Risk Analyses for geotechnical Tasks using practical Examples in the 'Europaviertel' in Frankfurt, Germany

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1 Geotechnical Risk Analysis

In civil engineering, the term 'risk' is defined by multiplying the probability of occurrence by the magnitude of the damage it may cause. This means that a low risk exists if the probability of an event occurring or the damage which it may cause is low. The greater the damage and the higher the probability of an event occurring, the greater the associated risk [1].

In geotechnics, the risk depends on a large number of parameters and conditions. The task is to reliably estimate or substantiate the consequences of a damaging event, and to determine the probability of this occurring. This requires a high level of professional experience and a representative database that can be accessed [1].

According to NUSSBAUMER et al. [1], the risk analysis process essentially consists of the four main elements of risk identification, risk assessment, risk control and risk monitoring. These are exemplified in Fig. 1. Risks can occur in almost all project phases, from acquisition to the guarantee phase, and can have different effects on the way the project develops. For this reason, the focus of any risk analysis should be on minimizing risks that are already known before the start of construction work and on discussing the identified risks with all project participants and parties to the contract. This discussion must be understood as a process with the aim of making the identified risks more transparent for all parties involved and at the same time clearly defining the areas of responsibility when the risks occur [1].

The observation method can also be mentioned as a final point for the minimization of risks. This is directly related to the prognosis established in the risk analysis and serves to verify and validate it. By applying numerical methods, predictions can be made about the behaviour of soils, such as changes in their deformation and stress, before construction begins. In the course of the construction work it is necessary to monitor these predictions with measurements using the observation method, and to assess the behaviour of the system. Such a detailed monitoring process can make a significant contribution to the identification of risks and at an early stage prevent risks from occurring.

Construction projects are subject to risks, from the project-planning stage through the design phase to the execution phase and the subsequent guarantee period. This paper explains geotechnical risk analyses using selected examples from the Europaviertel project in Frankfurt, Germany.

Geotechnics • Practical examples • Risk analyses

2 Description of the Project Area Europaviertel in Frankfurt

2.1 Location and Topography

The Europaviertel in Frankfurt is located between the trade fair and the main railway station. The project is being realised here as a development of the site of the former freight station. Site development work began in 2005 as a new city district with apartments, offices, hotels and social infrastructure, parks, and shopping and leisure facilities.

Fig. 2 gives an initial overview of the size of the project with an area of around 900,000 m² [2]. The project area is divided into Europaviertel West and Europaviertel East. The Emser Bridge, marked in red in Fig. 2, forms the boundary between the two areas.

2.2 History and existing Buildings

In 1996 it was decided that the freight station should be closed. Operations ceased in 1998, and in 1999

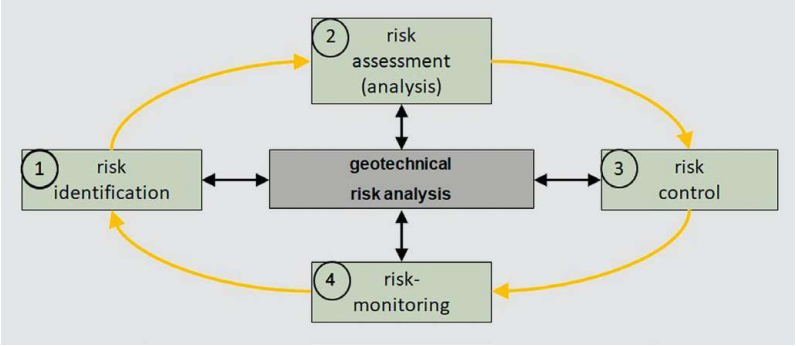


Fig. 1: Schematic structure of a risk analysis [1]



Fig. 2: Aerial photograph of the Europaviertel project area [3]

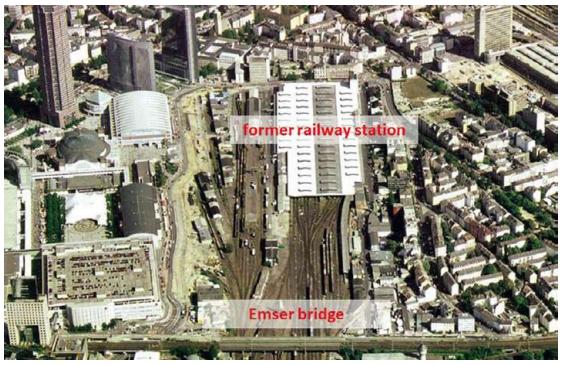


Fig. 3: Aerial photograph of the main freight station, Frankfurt, in 1997 [4]

the Frankfurt planning office Albert Speer & Partner (AS&P) was commissioned to draw up a framework plan for the future development of the project area [4]. Fig. 3 shows an aerial photograph of the former freight station in the middle of the project area. During the Second World War, the freight station was repeatedly the target of air raids, which makes the issue of freedom from explosive ordnance in the project area a topic of great importance when preparing a risk analysis.

2.3 Subsoil and Groundwater Conditions

From a geological point of view, the Europaviertel project area lies inside the Mainz Basin on the northern edge of the large tectonic rift zone of the Rhine Valley Rift [5]. Under artificial fills, the layers of the Quaternary follow with different thicknesses. The Quaternary strata consist of fluviatile terraced sediments of the River Main (sands, gravels and silts) as well as loess deposits and the products of their rearrangement and weathering. They are underlain by Tertiary sediments. In the project area, the Tertiary is formed by Miocene hydrobien layers consisting of an irregular sequence of clays, limestone banks, algal reefs and hydrobien sand layers, collectively known as the Frankfurt Formation. They reach a thickness of up to 100 m. The so-called rocky inflaty follow below the hydrobien layers and are more rocky and therefore less compressible than the hydrobien layers.

Surveys of the area of the former main freight station in the west of the project area revealed, among other things, a Pliocene (Tertiary) trench which was explored down to a depth of approx. 16 to 20 m below the surface. During exploratory drilling in the southeastern part of the project area, the top of the Pliocene trench was established at a depth of between approx. 6 to 12 m below ground level to approx. 12 to 20 m below ground level. The extract from the geological map in Fig. 4 shows the location of this trench, which is filled

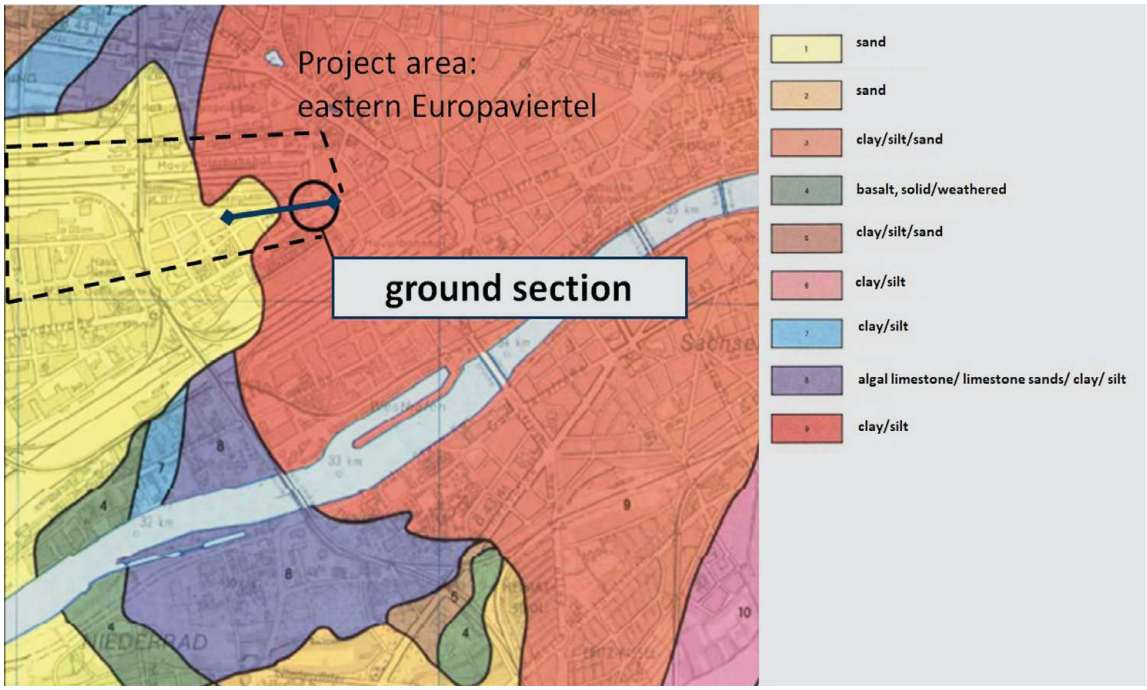


Fig. 4: Extract from the geological map 3 with documentation of the Pliocene trench [5]

with sands, gravels, silt and partly with very silty, fine sandy clays. In some areas, the Pliocene trench separates the Quaternary from the Tertiary layers of the Miocene. Experience shows that the boundary between the Quaternary and Tertiary periods is very undulating; an example of this can be seen in Fig. 5 which shows a section of the subsoil in the project area.

In the project area, the Quaternary sands and gravels and the Tertiary sands, gravels and the fissures of the limestone banks are all groundwater bearing. The areas of Tertiary clays and silts do not themselves carry groundwater and therefore have a blocking effect. In the area of the Pliocene trench, the Quaternary and Tertiary sands and gravels form an aquifer. Currently available information assumes the groundwater level GWConstruct at 93.00 m above MSL for the construction period.

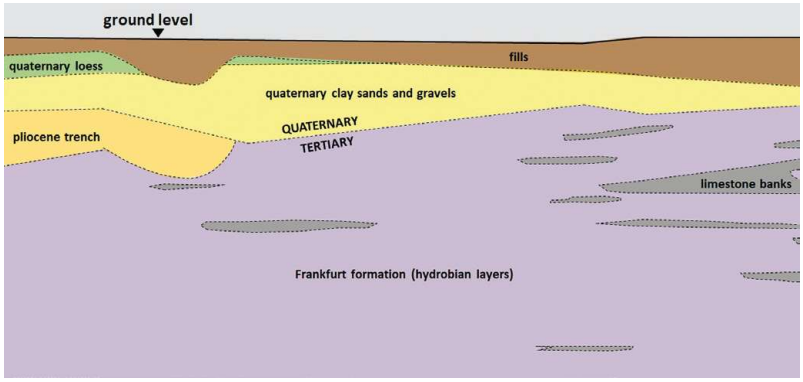


Fig. 5: Section through the south-eastern part of the project area

3 Risk Catalogue for the Europaviertel Project Area in Frankfurt

The preparation of a risk catalogue for the Europaviertel project area in Frankfurt is a central point in the implementation of a geotechnical risk analysis for such a project area. As this risk catalogue was drawn up after the completion of numerous construction projects in the Europaviertel and during the construction of current projects and others in the planning stage, it is possible to draw on findings and risks that were identified in advance or that have already materialised in the completed projects, and thus to list a large number of possible risk events which might threaten the success of the project. The list of risks in the risk catalogue refers here only to those risks that result from the system or subsoil risk in the project area; it is intended to act as a checklist for the risk analysis of projects, to serve as a store of information and to provide an overview of possible risks and their classification.

3.1 Structure of the Risk Catalogue

When drawing up the risk catalogue, the first step was to determine the contents and define the respective categories (RC) of the risk catalogue. The following lists the individual components of the catalogue and their classifications:

- **RC 1** Project risks and risk categories
- **RC 2** Definition and impact of the risk
  - **RC 2.1** Risk types, partial risks, and consequences and measures
  - **RC 2.2** Risk impact
- **RC 3** Risk assignment
  - **RC 3.1** Subsoil risk
  - **RC 3.2** System risk
- **RC 4** Risk assessment
  - **RC 4.1** Extent of damage of risk
  - **RC 4.2** Probability of occurrence
- **RC 5** Scoring result and risk value

The project risk section of the risk catalogue refers to the various categories associated with direct risks to a geotechnical project. In this context, the term category refers to the three key geotechnical disciplines: tunnelling, the foundation of structures and the construction of excavation pits.

The higher-order section 'definition and impact of risk' describes the main parts of the risk catalogue. In addition to the various types of risk, such as the inhomogeneity of the subsoil, or groundwater, the partial risks of the individual risk types are also dealt with and the implications of these and measures opposite them are considered. Finally, the effects of the risks on the project process or their influence on project activities are discussed.

3.2 Risk Types and associated partial Risks with Consequences

A total of nine risk types (RT) were defined in the risk catalogue. These can be assigned either to the subsoil risk, the system risk, or both. The nine risk types, whose partial risks are discussed below, are:

- **RT 1** Inhomogeneity of the subsoil
- **RT 2** Groundwater
- **RT 3** Geogenic/anthropogenic obstacles in the subsoil
- **RT 4** Anthropogenic (construction-related) soil contamination
- **RT 5** Earthquake
- **RT 6** Vibrations
- **RT 7** Foundation
- **RT 8** Planning approval procedure
- **RT 9** General Risks

3.2.1 RT 1 – Inhomogeneity of the Subsoil

The subsoil is characterised by considerable inhomogeneity of the existing strata in the project area consisting mainly of clays, silts, sands, and gravels (Quaternary and Tertiary).

The inhomogeneity of the subsoil and its components results in a large number of risks which are

Table 1: Partial risks of risk type RT 1 'Inhomogeneity of the subsoil'

Partial risk		Consequences and measures
RT 1.1	natural scatter of soil and rock mechanical parameters φ/c	▸ influence on stability ▸ increase survey density ▸ mathematical verifications with variation of the parameters ▸ limited or impossible optimization measures
RT 1.2	wide range of coefficient of permeability (horizontal and vertical)	▸ over-/underestimate of the water volume ▸ adjustment dewatering excavation pit ▸ additional decoupling/drainage into canalisation/ seepage basins ▸ pumping tests/ back analysis GW
RT 1.3	different stiffnesses within one soil layer	▸ extent of settlement ▸ settlement differences/tilting/angular rotation ▸ mathematical verifications with variation of the stiffness
RT 1.4	different layer thicknesses of the subsoil	▸ over-/underestimation ▸ bearing capacity/stability ▸ Increase survey density ▸ mathematical verifications with variation of the layer thicknesses
RT 1.5	limestone banks/ algal lime beds (water permeability/ stiffness)	▸ over-/underestimate of the water volume ▸ adjustment dewatering excavation pit ▸ tightness of the excavation pit ▸ settlement differences/cants ▸ abrasivity ▸ drillability/manufacturability
RT 1.6	quality (installation density/material) of backfilled areas at the freight station	▸ subsoil replacement/soil improvement ▸ landfill/disposal required ▸ increase survey density
RT 1.7	Pliocene trench	▸ over-/underestimate of the water volume ▸ over-/underestimate of the bearing capacity ▸ tightness of the excavation pit ▸ increase survey density
RT 1.8	contamination of the soil / geogenic impact	▸ subsoil replacement/soil improvement ▸ landfilling/disposal required ▸ increase survey density ▸ detailed sampling/analysis ▸ testing recyclability or landfilling

Table 2: Partial risks of risk type RT 2 'Groundwater'

Partial risk		Consequences and measures
RT 2.1	groundwater level during construction	**if < GWCons:** ▸ overestimate of extraction volume **if > GWCons:** ▸ underestimate of extraction volume / uplift of the base / effect on shoring ▸ groundwater monitoring ▸ take immediate measures (alarm and action plan)
RT 2.2	creation of a hydraulic short circuit between the groundwater levels	▸ tightness of the excavation pit ▸ bored-pile construction with water load ▸ if necessary, grouting of the bored piles ▸ adaptation of the planning (base of excavation pit/ foundation design)
RT 2.3	groundwater impoundment by enclosure of excavation pit/foundation	▸ if necessary, additional hydromechanical calculations ▸ measures against GW impoundment (e. g. culvert, groundwater window) and against ochre formation/sintering
RT 2.4	survey boreholes not properly plugged	▸ possible impairment of the tunnel-boring concept ▸ water ingress into excavation pit ▸ measures for backfilling/injection ▸ additional dewatering
RT 2.5	anthropogenic/ geogenic pollution of groundwater	▸ implement the requirements of water law permits ▸ groundwater remediation measures

clearly assigned to the subsoil or system risk and which can have a major influence on the structures founded on it.

Table 1 lists the identified partial risks resulting from the risk type Inhomogeneity of the subsoil and explains their implications and measures.

3.2.2 RT 2 – Groundwater

In the Europaviertel project area there are several layers of subsoil which are groundwater-bearing. These include the Quaternary sands and gravels, the Tertiary sands, gravels, which are aquifers of pore groundwater, and the limestone banks, which are classified as fissure aquifers or karst aquifers.

The non-water-bearing layers of the Tertiary clays and silts act as barriers, and this is often made use of for the relief of groundwater pressure in excavation pits.

In the area of the Pliocene trench, the Quaternary and Tertiary sands and gravels form a common aquifer.

After the inhomogeneity of the subsoil, groundwater constitutes the second type of risk and includes the partial risks listed in Table 2.

3.2.3 RT 3 – Geogenic/anthropogenic Obstacles in the Subsoil

This type of risk includes geogenic obstacles, such as large-size boulders, and anthropogenic obstacles, such as old foundations, anchor strands or power cables, which may have an influence on the execution of construction work in the subsoil. They are compiled in Table 3.

3.2.4 RT 4 – Anthropogenic (production-related) Contamination of the Subsoil

Contamination of the subsoil can occur on construction sites which work with various suspensions, injections or with varieties of construction plant. For this reason, careful handling and correct procedures are of great importance in such measures. Table 4 lists this risk type according to its position in the risk catalogue.

3.2.5 RT 5 – Earthquake

The Europaviertel project area in Frankfurt is located in earthquake zone 0 according to EC 8 – DIN EN 1998-1/NA. Although the probability of the earthquake zone being greater than zone 0 is negligible, it must nevertheless be listed as one item in the risk catalogue, since the structure can also be designed for this risk. Table 5 shows how this risk has been incorporated into the risk catalogue. A design according to EC 8 – DIN EN 1998-1/NA for a higher earthquake zone is the only conclusion from and measure against this risk. Extended design would be reflected in higher construction costs, additional research requirements and further planning measures.

3.2.6 RT 6 – Vibrations

The risk type vibration combines all risks arising from the effects of vibrations from construction equipment or, for example, from regular subway operations, and the resulting noise impact of the sound. Three partial risks result from the risk type vibration, and these are listed in Table 6.

3.2.7 RT 7 – Foundations

To a certain extent, the partial risks listed with the risk type 'foundations and excacation pits' overlap with partial risks of risk type RT 1 'inhomogeneity of the subsoil', but they can still be considered as independent risks. They are understood to be those risks which, as a result of the foundation of structures and the construction of excavation pits, can impair the structure itself on the one hand and neighbouring structures on the other. These impairments can result from the foundation itself, from entrained displacements, or from the subsoil. Table 7 shows the partial risks of this risk type.

3.2.8 RT 8 – Planning Approval Procedure

The risk type planning approval procedure is not necessarily a risk that can be directly assigned to the system risk or the subsoil risk, but it should nevertheless be mentioned in this risk catalogue as there are two partial risks of great importance in the project area. Table 8 shows the partial risks of this risk type.

3.2.9 RT 9 – General Risks

This final risk type deals with general risks that may affect a project. These include not only severe weather events, but also the presence of cultural remains in the subsoil. The partial risks and their implications and measures are listed in Table 9.

3.3 Impact of the Risks

The effects of the individual partial risks are a key item in the risk catalogue. Some of the effects and consequences of the various risks have been discussed as examples in the previous chapters. Furthermore, the risk catalogue should enable direct identification of the effects of a risk on a specific aspect (construction time, construction costs, extent of damage, etc.). Table 10 therefore shows the parameters with the impact of the identified risks and their abbreviations according to their designation in the risk catalogue.

3.4 Evaluation of Risks according to Probability of Occurrence and Impact

The basic structure of the risk catalogue is such that, in a first step, the risk categories to be examined are recorded and risks and partial risks are compiled; this is followed by a weighting of the various influencing factors.

The evaluation is based on the probability of occurrence and the impact on the project. Table 11 describes the probabilities of occurrence and weightings used to assess the individual partial risks, and Table 12

Table 3: Partial risks of risk type RT 3 'Geogenic/anthropogenic obstacles in the subsoil'

Partial risk		Consequences and measures
RT 3.1	constructibility of the excavation pit shoring (diaphragm wall, bored-pile walls)	▸ modification of the excavation pit safety concept ▸ measures for the tightness of the excavation pit ▸ abrasivity
RT 3.2	constructibility of the foundation design (foundation piles, single foundation)	▸ extent of settlement ▸ settlement differences/tilting ▸ modification of the founding design ▸ abrasivity
RT 3.3	influence on tunnel driving	▸ damage to the TBM (disc-cutter wear, disc change, shield blockage) ▸ adaptation of the tunnelling concept ▸ tunnel driving stopped ▸ abrasiveness
RT 3.4	explosive ordnance	▸ danger on site and in the vicinity ▸ standstill and construction stop ▸ focus and increase of type of accuracy of the ordnance-release measurement
RT 3.5	encountering artificial obstacles (excavation-pit enclosure, foundations, base sealings, pipework)	▸ settlement differences/tilting ▸ abrasiveness ▸ historic surveys ▸ geophysical surveys

Table 4: Partial risks of risk type RT 4 'Anthropogenic (construction-related) impacts on the subsoil'

Partial risk		Consequences and measures
RT 4.0	**contamination of the subsoil** due to construction work	▸ implement the requirements of water law permits ▸ limited recyclability ▸ landfill/interim storage, if applicable ▸ remedial measures

Table 5: Partial risks of risk type RT 5 'Earthquake'

Partial risk		Consequences and measures
RT 5.0	earthquake zone > zone 0	▸ according to DIN 4149 project area in earthquake zone 0 ▸ design according to DIN 4149 for earthquake > earthquake zone 0

Table 6: Partial risks of risk type RT 6 'Vibrations'

Partial risk		Consequences and measures
RT 6.1	vibration effects on adjacent structures (residential buildings / industrial plants)	▸ remedial measures ▸ construction standstill at sensitive data centres nearby ▸ adaptation of construction sequence / shoring concept ▸ architectural and geotechnical evidence-preservation procedure ▸ shielding concepts
RT 6.2	deformations and settlements due to driving	▸ remedial measures ▸ architectural and geotechnical evidence-preservation procedure ▸ concept development against vibrations
RT 6.3	noise due to vibration effects	▸ if necessary, additional hydromechanical calculations ▸ measures against GW impoundment (e. g. culvert, groundwater window) and against ochre formation/sintering

Table 7: Partial risks of risk type RT 7 'Foundations'

Partial risk		Consequences and measures
RT 7.1	**Foundation:** ▸ serviceability ▸ tilting/angular rotation **Excavation pit:** ▸ deformability	▸ remedial measures ▸ construction standstill at sensitive data centres nearby ▸ adaptation of construction sequence/shoring concept ▸ architectural and geotechnical evidence-preservation procedure ▸ shielding concepts
RT 7.2	resulting displacements	▸ remedial measures ▸ architectural and geotechnical evidence-preservation procedure ▸ concept development against vibrations
RT 7.3	type of foundation	▸ if necessary, additional hydromechanical calculations ▸ measures against GW impoundment (e. g. culvert, groundwater window) and against ochre formation/sintering

Table 8: Partial risks of risk type RT 8 'Planning approval procedure'

Partial risk		Consequences and measures
RT 8.1	keeping construction areas clear	▸ compliance with specified distances for development areas
RT 8.2	design taking subsequent construction projects into account	▸ additional foundation measures for planned/existing tunnels ▸ compliance with specified distances for development areas ▸ mathematical verification of serviceability and stability ▸ measurement and evidence-preservation concept ▸ alarm and action plan

Table 9: Partial risks of risk type RT 9 'General risks'

Partial risk		Consequences and measures
RT 9.1	occurrence of unforeseeable risks (natural disaster, fire)	▸ construction stop ▸ disruption concept with action plan
RT 9.2	encountering cultural relics	▸ construction stop ▸ preliminary archaeological survey ▸ preliminary geophysical survey

Table 10: Parameters considered with effects due to the risks

Parameter	Abbreviation
Construction time	BZ
Construction costs	BK
Amount of damage	SH
Stability	SI
Serviceability	GT
Additional survey requirement	EK
Research required (for example numerical calculations)	FB
Additional planning and construction measures	MS

Table 11: Risk catalogue – probability of occurrence of risks and their weighting

Probability of occurrence	Value [-]	Description
Very low	1	potential but unlikely risk
Low	2	suspected risk
Medium	3	
High	4	anticipated risk
Very high	5	

describes their significance and impact. A simple rating system with a classification from 1 to 5 was deliberately chosen to determine the probability of occurrence and the significance and impact, as a more detailed classification is not yet possible due to the lack of data and representative results for the project area.

The scoring result or risk value is the product of the values for probability of occurrence and significance. From the risk values, a classification of the relevance of the risks can be made. This classification into five risk levels is based on the scoring results. These are shown in Table 13. Risks that have a scoring value < 5 can be considered as fairly insignificant risks with a very low risk level. The significance of risks with scoring values between 6 and 10 can only be classified as low for the project; their risk level is low. From a scoring value of 11 upwards, the risks already have a greater influence, which can have a negative impact on the project. Risks that score between 21 and 25 have a very high degree of risk, are classified as extremely significant, and require closer examination, the definition of measures, and monitoring.

3.5 Scoring Results

The scoring results obtained from the risk catalogue and the resulting assignment to risk grades according to Table 13 for the partial risks listed in Tables 1 to 9 can be seen in the diagrams in Fig. 6.

The distribution of the scoring results shows that there are four partial risks, namely 1.3, 5.0, 6.2 and 8.1, which are classified as fairly insignificant with a very low risk level and with a very low damage impact. These four partial risks with a scoring result < 5 account for around 13.3 % of all identified risks. A total of ten partial risks, namely 1.5, 1.6, 2.1, 2.2, 2.3, 2.5, 3.2, 3.3, 4.0 and 9.2, can be assigned to the second category of scoring results from 6 to 10, which accounts for 33.3 % of all identified risks. The distribution also shows that six partial risks, namely 1.1, 1.2, 2.4, 3.1, 7.3 and 9.1, have a scoring result with an average of 11 to 15. Their share of the total risks accounts for around 20 % of all risks. The degree of risk with a high significance, i. e. a scoring result between 16 and 20, is achieved by a total of nine partial risks, namely 1.4, 1.7, 1.8, 3.4, 3.5, 6.1, 6.3, 7.2 and 8.2. This corresponds to a total of around 30 % of the identified risks. The highest risk level is achieved by partial risk 7.1. This risk, accounting for 3.3 % of all risks, is extremely important.

4 Risk-simulation Calculations for selected Projects in the Europaviertel

Some of the partial risks from the risk catalogue are now further explained with risk-simulation calculations or examples and their effects are examined in terms of the extent of damage or other cost factors. In particular, the risks of groundwater relief, serviceability, Pliocene trench and the risk of an area with planning approval are addressed.

4.1 Grand Tower – Groundwater Relief

4.1.1 Notes on the Project

The following shows a risk calculation for the groundwater relief of the Grand Tower in the eastern part of the Europaviertel. This risk calculation examines the influence of different layer thicknesses of the permeable layers on the one hand, and the influence of the residual water rate RW of the excavation pit on the total costs of groundwater relief on the other hand.

The Grand Tower construction project (**Fig. 7**) has an area of around 2,700 m². The foundation of the approximately 172 m high tower consists of a combined pile and slab foundation. The construction of the basement storeys was carried out under the protection of an impermeable trough-shaped excavation pit around 40 m x 70 m in size. The planned bottom face of the excavation pit was 8 to 11 m below ground level. The groundwater level during construction was set at GWCons = 93.00 m above MSL. In the course of the groundwater lowering, the water table inside the impermeable trough pit will be lowered to 85.40 m above MSL in the final excavation state. **Fig. 8** gives a clear overview of the boundary conditions of the excavation pit. The groundwater relief or residual-water drainage of the excavation pit includes three different drainage phases:

- Drainage of the excavation pit during excavation
- Controlled groundwater relief of the Tertiary aquifers below the base of the excavation pit (limestone banks and hydrobien sands) to protect the base of the excavation pit
- Collection and transport of surface runoff (precipitation)

The drainage of the excavation pit and the controlled groundwater relief of the limestone banks and hydrobien sands below the base of the excavation pit were carried out by means of relief boreholes and extraction wells above the groundwater level at the time of construction.

The groundwater lowering must continue in operation until the safety of the structure against uplift is achieved. Here, a construction period of eight months was anticipated.

The calculation of the total amount is based on the experience with groundwater lowering/relief in the Europaviertel. With a construction groundwater level and an embedment depth of the shoring wall of up to 20 m, this results in an extraction volume of approx. 60,000 m³.

4.1.2 Risk Simulation Calculation

The risk simulation calculation of groundwater relief is based on the variation of two parameters and their effects on the total extraction quantity. The residual water rate RW (risk A) and the free pore volume (risk B) were used as variation parameters. Both parameters were examined

Table 12: Risk catalogue – significance and impact of risks and their weighting

Meaning	Value [-]	Impact
Insignificant	1	BZ, BK, SH, SI, GT, EK, FB, MS
Low	2	
Medium	3	
Significant	4	
Very high	5	

Table 13: Degrees of risk depending on the scoring result as a product of values for probability of occurrence and significance

Risk level	Scoring result
Very low	< 5
Low	6 - 10
Medium	11 - 15
High	16 -20
Very high	21 - 25

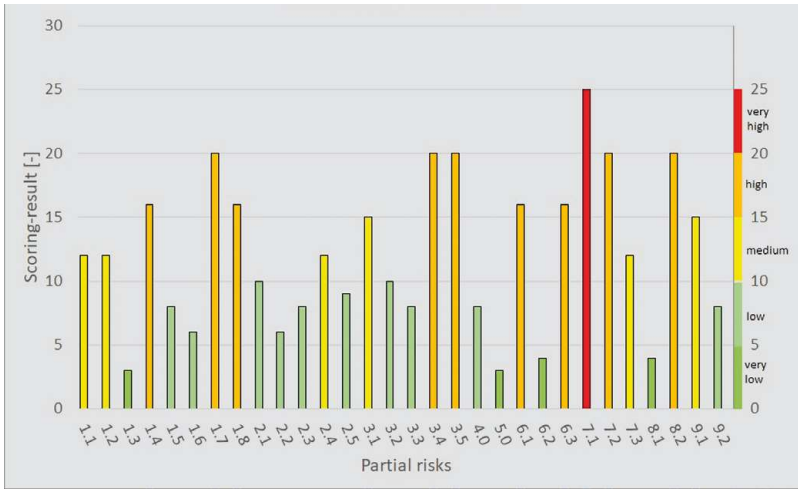


Fig. 6: Distribution of risk levels



Fig. 7: Grand Tower – photographed on 05.12.2018

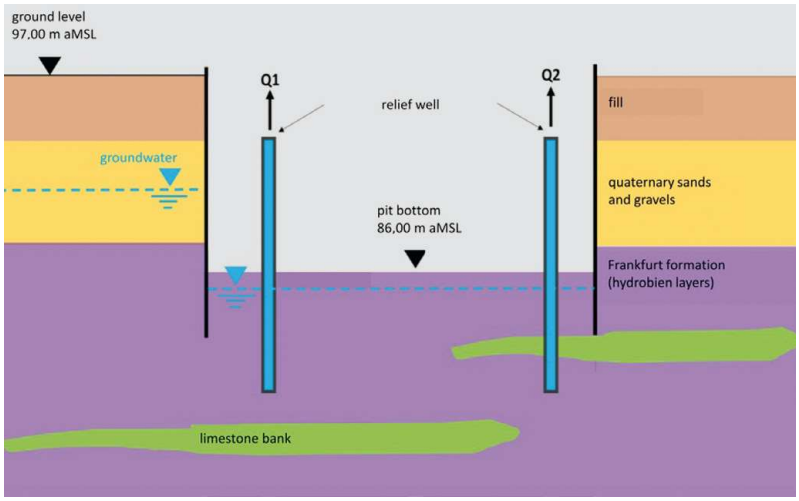


Fig. 8: Grand Tower – system sketch of excavation pit and dewatering

Table 14: Risk A – residual water rate

Risk [-]	Probability of occurrence [%]	Size of risk of residual water rate RW [l/s/1.000 m²]
RA1	5	1
RA2	70	1,5
RA3	15	2
RA4	10	3

Table 15: Risk B – free pore volume

Risk [-]	Probability of occurrence [%]	Size of risk of residual water rate RW [l/s/1.000 m²]
RB1	30	0,4
RB2	70	0,3

with regard to their size and an associated probability of occurrence. For the residual-water rate, a total of four risk magnitudes (RA1 to RA4) with different probabilities of occurrence resulted; these are shown in Table 14 below.

For risk B, the free pore volume, two magnitudes (RB1, RB2) were obtained; these were selected with different probabilities of occurrence (Table 15).

The occurrence probabilities E of all possible combinations of risk A with risk B are then calculated and the extraction volumes are determined (Table 16). There is a total of eight different possible combinations. All told, the extraction volume of the groundwater relief varies between 42,361 m³ (risk RA1 and risk RB2) and 113,380 m³ (risk RA4 and risk RB1).

Fig. 9 shows the probabilities of occurrence and the extraction volumes of the eight possible combinations. The primary axis indicates the probability of occurrence in percent and the secondary axis the extraction volume in cubic metres. Based on the extraction volumes and the probabilities of occurrence, it is possible to create a risk profile for the simulation calculation (Fig. 10). Conclusions regarding the quality of the input parameters can be drawn from the risk profile. If, for example, the curve of the risk profile is flat, a small change in the probability of an exceedance leads to a greater significant change in the risk magnitude. This points to a wide scatter of the input parameters. In the case shown here, the risk profile is steeply inclined. This means that a greater change in the probability of exceedance is necessary to increase the risk level of the extraction volume [6].

4.1.3 Evaluation

The risk-simulation calculation of groundwater relief has shown that the results of the extraction volume of 60,000 m³, calculated using empirical values, are still exceeded in 50 % of all cases of the independently selected and applied parameters. In the worst case, an extraction volume of around 114,000 m³ might have been expected, i. e. a doubling of the extraction volume. In addition, there is a danger that the entire groundwater management concept is underdimensioned, that the water volumes involved cannot be collected and that additional costs are incurred for replanning. The risk catalogue also indicates a large number of other risks which, taken together, can result in considerable costs for the client. In any case, the risk of groundwater relief is one that can be identified with a simple simulation calculation, and if it occurs, it can be protected against by simple means, such as additional capacity in the groundwater management concept.

4.2 DB Tower – Pliocene Trench Soil Stratum

4.2.1 Notes on the Project

The Pliocene trench has a scoring result from the risk catalogue of 20 out of 25 points; these will be discussed again in this section. The aim should be to investigate

Table 16: Calculation of the probabilities of occurrence E and extraction volumes for different combinations of risk A to the residual water rate to risk B to the free pore volume

Risk	RA1		RA2		RA3		RA4	
	E [%]	Volume [m³]	E [%]	Volume [m³]	E [%]	Volume [m³]	E [%]	Volume [m³]
RB1	1,5	44.489	21	61.825	4,5	79.160	3	113.830
RB2	3,5	42.361	49	59.697	10,5	77.032	7	111.702

the effects on the water-management concept when the risk occurs and to explain the resulting measures.

The subject of the Pliocene trench is dealt with on the basis of the construction project DB-Tower. The project consists of a 66 m high-rise building with adjoining plinth development on a continuous 3-storey basement. The loads of the high-rise building are transferred to the subsoil via a combined pile and slab foundation. The subsoil in the project area consists of Quaternary layers underlain by Pliocene sands/silts. Following below the Pliocene strata are the layers of the low-permeability landsnail marl and the Frankfurt Formation. The groundwater is about 4 m below ground level.

In this case, the position of the Pliocene trench in the excavation pit (**Fig. 11**) comes from the survey, which means that the risk of the Pliocene trench has been realised in this calculation example. In reality, the Pliocene trench was localised by a detailed survey programme and the existing conditions were considered during the planning process.

4.2.2 Risk Simulation Calculation

Taking the current state of knowledge into account, the risk simulation calculation for the Pliocene trench should show what additional extraction volumes can be expected if this risk occurs.

Fig. 12 shows that the shoring wall of the DB Tower does not end in the low-permeability soil layers as planned, but in an unexplored, deeper Pliocene trench. This causes a certain amount of leakage, through which groundwater flows unhindered into the excavation pit. The inflow to the excavation pit is determined to be about 32 m^3/h. With a construction period of eight months, this results in an additional total volume of 181,000 m^3 which must be contained.

4.2.3 Evaluation

An additional quantity of 181,000 m^3 in the realization of the risk of the Pliocene trench makes it clear how great the risk can become. Here, there is not only the danger of severely undersized dewatering, but also of a considerable increase in the costs for the discharge of these volumes of water.

The Pliocene trench is therefore a risk that can have far-reaching consequences and should be taken into account in construction projects in the Europaviertel. This risk can be limited by additional survey measures as well as dewatering concepts with additional capacity poten-

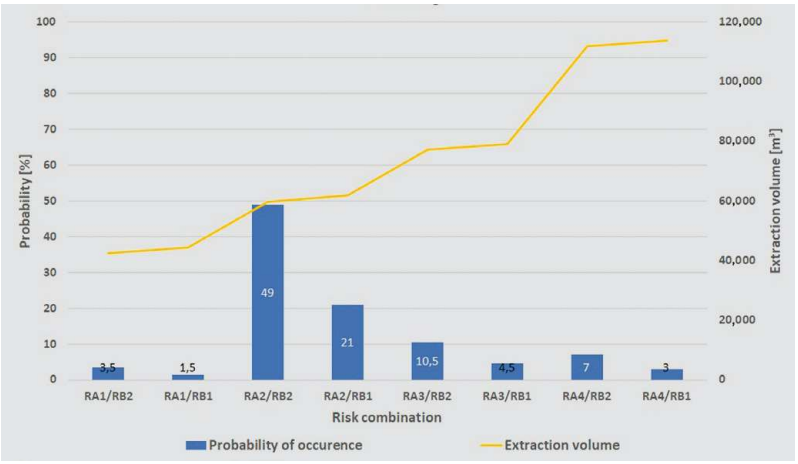


Fig. 9: Grand Tower Groundwater Relief – risk combinations and their probabilities of occurrence, extraction volumes

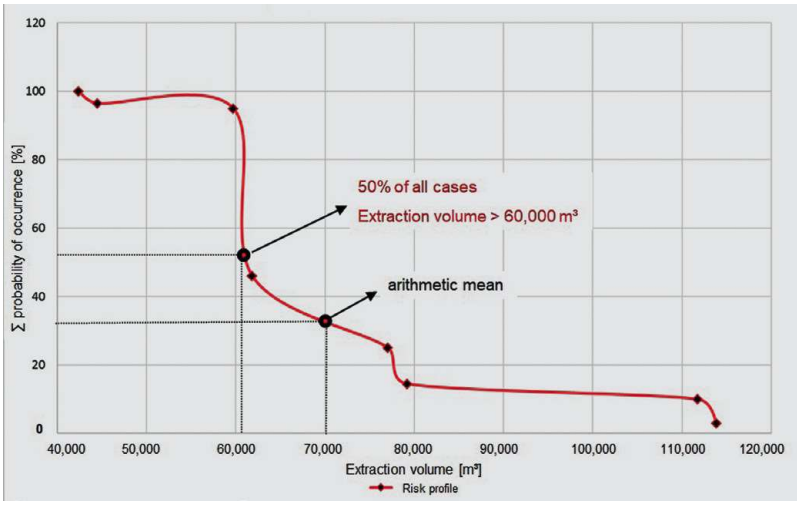


Fig. 10: Grand Tower – risk profile of groundwater relief

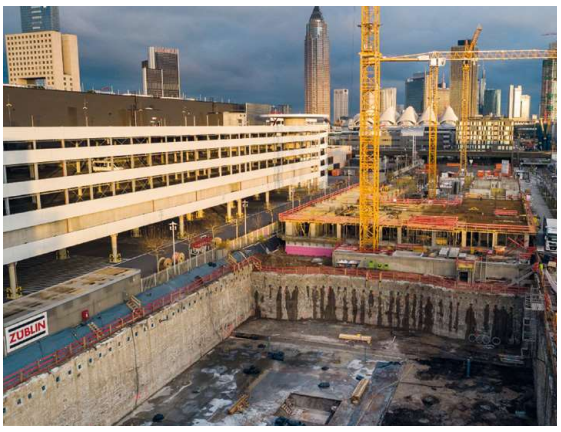


Fig. 11: DB Tower – photo of the excavation pit

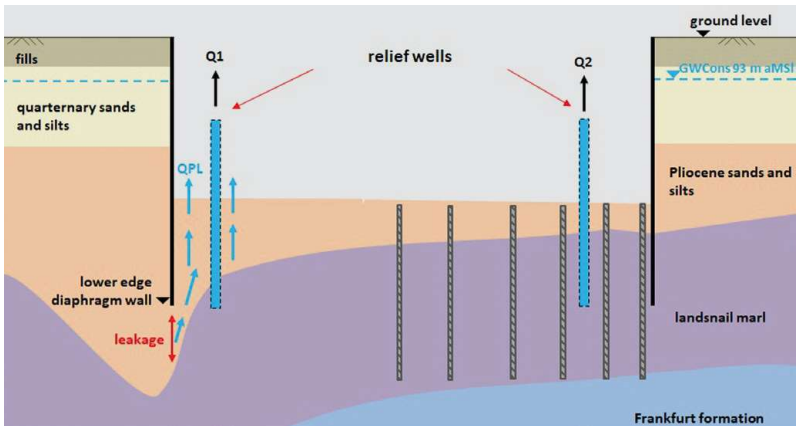


Fig. 12: DB Tower – cross section of the excavation pit [7]

tial if the risk occurs. Furthermore, when constructing the shoring in the excavation pit, particular attention should be paid to the presence of sandy layers around the bottom of the shoring, and the depth of the shoring wall should be adjusted if necessary.

4.3 Güterplatz Construction Project – Planning Approval

4.3.1 Notes on the Project

The partial risk RA 8.2 of the design for later construction projects of the risk type of the planning-approval procedure was determined to have a scoring result of 20 and will now be explained in more detail on the basis of the Güterplatz construction project. In this project, the Eden residential tower with a height of around 100 m, the hotel tower The Spin with a height of around 128 m and adjacent plinth buildings are being constructed on a total area of around 13,700 m² (Fig. 13).

Directly north of the Güterplatz project area, the U5 light-rail system has been approved. For this planned measure, a stiffened excavation pit at the Güterplatz station of the Verkehrsgemeinschaft Frankfurt am Main mbH (VGF) is planned with a depth of up to 20 m. The Güterplatz project area with the two high-rise buildings is within the planning-approval area and is subject to a freeze on changes. The planning-approval decision for the light-rail station does not take the planned development with the two high-rise buildings into account. Thus, the two high-rise buildings had to be planned in such a way that there would be no additional impacts on the planned Güterplatz station due to excavation pits and foundations.

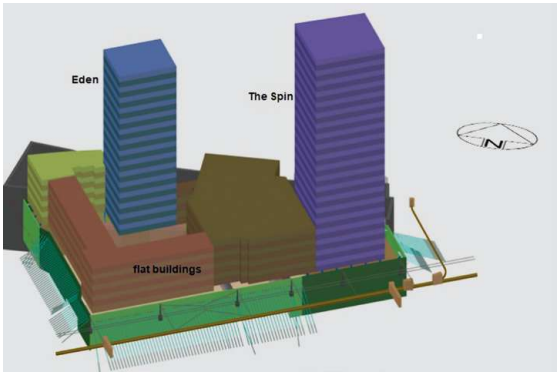


Fig. 13: Güterplatz construction project – 3D animation of the planned development

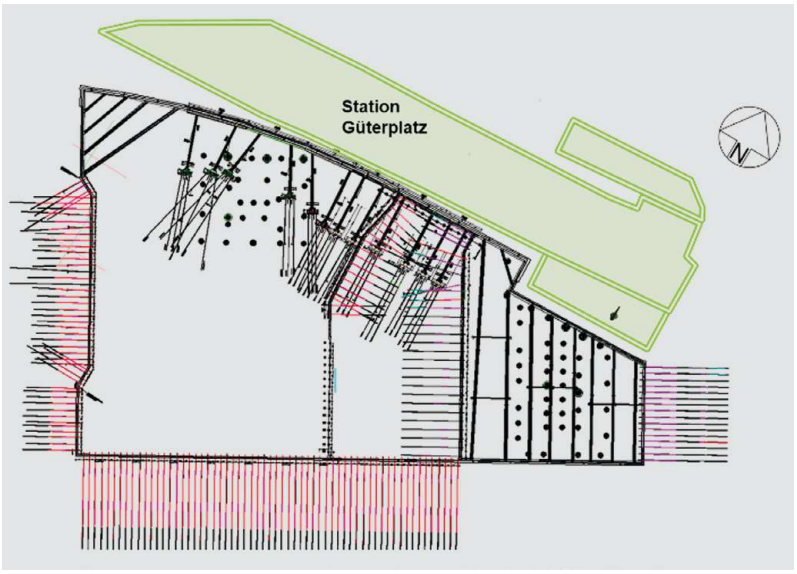


Fig. 14: Güterplatz construction project – site plan of the excavation pit [8]

The challenges in the realisation of the Güterplatz construction project lie in the complexity of the execution of the up to 10.5 m deep excavation pit and in the combined pile-slab foundations of both high-rise buildings with foundation piles up to 42 m long, as well as in the required verifications with regard to possible impacts on the Güterplatz station in the different project phases. Fig. 14 shows the excavation pit at Güterplatz and the planned excavation pit at the Güterplatz Station of the VGF to the north.

4.3.2 Verifications of Stability, Serviceability and the Effects on the light-rail Station

The verifications of stability and serviceability for the excavation-pit shoring and the foundation of both high-rise buildings as well as for the effects on the neighbouring Güterplatz station were performed using analytical and numerical calculations. The numerical simulations were carried out using two- and three-dimensional finite-element calculations with the Plaxis 2D/3D program system.

The creation of the numerical model (Fig. 15), the subsoil parameters and the calculation phases were agreed and selected in close cooperation with all the examiners involved. Fig. 16 shows a settlement plot of the serviceability analysis of 'The Spin'.

The numerical investigations of the effects of the construction project Güterplatz on the planned Güterplatz station were carried out by means of plate elements with upstream interface elements. Using these interface elements, it was possible to evaluate the normal stresses over the area. The effective normal stress distribution σ'_N was evaluated. The load difference between the installation phase of the shoring wall and the total load phase G + Q + W – A was determined. This evaluation of the differential stresses showed that the effective normal stresses on the shoring wall of the Güterplatz station differ negligibly for the calculation phases primary stress state and application of the total load.

4.3.3 Assessment

The realisation of the Güterplatz construction project has shown that ambitious construction projects in the inner city area directly next to areas that have been approved for planning are not always just a challenge of design and verification, but that a multifaceted coordination process must take place with the participation of

all third parties involved in planning, examination and approval, and with their examiners.

Here too, the use of numerical studies made it possible to establish principles and prognoses which are essential for the execution and for certain risks of the project. The evaluation of the changes in the effective stresses on the shoring wall of the planned Güterplatz station in the Güterplatz construction project would not have been possible on the basis of analytical calculations alone. The additional use of numerical calculation results served as a basis for discussion in the coordination process and thus led to constructive solutions in the planning process.

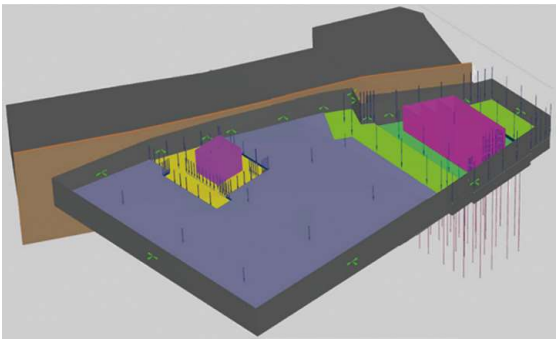


Fig. 15: Güterplatz construction project – numerical overall model [8]

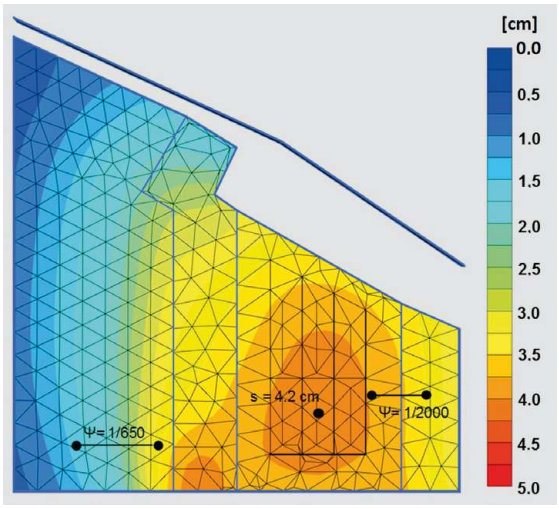


Fig. 16: Güterplatz construction project – settlement plot The Spin [8]

5 Conclusion

According to the definition of a geotechnical risk analysis given above, a risk analysis consists of the following four components:

- Risk identification
- Risk assessment (analysis)
- Risk control
- Risk monitoring

Risk identification is based on the example of the construction projects in the Europaviertel, whereby reference is made exclusively to those risks that can be assigned to the subsoil risk or the system risk.

Due to the large number of identified risks, a risk catalogue was drawn up which offers the possibility of bundling, comparing, and evaluating all recorded risks in a table. This risk catalogue is a key document, as all four components of a risk analysis are shown to advantage.

The individual risks are assessed using a scoring result as the product of the weighted values for the probability of occurrence and the impact of the risk. On the basis of this scoring result, further statements could be made about the relevance of certain risks. An identified risk with a high scoring result is therefore of particular relevance for the risk analysis of the Europaviertel and requires a high level of attention as well as the planning of measures to reduce the risk or minimise possible damage when the risk occurs.

Using risk examples and associated risk-simulation calculations with the highest rated results, the knowledge gained from the risk catalogue can be used to present and explain understandable calculation and optimisation approaches for these risks. From the findings of such risk-simulation calculations, various measures listed in the risk catalogue can result which minimise the impact of the risk or, if the risk materialises, ensure the continuation of construction work.

The preparation of a risk analysis for the Europaviertel project area gave a broad insight into the variety of risks associated with geotechnical issues in various construction projects. Since many of the identified risks can occur not only in the project area but also independently of the location of the construction project, it is advisable to apply the risk catalogue to other construction projects and to adapt it to these if appropriate. It is important to note that the probability of occurrence and the extent of damage should always be chosen in relation to the planned construction project and local conditions, and not be assumed to be the same as those of the Europaviertel project area.

In future, more emphasis should again be placed on the use of risk analyses in geotechnics. Particularly in to-

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day's world, where the planning and the execution of construction projects is becoming more closely intertwined, time should be taken for a close examination of the risks associated with the construction project. Risk analyses not only make it possible to meet the planned costs, but also to ensure that the construction schedule is met.

In the contractual relationship between contractor and client, a risk analysis can create a mutual understanding of responsibilities and tasks, and thus a good basis for cooperative and goal-oriented construction.

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