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Internet-based Tools for Risk Assessment for Coastal Areas

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ABSTRACT: The design of coastal defenses is traditionally deterministic. A means to an improved design is the probabilistic design. In order to carry out a probabilistic design various boundary conditions and the resulting hydraulic loads, i.e. wave parameters, water-levels, have to be taken into account. For a better overview the hydraulic loads for different boundary conditions are composed in an internet-based tool. Besides the hydraulic loads the resistance of the coastal protection elements had to be considered in probabilistic design. Information on the protection elements were therefore collected in an internet-based atlas. On this basis a risk analysis was carried out taking also into account the consequences of failure.

1 INTRODUCTION

At the German North Sea Coast the hinterland is protected from flooding by a system of coastal protection elements. The design of the artificial coastal protection elements like brushwood fences, summer dikes or main dikes is traditionally deterministic. Since various institutions are responsible for the design of coastal defences the sources of data are widely spread. In the moment only first steps have been undertaken to compose these data in one information system. Kaiser et al. (1999) proposed a data base for coastal protection management of Lower Saxony, Germany. The Ministry of Rural Areas, Agriculture, Food and Tourism of Schleswick-Holstein (1999) put forward an inventory of the values in the coastal hinterland being at loss in case of flooding.

Present data bases of coastal defenses in Germany comprise almost only some information on the coastal structures and their resistance but the loads are not incorporated in the data bases. The incorporation of loads is especially essential for an improvement of the deterministic design method towards a probabilistic one.

Both, a collection of the hydraulic loads and of the resistance of the coastal structures, were put into an internet-based atlas respectively inventory. Using these tools a risk analysis was carried out for the coastal area between the two German cities Wilhelmshaven and Bremerhaven located at the two major estuaries Jade and Weser.

2 BASIC DESIGN TOOLS

Every design process can be divided into two steps: the determination of the resistance of the coastal defense system and the estimation of the hydraulic loads. Comparing the resistance and the stress caused by the hydraulic loads the reliability of the coastal defense system can be determined (Fig. 1).

An atlas describing the coastal structures must contain all parameters required, e.g. the dimensions of the coastal protection elements and of the protected coastal area with the specific land use and infrastructure (Kaiser et al., 1999).

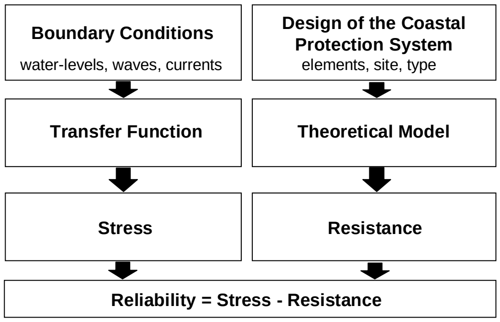


Fig. 1: Design steps

An example of the internet-based atlas of coastal protection elements is presented in figure 2 for the test area between the estuaries Jade and Weser. The atlas provides satellite images, topographic maps, aerial views and information like year of construction, location, height, width, length, photographs, technical drafts, construction materials, building costs and, if available, additional information of protection elements like sluices, storm surge barriers, dikes or revetments.

Apart from the characteristics of the protection elements statistics of the hydraulic loads, i.e. water-levels and waves, are introduced into the atlas of coastal protection elements. These information have been derived using the internet-based atlas of hydraulic loads (Fig. 3). The atlas provides information on the wave characteristics, i.e. significant wave height and mean wave period, for different water-levels and wind conditions. This information was derived using the numerical model Shallow Wave Nearshore (SWAN, Ris, 1998). Figure 3 shows for example the significant wave height calculated for a water-level of 4 m above German datum and northerly winds (330°) of 20 m/s. For this set of boundary conditions the hydraulic loads along the coast were determined using the data base of the atlas. Taking into account the joint probability distribution of different sets of water-levels and winds the statistics of the hydraulic loads directly at the coast were calculated.

The basic functionality of both atlases was realized within HTML. Data base operations were carried out employing JAVA. Both tools are used in the intranet of the University of Hannover while an internet version of the atlas of the hydraulic loads only provides a reduced functionality.

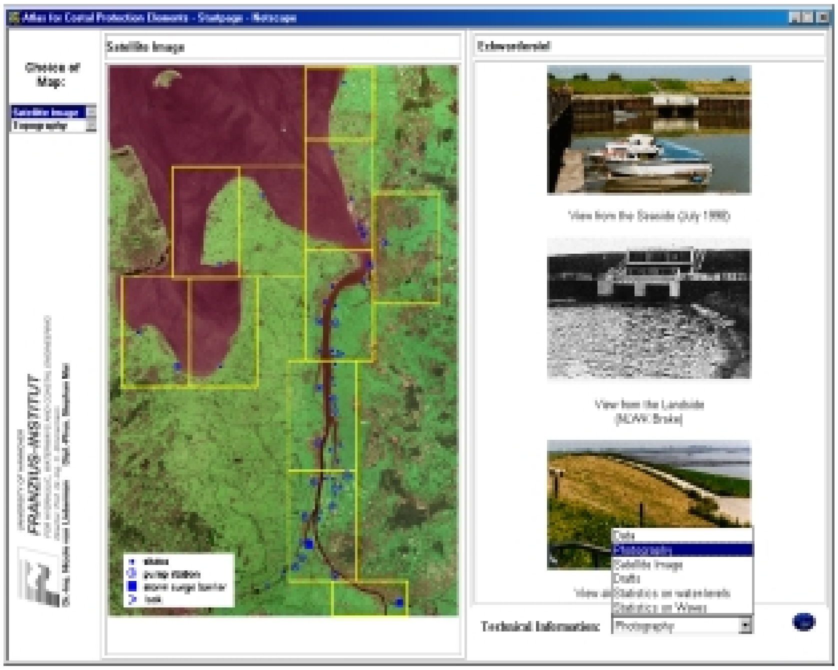


Fig. 2: Internet-based atlas of coastal protection elements

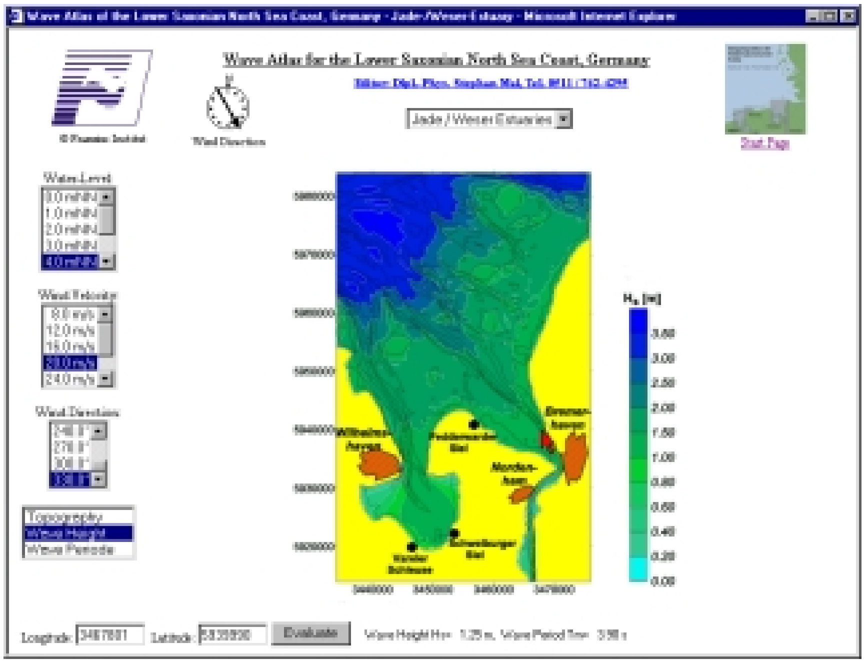


Fig. 3: Internet-based atlas of hydraulic loads

Using these tools the reliability of the coastal defence system was evaluated. As an example the reliability of a sea dike, the main coastal protection element, was calculated. Figure 4 shows different failure mechanism of sea dikes. The most important mechanisms are overflow and wave overtopping. A mathematical formulation of these failure modes is given by

$$Z = h_D - Thw - R_{98\%} \qquad (1)$$

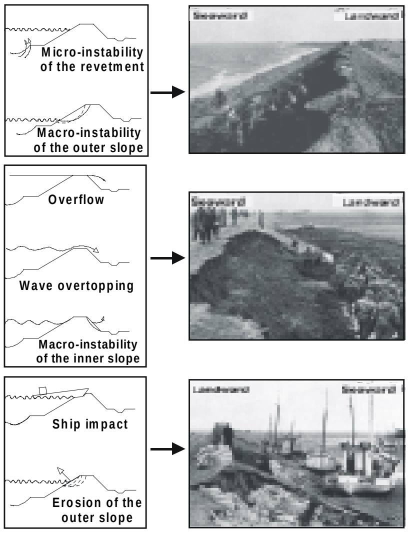
with

Z	reliability function
h_D	height of the dike
Thw	tidal high water-level
$R_{98\%}$	wave run-up

Using equation 1 failure occurs for $Z < 0$. Because the tidal high water-level and the wave run-up are stochastic parameters the reliability function is also stochastic (Mai et al., 1997). The probability of failure respectively the recurrence interval T is calculated by

$$\frac{1}{T_{Z<0}} = p_{Z<0} = \int_{-\infty}^{0} p_{Z(Z)} dZ \qquad (2)$$

$$= \int_{-\infty}^{\infty} \int_{h_D - Thw}^{\infty} p_{(Thw, R_{98\%})} dR_{98\%} dThw$$



(NMELF, 1979)

Fig. 4: Failure mechanisms (von Lieberman and Mai, 1999)

The wave run-up is calculated using the wave characteristics in front of the dike according to Battjes (1971):

$$R_{98\%} = \gamma \cdot 0{,}75 \cdot \frac{1}{n} \cdot T_m \cdot \sqrt{g \cdot H_S} \qquad (3)$$

with:

γ	roughness parameter
1:n	slope of the dike
T_m	mean wave period
g	acceleration of gravity
H_s	significant wave height

The recurrence interval of wave-overtopping at dikes along the Jade-Weser estuaries was calculated according to the scheme presented in equations 1 to 3. The input parameters for this scheme as the height of the dike, the distribution of the tidal high water-level, and the statistic of waves were exported from the atlas of coastal protection elements.

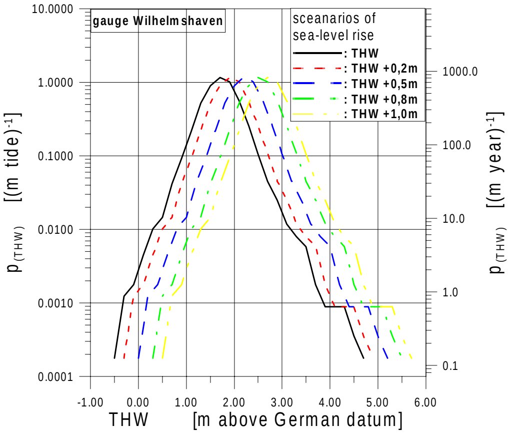


Fig. 5: Probability density function of tidal high water-level at gauge “Wilhelmshaven”

Figure 5 shows an example of the probability density function (pdf) of tidal high water-levels at gauge “Wilhelmshaven”. Different scenarios were introduced by shifting the pdf to higher tidal high water-levels. Figure 6 shows the recurrence interval taking into account different scenarios of sea-level rise.

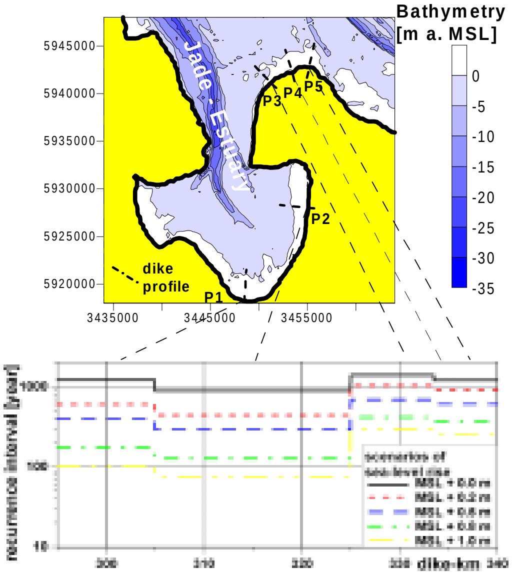


Fig. 6: Recurrence intervals of wave-overtopping for different scenarios of sea-level rise (Mai and von Lieberman, 1999)

3 RISK ANALYSIS

A measure for the design of coastal systems is the risk analysis. The risk R comprises an estimation of the failure probability $p_{Z(Z)}$ of the coastal protection system and the expected loss $C_{(Z)}$ in case of failure:

$$R_{(Z)} = \int_{Z<0} p_{(Z)} \cdot C_{(Z)} dZ \qquad (4)$$

The expected loss is calculated using the maximum loss and the damage factor depending on the inundation characteristics. Figure 7 shows the property asset for a county within the test area. The property asset was determined using public statistics. The distribution of values within the county was estimated using a top-down approach in order to scale down the property asset for the whole county to property assets on a 1 km x 1 km grid.

Within the property different types of values are distinguished in order to incorporate different damage factors for various types of values. Figure 8 shows damage factors of property asset as a function of the inundation depth in case of flooding. For example approximately 40% of the capital stock of the industry is lost in case of a flooding depth of 2 m.

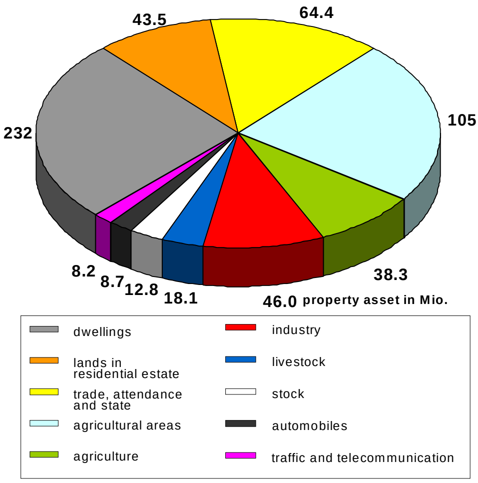


Fig. 7: Property asset of the county between the estuaries Jade and Weser (according to Schmidtke, 1990)

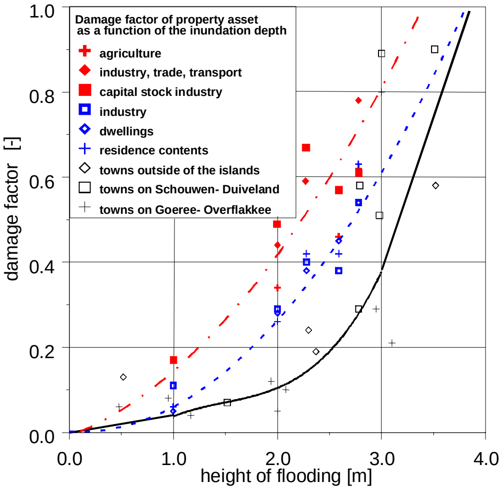


Fig. 8: Damage factor of property asset as a function of the inundation depth (CUR, 1990)

The inundation depth is calculated assuming dike breaches at different locations within the test area. The calculation was carried out using the numerical model MIKE21-HD (Abbot et al., 1985). Figure 9 shows an example of a dike breach at the Jade estuary flooding the hinterland approximately eight hours after low water during a storm surge in 1976. Taking into account former dike breaches the width of the dike breach was estimated with 200 m. At this location with a height of the hinterland of approximately 2 m above German datum a semi-circle of approximately 25 km² is flooded. The flooding depth decreases from 3 m directly at the dike to 0 m. Therefore the damage factor ranges from 0% to 80% according to Figure 8. Taking into account the flooding depth and flooded area (Fig. 9), the damage factor (Fig.8), and the property asset of the county between the estuaries Jade and Weser (Fig. 7) the costs C for this event are approximately 50 Mio. €.

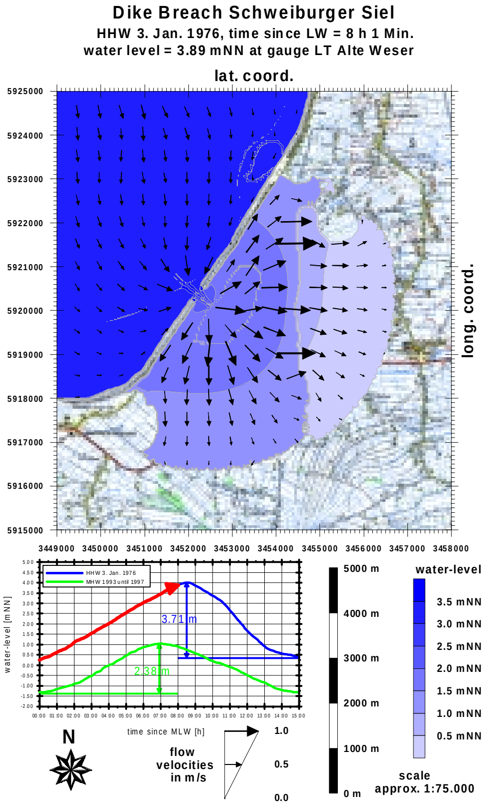


Fig. 9: Dike breach at the Jade estuary flooding the hinterland

The probability p_i of this event is approximately 0.001. This probability does not vary very much for dike breaches at other positions along the coast between the estuaries Jade and Weser. As well as the failure probability the expected loss due to flooding is rather independent of the location of a dike breach. The overall probability p_{total} of a dike breach at any location of this coastline is 0.002 considering the correlation of dike breaches at different positions at the same time. The correlation length (CUR, 1990) was calculated to

$$p_{total} = p_i \text{ x } (1+0.0054 \text{ x } l_D/l) \qquad (5)$$

with:

l_D length of the dike

l length of a dike segment (= 200 m)

The risk calculated according to equation 4 is approximately 100,000 € per year. The results of the risk analysis were implemented in the GIS ARC/VIEW. Major results were exported into the internet-based tools for risk assessment for coastal areas.

4 CONCLUSIONS

The developed internet-based tools help to clarify the problems in coastal protection management. They can help to optimize the allocation of investment in coastal protection in order to get the same standard of safety (in terms of risk) along the coast.

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