36. Duisburger Kolloquium Schiffstechnik / Meerestechnik
The Ship and the Offshore Wind-Energy

Weather-restricted Sea Transports Aboard Heavy Lift Ships

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Introduction

The heavy lift market is seeing a clear tendency towards heavier and larger cargo that cannot be treated routinely when transported overseas. Heavy goods on heavy lift ships are typically secured and lashed using accelerations according to Annex 13 of IMO's CSS Code. These standard accelerations are based on seaways occurring during winter in the most severe North Atlantic sea environment, representing maximum values valid for unrestricted sea conditions. Most weight and size critical sea transports are, however, taking place on more benign routes in milder seasons than winter season. Thus, Annex 13 offers to compute wave-induced design accelerations for the specific ship, route and season of the year. Following this option, so-called Response Amplitude Operators (RAOs) of the wave-induced accelerations are computed with ABB's seakeeping program Octopus Office and processed short-term statistically to yield design accelerations used to check the resulting cargo loads on the lashing gear and deck supporting structures. Here, the design accelerations are computed for a limiting significant wave height that allows high workability of the sea transport. To account for uncertainties of weather forecasts, DNV GL's α-factor procedure, yielding a comparably lower operational significant wave height than the design significant wave height, is applied. Finally, the workability of the sea transport is evaluated by analyzing the occurrence probabilities of the seaways with regard to the operational wave height using Global Wave Statistics' season dependent wave scatter diagrams. To ensure that the accelerations during transit will not exceed the design accelerations, SAL's heavy lift ships are equipped with acceleration sensors that are continuously monitored by the ship's navigating officer. Application of this new procedure is demonstrated by a recently conducted sea transport.

Weather-restricted sea transports

Critical sea transports of oversized or heavyweight cargo typically requires milder seaways to deliver the cargo safe and sound at the port of destination. Increasingly, SAL's clients ask for possibilities to transport size critical cargo fully erected in just one piece to avoid a costly assembly of its parts at the port of destination.

Figure 1: SAL's MV Lone with two port cranes sea-fastened on deck

Figure 1 shows two deck-stowed fully erected port cranes of barely 300 metric tons weight on their way from Wilhelmshaven to Sfax and Gabes in Tunisia. Transporting the cranes in one piece increases the transverse and vertical inertial forces significantly compared to a disassembled crane transport. Thus, high forces are transferred to the crane structures through the lashing lugs. If the crane structure cannot withstand those high inertial forces resulting from wave-induced accelerations in unrestricted seaway conditions, the seaway intensity along the route need to be limited by reducing its significant wave height.

Occasionally, such oversized cargo need to be positioned on the double bottom of an open hold. To avoid green water ingress into the open hold that compromises the ship's transverse intact stability, the maximum significant wave heights are to be reduced such that the relative motion between the free surface and the main deck level will never exceed the freeboard at the longitudinal position of the open hold's hatch corners.

Figure 2: SAL's MV Annegret with jacket top positioned on the double bottom

Figure 2 shows the jacket top, protruding from the open hold amidships, on its way from Fremantle, Australia, to the Pohukura gas field in New Zealand.
The advantage of limiting the seaway intensity is obvious, because milder seaways prevent structural damages to the cargo by reducing the cargo's extreme loads and fatigue loads. Furthermore, damages to the ship structures are more unlikely to happen. In particular, heavy cargo resting on tiny supports benefit from milder seaways because their high foot print pressures loading the supporting ships structures are significantly lowered. Last not least, the risk of vanishing transverse stability caused by green water inflow to the open hold is considerably reduced in milder seas.

Essence of weather-restricted sea transports

Standard sea transports and weather-restricted sea transports are specified in the design phase of the transport project. The transport project is documented in the so-called Operations Manual that describes the sea transport and handling of the heavy or oversized cargo from lifting it off the quay or barge with the shipboard cranes until discharging it.
Whereas standard ship transports, for instance, apply ship response from IMO or DNV GL regulations that are based on unrestricted service assumptions, weather-restricted sea transports take into account the seakeeping behavior of the heavy lift ship and the seaway characteristics of the particular route and season of the year the transport is scheduled. Thus, the maximum significant wave height $Hs_{maximum}$ the ship will encounter on the most severe route and worst season of the year will be significantly higher compared to the design significant wave height Hs_{design} of the weather-restricted sea transport. The consequence is that the ship response according to a weather-restricted Hs_{design} is significantly lower compared to the standard unrestricted $Hs_{maximum}$.
However, to conserve an equivalent level of safety for both transport methods, so-called α-factors of DNV GL are applied to further reduce Hs_{design} because of the uncertainty of on-board weather forecasts. Thus, the resulting operational significant wave height $Hs_{operational}$ will further prune the risk that the design ship response on transit is exceeded. As above mentioned rule-making institutions explicitly permit weather-restricted sea transports according to the described characteristics, entire adherence to their regulations is safeguarded.

SAL's weather-restricted sea transport method

In total, five steps are executed to conduct a weather-restricted sea transport on SAL's heavy lift ships. The first four steps are necessary to determine the limits of the significant design wave height and the significant operational wave height:

1. Motion analysis to compute transfer functions of the ship response with in-house linear seakeeping program Octopus Office from ABB
2. Determination of Hs_{design}
    - Short-term statistical analysis performed with Octopus Office to compute most probable extreme values (MPEs) of the motions and accelerations
    - The condition that the $MPE_{maximum}$ of the motion or acceleration must be lower or equal to the critical motion or critical acceleration yields Hs_{design}
    - Alternatively, a reasonably high workability determines Hs_{design} and the corresponding $MPE_{maximum}$ of the motion or acceleration
3. Determination of $Hs_{operational}$ because of uncertainty on forecasted significant wave heights on-board
    - Reduction of the design wave height Hs_{design} by multiplying it with DNV GL's α-factors yields the operational wave height $Hs_{operational}$.
4. Determination of the workability to conduct the transport
    - Likelihood to conduct the transport. Estimated downtime caused by high seas with significant wave heights that exceed $Hs_{operational}$.

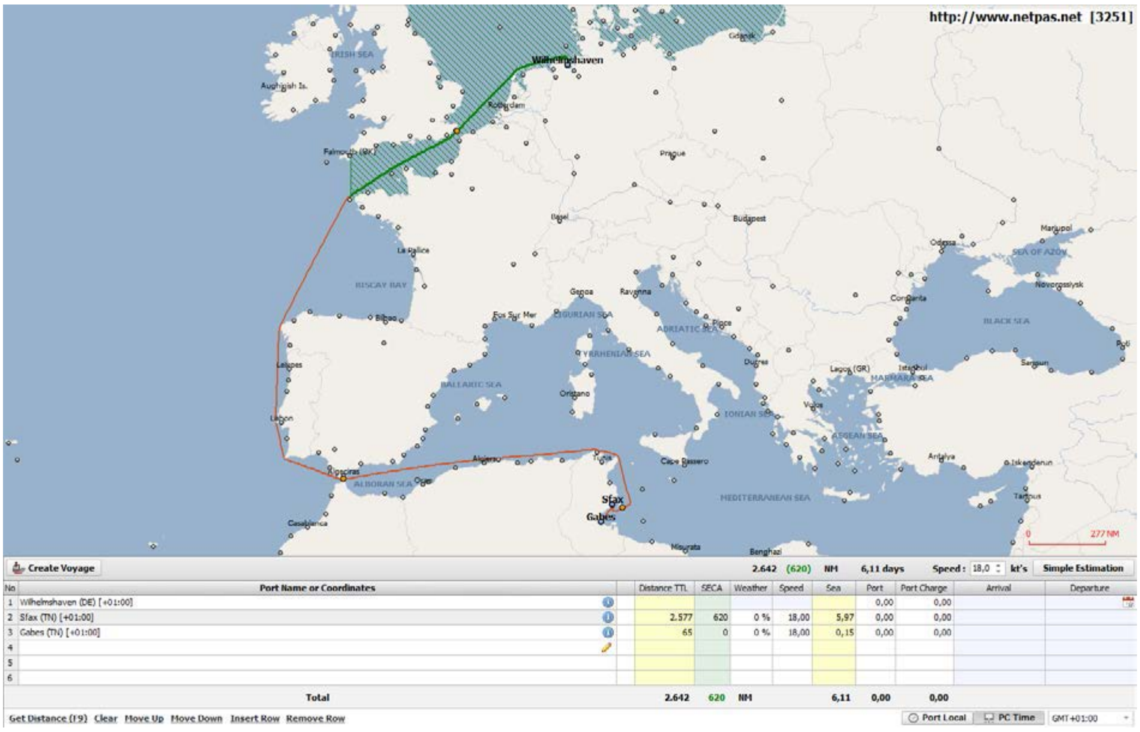
The last step of the transport project addresses monitoring of critical ship response on transit.

Application of SAL's weather-restricted sea transport method

Beginning of last year, SAL was contracted to transport two port cranes from Wilhelmshaven to the ports of Sfax and Gabes in Tunisia, stowed on-deck of MV Lone, see figures 3 and 4.

Figure 3: Deck-stowed cranes on SAL's MV Lone

The yellow crane was discharged in Sfax, the grey crane in Gabes. According to figure 4, the entire voyage from Wilhelmshaven to Gabes was estimated to take slightly more than six days at 18 kn service speed.



2.642 (620) NM 6,11 days Speed: 18,0 kt's

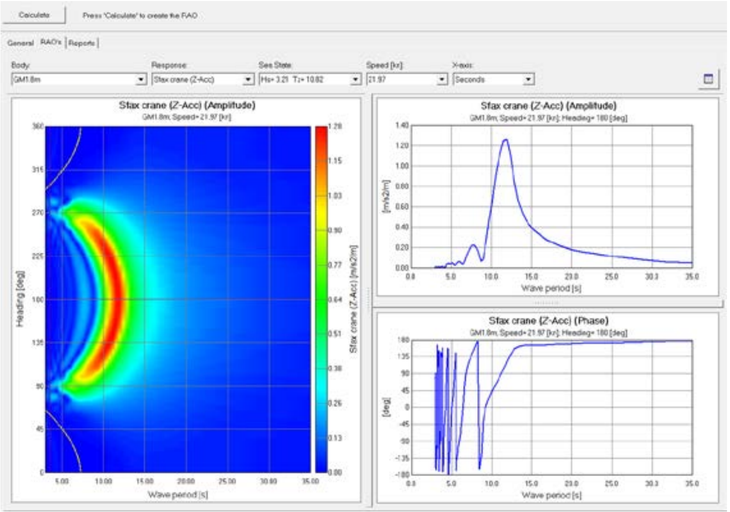
No	Port Name or Coordinates	Distance TTL	SECA	Weather	Speed	Sea	Port	Port Charge	Arrival	Departure
1	Wilhelmshaven (DE) [+01:00]						0,00	0,00		
2	Sfax (TN) [+01:00]	2.577	620	0 %	18,00	5,97	0,00	0,00		
3	Gabes (TN) [+01:00]	65	0	0 %	18,00	0,15	0,00	0,00		
4										
5										
6										
	Total	2.642	620	NM		6,11	0,00	0,00		

Figure 4: Seaway route from Wilhelmshaven to Sfax and Gabes

With 18 kn speed at 85% MCR, see figure 5, the ship is capable to rapidly reach a port of refuge in case of bad weather conditions.

Figure 5: Principal particulars of MV Lone

In the ***first step***, a motion analysis to compute the transfer functions (RAOs) was conducted.

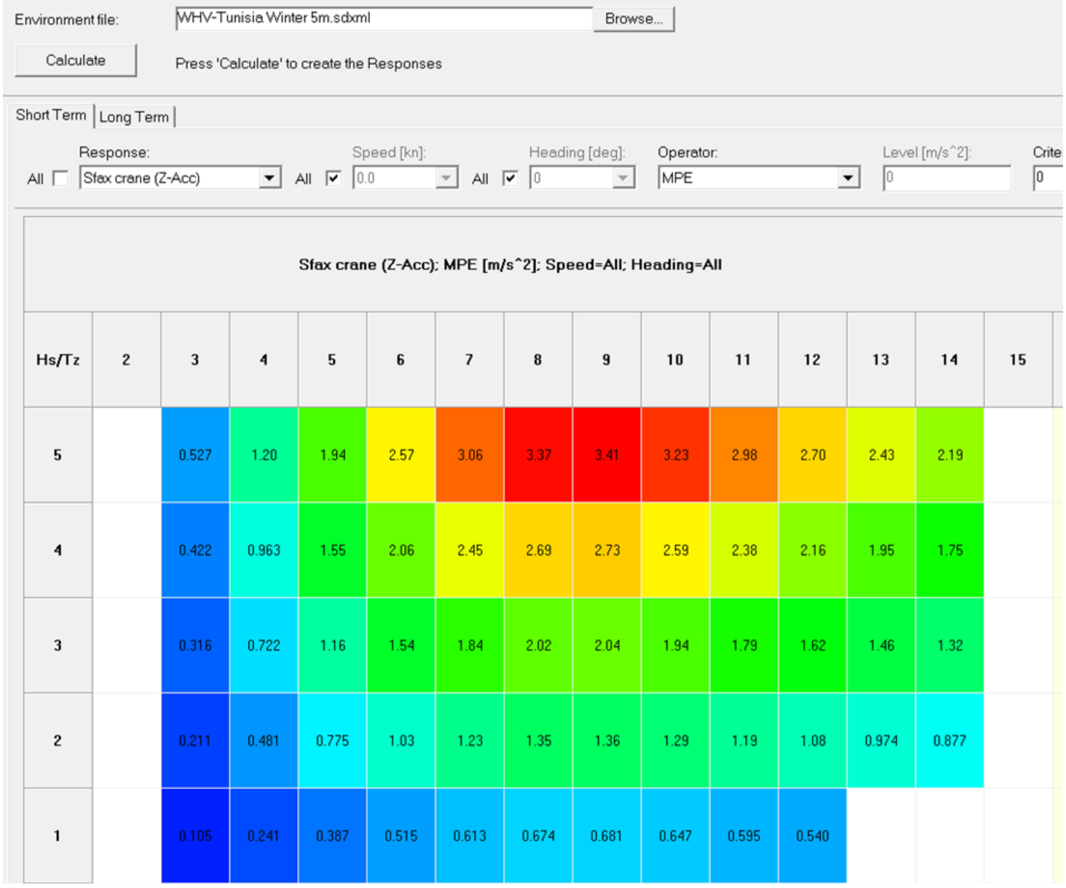


Body: GM1.8m
Response: Sfax crane (Z-Acc)
Sea State: Hs= 3.21 Tz= 10.82
Speed [kr]: 21.97
X-axis: Seconds

Figure 6: Vertical acceleration RAOs at Sfax crane's CoG

The plots in figure 6 reveal that highest values of Z-Acc are found in head waves at a period of 12.5 s.

In the ***second step*** Hs_{design} was determined. Above RAOs were processed short-term statistically to obtain the so-called most probable extreme values of the ship response in question.



Environment file: WHV-Tunisia Winter 5m.sdxml

Press 'Calculate' to create the Responses

Response: All ☐ Sfax crane (Z-Acc)
Speed [kn]: All ☑ 0.0
Heading [deg]: All ☑ 0
Operator: MPE
Level [m/s^2]: 0
Crite 0

Sfax crane (Z-Acc); MPE [m/s^2]; Speed=All; Heading=All

Hs/Tz	2	3	4	5	6	7	8	9	10	11	12	13	14	15
5		0.527	1.20	1.94	2.57	3.06	3.37	3.41	3.23	2.98	2.70	2.43	2.19	
4		0.422	0.963	1.55	2.06	2.45	2.69	2.73	2.59	2.38	2.16	1.95	1.75	
3		0.316	0.722	1.16	1.54	1.84	2.02	2.04	1.94	1.79	1.62	1.46	1.32	
2		0.211	0.481	0.775	1.03	1.23	1.35	1.36	1.29	1.19	1.08	0.974	0.877	
1		0.105	0.241	0.387	0.515	0.613	0.674	0.681	0.647	0.595	0.540			

Figure 7: MPEs of vertical accelerations at Sfax crane's CoG

Figure 7 shows the calculated MPE's of the vertical acceleration at the center of gravity of the yellow Sfax crane. Here, four ship speeds ranging from 0 to 21 kn were considered as well as all headings to the seaways. The client limited this critical acceleration to 3.5 m/s^2. The condition that the calculated MPEs must be equal or lower to 3.5 m/s^2 yields an MPE of 3.41 m/s^2 at a zero-upcrossing period Tz of 9 s and the corresponding limiting Hs_{design} of 5.0 m. Converting Tz to the peak period Tp yields 12.6 s, close to the 12.5 s wave period of the maximum vertical acceleration RAO.

In the ***third step*** the operational significant wave height $Hs_{operational}$ was determined. According to figure 4, the MV Lone can call a port of refuge at any position on the route within 24 hours if seaway conditions should deteriorate such that the forecasted significant wave heights would exceed $Hs_{operational}$. For an Hs_{design} of 5 m below table 4-1 gives an interpolated α-factor of 0.77 according to DNV GL. Thus, 0.77 * Hs_{design} yields a $Hs_{operational}$ of 4 m.

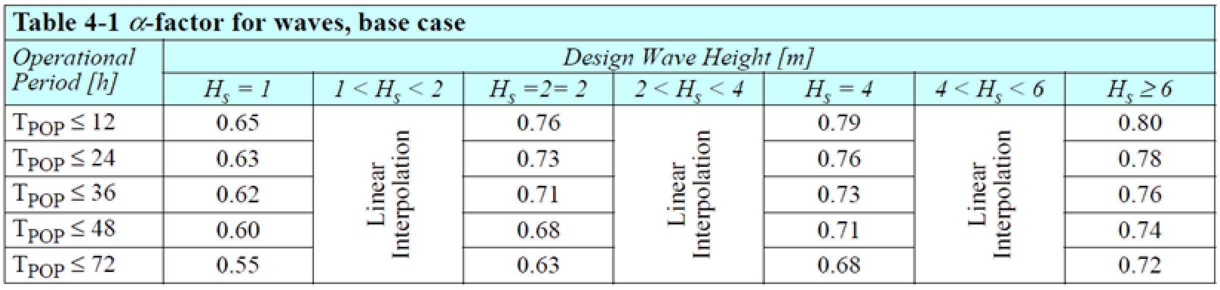


Table 4-1 α-factor for waves, base case

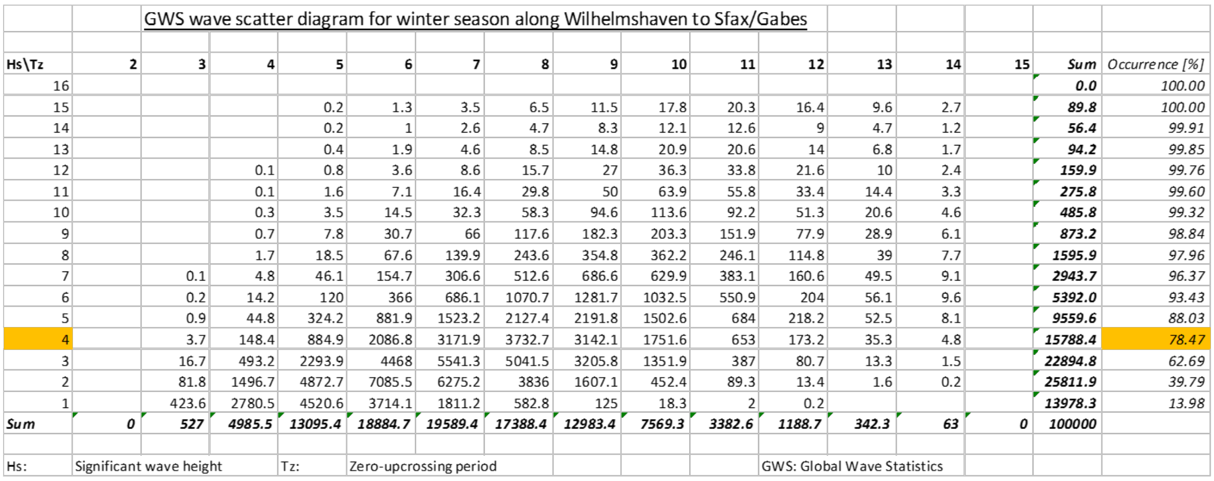
Operational Period [h]	*Design Wave Height [m]*						
	$H_s = 1$	$1 < H_s < 2$	$H_s = 2 = 2$	$2 < H_s < 4$	$H_s = 4$	$4 < H_s < 6$	$H_s \geq 6$
$T_{POP} \leq 12$	0.65	Linear Interpolation	0.76	Linear Interpolation	0.79	Linear Interpolation	0.80
$T_{POP} \leq 24$	0.63		0.73		0.76		0.78
$T_{POP} \leq 36$	0.62		0.71		0.73		0.76
$T_{POP} \leq 48$	0.60		0.68		0.71		0.74
$T_{POP} \leq 72$	0.55		0.63		0.68		0.72

Figure 8: Table 4-1 to determine α-factors for operational periods up to 3 days

In the ***fourth step*** the workability of the planned weather-restricted sea transport is checked.

Figure 9: Global Wave Statistics' sea areas 5, 11, 16, 17, 25 and 26 along the route

Here, the wave scatter diagram for the winter season was obtained by Octopus Office that makes use of the wave data base of Global Wave Statistics. Wave data for the sea areas 5, 11, 16, 25 and 26 along the route from Wilhelmshaven to Tunisia, see figure 9, were processed to yield the composed scatter diagram given in figure 10.



GWS wave scatter diagram for winter season along Wilhelmshaven to Sfax/Gabes

Hs\Tz	2	3	4	5	6	7	8	9	10	11	12	13	14	15	*Sum*	*Occurrence [%]*
16															***0.0***	*100.00*
15				0.2	1.3	3.5	6.5	11.5	17.8	20.3	16.4	9.6	2.7		***89.8***	*100.00*
14				0.2	1	2.6	4.7	8.3	12.1	12.6	9	4.7	1.2		***56.4***	*99.91*
13				0.4	1.9	4.6	8.5	14.8	20.9	20.6	14	6.8	1.7		***94.2***	*99.85*
12			0.1	0.8	3.6	8.6	15.7	27	36.3	33.8	21.6	10	2.4		***159.9***	*99.76*
11			0.1	1.6	7.1	16.4	29.8	50	63.9	55.8	33.4	14.4	3.3		***275.8***	*99.60*
10			0.3	3.5	14.5	32.3	58.3	94.6	113.6	92.2	51.3	20.6	4.6		***485.8***	*99.32*
9			0.7	7.8	30.7	66	117.6	182.3	203.3	151.9	77.9	28.9	6.1		***873.2***	*98.84*
8			1.7	18.5	67.6	139.9	243.6	354.8	362.2	246.1	114.8	39	7.7		***1595.9***	*97.96*
7		0.1	4.8	46.1	154.7	306.6	512.6	686.6	629.9	383.1	160.6	49.5	9.1		***2943.7***	*96.37*
6		0.2	14.2	120	366	686.1	1070.7	1281.7	1032.5	550.9	204	56.1	9.6		***5392.0***	*93.43*
5		0.9	44.8	324.2	881.9	1523.2	2127.4	2191.8	1502.6	684	218.2	52.5	8.1		***9559.6***	*88.03*
4		3.7	148.4	884.9	2086.8	3171.9	3732.7	3142.1	1751.6	653	173.2	35.3	4.8		***15788.4***	*78.47*
3		16.7	493.2	2293.9	4468	5541.3	5041.5	3205.8	1351.9	387	80.7	13.3	1.5		***22894.8***	*62.69*
2		81.8	1496.7	4872.7	7085.5	6275.2	3836	1607.1	452.4	89.3	13.4	1.6	0.2		***25811.9***	*39.79*
1		423.6	2780.5	4520.6	3714.1	1811.2	582.8	125	18.3	2	0.2				***13978.3***	*13.98*
Sum	***0***	***527***	***4985.5***	***13095.4***	***18884.7***	***19589.4***	***17388.4***	***12983.4***	***7569.3***	***3382.6***	***1188.7***	***342.3***	***63***	***0***	***100000***	

Hs: Significant wave height Tz: Zero-upcrossing period GWS: Global Wave Statistics

Figure 10: Wave scatter diagram composed of sea areas 5, 11, 16, 25 and 26 for the winter season

For an operational significant wave height $Hs_{operational}$ of 4 m the weather-restricted sea transport will not need to be suspended in almost 80% of the time, see orange marked fields in figure 10. Thus, the likelihood for the transport being realized is four days out of five days.

In the ***fifth step*** the sea transport is monitored. With on-board weather forecasts four days ahead the navigating officer will check every 12 hours that the significant wave heights are less or equal to 4 m. Furthermore, a spatial accelerometer was mounted at the CoG of the Sfax crane to monitor the longitudinal X-Acc, transverse Y-Acc and vertical Z-Acc accelerations on transit. The used sensor of SIRI Marine is shown in figure 11 below.

Figure 11: SIRI Marine spatial motion and acceleration sensor

It was checked by the navigating officer that following maximum acceleration values obtained for Hs_{design} of 5 m were not exceeded during the transit:

- Maximum X-Acc at Sfax crane's CoG = 0.27 * gravity acceleration
- Maximum Y-Acc at Sfax crane's CoG = 0.32 * gravity acceleration
- Maximum Z-Acc at Sfax crane's CoG = 0.36 * gravity acceleration

Here, the navigating officer monitored the measured recorded extreme and processed standard deviations as displayed on the screen of the SIRI Marine laptop, see figure 12.

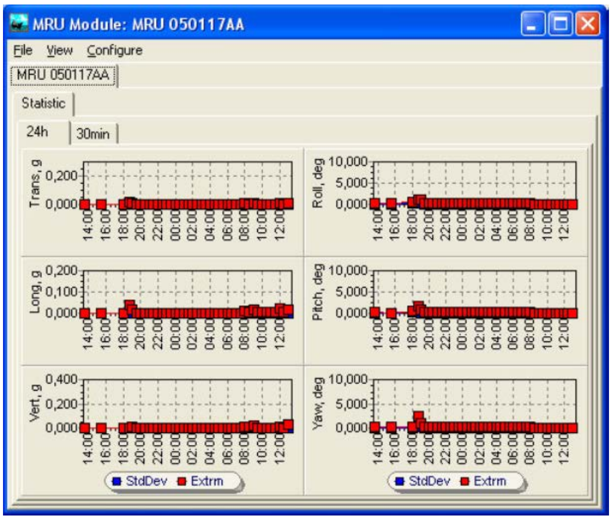


Figure 12: Plots of measured spatial motions and accelerations

Because of favorable weather conditions, the weather-restricted sea transport was realized without any stops.

Concluding remarks

The characteristics and benefits of weather-restricted sea transports of size critical and weight critical cargo were described and outlined.

Using the example of a recently conducted restricted sea transport of two port cranes from Wilhelmshaven to Tunisia, the process to design and execute a weather-restricted sea transport was demonstrated, see below figure 13.

Figure 13: MV Lone heading for Tunisia

SAL analyze about twenty weather-restricted sea transports per year, whereof more than ten are realized. Here, all realized weather-restricted sea transports did not suffer from any damages to the ship or cargo.