Geotechnical and Environmental Consideration by Planning and Construction of the Transportation Infrastructure in the Centre of Berlin

Stavros A. Savidis
Technical University of Berlin, Germany

Frank Rackwitz
Technical University of Berlin, Germany

Proceedings: Fifth International Conference on Case Histories in Geotechnical Engineering
New York, NY, April 13-17, 2004

GEOTECHNICAL AND ENVIRONMENTAL CONSIDERATION BY PLANNING AND CONSTRUCTION OF THE TRANSPORTATION INFRASTRUCTURE IN THE CENTRE OF BERLIN

Stavros A. Savidis
Professor Dr.-Ing.
Geotechnical Institute
Technical University of Berlin
Germany

Frank Rackwitz
Dr.-Ing., Research Associate
Geotechnical Institute
Technical University of Berlin
Germany

ABSTRACT

Since the mid of the nineties in the City of Berlin there have been built underground installations, i.e. railway and street tunnels as well as foundations deep embedded in the groundwater, with some extraordinary measures. The surface area of all tunnel constructions of the VZB-Project (inner city traffic tunnels in Berlin) amounts to approx. 240,000 square meters. The excavation pits for the tunnel structures have depths of more than 20 meters and widths of more than 100 meters. All this projects lead in the mid nineties to the characterization of the City of Berlin as Europe`s biggest construction site. A general overview of the transportation infrastructure project will be given here.

A number of technical problems had to be resolved and new strategies devised at the planning stage because of the geotechnical and hydrogeological conditions in the central area of Berlin, the environmental requirements concerning groundwater conditions, and interaction with the surrounding green area and the nearby existing buildings. Several methods of tunnelling constructions in cohesionless soils with high ground water level were applied, such as caissons, shield driven tunnels and trough-type excavations (cut-and-cover tunnels). The geotechnical and hydrogeological conditions will be presented and the planning and realization of the tunnelling construction methods will be explained in the paper.

Quality assurance was an important issue of the project and included an extensive monitoring system to ensure the quality of the constructions and to control the prior design and calculations. The impact of the project on the urban life and on the environment wouldn`t be minimized without a sophisticated project and ground water management. A very extensive measurement program in the frame of the quality assurance and geotechnical observation method was performed. It consisted of tension loading tests of single piles and groups of piles as well as measurements of anchor forces, wall deformations, uplift and leak water. Some data of monitoring are presented and discussed in this case history report.

INTRODUCTION

The main objective of that contribution is to give an overview of the huge geotechnical projects that were performed in the last years in Berlin and that are now just before the end of their completion. All this projects lead in the mid nineties to the characterization of the City of Berlin as Europe`s biggest construction site.

The fall of the wall, 1989, the German reunification in October 1990, and the decision of the German parliament of June 1991 to move the seat of the government from Bonn to Berlin have lead to a re-emerging of Berlin as a key junction in the German rail network and an important link for the entire European continent. Managing this increased rail traffic, the development of substantial new infrastructure became necessary, as fifty years of partition and isolation had crippled a once functional railway network.

Built over a century ago, this railway system had a number of terminus stations and an interconnecting ring route. The new system calls for upgrading the east-west route introducing a new north-south route and building a new central station “Lehrter Bahnhof” as junction between the east-west and north-south railway lines (Mönnich & Erdmann, 1997). The main technical part of this solution – that was called “Mushroom”-Concept due to the specific form of the traffic lines - with some imagination it can be found out (Fig. 1) that this planning solution forms a mushroom - the east-west lines form the cap and the brim and the north-south line form the stalk of the mushroom (Klapperich et al., 1999).

The essential technical part of this solution is the new 3.4 km long, four-track railway tunnel running through the city centre beneath the new government district, the Tiergarten Park, and the new development centre at the square Potsdamer Platz. Parallel to the railway line goes the national road B96 which also crosses the government centre. So it was necessary to put the road down in a tunnel. On the design and construction of these two tunnels, especially that for the railway, will be focused in that contribution.

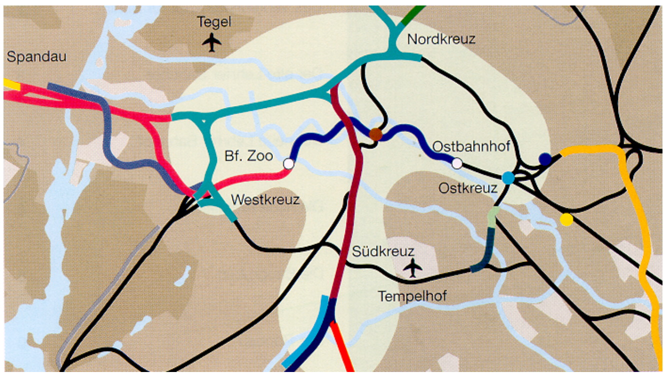

Fig. 1: "Mushroom"-Concept for the traffic lines in Berlin

OVERVIEW OF THE VZB-PROJECT

In Germany this infrastructure project in the city of Berlin is also called VZB-project, as an abbreviation of the German name: "Verkehrsanlagen im Zentralen Bereich Berlins" (Fig. 2). Figure 2 is that part of a city map of Berlin where the VZB-Project is situated. Here is really the heart of the city of Berlin, just that area where 12 years ago the wall divided the city in east and west. The boundary conditions for the design and construction, concerning environmental and existing building conditions are mainly formed by the following objects:
- The former Wall
- The River Spree
- The Channel Landwehrkanal
- The Park Tiergarten (a large green area that has to be protected)
- The Brandenburg Gate (a landmark of Berlin, especially during the time of the cold war)
- The Reichstag (the house of the German parliament)
- The Congress Hall

Parallel to these existing structures in the area of the square Potsdamer Platz it was planned the construction of some large new buildings of private investors such as the SONY-European Headquarter, ABB as well as debis, a sub-company of Daimler-Chrysler. In the northern part next to the parliament there was planned the new government centre with the new Chancellor office building and the new offices for the members of parliament. Among all this, from north to south passes the road tunnel B96 with a length of 2.4 km and the railway tunnel with a length of 3.4 km.

Some critical points for the project were the junction of the railway tunnel with the channel Landwehrkanal, the interaction of the two tunnels with the construction sites of SONY and debis at Potsdamer Platz, the passing of the tunnels below the Park Tiergarten and the government centre as well as the crossing of the tunnels with the river Spree.

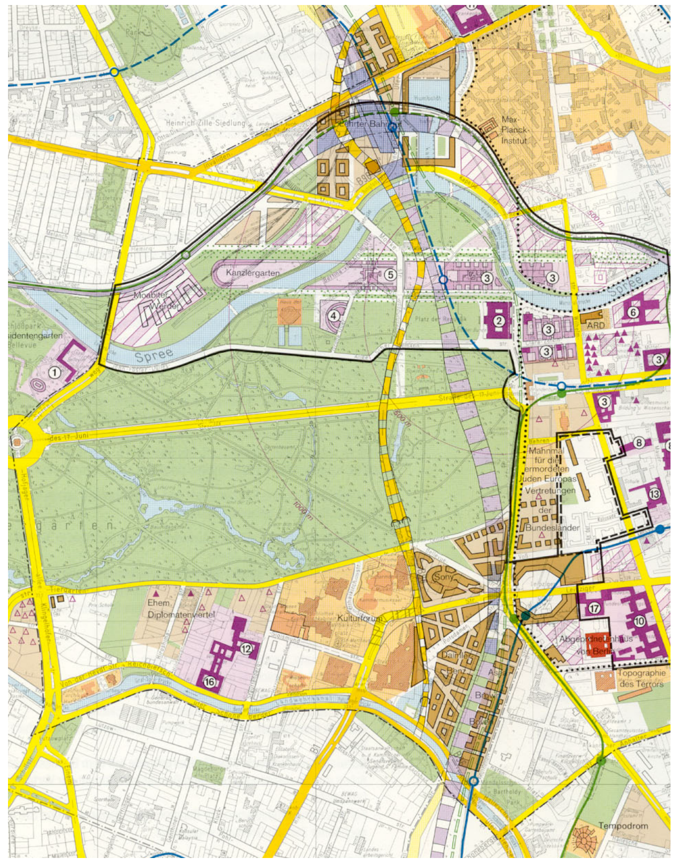

Fig. 2: City map of Berlin with the location of the VZB-Project

Figure 2 shows the road tunnel and the railway tunnel in the north-south direction, the railway lines in west-east direction, their intersection at the new main central station Lehrter Bahnhof and as mentioned before with some imagination the Mushroom concept.

GEOTECHNICAL AND ENVIRONMENTAL CONDITIONS

Because in the frame of the VZB-project new road and railway lines were planned, it was necessary according to the existing law to get a special permission on the base of a formal procedure. Main content of the proposal for that procedure is an extended study of the environmental impact of the project. This study is based among others on extensive geological, hydrological and geotechnical investigations.

Based on existing data of the region from the past an additional program of geotechnical investigations was planned.
This program included (Borchert et al., 1996):
- Bore holes with more than 150 mm diameter, in a sum of 7,000 m
- Bore holes with 80 to 150 mm diameter, in a sum of 1,000 m
- Dynamic and static penetrometer tests in a sum of 4,000 m
- Standard penetration tests in a depth greater than 20 m
- Pressuremeter tests
- Crosshole tests
- Pumping tests of short and long duration

The geology of the central area of Berlin is characterized by saturated deposits of the quaternary stratum. Three different glacial periods can be identified in the global area of Berlin. The glacial sediments are highly irregular in their horizontal and vertical distributions and also vary widely in their composition, which consists of tills, sands, gravel and boulder clays. The tills consist mainly of a sandy, clayish marl with numerous boulders and much gravel. Figure 3 shows a seldom boulder with extremely large dimensions of about 2 cubic meters.

Fig. 3: Boulder, found at the construction site

Special investigations are carried out to characterize erratic blocks and boulder material to obtain all necessary information for designing the machines for the shield driven tunnels. Mechanical strength properties (in compression, tension and bending) have been investigated in laboratory tests with original block material recovered from test pits and bore-holes. Reviewing the investigated results, the mass content of stones and blocks was determined to 2% and block dimensions of about 0.8 m, being a reference for dimensioning the rock crusher of the tunnel boring machine (Mönnich et al., 1997).

Figure 4 gives two simplified geotechnical profiles for the northern and southern part of the centre of Berlin. They consist of sandy tills (S) interrupted by discontinuous layers of silt (U) and marl (Mg). On the base of the marl one can find the stones and boulders (Y) that has been mentioned before. In a greater depth of 40 till 50 m there is an organic brown coal (Bku) layer of high density and low permeability. The marl and the brown coal layer have been used in several cases as natural horizontal impermeable layer for deep excavations.

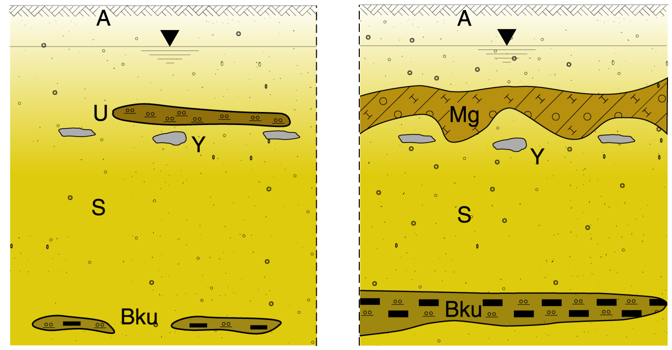

Fig. 4: Geotechnical profile
northern part (left) and southern part (right)

The key element for the environmental impact study is first the high level of the groundwater 2 till 3 m below the ground surface and second the high permeability of the sandy soils in the order of 10^{-3} till 10^{-4} m/s. Due to this fact at an early stage of the design it was understood that only groundwater protecting constructions has to be used to get the permission for construction. The alternative solution of dewatering of the ground water table by pumping the water by means of wells would affect a large area with negative influence on the vegetation, on the existing buildings causing settlements, on the timber piles of the old foundations and in general a disturbance to the natural hydrological system as well. Hydrogeological calculations have shown that 300 million cubic meter groundwater had to be pumped to produce dry conditions for the foundations. Such a solution is therefore a priori excluded.

METHODS OF TUNNELING CONSTRUCTIONS

Several methods of tunnelling constructions in cohesionless soils with high ground water level, such as caissons, shield driven tunnels, cut-and-cover constructions, have been applied in that project.

Caissons

The area of the caisson constructions south of the Landwehrkanal and in the northern part of Potsdamer Platz is of about 12,000 square meters. Some caissons have also been used as starting and returning pits for the shield machines. Details about the principle of a caisson installation are in general well known and they are not the subject of that contribution.

Six large caissons were used, the first one on the north side was used as starting pit for the shield machine, as mentioned before. Figure 5 gives an outside view of that caisson and one can recognize the 4 starting tubes for the shield driven tunnels.

Fig. 5: Caisson used as starting pit for shield driven tunnels

Shield Driven Tunnels

The 4 shield driven tunnel tubes have a total length of 4 times 1,300 m equals 5,200 m. They were constructed in the following way (Brux, 1999):
The lower part starts from the caissons – mentioned before - passes under the Landwehrkanal and stops in the southern part of Potsdamer Platz (Length: ca. 570 m). The upper part also with 4 tubes starts from the northern part of Potsdamer Platz passes under the Tiergarten Park and stops just before the government centre (Length: ca. 710 m). Two Mix-shield machines from the German company Herrenknecht were used with a diameter of 9 m and a total length of 54 m.

The Cutterhead of the Mixshield machine consisted of:
- 5 spokes
- 32 parers
- 16 roller chisels
- 1 central cutter
- 1 stone crusher

The cutting wheel rotational speed was 4 revolutions/minute and the shield machine had 28 presses with 2,000 kN (200 t) capacity each that means a total capacity of 56 MN (5,600 t). The stone crusher has been designed for a maximum Boulder-Diameter of 0.80 m.

Cut-and-Cover Tunnels

The third method of a groundwater protective construction that mostly was used in the project was the cut-and-cover solution, also called wall-slab or trough-type construction. It has to be build with watertight vertical walls and a horizontal base slab with anchors (or without depending on its depth) to prevent uplift.

There are mainly two variants of that construction (Fig. 6). In both of them the walls are constructed as watertight diaphragm walls.

In the first variant the base slab is build as an underwater concrete slab (Fig. 6, right). Because of the high pressure acting below the slab an anchoring of the slab before pouring is necessary to avoid uplift.

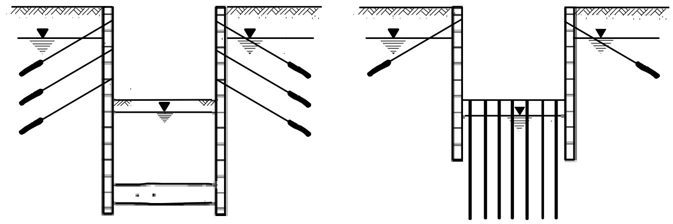

Fig. 6: Trough-type excavations

In the second variant (Fig. 6, left) the slab is constructed as an injection layer (mostly by using the hydrojet grouting). Because of the slab is build deep in the soil the soil weight above the slab prevents the uplift of the slab. Of course in that case the vertical walls must be longer than in the variant on the left and have to reach till the depth of the slab to ensure a trough-type construction.

As an approximation to become an idea about the dimension of the construction one can have for a 15 m depth of the excavation below ground water level, about 15 m length for the anchor piles or a 30 m deep wall below groundwater level. In both cases the base is about 1.5 m thick.

Two different types of anchor piles have been used in that project (Fig. 7). The mostly used RI-pile consists of H-section steel profile that will be vibrated into the soil (Fig. 7, right). During the vibration the gap produced by an expansion at the lower end of the pile is filled by mortar injected during the vibrations by means of tubes attached to the pile. On the pile head there is a steel plate fixed which will be embedded later in the concrete slab. Instead of vibrating injected piles bored piles of small diameters the so called GEWI-piles can be used (Fig. 7, left). The bore hole is filled with cement mortar after installation of the pile. The slab anchor piles have been placed with a distance of about 3 by 3 m. The Quality Assurance required that after the installation of the anchor piles, 3 percent of them had to be tested in situ, which has been also performed from a pontoon. The pile heads are embedded in the final concrete base slab, which has been placed underwater with the aid of divers.

The length of the tie-backs of the diaphragm walls is from 15 till 70 m with maximum anchor forces of about 1,500 kN. Each anchor comprises a circ of 9 strands that is embedded into the grouted portion. Some of the anchors are temporary and were removed later with systems patented and used here for the first time.

From the about 240,000 square meters area of the tunnels the trough excavations (wall-slab constructions) cover about 200,000 square meters.

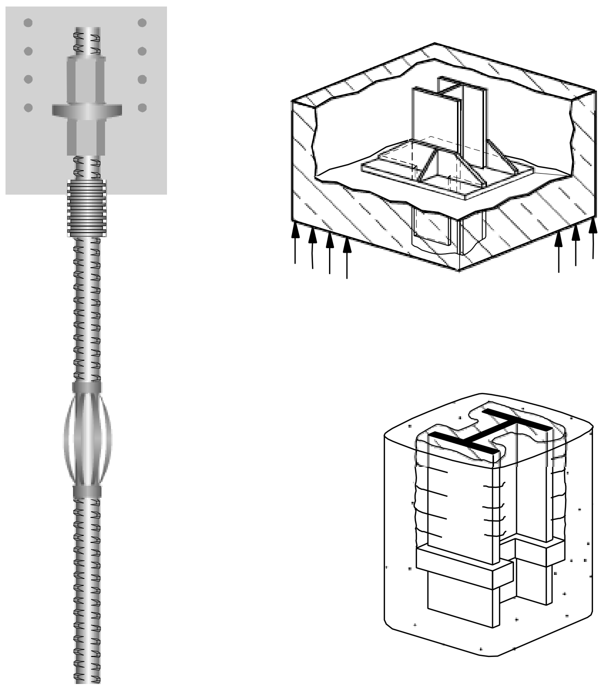

Fig. 7: Anchor piles for concrete base slabs: GEWI-pile (left) and RI-pile, head (top right) and tip (bottom right)

QUALITY ASSURANCE AND IN SITU MEASUREMENTS

Quality assurance was an important issue of the project and included an extensive monitoring system to ensure the quality of the constructions and to control the design and calculations. The impact of the project on the urban life and on the environment wouldn`t be minimized without a sophisticated project and ground water management.

Groundwater Management

The environmental authorities established strict requirements for a minimum movement of the groundwater level. For the inflows of the trough-type excavations a value of 1.5 l/s, related to the watered excavation wall as well as base slab area, has been ascribed as design criteria (Mönnich et al., 1997, Klapperich & Struffert, 1997). In the case of a disaster and therefore of an excessive drop in groundwater levels, the capacity to return water from the construction pits to the natural groundwater stock using infiltration wells was established. In order to control the groundwater level, a network of over 100 measuring points had to be installed over an area of about 4 km² around the sites. The water levels have been measured hourly and the data were partly transmitted automatically by radio and partly collected and brought to the logistics office by construction workers. The authorities responsible have direct access via computer to the information in the monitoring system. A specially developed numerical groundwater model simulated the potential effects of different construction stages on the groundwater level in advance. The necessary amount of infiltration water to stabilise the groundwater balance could be determined at the same time. The logistics office handled about 14 million m³ of groundwater during the whole construction period.

Geotechnical In Situ Measurements

A very extensive in situ measurement program in the frame of the quality assurance has been performed. It consists of the following topics:
- Tension loading tests on single piles and groups of piles
- Measurements of anchor forces
- Measurements of wall deformations
- Measurements of concrete base slab uplift
- Leak water measurements

A dewatered trough-type excavation with RI-piles can be seen in Fig. 8. One can recognize the horizontal inclinometers on the concrete base slab for the measurement of the uplift. The heads of the RI-piles and the one row of tie-backs just above the groundwater level can be seen in Fig. 8 too. The horizontal inclinometer is shown in more detail in Fig. 9.

Fig. 8: Trough-type excavation after dewatering

Fig. 9: Horizontal inclinometer for uplift measurement

Numerical calculations with the finite element method were performed for the prediction of the wall and slab displacements. The calculated maximum base slab heaving of about 41 mm after dewatering underestimates in that case the measured values as shown in Fig. 10 (Savidis et al., 1999).

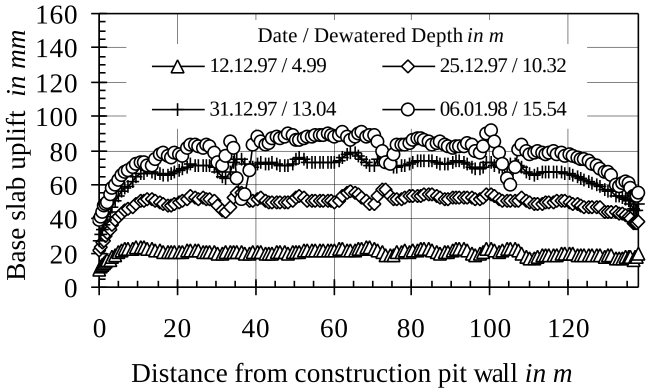

Fig. 10: Measured uplift of the concrete base slab

The underestimation was mainly due to the fact that the softening of the soil due to the excavation and pile driving was not fully concerned in that numerical analysis.

Logistics concept

The severe constraints coupled with the absolute necessity to make the vast site reachable for construction-related transport, led to an unusual logistic solution. The two public (DB, Berlin Senate) and three private investors in the overall development of Potsdamer Platz founded their own logistics office to address the logistical challenges globally, for the entire site.

The principal task of the logistics office is to arrange about 90% of all delivery and disposal of goods, materials and waste for the gigantic building site via rail and water routes. The logistics office has to ensure the safe, economical, efficient and environmentally friendly supply and clearing of all involved construction sites. The heart of the concept are 2 logistics centres in the north and in the south of the project area. An internal road and railway transport system has been built to connect the logistics centres via bridges to the sites without interfering with the public traffic. The logistic centres have established various service facilities for the construction companies. All contractors are bound to the exclusive use of the following services provided in the logistics centres:
- Removal of all excavated material by rail or water
- Manufacture and delivery of all ready-mixed concrete
- Organisation of the delivery of general cargo by rail, including transport to the construction sites
- Collection of sorted building refuse and transportation to recycling plants, etc.,
- Acceptance and discharge (draining off or reinfiltration) of all groundwater from the excavation pits, including groundwater management (about 14 million m³).

CONCLUSIONS

Europe's biggest construction site of the nineties is just before the end of its completion. Especially for the geotechnical engineers involved in the project that has been a huge challenge. The existing geotechnical and hydrogeological conditions in the centre of Berlin, i.e. mainly sandy soils with high permeability in conjunction with a groundwater table just about 2 – 3 m below ground surface, as well as the necessity to save the environment in the vicinity have lead to the geotechnical constructions which have been applied. They consist of deep trough-type excavations, caissons and shield driven tunnels. A special logistics concept has been developed and successfully applied to prevent the city centre of Berlin from a traffic collapse due to the construction works over years. All the experience gained from that huge project gives lessons for similar projects in the future, not only in Berlin and Germany.

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