Results of five monitoring networks to measure loads and deformations at different quay wall constructions in the port of Hamburg

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ABSTRACT: In the last couple of years, the Institute of Soil Mechanics and Foundation Engineering at the Technical University of Braunschweig (IGB·TUBS) has carried out extensive measurements at five different quay wall constructions at the port of Hamburg. One important result, which was received at all different investigations is: the total load on the wall is nearly constant. The load on the retaining wall is not dependent from the tidal waterlevel. The extrema of water- and earth-pressure loads occur postponed. The loads from the water pressure are almost completely compensated with the change of the effective stresses. After this results and experience, the IGB·TUBS has carried out a higher extensive measurement concept for the first construction stage of the Container-Terminal Altenwerder in the port of Hamburg. About the important results and the innovations is written here.

1 INTRODUCTION

The general load estimations and design methods for quay walls at the port of Hamburg are based on long-term experiences with sheet pile constructions. The reason for the comprehensive measurement and evaluation programs were the necessary growth of these quay walls, which required new construction principles for retaining/slurry walls or large combined sheetpile walls. A great problem for these large quay walls in the port of Hamburg are the shingle layers of the transitionary zone between Pleistocene and Tertian layers which contain large stones (with diameters up to 1,70 m). For additional interpretation of the deformation behaviour of these constructions which grow with the new container-ship-generations, the Institute of Foundation Engineering and Soil Mechanics of the Technical University of Braunschweig (IGB·TUBS) was engaged by the 'Amt fuer Strom- und Hafenbau' of the Free and Hanseatic Town of Hamburg with the transaction of the examinations of several different quay wall constructions. An overview of the locations of the examined quay wall constructions in the port of Hamburg shows Figure 1.

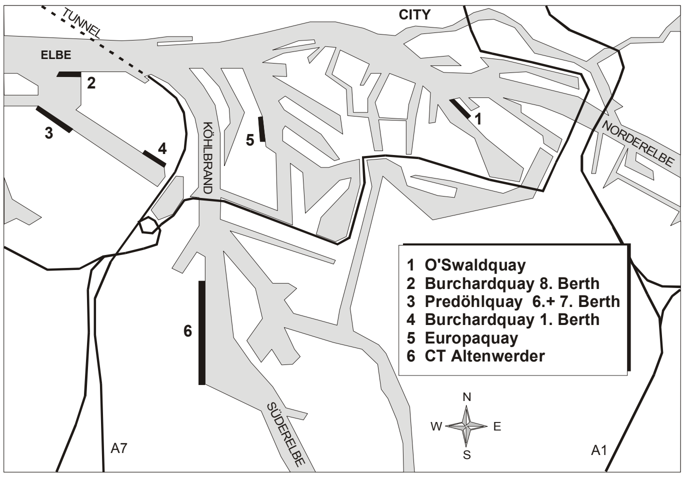

Figure 1. Overview of the investigated quay walls by the IGB·TUBS in the port of Hamburg.

Table 1. Designation of the investigated quay walls.

Designation	Year
O'Swaldkai, West	(1992 - 1996)
Athabaskakai, 9. Berth	(1993)
Burchardkai, 8. Berth	(1994 - 1997)
Predöhlkai, 6. Berth	(1996 - 1998)
Burchardkai, 1. Berth	(1997 - 1998)
Europakai	(1997 - 1999)
Predöhlkai, 7. Berth	(1998 - 1999)
Altenwerder, 1. construction stage	(1999 - 2000)

2 MEASUREMENT CONCEPT

The conception of the measurements was developed from following questions: size and development of the anchor strengths, bending of the wall as well as the total load on the wall, which result from active earth pressure, pore-water pressure, additional loads and bracing as a result of the quay slab piles.

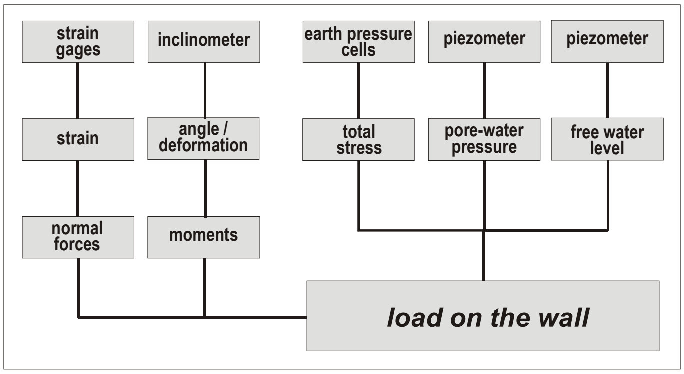

Figure 2. Measurement concept.

The most important elements in this measurement concept to investigate the total load on the wall are the earth pressure cells and pore-water pressure piezometers (Maybaum, 1996).

The risk of loss of measurements data in an observation horizon was reduced by the double order of all measurement instruments. The double order enabled the control of each measurement instrument simultaneously. Another control of the system in consideration on the investigation of the earth pressure on the wall can take place through the calculation of the loads from the measured distortions of the wall (Rodatz et al., 1995).

The installation of the combined earth and pore-water pressure cells took place after the completion of the quay slab. This had the disadvantage, that the primary stress in the ground and the changing of it infected by the construction progress is unknown. At the present project at Altenwerder, all measurement instruments were installed before any construction work had begun.

3 RESULTS

3.1 *Load on the wall*

The load alterations on the wall as a result of the tide during a high water event are represented in Fig. 3 exemplary for block 7, depth-situation -11,0 m below sea level. The effective stress that emerged from the difference of the measured total stress as well as the, at the same place, measured pore-water pressure. The excess water pressure was calculated as the difference between the outside water level and the water level behind the wall. The sum of effective stress and excess water pressure is the total load on the wall.

The represented measurements over until now four years have yielded that a constant load on the wall can be found in all measurement layers (Gattermann, 1998).

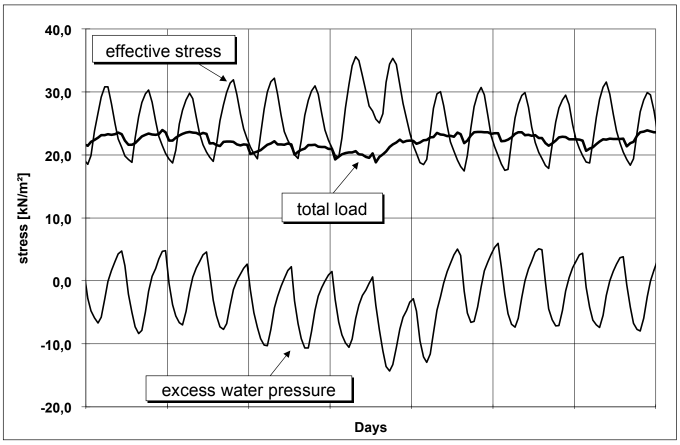

Figure 3. Exemplary constant load on the Burchardquaywall at a high tide event (28.10.96 - 05.11.96).

An interpretation of these results can't given conclusive. An influence by the wall/quay-slab/back-wall onto the pressure of the enclosed pore-air with tidal water level was observed. An influence by the length of the hinterland behind the wall require further examinations. The short length of the hinterland at the O'Swaldquay (ca 100 m) and at the Burchardquay (60 m) was one of the reason for the examinations at Altenwerder.

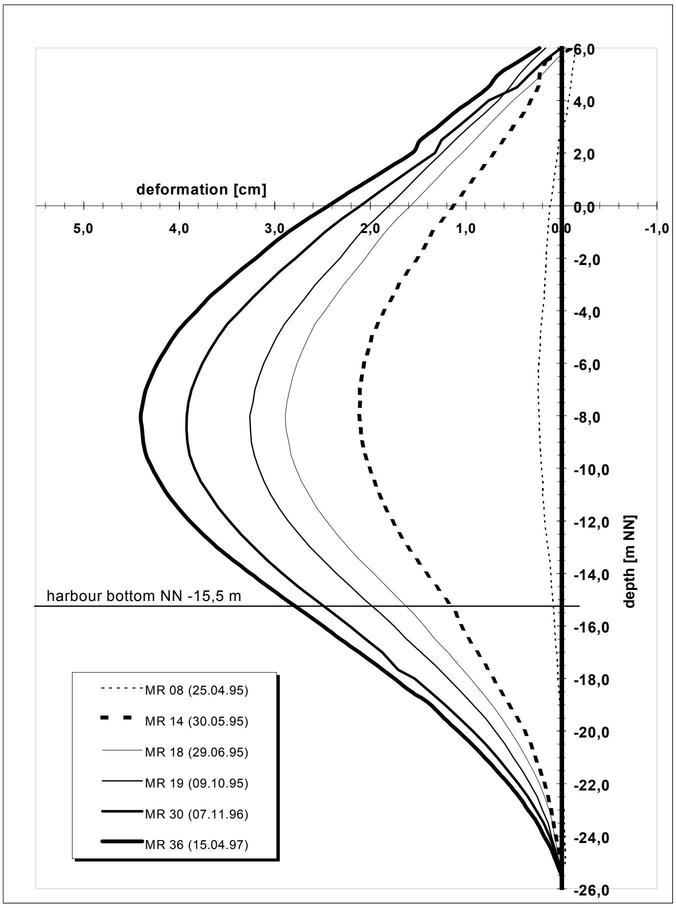

Figure 4. Measurement of deformations in regard to the zero measurement in spring 1995 - measurement point 02, block 7

3.2 *Distortion measurements*

The deformation measurements are represented in Fig. 4 for the measurement point 02 at the Burchard-quay. The time period amounts from test series 08 (shortly after the beginning of the digging in front of the wall) until test series 36 (one year after finishing the quay installation). For the representation, the foot point was assumed to be stable static. A foot displacement infected of the results of measured head points is tendencies in the millimetre area to the land side.

A maximum load on the wall was determined in a depth of -8,0 to -9,0 m below sea level of 4,0 cm. At the foot of the wall, a curvature alteration can be recognised, resulting from a possible fixation at the foot of the wall. No wall movements were determined during a tide.

3.3 *Summery of the measuring results and calculations*

Summarising it can be determined that:

- the investigation of the earth pressure on the basis of Coulombs theory was moderately applicable in every state of construction, as far as water overpressure is generally not considered,
- the reduction of the earth pressure at rest on the active earth pressure could be proven scientifically / technically,
- the measurement results do not occur due to an overload of single parts of the construction,
- the quay wall is more than sufficiently dimensioned and stable.

4 CONTAINER TERMINAL ALTENWERDER

4.1 *Introduction*

A brand new container terminal for the newest container ship generation is actually under construction. The construction work began in April 1999 and will be finished in December 2000. In autumn 2001 the terminal will be putting into operation.

The first construction stage with a length of approx. 955 m (whole length: 1.400 m) covers two berths for the ships. Wing walls in the north and south ensure the transition between berth and embankment.

The terminal traffic area is protected against tidal flood by a height of +7,50 m above sea level. With a harbour depth of -16,70 m result a height of the construction of 24,20 m. The container-crane-track has two widths: 18,0 and 35,0 meter (see Fig. 5).

To manufacture the wall, a 1,20 m wide trench was excavated and stabilised with a Bentonite clay slurry. The suspension was enriched with cement and should harden to a mortar with approximately the same qualities of the surrounding ground. Into the soft suspension double H-beams (HZ975A-24 S 390 GP, length: 32,60 m) were put in with locks and inter planks (AZ 18-10 S 240 GP, length: 27,45 m). Inclined H-beams as anchors (interval: 2,95 m, inclination 1:1,3, length: 45,0 m) carry the horizontal forces into ground. Steel piles (∅ 1219,2 x 16 mm, S 355 GP, interval: 4,92 m, length: 30,30 m) supporting the concrete head-beam and reduce the risk of the scour formation with their clearance of 3,54 m to the wall.

Two inclined and one vertical row of in-situ driven concrete piles (∅ 51 cm, B35) supporting the quay slab. To reduce the water pressure load onto the wall, there were built in windows at the inter planks from +2,75 m till -1,50 m mean sea level. Through these windows (length: 4,50m) the soil can float out to the bottom of the harbour. The inclination of this emerging slope will be 1:4.

This reduction of water pressure load and the steel piles in front of the wall are state of the art in quay-wall construction in Hamburg.

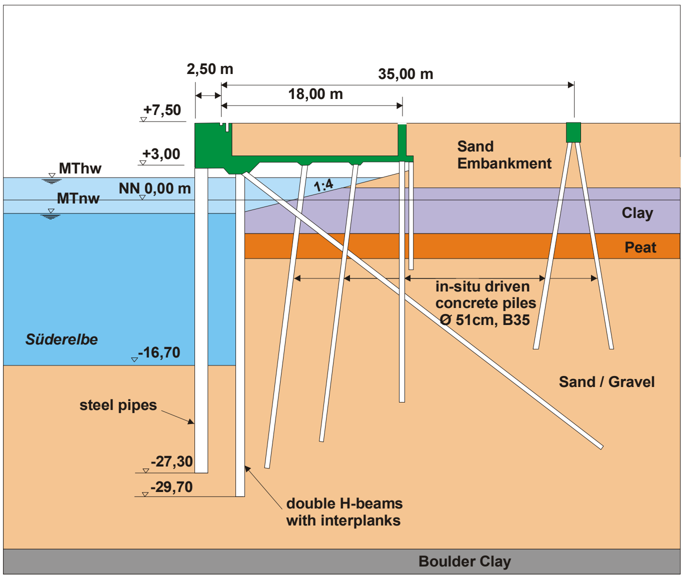

Figure 5. Container-Terminal Altenwerder (cross-section).

5 INSTALLED MEASUREMENT INSTRUMENTS

5.1 *Introduction*

The 'Amt fuer Strom- und Hafenbau' of the Free and Hanseatic Town of Hamburg assign the task to clarify following formulation of questions:

- Determination of wall deformations
- Determination of the active earth pressure and for the first time of the passive earth pressure onto the wall
- Determination of the working load (skin friction) and deformations of the inclined stay piles

To carry out these extensive measurements successfully, there were installed multiplicity measurement systems in two different geological sections (block 10 and 20) of the construction.

The measurements which were reproducible and controllable (inclinometer / sliding micrometer) were carried out once in each of these two blocks. The electric earth pressure cells were carried out twice per block to confirm their results.

5.2 *Inclinometer*

One inclinometer steel casing (□ 50x50x4 mm) was weld on the web of the middle H-beam of the block to monitor the deflection and deformation of the wall under load of earth pressure.

5.3 *Earth pressure cells*

Earth pressure cells or total pressure cells measure the combined pressure of effective stress and pore-water pressure. For this reason, the combined total- and pore-water pressure cells were installed, with whom the total and the pore-water pressure can be measured at the same place. The effective stress can be received as the difference of the two measured pressures.

In Altenwerder were the combined cells placed in five different depths behind the wall (-3,50, -8,0, -16,0, -21,0 and -26,0 m below mean sea level) and in two different depths before the wall (-21,0 and -26,0 m below mean sea level). The electrical leads are running in a casing borehole. The casing between the steel pipes and the wall stands for all time after the digging of the embankment.

The deepest cells were placed in-situ ground with a new linkage, which guaranteed the parallel position of the cushion to the wall in a depth of about 30 meter. The next cushions in upper levels were embedded in the back-filling (same density as the surrounding soil) of the borehole with one layer of Bentonite pellets as packing.

The installation of these earth pressure cells was done with a round linkage of one meter length each so far. These installation has three disadvantages:

- the parallel position of the cushions could not be guaranteed
- the screwing of each linkage segment has to be cleaned carefully
- the short length of one meter caused a lot of time at the assembly

The new linkage, which was developed and built by the IGB·TUBS presented like this:

\+ it is a square hollow section made in aluminium (□ 50x50x4 mm)
\+ the length of each segment is 3 meter and has plug-in connections
\+ it is very lightweight but with high stiffness which is the precondition to absorb safely the jacking forces

The placing of the first combined earth pressure cells figured out one problem: the friction of the cushion wasn't high enough to disengage it from the linkage. The cushion was pull out again every trial. The remedial action by the IGB·TUBS was to modify the cushions with four special wings each. The wings (spring steel) were fixed at the upper face of the cushion to increase the resistance (Fig. 6). After this modification all cushions were placed in successfully.

Figure 6. Earth pressure cell with modified wings

While the construction stage, the electrical leads in every measurement section were laying into independent Datataker (Data Electronics, Australia). The Datatakers can supply each instrument and store the data every 30 min. up to 8 weeks. After completion of the construction works the data can be distance controlled via modem from Braunschweig.

5.4 *Sliding micrometer*

To determine the size and development of the anchor strength, the pipe casing was grouted within two square channels (110x110x10 mm) which were weld onto the upper and bottom level of the 45 m long inclined H-beam. Up to now the determination was determined with strain gages at the top of the inclined anchor. The sliding micrometer determine the axial deformation of every meter of the adjacent measurement points. with a precision of ±0,002 mm. With these measurements it is possible to determine the skin friction of the inclined pile over his whole length. The bending of the pile can determined with the inclinometer probe in the same pipe casing.

6 REFERENCES

Gattermann, J. 1998. Interpretation von geotechnischen Messungen an Kaimauern in einem Tidehafen, *Mitteilung des IGB·TUBS*, 59.

Maybaum, G. 1996. Erddruckentwicklung auf eine in Schlitzwandbauweise hergestellte Kaimauer, *Mitteilung des IGB·TUBS*, 52.

Rodatz, W. & Maybaum, G. & Gattermann, J. 1995. Pressure and deformation measurements at two retaining walls at the port of Hamburg, *Proc. of the 4th Intern. Symposium Field Measurments in Geomechanics (FMGM 95)*, Bergamo, Italy, S. 291-299.