ANALYSIS OF THE SPECIAL TRANSPORT CONDITIONS ON BOARD

Work Package 2.1

ALBERO Project

Institut für Sicherheitstechnik/Schiffssicherheit e.V.

Ship movements due to external influences

Ship movements essentially result from the wind and swell. The ship may move around all three axes:

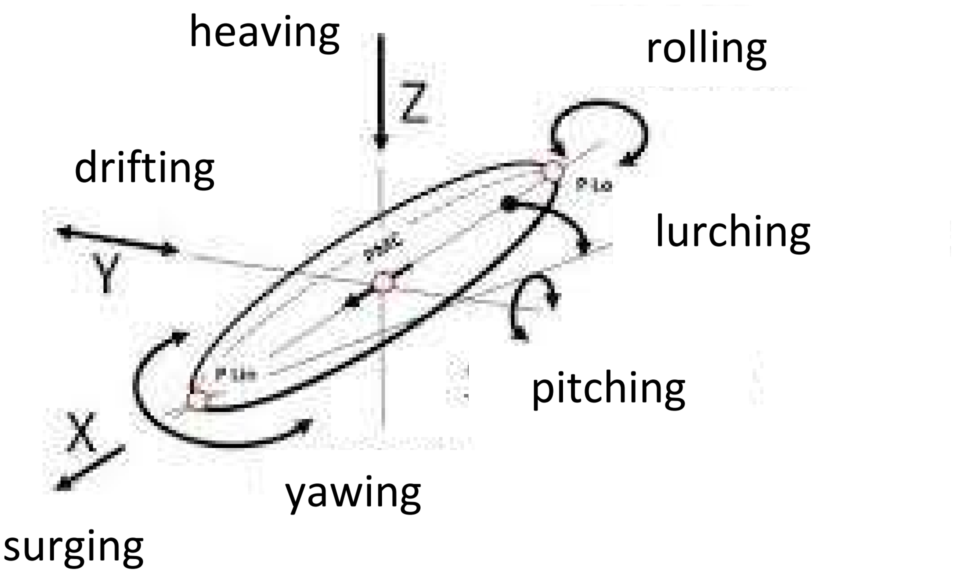

Figure 1: possible ship movements [1]

Long-term studies have been carried out on wind conditions in the Baltic Sea [2]. The so-called relative storm frequency rSH was determined (Table 1, Figures 2 and 3) for the period 1950 - 2005. A storm is defined as a wind force greater than or equal to 8 Bft. Thus, the rSH value indicates the percentage of a year in which wind forces exceeded 8 Bft. The total time of the year is taken as a basis.

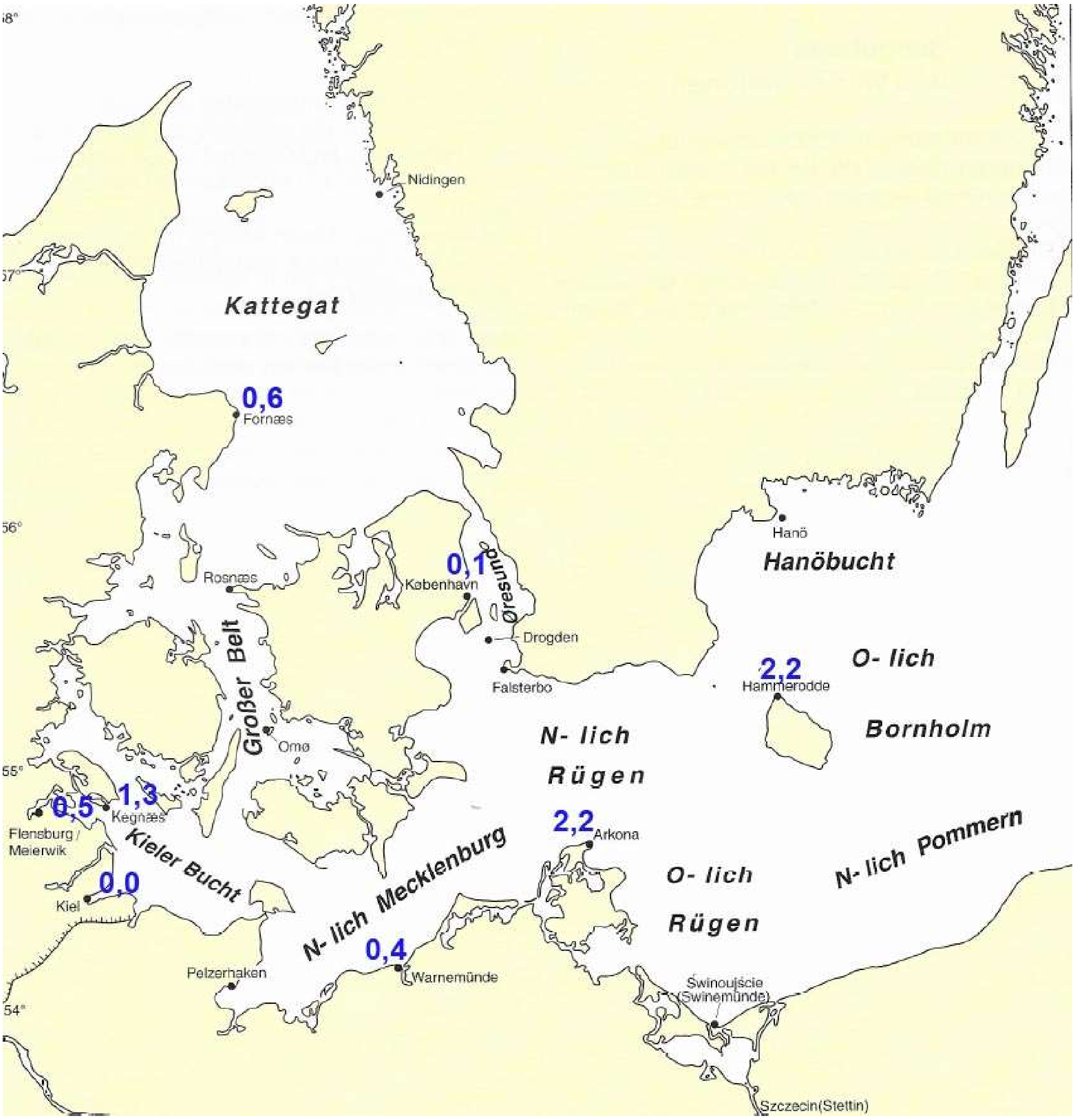

Figure 2: marked in blue: relative storm frequency in the Western Baltic Sea rSH % [2]

Figure 3: marked in blue: relative storm frequency in the Eastern Baltic Sea rSH % [2]

area	Fornaes	Kopen-hagen	Kegnaes	Flens-burg	Kiel	Warne-münde	Arkona	Hamme-rode
rSH [%]	0,6	0,1	1,3	0,5	0,0	0,4	2,2	2,2
days/year	2,19	0,36	4,75	1,82	0	1,46	8,03	8,03

area	Klaipeda	Norra Udde	Lands-ort	Svenska Högarna	Kallbada-grund	St.Peters-burg	Market	Hapa-randa
rSH [%]	0,3	2,0	1,8	1,9	1,3	0,0	1,9	0,1
days/year	1,09	7,3	6,57	6,93	4,74	0	6,93	0,36

Table 1: relative storm frequency in the Baltic Sea rSH % [2], conversion into days

The analysis presented shows how often per year an actually wind force consistently existed above 8 Bft. Other statistics define a storm day as a storm day if ANY time on that day there was a wind force of more than 8 Bft [3]. This means that even if this wind force was reached or exceeded for only 1 hour during the day, the day counts as a storm day. The following values can be found for the Baltic Sea (averaged from 1981 to 2010):

location	storm days
Boltenhagen	56
Warnemünde	51
Schleswig	42
Kap Arkona	117
average entire Baltic Sea	39

Table 2: storm days in the Baltic Sea [3], as per 19th February, 2019

Combining both statistics, it can be concluded that Arkona and Hammerode are the stormiest regions in the Baltic Sea and that accordingly a maximum of approximately 117 storm days per year can be expected on the entire Baltic Sea, as this is the value for Arkona and Hammerode, respectively. However, it is also clear that the storm risk depends strongly on the ferry connection. The Sassnitz-Trelleborg line or the Kiel-Klaipeda lines pass through the stormiest areas, while the Rostock-Gedser line runs in very sheltered territory.

The wave height does not correlate 1:1 with the storm statistics, because a wave also needs free stretches to build up. For ferry traffic on the Baltic Sea, the *Memorandum of Understanding for the Transport of Packaged Dangerous Goods on Ro-Ro Ships in the Baltic Sea (MoU)* [4] applies, among others (see file Transport of Dangerous Goods on RORO Ferries). This defines areas of low wave height: A Low Wave Height Area (LWHA) is a sea area where the significant wave height of 2.3 m is not exceeded in more than 10% of the year. Figure 4 shows the conditions in the Baltic Sea. The ferry routes to Gedser and Trelleborg considered in the project are therefore all located in areas with low wave height.

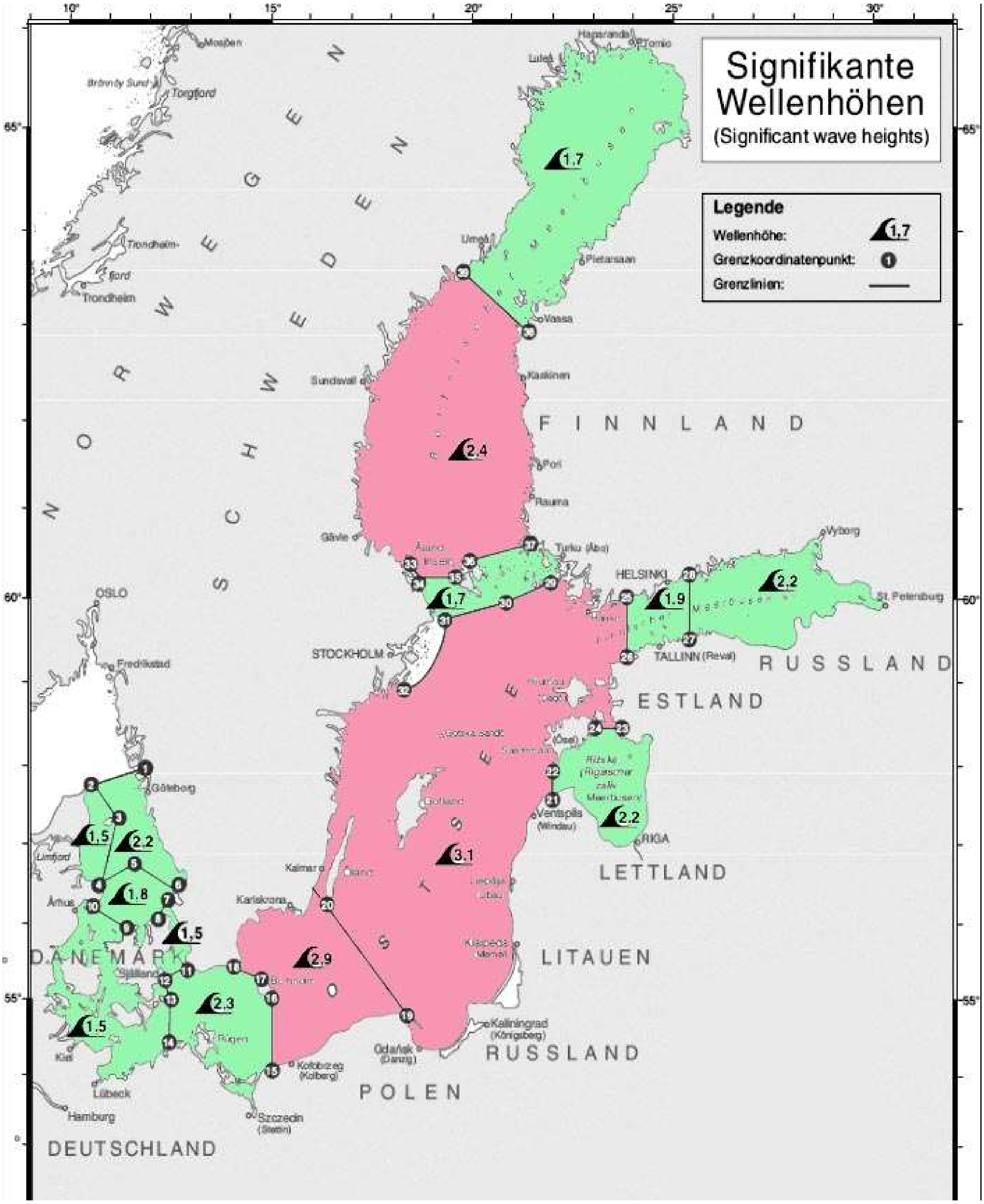

Figure 4: low wave height areas (green) as defined in the MoU [4]

The expected roll angles depend on many factors: the shape of the ship, the wave height, the wave frequency, the wave direction, the center of gravity of the ship, etc. For ro-pax ferries, there are model calculations for the roll angle as a function of the stowage of the vehicles and thus of the center of gravity [5]. This, it was determined that for significant wave heights of 3 m, maximum roll angles of 15° can be expected (Figure 5). However, this represents an absolute extreme value for a very unfavorable loading condition (very large distance between center of gravity and roll axis GM = 1.4 m). For a typical loading condition (GM = 0.6 to 1.0 m), maximum roll angles of 10.5 to 12.5° were calculated for a wave height of 3 m. According to [2], maximum wave heights of 3 m can be expected in coastal areas of the Baltic Sea even at wind force 8 (up to 5.5 m in open sea areas of the Baltic Sea). The ferry lines considered within the project operate close to the coast. Thus, the calculations are consistent with the statements of the ship crews interviewed, according to which roll angles of approximately 10° can occur in strong winds (i.e. 3 m wave height). Transferred to a significant wave height of 2.3 m, according to the low wave height definition of the MoU [4], this results in 8 to 9.5°.

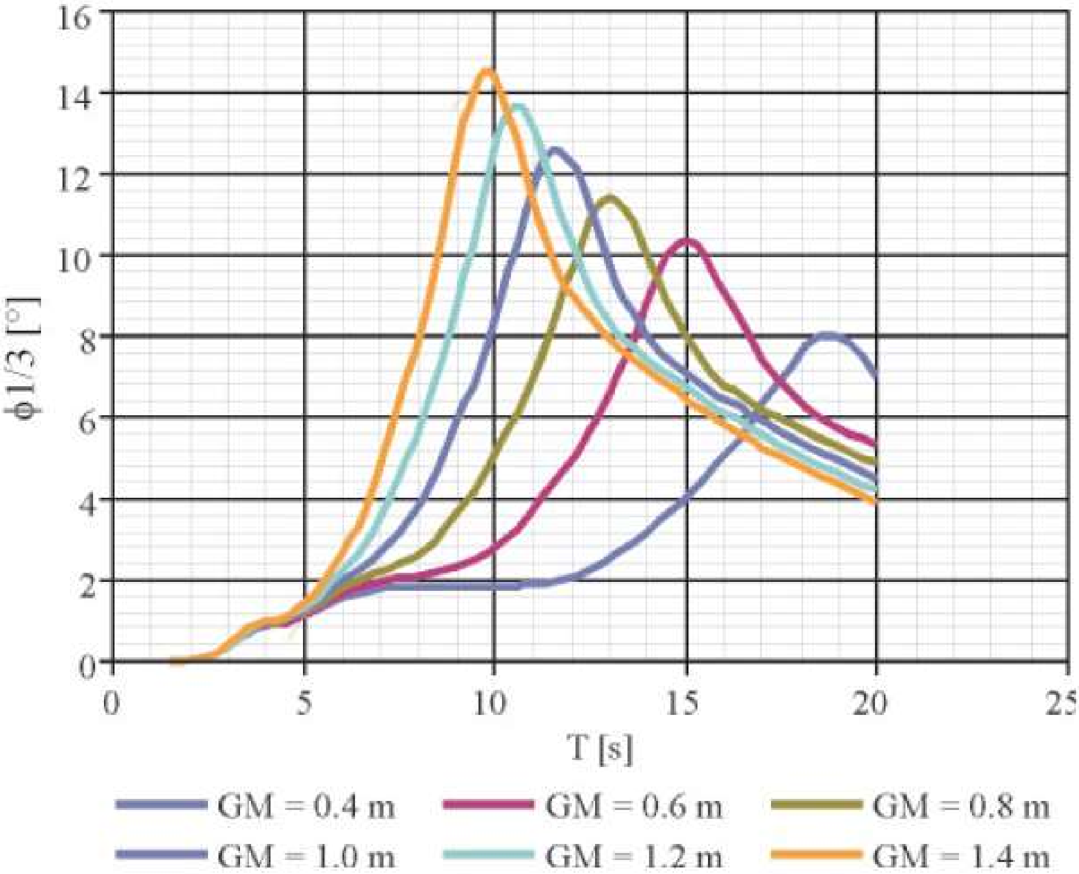

Fig. 3. Significant ship roll amplitudes in function of the characteristic wave frequency T, and: GM = var, Hs = 3 m, β = 60° (where: 0° – head wave, 180° – aft wave), v = 0 m/s

Figure 5: roll angle as a function of loading condition for a significant wave height of 3 m [5]

Deviating from the Memorandum of Understanding, the long-term weather statistics of the BSH [2] indicate average wave heights of approximately 1.0 m over the year for the western Baltic Sea; in the winter months, monthly averages of 1.5 m are reached. Such wave heights result in roll angles of 3.5° to 6°. Based on the statements of the crews that roll angles of approximately 10° are to be expected ONLY in heavy seas, the approach of a roll angle of 5° to be applied for average normal operation seems reasonable.

The roll angle is related to the roll time, this is the time for a complete movement from the center position of the ship to heel to one side, back to the maximum deflection on the other side and back to the center position. For small roll angles (smaller than 10°), the roll time is independent from the deflection [6], [7]. Then, for the calculation of the rolling time, the simplified formula according to [7] applies:

$T = (f \times B) / GM^{1/2}$

Here, f is a factor between 0.7 and 0.9 depending on the ship type and loading condition and B is the width of the ship (for the ferry "Berlin" B= 24.8 m). If one sets an average f = 0.8 and a GM = 1 m, one thus obtains a rolling time of approximately 20 seconds for small angles (< 10°).

Salinity and Humidity

The humidity over the Baltic Sea is relatively constant throughout the year between a minimum of 77 % in summer and a maximum of 88 % in winter. The average value is 83 % [2].

The salinity of the Baltic Sea is composed of incoming salt water from the North Sea and fresh water from rivers and rainwater. The further one moves to East, the lower the salinity of the Baltic Sea becomes. For example, the salinity on the coast of Schleswig-Holstein is around 1.5 to 1.8 percent, while between Sweden and Finland only 0.3 to 0.5 percent is measured, see Figure 6 [8]. By comparison, the North Sea has a salinity of 3.5 percent.

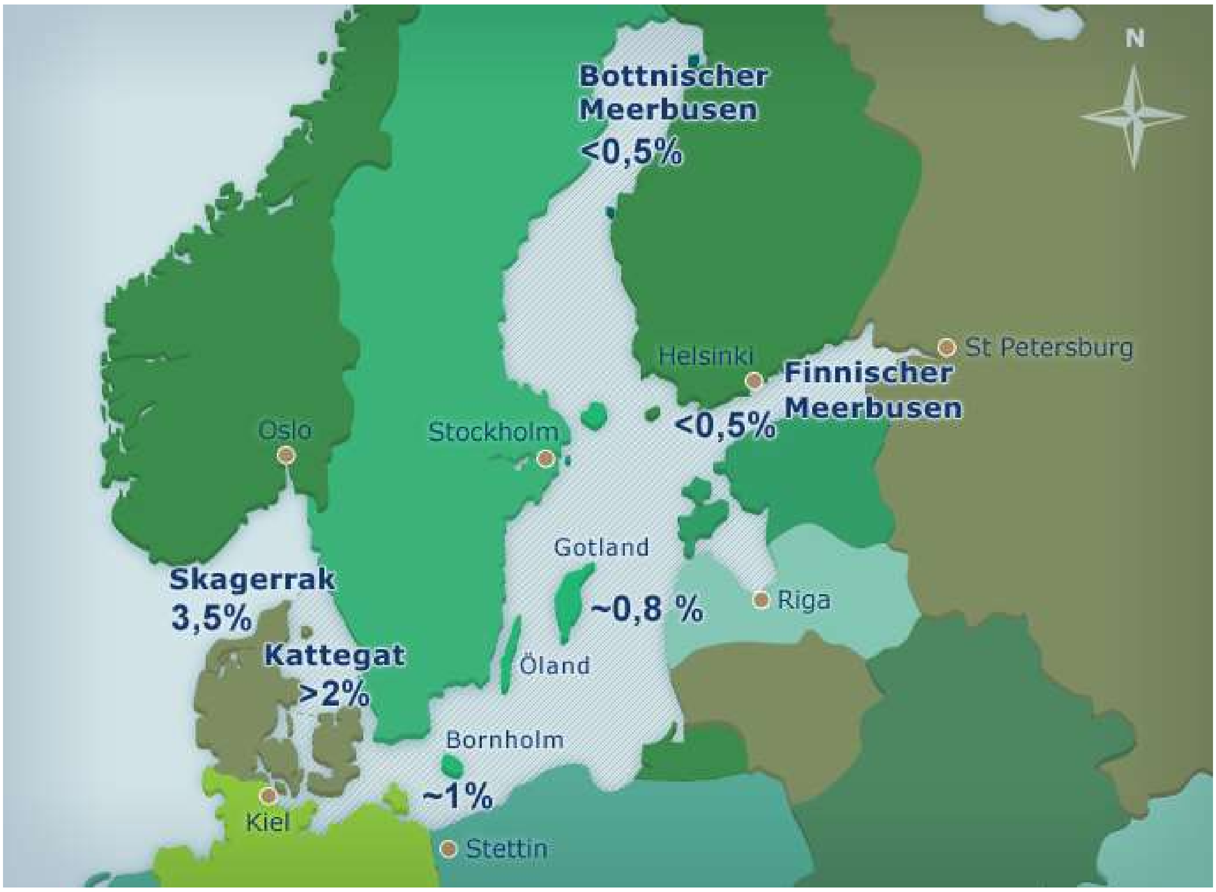

Figure 6: salinity oft he Baltic Sea [8]

Figure 6 shows average values. More precisely, salinity also changes significantly with water depth, increasing for deeper layers. For the sea area considered witin the project, the salinity at the surface (water depth 0 to 20 m) is about 1.0 % [2], [9].

For the salinity in the surf air, data of 1 mg salt per cubic meter of air were found. All literature references found referred to a determination from the year 1955 [10]. However, since the salinity of the water is already low, it can be assumed that the salinity of the air is also very low.

Vibrations due to propulsion systems on board

The propulsion systems on board (propellers, engines and auxiliary machinery) generate vibrations during their operation. The fundamental frequency of propellers is around 20 Hz for fixed-wing propellers between 5 and 6 meters in diameter, and 10 Hz for propellers between 8 and 10 meters in diameter. [11] Engine vibration is caused by the periodic piston / crankshaft motion. Excitations caused by free forces and moments in the engine can be transmitted to the ship's structure, especially in medium-sized ships with 2-stroke engines. Ship engines oscillate, depending on the engine load, mainly between 3 and 100 Hz [11], [12] but also have small portions in higher frequency ranges up to 300 Hz (Figure 7) or more.

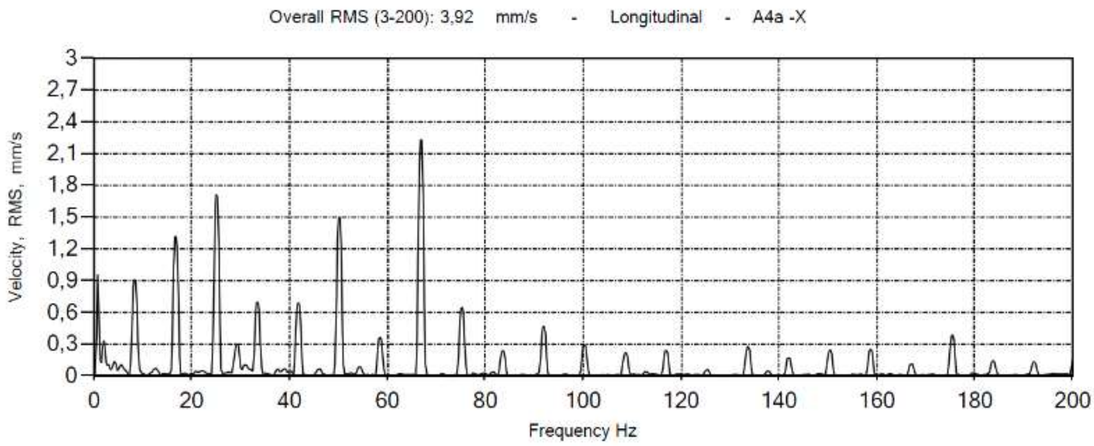

Figure 7: frequency spectrum of vibrations of a marine engine (Wärtsilä W32/34 V engine at 100% load) [12]

Summary

The following conditions are expected while crossing the Baltic Sea:

	WORST Case **entire Baltic Sea**	**Normal Case** **ALBERO-Scenario**
wave height	5,5 m	1,0 m
roll angle	27°	5°
roll time (GM = 0,6)	no linear dependency	ca. 20 sec
storm days	117	39
humidity	88 %	83 %
salinity of the water	ca. 2 %	ca. 1 %
salinity of the air	1 mg/m^3	1 mg/m^3
vibrations	3 to 100 Hz	3 to 100 Hz

table 3: summary of transport conditions – „worst case“ and „normal case“

In accordance with this, test conditions for batteries should be designed for simple transport or during charging.

Literature

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