Barge motion responses in the South China Sea

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Abstract

Drawing from standard design criteria, together with available motion characteristics data for sea-transports within SMEP, this note documents the effect of barge motion responses unique to South China Sea, and illustrates sensitivities of positioning the cargo on barges, while also highlighting its relative severity compared to responses in North Sea.

1 Introduction

Due to logistics, quality control, and prohibitive costs, offshore structures, viz., jackets, topsides, modules, piles, and vendor equipment are typically fabricated onshore, and then towed to their intended service locations offshore. Further, the cargo is conventionally supported and transported on an un-propelled barge, and towed using tug boats. Transportation analysis, and resulting stresses arising out-of, therefore, become important aspects in ensuring pre-service compliance for an offshore structure or equipment transported.

DEP 37.19.00.30-Gen.[1], which is a DEM-1 document, generally covers the guidance and practice of all offshore structures within Shell, and in lieu of results from a full motion analysis, it offers default motion responses for standard transportation of varying barge sizes in §8.6, which is further based on Noble Denton criteria.[2]

Whereas SMEP, which has historically practised a region-specific set of default motion responses, advises[1] that the DEP 37.19.00.30-Gen., default "values should not be applied for transportation in benign Malaysian waters," before proceeding to furnish motion responses appropriate for use in the region. The benignity of transportation in Malaysian waters of South China Sea however may be misplaced, and by implication, misunderstood, as benignity of environment for jacket structures in-place does not necessarily translate into benign sea transport forces on the cargo. In fact, transportation in Malaysian waters of South China Sea can be, and often is, more severe than in North Sea. This note illustrates this discrepancy with evidence, and further aims to not only elevate the due importance of sea transportation in design, but also recommends suitable amendments in applicable practices and standards from conclusions here in.

[1] §8.6, SES 10.1, Rev.5.[3]

2 Sea transportation analysis

Sea transportation analysis is one of the necessary design checks that is carried out to determine structural adequacy of the cargo during its pre-service life. Specifically, it helps with the following:

- Assess and design the structure for stresses that develop during sea transportation
- Design additional temporary members (sea-fastenings) for support during transport, as required, and optimise structural design and positioning of the cargo, where possible
- Strengthen structure to suit onerous action forces, orient member spanning to be beneficial and economical during tow

2.1 Factors affecting tow

The following affect tow, viz., (a) sea state, (b) size and characteristics of the cargo barge, (c) size, weight, and C.O.G of the cargo, and (d) tow route.

In the above, it should be noted that normal tow is assumed, and any abnormality w.r.t. tugs, tow hardware, or significant changes in weather are not considered, as these issues are outside the scope of this note.

2.2 Barge motion responses

Barge motion responses are determined by performing (time domain or *at least* frequency domain) barge motion analyses, taking cargo characteristics and tow route into account. In the absence of such a detailed assessment, default motion responses are often furnished in recommended practices (or in technical specifications), which correspond to the nature of sea transportation and barge characteristics. Since such a generic criteria does not explicitly illustrate the sea state, viz., wave steepness, significant wave height, or wave period, et al., these may be deemed somewhat conservative.

For medium sized barges, default barge motion responses are as in Table 1.[2]

Table 1: Motion responses for a medium sized barge

	LOA (m)	*B (m)*	α	T_r *(s)*	β	T_p *(s)*	*gh* (m/s^2)
North Sea	> 76.0	> 23.0	20°	10.0	12.5°	10.0	0.2g
South China Sea	91.44	27.43	12.5°	5.0	8.0°	5.5	0.2g

To review responses in practice, and check for consistency and validity of guidance in SES 10.1, barge motions from sea transports of 22 topsides, 13 jackets, and 16 miscellaneous structures (viz., 3 bridges, 9 living quarter modules, 2 flare tower sections, 1 helideck, and 1 equipment) were collated for summary in Table 2.

[2] Medium sized barges are most commonly used by SMEP in Malaysian waters of the South China Sea, and are hence illustrated for comparison.

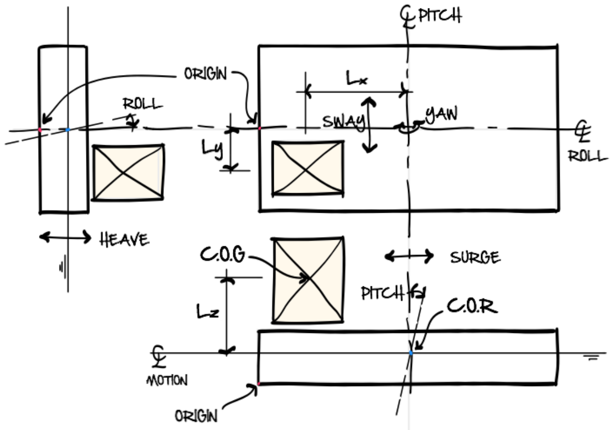

Figure 1: Position of cargo w.r.t. barge centre of rotation

Table 2: Motion responses from installations in South China Sea for medium sized barges

		Jacket	*Topside*	*Miscellaneous*
Roll	α (°)	14.1	16.4	15.0
	T_r (s)	8.7	7.5s	8.4
Pitch	β (°)	5.9	6.0	6.8
	T_p (s)	8.8	8.1s	9.1
Heave	gh (m/s^2)	0.2g	0.3g	0.3g

The results above reflect consistency in the type, weight and C.O.G. of structure or package transported, in which jacket category appears to have the lowest of roll angles with longer associated full cycle period, where as both topside and miscellaneous structures exhibit higher accelerations, either due to high C.O.G., or due to insignificant mass. Higher accelerations could also potentially be due to shallower vessel draught during sea transportation, which would help reduce tow duration, but regarding which there exists inconclusive evidentiary data.

From performance data in Table 2, it can be seen that the motion responses adopted for South China Sea in SES 10.1 are better represented, with SES 10.1 values (Table 1: South China Sea) being appropriately onerous covering most, if not all, use cases, aside from being certainly different from those furnished in default motion responses in the DEP.[1]

Despite these evidences, responses compared in Table 1 do not readily reveal their relative severities, and may even offer a generally incorrect impression of benignity in the case of South China Sea, since all values seem lower which, to the uninitiated, appears less severe. The severity therefore is better understood by computing accelerations based on motion responses instead, which is addressed in the following section.

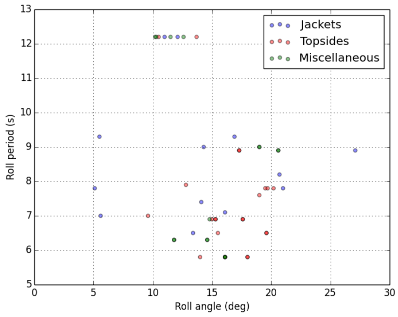

Figure 2: Roll motion response scatter

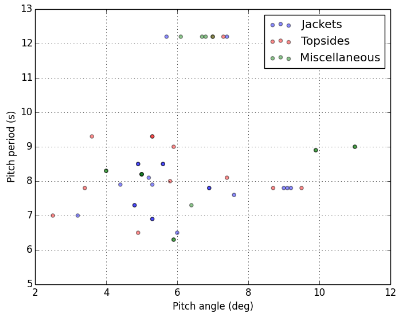

Figure 3: Pitch motion response scatter

2.3 Accelerations

Maximum acceleration, in an SHM without phase information, may be computed as follows:

$$\theta = \omega^2 \cdot a \tag{1}$$

From above, *roll* acceleration takes the form:

$$\theta_r = \left(\frac{2\pi}{T_r}\right)^2 \cdot \alpha \tag{2}$$

Similarly, *pitch* acceleration takes the form:

$$\theta_p = \left(\frac{2\pi}{T_p}\right)^2 \cdot \beta \tag{3}$$

The *roll* (α) and *pitch* (β) amplitudes are in radians above. Correspondingly, θ_r and θ_p are in rad/s^2.

Surge and Sway single amplitudes each can be calculated using *Pitch* and *Roll* parameters respectively, and therefore, they are often not furnished.

Surge (in terms of g) can be calculated as follows:

$$Surge = 1.0 \cdot g \cdot sin\beta \tag{4}$$

and *Sway* (in terms of g) can be calculated as follows:

$$Sway = 1.0 \cdot g \cdot sin\alpha \tag{5}$$

Table 3: Accelerations

	θ_r (rad/s^2)	θ_p (rad/s^2)	gh (m/s^2)
North Sea	0.14	0.09	1.96
South China Sea	0.34	0.22	1.96
Increase	143%	144%	–

From the above, it is evident that accelerations in South China Sea in both *roll* and in *pitch* are higher above North Sea by over 140%, which is not revealed when simply reading responses in Table 1.

These increases in accelerations are primarily due to *reduced* full cycle periods in South China Sea. In other words, *lower periods* in the denominator of non-linear equations drive accelerations up.

It is generally recognized that maximum pitch response occurs when the effective wavelength parallel to vessel length axis is two to three times the vessel's length. Then the vessel will be riding the slope of the wave. Under such a condition, surge is maximum too.

A sea of shorter wave length, acting at an angle to the vessel's axis (also known as quartering wave), can also produce a significant pitch response. The directional spread of waves can also cause a response in pitch even in a beam sea. Similarly, even when the barge is headed directly into the sea, there can be a significant response in roll.[4]

The general design trend in offshore construction vessels is to make their length equal to or larger than the maximum wavelength in which they are expected to work — although medium category vessels are too short compared to 2–3 times wave lengths in South China Sea. (See Figure 10.) That said, an unintended consequence of using longer vessel (where applicable), in order to ride two wave crests, is that it reduces the full cycle period, thereby further amplifying responses inadvertently in certain seas like the South China Sea, as evident from above. In turn, inertial forces increase as a consequence of higher accelerations (Newton's second law of motion), as we can see in §2.4 below.

2.4 Inertia forces

Roll and Heave

Vertical force from ROLL:

$$F_{vr1} = W \cdot \left(cos\alpha + \theta_r \cdot \frac{L_y}{g} \right) \tag{6}$$

Vertical force from heave corresponding to ROLL:

$$F_{vhr} = \left(\frac{W}{g} \right) \cdot gh \cdot cos\alpha \tag{7}$$

Horizontal force from ROLL:

$$F_{hr1} = W \cdot \left(sin\alpha + \theta_r \cdot \frac{L_z}{g} \right) \tag{8}$$

Horizontal force from heave corresponding to ROLL:

$$F_{hhr} = \left(\frac{W}{g} \right) \cdot gh \cdot sin\alpha \tag{9}$$

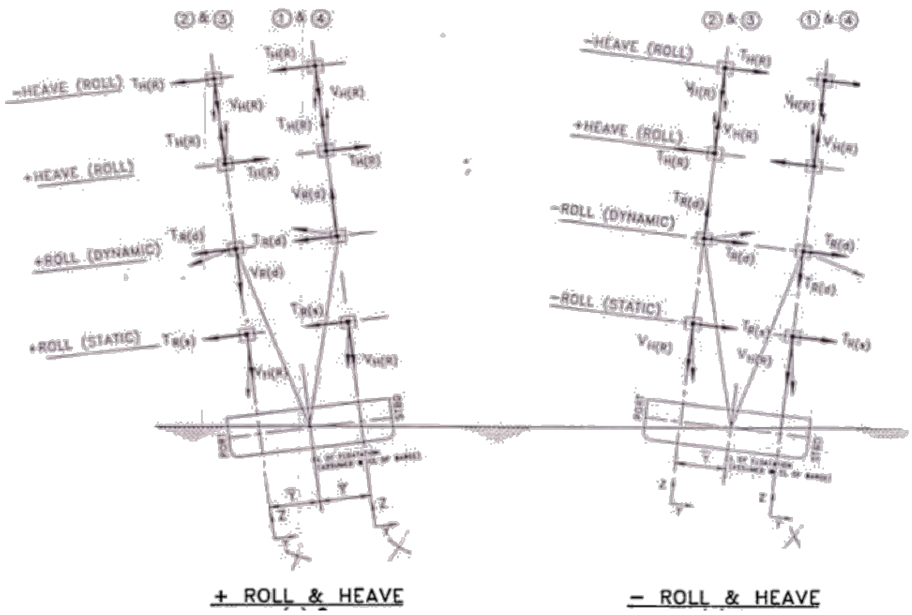

Figure 4: Roll and Heave

Pitch and Heave

Vertical force from PITCH:

$$F_{vp1} = W \cdot \left(cos\beta + \theta_p \cdot \frac{L_x}{g} \right) \tag{10}$$

Vertical force from heave corresponding to PITCH:

$$F_{vhp} = \left(\frac{W}{g} \right) \cdot gh \cdot cos\beta \tag{11}$$

Horizontal force from PITCH:

$$F_{hp1} = W \cdot \left(sin\beta + \theta_p \cdot \frac{L_z}{g} \right) \tag{12}$$

Horizontal force from heave corresponding to PITCH:

$$F_{hhp} = \left(\frac{W}{g} \right) \cdot gh \cdot sin\beta \tag{13}$$

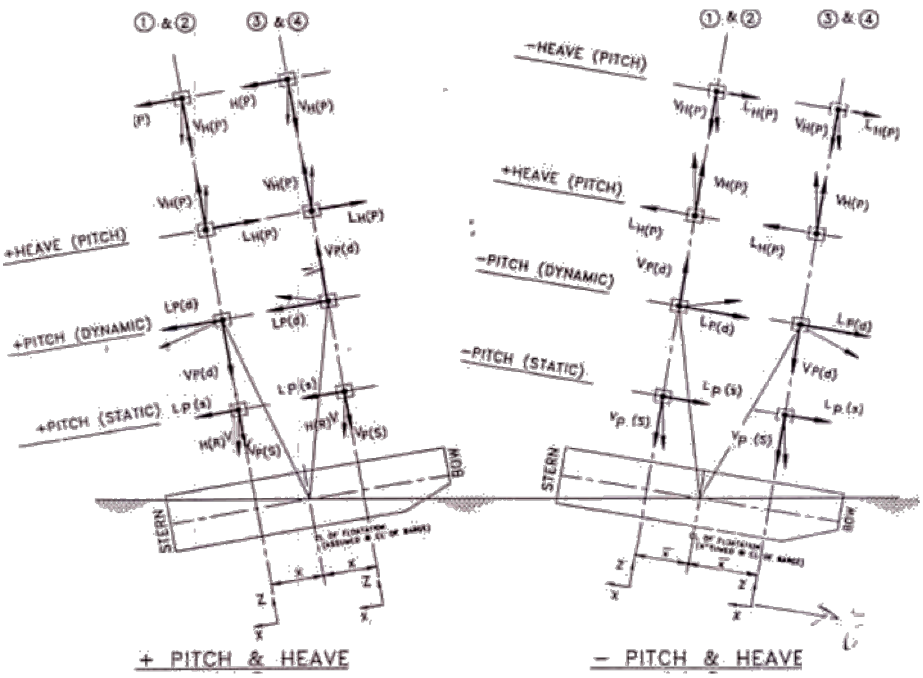

Figure 5: Pitch and Heave

Load combinations

Phasing is assumed to combine, as separate load cases, the *severe* combinations of the following:

- Simulating *Beam* seas: 100% Roll and 100% Heave
- Simulating *Head* seas: 100% Pitch and 100% Heave
- Simulating *Quartering* seas: 50% Pitch, 50% Roll, and 100% Heave

In addition, effective horizontal shear force due to barge inclinations, corresponding to the maximum pitch / roll angle, may be included in the cases above. Typically, wind forces are not considered in the above combinations.

PITCH and HEAVE:

$$F_{vp} = \pm F_{vp1} \pm F_{vhp} \tag{14}$$

$$F_{hp} = \pm F_{hp1} \pm F_{hhp} \tag{15}$$

ROLL and HEAVE:

$$F_{vr} = \pm F_{vr1} \pm F_{vhr} \tag{16}$$

$$F_{hr} = \pm F_{hr1} \pm F_{hhr} \tag{17}$$

where, W is weight of cargo on the barge; L_x, L_y, and L_z are distances between COG of cargo and barge COR.

It is useful to compare inertia forces when $W = 1$, and $L_x = L_y = L_z = 0$ to remove the influence of mass and cargo eccentricity, before introducing them later, in order to ascertain the influence of only the motion responses on forces.

Table 4: Inertia forces with unit mass, without cargo eccentricity

ROLL + HEAVE, PITCH + HEAVE

	F_{vr}	F_{hr}	F_{vp}	F_{hp}
North Sea	1.13	0.41	1.17	0.26
South China Sea	1.17	0.26	1.19	0.17
Increase	4%	-37%	2%	-35%

ROLL - HEAVE, PITCH - HEAVE

	F_{vr}	F_{hr}	F_{vp}	F_{hp}
North Sea	0.7	0.27	0.78	0.17
South China Sea	0.78	0.17	0.79	0.11
Increase	4%	-37%	1%	-35%

Table 5: Inertia forces with unit mass, with cargo eccentricity

ROLL + HEAVE, PITCH + HEAVE

	F_{vr}	F_{hr}	F_{vp}	F_{hp}
North Sea	1.27	0.55	1.45	0.35
South China Sea	1.52	0.61	1.86	0.39
Increase	20%	11%	28%	11%

ROLL - HEAVE, PITCH - HEAVE

	F_{vr}	F_{hr}	F_{vp}	F_{hp}
North Sea	0.89	0.42	1.06	0.27
South China Sea	1.13	0.52	1.47	0.34
Increase	27%	24%	39%	42%

As eccentricities get nullified, increases become consistent, as seen above. Vertical forces dominate with increases up to 4%, while lateral forces reduce by 37%, thus reinforcing conventional wisdom that centring the cargo w.r.t. barge COR offers the overall benefit reducing inertia forces on cargo, and in this comparison, lateral forces in particular.

In practice however, lateral forces, which are driven by elevation of cargo relative to barge COR (L_z), the 37% reduction is unlikely because in SMEP, with 6.1m barge depth and structure expected to be placed at a minimum height of 3m above the barge deck, COG of the cargo, particularly for a structure that is need to be loaded out, is likely to be at least 6m above barge COR, thus nullifying this reduction, as evidenced in Figure 8.

Now, when we try the same situation but with cargo eccentricity (W = 1; L_x = 30m, L_y = 10m, and L_z = 10m, just as an example for determining responses in both seas with these consistent inputs), here is what we get.

As evident from above, compared to North Sea, increases in inertial forces in South China Sea are dramatic as eccentricities increase. In addition, the operating (1 month return) peak period in South China Sea ranges from 7.8s up to 10.2s, with the lower values prevailing somewhat nearer to coast line, while the higher ones occur further away from. (See Figure 9.)

Effect of cargo eccentricity

To understand the influence of eccentricities more, a range of L_x, L_y, L_z were considered (L_x: 0–50m; L_y and L_z: 0–30m). Following graphs illustrate the influence of eccentricities over inertia forces.

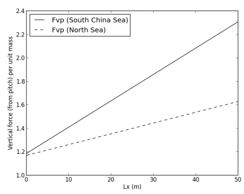

Figure 6: Effect of L_x on inertia forces

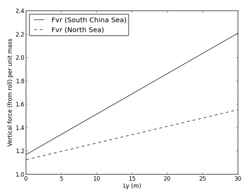

Figure 7: Effect of L_y on inertia forces

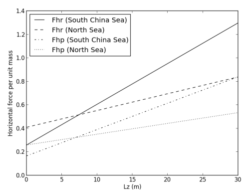

Figure 8: Effect of L_z on inertia forces

2.5 Metocean conditions

Using available information, viz., *Hs* and *Tp* in Metocean reference documents for Sabah and Sarawak [5], wave characteristics, viz., wave lengths, wave celerities, and wave energies were computed [6] for 23 locations/fields (4 in Sabah, 19 in Sarawak), which are summarized below.

Table 6: Average metocean conditions in South China Sea for one month return period

	Sabah	*Sarawak*
Water depth, d (m)	43	89
Significant wave height, Hs (m)	5.0	3.5
Peak period, Tp (s)	11.4	9.2
Wave length, L (m)	189	132
Wave celerity, C (m/s)	16.6	14.4
Wave energy, E (kJ)	58.3	20.0

When barge motions corresponding to South China Sea in Tables 1, 2 and from Figure 9, one can see that they tend to coincide, coupling frequencies, resulting

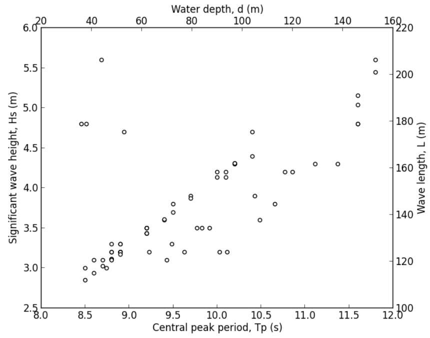

Figure 9: Metocean data scatter for one month return period for Sabah and Sarawak

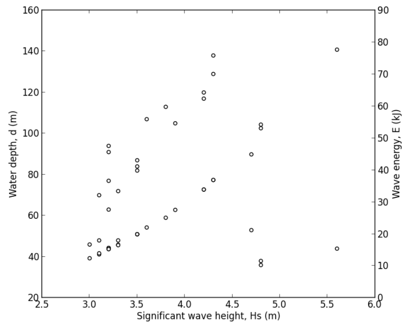

Figure 10: Hs, d, wave energy scatter for one month return period for Sabah and Sarawak

in high dynamic force amplifications over and above forces in Tables 4, 5, which further need to be considered. (The results in Tables 4, 5 above do not include these additional amplifications. Hence it's important to perform a time-domain, or at least a frequency domain analysis using conditions along the tow route to determine these dynamic amplification factors or RAOs.)

3 Conclusions

Comparing barge motion responses, this note demonstrates the general severity of sea transports in South China Sea over those prevailing in North Sea. The following are noted:

1. For medium sized barges that are most commonly used by SMEP in South China Sea, the default barge motion responses, pitch and roll specifically, are about 140% higher than for those recommended in DEP 37.19.00.30-Gen.[1] This is shown in Tables 1, 2.

2. As a consequence, cargo eccentricities further amplify inertia forces with similar increases in South China Sea compared to North Sea. These are illustrated in Figures 6–8.

3. In lieu of a full barge motion analysis, the region-specific technical specification practiced by SMEP adequately considers the additional severity in §8.6 of SES 10.1[3], and is duly justified.

4. It should further be noted that the general benignity of the environment that may be true for fixed offshore structures in-place, may not extend to sea transportation in South China Sea.

References

[1] DEP Specification – *Fixed steel offshore structures (Amendments/Supplements to ISO 19902:2007)*, DEP 37.19.00.30-Gen., February 2011.

[2] GL Noble Denton, *Guidelines for Marine Transportations*, 0030/ND, March 2010.

[3] Technical Specification – *Fixed Offshore Steel Structures*, SES 10.1, Revision 5, October 2010.

[4] B.C. Gerwick, Jr., *Construction of Marine and Offshore Structures*, §5.2 Marine and Offshore Construction Equipment, Third Edition, CRC Press, 2007.

[5] SSB/SSPC Metocean Reference Document for Sabah and Sarawak, MRD 6.1.

[6] N.D.P Barltrop, A.J. Adams, *Dynamics of Fixed Marine Structures*, Chapter 6: Waves and wave loading, Third Edition, Butterworth Heinemann.