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Particular demands on deformations of building pit side

T. Siemer & S. Herzberg
IBTB Ingenieurgesellschaft für Bautechnik mbH, Berlin, Germany
H. Fricke
MPG Magnetschnellbahn-Planungsgesellschaft mbH, Berlin, Germany

ABSTRACT: The Transrapid project – with 450 km/h high speed travelling from Berlin to Hamburg- is introduced in this report. Particularly heavy traffic is to be expected between the burgeoning metropolitan areas of Berlin and Hamburg. The Transrapid magnetic levitation (MAGLEV) transportation system is intended to help cope with this traffic within a few years, while making it more attractive for users and environment friendly.
For the construction of the traffic installations in the area of the Lehrter Station in Berlin, the largest open building pits in Germany with respect to building pit area and depth is currently being built. The report introduces the specific design concepts that have been developed for these deep building pits. The main requirements for the construction and engineering services are discussed based on state of the art analytical methods and on-site measurement results.

1 INTRODUCTION

1.1 *General*

Traffic flows have changed considerably in Germany following national reunification, rising especially sharply on routes between eastern and western Germany. Particularly heavy traffic is to be expected between the burgeoning metropolitan areas of Berlin and Hamburg. The Transrapid magnetic levitation (MAGLEV) transportation system is intended to help cope with this traffic within a few years, while making it more attractive for users and environment friendly. Every fifteen to twenty minutes, a Transrapid will set off in either direction, gliding along the almost 300-kilometer line linking Germany's two largest cities, and reaching its destination in less than 60 minutes, possibly stopping somewhere in the Schwerin region.

1.2 *Building pits*

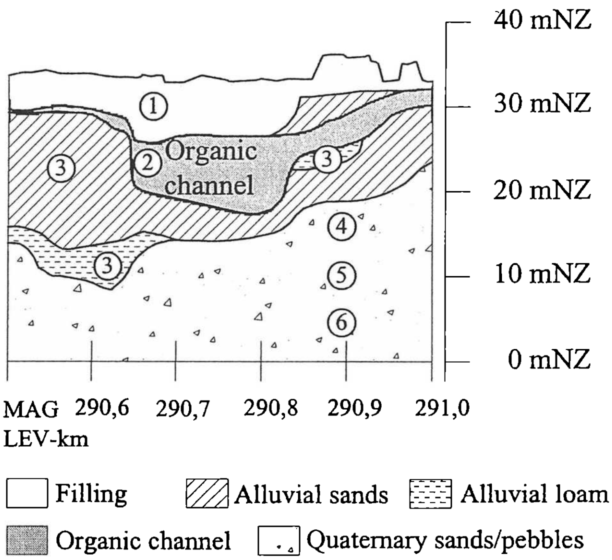
For the construction of the traffic installations required for the Transrapid in the area of the Lehrter Station in the Berlin traffic junction, the largest open building pits in Germany as regards building pit area and depth under the ground-water table are currently being built. The special geological situation of the Berlin subsoil and the fact that the lowering of the groundwater level is currently impermissible in Berlin for ecological reasons, means that new solutions for planning and constructing watertight building pits are required. The following report deals with the building pits and their special design methods. The report also refers to the special geological situation of the Berlin subsoil. The calculations for the building pit sides carried out here are compared with current measurement results.

Figure 1. Geological map of Berlin (LGRB 1995).

2 GEOLOGY AND GEOTECHNICAL REPORT

Berlin is part of the young moraine landscape of the North German-Polish depression. The uppermost deposits and the morphology of the Berlin subsoil result from the Weichsel glacial from the Quaternary Era.

In the three stages of the ice retreat out of the Weichsel glacial, the melt-waters created three broad, east-west facing original stream valleys, one after the other, in and around Berlin: the Eberswald original stream valley, the Berlin original stream valley and the Baruth original stream valley (Fig. 1, LGRB 1995).



No	Soil	Friction angle φ[°]	Unit weight γ/γ' [kN/m³]
1	Filling	28	18 / 11
2	Organic channel	15	14 / 4
3	Sands, organic admixtures	30	17 / 8
4	Sands, loose	32,5	17,5 / 9,5
5	Sands, medium density	35	18 / 10,5
6	Sand, dense	37,5	19 / 11

Figure 2. Geological longitudinal section.

Tertiary sands and pebbles form the pre-quaternary subsoil of Berlin. These tertiary layers lie at 80m to 180m under ground level and thus have no influence on usual constructions. The above-lying quaternary deposits from the Elster, Saale and Weichsel glacials and the intermediate interglacial (warm times) reach layer thickness of up to 130m. They consist of sands, pebbles, coarse clays and shifting marl, with interstratification of fine sands, clays, muds and sapropel. The glacial soils from the Pleistocene Period were superimposed in areas with alluvium soils. These are predominantly located in wide-ranging lowlands and in the narrow, but deep melt-water channels. In these channels there are organic deposits such as peat and muds. In the area of the Lehrter Station, the organic deposits are described as the „Organic Channel" (Fig. 1 and 2). This „Organic Channel" is of great significance for the planning and the construction of the building pits in the area of the Lehrter Station.

Figure 2 shows the geological longitudinal section through the Berlin subsoil. The „Organic Channel" is marked separately. The building pit with which this report deals lies in the range of influence of the „Organic Channel".

The subsoil model is derived from the geological model (Jessberger + Partner 1998). Soil types with the same or similar physical properties are combined into soil layers for the design as shown in the table in Figure 2. The „Organic Channel" with the subsoil without loading capacity can clearly be seen.

3 HYDROLOGICAL CONDITIONS

Due to the location of Berlin in the range of influence of the original stream valley, there is a high groundwater level. Therefore a special design is needed for the construction of the building pits with depths of up to 20m with groundwater protecting construction methods.

The building construction of watertight open building pits therefore is of central significance as:

- Building pit and base sealing with natural existing dense marl layers; integration of the side into the marl layer
- Building pit and base sealing with a low-lying or high-lying soft-gel or jet grouting base
- Building pit and base sealing with an underwater concrete base

Naturally sealing marl layers are not present in sufficient quantities in the area of the Lehrter Station. Soft-gel bases are not currently implemented in Berlin following the authorities. Jet grouting is technically only of limited use due to wood and charcoal interstratification, especially in the area of the „Organic Channel".

Therefore, the base sealing problem is being solved with an underwater concrete base.

4 CALCULATION METHODS ACCORDING TO THE "GBOB"

The experience gained so far in the design and construction of the building pits and buildings at the Lehrter Station and other major construction sites in Berlin have been summarised by the PVZB in special calculation methods (GBOB 1997).

The GBOB specifies the calculation approaches for single-braced building pit sides with an underwater concrete base as a base sealing. These methods towards the consideration of the service limit state of the building pit side are described towards two construction phases:

- Construction phase (1): Excavation down to the excavation base oft the underwater concrete base.
- Construction phase (2): Draining of the building pit after adding the underwater concrete base and its anchoring.

4.1 *Construction phase 1*

The static system in construction phase 1 is a point-braced side at the head of the of the building-pit side and also a point-braced side on the base bearing without horizontal deformation in the height of the resulting earth resistance E_p" (Point bearing, Fig. 3, top).

The magnitude of this earth resistance is definitively a function of the side deformation. In the calculation with immovable bearing (E_p"), this effect is only considered in simplified terms. The earth resistance e_p is reduced by the safety coefficient η to $e_p'=e_p/\eta$.

Experience from the building pits in the area of the Lehrter Station show that the dependence of the magnitude on the earth resistance η_p as a function of the side deformation is even strengthened by the existing sand under lifting forces. The base for calculation according to the GBOB therefore intend the use of $e_p'=e_p/3$, thus only 1/3 of the full earth resistance.

For improved calculation of real system behaviour with view to the relation between earth resistance and deformation at the base bearing, in a further calculation approach, bedding springs are used in place of the earth resistance. The resultant bedding stresses are pre-located to the base bearing (Bedding approach, Fig. 3, middle).

The deformation of the side base required for the activation of e_p' then amounts to $\Delta u_1=0.006*t$ (Fig. 3, bottom). "t" is the integration depth of the building pit side. This deformation has to be proved to a depth of 1/2 to 2/3*t. If the above-mentioned condition for the side deformation is not kept to in the calculation, then the calculation has to be varied with new bedding values. By means of an adaptive bedding adjustment in the calculation, it is ensured that the bedding stresses σ_{cB} do not exceed the permissible earth resistance e_p' (Fig. 3, middle).

The classical active earth pressure is generally used for the calculation of the building pit side:

- The building pit side is capable of deforming, such that an active slipping earth wedge exists.
- The deformations for the building pit side and buildings can be tolerated.

If there are buildings near to the edge of the building pit side, then the increased active earth pressure $e_a'=0.5(e_a+e_0)$ has to be used. "e_a" is the active earth pressure, "e_0" is the earth rest pressure.

The water table in the building pit is equal to the groundwater table. The active earth pressure and the resultant deformations and bending moments with point-braced and embedded base bearing are shown in Figure 3.

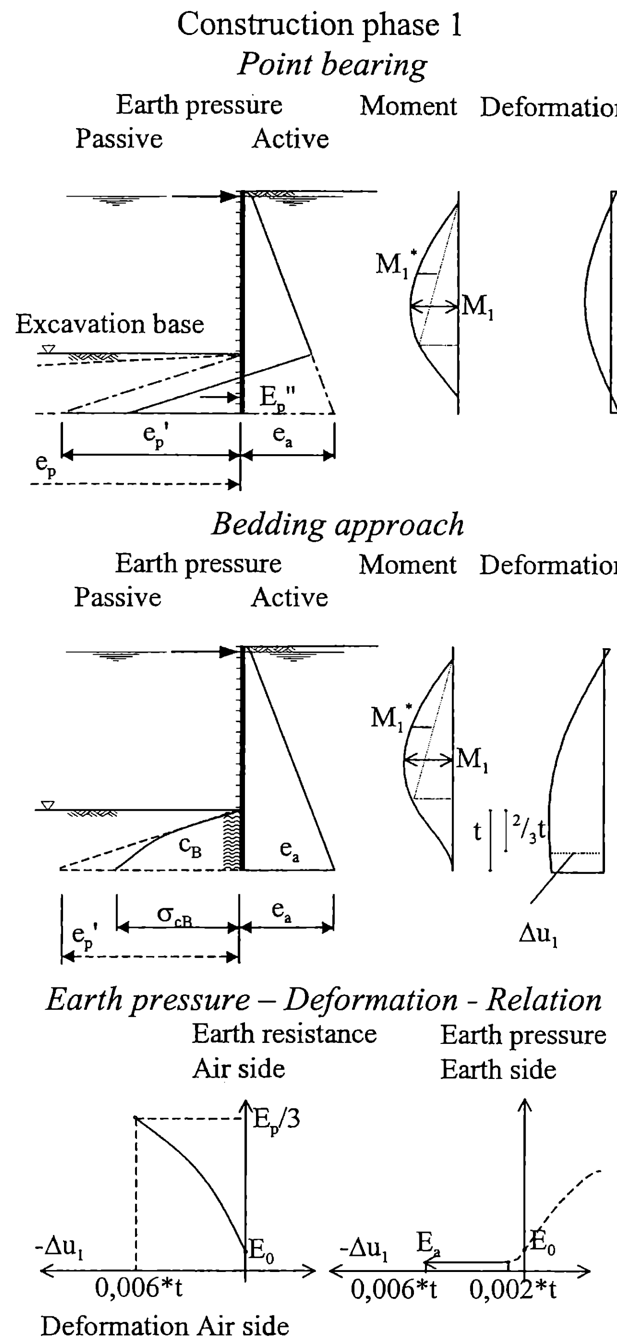


Figure 3. Construction phase 1.

4.2 *Construction phase 2*

Construction phase 2 describes the building pit side after adding the underwater concrete base with its anchoring and after the draining. The building pit side is braced at the top. The base bearing is formed by the hardened underwater concrete base. The static system corresponds to a two point bending beam with a cantilever beam at the base bearing.

The difference between water level "$w_ü$" outside and inside the building pit after draining the water is assumed to be a load on the earth side (Fig. 4, top). This leads to a backward deformation of the side underneath the underwater concrete base. The side base moves at Δu_2 towards the earth side (Fig. 4, middle).

The earth resistance applied on the air side is thus reduced in relation to the magnitude of this backward deformation Δu_2. The earth resistance $e_p' \leq e_p/3$

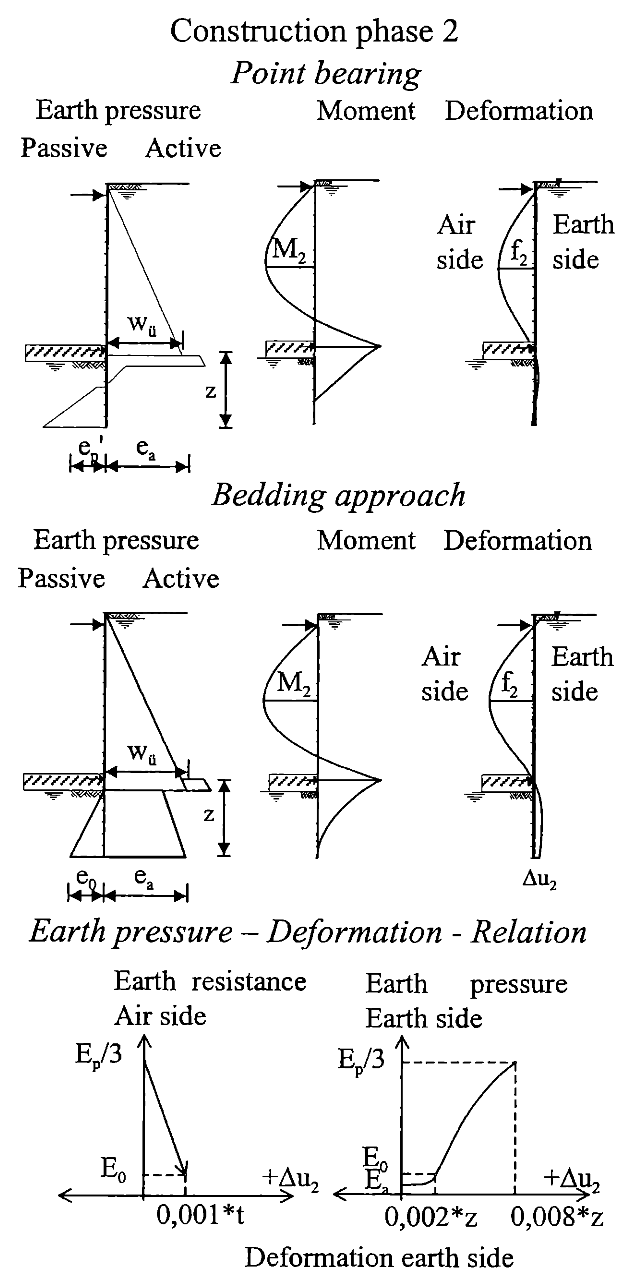


Figure 4. Construction phase 2.

falls (according to the GBOB) at Δu_2=0.001*t to the earth rest pressure e_0 (Fig. 4, bottom). Thus, a relocation of the earth resistance forces from the subsoil underneath the building pit base onto the underwater concrete base comes into effect for the earth pressure load occurs. The relocation applies a supporting force to the underwater concrete base.

On the earth side, an earth resistance builds up due to the deformation of the side base against the earth. According to the GBOB, this earth resistance is dependent on the backward deformation Δu_2 (Fig. 4, bottom). In the case of Δu_2=0.002*z, the active earth pressure e_p' from construction phase 1 is increased to the earth rest pressure e_0. "z" is the distance between bearing point in the height of the underwater concrete base and the bottom of the side base.

The difference water pressure and the earth pressure underneath the underwater concrete base, as well as the resultant deformations and bending moments are shown in Figure 4.

5 PRACTICAL USE OF THE "GBOB"

The calculation approaches according to the GBOB are now being applied for a building pit side at the Lehrter Station directly next to the Transrapid project, and compared to on-site measurement results for the deformations.

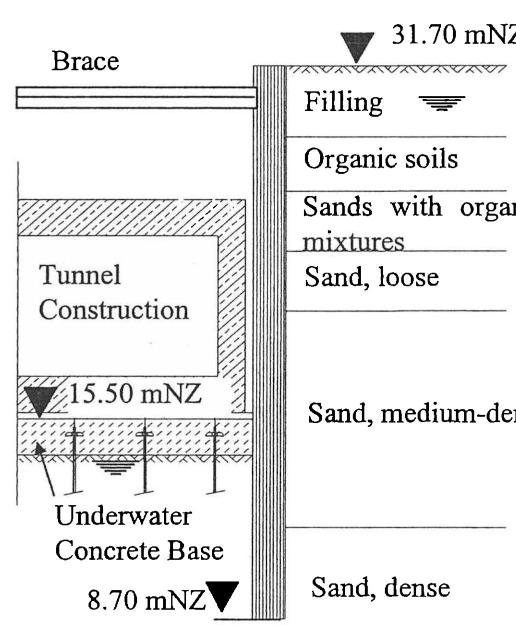


Figure 5. Building pit side MAGLEV.

The proof of the deformations, i.e. the service limit state, is important for such deep building pits with high groundwater level, because decisive significance is allocated to the tightness of the building pit side for general safety and for the construction. Different deformations between neighbouring diaphragm wall elements or in the depth of the underwater concrete base can lead to a failure of the sealing function. The incoming groundwater can lead to dangerous situations for the construction workers and complicate the construction progress.

5.1 *Building pit cross-section*

Figure 5 shows a building pit cross-section in the area of the Lehrter Station which is representative for the Transrapid project. It shows the static system and the soil layers for the subsequent calculations. The soil properties are specified in the table in Figure 2. The situation with organic soil layers and loose sands increases in an easterly direction.

5.2 *Calculation and measurement results*

In Figure 6, the calculations with a point-braced base bearing (dotted line) and with a bedding approach on the base bearing (continuous line) are compared with measurement results (symbols).

Construction phase 1 is definitively characterised by the underwater excavation up to the level of the underwater concrete base.

Construction phase 2 is only of interest for the calculation with the proportion of the load from the difference water pressure after draining the water outside the building pit. On examination of the total deformation the installation of the „GEWI" piles with respect to the lifting forces in the underwater concrete base and the event of draining the building pit are important.

In construction phase 1, the calculated deformations in the case of the bedding approach in the field (45.6cm) and at the level of the underwater concrete base (44.8cm) are clearly greater than in the case of the measurement (21.5cm field and 22.5cm base). This results from reduced bedding values at the base bearing, according to the deformation criteria from the GBOB (Fig. 3, bottom) as regards achieving 1/3 of the earth resistance in the sand under lifting forces.

For the calculation with point bearing (30.9cm field and 19.2cm base), there are results in a similar order of magnitude. However, the good consistency of the results in the field and in the area of the underwater concrete base disappears when the bearing is moved into deeper side depths in the case of an extension of the side length with the same excavation depth.

The total deformation of the building pit side is calculated by the addition of construction phases 1

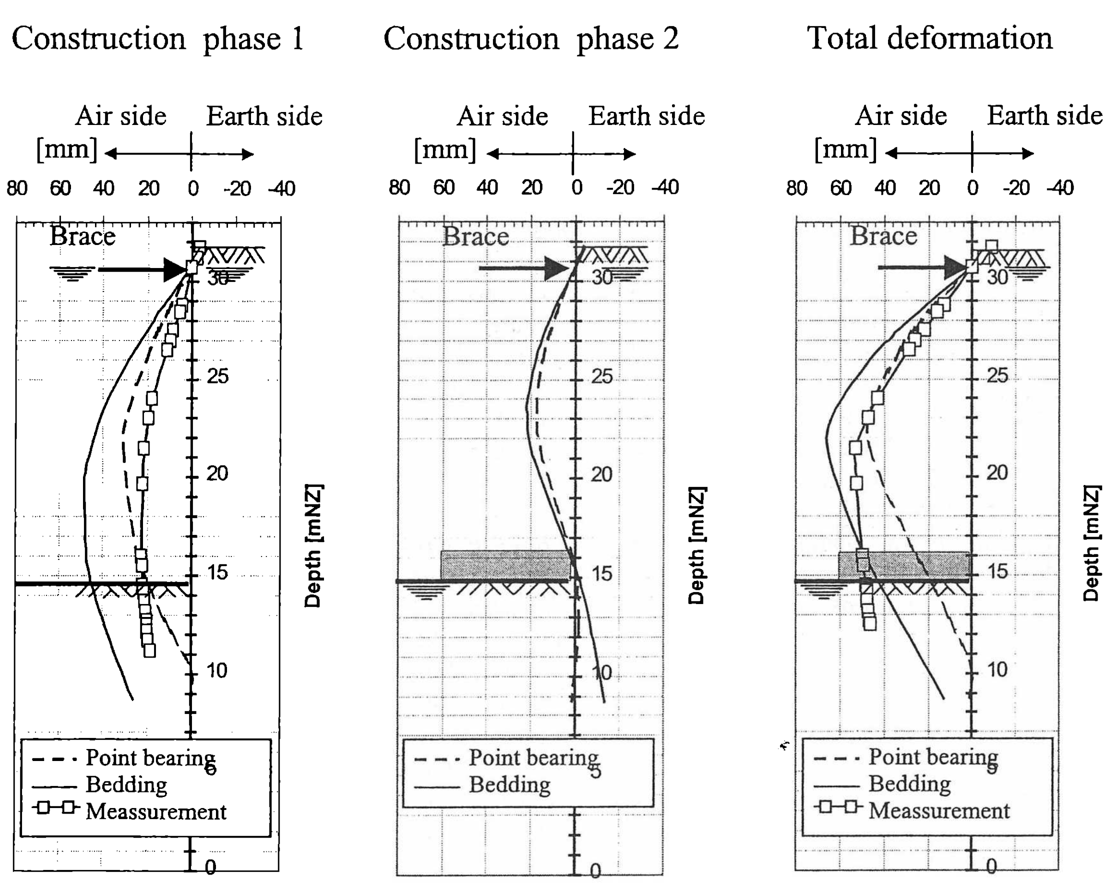


Figure 6. Calculation and measurement results.

and 2 after the installation of the anchoring of the underwater concrete base and after draining of the building pit.

This total deformation is described well at the level of the underwater concrete base by the calculation method of the GBOB with bedding approach.

Here, the definitive part of the deformation from the installation of the „GEWI" piles and the associated loosening of the soil at the base bearing seem to be well predicted.

Triantafyllidis 1998 describes this significant increase in the deformation as a reduction of the bedding in the area of the side base for a building pit at Potsdamer Platz in Berlin. He calibrates the constant bedding approach K_{St}=40MN/m^2 by means of several calculations with a reduction factor at K_R=2.4MN/m^2. In this way, a good consistency between measurement and calculation is obtained.

For these two practical applications with comparable static systems, but different soil properties, the deformation of the building pit sides can be predicted well with a bedding approach.

In the field, the deformation (65.8cm) calculated with bedding approach is slightly less than the deformation measured (53.2cm). The calculation with point bearing describes the measurement well up to approx. half of the height of the side. However, the deformation at the level of the underwater concrete base is clearly less. Here, the static system is decisive, as was already mentioned in chapter 4.1.

The reason for greater calculated deformations in the upper section of the building pit side can be explained e.g. to low rigidities EI_{II}=2/3EI_I over the entire side length. EI_{II} means a calculation in the cracked state (mode 2). In fact, the building pit side passes over into the cracked state with increasing depth and deformation.

Calculations with 1/1EI up to 26 mNZ, 2/3EI up to 15mNZ and 1/1EI up to the bottom of the pit side lead to a much better agreement with the measured values.

In order to reduce the total deformations due to the installation of the „GEWI" piles, the installation procedure for the piles in the side area was changed in that the drilling speed was clearly reduced and the sequence of the installation was changed in the case of the deep building pits at the Lehrter Station. In this way, the total side deformations could be clearly reduced.

CONCLUSION AND FURTHER VIEW

The calculation methods for the design of the deep building pits for the traffic installations in the area of the Lehrter Station in Berlin are summarised in the GBOB 1997. A comparison of state of the art calculations and current measurement results for deep, single-braced rigid building pit sides with underwater concrete base show:

- The earth resistance-deformation relationships in the GBOB allow a safe estimation of the order of magnitude of deformations.
- Additional building pit side deformations due to the installation of the anchoring of the underwater concrete base are correctly predicted.
- The global reduction of the pit side rigidity for taking into consideration the cracked state in mode 2 leads to higher calculation results.
- Calculations with graded values for the side stiffness lead to a much better agreement with the measured values.
- The results shown here can be comprehended through the comparison with measurement and calculation results from literature.

Overall, the results described here show that in the case of such deep building pits with such large effective spans and at the same time, difficult soil conditions, a combined measurement and calculation procedure for the design and construction appears to be meaningful. After a calibration of the calculation approach with comparable systems, the construction can be designed. Duddeck (1996) has drawn similar considerations. Constant monitoring of the deformations by means of in-situ measurement programmes is useful to check the design results. In the case of large discrepancies between the predicted and measured deformation, the planning has to be reworked in order to avoid risks to the building pit side in its service state where possible.

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