Uetiberg Motorway Tunnel (Switzerland)

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ABSTRACT: Measuring 4.4 km, the Uetliberg Tunnel is the longest of the four tunnels which will make up the Zurich western bypass. A variety of driving techniques are being employed on the Uetliberg Tunnel, the most interesting of which is the use of the tunnel boring machine with the tunnel bore extender (TBE), with its undercutting technique and a boring diameter of 14.40 m, which will be in action from spring 2003.

1 OVERVIEW OF THE ZURICH WESTERN BYPASS

On 13th September 1996 the first sod was turned at the Birmensdorf bypass to mark the start of the construction work on the Zurich western bypass. The western bypass will ease traffic congestion considerably for the people living both in Greater Zurich and in the city itself who are affected by commuting and by the ever increasing volumes of traffic.

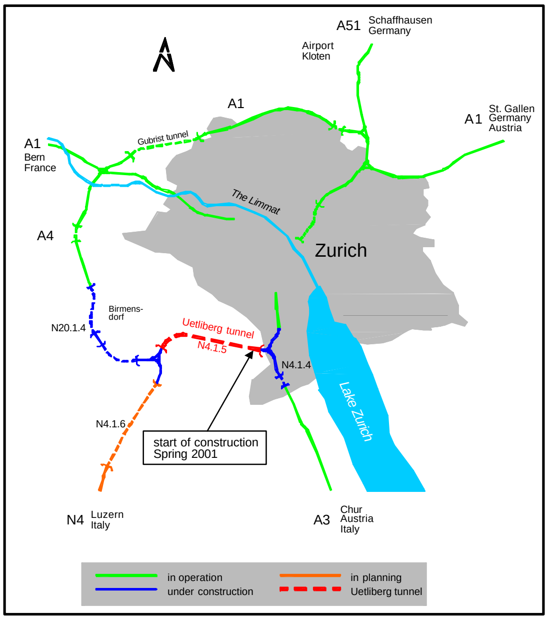

Fig. A: Highways in Greater Zurich

The Zurich western bypass is divided into the following three highway sections for the construction project:

– Birmensdorf bypass (N20.1.4 highway)
– Zurich-South interchange (N4.1.4 highway)
– Uetliberg Tunnel (N 4.1.5 highway)

The 4.4 km long Uetliberg Tunnel is the key structure in the Zurich western bypass and connects the Birmensdorf bypass (N20.1.4) in the west with the existing Zurich-Chur highway (A3 motorway) in the east.

Characteristics of the Zurich western bypass

The western bypass will be 10.6 km long, 8.4 km (or about 80 per cent) of which will be in tunnels.

The Zurich western bypass rises slightly from west to south from about 470 m to 540 m above sea level (Filderen) and then drops again in the Uetliberg Tunnel to 430 m.

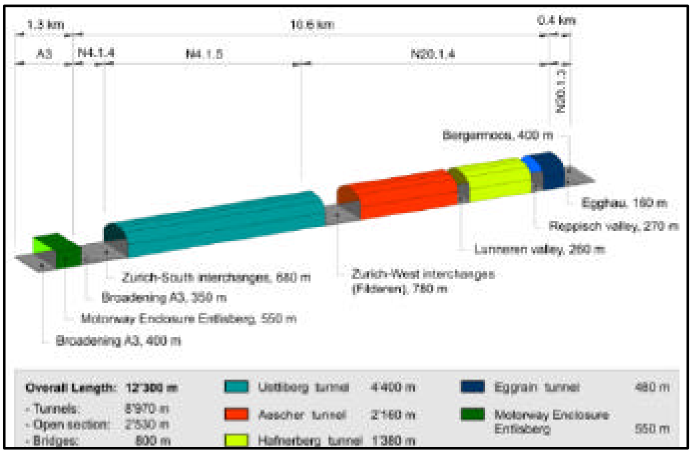

Fig. C: Characteristics of the Zurich western bypass

2 UETLIBERG TUNNEL (N4.1.5)

The project consists of two parallel tubes, each about 4.4 km long. They are connected every 300 m by a cross-cut with pedestrian access and every 900 m by a cross-cut with vehicular access. The SOS niches will be 150 m apart. There will be a station with equipment and installation rooms at both the west and east portals.

Fig. D: Overview of project N4.1.5 Uetliberg Tunnel

There is an underground central ventilation station in the Reppisch Valley (Landikon) which is located over a traffic interchange which is also underground. The tunnel is normally ventilated in both directions by the natural longitudinal ventilation / piston effect. A system of environmental ventilation is installed for the Basle tube which permits the air flowing out of the tunnel to be extracted before the Wannenboden portal. The air is fed back along 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.

2.1 *Logistics / Infrastructure*

Construction of the Uetliberg Tunnel will produce a total of 1.7 million solid m^3 of muck and spoil material. Most of the excavated material that cannot be re-used in the project area will be transported by rail to gravel pits in the northern part of the canton of Zurich which have to be filled under official regulations. Suitable rail loading facilities for the spoil material are located on the west and south sides.

About 70% of the total spoil, representing 1.2 million solid m^3, is generated by the Reppisch Valley cut-and-cover and the tunnelling that starts at that point. For this reason the tunnelling site in Landikon is connected by a conveyor belt to the rail loading facility in the Filderen area. The muck and spoil material is transported to the rail loading facility via this conveyor belt. On the return trip the same conveyor belt carries the aggregate for concrete production in Landikon.

As soon as the tunnel boring machine starts to drive into the molasse section of the Uetliberg, the material will be transported directly from the working face to and with the rail loading facility, via a continuous belt system spanning 1,760 m (it will ultimately be approx. 4,800 m long) to the rail loading facility in the Filderen area.

2.2 *Geology*

From west to east the Uetliberg Tunnel undercuts the two parallel Ettenberg and Uetliberg hills. The Reppisch Valley lies in-between, dividing the tunnel structure into two separate tunnels that have to be dug (the 710 m long Eichholz Tunnel and the 3,450 km long Uetliberg Tunnel).

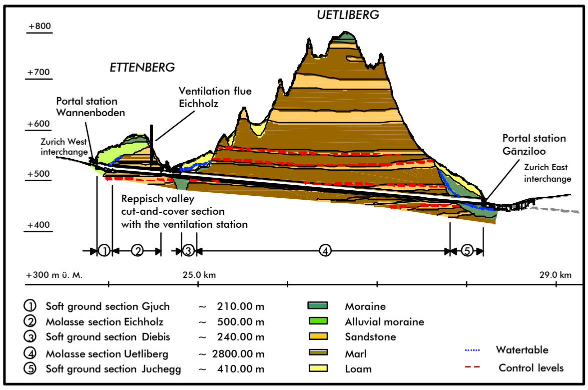

Fig. G: Geological length profile

Eichholz (L= approx. 500 m) and Uetliberg (L= approx. 2,800 m) molasse sections

The molasse sections comprise flat-bedded strata of the upper fresh water molasse, an alternation of hard sandstone seams and soft marl strata. The maximum capping of the tunnels under the Uetliberg is approx. 320 m. The Eichholz and Uetliberg molasse sections are reached by approaching the three soft ground sections of Gjuch, Diebis and Juchegg.

Gjuch soft ground section (L = approx. 210 m)

The Gjuch soft ground section (at the Wannenboden west portal) cuts through a very heterogeneous end moraine called the Wettswil moraine complex. The water table rises from the centre of the tunnel profile at the start to above the tunnel roof in an easterly direction.

Diebis soft ground section (L = approx. 240 m)

The Diebis soft ground section (east of the Reppisch Valley cut-and-cover section) consists of a base moraine overlaid with slope wash. 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 50 metres of tunnel, the whole cross-section is in the moraine. In the Diebis soft ground the whole tunnel cross-section is in ground water.

Juchegg soft ground section (L= approx. 410 m)

The Juchegg soft ground section (at the Gänziloo east portal) consists of a base moraine composed initially of sandy-gravels and then of clay-like sands. Above it lies the Uetliberg loam, which goes up to the centre of the tunnel cross-section at the portal. After about 70 metres of tunnel 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

2.3 *Construction phases / Programmes*

The tunnel will be driven downwards from the Reppisch Valley excavation site, which will be completed in stages by 2003, under the Uetliberg through to the Zurich-South interchange in the Brunau area.

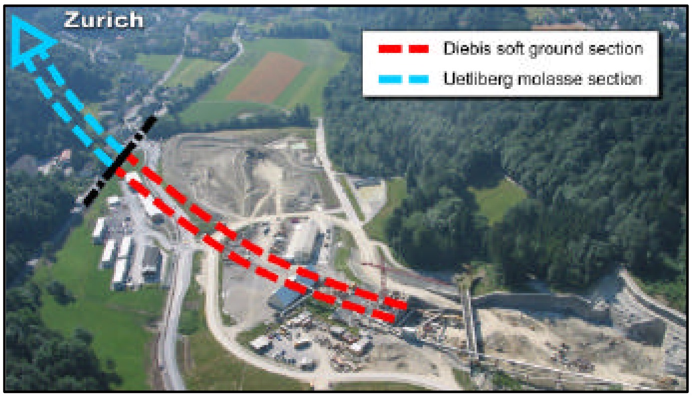

Fig. H: Landikon installation site / Reppisch Valley excavation site

From April 2001 to May 2002 the two tunnel tubes in the Diebis soft ground section (LG-DIE) were excavated from the Reppisch Valley excavation site in Landikon applying a core construction method and the starting caverns for the later tunnel bore extender were blasted. The tunnel boring machine (TBM) (Wirth TB III 500 E, 5.00 m diameter) was installed in the Basle tunnel tube at the start of April 2002; it has been used to bore open the entire molasse section of the Uetliberg (MO-UET) since mid-May 2002. From spring 2003, the 5 m wide pilot tunnel in the molasse section will be widened to a final cross-section of 14.20 to 14.40 m using a tunnel bore extender (TBE). Boring out a pilot tunnel, following by extending it with a TBE, will then be repeated in the Chur tube.

The upward driving of the Juchegg soft ground section (LG-JUC) from the Gänziloo excavation site has been under way since February 2002. The initial metres (approx. 50 m) of the tunnel drive are also being done in the Uetliberg loam in a core construction method protected by a pipe screen system.

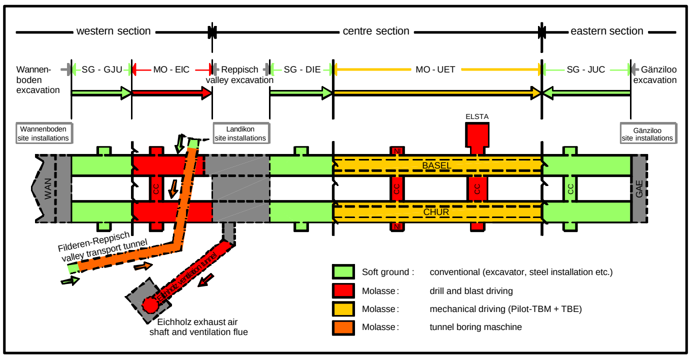

Fig. I: Driving directions and technology

At the start of April 2002 work also got under way on the downward driving from the Wannenboden excavation site under the Ettenberg in the direction of the excavation site in the Reppisch Valley. First of all, the tunnel has to be driven through the Gjuch soft ground section (LG-GJU) followed by the Eichholz molasse section (MO-EIC).

Fig. J: Portal view of the Gänziloo excavation site / driving the Juchegg soft ground section

2.4 *Project elements and driving procedures*

Normal cross-sections

The normal cross-section is divided into 3 parts:

– the core carriageway space
– the exhaust air duct (separated from the carriageway space by an intermediate ceiling)
– area under the carriageway with the service duct

The horseshoe cross-section, which is used in all the soft ground sections and in the Eichholz molasse section, is about 14.70 m wide and about 12.70 m high. The excavated area is approx. 143 to 148 m².

The normal cross-section of the Uetliberg molasse section, which is about 2,800 m long, is 14.40 m wide and 14.20 m high. The excavated area is approx. 160 m².

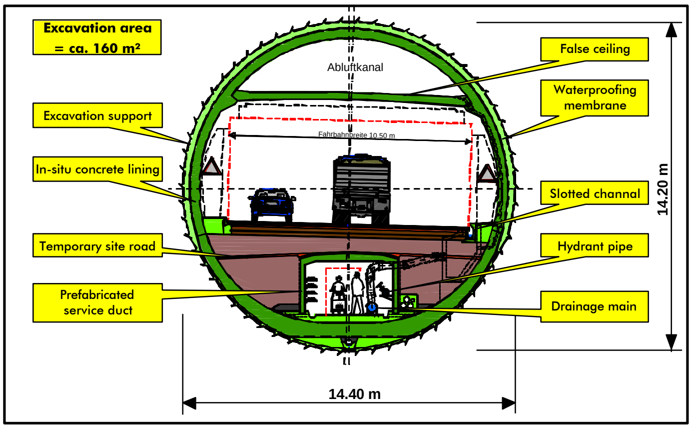

Fig. M: Normal cross-section of the Uetliberg molasse section

Each tunnel tube has two lanes and a hard shoulder with a total carriageway width of 10.5 m. The camber is 2.5% on the straight and up to 5% on the bends..

The tunnels are lined with a full sealing double skin. 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, which is almost dry.

Driving in the Gjuch, Diebis und Juchegg soft ground sections

All the soft ground sections are being driven in a core construction method. The excavation support in the soft ground sections consists of steel arches (HEB-180 girders spaced 1 m apart) and 25 cm thick steel fibre-reinforced shotcrete.

Driving in the Eichholz molasse section

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

Driving in the Uetliberg molasse section

The tunnel is being excavated using a tunnel boring machine (5.0 m diameter) followed by a tunnel bore extender which uses an undercutting technique. The tunnel bore extender will be used to widen the previously cut pilot tunnel to its full cross-section of ∅ 14.20 to 14.40 m. The safety equipment, comprising cable bolts, Swellex bolts, mesh and shotcrete (possibility exists to install steel) will be installed directly behind the boring head. The sealing, the base, the service duct (prefabricated elements) and ball fill on the sides will be created under the trailer. The lining and the intermediate ceiling will be installed in stages in the rear.

2.5 *Experience up to now with driving soft ground section*

As we have already mentioned, the soft ground sections are being driven in a core construction method

It was divided into seven sub cross-sections as follows:

①	Upper side-wall galleries	2 x 17.35 m^2
②	Lower side-wall galleries	2 x 22.55 m^2
③	Crown	24.30 m^2
④	Core	26.66 m^2
⑤	Base	16.84 m^2
	Total	147.60 m^2

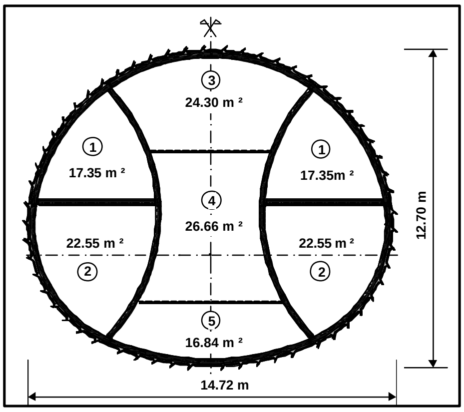

Fig. P: Sub cross-sections of the core construction method

Driving the side-wall gallery

The upper side-wall galleries are excavated in metre steps by midget excavators and sealed immediately after excavation with a layer of shotcrete, 5 cm or so thick. The steel girders (HEB 180) are installed at metre intervals to protect the seal. After a further excavation, the installation girders were sprayed for steel fibre wet shotcrete. Additional securing measures such as pointed metal bars, mesh and drainage pipes have to be installed in the roof area on account of the occurrence of water and to improve safety conditions.

Driving the crown

In order to drive the crown with a span width of approx. 8 m, a 20 m long pipe screen system was created during the starting phases in the Diebis and Gjuch soft ground sections, comprising 29 pipes with a diameter of 152.4 mm. The first 50 m of the tunnel in the Juchegg soft ground section are created with the protection of a pipe screen system. The following additional construction resources were defined to follow on from the pipe screen system:

- securing the roof area with lances, 30 mm diameter, 4 m in length
- anchoring the drilling face with nine 15 m long steel self-drilling bolts and an overlap of 3 m
- in addition, drainage pipes at the drilling face where there is a build-up of water.

The procedure for installing the securing elements will be done along the same lines as driving the side-wall gallery. The additional measures are decisive for safety and for reducing deformation while the roof is being excavated.

Working the core

In order to reduce deformation across the entire cross-section, the base ring must end 40 m from the crown face. An additional condition is that the inner side-wall gallery walls may only be excavated 6 m behind the crown face.

Base excavation level, ring seal

As soon as the crown is excavated to a depth of 12 m, the work switches to the base excavation. This is done in 12 metre steps from the tunnel face in the direction of the portal.

Fig. R: Core construction method, base excavation with ring seal

Where there is a build-up of mountain water, measures have to be taken to ensure that the water is removed from the base area before the sealing layer is applied. In order to facilitate this, additional drainage measures are installed, such as leafs with ledges, seepage ditches and pump shafts.

2.5.1 *The structural monitoring during driving in the Diebis soft ground section*

The metrological monitoring of the tunnel driving is carried out using a variety of measuring equipment, such as piezometers, 3-D convergence measurements, extensometers, distometers, cross-section surveys and steel extension sensors (strain gauges)

The deformation values calculated beforehand by the project coordinator were about 5 to 10 cm. The comparison with the effective deformation measurements and the total deformation confirmed the values calculated

2.6 *Tunnel bore extender (TBE) with undercutting technology*

A tunnel bore extender (TBE) with undercutting technology will be deployed in the Uetliberg molasse section in spring 2003. The boring head is currently being prepared for use by Wirth AG, and the Uetli Joint Venture is making arrangements for the trailer. The individual elements of this process have already been used with great success on many occasions in practice (extenders at a driving length of over 14 km) or have been tried out in extensive trials in Germany and Canada (undercutting technology), although they have never been used together.

2.6.1 *Extension technique*

The extension 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 tunnel lining (concrete laid over profile sections) because of the less destructive nature of the excavation and the circular, statically favourable cross-section.

The tunnel bore extender (TBE) being used in the Uetliberg Tunnel is essentially based on the driving installation which has already been used successfully in the Tunnel de Paracuellos (Spain) and in the Tunnel de Sauges (Switzerland). As the TBE variant tendered by the contractor is mounted on the existing, tried and tested driving installation, the installation costs for the provision of a tunnel boring machine of this magnitude could be kept relatively low.

2.6.2 *Undercutting technology*

Liaising closely, the Uetli Joint Venture and the manufacturer of the tunnel bore extender have evaluated the technical capabilities for deploying the extender with a new cutting technique, undercutting.

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

2.6.3 *How undercutting with a TBE works*

As before, the boring head of the TBE 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 tunnel cross-section. The cutting rollers are offset both axially and radially to the axis of the tunnel and arranged on axial moving slides on the boring arms. As the boring hear rotates and the slides move in a radial action at the same time, each roller follows a spiral path around the axis of the tunnel.

As the outer roller advances, this creates a stepped face, so that each of the cutting rollers can shear off the rock into a free space (undercutting principle). When boring starts on a so-called "shot" (axial excavation section per radial stroke of the slide), the inner cutting rollers start in the pilot bore, for example, and the outer rollers start at the last level bored by the inner rollers.

The length of the shot is limited to a maximum of the axial displacement of the cutting rollers on a slide (SA = 200 mm). Smaller shots may be selected depending on the strength of the rock.

As the six-armed boring head rotates, with its six cutting rollers on each arm, 36 cutting rollers are moved on six spiral paths, 60° apart, from an inner boring diameter to an outer boring diameter (p x z_A).

Once the nominal boring diameter (14.00 m) has been reached, the slides are retracted again radially to the smallest diameter (4.50 m). The boring head is then moved axially by a shot (e.g. SA max. 200 mm), and the next step starts.

As the shear forces of the blades are applied in a radial direction, compared to conventional cutting techniques the force components of the thrust action are neutralised by the diametrically opposite arrangement of the boring arms. Due to the small number of cutting rollers (six per boring arm) with a contact pressure of approx. 100-120 kN/cutter, this also reduces the requisite torque at the boring head considerably for releasing the rock. The loss of the large contact pressure forces (thrust) and the resulting high torque loads of the tunnel permit the enlargement of the boring head in an existing TBM.

The TBE 500/1440 H/HAST can be used to extend sections and tunnels, with a pilot bore of 4.70-5.00 m in diameter in stable, drillable rock, to a diameter of 14.00/14.40 m.

The boring head described below is designed to be extended in diameter from 4.70 m to 14.40 m using the undercutting technique.

2.6.4 *Boring head*

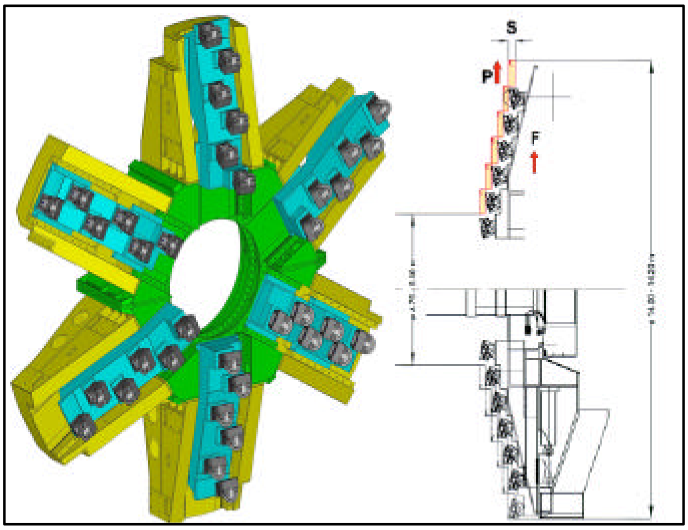

Fig. S: Boring head base and longitudinal section of boring head and power flow

An extender boring head, designed for a boring diameter of 14.00/14.40 m with a pilot diameter of 4.70 m, consists of the boring head base, which is made up of two parts for transporting reasons and six screwed-on extension arms. Each of the extension arms is fitted with a radial-action slide, each with six cutting rollers. The cutting roller holders for single-ring discs are offset in step formation, facilitating a maximum, axial shot length in undercutting at depths of 200 mm.

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

The slides are guided along slide faces whereby a drilling diameter between 14.00 m and 14.40 m can be set steplessly.

2.6.5 *Advantages of combining the TBE with the undercutting technique*

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.

2.6.6 *Disadvantages compared to a conventional shield-type 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.

2.6.7 *Description of the tunnel bore extender*

The base machine for the TBE 450/1440 tunnel bore extender comprises the following modules:

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

2.6.8 *Technical data for the TBE 450/1440*

Boring head	
Diameter, nom.	DN = 14.00/14.40 m
Boring head drive	10 x 250 = 2,500 kW
Torque, nom.	4,800 kNm
Rotating speed of the boring head	0 – 3.7 rpm
Torque, max. at n = 2.8 rpm.	6,430 kNm
Cutting face	36 x ED/H LKG – 3
Thrust	
Contact pressure of the boring head	15,000 kN
Boring stroke	1,500 mm
Driving speed	0 – 4 m/h
Thrust cylinders	4 x
Cylinder diameter	400/300 mm
Hydraulic pressure	300 bar
Conveyor belt	
Belt width	1,200 mm
Electric equipment	
Installed electric power	2,800 kW
Transformer	4,000 kVA
Input voltage	10,000 V / 50 Hz
Engine voltage	660 V / 50Hz
Weight of the TBE and trailer	
	approx. 1,000 T

2.6.9 *Assembly and dismantling*

The pilot TBM and the TBE are 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 TBE will be dismantled in the dismantling chamber and be transported back through the tunnel. They will then be reassembled in the second specially prepared starting cavern for the purposes of driving the Chur tunnel.

2.7 *Up-to-date progress report*

Diebis soft ground section

The excavation work is complete on the Diebis soft ground section.. Work will be under way on the inner lining (full sealing, base concrete, service duct and back filling at the sides) in August 2002.

Uetliberg molasse section

The pilot tunnel to be subsequently expanded with the TBE has already been driven to a depth of 670 m. Driving is currently progressing at a daily rate of approx. 25 m. It is estimated that we will hole-through to the ventilation tunnel, coming in the opposite direction, at the end of 2002.

Fig. V: Driving the pilot tunnel

Juchegg soft ground section (driving from the Zurich side)

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 50 m in the Basle tube. The driving of the ventilation tunnel (upper right side-wall gallery) is currently at a depth of approx. 230 m. The driving in the upper left side-wall gallery is at a depth of 180 m. The ventilation tunnel is currently running in the opposite direction to the driving of the TBM. In the Chur tube, 50 m of the tunnel has already been excavated to its full cross-section.

Gjuch soft ground section (driving from the Wettswil side)

Work got under way driving both tubes of the Gjuch soft ground section in April 2002. 80 m progress has been made in the Basle tube and 20 m in the Chur tube, both at full cross-section.

Eichholz exhaust air shaft

The sinking of the exhaust air shaft in the soft ground (22.80 m) is complete. The blasting excavation will start in the shaft (37.80 m) in August 2002.

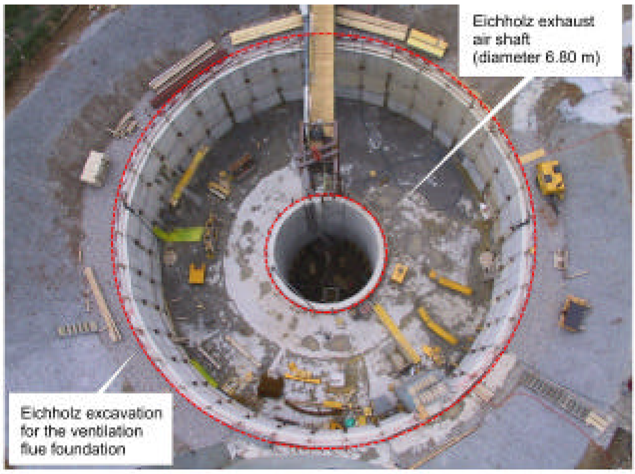

Fig. W: Driving work on the exhaust air shaft

For further information, click on:
www.westumfahrung.ch (client)
www.uetlibergtunnel.ch (project coordinator)
www.arge-uetli.ch (subcontractors)

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