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Dynamic Analysis of Spar Hull Transportation

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Abstract: The transportation of a truss-spar hull from a transport barge of 6000 ton topside module on the spar hull is investigated in the present study. Two possible routes from a fabrication yard in Teeside, England to the Gulf of Mexico are considered in the paper. The results of motion responses of the transport barge obtained from a spectral analysis and the limiting criteria of sea fastening, deck wetness and lateral acceleration are compared and the route selection is discussed. Long-crested waves and short-crested seas as well as the joint probabilities of significant wave heights and wave periods in different sea areas are considered. Generally speaking, the results for long-crested seas are higher than those for short-crested waves.

Key words: Transportation, Truss Spar, Hydrodynamic Motion Analysis, Spectral Analysis, Critical Analysis

Nomencalture

$\xi_k, \dot{\xi_k}, \ddot{\xi_k}$ =k-th mode of motion, velocity, acceleration

M_{jk}, A_{jk}, B_{jk}, C_{jk}=Mass of structure, Added mass, Damping coefficient, Restoring coefficient

F_j^W, F_j^V=Wave induced force, Viscous induced force

$()_{1\sim 6}$ = Surge, Sway, Heave, Roll, Pitch, Yaw direction respectively

$()_R$ = Relative motion

$()_{nS}$ = n-th mode of spar response

1. Introduction

After offshore structures are built onshore, they need to be transported to the offshore installation site. Different types of structures require different methods of transportation and installation and also different transportation methods can often be used for the same type of offshore structure.

Major transportation related matters such as sea conditions, transportation route, motion response, and safety are discussed in this paper. The objectives of paper are:

- To select routes with weather considerations.
- To estimate the benefits of weather routing.
- To estimate dynamic loads and motion responses
- To find the environmental limit for the safety

In order to achieve these objectives, the calculations of motion response amplitude operators of barge and of the sea fastening loads were performed. A spectrum and short-term statistical analysis has been carried out to estimate the significant values of roll motions, lateral and vertical accelerations and of the probability of deck wetness in irregular waves.

2. Specification of a case study

In the investigation, a dry transportation for the spar hull specified in Figure 1 and Table 1 by

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means of barge S44, given in Figure 2 and Table 2, is considered.

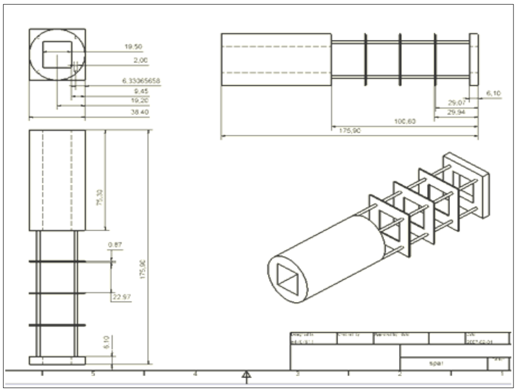


Figure 1: Basic drawing of the assumed Spar

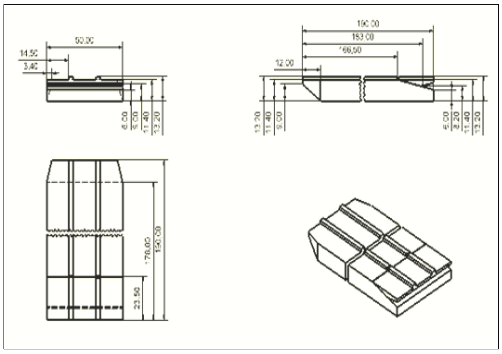


Figure 2: Basic arrangement drawing of Barge

Table 1: Principal particulars of the Spar.

Buoyancy cylinder	
Length overall	175.90 m
Length / Diameter	75.3 /38.4 m
Moon pool	19.50 m
Draught / Freeboard	100.6/ 75.3 m
Displacement	17,232 tonnes
Anti-heave plate	
Length / Breadth	38.4 /38.4 m
Depth	0.87 m
Motion characteristics	
KG / KB	49 / 49.4 m
Radius of roll, pitch gyration	43.9 m
Radius of yaw gyration	0 m

Table 2: Principal particulars of Barge S44.

Length overall	190 m	
Breadth / Depth	50 / 11.4 m	
	w/o spar	w/ spar
Draught	3.8 m	5.7 m
Displacement (m^3)	37,730	54,150
Ballast displacement	0 m^3	0 m^3
KG	2.0 m	12.2 m
Radius of roll gyration	19.8 m	27.4 m
Radius of pitch gyration	45.9 m	62.2 m
Radius of yaw gyration	45.9 m	45.9 m

The barge is assumed to be towed at 8 knots, constructed in Teeside, England and expected to be installed in the Gulf of Mexico. The journey of transportation may encounter harsh weather. Reducing the potential risk of severe environmental loads on the spar and saving transportation time are the reasons for choosing dry transportation.

3. Routing

The criteria for operational limits of motions and accelerations are very project specific, and no authoritative criteria are present yet. Nevertheless, the most widely used deterministic motion criteria are those introduced by Noble Denton [1] for flat bottom cargo barges and other types of carrier vessels.

In the present study 10 year return period wind and wave environmental conditions are considered as input to choose a transportation route. The choice of the 10-year return period is common practice for transportation design and is recommended by IMO Guidelines for Safe Ocean Towing [2]. The routing analysis is thus involved with a hydrodynamic analysis and a statistical weather information analysis.

Two possible routes are considered and compared for transit from the construction site in Teeside, England (4.27E, 51.55N) to the installation site in the Gulf of Mexico (79.56W, 32.47N). The first route is a normal passenger transportation route which is assumed to be the fastest and shortest way and the second is a modified route taking into account global wave statistics data to minimize the motion responses of barge S44.

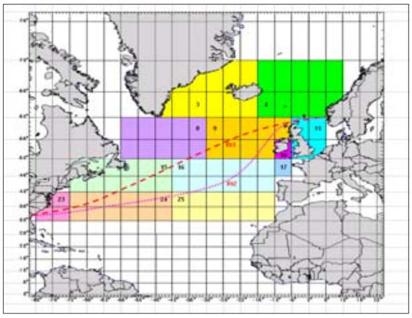


Figure 4: Alternative transport routes for barge S44

The distance of route 1 is 7110km (3658 nm) which passes through sea areas 8, 9, 11, 15, 16, 23 and 24, and it takes around 19 days at the assumed constant transport speed. Route 2 covers areas 9, 11, 16, 23, 24 and 25 and takes around 21 days for a distance of 7975km (4103nm). These routes are shown in Figure 4.

Figure 5 shows the probability of wave height for route 1, indicates that high latitude zones experience more severe weather conditions than other sea areas. The probabilities of wave heights for routes 1 and 2 and the related area statistics (notation: Rt) are compared in Figure 6, where the wave height probability calculations for both routes also include the percentage of journey time passing through each zone while the area statistics are the wave height probabilities in the passing zones.

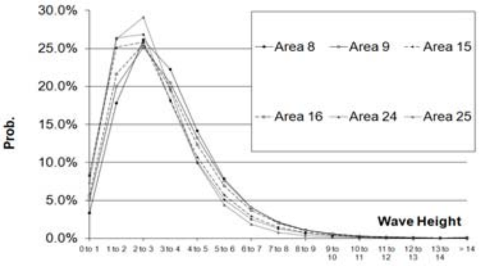


Figure 5: Probability of wave heights to be experienced

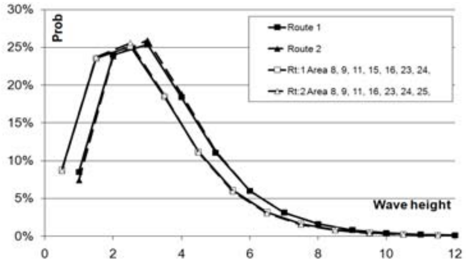


Figure 6: Probability of wave height for different routes

The difference between the wave height probabilities with and without the effect of journey time is insignificant. Comparison between the wave height probabilities for routes 1 and 2 as shown in Figure 6 reveals that route 2 has more probability of lower wave heights and is expected to experience milder weather conditions than for route 1.

4. Motion Responses in a Seaway

Frequency domain motion analyses are carried out to estimate the motions and accelerations of a vessel during transport. The coupled linear motion equations of a ship travelling at a forward speed U in regular waves are expressed as [3]:

$$\sum_{k=1}^{6}[(M_{jk}+A_{jk})\ddot{\xi}_k+B_{jk}\dot{\xi}_k+C_{jk}\xi_k=F_j^W+F_j^V] \qquad (1)$$

In the case, it is assumed that the incident waves upon the body are plane progressive waves of small amplitude ζ, encounter frequency ω_e, wave number k, and heading angle β, defined as:

$$\zeta=\sum_{a=1}^{6}\zeta_a e^{i[k(x\cos\beta+y\sin\beta)-\omega_e t]} \qquad (2)$$

5. Dynamic effects

The structural analysis needs to be carried out against the dynamic loads [4] including such as:

- Relative motions and accelerations with structural coupling effects.

- Deflections of transport vessel, if significant.
- Direct wave loads due to the inundation of cargo

5.1 Significant response

If the wave spectrum is taken to be narrow banded, the Rayleigh probability law can be applied to the probabilistic prediction of responses in random seas. The significant value of the response amplitude $\zeta_{1/3}$ is given with response spectrum area m_0 by:

$$\zeta_{1/3} = 2\sqrt{m_0} \tag{3}$$

5.2 Deck wetness

The motion of any point on barge $\vec{S}$ is written as:

$$\begin{aligned} \vec{S} &= (S_1, S_2, S_3) \\ &= (\xi_1, \xi_2, \xi_3) + (\xi_4, \xi_5, \xi_6) \times (x, y, z) \end{aligned} \tag{4}$$

where $S_{1,}S_2$ and S_3 are the longitudinal, lateral and vertical motions with point (x,y,z) respectively and x,y and z are the longitudinal, lateral and vertical distances of the selected point from the origin of a rectangular coordinate system.

When the relative vertical motion between the local ship section and the alongside waves is greater than the local freeboard, deck wetness will occur at the section. By using Eq. (2) and Eq. (4), the relative vertical motion ξ_{R3} is obtained as:

$$\xi_{R3} = S_3 - \zeta = [\xi_3 + y\xi_4 - x\xi_5] - \zeta \tag{5}$$

The probability of deck wetness for local freeboard Z_f is expressed with the vertical motion relative to the wave, ξ'_3, and the area under the relative vertical motion spectrum, m'_{R0}, as follows:

$$\Pr(\xi'_3 > Z_f) = \exp(-Z_f^2/2m'_{R0}) \tag{6}$$

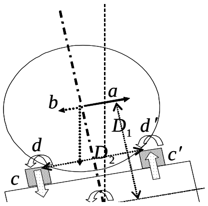
5.3 Lateral acceleration & sea-fastening failure

Differentiating response twice with respect to time yields the local lateral acceleration, at any point on the barge as:

$$\ddot{\xi}_{R2} = \ddot{\xi}_2 + x\ddot{\xi}_6 - z\ddot{\xi}_4 \tag{7}$$

The probability of sea-fastening failure acceleration, Z_d is expressed with the limit state of acceleration of sea-fastening A_{Lim} with acceleration spectrum area m'_{a0} as follows:

$$\Pr(A_{\mathrm{Lim}} > Z_d) = \exp(-Z_d^2/2m'_{a0}) \tag{8}$$



$$\begin{aligned} a &= \ddot{\xi}_{2S} \sin(\xi_4) \\ b &= g \sin(\xi_4) \\ c &= -c' = F_D \\ d &= d' = M_D \end{aligned}$$

Figure 7: Force and moment diagram due to coupled motion

With reference of **Figure 7** for notation, the force due to the moment of the coupled beam motion with the moment arm ratio, D_1/D_2, and mass of spar, m_s, is expressed as:

$$F_D = D_1/D_2[\ddot{\xi}_{2S} - g\sin(\xi_4)]m_s \tag{9}$$

6. Numerical Results

The foregoing wave spectrum is a point spectrum without accounting for the dispersion of wave energy in various directions. The directional distribution of the wave energy is assumed to be described by a cosine square function with spreading angle of 90° as recommended by ITTC [5].

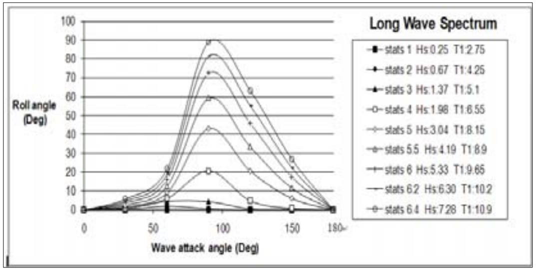


Figure 8: Significant roll motions in long-crested seas

Figure 8 to Figure 9 show the significant values of the roll motions of barge S44 with forward speed at different wave angles and significant wave heights in long-crested seas and in short-crested waves respectively. It is evident that the largest roll motion occurs in beam seas and decreases with wave angle away from beam seas while the smallest roll motion takes place in head seas.

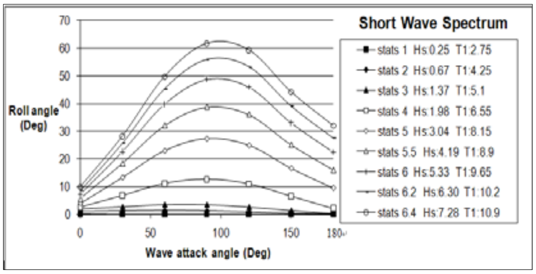


Figure 9: Significant roll motions in short-crested seas

The co-ordinates of locations for checking accelerations and deck wetness are given in Table 3. The utmost fore deck position of barge S44 is selected for deck wetness while the centre of gravity of the spar hull is chosen for the acceleration checks.

The deck wetness at the fore end of barge S44 is considered and its probabilities are shown against various wave angles at different wave heights and periods in **Figure 10** and **Figure 11** for long- and short-crested seas respectively. It is not surprised that no deck wetness is observed at sea-states 5 and below since the freeboard is 5.7m. If a limiting level of deck wetness probability of 5% is imposed, barge S44 will not be able to operate above sea state 6.2 in bow oblique waves 150° or in head waves.

Table 3: Co-ordinates of locations for acceleration and deck wetness check (Unit: m)

Mode	X from midship	Y from centreline	Z above baseline
Deck wetness	95	0	5.7
Accel.	0	0	26.7

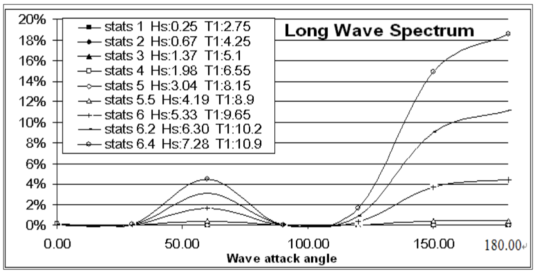


Figure 10: Wet deck probability in long-crested seas

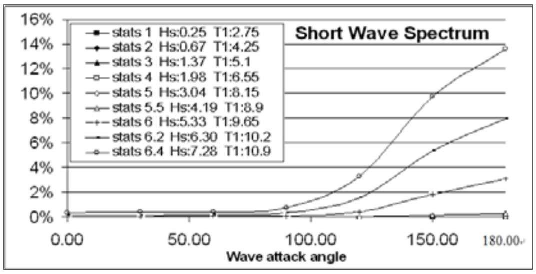


Figure 11: Wet deck probability in short-crested seas

The joint plate material for welding is assumed to be "Structural steel ASTM A36 steel" are shown in Table 4, and the sea-fastening information is given in Table 5. The failure is defined when the weld part of steel reaches the yield strength.

Table 4: Mechanical properties of ASTM A36 steel

Yield strength	Ultimate strength	Density
250 MPa	400 MPa	7.8 g/cm³

Table 5: The sea-fastening information

Name	Value	Unit
number of joint	6	n/a
Weld thickness	4	mm
Length of welding	2	m
Yield stress	250	Mpa
Yd / Welding factor	60 / 85	%

The sea-fastening failure probabilities for the barge seas at different wave heights and wave encounter angles are illustrated in Figure 12 and Figure 13 for long- and short-crested seas respectively.

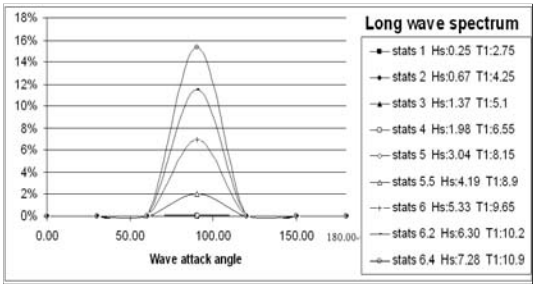


Figure 12: Sea-fastening failure probability at different headings in long-crest seas

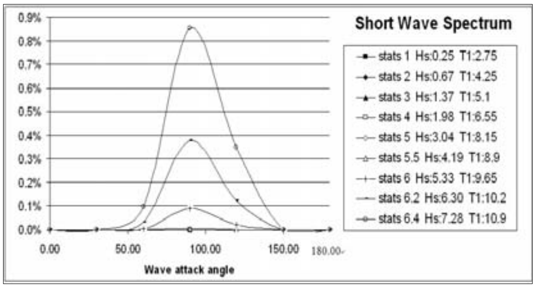


Figure 13: Sea-fastening failure probability at different headings in short-crest seas

7. Conclusion

The wave statistical data shows that high latitude zones have a higher percentage of severe weather conditions than occur in the lower latitude zones.

Two possible routes were compared and found that route 1 has a higher probability of lower wave heights and mild weather conditions than for route 2.

The results of deck wetness from the head seas are shown to have the highest wet deck probability in both long and short-crested seas. However, no deck wetness was found at sea-state 5 and below since the freeboard was set at 5.7m. however if a limiting level of deck wetness probability of 5% was imposed, barge S44 will not be able to operate above sea state 6.2 in bow oblique waves 150° or in head waves.

The sea-fastening failure probabilities at different wave heights and wave angles in both long- and short-crested seas were calculated. Under the wave conditions of sea-state 5, the maximum significant lateral accelerations were 0.2 m/s^2 in both long- and short crested seas.

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[5] ITTC(:International Organization for Standardization,) “Report of the Cavitation Committee”, 12th ITTC, Rome, Italy, vol. 1, 1969.

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