Structural and Geotechnical Investigations for the Remediation of Jetties and Seawalls on Heligoland

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ABSTRACT: Heligoland is a German offshore island located about 50 km from the German coastline in the North Sea. Storm surges, especially in 1954, caused massive destruction and damage to the jetties and seawalls. Moreover, the "Big Bang" blast in 1947 as well as wartime bombardments lead to extensive rock fracturing.
Due to these impacts the jetties and seawalls displayed serious structural deficiencies, such as differential settlements and potential instabilities. Against this background, a site investigation was carried out for the geotechnical design of the remedial measures.
Special drilling rigs were used, equipped with an interchangeable drill head for both sonic and wireline drilling methods while incorporating an automatic drilling data acquisition system. This allowed high quality structural and rock cores and samples to be obtained in accordance with sampling and testing standards.

Keywords: Investigation, Sonic drilling, automatic drilling data acquisition, geological modelling.

1 PROJECT OVERVIEW

Heligoland is a German offshore island located about 50 km from the German coastline in the North Sea. It is the only rocky island in the German Bight and owes its formation to vertical uplifting of Triassic sandstones of the "Buntsandstein" due to diapiric rise of underlying evaporites of the "Zechstein" basin.

Most of the todays shore protection in the west of the island and the large jetties and seawalls where constructed between 1903 and 1927, when emperor Wilhelm II had turned Heligoland into a navy base. After World War I major parts of the western jetty were rebuilt resulting in the todays shape (figure 1).

World War II and storm surges, especially in 1954, caused massive destruction and damage to the jetties and seawalls. Moreover, the "Big Bang" blast in 1947 as well as wartime bombardments lead to extensive rock fracturing.

Due to these impacts the jetties and seawalls displayed serious structural deficiencies, such as differential settlements and potential instabilities, the remediation of jetties and seawalls are required.

Figure 1. Development of Heligoland (main island) since 1890 (after KRUMBEIN, 1975).

Against this background, a site investigation for the geotechnical design of the remedial measures was set-up. It focused on detailed examination of the condition of the current structures, the foundation base and of the quality of the underlying rock. The investigation aimed at providing information on possible doline structures, sinkholes and the presence of potentially sensitive sedimentary deposits such as shales and sandstones with intercalated evaporite layers.

Overall 84 investigation drillings with a total length of almost 1,000 m were executed, using special equipment, drilling methods and data acquisition.

For these structural and geotechnical challenges special drilling rigs were used, equipped with an interchangeable drill head for sonic and wireline drilling methods, while incorporating an automatic drilling data acquisition system. This allowed high quality structural and rock cores and samples to be obtained in accordance with sampling and testing standards.

2 GEOLOGY

The part of Heligoland visible today consists mainly from red mudstones intercalated with beige colored sandstones layers with different thickness of the stratigraphically unit "Buntsandstein" and therefore is far older than all nearby German Islands in the North Sea.

Heligoland owe its emergence from approx. 255 Mio. (upper Permian) old enormous salt and sulfat deposits, which were generated by repeated evaporation over a shallow inland lake. During Cretaceous and Tertiary, the Permian salt was mobilized– due to its lesser density – under the weight of younger sediments. The salt layers became ductile, started to rise along weaker areas and lift and tilt the covering layers. Heligoland is in the center of such an elliptical salt dome with a longitude axes directed from northwest to southeast. Due to this, the formation of the "Buntsandstein" is lifted for approx. 3.000 m.

The lower formation of the "Mittlerer (Middle) Buntsandstein", the so called "Volpriehausen-Folge", is the stable basis of the "Buntsandstein" on the island. Due to the dip angle of about 17° towards northeast this formation is mainly apparent along the down part of western coastline of the island.

The overlaying formations: "Detfurth-, Hardegen and Solling-Folge" consist of weak mudstones. These formations are visible at the upper part of the west- and the east slopes of the island. The youngest stratum of the "Buntsandstein", the "Obere (Upper) Buntsandstein (Röt)" is just as little exposed above ground as the "Untere (Lower) Buntsandstein". Its soft clay, sulfate formations (gypsum) and mudstones rocks stretch out in the strait between the "Mittlere (Middle) Buntsandstein" of Heligoland and the younger limestone of the nearby island (called "Düne") and form the seabed.

The layers of the "Oberen (Upper) Buntsandstein" therefore also form the existing subsoil in the predominant part of the investigated eastern seawall.

3 STRUCTURAL AND SOIL INVESTIGATION

3.1 Investigation Objectives

The western seawall construction is made from concrete caissons founded on the rock surface. The total height of the caissons is around 10 m. The caissons are filled with concrete blocks, sand in the lower parts and cemented concrete blocks just below the covering slab with a thickness of around 2 m. The width of the seawall is around 8 m. Other parts of the seawalls are constructed from precasted concrete elements in different shapes and different backfills. Due to required repair works after storm damages, special sections were made from wooden cages filled with cobbles and blocks, supported by dams on both sides (figure 2).

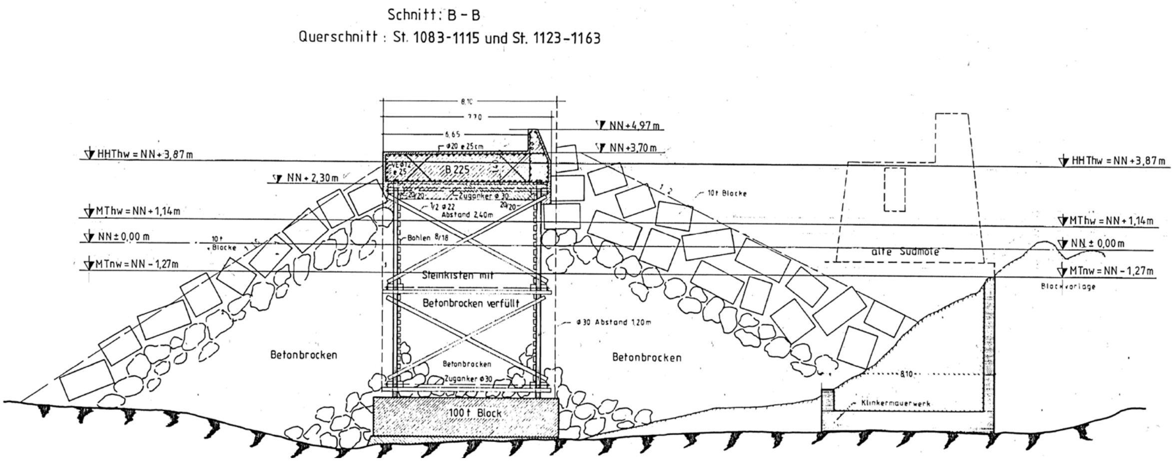

Figure 2. Sewall construction after storm damages within the southern seawall.

Due to partly visible deformations in the seawall, the different seawall constructions and due to expected varying subsoil conditions, a narrow grid of borings was set up with regard to the objectives of the structural and soil investigations:

- Investigation of the caissons and seawall backfill material
- Investigations of the interface seawall construction and rock surface, which requires a complete recovery, also in weak or soluble rocks
- Soil and rock investigation within the depth of influence of future constructions

In total 84 borings were planned with a depth down to around 20 m for solid rock and down to 50 m, where soluble soils were expected.

3.2 Drilling Equipment and Methods

From previous investigations in other walls on the island obstacles, such as wood, steel and granite cobbles with a high unconfined compression strength were expected within the backfill. Usually these obstacles go along with high core loss. On the other hand, the objective of an extensive investigation of the backfill material itself, the foundation base as well as different rock types requires a complete core recovery.

For these structural and geotechnical challenges special drilling rigs were used, equipped with an interchangeable drill head for both, sonic and wireline drilling methods while incorporating an automatic drilling data acquisition system.

The major difference between conventional rotary and sonic drilling is, that the sonic drilling head includes an oscillator motion additional to the rotary motion, causing high vibratory forces (50-150 Hz) up and down while being pushed down and rotated. The combined vibratory, rotary, and axial forces allow a drilling, producing continuous large sample cores without or with little addition of air or water. It overcomes hydraulic fracturing, borehole erosion, and vulnerable structures. (Orberger, 2018)

Meanwhile sonic drilling is part of standards all over the world e.g. USA (ASTM), UK (BS) and Germany (DIN).

As sonic drilling will guarantee a good core recovery in the backfilled material, even when obstacles needs to be cored, sampling of rock will be impacted by the energy of drilling. Especially with regard to core integrity and massive reduction of the natural water content sonic drilling will not allow sampling of good quality shale-, silt- and mudstone cores. All coring within the rock therefore where executed using a wireline drilling method. The rock has been sampled in liners.

The drilling machine is capable to change in between the drill heads at any time of the boring, so the team on site could react on any possible core loss within the drilling. Especially for the drillings where sinkholes or doline structure were expected eventual core loss could evaluated by changing the drilling head.

3.3 Data Acquisition

In all boring drilling data as penetration rate, torque, pull down pressure and other data have been recorded constantly automatically. The data should assist interpretation of the direct boring results.

4 GEOLOGICAL AND GEOTECHNICAL MODEL

4.1 Core Recovery

The drilling method could be implemented during investigation as planned. The core recovery in the seawall was almost 100 %, as expected, even obstacles have been encountered more than expected.

An example of the core recovery is shown in figure 3. It shows cores taken from the structural concrete (4 m to 4.75 m), the backfill (until 11 m), the base concrete (until 12.5 m) and the rock in the interface to the foundation. Massive steel parts at the base of the backfill did not affect the core recovery.

Using the recorded drilling data a gap of around 15 cm between the structural concrete at -4,75 m and the top of the backfill could be detected.

Figure 3. Core from Boring BKF -W-12/2021; 4 m to 15 m.

4.2 Geotechnical Model

With the results of the soil investigation, the seawalls could be properly investigated with regard to its backfilling. Also, the foundation base was inspected by the borings in a reliable way. In a detailed analysis of the samples from the seawalls together with the recorded data from the drilling rig, also a good prediction of possible gaps within the construction, the quality of the structural concrete at the top and especially at the foundation base could be made.

Based on a preliminary assessment of the data, the geotechnical engineers were able shortly after the investigations to rate the overall stability from the geotechnical point of view. Due to the good conditions at the foundation base, ground failure or shearing at the base could be excluded from possible reasons for the visible damages in the seawall.

On the other hand, the investigation results from the structural elements of the seawalls gave a clear indicator for possible deficits in the construction and therefore indicates further detailed structural investigations for the planned Remediation of the investigated seawalls and jetties.

Figure 4 shows a detail of the underground model at the eastern seawall. Both, stratigraphy and quality of the soil and rock could be described in the model in detailed, even heterogeneous conditions have been found in this area. Quaternary sediments in the filled sinkhole, soils and weak rock of the leached sulfate formation could be investigated with sonic drilling, in rock formations and remaining gypsum layers wireline drilling was used.

Using Standard Penetration tests during sonic drilling, recorded drilling data and laboratory tests on samples in the investigated soil and very soft rock formations the classification of these layers could be done without using ramming investigation methods, as foreseen under different circumstances in other projects.

5 SUMMARY

An investigation program with around 1,000 m of drilling in seawalls, its foundation base and various underground conditions along its extension was successfully performed within 6 month using an interchangeable drill head for both sonic and wireline drilling methods. Even heavy obstacles as steel and wood was found within the backfilled seawall body a core recovery of almost 100 % could be reached. Furthermore, the used drilling methods under the help of recorded drilling data was capable to indicated gaps between different materials.

Due to the flexible use of the drilling methods also different types of soils and rock was encountered in a good quality, so both: the structural and the geological information was brought into a highlevel geotechnical model as the basis for the design of any required remediation works along the seawalls of Heligoland.

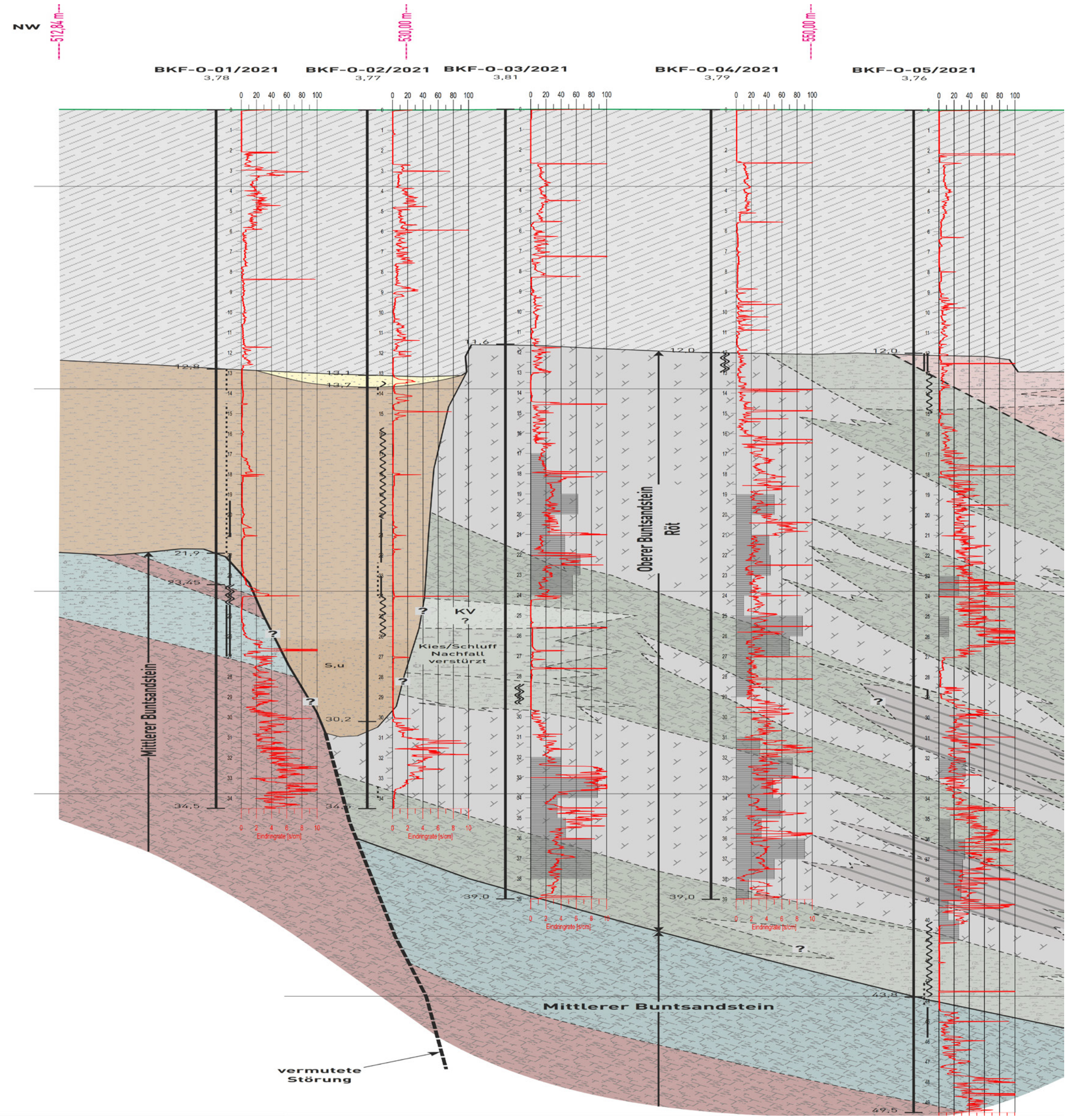

Figure 4. Detail of the geological underground model at the eastern seawall (length around 50 m).

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