Die Küste, 81 (2014), 473-479

Recent Developments in Hamburg's Coastal Protection

Jan-Moritz Müller and Gabriele Gönnert

Summary

In 2012 Hamburg's government decided to raise the design water levels of the tidal River Elbe in the Hamburg region by about 0.80 m. As a consequence, the primary flood defences in the city have to be reinforced and heightened during the next 25-30 years. Prior to implementing the strengthening program for the dikes and sea walls, extensive design work has to be carried out, including wave simulations and the determination of freeboard heights, resulting in new crest levels for the various coastal flood protection facilities in the city.

Keywords

flood protection in Hamburg, hydrodynamic loads, mathematical modelling, EurOtop, SWAN, design water levels

Zusammenfassung

Im Jahr 2012 hat der Senat der Stadt Hamburg neue Bemessungswasserstände für den Hamburger Bereich der Tideelbe beschlossen, die etwa 0.80 m über den bisher gültigen liegen. In den kommenden 25-30 Jahren werden die Hochwasserschutzanlagen erhöht und verstärkt werden müssen. Vorab sind jedoch umfangreiche Arbeiten zur Ermittlung des neuen Bemessungsseegangs und der neuen Freibordhöhen nötig, die zu den neuen Ausbauhöhen der vielfältigen Flutschutzbauwerke Hamburgs führen.

Schlagwörter

Hochwasserschutz in Hamburg, hydrodynamische Belastung, mathematische Modellierung, EurOtop, SWAN, Bemessungswasserstände

Contents

1 Introduction 474
2 Strategy for the primary storm flood defence of Hamburg and HafenCity 474
3 Design water levels – multi-method approach 475
4 Wave modelling 476
5 Wave overtopping and dike profile 478
6 Implementation of the improvement program 478
7 References 479

1 Introduction

Rising sea levels are threatening coastal regions, especially cities located in estuaries and river deltas. Raising the height of the primary flood protection constructions such as sea dikes and barriers in city areas often causes problems due to the limited availability of space, financing and finding economic and environmentally sustainable solutions that provide on the one hand a very high safety standard and on the other, accommodate the different interests.

The city of Hamburg is located at the Elbe estuary, about 110 km away from the North Sea, from which this region of northern Germany is seriously threatened by storm surges. In addition to the storm surges, high river runoff from inland rivers into the Elbe should not be neglected. The river marshes can be threatened by both risks simultaneously. About 45% of the city is located in low lying areas, which without dikes, would be flooded by storm surges. The total surface of the low area protected by dikes is 342 km², with around 326,000 inhabitants living there.

Coastal flood protection in Hamburg is divided into three parts: public flood protection, consisting of flood protection walls and sea dikes, private flood protection, mainly applied as individual object protection in the HafenCity, and flood protection in the harbour area. The 103 km long public flood protection in Hamburg consists of 78 km of dikes, 25 km of sea walls and 86 other constructions inside the primary flood defences, such as pumping stations, locks and barriers. Since the water level in the Elbe estuary is influenced by the North Sea tides, the dikes along the River Elbe in Hamburg are classified as coastal protection.

2 Strategy for the primary storm flood defence of Hamburg and HafenCity

The height of Hamburg's flood protection constructions has been increased several times during the past decennia. When a new flood protection barrier is being built or an existing one significantly reinforced as part of a construction program, allowance must be made for a possible further increase of 0.80 m (extension capacity) in the future. This strategy enables the planners to extend the construction in an economical way.

In the 1990s, the Government of the City of Hamburg created a Masterplan to build a new residential and business district in an old harbour area that is no longer used for trading purposes. This Masterplan was approved by the Hamburg Senate in 2000. The new district, known as HafenCity, is located outside the area that is protected by the public flood defence. The buildings in this area need to be protected by individual object protection, such as flood gates, or they have to be built on artificially elevated ground. This safety concept is based on a high level of personal responsibility by the people living and working in this area. The new HafenCity district consists of two parts. One is situated around the Speicherstadt, which is characterized by old warehouses that were built at the end of the 19th century. The street level in this part is still on the same level as the old harbour area, and is below the current design water level. This area can become flooded so buildings have to be protected by individual object protection. The other part of HafenCity is built on artificially elevated ground which is high enough to stay dry during high storm tide water levels. No object protection is needed for the buildings on these higher levels. Some of these new buildings are connected to lower ground levels where object protection is needed. The higher elevated streets are connected by evacuation bridges to areas that are protected by the public sea defence. During high storm tide water levels, people can safely leave the higher areas and cross into the safe city centre of Hamburg. The height of the artificially elevated dwelling mounts is determined just like all other flood protection facilities in Hamburg by taking into account the design water level and the local wave conditions. The freeboard at some places in the HafenCity could be reduced slightly by building stairs instead of vertical flood protection walls, as stairs reduce the amount of wave run up. The object protection on the buildings must be designed to withstand not only water pressure, but also ice loading and ice movement. Ice sheets on the River Elbe or in the harbour basins, and high water levels can occur at the same time so object protection along the HafenCity waterfront has to be extra robust up to a certain height to avoid damage to buildings in exposed places.

3 Design water levels – multi-method approach

The design water level is defined as the highest expected water level in a particular region for a certain period of time. It includes astronomical tides, wind surge, external surges and high river runoff. The design water level for the city of Hamburg is determined by the tidal gauge at Cuxhaven. The Cuxhaven values were determined by three methods. The different components that cause the highest storm surge water levels were combined non-linearly by a multi-method approach, which includes deterministic superposition, and numerical and statistical methods. Subsequently, the German Federal Waterways Engineering and Research Institute (BAW) transferred the Cuxhaven water level to Hamburg by a hydrodynamic-numerical model. In Hamburg, the design water levels along the River Elbe reach heights of between 7.90 m and 8.60 m above sea level (see Fig. 1). In the model simulations, a river runoff into the Elbe of 2200 m^3/s was taken into account.

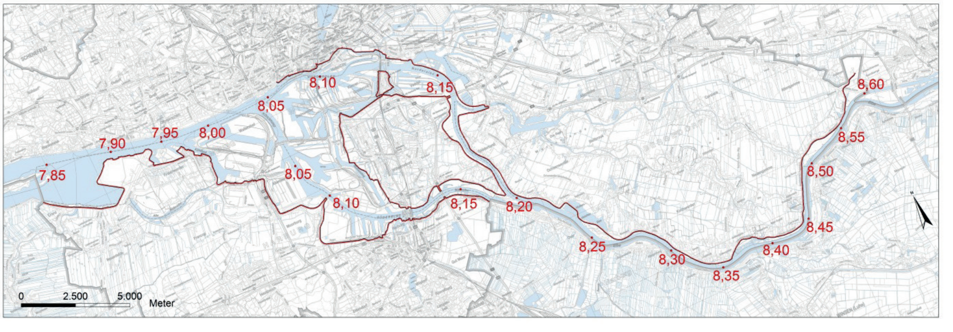

Figure 1: New design water levels for the River Elbe at Hamburg and primary flood protection (red line) (LSBG Hamburg).

Climate change and its consequences will have serious effects on the safety of people and economic values in coastal areas. These uncertainties necessitate new multi-dimensional protection concepts for the dimensioning of coastal protection facilities. In practice, a design level is verified by the required safety standard in a specific region. A probability of occurrence is associated with the design level. This value has to be compared to the required safety standard. If the safety standard for the calculated design level differs from the analyzed safety standard for European metropolitan areas, the design level can be modified in order to ascertain the most effective coastal protection concept.

The developed approach to determine a new design water level for Hamburg involves detailed analysis of the highest single storm-surge components, springtides, external surge and wind surge. The analysis of the storm surge components showed that a combination of all components in their maximum observed value during the same storm surge event has not yet been observed. With regard to the aim to calculate physically feasible extreme events, hydrological feasibility in terms of combinations of all storm surge components have been investigated and found to be meteorologically and hydrologically feasible. As a result, the highest components from the different events are combined in the resulting extreme storm surge event, calculated by using the new approach, taking their non-linear interactions into account.

A multi-method approach has been developed for calculating the non-linear effects between the components. For this approach, alternatives for the calculation of extreme events were evaluated. It transpired that empirical, numerical and statistical methods present important and essential results, each possessing various restraints. In order to utilize the advantages and minimize the limitations and uncertainties, a multi-method approach was developed in which existing methods were exercised and brought together. Where several methods reach the same result, it can be considered reliable. Should the result be confirmed when comparing it with the safety standard for the research area, a basis is provided for spending millions of Euros of tax funding on coastal protection facilities. Examination of the storm surge curve is a special characteristic of this approach, which enables consideration of the whole storm surge run. The basic concept is to regard the results as ascertained only if they are proven by multiple, currently valid methods (GÖNNERT et. al. 2013).

The climate factor is a reserve to maintain the safety standard for a defined period, normally for a further one hundred years. Also considered above all else in the climate factor is a rise in sea level, which in general is the most important influencing factor for future storm surge characteristics. Research analyses point out a huge range of sea level rise projections at the regional level up to the year 2100. An exploratory study analyzed these investigations in terms of a reference study (GÖNNERT et al. 2010). The regional scenarios for sea level rise in the North Sea range from just a few centimetres to 115 cm. Based on this information, the climate change factor must be specified in height for the investigation area; this will always be a technical as well as a specific political decision.

4 Wave modelling

The wave climate and the wave transformation in front of the primary sea defences in Hamburg were computed by the third-generation wave model SWAN (BOOIJ et al. 1999; RIS et al. 1999). Simulations were carried out for the design water level for different wind directions to get the critical wave conditions for every section of the sea defences in Hamburg.

Since the design water level is defined as the crest of the highest expected storm tide curve, currents were not taken into account. Areas in front of the primary sea defences that are on a lower level were assumed to be flooded. The following parameters have been extracted from the wave model at several points in front of the flood protection structure: significant wave height, mean wave period, wave direction, directional spreading and water depth. A uniform wind field was used for all computations with a constant wind speed of 20 m/s and a direction ranging from 180° N to 360° N in sectors of 10 degrees. Westerly winds are mainly responsible for extremely high storm tide water levels in the Elbe estuary. The water level ranges from 7.90 m above sea level at the seaward boundary of the Hamburg part of the river Elbe, rising up to 8.60 m above sea level at the landward boundary near the city of Geesthacht. The water level surface data was taken from the calculations that were carried out by the German Federal Waterways Engineering and Research Institute.

It is assumed that no buildings exist on quays and polders in the harbour area because they might not exist at the time of the design storm surge. In this way, a conservative estimate of the extreme wave conditions is obtained, ensuring that the resulting protection works are safe, regardless of the possible future situation. Polder walls in the harbour area are schematized as walls with a height of 7.50 m above sea level. They are flooded with water levels of about 8.10 m above sea level to let them function as submerged breakwaters for the extreme wave conditions in the harbour area.

The harbour area is situated almost completely outside the primary sea defences of Hamburg, so it can become partially flooded during extreme storm tide water levels.

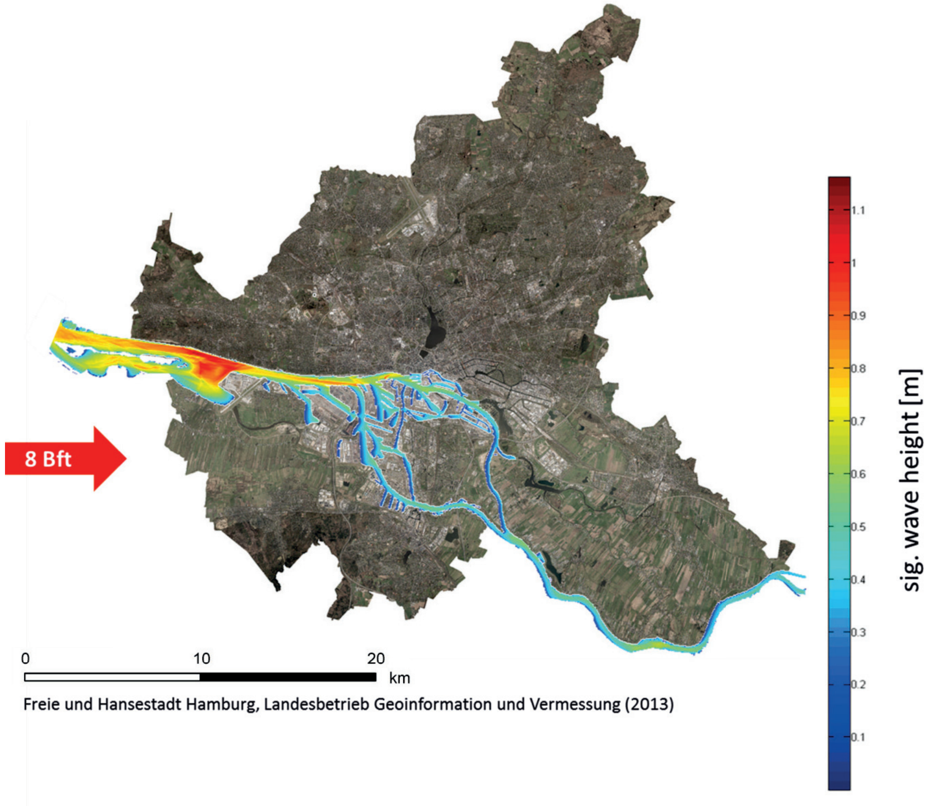

Figure 2: Wave climate in the tidal River Elbe in Hamburg for normal high tide and westerly winds.

5 Wave overtopping and dike profile

In Hamburg the EurOtop (EurOtop Overtopping Manual, 2007) approach was chosen to determine the freeboard of the public coast protection constructions. The allowance for wave overtopping on the dikes in Hamburg is 0.5 l/m/s. The minimum freeboard for dikes is fixed to 0.5 m and for vertical flood protection walls to 0.3 m.

Various Matlab-scripts were developed for calculating the necessary freeboard. The freeboard is calculated automatically by the scripts every 10 m along the public flood defence according to the orientation of the flood protection construction, the critical wave direction and wave height. The procedure determines whether the construction is a vertical concrete wall or a "green" sloping dike covered with grass. The results are stored in tables together with the latitude and longitude co-ordinates, dike-kilometer, critical wave conditions, local design water level, freeboard and the resulting crest height of the flood defence. The crest height is the final height that has to be guaranteed at each location and has to include a certain amount of height for possible settling.

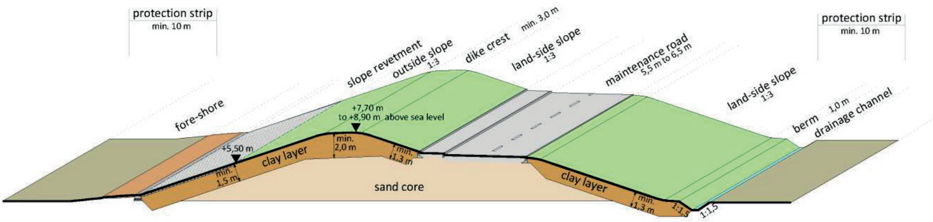

Figure 3: Typical dike profile in Hamburg.

A typical profile of a Hamburg sea dike is shown in fig. 3. The dike has grass-covered slopes on both sides with a gradient of 1:3. Open stones are placed on the lower part of the outer slope to protect the dike against ice loading and ice damage. Ice sheets on the River Elbe moved by tidal currents and water level changes could do considerable damage as their dimensions reach several. The dike profile also includes an asphalted road on the landward side to guarantee access to every place along the public sea defence during a severe storm surge event.

6 Implementation of the improvement program

Before the improvement program can begin, the order of the measures to be taken must be determined and a priority program developed. The various sections of the public flood defence were investigated according to their urgency for improvement, and criteria were defined. The first criterion was the difference in the existing height compared to the new design crest height. Another was the need for urgent maintenance on the dikes and sea walls. The vulnerability of the areas behind the sections was also taken into account. Thus it was possible to make a ranking of the urgency for raising and improving the various sections of the 103 km long public sea defence in Hamburg.

Prior to raising the height of the whole public sea defence structures in Hamburg, the height of the HafenCity extension area had to be calculated following the described procedure. The elevated residential areas of this new district outside the flood protected part of the city are currently under construction. The time needed to build all the new dikes and sea walls of the public sea defence in Hamburg is estimated to be at least 25 to 30 years.

7 References

BOOIJ, N., RIS, R.C. and HOLTHUIJSEN, L.H.: A third-generation wave model for coastal regions, Part I, Model description and validation, J. Geophys. Res. C4, 104, 7649-7666, 1999.

EUROTOP OVERTOPPING MANUAL: Wave Overtopping of Sea Defences and Related Structures: Assessment Manual (Die Küste 73), 2007

GÖNNERT, G. et al: Der Meeresspiegelanstieg. Ursachen, Tendenzen und Risikobewertung. Die Küste, Heft 76, 2010.

GÖNNERT, G.; GERKENSMEIER, B.; MÜLLER, J.-M.: Ermittlung des Sturmflutbemessungswasserstandes für den öffentlichen Hochwasserschutz in Hamburg, Berichte des Landesbetriebes für Straßen, Brücken und Gewässer, Heft 12, 2012.

Masterplan HafenCity; Freie und Hansestadt Hamburg, Bürgerschafts-Drucksache Nr. 16/3909.

For further information please visit: www.LSBG.Hamburg.de.