

# Permanent Construction and Geo Monitoring Programs for Quality Assurance of the Construction and Operation of the Danube Harbour Straubing

Richard A. Herrmann<sup>1\*</sup>, Thorsten Lauber<sup>2\*</sup>

\*1 Geotechnical Institute, University of Siegen, Germany,

\*2 GEOTECHNIK GmbH, Prof. Dr.-Ing. Herrmann & Partner, Germany

## 1 Introduction

The Straubing harbour on the Danube international waterway is one of the youngest harbour facilities in Bavaria and the Federal Republic of Germany. Due to the geological characteristics on this part of Danube at the boundary of the Moldaunubikum with an earlier tributary of the Danube and gneiss in the area of the harbour basin, a special geotechnical design for the construction of the harbour was necessary.

For this reason the construction and operation of the harbour to today have been accompanied by permanent construction and geomonitoring programs. The basis for the geotechnical investigations and the execution of the construction was a special geomonitoring program. Results are presented in the following discussion.

The results of the geotechnical investigations -DIN 4020 [1]- and their interpretation were the bases for the on-site studies to select the sheet pile wall insertion technique and to develop a new construction method. Based on these results, a new construction method could be applied for the first time. It was described in MOSER, HERRMANN, JUNG (2001) "Inserting Sheet Pile Walls by Vibration and Injection Technology using Hydraulic Pressure also for Permanent Structures", 3rd. Austrian Geotechnical Conference 2001 [2]. The application of the new method was documented by permanent instrumentation monitoring as a part of the quality management.

From an available groundwater model for the groundwater peak of the harbour, the stability of the harbour structure in case of heavy drawdown caused by rapidly-falling Danube water levels in relation to a high groundwater wave was reviewed. For this reason - next to extensive numeric modelling - a monitoring system was installed within the area of the harbour using a linear arrangement of groundwater measuring points (wells of larger diameter with permanent monitoring of the water level). These wells also serve as defence

wells in case of accidents, e.g., contamination of the groundwater from accidents in harbour operations.

The owner and the supervisory authorities, for reasons of stability and guarantee, from the beginning required a long-term monitoring of the harbour structure. Apart from the monitoring of the sheet pile wall deformations caused by the hydraulic load, earth pressure load and the load from the harbour operation, e.g. from the heavy slab load (handling of heavy goods), monitoring of the bottom of the harbour is important because of the erosion from ship's screw propellers which so far cannot be done with automatic measuring systems.

On the basis of the construction and geomeasuring systems which were installed while building the harbour, a quality assurance plan was contrived and elaborated for the management of the facilities to assure safe and secure operations through the assistance of the monitoring systems. The concept of the quality assurance plan based on the construction monitoring and geomeasuring techniques is presented below.

## **2 General**

The special industrial area association with Danube harbour Straubing assigned the authors to elaborate a conclusive appraisal, a geotechnical report and development of a quality control system based on geomonitoring programs, for the construction and permanent operation of the Danube harbour. In the geotechnical report a quality assurance plan for the monitoring of the structural security of the Danube harbour was to be drawn up.

In 1993 author \*1 was commissioned to carry out a geotechnical testing program. This was followed up by performing indirect soil explorations by the use of dynamic penetration tests in accordance with DIN 4094 [3] and with the support of direct subsurface examination using borings according to DIN 4021 [4].

Connected to this was subsequently the elaboration of the construction site soils and justification for the establishment of the Danube harbour, and the assignment of other geotechnical consultation and support as well as the quality assurance for the earthwork as backfill for the sheet pile wall. The geotechnical work and consultations were taken over starting from April 1994 by GEOTECHNIK GmbH, Prof. Dr.-Ing. Herrmann & Partner.

According to groundwater model computations of other geohydraulics, there was a water pressure difference between outer ground water and basin interior water of a maximum of

3.75 m. Static computations of the sheet pile walls resulted in an allowable maximum positive water pressure of 1.20 m. The participating engineering office, "Büro für Hydrogeologie und Geohydraulik", delimited the ground water storage behind the sheet pile walls to a height of 1.2 m and a drainage system was recommended.

The call for tenders for the drainage system around the harbour basin resulted in offers up to 1.97 million Euro. To minimize costs before awarding a contract, alternative variants up to the complete omission of the drainage were first tested. After an evaluation of the measured water levels in the groundwater observation levels, lower values appeared after the production of the sheet pile wall in relation to the geohydraulic-prognosticated water levels by around approximately 1.90 to 2.00 m.

This result was evaluated externally geotechnically/geohydraulically. The result of this evaluation can in summary be presented in such a way that in the static computations a differential water pressure,  $\Delta w_{\bar{u}}$ , should be set at from 2.1 to 2.4 m. Thereby, the stability of the sheet pile walls was assured in the event of failure of the drainage system. For the main north-side wall a possible positive water pressure,  $\Delta w_{\bar{u}}$ , of 2.75 m was determined, and for the south-side main wall as well as the west-side head wall a possible difference between interior ground water and external basin of 2.40 m. Drainage failure could only be ascertained on the basis of the installed geomeasuring system.

Construction of the Danube Harbour Straubing commenced in October 1994 with the site installation and was completed in 1996. With the project "The New Construction of the Danube Harbour Straubing-Sand" an altogether approximately 700 m long and 90 m wide basin was established. At the south side of the basin a 625 m long quai with a crane track for 2 cranes was built, and at the northern side a 390 m long quai with one crane track (1 crane).

Within the inlet from the Danube a circular expansion was made of the basin with a diameter of 120 m for ship turning. A RoRo ramp was installed at the head wall (west) to enable loading the ships with wheeled vehicles and trucks. For fastening the ships at the RoRo ramp, three mooring post were placed at intervals of 30 m around the harbour.

Bank stabilization was implemented as a "classical" solution with a steel sheet pile wall with and an anchorage of anchor walls of round steel bar. In the southwest area of the basin next to the quai wall a heavy-load slab was created founded on site-manufactured driven concrete piles according to DIN 4026 [5] and bored piles according to DIN 4014 [6]. The Danube harbour was opened on 28 June 1996 and it's regulation handed over.

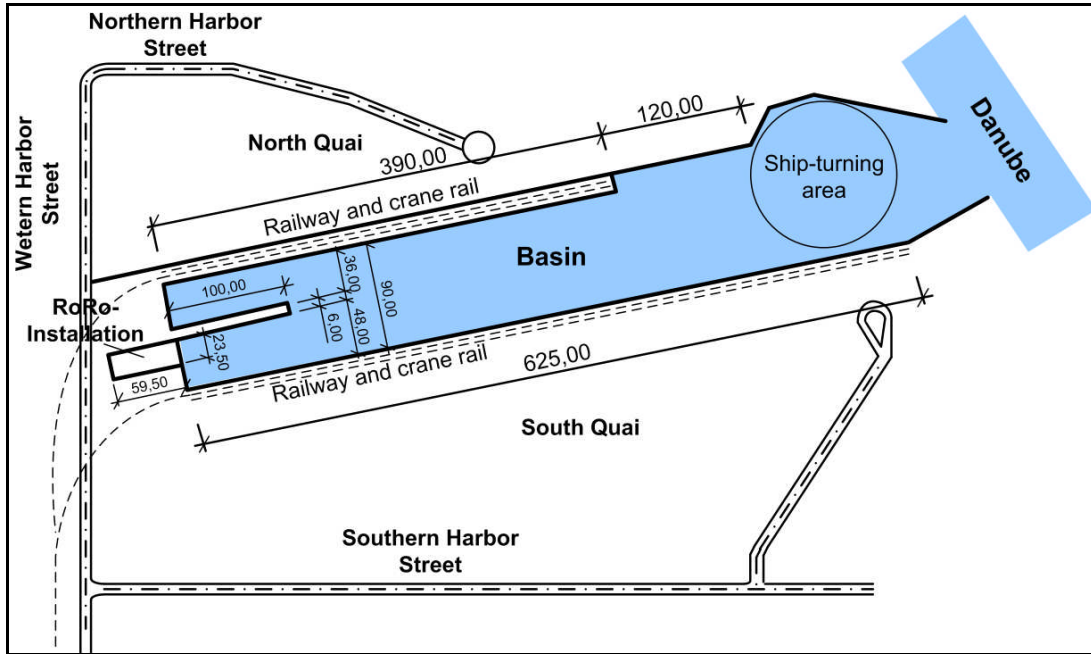


Fig. 1: Plan view of the Danube Harbour Straubing



Fig. 2: Aerial photograph of the Danube Harbour Straubing in operation after completion

### **3 Geotechnical/Hydrogeological Conditions**

#### **- Field Measurements in Geomechanics (FMGM) for Geotechnical Investigations**

##### **3.1 Geotechnical Reconnaissance Prior to Construction of the Danube Harbour**

In the planning and geotechnical execution for the construction of the Danube harbour, the first available information about the site geotechnics were the soil profile and ground water observation well installation data from two sites of the Danube development between Straubing and Vilshofen by the Rhein-Main-Donau AG. Altogether nine exploratory borings were made (BK 1 to BK 9) along the north and south quai locations and three additional ground water observations wells installed by the Bayerische Landeshafenverwaltung (Bavarian Harbour Authority).

In addition there were five heavy dynamic penetration tests made along the planned axis of the basin in accordance with DIN 4094, and a summary of the results were presented in a report. The results of these preliminary investigations were considered in the planning and elaboration by author \*1 of the primary geotechnical investigation program for the harbour construction pursuant to the recommendations of the EAU [7] and DIN 4020 [1]. In the course of the principle investigations during the period September-November 1993, altogether 44 exploratory borings in accordance with DIN 4021 [4] were put down along the planned locations of the river-side and the inland-side walls and the head wall of the port at intervals of 50 m or less.

Indirect soil explorations were made on both sides of the line of borings by heavy dynamic penetration test according to DIN 4094 [3] at intervals of at most 50 m in order to establish the relative soil strengths and to delineate the boundary layer. Altogether 74 soundings were put down to a maximum depth of 20 m. In the plan area of the basin an additional very deep heavy penetration test was made for the founding of three mooring posts for anchoring ships at the Ro-Ro ramp.

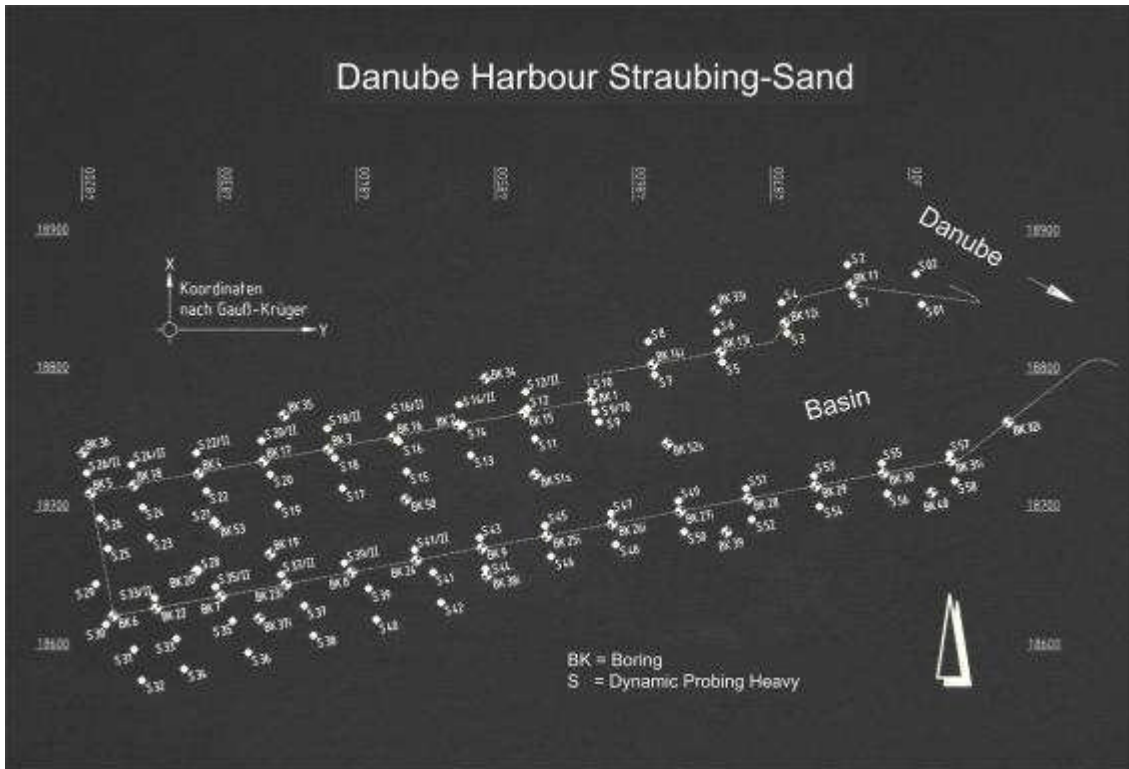


Fig. 3: Layout plan of the geotechnical investigations (borings/soundings)

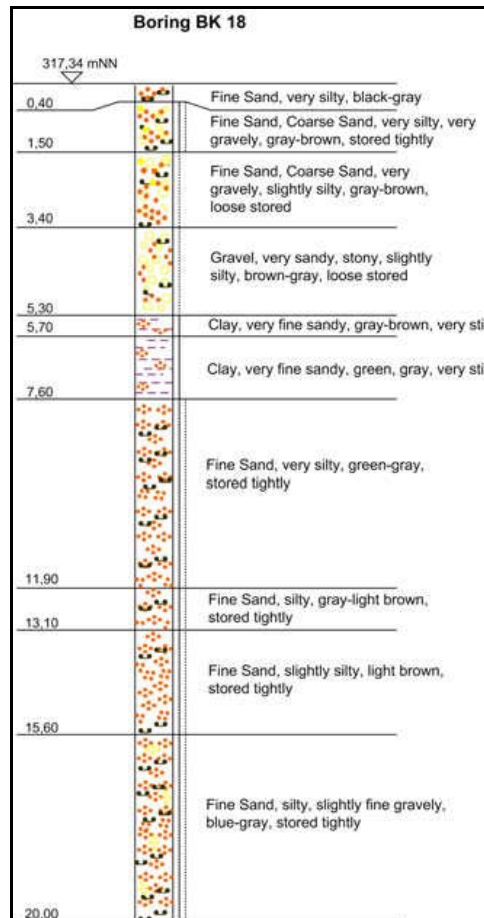


Fig. 4: Results of the geotechnical investigations - example of boring BK 18

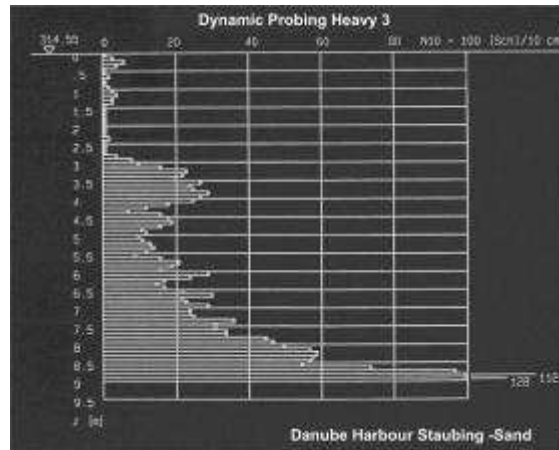


Fig. 5: Results of the geotechnical investigation - example of sounding DPH 3

In order to establish the soil-mechanics characteristics, samples were taken from the borings during the main geotechnical investigations and tested in the laboratory. The laboratory tests included all of the basic soil properties and characteristics for the compressibility and shear strength of the materials.

### 3.2 Hydrogeological Conditions Prior to Construction of the Danube Harbour

For the evaluation of the hydrogeological conditions before the harbour construction, groundwater hydrograph curves and groundwater tables from observation wells were available by the Rhein-Main-Donau AG back to 1979.

Table 3-1: Evaluation of the level hydrograph curves/recordings of the groundwater measuring points

GW-measuring point [Time Interval]	Year MW entire monitoring period	Year MW before harbour construction (until 1994)	Annual Min. before harbour construction (until 1994)	Annual Max. before harbour construction (until 1994)
R 144 [1990-1999]	315.98	315.99	315.53 [1990]	316.68 [1991]
- example data/excerpt from the table				
R 151/3 [1994-1999]	315.01			

all data in [m, Mean Sea Level]

MW = mean-water level

## 4 Geomeasuring Programs Before and During Construction

### 4.1 Installation of the Sheet Piles

Due to the very heterogeneous geotechnical situation at the geological contact of the Danube with soft to mushy soils - within the area of an old ox-bow of the Danube - to very dense tertiary sands as well rock outcrops, a geomeasuring program (FMGM) for the trial installation of a sheet pile wall was geotechnically recommended and instituted. The trial installations of sheet piles were undertaken under two research programs.

In the first test program the suitability of installation with pile driving at three diverse geotechnical locations was tested, whereby altogether in each case 7 double sheets in lengths from 18 to 20 m were hammered with and without interlocking. With the assistance of predrilling the necessity of driving progress (3 blows per 10 cm penetration) could be waived. During the third test-driving trial in the area of shallow rock, the pile driving had to be abandoned due to the very high driving resistance.



Fig. 6: Trial with classical pile driving



Fig. 7a/b: Trial using vibrating injection procedure

In a second trial program the liquefaction and the vibration capability of the tertiary soils and installation by vibrating were explored with the help of injection driving. At location 1 in the western area of the north quai and at location 2 in the middle of the south quai the sheet piles were installed by vibrating injection in 14 and 18 minutes, respectively.

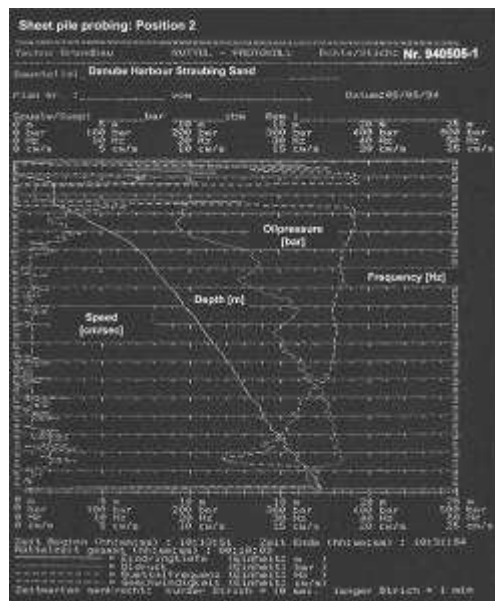


Fig. 8: Measurement Records of Vibrating Injection Trial

In the area of the shallow rock no considerable progress could be achieved after more than 30 minutes of vibrating injection. The end depth of the piles in the rock layer by this method in relation to hammering could be slightly increased, as the vibratory effect acts like a percussion hammer and thereby loosens and breaks up the rock. Since penetration into the rock with this installation method was also not possible, for the area of shallow

rock it was recommended to employ explosives to create a slit of broken rock and to install the sheet piles in this crevice of loosened material.



Fig. 9: Trials in the rocky area (driven sheet pile on left, vibrated sheet pile on right)

#### **4.2 Investigation the Consortium**

The direct and indirect soil explorations in the context of the geotechnical reconnaissance for the establishment of a heavy-load slab and the development of the sheet pile wall in the rocky part of the southwestern portion of the harbour area were supplemented by the ARGE consortium with four additional component-related exploration auger borings and a deliniation of the rock horizon by penetration with a sheet pile using vibrating injection.

#### **5 Quality Assurance Program for the Operation of the Danube Harbour**

For the operation of the Danube harbour - on the basis of the FMGM (Field Measurements in GeoMechanics) the following quality assurance plan was submitted.



## 5.1 General

According to the EAU [7] the security of sea ports and inland harbours is to be proven by checking the static computations submitted for the construction situation and the final completed state. But harbour facilities can themselves undergo short-term or long-term changes in service life and thus also yield changes in the proven security. This evaluation is here particularly valid under the aspect of the permissible water pressure differences and the omission of the drainage. The Danube Harbour Straubing has been conceived for at least a medium traffic age of 50 years or more due to planning and structural implementation.

In connection with higher water pressure differences between the interior water and external water as well as by the lapse of the drainage or other systems like the previously existing design depth to the bottom of the harbour basin, a classification in the sense of Chapter 15 "Measurements of Established Installations, Modelling Tests", i.e. the recommendation E 193 (Monitoring and inspection of waterfront structures in seaports) was proposed. In the 1996 EAU edition the provisions corresponded to those of the 1990 EAU, but regulated in less detail because of the inclusion of new security concepts.

In connection with the planning period and implementation time, the provisions of the EAU 1990 were imposed as a basis. Under 15.1.1. General (E 193) was specified: "Periodic monitorings and examination of bank revetments are necessary, in order to ensure that the construction conforms with all design conditions and a safe execution of all activities taking place on, in front of or behind the bank revetment is guaranteed."

References were made to appropriate regulations within other areas, like DIN 1076 [8] Engineered Structures in Roads and Streets, Supervision and Examination and VV-WSV 2101 Inspection of Construction Work (139). Monitoring and inspections extend to the stability, the operability and the structural condition of the construction work, as far as these are necessary for the security of the units and their traffic safety.

The construction supervision consists of in the inspection of the construction works without large assistance, like scaffolding and the likes, but using existing installations and accesses and from accessible openings of the works. The construction examination is the investigation of the works through the use of all necessary auxiliary devices by a specialized engineer, who can also judge static, structural and hydromechanical conditions of the construction works.

The basis of the monitoring and examinations are the design, the actualized appropriate detailed drawings and the site book. Such a book contains an overview of the most important construction work data and serves as a registry of the aforementioned inspections and examinations (see DIN 1076, Appendix B).

It contains among other things the presentation of objects, cross sections, all design loads, basic ship dimensions, water levels, computational soil characteristic values as well as perhaps also the computation and design of the equipment, as far as they can be for important examinations and not be available in a particular construction document. Special meaning is attached the complete data collection of the monitoring and inspection results, which constitute the basis for necessary maintenance or repair measures (see also E 194, section 10, 14).

These periodic monitorings and examinations are to be specified in a standardized way. For an optimum monitoring and examination of bank revetments suitable experienced engineers are to be available, which ensure a constant and thorough control. If no regulations which are based on experience are available, then the following is recommended/commended:

## **5.2 Supervision Method According to DIN 1054-100 [9] and EAU 1990**

### **Execution of the Monitoring and Examinations According to EAU 15.1.2**

#### **5.2.1 Inspection According to Paragraph EAU 15.1.2.1**

Depending on the age and structural condition of a bank revetment as well as demands and operational requirements, the frequency of inspections is to be specified and permanently adapted. For individual parts, e.g., for bumpers, different periods are to be scheduled if required.

For normal cases it is recommended carry out inspections each year. It is necessary that damage, which arises between two inspections, be promptly announced so that necessary repairs - if possible - can be immediately implemented. Independent of inspections it is to be regularly observed that allowable loads are not exceeded. This is valid also for scour events, which are discovered during soundings in the harbour basin.

#### **5.2.2 Control of the Deformations of the Quai**

Measurement according to EAU 15.1.2.2.

The following periodic measurements are recommended:

- Measurement of possible horizontal movements of the waterfront structure,
- Measurement of possible settlement of the waterfront structure,
- In special cases with waterfront structures with high land wave and thin concrete cover, measurement for the determination of possible tilting of the waterfront structure (rotation measurements); (Fig. E 193-1)

In addition, first, the initial situation is to be established by measurements right after the completion of the waterfront structure, also with reference to E 80, Section 7.1 (null measurement). Depending upon building site soil conditions, type, age and structural condition of a work as well as its usage and operational requirements, appropriate periods are to be specified/set forth for measurements and permanently adapted.

In the first year measurements should taken several times, then once annually. If, thereby, a constant condition of the structure is found, the interval between measurements can be increased. The accuracy of the levellings should be at least 1 mm. The accuracy of the horizontal measurements can be less and depends on the local situation (among other things of the distance between the fixed points). However, it must amount to at least 5 mm.

### Horizontal Deformations of the Quai

The result of the deformation measurements (XY coordinates) of the sheet pile wall is summarized for reasons of clarity in the following table. The result of the 1st and 2nd null measurements and the 3rd and 4th check measurements as well as the deviations between the average value of the null measurement and the respective check measurements as well as between the 3rd and 4th check measurement are presented.

Table 5-1: Results of Horizontal Deformation Measurements of the Quai

Point NR.	1st and 2nd Null Measurement		3. Check measurement (3rd KM)		4. Check measurement (4th KM)	
	Measured value 02.02.1996	Measured value 05.02.1996	Δ Null-Measurement - 3rd KM	Δ Null-Measurement - 4th KM	Δ 3rd KM. - 4th KM	
	Right (Y)	Highly (X)	Right (Y)	Highly (X)	Right (Y)	Highly (X)
100	48205.788 <u>48205.788</u> 48205.788	18713.707 <u>18713.716</u> 18713.712	<u>48205.785</u> -0.003	<u>18713.719</u> +0.007	<u>48205.786</u> -0.002 (+0.001)	<u>18713.709</u> -0.003 (- 0.010)

- example excerpt from the table

Evaluation of Measurement Results:

The results of the measurement program to observe the horizontal deformations of the quai show maximum deviations between the average value of the null measurement and the 4th check measurement from +0.010 to +0.013 m for three measuring points (Point Nr. 600, 700 and 800) in the Y-direction and of +0.010 m for the measuring point 5900 in the X-direction. These measured values are at the limit of the attainable accuracy, and there are still influences to take into consideration like wind, temperature, sun exposure, etc.

Table 5-2: Quality Assurance System in Checking Horizontal Deformation of the Quai

Location	South Quai/RoRo Ramp/Head Harbour basin	Type of Measurement	Frequency of Measurement
Quai	Horizontal Deformations of Quai +)	Geodetic Precision Survey	- every 5 years *)

+) on the basis of the available measuring raster (point No. 100 - 7800)

\*) starting from the end of the guarantee period

Table 5-3: Result at Point 100 in Checking Vertical Deformation of the Quai

Point NR.	Null Measurement 02.02.96 [MSL]	3rd Check Measurement	4th Check measurement
100	318.702	- no measurement	- no measurement

Table 5-4: Quality Assurance System in Checking Vertical Deformation of the Quai

Location	South Quai/RoRo Ramp/Head Harbour basin	Type of Measurement	Frequency of Measurement
Quai	Vertical Deformations of the Quai+)	Geodetic Precision Measurement	- every 5 years*)

+) on the basis of the available measuring raster (point No. 100-7800) starting with the measurement by the ARGE consortium at the end of the guarantee period

\*) starting from the end of the guarantee period

In the context of the geodetic measuring program in the interval from January 1998 (null measurement) up to February 2000 (1st subsequent measurement) the elevation of track 4 (water-side rail of the loading track) was measured. In the observation period, i.e. in one interval of approximately 2 years, a maximum elevation change ("settlement") of the track

of 2 mm was measured, which lies in the range of the measuring accuracy attainable (influences of the weather, temperature, etc.).

### 5.2.3 Control of the Hydrologic Conditions of the Harbour

#### Checking of the Drainage According to EAU 15.1.2.3

The operation of the drainage systems are to be inspected periodically. For this reference is made to E 32, E 51 and E 75 (Sections 4.5, 4.4 and 4.6). Only in areas subjected to tides are measurements according to Section 15.1.2.2 to be carried out, to find out if there is positive water pressure by simultaneously recording the low-water levels and the ground-water level directly at the waterfront structure, in order to ascertain that the actual occurring positive pressure does not exceed the design. Along with the evaluation of the quantity of drainage water, a visual control of the drain openings is to be made.

#### a) Checking of the Basin Water Level

In the harbour basin the water level is to be measured at a central gauge. The data are to be documented and become a component of the quality assurance system. The measured data are documented in the operations reports.

Table 5-5: Quality Assurance System as a Check of the Harbour Basin Water Levels

Location	Level in the Middle of South Quai	Type of Measurement	Frequency of Measurement
Harbour Basin	Installation in the Middle of South Quai	Level reading equipped with marking of the elevation 315.40 and 311.80 MSL, and if necessary with limit value transmitters for the acoustic and/or optical indication of the limit values	<ul style="list-style-type: none"> <li>- weekly</li> <li>- daily under flood conditions with <math>H \geq 315,40</math> MSL (HQ1) and/or low water levels with <math>H \leq 311,80</math> MSL (MNW)</li> <li>- exact definition of the measurement when limit values exceeded in coordination with a specialized engineer“</li> <li>- (provisionally limited to the period of 5 years)</li> </ul>

MNW = middle low water-level

#### Explanation Concerning the Determination of HQ1:

For the Determination of HQ1, i.e., the discharge of floodwater and/or water level of a flood with a one-year probability within the range of the Danube Harbour Straubing-Sand, the

HQ1-Wert of the Pfelling gauge was consulted and transferred to the water level elevation in the Danube Harbour Straubing-Sand.

**b) Checking of the External Water Level**

The checking of the external water level together with the lapse of drainage has a special meaning. In the long-term behavior itself deviations may be due to external influences or changes in the area of the permeability of the material being flowed through, which result in reduction of the efficiency of the drainages among other things. The data collection of the ground water levels follows by locations of the existing groundwater measuring points.

Table 5-6: Quality Assurance System as a Check of the Outer Ground Water Levels

Location	Level 1 PS/4	Level 2 PS/3	Level 3 PW/3	Type of Measurement	Frequency of Measurement
Harbour Basin	Level PS/4 at the eastern end of the South Quai	Level PS/3 within the middle area of the South Quai	Level PW/3 at the head of the port in the corner with the South Quai	Plumb Bob Measurement (Light Plumb Bob)	- weekly - daily under flood conditions with $H \geq 315,40$ MSL (HQ1) and/or low water levels with $H \leq 311,80$ MSL (MNW) - exact definition of the measurement when limit values exceeded in coordination with a specialized engineer - (provisionally limited to the period of 5 years)) *

\*) Definition of a further measuring program after the end of the guarantee period by the consultant and specialized engineer

The selection of the gauge affected the relevant water pressure differences on the sheet pile wall. The groundwater monitoring points were conceived to measure, i.e., observation of the ground water levels, the quaternary ground water in steps.

In the monitoring system only the water levels directly behind the sheet pile wall were included, the farther gauges together with the ground water downward gradient exhibit higher ground water levels, which are not relevant, however, for determining the stability of the sheet pile wall.

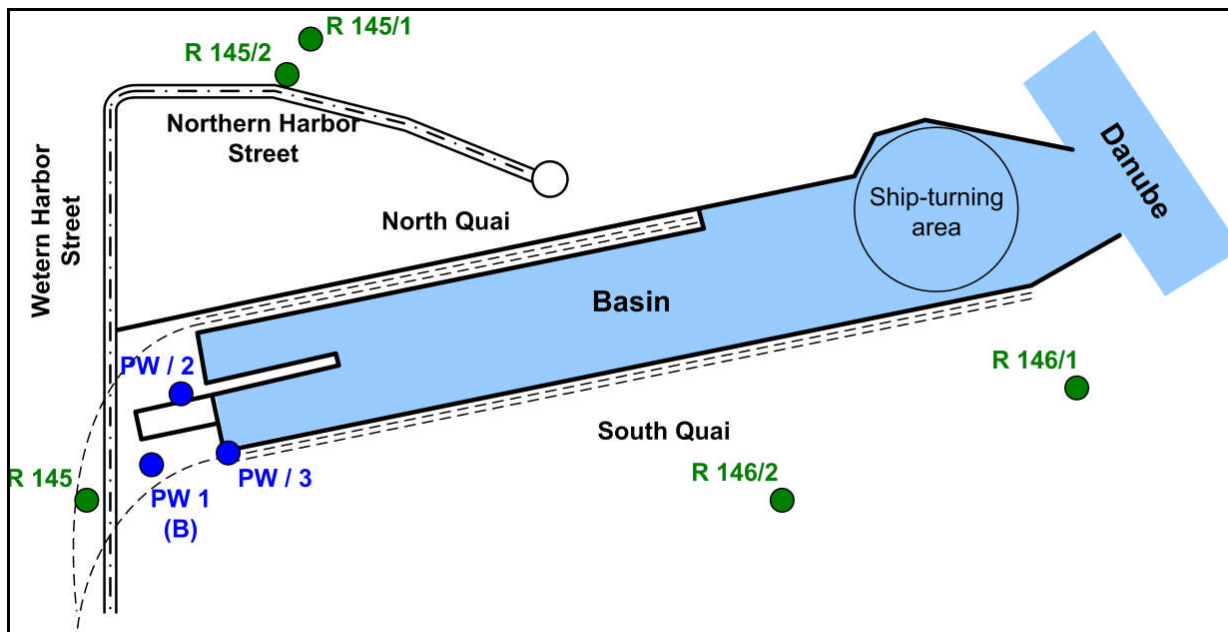


Fig. 11: Plan view of the groundwater monitoring locations

### c) Checking of the Drainage

Checking of the drainages necessary and is coupled with the data collection of the ground water influences or a possible deviation linked to a check on the functioning capability. A data collection of the flow quantities from the drains can be accomplished with the classical hand measurements.

Table 5-7: Quality Assurance System as a Check of the Drain Water Quantities

Location	Drainage 1 Discharge Opening [s]	Drainage 2 Discharge Opening [n]	Type of Measurement	Frequency of Measurement
Harbour Basin Ro-Ro Unit	Beside Ro-Ro Unit	Beside Ro-Ro- Unit	Hand Measurement of the quantity of water with 3 single trials, visual control of the drain openings for the evaluation of the operability	Twice annually

### 5.2.4 Checking of Harbour Basin Bottom Based on FMGM

Plumbing according to EAU 15.1.2.4

The depths of the harbour basin bottom in front of the quai walls should be checked periodically (once a year). The frequency of the plumbing should be more when there is

danger of build-up from scour or depositions of silt. For this reference is made to E 37, E 80 and E 139 (Sections 6.9, 7.1 and 7.3).

Hand plumb bob soundings are to be made perpendicularly to the quai wall in lines every 10 m to a maximum of 25 m. Along these perpendicular lines, soundings should be made every 5 m. Depending on the results of the plumb bob soundings it can be decided to use larger intervals. Within critical areas the distance should be limited to about 5.0 m. When measured by sonar, a hand bob sounding must be made directly in front of the quai wall, because scour formations occur most often next to the wall.

**a) Control of the Harbour Basin Bottom Near the Quai Wall**

Since in the area near to the sheet pile wall sonar soundings furnish inadequate results and on the other hand the precise data collection of the geometry is needed for the foot abutments, it is recommended to resort to classical procedures - to rod soundings - for measurements.

Note: The classical measurement "rod sounding" is to be combined with geodetic measuring methods, such as GPS measuring systems. This recommendation is valid in particular with noted relevant irregularities.

Table 5-8: Quality Assurance System as a Check of the Harbour Basin Bottom Near to the Quai Wall

Location	Grid lengthwise to the port axis [m]	Grid transverse to the port axis [m]	Type of Measurement	Frequency of Measurement
Near to the sheet pile wall	10	0, 1, 3, 7, 15	Rod Sounding	Annually

) \* NB: The existing raster of the 4th measurement is to be maintained

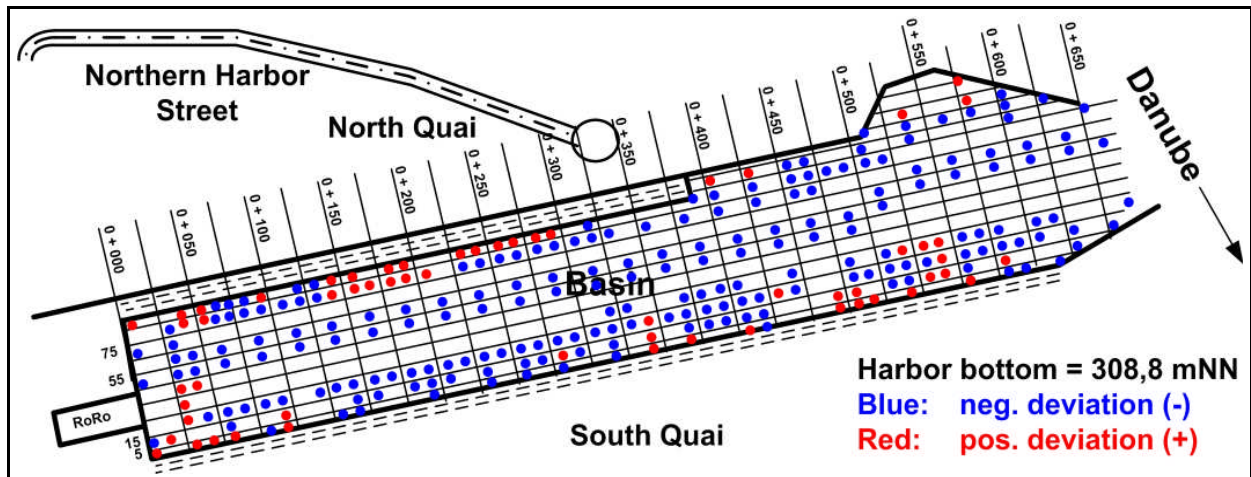


Fig. 12: Results of the rod soundings near the sheet pile walls

**b) Control of the harbour sole in the harbour basin outside of the near field of the sheet pile wall**

This area of the harbor basin is the area apart from that next to the sheet pile walls, i.e. the portions measured by rod soundings and the following specified under c) and d). A data collection of the actual condition of the basin bottom cannot be performed here any more by rod soundings. For these areas sonar soundings are sufficient with regard to the surface covered and accuracy.

Table 5-9: Quality Assurance System as a Check of the Bottom in the Area of the Harbour Basin

Location	Grid lengthwise to the port axis [m]	Grid transverse to the port axis [m]	Type of Measurement	Frequency of Measurement
Middle area of the harbour basin	< 5)*	< 5)*	Sonar Sounding	every 2 years) +

) \* Evaluation grid

) + By significant deviations in the results of the annual rod sounding measurements is to be immediately carried out

**c) Checking of the Basin Bottom in the Ship Turning Area**

The ship turning area is to be associated in a general manner with the area after c).

Table 5-10: Quality Assurance System as a Check of the Harbour Basin Bottom in the Ship Turning Area

Location	Grid lengthwise to the port axle [m]	Grid transverse to the port axle [m]	Type of Measurement	Frequency of Measurement
Ship turning area	< 5)*	< 5)*	Sonar sounding	Every 2 years) +

) \* Evaluation grid

) + By significant deviations in the results of the annual rod sounding measurements is to be immediately carried out

**d) Checking of the Bottom of the Harbour Entrance up to the Navigation Lane**

Table 5-11: Quality Assurance System as a Check of the Bottom of the Harbour Entrance up to the Navigation Lane

Location	Grid lengthwise to the port axle [m]	Grid transverse to the port axle [m]	Type of Measurement	Frequency of Measurement
Harbour entrance	< 5)*	< 5)*	Sonar sounding	Every 2 years) +

) \* Evaluation grid

) + By significant deviations in the results of the annual rod sounding measurements is to be immediately carried out

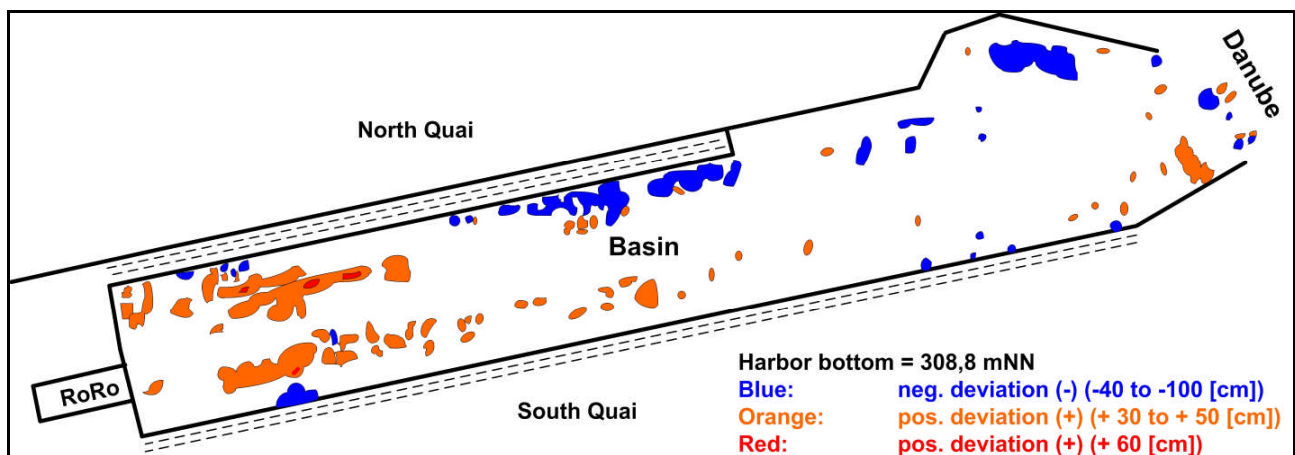


Fig. 13: Results of the sonar soundings in the harbour basin, ship turning area, and Danube harbour entrance

### **5.2.6 Checking for corrosion According to EAU 15.1.2.5**

Periodically the sheet wall steel is to be inspected for corrosion, both under and above water. The steel thicknesses can be determined among other ways by means of ultrasonic measurements, whereby an accuracy of  $\pm 0.2$  mm is necessary. Here too, measurements should be carried out urgently at certain specified points immediately after completion of the waterfront structure at the points of maximum stress.

After the initial measurements it should be established when and at which places the next check measurements are to take place. The usual checking for corrosion in the wet-dry area can be judged visually at low water levels by specialized engineers. In the other areas visual checking is to be carried out punctually. A thickness measurement is necessary with corrosion phenomena. Particularly the corrosion is to be checked annually by a specialized engineer (a personal point-inspection log) in areas subjected to salt water.

### **5.2.7 Notes on Maintenance and Inspection Costs**

These costs should be gathered and kept in order to gain from experiences for later cases.

## **5.3 Operations Reports Book of the Danube Harbour**

In the operations reports book all monitoring and inspection results are to be fully collected as part of quality assurance.

Furthermore, in an prepared annual report the results of the measurements and adopted measures such as crane blocking and reduction of permissible surface load [30 kN / m<sup>2</sup>] and others by the specialized engineer during operation of the Danube harbour are to be listed or shown.

### **5.3.1 Data Acquisition**

The data acquired from the observation of the horizontal and vertical deformations of the quai should be tabulated with the results of the measurements in the form of north and east coordinates and the elevation of the point. The results of measurements of the elevations of the harbour basin water level and ground water levels should be compiled in a tabular calendar listing.

Checking of the quantity of drain water at the RoRo installation is accomplished by three individual measurement trials by hand.

The discharge quantities/flow rates measured, thereby, are to be logged just like the visual control of the drain openings and are to be attached to the measurement report in the form of a table.

The annual checking of the harbour basin bottom in the area near to the sheet pile walls using rod soundings are affected in the previous measurement grid. The results of measurement are to be listed in a table and be presented and evaluated afterwards in a layout plan. The sonar bottom sounds normally in a 2-year rhythm of the interior harbour basin and in the ship turning area and the harbour entrance up to the navigation lane are to be presented in a grid of  $< 5 \times 5$  m in a layout plan.

Control of the sheet pile wall for corrosion is affected via a specialized engineer embraced in a tabular listing of the inspection results. In it the position description, corrosion phenomena found and measured layer thicknesses if necessary as well as the definitions for the prevention of further steel corrosion and/or necessary safeguard measures, are included.

### **5.3.2 Presentation**

The tabular listed results of the inner and outer groundwater level measurements are to be summarized and presented in elevation hydrograph curves. The GW and/or basin water hydrograph curves and the table of the maximum water level differences are to be drawn up annually in a quality assurance report and the component of the operations reports book to be attached.

## **6 Summary and Concluding Remarks**

The establishment of the Danube Harbour Straubing and its continued operation have been accompanied by permanent construction and geotechnical monitoring programs. The basis for the geotechnical investigations and the execution of the construction was a special geomonitoring program, the results of which were documented in this presentation. The results of the geotechnical investigations and their interpretation were the bases for the on-site studies to select the sheet pile wall insertion technique and to develop a new construction method. Based on these results, for the first time a new construction method could be applied, MOSER, HERRMANN, JUNG [2]. The application of the new method was documented by permanent instrumentation monitoring as a part of the quality management.

For the operation of the Danube Harbour based on the EAU 1990 (Recommendations of the Working Group for Waterfront Structures Harbours and Waterways of the DGGT), a quality assurance system was conceived and implemented, embodied in a distinct quality assurance program. This follows from the construction of the harbour with the installation of the construction and geomeasuring systems. The concept of the quality assurance plan on the basis of the construction and geomeasuring techniques were presented in this report.

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## Authors

Univ.-Prof. Dr.-Ing. Richard A. Herrmann  
Institut für Geotechnik  
Universität Siegen,  
Paul-Bonatz-Straße 9 – 11, 57068 Siegen

[richard.herrmann@uni-siegen.de](mailto:richard.herrmann@uni-siegen.de)

[www.geo.uni-siegen.de](http://www.geo.uni-siegen.de)

Dipl.-Ing. Thorsten Lauber  
GEOTECHNIK GmbH  
Prof. Dr.-Ing. Herrmann & Partner  
Lammelbach 5, 91567 Herrieden

[GEOTECHNIK\\_GmbH@t-online.de](mailto:GEOTECHNIK_GmbH@t-online.de)