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Feasibility Studies on a Planned Deep Water Port in Germany

- Wave Load and Wave Overtopping at the Quay Structure -

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Abstract

At the German Jade-estuary a new deep water port is planned. A feasibility study on the new container terminal comprises a cost-benefit analysis, the preliminary design of terminal infrastructure and the modelling of terminal operations as well as the design of the quay wall. The design of the quay wall is based on geotechnical investigations, analyses of the change in tidal effects due to the planned terminal, and of its environmental consequences as well as on wave loads and wave overtopping.

Introduction

The existing two main German container ports, Hamburg and Bremerhaven, are connected to the North Sea via access channels of 14.50 m depth. Therefore the largest container ships with loads of more than 8000 TEU can reach these harbours only during tidal high water [1]. A deepening of the existing access channels is subject to objections because of environmental impacts. For this reason and because of the increasing overseas container business plans for a new German deep water port, called JADEPORT, are underway. The new harbour is planned at the Jade-estuary north of the existing dock harbour of Wilhelmshaven (Fig. 1).

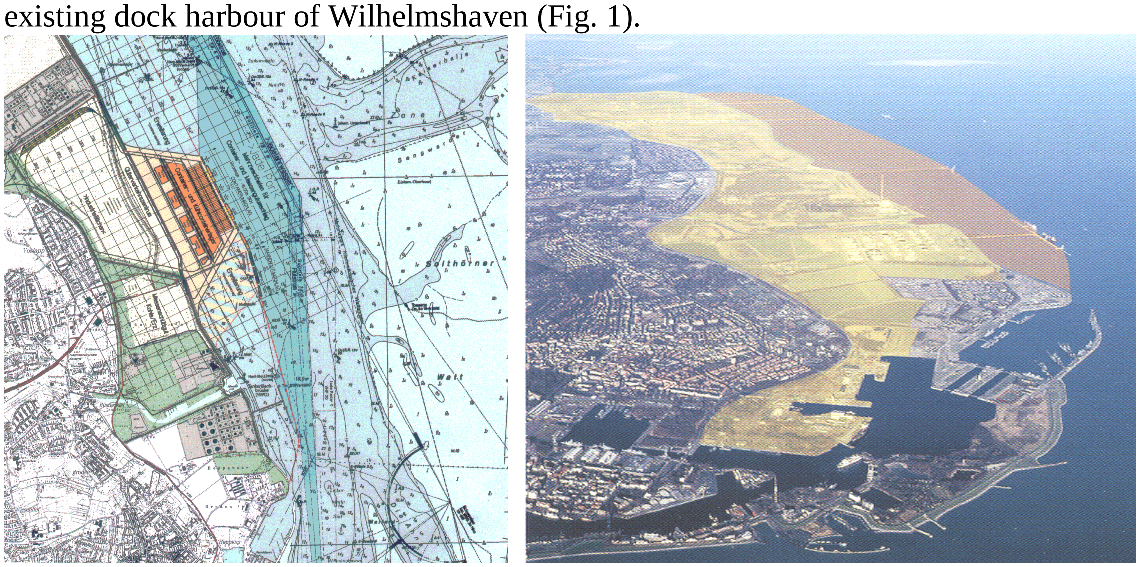

Fig. 1 Location of the planned deep water port at the Jade-estuary, Germany
(left: topographic chart, right: aerial view [2])

The existing approach channel has a natural depth of 18.50 m requiring no major maintenance dredging. Besides a cost-benefit-analysis and studies on the operation of the new container-terminal and its environmental impact, the hydraulic conditions, especially wave load and wave overtopping, at the new quay wall were analysed within a feasibility study. The analysis of wave impact on the quay wall is analysed here.

Wave load and wave overtopping are important parameters for the design of the quay wall of the planned container. Typical design types of quay walls are given in figure 2. Wave overtopping at a standard vertical wall (Fig. 2a) can be reduced significantly by a curved parapet at the top of the wall (Fig. 2b) or by an absorbing chamber (Fig. 2c) [3]. Fig. 3 shows the final design of the quay wall of the JADEPORT, i.e. a vertical wall with curved parapet. An alternative design with absorbing chamber, having been realised at the container terminal of Bremerhaven in 1994/97, was rejected for economic reasons.

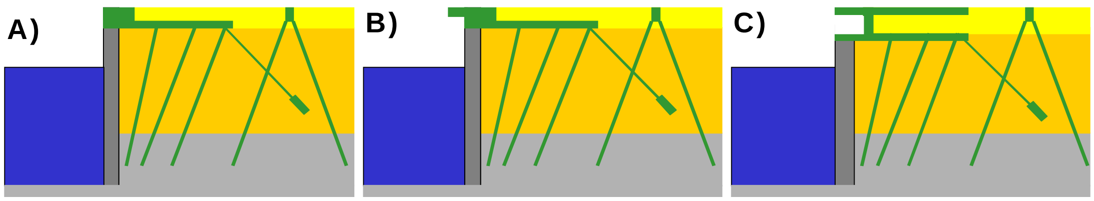

Fig. 2 Typical designs of quay walls: a) vertical wall, b) vertical wall with curved parapet (nose), c) vertical wall with wave absorbing chamber

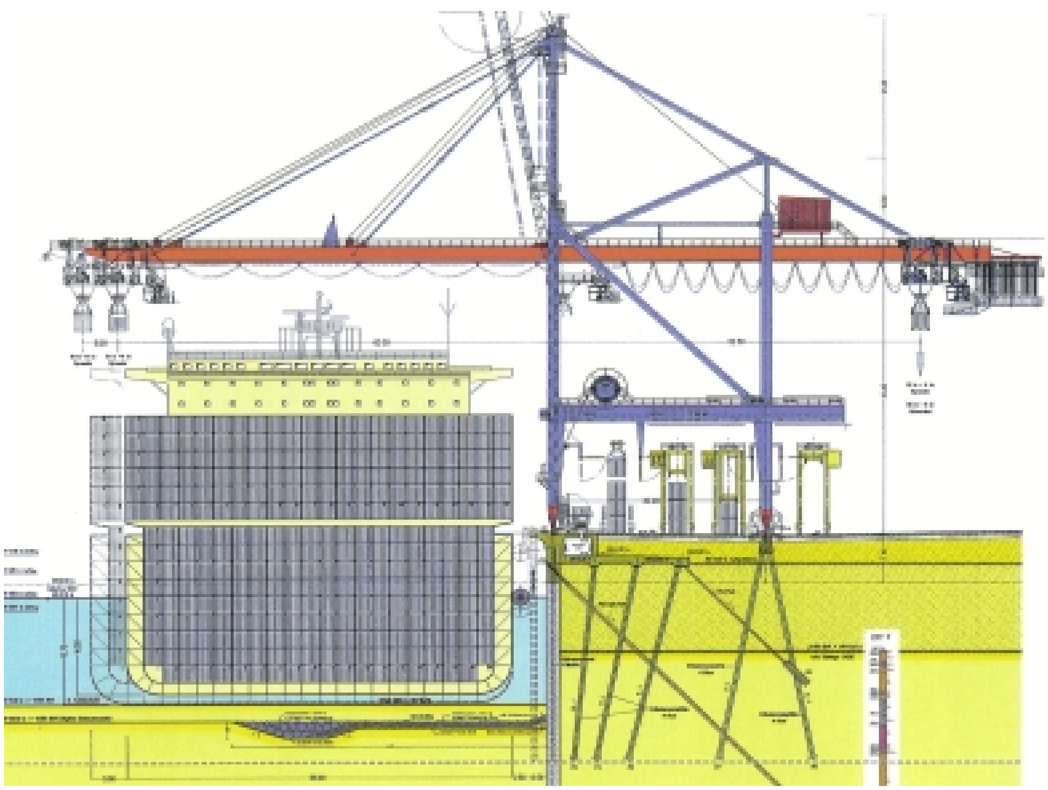

Fig. 3 Draft of the planned quay [2]

The height of the quay wall is set to 7.50 mNN (m above German Datum ≈ m above MSL) based on storm surge water levels in the German Bight.

Design Storm

Extreme wave attacks on the planned quay wall are originated from storms over the North Sea. Table 1 lists the maximum historically recorded tidal high water-levels at a gauge near Wilhelmshaven and the corresponding wind conditions. The highest tidal high water-levels HHThw are generally related to westerly to north-westerly winds with a maximum for a wind direction of 280° (Fig. 4).

date	Tidal high water-level Thw (mNN)	Wind velocity u_{10} (m/s)	wind direction (°)
16.02.1962	5.23	22.1	280°
21.01.1976	4.86	19.8	270°
03.01.1976	4.76	22.4	300°
(04.01.1976)	(4.05)	(14.1)	(340°)
31.12.1977	4.74	17.7	320°
19.11.1973	4.56	22.1	320°

Tab. 1 Historic storm conditions at the planned quay wall

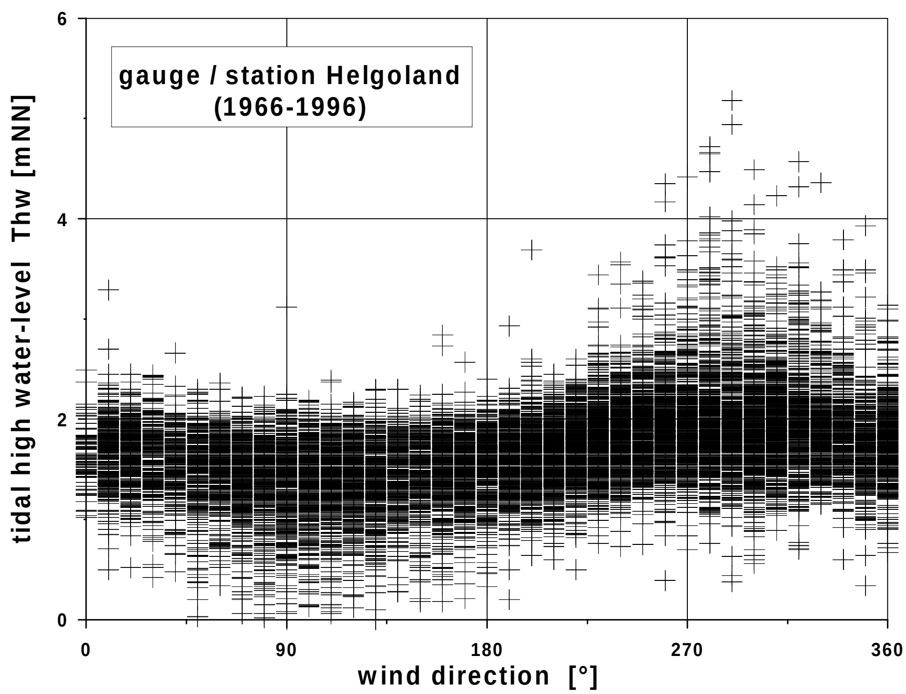

Fig. 4 Correlation of tidal high water-level and wind direction at the gauge / meteorological station of Helgoland in the German Bight

For these storm conditions the planned container-terminal is located on the lee coast, which is a great advantage compared to the existing terminal in Bremerhaven because maximum water-levels do not coincided with maximum wave heights, Fig.5.

Numerical Simulation of Wave Propagation

The wave load at the planned quay structure was estimated carrying out numerical simulations of the wave climate in the estuaries of Jade and Weser using the model SHALLOW WAVES NEARSHORE (SWAN) [4]. The wave model was calibrated using field measurements of the wave parameter (buoy data) collected in a monitoring programme near the island of Pellworm at the North-Frisian coast of Germany [5]. This calibration was also used for modelling waves in the estuaries Jade and Weser. Fig. 5 shows an example of the wave propagation in the estuary during an extreme storm event.

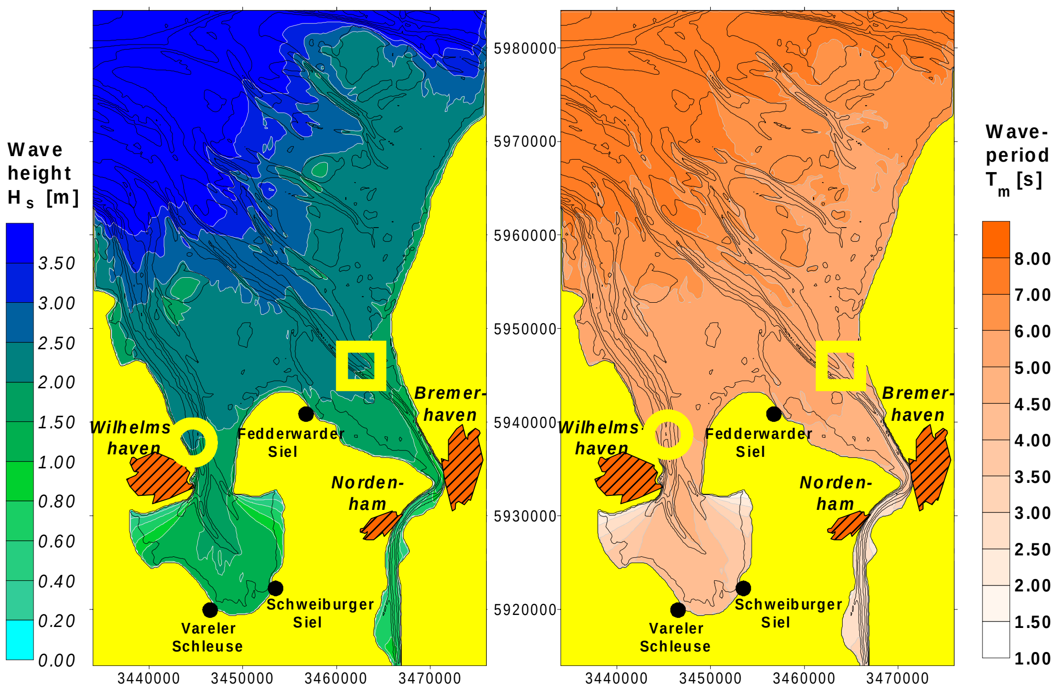

Fig 5 Wave characteristics within the estuary of Jade and Weser
-significant wave height (left) and mean wave period (right)-
during an extreme storm surge (water-level: 6 mNN, wind: 24 m/s, 0°)
(circle: reference point near the planned quay, square: location of wave rider buoy)

The incoming wave field at the northern boundary of the model was parameterised by deepwater wave forecasting equations assuming fully arisen sea [6]. The parameterisation was checked by comparison with results of the instationary long-term numerical wave forecast of the "Bundesamt für Seeschiffahrt und Hydrograhie" (BSH) – the German institute for hydrography – for the whole North Sea (Fig. 6).

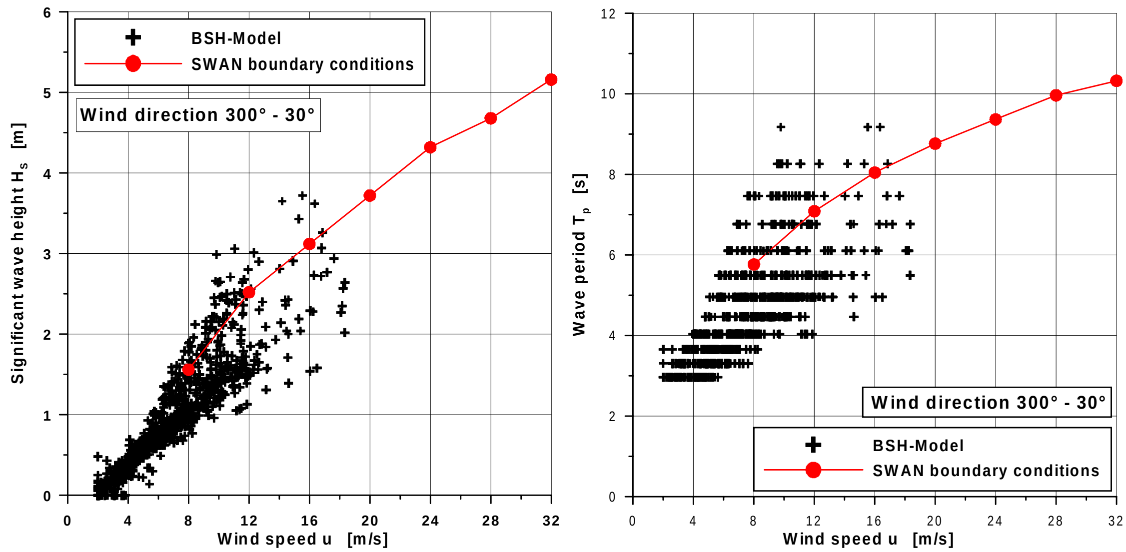

Fig. 6 Comparison of boundary wave characteristics– deepwater wave forecasting equation versus instationary numerical wave forecast significant wave height (left) and peak wave period (right)

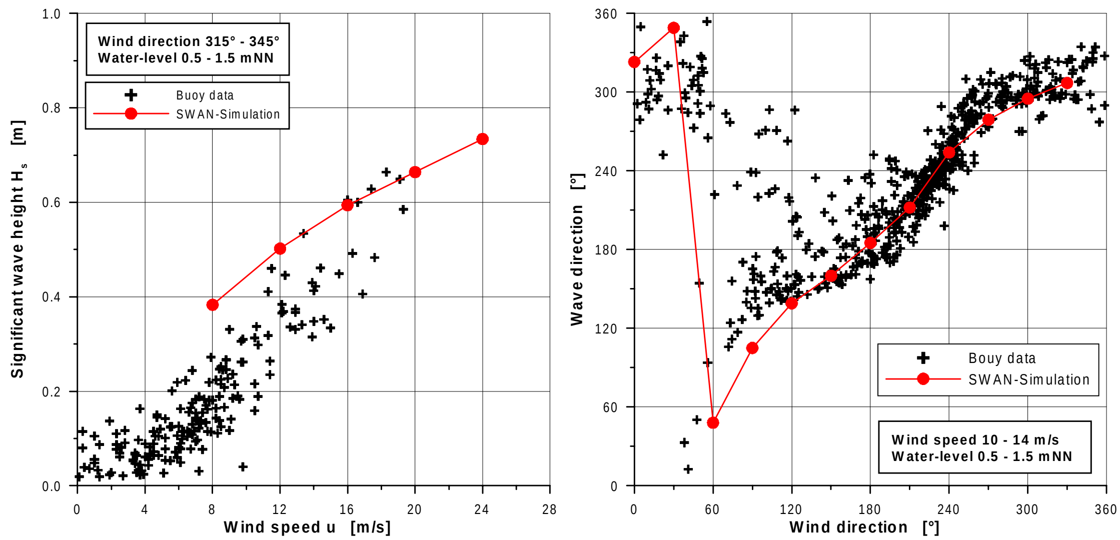

Fig. 7 Relation between wave parameters and wind results of long-term measurements (black) and of stationary simulations (red)

The results of the presented wave model were tested using wave data collected with a wave rider buoy deployed at the position in the estuary Weser, marked in Fig. 5, during the construction works of the Container-Terminal CT III in Bremerhaven in 1997/1998 [7]. An example of wave height and direction is shown in Fig. 7. The experimental data are widely scattered. The stationary wave simulation gave a good estimate of the maximum significant wave height as a function of wind speed and represent the relation between wave direction and wind direction, especially for northerly winds, with good result.

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Wave Load on the Quay Structure

The numerical simulations of wave propagation were carried out for water-levels from 4 mNN to 6 mNN and winds with speeds from 16 m/s to 32 m/s and directions from 270° to 90°. Fig. 8 shows the dependence of the wave parameters at the planned quay structure, derived from numerical simulation (see Fig. 5, circle), on the wind direction for different water-levels. Significant wave height and mean wave period are maximal for wind direction from 0° to 30°. The maximum wave height ranges from 1.8 m to 2.2 m, the maximum mean wave period ranges from 4.6 s to 5.1 s for storm surge water-levels from 4 mNN to 6 mNN and a wind speed of 24 m/s. The mean direction of the waves at the quay varies form approximately 5° to 25° for wind directions from 0° to 30°. Due to the orientation of the planned quay (334°) this corresponds to an angle of attack from 59° to 39°. A perpendicular wave attack on the quay wall is related to wind directions of 80°.

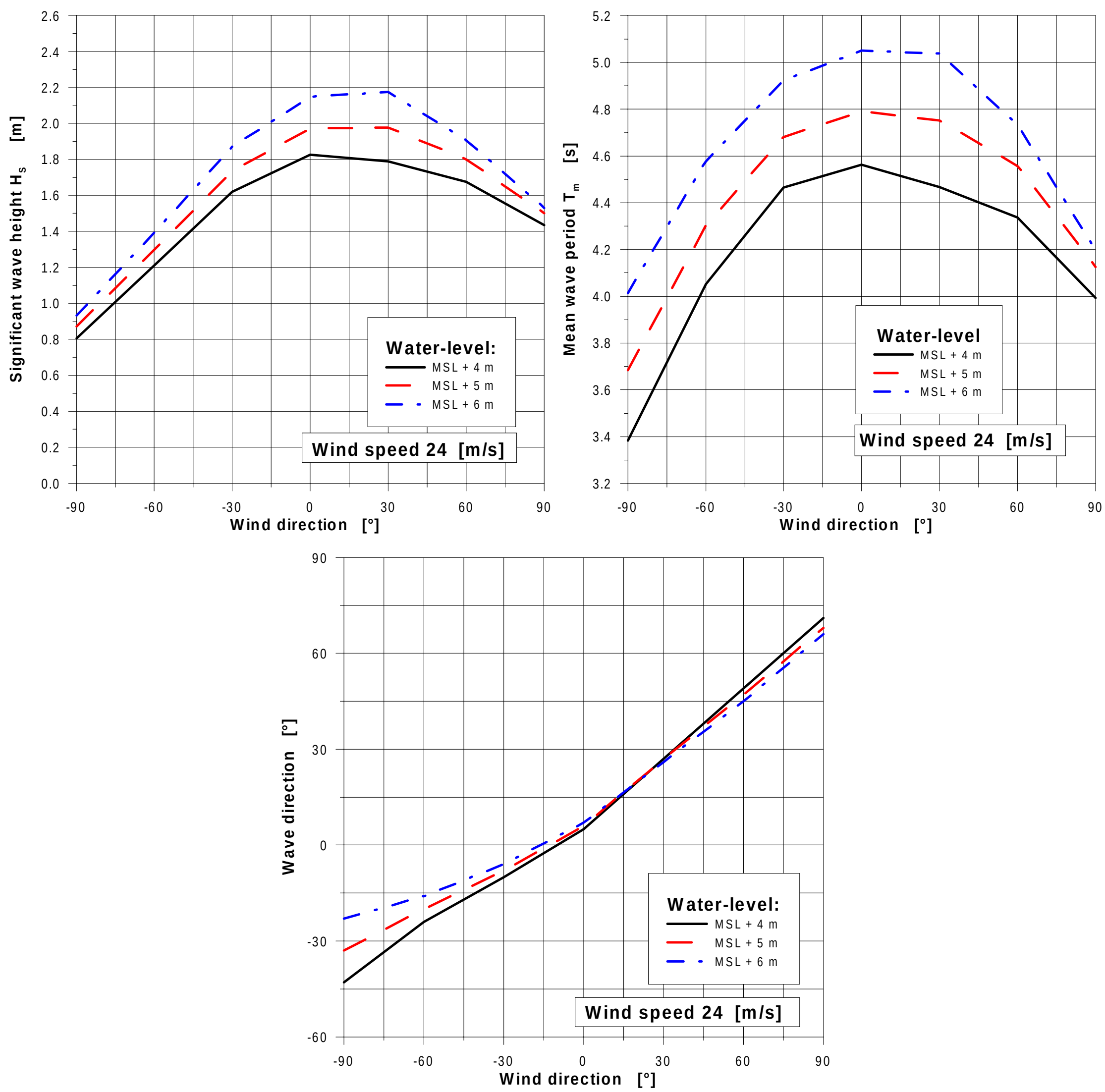

Fig. 8 Wave load at the planned quay wall - significant wave height (top left), mean wave period (top right), mean wave direction (bottom)

Calculation of Wave-Overtopping

The overtopping rate at the planned vertical quay wall was calculated from the wave load at the structure using a formulation proposed by Franco [8]

$$q = \sqrt{g \cdot H_s^3} \cdot 0.082 \cdot \exp\left(-3 \cdot \frac{R_c}{H_s \cdot \gamma_{\beta\sigma} \cdot \gamma_{geom}} \right) \tag{1}$$

$$\gamma_{\beta\sigma} = \begin{cases} 0.83 & \text{for} \quad \beta \le 20° \\ 0.83 \cdot \cos(20° - \beta) & \text{for} \quad \beta > 20° \end{cases} \tag{2}$$

$$\gamma_{geom} = \begin{cases} 1.000 & \text{Plain wall} \\ 0.783 & \text{Plain wall with nose} \\ 0.722 & \text{Plain wall with wave chamber} \end{cases} \tag{3}$$

with the significant wave height H_s, the freeboard of the quay wall R_c and the angle of wave attack β. Fig. 9a shows the rate of wave overtopping at a plain wall as a function of wind direction. The maximum overtopping rate ranges from 0.4 l/m/s to 60.0 l/m/s for storm water-levels from 4 mNN to 6 mNN and north-easterly winds with a speed of 24 m/s. But the maximum overtopping rate is significantly reduced in the event of a more probable north-west storm, not exceeding 1.0 l/s/m. For all historic storm surges, mentioned in Tab. 1, the overtopping rate does not exceed 0.001 l/s/m. Additional features at the vertical quay wall, like curved parapet (nose) and absorbing chamber, reduce the maximum overtopping rate up to 50 % (Fig. 9b).

a) b)

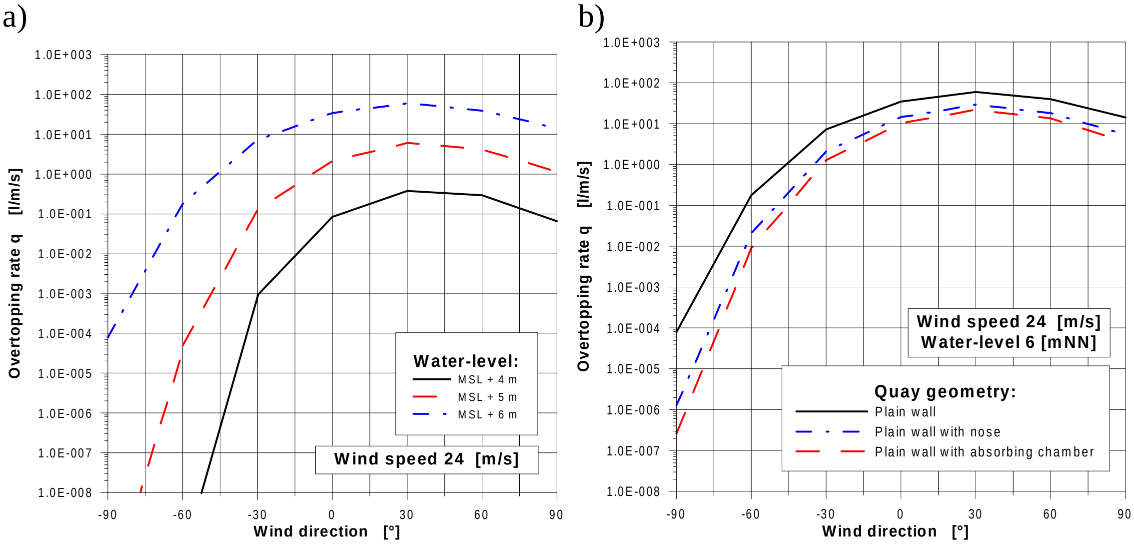

Fig. 9 Wave overtopping at the planned quay wall
plain wall for different water-levels (left)
different wall geometries for a water-level of 6 mNN (right)

Results

The calculation of wave overtopping at the quay wall of the new deep water port JADEPORT near Wilhelmshaven confirmed that the chosen design (plain wall with curved parapet) assures the functional safety of the container terminal. For all historic storm events the overtopping rate is less than 0.001 l/s/m, the upper limit of safe vehicle operations on the quay at all speeds given by Franco [9].

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