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RELIABILITY ANALYSIS OF RIVER DIKES CASE STUDY: ELBE RIVER IN SAXONY, GERMANY

Part of the research project PCRiver - Reliability and Risk Analysis in River Flood Protection under Consideration of Geotechnical, Hydrological and Hydraulic factors

National joint research activity RIMAX – Risk Management of extreme flood events supported by the German Federal Ministry of Education and Research (BMBF)

Risikomanagement extremer Hochwasserereignisse
rimax

Software Package PC-Ring

- Particular threat of the Netherlands by floods
- Absolute safety against flooding does not exist

Modern Risk Management on the basis of the Software PC-Ring

- Determination of the failure probability of dikes
- Systematic determination of the probability of inundation of the hinterland

Fig. 1: Dike ring areas under investigation in the Netherlands

Aims

- Extension of PC-Ring to inland river areas in Germany
- Identification of weak elements within flood protection systems
- Cost-benefit-analysis as basis of an efficient Risk Management
- Recommendations for the reduction of the risk of flooding

Failure Modes

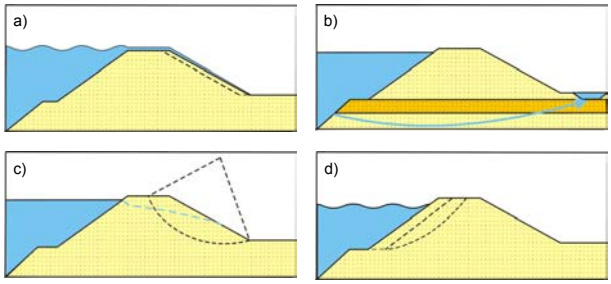

Fig. 2: Scheme of considered failure mechanisms a) Overflow / wave overtopping, b) Uplift / piping, c) Slope instability, d) Damage of the revetment on the waterside

For a reliability analysis, a **limit state equation Z=R-S** needs to be defined for each failure mechanism under investigation. Failure is defined if the acting forces S exceed the resisting forces R of the structure and therefore Z < 0. If both, acting and resisting forces are described by a probability density function, the **failure probability P(Z<0)** can be determined as the area being intersected by the two density curves R and S. First, the failure probabilities for the various failure modes are combined for one dike section. Afterwards, all dike sections within a dike stretch are combined taking a spatial variability and correlation of the inherent input parameters into account.

Case Study: Elbe River in Saxony, Germany

Fig. 3: Dike sections and available subsoil samples

PC-Ring is being applied on dike investigations along a **2.3 km long river stretch** in the vicinity of the city of Mühlberg along the Middle Elbe River in Saxony. This dike stretch has been subdivided in three sections of different characteristics. The applicability of the software meeting the particular conditions of the area of investigation and the available data is being tested in great detail within an **extensive sensitivity analysis**.

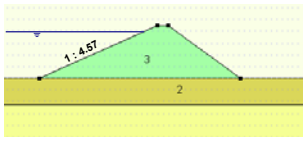

Fig. 4: Dike cross section at Elbe km 129.1 - 129.9

Soil Investigation

The uncertain quantities are introduced in the reliability analysis as stochastic input parameters. They are defined by their **mean value, standard deviation or coefficient of variation and their correlation length**. In order to obtain these statistical moments, an **evaluation of a wide data base** is usually required.
The **Environmental Information System of Saxony** provides extensive information on soil layers, grain size distributions, clay classification and standard penetration tests. With the help of common correlations of Soil Mechanics (German codes, Schmertmann (1978)) further estimates of permeabilities and shear strengths of the layers may be obtained. In other cases in which the data base is rather weak, the statistical properties are adopted from Phoon&Kulhawy (1999). If the data base provides sufficient data, the **effect of spatial correlations** of the soil properties is taken into account using a Point Kriging procedure.

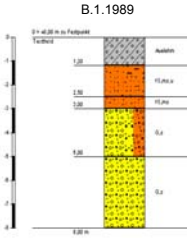

Fig. 5: Example of profile of a borehole

Hydraulic Boundary Conditions

The hydraulic loadings are defined by the **hydraulic boundary conditions** of the system, i.e.

- local water levels and
- local wind induced waves

at each cross sections under investigation. The respective input parameters are defined by appropriate **statistical models** or generated by **numerical simulations**, respectively.
The prevailing processes or variables for the determination of the input parameters for inland river investigations are

- discharge & water level,
- duration & shape of the flood waves and
- wind speed and direction.

The **hydrological basis** of the probabilistic computations is formed by the statistical variables return period T(Q) [a] of the extreme discharge events and the mean exceedance duration N(Q) [d] of a certain discharge level. Therefore, it is required to evaluate **discharge hydrographs** in an appropriate manner and prepare the data for the PC-Ring computations in terms of Workline (return period) und Exceedance Duration Line.

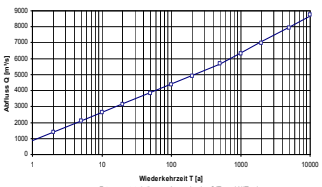

Fig. 6: Workline at the gauge station Dresden as input for the PC-Ring computations along the Elbe case study site (basis: yearly extremes from 1851 - 2002)

Comparison of Failure Probabilities

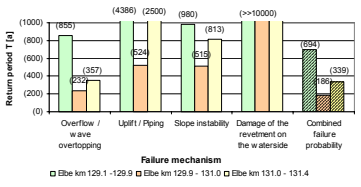

Fig. 7: Comparison of the return periods [a] with respect to the failure modes for the dike sections Elbe km 129.1 - 131.4

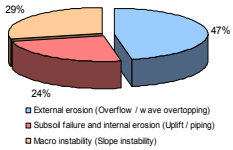

Fig. 8: Frequency of dike breaches at dike stretches of homogeneous composition in Saxony, Germany during the Elbe flood 2002 with respect to their major failure modes (Source: „Analyse der Deichbrüche an Elbe und Mulde während des Hochwassers im Bereich Sachsen", TU Dresden, Institute for Hydraulic Engineering and Applied Hydromechanics, for the Dam Authority of Saxony, April 2005) (modified)

- Validation of the results by comparison to common design practice by adapting dike height to HQ_{100}-water level
- Overflow / wave overtopping is the governing failure mechanism
- Failure probabilities for uplift / piping and slope instability are of comparable order of magnitude
- Minor influence of wind ⇨ Wave effects can be neglected
- Comparison of the failure probabilities for the different failure modes shows similar tendencies as the frequencies of dike breaches during the Elbe flood 2002 in Saxony, Germany

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