ЮБИЛЕЙНА НАУЧНА КОНФЕРЕНЦИЯ

РЕЗЮМЕТА ОТ ДОКЛАДИ

JUBILEE SCIENTIFIC CONFERENCE

ABSTRACT OF CONTRIBUTION

65 години

УНИВЕРСИТЕТ ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ

2007

65 years

UNIVERSITY OF ARCHITECTURE CIVIL ENGINEERING AND GEODESY

УНИВЕРСИТЕТ ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ
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Sofia, May, 2007

FOREWORD

In 1941 the National Assembly passed a bill (SG, 12.06.1941) and in 1942 the King Boris III signed a decree (4.02.1942) for the foundation of a Higher Technical School (HTS) with two faculties: Civil Engineering and Architecture, and Mechanical Engineering. This laid the foundation of the higher education in the field of architecture, civil engineering and geodesy in our country. In 1945 HTS was transformed into State Polytechnics, wherefrom the Institute of Civil Engineering (ICE) derived in 1953. In 1963 ICE was renamed Higher Institute of Civil Engineering (HICE). In its turn, HICE was renamed Higher Institute of Architecture and Civil Engineering (HIACE) in 1977. In 1995, with a resolution of the National Assembly, HIACE was transformed into University of Architecture, Civil Engineering and Geodesy (UACEG). During all this time the University realises a large-scale training and research activities.

This Jubilee Scientific Conference is organised on the occasion of the 65th anniversary of the higher education in architecture, civil engineering and geodesy in Bulgaria. It comprises almost all scientific fields covered in the University. More than 180 papers will be presented and more than 276 authors from the country and abroad will participate in the conference. The international participation is significant, which we regard as recognition of the prestige of our University.

Papers will be published on CD.

We thank all the participants and guests of the Conference and wish them a fruitful and pleasant stay.

May, 2007 **The Organizing Committee**

TRANSPORT ENGINEERING AND GEOTECHNICS

SELECTED CONSTRUCTION SOLUTIONS ON TUNNELLING VIENNA UNDERGROUND LINE EXTENSION U2

Georg Jodl, Gernot Altinger, Ingo Heegemann, Andreas Jurecka[1]

The extension of the underground line U2 is due to existing hydro-geological conditions and because of the crossing of the river "Donaukanal" posing a challenge to all participants involved in this project.

The crossing of the „Donaukanal", which is a river with a width of about 50 meters, was achieved within the contract section U2/1 using the method of ground freezing. Both common techniques of nitrogen freezing and brine freezing have been applied in combination first time.

In order to ensure an area-wide lowering of the groundwater – within the contract section U2/2 – 240 wells had to be drilled each with a depth of about 40 meters. Due to the high number of wells a regulation and control system has been installed. This system assures an overview from a central place on the current capacity of each pump and may warn the responsible technician in case of failures. It moreover helps to process and analyze the large amount of data.

Jet grouting was used to build protection shields against uncontrollable water ingress both from the tunnel as well as from the surface. The intention was to ensure safe tunnelling conditions and to facilitate driving. When erecting the shields from the tunnel head, excavation could only be done alternately. From the surface it was possible to jet grout in advance to the heading and hence save time. Major parts of the jet grouting were not included in the original contracts. In some places the hardly predictable circumstances of the ground made it necessary, in other parts a shortening of construction duration could be achieved through amicable adjustment of the contract.

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65 ГОДИНИ
УНИВЕРСИТЕТ ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ – СОФИЯ
ЮБИЛЕЙНА НАУЧНА КОНФЕРЕНЦИЯ

65 YEARS
UNIVERSITY OF ARCHITECTURE, CIVIL ENGINEERING AND GEODESY – SOFIA
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SELECTED CONSTRUCTION SOLUTIONS ON TUNNELLING VIENNA UNDERGROUND LINE EXTENSION U2

Hans Georg Jodl, Gernot Altinger, Ingo Heegemann, Andreas Jurecka[1]

General remarks

The increasing number of inhabitants as well as the need of reduction of air pollution demands a rising standard of the public transport system. The City of Vienna meets those expectations with the expansion of the underground network. Presently it spans over 65.6 km and contains five lines (U1, U2, U3, U4, U6). Extensions are on the way on the line U2.

The elongation of the U2 is especially necessary because of the expansion projects to the 22[nd] north eastern district of Vienna named Aspern and also because of the European soccer championships (EURO 2008) that will amongst others take place in Vienna. So far the Ernst-Happel-stadium with a capacity of about 50,000

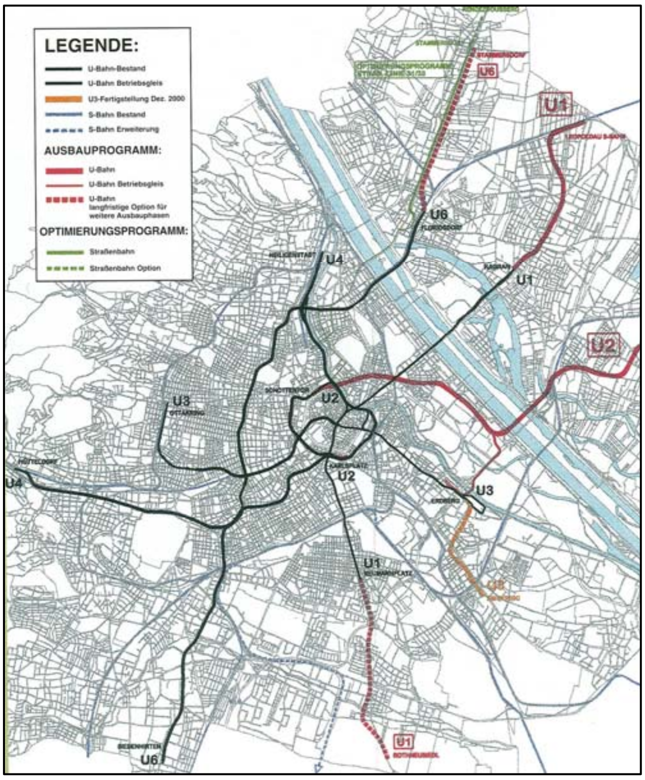

Figure 1: Overview over Vienna Underground [12]

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spectators is reachable by public transport only by tramway. At present, the line U2 stretches over a length of 3.5 km from station Karlsplatz to the station Schottenring.

The complete extension, which is of a length of 9.0 km, takes place in two phases. The first stage, which is 3.9 km in length leads from Schottentor to the stadium, consists of five contract sections and contains as well five stations. This way the recently modernized fair grounds and the Ernst-Happel-stadium become connected to Vienna's underground network. Three of the mentioned five contract sections are built underground by tunnel-driving.

The completion of this first stage will be in May 2008. The construction of the second phase (from the stadium to Aspernstraße with a length of 5.1 km) started in October 2006. All parts of this phase are built conventional above ground level. After completion of the U2-extension Vienna's underground network will total up to 74.6 km.

Description of the contract sections

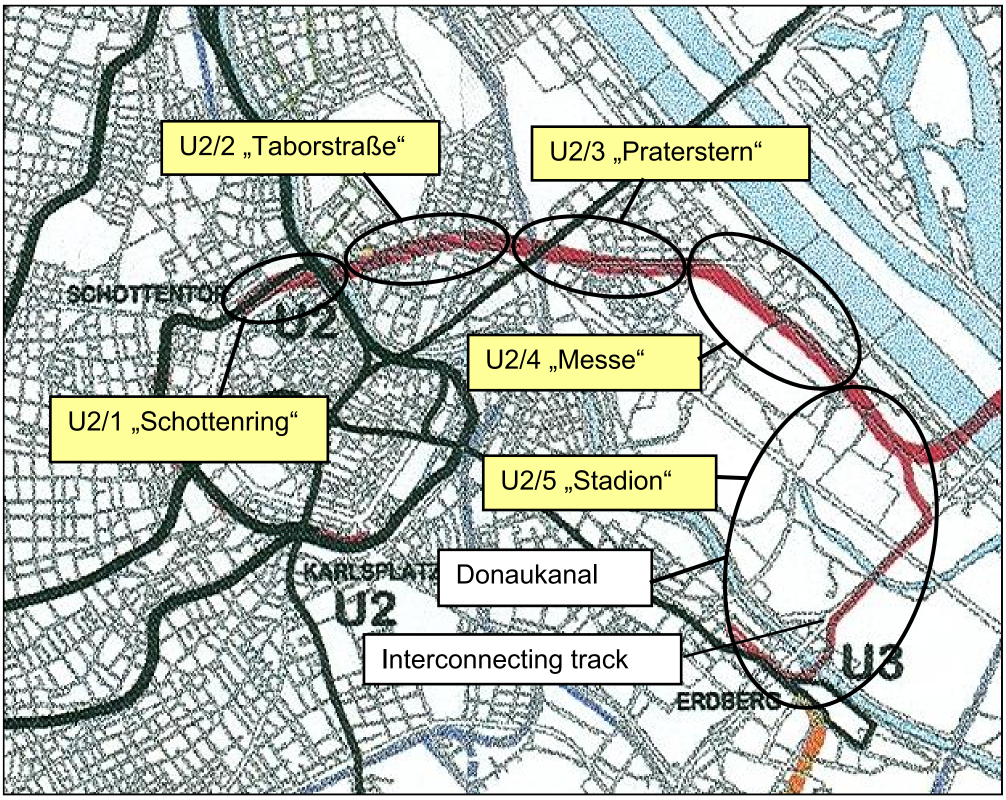

Figure 2: Overview of the 5 contract sections of the first extension phase

Section U2/1

The contract section U2/1 „Schottenring“ is the first one in the line of the extension phase, which construction started in 2003. It is built partly in open cut tunnelling as well as in conventional tunnel methods. Probably the greatest technical challenge of this section is the crossing of the about 50 meter wide river “Donaukanal”. Almost the entire section of the new station Schottenring, with an excavation profile of about each 67 m² is situated below the river.

Section U2/2

The contract section U2/2 „Taborstraße“ consists of three pits and three dual tunnelling sections. Two of the pits are finally used as parts of the station-building. During construction of this about 1,400 meter long section one of Europe’s largest groundwater lowering projects has been realized. The groundwater table had to be lowered by some 18 m.

Section U2/3

The contract section U2/3 „Praterstern“ consists of one large pit which is used as a station-building during operation and two dual tunnelling sections. The total length is about 630 m and the station “Praterstern” is about 160 m long and built in open trench. Users will have the possibility to transfer to U1 as well as to the regional railway.

Section U2/4

The contract section „Messe“ is partly constructed in cut-and-cover method. First in the ground and towards U2/5 (in the area of the new fair) trains will be run in raised position. This section contains two station-buildings (“Messe” and “Krieau”) and is about 1,500 m long.

Section U2/5

The contract section U2/5 „Stadion” contains the station „Stadium“ and a underground connection track to the service station in Erdberg. This track is about 1,750 m long and has a diameter of 6.55 m. Again the Donaukanal-river is crossed by using this time a hydro shield.

Construction Solutions

The extension of the underground line U2 is due to existing hydro-geological conditions and because of the crossing of the “Donaukanal” a challenge for all participants of that project. The following chapters give a detailed description of four technical solutions which were deployed in the contract sections U2/1 to U2/3.

Ground Freezing

The crossing of the Donaukanal-river in the contract section U2/1 was built in mining technique, protected by Europe’s largest ground freezing project. Geological conditions in the area of the station “Schottentor” can be described as sandy gravel, below the river there is tertiary silt and clay.

Freezing process techniques: The freezing is a temporary measure in order to obtain reliable waterproofing against the groundwater respectively the Donaukanal-river and moreover the frozen ground generates stable arches. The requirements to be able to apply this method are a certain water percentage (>5% up to 7%) of the ground as well as a relatively low floating speed (1 to 3 m per day) of the groundwater. For establishing the cylindrical freezing bodies, thermal energy is taken out of the ground by circulation of a freezing agent in steel pipes. Finally the water in the pores of the ground will freeze. Depending on how lowering of the ground temperature takes place it can be differentiated between nitrogen freezing and brine freezing.

For *brine freezing method* an aqueous saline solution is used as freezing agent. The brine is cooled down to -20°C to -40°C by cooling machines. The brine is pumped by a rotary pump into the freezing lances and conducted back to the cooling machine again (closed circulation). For *nitrogen freezing* liquid nitrogen LN_2 with a temperature of about -196°C is brought into the freezing lances. It is not pumped but flows into the system due to the pressure in the holding tank. Different from the brine freezing, the liquid nitrogen gets transformed into gaseous nitrogen when it warms up and gets back into the atmosphere leaving an exhaust pipe (open system).

Highlights: At the contract section U2/1 both of the mentioned methods were combined. The aim was to benefit from each method. During the phase of lowering the temperature nitrogen freezing was deployed in the area of the tunnel crown (thickness of the freezing body: about 3.5 m) in order to build up the body as fast as possible and minimize the uplift of the ground surface with respect to the heritage-protected ancient lock building of famous Austrian art nouveau architect Otto Wagner. Furthermore this way guaranteed the possibility of post-freezing in case of finding soft patches in the freezing body at a later time. This is especially important to maintain the impermeability. After the first phase the brine freezing method was inserted, which was used to establish and maintain the closed ring with a thickness of about 2.0 m (see Figure 3). Since the freezing body had to be kept in place until the inner concrete shells of the tunnels were finished there could be drawn economical advantages through using the lower priced brine freezing.

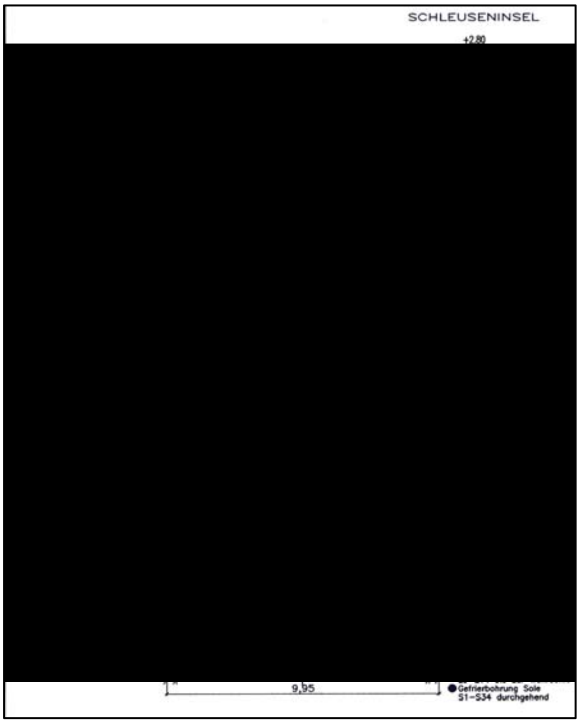

Figure 3: Cross Section of Tube 2 [3]

In order to put the freezing lances in place it was necessary to bore horizontal holes. Those were drilled from two pits located at both river banks. The total length of the bore holes is about 9,700 m with single lengths reaching 40 m. To ensure a closed frozen ring a maximum divergence of 60 cm between the bore holes was allowed. To control and regulate the freezing system a large number of automatic bore hole thermometers had to be installed. The responsible technicians were able to access the data via internet. During the 10-months-phase of freezing a total volume of 14,000 m³ soil had been frozen.

Station tubes: After completion of the closed freezing ring the heading using the New Austrian Tunnelling Method (NATM) was started. Soil was broken out by tunnel excavator with an attached milling cutter. The embrasure was secured by shotcrete, steel reinforcement and tunnel arches. One tube was built after the other. After finishing the heading the impermeable final lining (concrete with polypropylene fibres securing modern fire protection) was casted. After completion of the final lining the freezing system was taken out of operation and the defrosting process was started.

Ground Water Lowering

Basic conditions in the contract section U2/2: During the environmental impact assessment it was decided to drill 240 wells with depths of about 40 meters. Because of this area with dense building characteristic the wells are located in the streets as well as in numerous backyards of the houses. Combination wells were deployed which had the advantage to drain the upper layer of gravel as well as the regions of sand below the clay,. The pumped water was fed into one of three main pipelines leading to the Donaukanal-river downstream.

Figure 4: Overview wells [6]

Before starting construction field tests were conducted. These tests showed that – taking into account the soil condition in that area – in case of a breakdown of a group of wells a fairly quick rise of the groundwater level must be expected. This could lead very fast to a rise of the groundwater level up to the area of the invert. The result would be a serious reduction of the soil stability containing mainly sand. Therefore the contractor had to develop an electronic monitoring system.

Control and monitoring systems: Aim of this system is to give a centralised survey over the whole system at any time so that messages of missing flow rates from failing wells are sent to the technician in charge automatically. Moreover economically processing and interpreting of the large amount of data gained could be conducted by the contractor. The described system was developed by a Viennese engineering company and is able to operate 270 pumps automatically, to gain and govern data from 800 sensors, visualising them and hence compiling command controls.

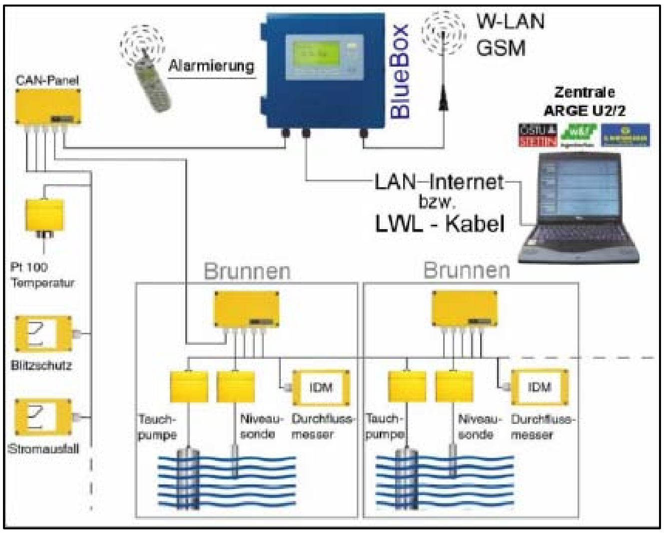

Figure 5: Connection sheme of the well system [6]

Consistently recording of all level, flow and temperature values as well as response times is safeguarded by this system. Each pump is equipped with a temperature sensor as they are exposed to high loads. Each well contains an inductive flow meter for the recordation of the pumped water and a pressure sensor for the determination of the exact water level in the well. The whole contract section was divided in nine pumping arrays with 30 pumps each.

The centrepiece for the operation of the pumps is the so-called “BlueBox”. It is a recordation and control computer that identifies a pump module directly after its attachment and starts recording data immediately. All nine “BlueBoxes” are connected to the headquarters via fibre optical cables. On an analysis computer the ground water lowering can be checked, analysed and operated with specific visualising software. The visualisation can be carried out in four levels, depending on the desired information content. The obtained data can be merged to daily or monthly reports that are basis for billing.

To avoid endangering of the tunnelling personnel in case of failure a fast reaction of the technician in charge is necessary. In the case of e.g. the failure of a pump this is recorded by the “BlueBox” and the person in charge is informed by GSM text message as well as the event is shown on the analysis computer in the office. When a failure of individual pumps of one group occurs the discharge flow of the neighbouring pumps is automatically increased.

The vantages of this system are:

- Increased protection of the tunnelling personnel through a quick alarming system respectively an automated failure compensation mechanism
- Optimisation of the ground water lowering and energy consumption
- Cost reduction by operation without pump guard
- Cost reduction by automatic data evaluation and compilation disposing a comprehensible basis for billing.

The system, developed during the work preparation has proved itself during the construction phase of the project and can be reused in future projects with large scale ground water lowering. The complete ground water lowering however could not be achieved in partial areas. Therefore additional wells as well as jet grouting were necessary.

Jet Grouting

General: Jet grouting is used for solidification of the subsoil as well as for the sealing of building pits.

With this method, differently from other conventional low-pressure injections, the soft ground gets replaced by a mixture of the remaining granular structure and a cement suspension. After a suspension supported borehole is made (usual diameter 15 cm) the ground is cut by high pressure (400–600 bar) cement suspension jets in the bottom part of the drill pipe. By means of rotating the drill pipe and simultaneous retracting a column shaped cement-ground-compound (diameters ranging from 80 to 300 cm, depending on method and soil conditions) is created. As opposed to conventional ground solidification methods jet grouting can be used effectively for solidification and sealing of all soils as far as low compacted clays.

Figure 6: Drilling rig for horizontal underground jet grouting

Areas of application are ground solidification (e.g. underpinning, stabilisation in tunnelling) and sealing of the ground (e.g. column walls, water proof bottom plates, jet grouting shields in tunnelling).

Methods: Executing the contract sections of the Vienna underground lines U2 jet grouting was used for sealing (e.g. U2/2 and U2/3) as well as ground solidification (e.g. U2/3). Two different methods were utilised, on the one hand horizontal production of jet grouting umbrellas from the tunnel face as well as vertical or angular columns from the surface.

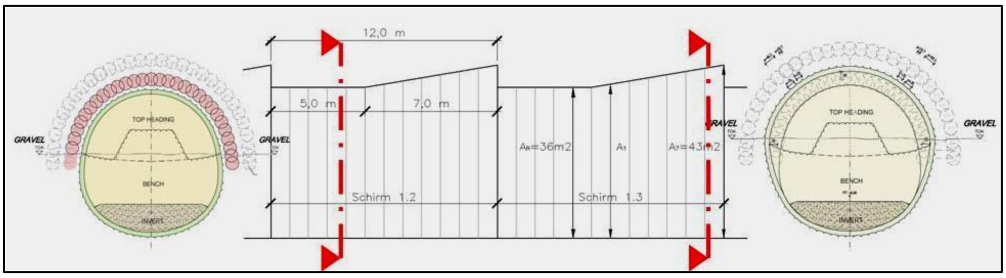

Figure 7: Jet Grouting Umbrella in Cross and Logitudinal Sections [10]

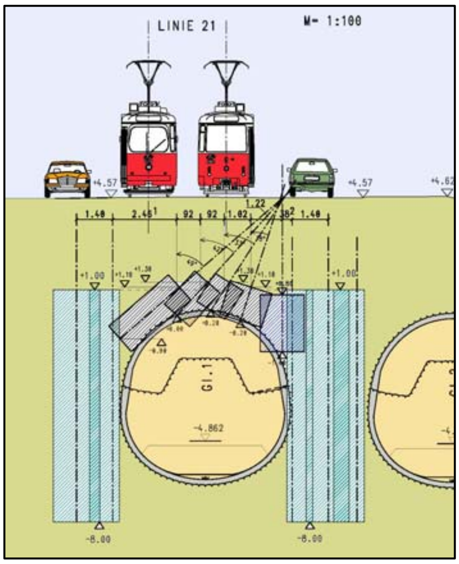

Figure 8: Vertical Jet Grouting [10]

Horizontal Jet Grouting: For the production of the horizontal jet grouting umbrellas slightly angular upwards, quasi-parallel drillings were made out of an extension of the cross section. The approximately 15 m long overlapping columns result in an "umbrella". This umbrella can, if necessary, be supplemented by a bulkhead covering the tunnel cross section at the end of an umbrella to avoid sudden water ingress when retaining soil layers are dipping the top heading. For the bulkhead void boreholes with the length of the umbrella boreholes are needed. Multiple following umbrellas usually require boreholes in longitudinal section with approximately 3 m overlapping. The bulkheads have to be demolished when reached by the tunnel face.

This method was utilised at the U2/2, where the impermeable stratum showed cavities hence the groundwater lowering could not remove the remaining water. Using this method prevented water inrushes and downfalls. The time consuming station heading project by means of a side wall drift could be replaced by umbrella protected full profile heading. In addition a higher rate of advance could be obtained. The overall advance rate however was conditional upon the intermittent jet grouting lower than anticipated. At U2/3 contract the same measure (as well as vertical jet grouting) was only used for ground solidification, to avoid large scale filling injections in coarse gravel and therefore gain increased advance rates.

Problems for the construction operation arise from the necessary alternation between jet grouting and tunnelling and hence resulting low efficiency of either jet grouting machinery or tunnelling personnel (they can be reduced from two to one in a two tube tunnel).

As a certain expertise and specialised machinery are necessary for underground jet grouting this task is often assigned to a subcontractor.

Jet Grouting from the Surface: This method was used for two different reasons and in two different implementations. On the one side it was used in form of a vertical column-wall on both sides of the future tunnel as means of sealing, and on the other side aligned to the cross section of the tunnel, mostly angled columns with differing void borehole lengths, hence creating an "umbrella" for ground solidification. Reasons for the second implementation again are also acceleration of the tunnelling works, whereas tunnelling works had not to be intermitted contrary to horizontal jet grouting.

As a major disadvantage vertical jet grouting from above can only be carried out in areas without buildings also serious traffic disruptions have to be considered if carried out on roads.

Reasons for the additional measure jet grouting umbrella: All jet grouting measures at contract sections U2/2 and U2/3 were – except for the vertical column walls for sealing – carried out as additional orders. Not included in the initial tender, these measures either had to be carried out due to technical reasons or were offered initiatively by the contractor.

Technical reasons: Technical necessity occurred in areas where the groundwater flow could not be controlled due to geological unpredictable conditions, although accurately examined, hence making conventional tunnelling impossible, extremely risky or very time intensive. These problems were discussed in periodic tunnel meetings calling in a "tunnelling expert".

Legal reasons: Following Austrian law regulations concerning ground risks the reasons for these measures were allocated in the responsibility sphere of the client leading to a contractual extension of the construction period.

Technical advice: The tunnelling expert should be consulted as per Austrian Standard ÖNORM B 2203-1 "Underground works – Works contract – Part 1: Cycling driving" for difficult projects especially for geotechnical and tunnelling advise as well as for settling technical disagreements. In this case differences occurred because the additional measures were causing high costs and client and contractor were discordant if respectively how and in what amount additional measures were needed.

Initiative of the contractor: In other cases (U2/3) umbrella jet grouting was according to the client technically not necessary. The contractor however was confident that the utilisation of jet grouting in some areas could lead to vantages for both parties. The advantage for the client would mainly be a shorter construction period. The contractor mandatory assured this reduction of construction time. This was essential for the client, as the contractor had obtained a longer construction time because of modified conditions, and the completion date could not be altered due to EURO 2008. The motivation for the contractor was on one side security concerns, and on the other side price advantage due to modified conditions.

Tunnel Excavation Portal

In contractual section U2/2 the commissioned joint venture used a new tunnel excavation portal for the excavation at the heading. The rail supported girder construction is formed to a portal that has two lengthwise adjustable courses in the crown. On one course a hydraulically moveable scaffolding is installed, to execute all necessary works in the cross section (e.g. placement of reinforcement, spraying of concrete). On the second course a complete drill rig with two booms is mounted at the rig so that it can likewise be moved in tunnel axis. The boring equipment can be used for positioning lances and steel plate lagging as well as for the jet grouting of the umbrellas. The used tunnel excavator which can move through the portal is an Schaeff ITC 312.

Figure 9: Tunnel Excavation Portal [12]

Main advantage of this excavation portal is the uncoupling of the different repetitive operating cycles of tunnel excavation in the two working levels crown and bench. Hence activities normally conducted one after another can be executed parallel and mounting times of the equipment can be minimised. This proves to be an advantage in inner city metro tunnelling when the cross sections are usually small (ca. 35 m^2). The described vantages lead to shorter advance times and hence to higher outputs. As for this contractual section, because of unexpected hydro geological circumstances jet grouting had to be used in some areas, the vantages could not be used in their complete extend.

Conclusion

The first extension phase of the Underground line U2 is making high demands on all involved parties due to crossing the “Donaukanal” twice, underpinning partially desolate buildings above the tunnels and probably Europe’s largest automatically operated groundwater lowering project. In addition unexpected hydro geological circumstances caused problems. The collaboration and teamwork of all contractual partners allowed that all problems could be solved. The changed conditions and resulting extra costs as well as building time extension were evaluated and reviewed by various consultants satisfying all parties involved. From today’s perspective all works are on their way assuring the completion of the underground works accurately timed for the EURO 2008.

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