Special Building Method for a Storm Tide Protection Construction on the Baltic Sea Coast

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Abstract

On the Baltic Sea coast in the year 2002 / 2003 in the surroundings of the oldest German sea bathing location in the section of the “Heiligen Damm” a storm tide protection facility which was not constructed for the reference water level was extended and reinforced in such a manner that it could resist a storm wave with the reference water level.

In the coastal section before the beginning of the extension measure for the reduction of the coastal parallel transport of sediment, sand rainbowing has been carried out in connection with a wooden jetty system.

In the lecture, based on the assessment of the institute for hydraulic and coastal engineering, University of Rostock (Prof. Dr. Ing. habil. S. Kohlhase), the planning implementation of a reinforcement of the revetment with an attached storm tide protective wall at a length of ca. 1,400 m will be treated.

What’s special about the measure is that the historic “Heiligen Damm” could not be changed in the available elevation and expansion on the land side.

The other revetment which are common on the coast could be reduced by 1.5 m in the crown height through the building method (jetty in the beach ridge, combination revetment part with berm as promenade and flood protection wall with wave deflector).

On the 1,400 m long coastal section, coastal protection has been combined with the simultaneous tourist use.
1 Basics of the Planning

It has been historically proven that in the lowland between two cliff line sections an earth-fill dam, which is some 5,000 m long, was naturally formed after a strong storm tide. The “Heilige Damm” owes its name to this.

Until the year 1899, the dam was flooded again and again during strong storm tides and led to great damage in the land area.

According to the technical possibilities at that time, for the first time in 1899 the dam was provided with an revetment up to a height of some + 3.0 m, this dam afterwards was reinforced the last time between 1966 and 1970 to a height of + 3.3 m. With the given cubature (integration in the flat water area, construction of the revetment) subsequent calculations showed that the measurement was only considered to be safe against a reference water level of 1.5 m.

Because of this fact, prior to a further reinforcement of the dam, extensive scientific examinations based on model calculations have been made. In addition, measures, which have already been carried out according to the newest scientific knowledge in the surroundings of the coastline under pressure, have been taken into consideration.

Used for our planning tasks were:

- Assessment “Hochwasserschutz Ortslage Heiligendamm”, Institut für Wasserbau, University of Rostock, Prof. Dr.-Ing. habil. S. Kohlhase, 1998
- Gutachten „Deckwerk Heiliger Damm, Sicherung gegen Bemessungshochwasser“ Institut für Wasserbau, University of Rostock, Prof. Dr.-Ing. habil. S. Kohlhase, 1998
- Tasks of the State Office for the Environment and Nature as project supporter “To complete the flood water protection system in such a way that if possible with the retention of the cubature of the Heilige Damm in the current form remains and as a tourism side effect a ridge beach should result in front of the safety measure.”

2 Goals of the New Planning

To ensure the safety against flooding, the safety measure on the coastal sections would have to be extended and partially rebuilt anew so that a storm tide with the reference water level of + 2.8 m can be resisted.
Without a reinforcement of the flood water protection system, we can count on extensive overpouring of waves and a partial destruction of individual revetments if a very serious storm tide occurs. The water of the Baltic Sea will reach large parts of inhabited areas and will lead to flooding there.

Based on the assessment, three planning construction variations have been worked through.

1. Securing through a shore protective wall with deep foundations
2. Securing through an revetment
3. Securing through an revetment in combination with a flood protection wall

The variations 1 and 2 have not been taken into further consideration after extensive processing since a shore protection wall could not be financed and the classical revetment solutions would have made necessary a widening and heightening of the dam to ca. + 5.1 m.

The combination of the securing through an revetment with a flood water protection wall on the dam was planned, authorized and realized in the years 2002 to 2004.

3 Load Parameter for the Protection Construction
Taking into consideration the geological relationships, the sea state climate, the hydrodynamic and metrological relationships, the wind and water level data available, the load parameters could, after extensive consultation with the authorization authorities, be determined as follows:

Normal water level: - 0.1 m SL
Reference flood water: + 2.8 m NL
Wind speed: 25 m/s
Wind direction: NE

The coast runs at an angle of about 250° relating to N

See state, flood water: 
\[ d = 15 \text{ m} : H_{1/3} = 2.72 \text{ m} \]
\[ F = 6.5 \text{ s} \]

Breaker wave height in the area of the UL: \[ H_{b/UL} = 2.5 \text{ m} \]

Shore inclination \[ 1 : m = 1 : 40 \]

Breaker coefficient: \[ k_b = \frac{d_b}{H_b} = 1.16 \]

Reference wave height

On the sea side of the construction: \[ H_{bem} = H_{b/UL} = 2.5 \]

Remaining wave height on the land side of the revetment with inlet normal for coasts: ca. 1.0 m

3.1 Structure parameter sediment securing sea side

30 wooden jetties 30 to 40 m long to a water depth of ca. – 2.5 m SL with land side integration in the revetment of the shore protection

3.2 Structure parameter revetment

Length of the revetment: 1,380 m
Crest height: + 3.5 m SL
Crest width: Berm 2.0 m, Path connection 5.0 m
Inclination of the cover layer: 1 : 4
Foot protection skid lower edge: – 1.7 m SL
Skid upper edge: – 0.2 m SL
Overflow amount: < 10 l/s
3.3 Structure Parameter Flood Protection Wall and Promenade

- Length of the protective wall: 1,400 m
- Upper edge of the wall: + 4.2 m SL with wave deflector
- Foundation depth of the wall: + 1.8 m SL
- Berm of the revetment: 2.0 m wide clamped
- Promenade: 5.0 m wide
- Dam transitions: Steel flood doors w/h = 1.2 / 0.7 m
- Blinds in the wall: Planting of roses

4 Realized Civil Engineering Solution

4.1 General

After an assessment of the plan documents and trial excavations, the removal of the available revetment was recommended and carried out.

After profiling the core of the dam, in sections a new revetment construction with geotextile, filter, cover layer followed.
As already suggested in the assessment of the Institute for Hydraulic and Coastal Engineering of the University of Rostock, with the construction method the combination of revetment and a wall placed on the dam has been realized.

For building logistic reasons, the measure had to be divided into two sections.

- Work on the dam crest, construction of the flood protection wall
- Work in the beach area and on the revetment of the dam

With this process, additionally building was possible even in the time when flooding was most likely from November to April. Thus it was ensured that with the occurrence of larger sea condition burdens during the work at least the existing flood protection could be adhered to.

4.2 Work on the Flood Protection Wall

The trafficability with construction devices followed on the dam crest in the very limited area of the available path connections.

On the dam a trench was made and a retaining wall which was 2.4 m high with a 1.5 m wide foot made of site-mixed concrete was set up. The upper edge of the wall is only 0.7 m above the crest of the dam.

With the calculation proposal, the assumption was made that with over flooding of the revetment located on the sea side and an erosion of the dam crest in front of the wall, a mounting depth of at least 1.2 m should remain.

The foot of the wall, which is ca. 1.5 m wide, is in the trench and the rising wall has been constructed in press-molded segments of some 12.0 m in the head area on the sea side. The concrete gaps between the concrete sections were secured with gap bands.
The composition of the concrete has been selected in such a way that the frost and thawing salt resistance as well as the resistance to sea water is ensured.

In order to ensure the accessibility on the dam crest for the intended use, in regular intervals small flood gates made of steel w/h 1.2 m / 0.7 m have been integrated into the wall.

4.3 Work in the Beach Area on the Foot of the Dam

The trafficability with construction devices followed parallel to the beach. The transport of the stones for the renewal of the revetment followed by sea. A docking possibility (turnover of sea vehicles on land) has been temporarily created for the duration of the construction time by the construction companies carrying out the work.
On the sea side, between the jetty fields extensive walls of beach sand have been
made in order to be able to build in the skid with a foundation depth of – 1.7 m SL.

After profile suitable inclusion of a geotextile, the skid sole was filled with a 50 cm
thick filter made of rubble (border length of 0.25 to 0.45 m). As a skid foot model a
60 cm thick rubble layer (border length ca. 0.6 m) to a height of –0.2 SL was
packed storage stable.
4.4 Work on the Revetment

Arranged on the skid which has already been produced, the new revetment construction with a slope of 1 : 4 was built continuously in several working stages.

The construction sequence followed from east to west. The available revetment stones are gradually placed in sections on the existing revetment. Behind the skid foot model the revetment is constructed with geotextile, filter layer and cover layer from the existing water building blocks or water building blocks which are to be newly delivered with block weights of 1.2 – 2.0 t. After completion of the revetment, on the crest area a 2.0 m wide berm was additionally clamped. The sea side sea sand walls were placed on the skid up to ca. 1.2 m SL. This placing on formed the basis for the growth of the beach which occurred after the construction which has formed from the sediment transport running parallel to the coast in the wooden jetty fields.

Picture: directly after completion

Picture: revetment construction
4.5 Work on the Revetment

Behind the sea side berm of the new revetment and the flood protection wall, a promenade has been created on + 3.5 m SL with a width of 3.5 m with 1.0 m plant strip. As a protection for the promenade users in addition the berm of the revetment is clamped.

Picture: Revetment / Promenade after construction

4.6 Installed Masses

For the securing of the 1.4 km long coastal section, the following amounts are installed.

- 55,000 m² Geotextile
- 29,000 t available revetment stones (removal and fitting)
- 20,000 t filter stones with border measurement of 0.3 to 0.45 m
- 4,000 t rubble with border measurement of 0.6 m (to clamp)
- 55,000 t revetment stones between 1.2 and 2.0 t individual weights
5 Measurement Flood Protection Wall

For the reinforcement of the revetment height which is not sufficient a concrete wall was built. The head area was made into a wave deflector at a height of +4.2 m SL so that an overflow water amount of \( q < 1.0 \) l (s/m) has resulted.

Since the wall is at least 5 m behind the revetment, with a revetment height of +3.5 m SL and a reference water level of +2.8 m SL a breaking or already broken wave was assumed. For the remaining wave height behind the revetment 1.0 m has been assumed for the calculation.

5.1 Design for Breaking Wave

The design for a breaking wave follows according to GODA (EAK 2002)

5.2 Outer Stability

Proven for the outer stability:

- Slide stability and
- Steadiness
5.3 Inner Stability

Proven for the inner stability:

- Increments and
- Design

6 Design Revetment

The available revetment was newly built on the entire length with an inclination of 1 : 4. The revetment height is 3.5 m SL, the 2 m wide horizontal berm built into the dam made of block stones is in addition necessary for energy dissipation.
As a foot protection, a new model is created at a height of ca. – 0.2 m SL with gravel. The lower end of the covering layer is reinforced to a skid. In the areas where construction was not made on the available revetment, a geotextile is planned as a filter.

A revetment with a 2 layer construction of the cover layer and an inclination of 1:4 has been selected. The calculation of the revetment follows with the formula according to Hudson.

\[ W_{erf} = \frac{\gamma_r \cdot H_{Bern}^3}{K_D \cdot (S_r - 1)^3 \cdot n} \]

with \( W_{erf} \) required weight of the individual block in kN
\( \gamma_r = 26 \text{ kN/m}^3 \) gravel weight
\( \gamma_W = 10 \text{ kN/m}^3 \) specific weight of the water
\( S_r = \gamma_r / \gamma_W = 26/10 = 2.6 \)
\( H_{Bern} = 2.5 \text{ m reference wave height} \)
\( n = 1:4 \) embankment slope
\( K_D = 2.0 \) rubble, sharp edged, 2 layers

\[ => W_{erf} = 12.4 \text{ kN} \]

For the characteristic length of the diameters of the stones thus resulting

\[ D_r = \sqrt[3]{\frac{W_{erf}}{0.245 \cdot \gamma_r}} = 1.25 \text{ m} \quad \text{or the border length: } D = \sqrt[3]{\frac{W_{erf}}{\gamma_r}} = 0.78 \text{ m} \]

From these calculated results, the following construction was selected:

Cover layer   Block stones individual weight >1.2 t \( \rho_S \geq 2.6 \text{ t/m}^3 \)
Border length ca. 0.8 m, repr. stone diameter 1.25 m

Foot model Gravel, border length 0.3 to 0.45 m, $\rho_s \geq 2.6 \text{ t/m}^3$

Geotextile Punch durability 1200 Nm

Highest tensile force length > 14.4 kN/m, width > 21.6 kN/m

Surface weight > 6100 g/m²

7 Prospect

The combination of jetties, revetment and a wall placed on the protective dam has used the lowest possible surface need in the land area.

The construction has already taken on a strong sea condition burden without destruction. The protective function against the designed flood will certainly be reached.

The side effects desired by the customer for the use of the beach have occurred without having to fill in sand. The crest of the dam is used as a promenade.

Through the selected construction method, the combination of a protection against flooding and use for tourism has become possible.

Picture: Promenade 2 years after completion date 2006
8 List of literature

Assessment Assessment, Hochwasserschutz Ortslage Heiligendamm, Institute for hydraulic and coastal engineering, University of Rostock, Prof. Dr.-Ing. habil. S. Kohlhase, 1998.

Assessment, Deckwerk Heiliger Damm, Sicherung gegen Bemessungshochwasser Institute for hydraulic and coastal engineering, University of Rostock, Prof. Dr.-Ing. habil. S. Kohlhase, 1998.


