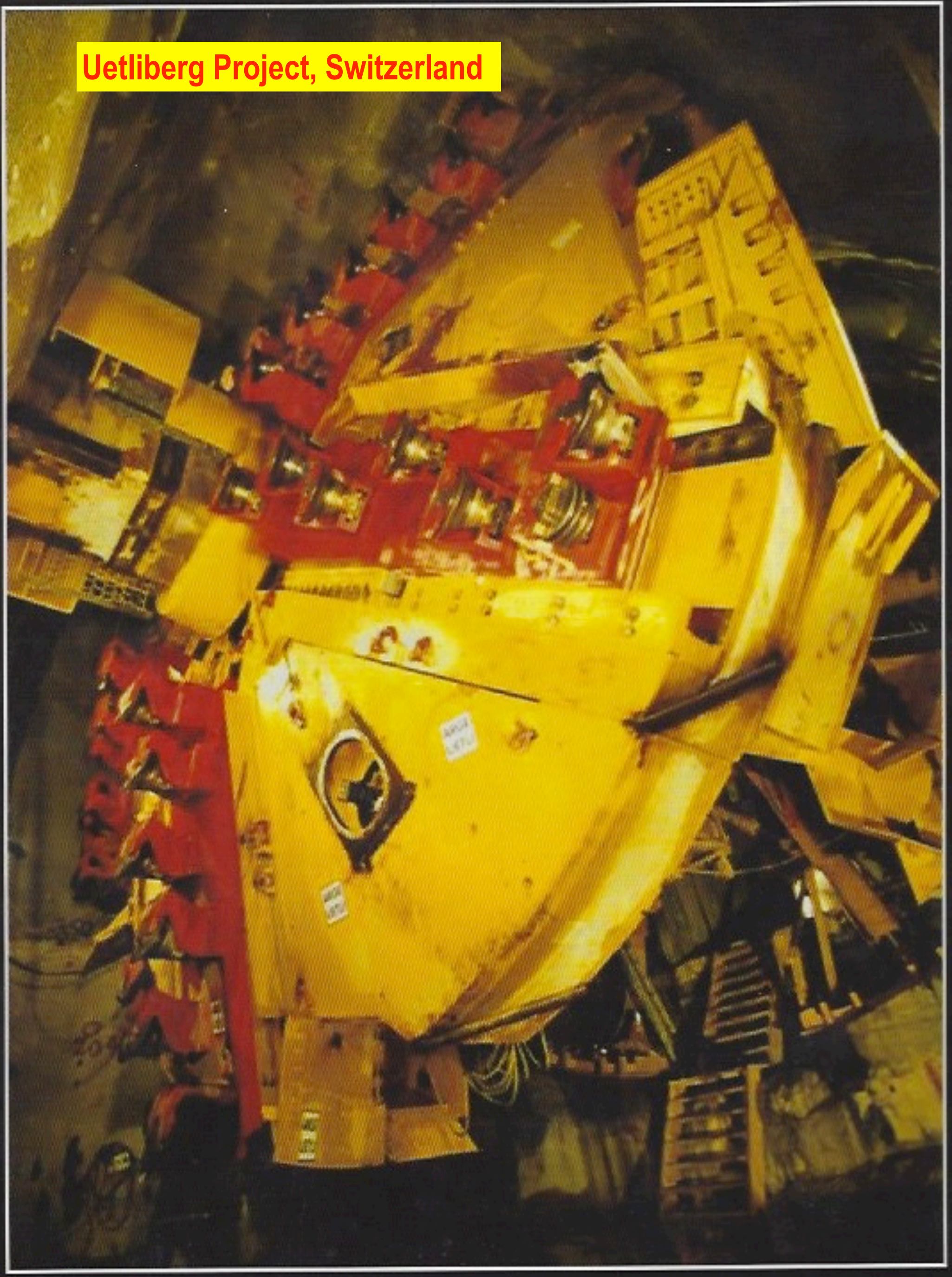
Uetliberg Project, Switzerland



Multiple methods for Uetliberg tunnel

The 4.4km long Uetliberg Tunnel, the key structure on Zurich's western bypass, is being constructed by an array of techniques. Daniel Marti and Stefan Maurhofer of the project consultant Amberg Engineering, Josef Bolliger, project leader for the Uetli JV and Otto Schnelli representing the client discuss progress

Above right: Fig 1 - Location map

Below: Fig 2 - Longitudinal section

The 10.6km long Zurich western bypass, currently under construction, has been designed to ease the serious traffic congestion currently affecting Switzerland's financial capital (figure 1). The bypass, that will divert traffic from the city by connecting the existing A3 and A4 highways, includes four tunnels totaling 8.4km (around 80% of the route). The US$746M, 4.4km long twin-tube Uetliberg tunnel is the longest of these and possibly the most challenging. A variety of driving techniques are being employed to tunnel through the rock and soil, the most interesting being the use of a TBM equiped with a 14.4m diameter reamer using the undercutting technique. Although well established techniques in their own right, combining a reamer with undercutting at the Uetliberg is thought to be a world first for the tunnelling industry.

Geology

The dominant geology along the alignment (figure 2) is through the 500m long Eichholz and 2.8km long Uetliberg molasse sections where the harder rock strata comprises flat-bedded strata of the upper fresh water molasse, an alternation of hard sandstone seams and soft marl strata.

The three other tunnel sections are through soft ground. Firstly, the 210m long Gjuch section (at the Wannenboden west portal) which cuts through a very heterogeneous end moraine called the Wettswil moraine complex consisting of a loamy, sandy gravel. The water table rises from the centre of the tunnel profile at the start to above the tunnel roof in an easterly direction. Secondly, is the 240m long Diebis section consisting of a base moraine overlaid with slope wash. The slope wash consists of moraine

material and fine particles. At the start of the soft ground section, about half the tunnel cross-section lies in the slope wash, which then rises towards the east. After about 50m, the whole cross-section is in the moraine. In the Diebis soft ground the whole tunnel cross-section is in ground water.

Finally, is the 410m long Juchegg soft ground section comprising a base moraine composed initially of sandy-gravels and then of clay-like sands. Above this lies the Uetliberg loam, to the centre of the tunnel cross-section at the portal. After about 70m the whole cross-section is in the moraine.

The water table is below the tunnel cross-section at first, rising at the interface between the sandy-gravels and the clay-like sands of the moraine. At the interface between the soft ground and the molasse, the whole tunnel cross-section is in ground water.

Normal cross-sections

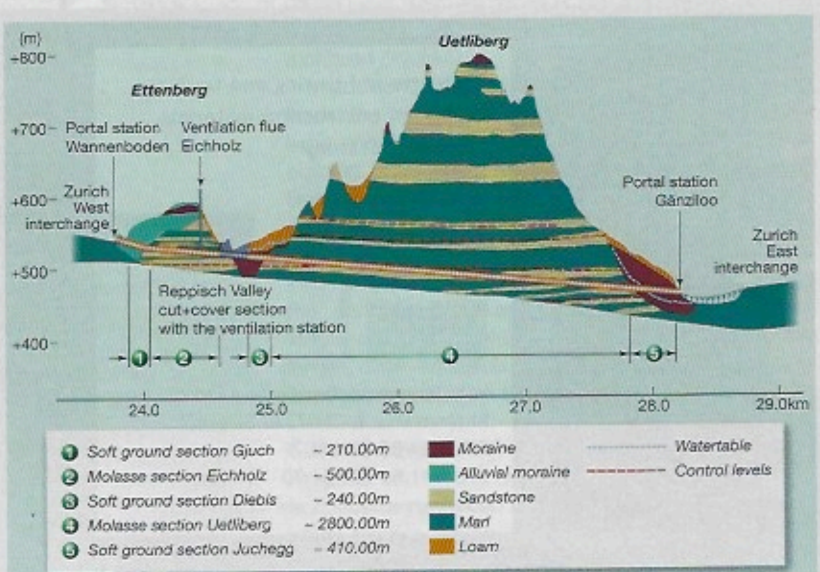
All of the soft ground tunnels and the Eichholz molasse section are being excavated as a horseshoe cross-section, 14.7m wide and about 12.7m high with an excavated area of 143m² to 148m².

The exception to this is the 2.8km long Uetliberg molasse cross-section that is 14.4m wide and 14.2m high with an excavated area of approximately 160m².

The tunnels are designed with a fully sealing double skin lining. The seal is pressure-maintaining in the Gjuch, Diebis und Juchegg soft ground and Eichholz molasse sections and drained (depressurised) in the Uetliberg molasse section.

The parallel tubes will be connected every 300m by cross passages for pedestrians and every 900m for vehicles. SOS niches will be situated every 150m.

There will be an underground central ventilation station in the Reppisch Valley (Landikon) located over the underground traffic interchange. The tunnel will



normally be ventilated in both directions by the natural longitudinal ventilation/piston effect. A system of environmental ventilation is designed for the Basle tube which permits the air flowing out of the tunnel to be extracted before the Wannenboden portal. The air will be fed back through a network of ducts along the tunnel tubes located above the intermediate ceiling to the central ventilation station in the Reppisch Valley, where it is discharged outside via the exhaust air tunnel and Eichholz shaft.

Construction phases

The tunnel is being driven downwards (1.6%) from the Reppisch Valley excavation site through to the Zurich-South interchange in the Brunau area (figure 3).

Construction by sequential excavation started from the Reppisch Valley site in April 2001 on the two tubes in the Diebis soft ground section (SG-DIE = 2 x 240m). The section was completed in May 2002. A 5m diameter Wirth TB III 500 E TBM was installed in the Basel tunnel tube at the start of April 2002 and is currently boring a pilot tunnel through molasse section of the Uetliberg (MO-UET = 2 x 2,800m). From spring 2003, the 5m wide pilot tunnel will be widened to a final cross-section of 14.2m to 14.4m using the TBM with a reamer. The pilot TBM and the reamer will be partially pre-assembled before the portal in the Landikon excavation site and then transported to the starting cavern of the Basle tube where the assembly process will be completed. After driving the Basle tube, the TBM and the reamer will be dismantled in the dismantling chamber and transported back through the tunnel. They will then be re-assembled in the second specially prepared starting cavern for the purposes of driving the Chur tunnel.

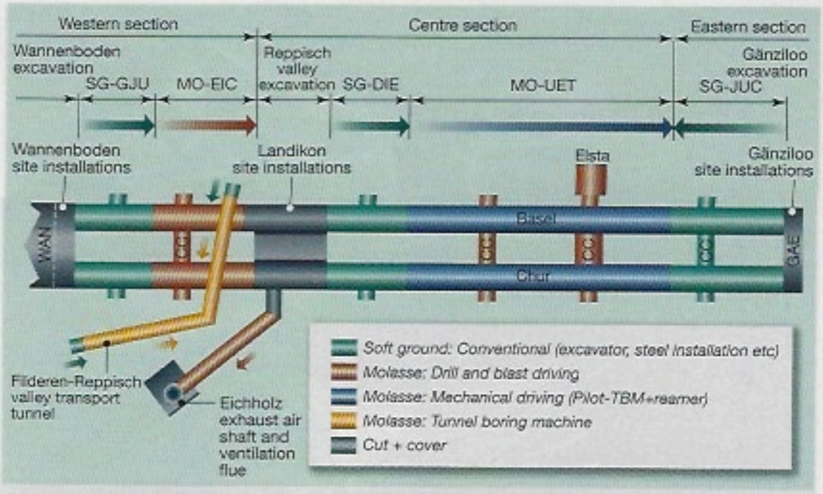
The upward driving of the Juchegg soft ground section (SG-JUC = 2 x 410m) from the Gänziloo excavation site (Brunau side) started in February 2002. In April 2002 work also got under way on the downward drive from the Wannenboden excavation site under the Ettenberg towards the Reppisch Valley site. This section of the Uetliberg tunnel has to be driven firstly through the Gjuch soft ground section (SG-GJU = 2 x 210m) followed by the 500m long Eichholz molasse section (MO-EIC).

Driving lesson

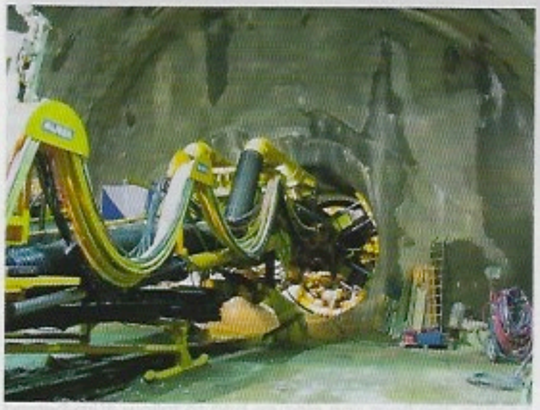
All the soft ground sections are being driven by sequential excavation with support consisting of steel arches (HEM-180 girders spaced 1m apart) and 250mm thick steel fibre-reinforced shotcrete.

The 500m section under the Ettenberg (Eichholz molasse section), will be blasted, divided into the crown, bench and floor.

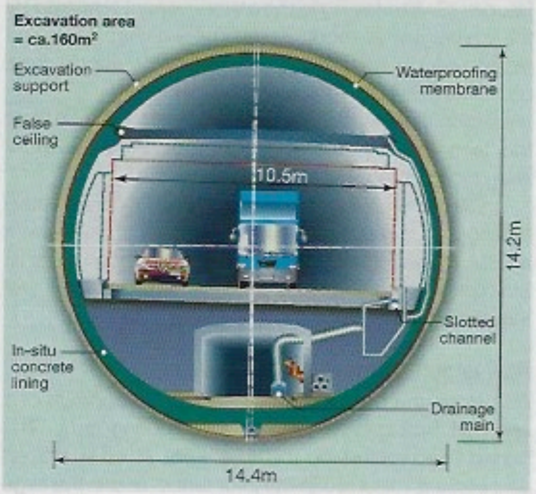
The Uetliberg molasse tunnel is being excavated by the 5m diameter Wirth TBM then reamed to its full cross-section of 14.2 to 14.4m diameter using the undercutting technique. The support here comprises cable bolts, Swellex bolts, mesh and shotcrete and is being installed directly behind the boring head. The final lining and the intermediate ceiling will be built in stages behind the machine.



Above: Fig 3 - Driving directions and methods used during construction of the Uetliberg Tunnel



Left: The 5m diameter Wirth pilot TBM gets under way on the Basle tube



Bottom left: Fig 4 - Finished cross section of the Uetliberg's Molasse section constructed by 5m diameter pilot TBM and 14.4m diameter reamer

Driving the Diebis soft ground section

As with the other soft ground sections, the Diebis drives have been divided into seven sub cross-sections: 2 x 17.35m^2 upper side-wall galleries on both sides; 2 x 22.55m^2 lower side-wall galleries on both sides; a 24.30m^2 crown; a 26.66m^2 core; and a 16.84m^2 base, giving the total 147.60m^2 area.

The upper side-wall galleries were excavated in metre steps by mini-excavators and immediately lined with a 5cm thick layer of shotcrete. Steel girders (HEM 180) were then installed at metre intervals to protect the seal (the seal layer is created with furnace-dried, prefabricated dry shotcrete due to its quick availability and increased safety). After a further excavation round, the installation girders were sprayed with steel fibre reinforced wet shotcrete. Rockbolts, mesh and drainage pipes were also installed in the roof due to the presence of water and to improve safety conditions.

In order to drive the crown with a span width of 8m, a 20m long pipe umbrella was created during the initial construction phases comprising 29 x 152.4mm diameter pipes. The first 50m of the Juchegg soft ground tunnel were also built this way. Following the pipe screen, the roof was secured with 30mm diameter, 4m long lances. The drilling face was then anchored

Parties involved in the construction project

Client: Engineering Department of the Canton of Zurich; Office of Civil and Underground Engineering; and the National and Main Highways Dept

Project and construction work management:
Amberg Engineering Ltd

Contractors:
Uetli Joint Venture
Zschoke Locher Ltd;
Murrer Ltd;
Prader Ltd; Tunnelbau CSC Bauunternehmung Ltd;
Wayss und Freytag Ltd;
Alpine Mayreder Bau GmbH;
ZüblinSchlittlerSpaltenstein Bau Ltd

Above: Sequential excavation through the Diebis soft ground section

with nine 15m long steel self-drilling bolts with a 3m overlap, with additional drainage pipes at the drilling face where there is water build-up.

The procedure for installing the support was the same used whilst driving the side-wall gallery. The additional measures were required for safety and for reducing deformation during roof excavation.

Base excavation level, ring seal

In order to reduce deformation across the entire cross-section, the floor ring closure had to follow 40m behind the crown face with the inner side-wall gallery walls being excavated 6m behind the crown face. The core was not excavated vertically, as originally planned, but connected to the base level with a ramp. As soon as the crown was excavated to 12m, the work was switched to the floor excavation. This was done in 12m steps from the face in the direction of the portal. The work progressed 3m-4m at a time in which waterproofing, steel support and steel fibre wet shotcrete were placed.

Where build-ups of water occur, measures had to be taken to ensure that the water was removed from the base area before the sealing layer was applied. In order to facilitate this, additional drainage measures were installed, that included customised membranes, seepage ditches and pump shafts.

Monitoring in the Diebis soft ground

Construction monitoring is carried out using a variety of equipment, such as piezometers, 3D convergence measurements, extensometers, distometers, cross-section surveys and steel extension sensors (strain gauges).

Deformations/movements are also monitored with optical 3D convergence measurements, distometer measurements and cross-section surveys. The convergence measurements showed that there were practically no measurable signs of deformation when driving the upper side-wall gallery. When the lower side-wall gallery was excavated, the upper side-wall gallery subsided by about 25mm. At the same time, the distometer measurements showed that there was a horizontal narrowing of the cross-section of the order of 10mm to 15mm. Deformation of up to 10mm was detected after excavating the crown. Deformation of about 30mm was recorded again in the ring seal, leading to total deformation of approximately 70mm. The cross-section surveys conducted at different times, i.e. before or after the ring seal, revealed values of the same scale. The deformation values calculated beforehand by the project coordinator were about 50mm - 100mm. The comparison with the effective deformation measurements and the total deformation confirmed the values calculated.

Progress report

Excavation of the Diebis soft ground section is complete as are the assembly caverns for the reamer in both tubes. The pilot tunnel has already been driven to 1500m in the Basle tube with current progress of approximately 25m per day reported. The hole-through of the ventilation tunnel, driven in the opposite direction, is on schedule for the end of 2002. Work got under way driving the Juchegg soft ground section in February 2002. The roof and the lower side-wall gallery have been excavated to a length of 50m in the Basle tube. The driving of the ventilation tunnel (upper right side-wall gallery) is currently at approximately 400m. The upper left side-wall gallery is at 180m. Construction started on both tubes of the Gjuch soft ground section in April 2002. To date, 140m progress has been made in the Basle tube and 20m in the Chur tube, both at full cross-section. The sinking of the exhaust air shaft in the soft ground (22.8m) is complete with blasting of the remaing 37.8m having begun in August. At the current rate of progress the project is well on schedule for the planned commisioning date in 2008.

Reaming with undercutting technology

The Wirth TBM fitted with the 14.2m diameter reamer, utilising undercutting technology, will be deployed in the Uetliberg molasse section in spring 2003. The boring head is currently being prepared by Wirth AG, whilst the Uetli JV is making arrangements for the back-up. The individual elements of this process, i.e. reaming and undercutting, have already been used with great success on many occasions in practice or have been tried out in extensive trials in Germany and Canada (undercutting technology). Although used in mining, it is believed they have never been used together on a civil engineering tunnelling project.

The reaming technique facilitates the mechanical driving of a wide area of the tunnel cross-section with direct rock securing, which can be adapted to suit the geological conditions met. Compared to conventional extending, it allows considerable savings both in terms of the rock securing resources used and the lining because of the less destructive nature of the excavation and the circular, statically favourable cross-section.

The reamer being used is essentially based on the driving installation already used successfully in the Tunnel de Paracuellos (Spain) and in the Tunnel de Sauges (Switzerland). As the reamer variant tendered by the contractor is mounted on the existing, tried and tested driving installation, the costs of supplying a complete TBM of this size were negated.

Liaising closely, the Uetli JV and Wirth have evaluated the technical capabilities for deploying the extender with undercutting.

Undercutting has been acknowledged as an effective cutting principle ever since the early days of boring with a TBM. In this technique, the cutting rollers work against the rock's tensile strength, which is considerable lower that the compression strength.

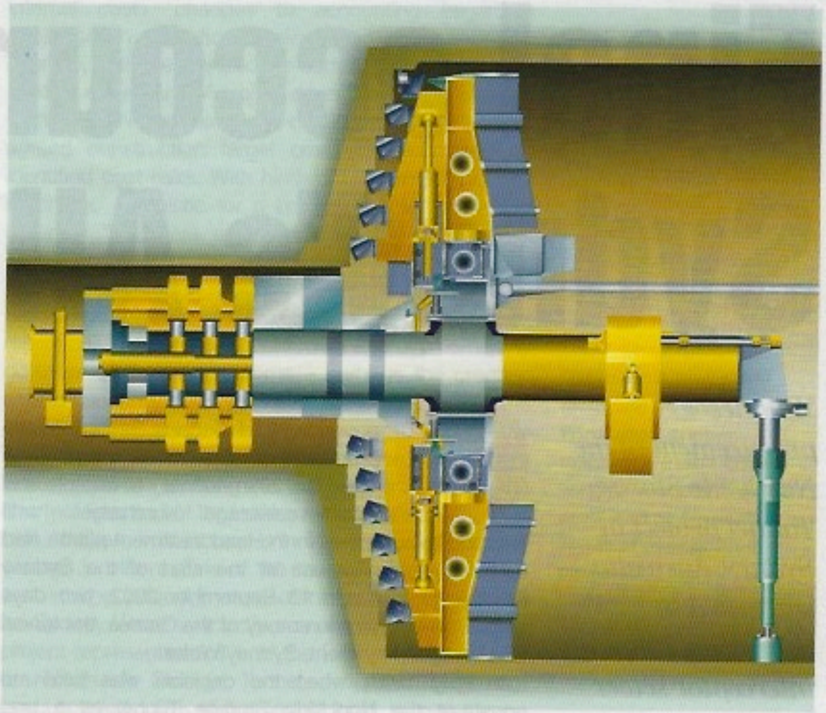
How undercutting with a reamer works

As before, the boring head of the reamer consists of a two-part boring head base and six boring arms. The boring head rotates on the inner kelly which is braced and bearing-mounted in the pilot tunnel and in the large unnel cross-section. The cutting rollers are offset both xially and radially to the axis of the tunnel and arranged on axial moving slides on the boring arms. As the boring ead rotates and the slides move in a radial action at he same time, each roller follows a spiral path around he axis of the tunnel. As the outer roller advances, this reates a stepped face, so that each of the cutting ollers can shear off the rock into a free space undercutting principle). When boring starts on a so-alled "shot" (axial excavation section per radial stroke f the slide), the inner cutting rollers start in the pilot ore, for example, and the outer rollers start at the last evel bored by the inner rollers.

Inserts screwed into the cutting roller holders act as eceptacles for the cutting rollers and can be xchanged quickly if they are damaged.

The length of the shot is limited to a maximum of the xial displacement of the cutting rollers on a slide (SA = 00mm). Smaller shots may be selected depending on he strength of the rock. As the six-armed boring head otates, with its six cutting rollers on each arm, the 36 utting rollers are moved on six spiral paths, 60° apart, om an inner boring diameter to an outer boring iameter (p x z_A). Once the 14m boring diameter has een reached, the slides are retracted to the 4.5m ameter. The boring head is then moved axially by a hot (e.g. SA max. 200mm), and the next step starts.

As the shear forces of the blades are applied in a dial direction, compared to conventional cutting chniques the force components of the thrust action e neutralised by the diametrically opposite rangement of the boring arms. The small number of utting rollers (six per arm) with a contact pressure of pproximately 100-120kN/cutter also reduces requisite rque at the boring head for releasing the rock. The ss of the large contact pressure forces (thrust) and the sulting high torque loads of the tunnel permit the largement of the boring head on an existing TBM. e reamer can extend tunnels with a pilot of 4.7m-5m diameter in stable, drillable rock, to a 14.4m diameter.



Above: A typical reamer set up showing the pilot tunnel being used for bracing the main machine

Technical data for the 450/1440 reamer

Boring head	
Diameter, nom.	DN = 14.00/14.40m
Boring head drive	10 x 250 = 2,500kW
orque, nom.	4,800kNm
Rotating speed of the boring head	0 – 3.7rpm
orque, max. at n = 2.8 rpm.	6,430kNm
Cutting rollers	
Cutting face	36 x ED/H LKG – 3
hrust	
Contact pressure of the boring head	15,000kN
oring stroke	1,500mm
riving speed	0 – 4m/h
hrust cylinders	4
ylinder diameter	400/300mm
ydraulic pressure	300bar
racing	
racing force	42,500kN
racing plates	12
ylinders	24
ylinder diameter	275/200mm
lax. hydraulic pressure	300bar
onveyor belt width	1,200mm
lectric equipment	
stalled electric power	2,800kW
ansformer	4,000kVA
put voltage	10,000 V / 50Hz
ngine voltage	660 V / 50Hz
eight of reamer and trailer	approx. 1,000T

Reamer description

The base machine for the reamer, called the Tunnel Bore Extender (TBE) 450/1440 comprises the following modules:

- boring head with bored material shovels and scrapers;
- inner kelly with boring head bearing and drive mechanism;
- outer kelly and bracing;
- machine and boring head support;
- trailer, drive aggregates, hydraulic tank, control hydraulics, electric switchgear and control stand.

Advantages of reaming with undercutting

The undercutting principle causes lower forces to be exerted on the TBM (main bearing, inner kelly). This meant that there was no reason why an existing machine could not be used/modified. Other advantages of the driving device selected by the Joint Venture:

- low energy consumption during excavation;
- short boring head structure because there is no need for thrust forces in the direction of the tunnel, enabling the rock face to be secured close to the drilling face;
- facilitates localised overlapping of the circular profile;
- savings in mass by optimising the adaptation of the excavation - the rock face can be secured between boring arms when the machine is idle;
- low dust development on account of the minimal destruction of the bored material;
- environmentally-friendly excavation of the rock in the area of the drilling face/pilot tunnel as the rock is not subjected to any stress parallel to the pilot tunnel.

Disadvantages compared to a shield TBM

- conventional securing dictates the driving power (rock classes);
- lumpiness of the material is dependent on the existing layer packets;
- changing boring tool attachments in front of the boring head;
- no protection with the shield in the L1.

T&T

Mixed method success

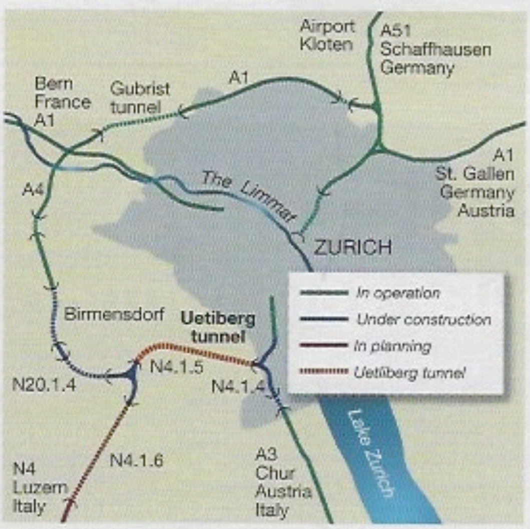
On 21 October 2004, an audience of BTS members and guests heard a presentation on the construction of the Uetliberg Tunnel, part of Zurich's west by-pass. The speaker was Stefan Maurhofer, overall project manager and chief construction manager for Amberg Engineering Ltd

The Uetliberg Tunnel Project in Switzerland forms part of a major by-pass contract to the south-west of Zurich. When completed, the project will connect the Birmensdorf by-pass in the west to the existing Zurich-Chur National Motorway (A3) in the east (figure 1). The overall project will provide a 12.3km long highway circle around the city (*T&TI*, Nov '02, p24).

The project consists of two parallel tunnels, each 4.4km long, which fall at a gradient of about 1.6% east to west. The tunnels are equipped with pedestrian cross passages every 300m and vehicular crossovers every 900m. There are three lane crossover points in the tunnel, which will be used in the event of accidents, fires and for maintenance purposes. There are also SOS niches every 150m.

An underground ventilation facility will be situated at Landikon in the Reppisch Valley where there is low cover to the tunnel (figure 3). Axial ventilation will be used in the tunnels when required. As one-way traffic is maintained in each bore this provides a 'piston' effect for normal airflow through the tunnels. In the event of a fire, air and smoke can be exhausted at intermediate points into the tunnel ceiling void and then exhausted from the air stack in the Reppisch Valley.

The tunnels are to be constructed in two main cross-sectional areas. For soft ground sections the tunnel area is 148m^2 and for the harder rock section the size increases to 160m^2 (figure 2). There is also a short, 300m long, section of cut and cover tunnel. This is situated in the Reppisch Valley and required a special bridge to carry the valley river over the works whilst construction took place. A flooded river over-topping the bridge was a major risk to the project.



Above: Fig 1 - Map of Zurich showing the location of the Uetliberg Tunnel

Geology

From west to east the Uetliberg Tunnel passes under two parallel ranges of mountain, the Ettenberg and the Uetliberg (figure 3). Between them lies the Reppisch Valley, which divides the tunnel into two distinct sections. The western section under the 600m high Ettenberg Mountain is called the Eichholz Tunnel and is 710m long. The eastern Uetliberg Tunnel lies under the 800m high Uetliberg Mountain and is 3,450m long. A short cut and cover section in the Reppisch Valley provides a connection between the main tunnels. The maximum overburden lies above the Uetliberg Tunnel at approximately 320m.

The ground conditions in the tunnels consist of moraine, alluvial moraine, sandstone, marl and clay. From the west end at Wannenboden the Eichholz Tunnel passes through soft ground moraine in the form of loamy, sandy gravel for about 210m. This is a soft ground section of tunnel.

The next section of tunnel is in much harder molasse that has alternating bands of sandstone and soft marl for 500m before it reaches the Reppisch Valley. This section of tunnel is to be constructed using drill and blast excavation methods.

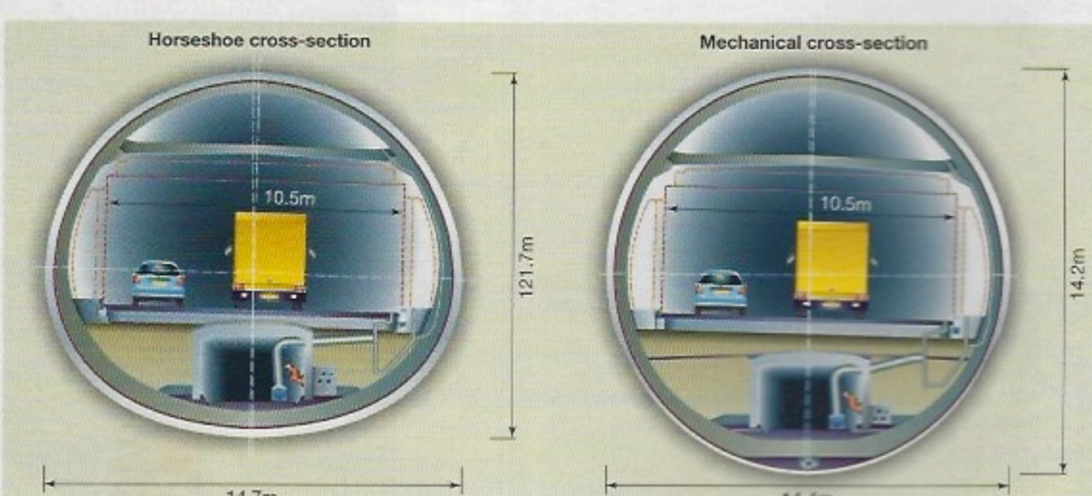
From the Reppisch Valley the Uetliberg Tunnel starts in the Diebis soft ground material, which is ground-up moraine containing the full range of particle sizes from 'flour' up to stones and boulders. Part of this 240m section of tunnel is under the water table.

The next 2,800m long section of the Uetliberg Tunnel passes through hard sandstone molasse, which will be driven by TBM methods. The final 410m of tunnel at the east portal is in soft ground conditions. These start as a gravely sand and then turn into a sandy clay. The groundwater table is above the tunnel at first, in the soft ground, then falls to below the tunnel at the east portal.

Excavation methods and support

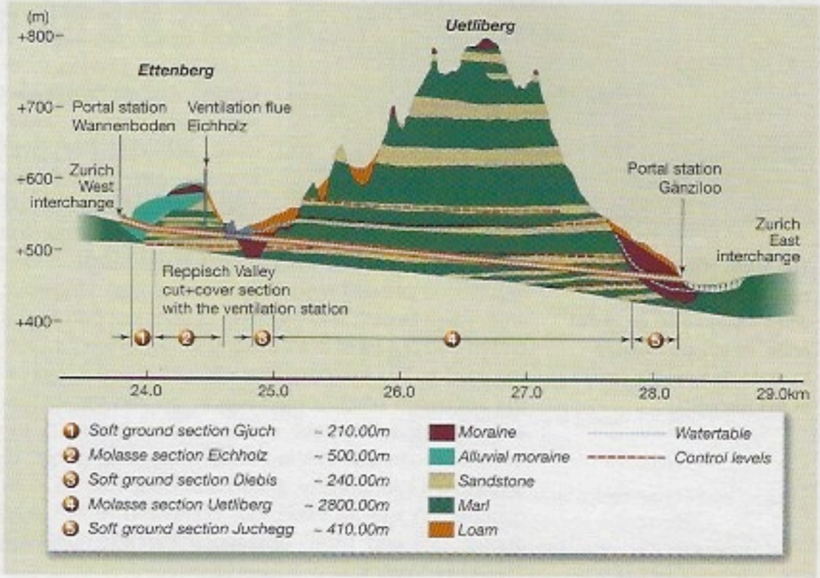
There are three main methods of excavation for the tunnels: In the soft ground, mechanical excavators work on a sectional 'Core Construction Method'; drill and blast has been adopted for the hard sandstone molasse under the Ettenberg Mountain; and a 5m diameter Wirth pilot TBM tunnel through the Uetliberg molasse before final excavation by a Tunnel Bore Extender (TBE).

Ground support in the soft conditions employs steel arches at 1m centres and then 250mm thick steel fibre reinforced shotcrete. Additional measures such as



Right: Fig 2 - Typical soft ground horseshoe cross section and harder rock TBM/E excavated cross section

on the Uetliberg Tunnel



Above: Fig 3 - Longitudinal section of the tunnel

spiles, face support anchors, local dewatering, drainage holes, pipe roofing and grout injection have all been used to some extent in the soft ground.

The drill and blast section utilises mesh reinforced shotcrete and rock bolts. Steel arches have also been used in critical zones, in particular where the tunnel passed under the existing Landikon railway tunnel.

The pilot tunnel supports are removed just prior to the TBE arrival, although fibreglass bolts are left in and removed by the TBE. Once excavated by the TBE, the tunnel is supported immediately behind the cutterhead with cable bolts, Swellex anchors, steel nets and shotcrete. Again in critical zones steel arches have been used.

In the soft ground a horseshoe shaped cross section has been adopted, which is 14.7m wide by 12.7m high. In the hard molasse ground of the Uetliberg Tunnel excavated by the TBE, a cross section of 14.4m wide by 14.2m high is created by special over cutting discs produced this non-circular tunnel shape. The final tunnel cross-section is divided into three parts; the traffic chamber, the exhaust air duct and the substructure service duct (figure 2).

The TBE or undercutting system

Maurhofer then described the undercutting system used on the TBE. He explained that traditional hard rock TBM's have the roller discs fitted into the cutterhead at right angles to the face. The ram pressures then force the discs to cut a groove in the rock in the face. The full pressure of the TBM can pass through the axis of the rollers and can cause significant wear and damage very quickly. The Wirth TBE undercutting system has 36 cutting discs mounted on six radial arms, which are inclined backwards from the centre of the tunnel, away from the face. The discs are however mounted almost parallel to the tunnel face but on a slide arrangement, which moves the discs radially away from the centre but also outwards. Cutting then takes place in a series of radial steps.

The TBE does not have to move forward or apply any forward pressure until the cutting discs have cut their full paths and have been retracted on their slide back to the centre. The machine is then free to move forward to the next cutting position. The cutting force on the discs is closely controlled by the force in the slides and as such, damage and wear to the discs is much reduced. Maurhofer said that the TBE has performed very well, with a best weeks performance of 63.5m and a best daily total of 15m. He compared this to the drill and blast performance at best of 2.5m-3.5m per shift and with the TBE the invert is completed as well.

There is also a moveable platform on the TBE where operatives can assemble the mesh, rock bolts and shotcrete concurrently with excavation.

Logistics and costs

The contract states that all material movements are to be by train. This is for muck out and concrete in. The client organises all cement deliveries; and the spoil is dumped outside the tunnel, with the client then taking it away to tip in old gravel quarries that require filling. This works very well. The tunnel will generate about 1.7M cubic metres of broken rock and debris. Some of this is used by the client to backfill the central service duct in the invert of the tunnel. The rest goes to tip.

The total cost of the Uetliberg Tunnel will be around US$986M. This is made up of general costs (US$158M), land acquisition (US$4.4M), tunnel construction including roadway (US$625M), finishings and M&E equipment (US97M), and material transport (US$101M).

Questions from the floor

Chairman of the meeting, Bill Grose, then asked for questions from the floor:

Jackie Skipper, engineering geologist for the Natural History Museum, asked how the groundwater flow was controlled in the molasse? Maurhofer replied that there was no water in the molasse, only dust. The molasse are sedimentary schists with sandstone bands but they contain no water.

Neville Harrison, Mott MacDonald, asked why the tunnel was driven with a pilot tunnel when it looked very suitable for a full-face machine? Maurhofer explained that the first tender was for 'drill and blast' throughout and then a pilot tunnel was added for ventilation and safety. The JV had thought about a full face TBM and also the TBE System. Only three weeks before tenders

Below: The Wirth TBE undercutting discs

Below: Excavation in the Diebis soft ground section

The Wirth TBE undercutting system comprises cutter discs mounted on six radial arms, which are inclined backwards from the centre of the tunnel

were due back in, the client issued a statement to say no full face TBM's were to be used. The TBE system then fitted the bill because in theory it wasn't full face and the team won the tender on this system.

Hayden Davies, of Union Railways, asked how safe working areas were provided for men working just behind the TBE cutterhead? Maurhofer replied that the majority of rock falls occur inside the cutterhead and regulations prevent men from entering this dangerous area. Rock bolting and meshing occurs just behind the cutterhead but there is a travelling stage, which protects the men in this location. There is just one occasion in the sequence when a man has to go into the danger area to place the hose connection to pump-up the 'swellex' bolts but this is for no more than about 15 seconds. Unfortunately a bad accident had recently occurred in this situation, but compared to the risks during 'drill and blast' operations the risk here was considered very low.

Nigel Legge, Mott MacDonald, asked what precautions were taken in the soft ground conditions? Maurhofer explained that steel sets were placed at 1.5m centres with wire mesh protection and then sprayed with a 150mm thick shotcrete lining. Steel lances (spiles) were also used, which were grouted. In the face 18m long fibreglass lances were used. This system was employed for all the soft ground and was never varied. It was highly successful in getting through the bad areas, as everyone knew exactly what we needed to do.

David Brook, independent consultant, asked if any face instability was encountered during the drives? Maurhofer said that they had encountered some instabilities. These were due to the presence of ground water, particularly where there was a lot of loam in the moraine. The JV chose to cut the excavation down to 5m^2-6m^2 only. Some big settlements, up to 90mm, were experienced with the open crown excavation, but these were very much reduced when using the smaller sized excavations. Where they could, they pumped or drained the water away but sometimes they had to advance with the water still present.

Shani Wallis, technical journalist, asked what the strength of the rock encountered was and also what was the rate of cutter wear? She also asked if they had gained an idea from the pilot tunnel about the likely cutter wear in the main drive?

Maurhofer replied that the strength of the rock was not identified but as the pilot tunnel was driven by conventional TBM and the finished tunnel diameter by the specialised TBE system, a direct comparison could not be made between the two. There was a problem changing cutters with the 'extender' as falling materials hit the cutters and made access very difficult. In order to change the cutters, steel lances were installed in the face and a steel safety cage, much like a 'tent', was made with steel wire ropes to protect the operatives working on the cutters.

A member then asked about the movement of materials by train? Was this effective?

Maurhofer explained that all materials both into the site and out of the site had to be moved by train. All train movements were organised by the client even though the disposal of spoil area was some 50km to 70km to the north of the site. The client also provided the concrete for the works and used some of the rock spoil as aggregate in the concrete. The contractor was unhappy about this arrangement at first, but it did work very effectively.

Clare Glenton, High Point Rendel, pointed out that there had been some recent instances in tunnels like these of shotcrete not sticking to the rock and asked if there had been a problem on this project? Maurhofer said yes, there had been a problem in the pilot tunnel, but it was found to be down to a fine layer of dust on the surfaces of the rock. There was no such problem in the larger tunnel.

Andy Kendall, Morgan Tunnelling, asked what was the arrangement with mesh and ground anchors in the small diameter pilot tunnel? Maurhofer explained that wire mesh with steel anchors was used at first in the pilot tunnel, but were then removed as this would have been detrimental when excavation of the main bore took place. Glass fibre bolts, without steel mesh, were then used throughout the pilot bore so as not to affect the main drive.

Bill Grose, Arup and chairman of the meeting, asked what the safety record was like on site? Maurhofer said that they had one fatality when a surveyor stepped out of a cross passage into the path of a haulage truck. They had also had a serious accident with the operative that had to place the hose on to the 'Swellex' anchors, as mentioned before.

Anthony Umney, consultant, asked about the final design criteria for the tunnel in service? Maurhofer replied that there are to be two operating lanes and a hard shoulder. Pedestrian access passages are located every 300m, vehicle crossings at every 900m and 'SOS' telephones at every 150m. All the safety features are to at least current standards and in places have been over-designed for 100% safety.

Andrew Smith, Joseph Gallagher, asked how was the labour force organised and if there were many nationalities involved? Maurhofer explained that the labour force was from the JV members. There was a majority of Austrian workers, but on the TBE there were Portuguese, Italians and Austrians.

Tony Deane, Mott MacDonald, asked how the JV was paid and who took the risk on the ground conditions? Maurhofer said there were two big books full of prices, from which any situation could be priced. They reacted quickly on costs; measuring every day and this was signed for and was paid every month. So 90% of the work was signed for and paid up quickly. The owner/client took the risk on the ground conditions.

Bill Grose then asked if there had been any claims? Yes, said Maurhofer, "you claim for good rock and then you claim for bad rock. It's the usual story."

Rapporteur: Jack Knight

T&T

Below right: The TBE's backup system in operation

Parties involved in the project

Client: Engineering department of the Canton of Zurich; Office of Civil and Underground Engineering; and the National and Main Highways Dept.
Project and construction management: Amberg Engineering Ltd
Contractor: The Uetli JV, consisting of Zschokke, Murer, Prader, CSC, Wayss and Freytag, Alpine Mayreder and Zublin.

Progress on the Uetliberg Tunnel can be followed on the project's web site: www.uetlibergtunnel.ch