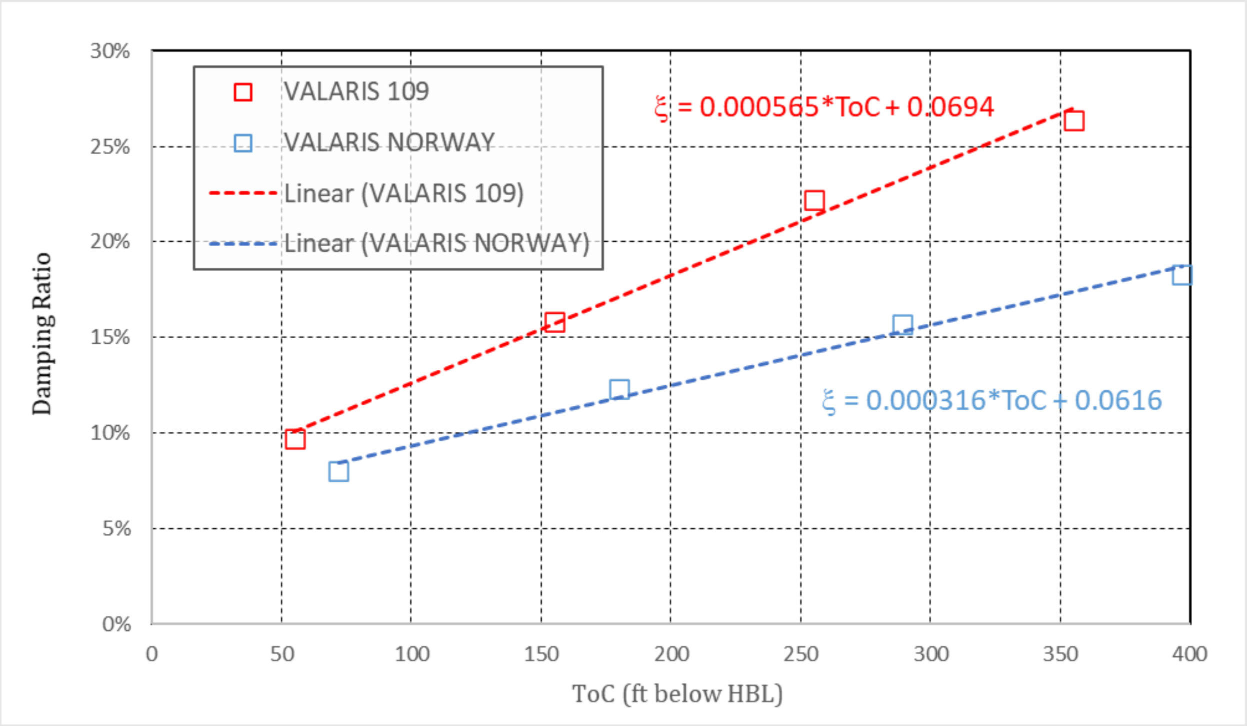

Figure 13 – Variation of Pitch Damping Ratios with ToC

OBSERVATIONS

From the results presented in the previous sections, the following observations can be made.

1. Pitch damping ratios increase almost linearly with ToC position.

2. Extrapolating the results to ToC=0 (i.e., the case with the legs fully retracted) would predict damping ratios of 6.2% for the VALARIS NORWAY unit and 6.9% for the VALARIS 109 unit (as taken from the intercept of the trend-lines in Figure 13). SPH simulations for the case with the legs fully retracted produced damping ratios of 5.9% and 7.1%, respectively.

3. The pitch damping ratios for the VALARIS 109 unit (the smaller of the two units analyzed in this study) are noticeably higher than those for the VALARIS NORWAY unit. Re-examining the results, it is noted that when comparing damping values, as opposed to damping ratios, the two units have the same amount of damping at ToC = ~220ft, but both the damping coefficient and the damping ratio increases more rapidly with ToC for the smaller of the two units. The damping values per ToC position are shown in Figure 14. It is also noted that an exponential increase in the pitch damping coefficients with increasing ToC position is evident in Figure 14.

4. From Figure 14, it is evident that the extrapolated coefficients at a ToC of 0ft are higher for the VALARIS NORWAY than those of the VALARIS 109. This is in line with the expectation that the hulls with larger perimeter would produce larger amounts of viscous damping.

5. The calculated natural periods from the SPH and Diffraction Analysis models are close but differences up to 7% were observed.

6. Given that the larger differences in natural periods from the SPH and Diffraction Analyses are for cases where the VCG was furthest from the center of floatation, it is likely that the linearized form of the stiffness matrix is at least part of the reason for the discrepancies.

7. The expectation is that the trends observed herein for pitch would be transferrable to roll as well.

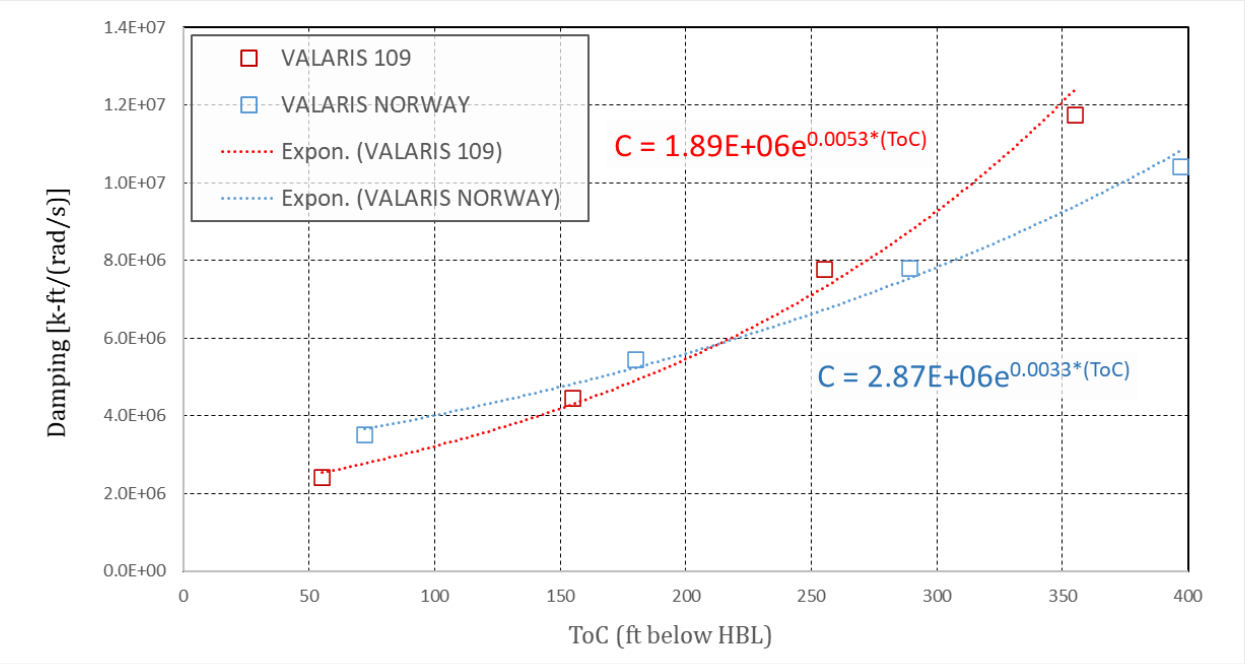

Figure 14 – Variation of Pitch Damping Coefficients with ToC

SUMMARY AND CONCLUSIONS

A series of analyses were carried out utilizing SPH to establish the effective pitch damping ratios for two jackup designs. For each of the two jackup models, four (4) Tip of Can (ToC) positions were considered and the calculated natural periods and damping ratios were compared against those from diffraction analyses. In these models, the truss portions of the legs were ignored.

The authors recognize that at this stage, without confirmation of the damping ratios from the field or scaled model testing, the results may only be taken as qualitative rather than quantitative, especially given the fact that they are based on a single set of particle density values for the SPH models and the fact that the models did not include the truss legs. However, the results clearly show that pitch damping ratios increase significantly as the ToC moves further and further below HBL, reaching values well over 10% of critical damping.

While the level of damping influencing the motions of a jackup prior to making the decision to go or not go on location is fully accounted for in the unit's response, these decisions are often made based on weather forecasts and calculated response estimates. The results presented in this paper indicate that the pitch (and therefore roll) damping ratios increase with amount of deployed leg length. Therefore, using a constant damping ratio for all cases can be overly conservative based on the results of this paper.

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