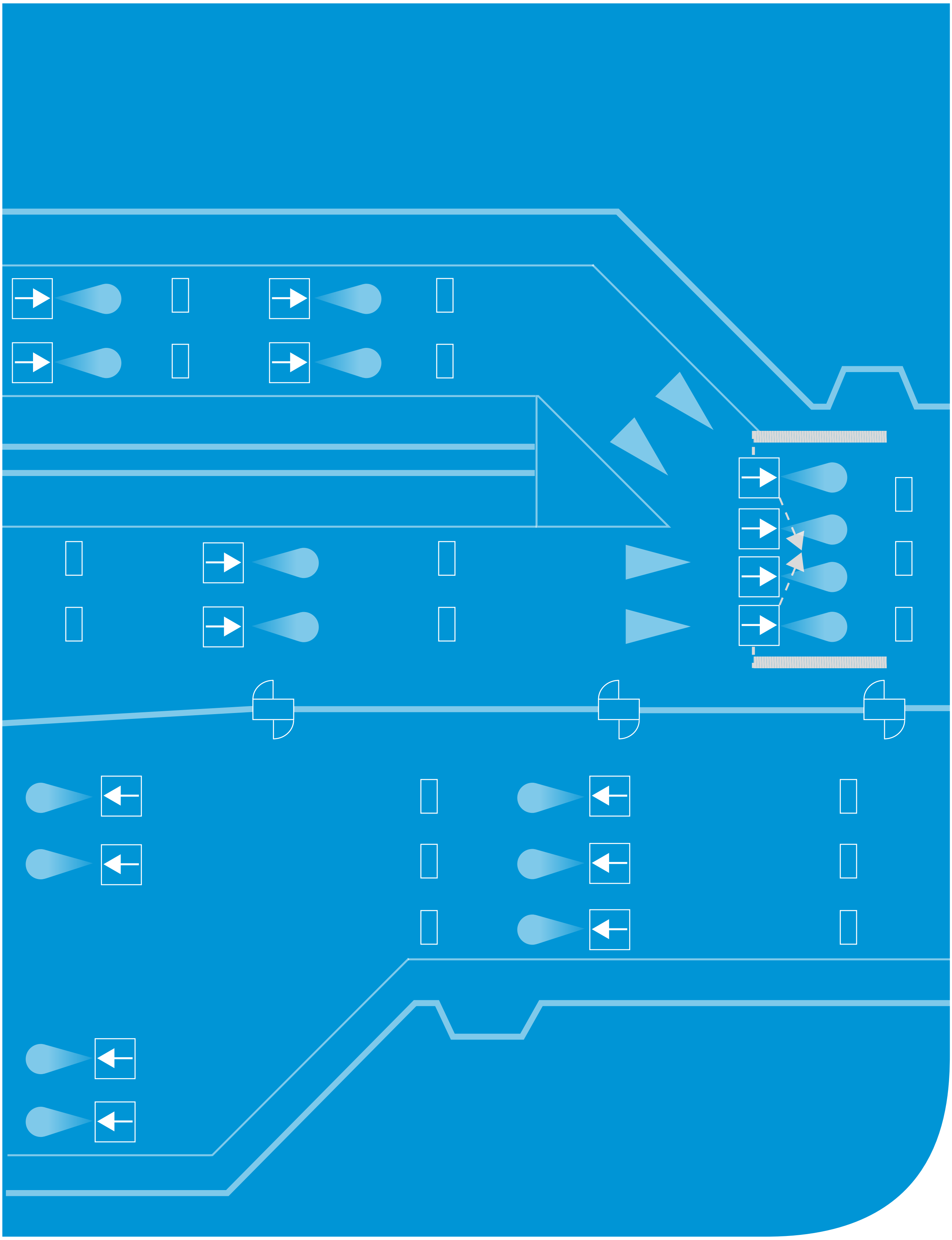
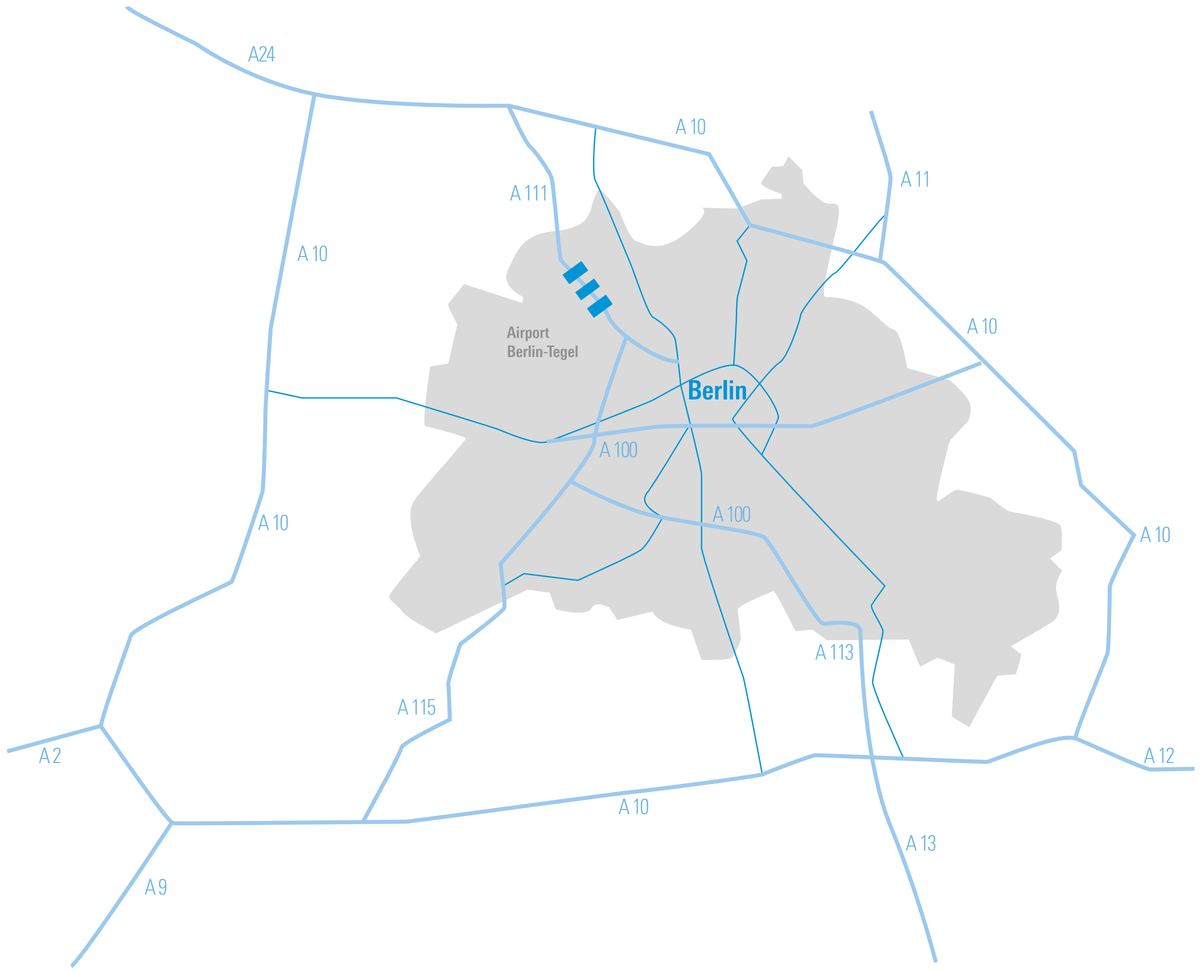
Tunnel at Tegel Airport Berlin (motorway A111)

general renovation and technical and safety retrofit

SSF Ingenieure





Site plan tunnel Tegel Airport

Introduction

Reacting to some devastating tunnel fires in several European States, the safety requirements in road tunnels were put under the microscope on national and European level. The EU integrated these examinations into Directive 2004/54/EC of the European Parliament and of the Council of 29 April 2004 on minimum safety requirements for tunnels in the Trans-European Road Network. As a result, in Germany the "Directive for equipment and operation of road tunnels" (RABT 2006) was updated and completed and a comprehensive retrofit programme for tunnel installations on federal highways as well as a list of prioritized projects to eliminate considerable safety breaches was published.

Priority was hence given to renovation and technical retrofit of the tunnel at Tegel Airport Berlin as important part of motorway A111 in Berlin which was in a very bad constructional state and whose safety technical equipment was completely out-of-date.

The existing tunnel

Motorway A111 with the Tunnel at Tegel Airport is part of the most important northern connection to the Berlin Ring Road A10 and thus Berlin's most frequented link in direction North with over 90,000 vehicles/24h (13% HGV traffic). The tunnel commissioned in 1979 undercrosses the runway of Tegel Airport Berlin.

Grafik: ediundsepp

The length of the tunnel shaft east (direction south) amounts to 967 m, tunnel shaft west (direction south) is in total 878 m long. In connection with the adjoining motorway interchange A111 at Reinickendorf, three tunnel sections and two transition areas of in total 560 m length branch off into other structures. The entry and exit areas constructed as deep troughs are linked on the southern side and are in total 620 m long.

The tunnel with two separate shafts was built in cut-and-cover method with sloped construction pits accompanied by groundwater lowering. The structure was formed as double-cell closed frame made of reinforced concrete. The whole tunnel lies approx. 3 to 4 m in the groundwater.
The outer walls are 0.80 m thick, the middle wall was designed with a thickness of 0.60 m. The foundation slab with depressions in order to hold pipes for line drainage has a regular thickness of 1.20 m. The roof slab is on average 1.00 m thick. The clearance within both tunnel shafts is at the regular cross-sections approx. 10.50 m, the headroom amounts to a maximum of 5.5 m and a minimum of 4.81 m.

The main tunnel consists of 36 mildly reinforced blocs which are 30 m long and 23 m wide. Only the roof slab in the widened area of the northern tunnel branch-off with filtering lanes up to 38 m long because of their spans. The construction costs amounted at the time to around 40 m. €.

The existing tunnel and the connected troughs were designed as bitumen coated slab. The outer sealing against groundwater was assured by 3 layers of bituminous sheets all around the tunnel. Underneath the assessed water level, additional layers of bitumen sheets were assembled in the area of the floor and wall slabs; so that these areas are sealed with 4 layers in total. In the joint area, a 30 cm wide reinforcement made of 0.2 mm thick Epoxal ribbed bands (aluminium) was assembled with 2 layers in the floor area and 1 layer in the other areas. As mechanic protection a supplementary concrete layer was applied to the ceiling and the floor. The walls were covered with face walling on the outside.
The joints between the 30 m long tunnel blocs were implemented as contraction joints. A bitumen layer was applied to the joint surface against which the following bloc was concreted; this procedure led to joint widths of only 2 to 3 mm. Only in the area of the floor and ceiling the effective joint width was enlarged towards the sealing layer, thus optimizing deformation of the sealing ensemble.

Constructional damage

During utilization for more than 25 years, severe damages in the area of the bloc joints occurred. Especially in the winter, partial close-offs of some lanes were necessary as groundwater infiltrated by the damaged bloc joints which then froze. Moreover, at the joint edges heavy chippings appeared because of the contraction joints.

Due to piston effect caused by traffic, temperature variances between +25° to – 20° C occured in the tunnel throughout the year resulting in movements of the bloc joints. In the context of cause studies in 1990 and 1991, measures of the joint movements were taken. The results showed maximum joint openings of the 30 m bloc joints reaching up to 20 mm. The bitumen sealing layers on the outside were unable to compensate durably such movements in the area of the contraction joints and failed on numerous joints. The walls in the tunnel were covered with ceramic tiles in thick mortar. During use of the tunnel, large areas came off the walls because of infiltrating water and other causes, or hollow spaces formed behind them. The protecting cover required for fire safety was not present in this area.

The ceiling cover as mineral fibre gunned plaster could not be considered under aspect of fire protection at the state-of-the-art because of its material composition and thickness.

Constructional renovation

For general renovation and security retrofit, both tunnel shafts were shut down completely at the same time. The decisive reason for that was next to the qualitatively high implementation, the efficient and interface-reduced execution of the works in order to completely remove the whole tunnel core and renew the traffic, operation and especially safety relevant technology installations. An implementation in several work steps whilst maintaining traffic partially would have caused too many problems during execution. Comprehensive studies, with regard to different construction stages and different renovation and traffic diversion scenarios, were carried out in order to find the best solution.

Close-off of both tunnel shafts could finally be limited to 18 month.

A steady traffic flow was achieved by elaboration of an efficient detour route. For that the existing control circuits of the traffic lights had to be re-programmed in a large area.

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1 Cavity behind ceramic wall lining
2 Dismantling to the old tunnel's bare concrete
3 Leakages in the block joints

To maintain public transport, a bus lane was installed on a traffic light-free deviation route. An approx. 85 m long makeshift bridge was built to enable fast crossing over the main traffic route.

The first construction phase consisted of completely removing the core of both tunnel shafts. All operation and traffic installations were taken out before removing the core. Then, the lanes were demolished completely including all sealing layers and emergency paths. Removal of the core finished with the complete demolition of the existing ceiling cover and gunned plaster spread in very uneven layers. During conversion, contaminated material (e.g. tile mortar, asbestos tubes underneath the deck) had to be disposed of; to do so, a special work container unit had to be installed on site.

Renovation of bloc joints

Infiltrating groundwater in the bloc joint areas was one of the most essential constructional damages which led again and again to restrictions of the tunnel's operation. Renovation of the damaged areas from the outside was not feasible as this would have entailed partial shutdown of Tegel Airport as well as extensive groundwater lowering. Both measures had to be excluded on account of economical reasons and permissions.

The evaluation of damages showed that water was infiltrating in the bloc joint areas. Water carrying cracks in the base slab or the outer walls seemed not to be evident. The existing surface sealing in connection with reinforced concrete constructions seemed not disturbed in its function, the core concrete of bottom and wall in good state; both were confirmed during renovation works. Renovation of the sealing layer on large surfaces (e.g. additional internal sealing with an inner shell) could thus be excluded during considerations for structural improvement of the tunnel shafts. A connection between the new joint sealing to be placed on the outside and the base slab (air side) to the outside bituminous sealing (underside) was not followed and was not achievable from a technical point of view. The main design focus was set on a durable concept of the new overhead joint formation of the bloc joints and the careful design of all constructional details. For the base area an expansion joint with a special transition to the elevated wall areas had been developed which comprised a 35 cm thick elastomeric joint tape at the inside which was integrated – nearly at the same level – through newly built upturned concrete edges along the joints in the base concrete. Parts of the base concrete on both sides of the joint had to be removed for construction of the upturned edges and a sufficient embedding of the joint tape

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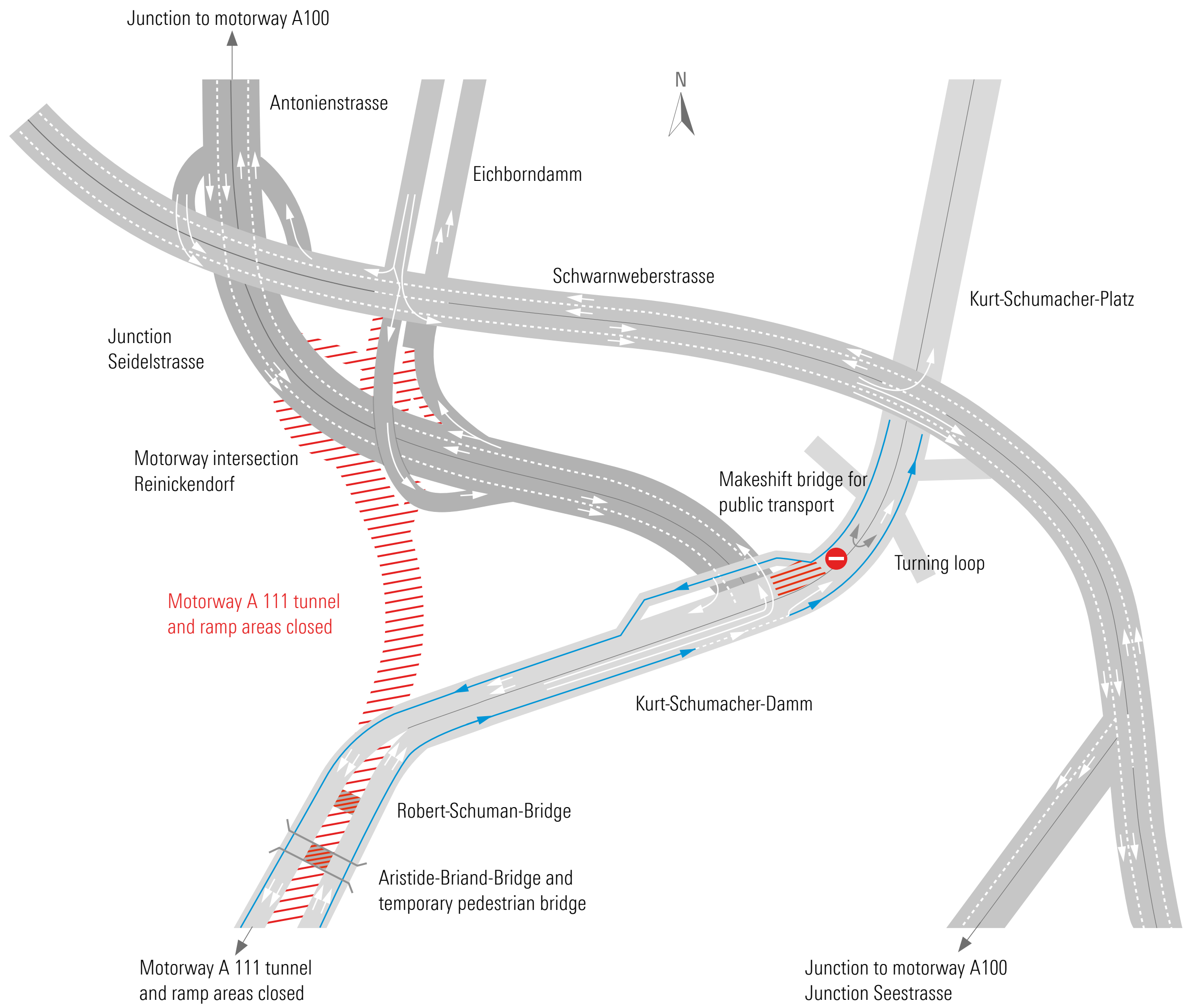
Grafik: ediundsepp

Detour routes – schematic representation



by high-pressure water jet. Re-profiling of the demolished areas and the construction of the upturned edges were implemented with self-compacting concrete of quality C30/37. For construction of the external geometry of the upturned edges, a cover structure with funnel-shaped concrete case at the highest points of the transverse slope was planned analogous to the joint to be constructed.

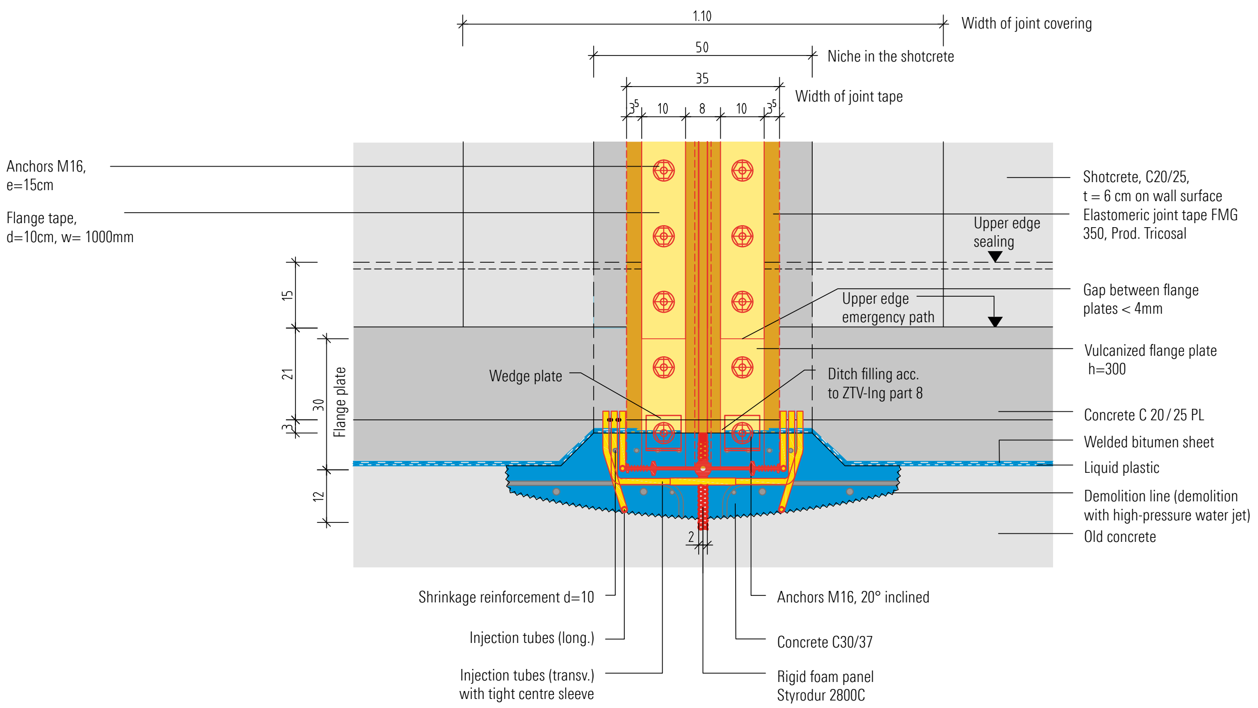
To better evaluate the planned joint construction and constructional feasibility, already in the draft phase a 1:1 model was built which showed the transition floor to wall. Moreover, the services to be delivered included the construction of two model joints to be built under 'in-situ' conditions. By constructing the model joint, the determined work stages and the suitability of the self-compacting concrete were tested in practice. At the cutting surfaces, the cavity-free assemblage of the concrete and durable integration of the joint tape was put under examination.

In order to execute the construction of the new bloc joints' sealing, detailed execution instructions and comprehensive indications for quality control were issued.

Joint renovation wall/ceiling

The new bloc joint sealing in the area of the walls and the ceiling was built by clamp construction. Each clamp was made to measure. The elastomeric joint tape and the actual clamp construction were adapted exactly to the conditions of the existing joint and the specific form of the object. In principle, the clamps have to form a completely closed and gap-free system together with the new floor joints in order to seal properly. Anchor diameter, distance between anchors, dimensions of clamp flanges, particular flanges and connecting pieces as well as tightening torque had to be adapted to the construction and exerted stresses. Moreover, special requirements were presented to the ground (minimum compressive and surface tensile strength, void-free, even, proper and free of burrs). It was also important that an even contact pressure was achieved to obtain the wanted durable sealing effect. The necessary contact pressure for the 35-cm-wide elastomeric joint tape was achieved by 100-mm-wide and 10-mm- thick stainless steel sheets (material n° 1.4529) and anchors M16 installed at a distance of 15 cm. A very careful pre-treatment of the joint flanks and edges was prerequisite for applying the full contact pressure. The arrangement of natural rubber strips underneath the joint tapes served to compensate last unevenness in the area of the joint flanks. The contact pressure to be achieved was at 2.0 MN/m² per dowel. To assure the required fire resistance category F90, sealing joints on the wall and the tunnel ceiling were equipped with specially developed covering systems.

Block joint detail corner joint wall/ceiling
Prefabricated channel and joint cover not shown



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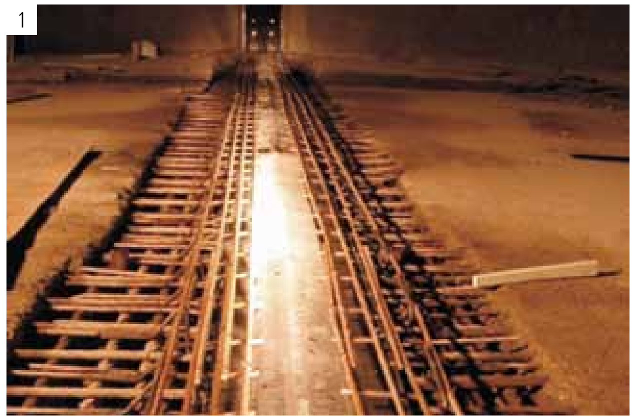
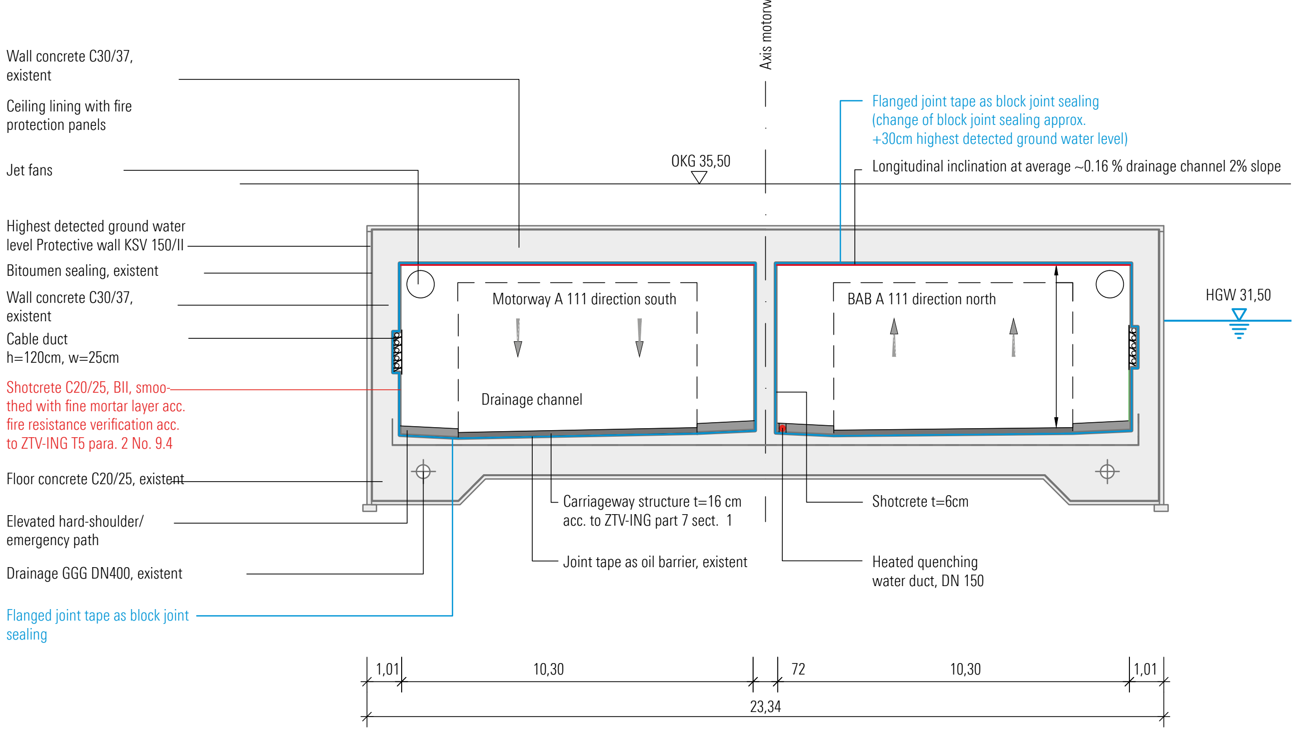


1+2 Posing and fixing of joint tape prepared in-situ and completion of reinforcement
3 Adjusting and flanging of special construction at the transition floor – wall

Regular cross-section of tunnel



1 **New carriageway** structure incl. sealing
2 **General renovation** in the trough area
3 **Constructional fire protection** at wall areas by a 6-cm-thick shotcrete layer with galvanized reinforcement mat

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picture credit: SSF Ingenieure GmbH

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Renovation of wall surface

After preparation of the undercoat by high-pressure water jet and concrete renovation works of the external and middle wall areas, a double layer of shotcrete was applied to damaged areas in accordance with ZTV-ING (German additional technical conditions of contract for engineering structures) at a minimum thickness of 6 cm. Onto the shotcrete layer with grains 0/8 mm and a compressive strength of C30/37, gunite mortar was applied in order to have an even surface of 5 mm on 4 m slats. To have the necessary fire resistance category, the layer was reinforced by a galvanized mat Q131.

The niche surface of the external wall for cable routes was formed by shotcrete. To obey minimum required dimensions, a 3 cm shotcrete layer with grains 0/4 was applied. The fire protection reinforcement was assured by galvanized mats N141. After laying the cables, the cable ducts were covered with removable fire protection plates of resistance category E90. In total, about 33,500 m² shotcrete were used in 42 days during works taking place round-the-clock.

To complete wall renovation, a controlled surface protection system, suitable for use of de-icing salt in the area of the spray mist installations, in colour RAL 9010 (pure white) was applied to improve light reflections in the tunnel and to simplify at the same time cleaning of the walls. Only in the area of the emergency exits, for better distinction, the colour RAL 6029 (green) was used. To minimize luminance in the tunnel entry and exit areas, wall colours were shaded: dark in the trough area, grey in the exit area and green in the approach section.

Deck surface

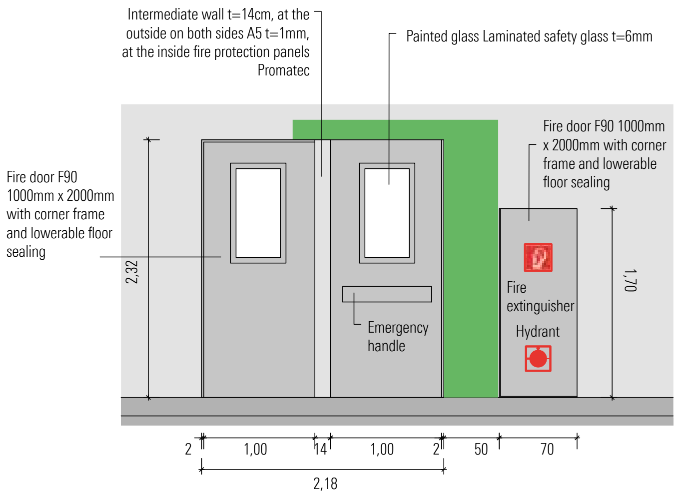
The base slab of the tunnel shafts was carefully cleaned by shot peening. Then damages and cracks were assessed and renovated according to indications of the construction management by crack grouting and concrete replacement. Further works were accomplished according to ZTV-ING with an epoxy resin foundation and a welded bitumen sheet which was strengthened along the future emergency paths with stainless steel laminated welded bitumen sheets and glass fleece bitumen sheets. At the transition base slab to wall a polyurethane liquid plastic sealing was used including a supplementary connecting layer at the 20-cm-wide transition between liquid plastic sealing and welded sheet. To protect the sealing, a 4-cm-thick mastic asphalt coating was applied; on top of it an asphalt binder with variable height (4 – 8 cm) was set as intermediate layer as well as 2 layers of stone mastic asphalt. The covering layer was used with clarification. Along the outer tunnel walls, new at least 1-m-wide emergency paths made of concrete C25/30 LP were built. Arrangement of the reinforcement in view of retrofitting visual guidance devices was essential. Along the centre wall, covered prefabricated concrete elements were cast in order to hold heat-insulated quenching water ducts with tracing heating.

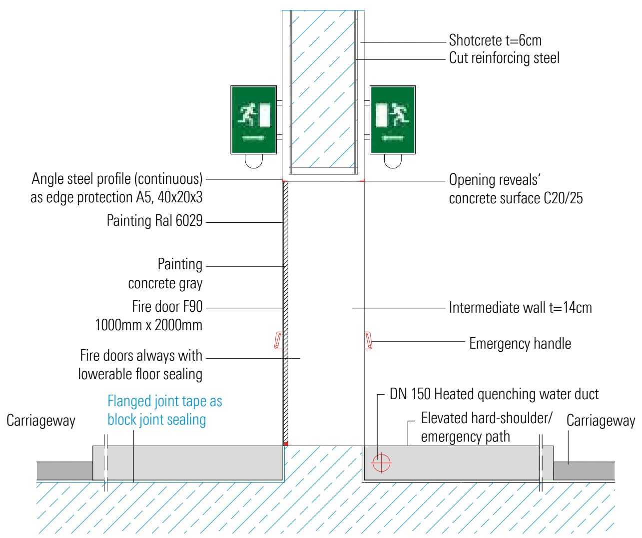
Renovation of ceiling surface

Fire protection in the ceiling area was achieved by fire protecting plates of 25 mm thickness. They were mounted directly onto the ceiling which still contained some remains of the shotcrete. Evenness was achieved by use of strips placed in-between with a thickness of 10 mm. The regular dimensions of the fire protecting

Overview of quantities (estimated)	
Tunnel floor space	21.200 m²
Surface of connected structures (troughs, transition areas, single-cell tunnel sections	16.100 m²
Ceiling surface (fire protective panels)	24.000 m²
Wwall surface (matt reinforced shotcrete)	25.000 m²
Bloc joints (30 m blocs) in the tunnel area	900 per meter
Bloc joint (10 m blocs) in the trough area	750 per meter
Wall surface of entry and exit ramps (matt reinforced shotcrete)	8.500 m²
Deck surface of the tunnel and connected trough sections	38.000 m²
Emergency paths	4.000 m

left: View after renovation
right: Middle wall openings after renovation





plates are 625x3000 mm, fixed with nail anchors of material quality 1.4529. In the areas where later on operation and traffic technical installations were necessary, special adaptation measures had to be taken. Sealing of remaining border joints as well as joints of fastening and assembly material was done by fire protection putty.

Further renovations:

- Renovation of ramp areas (North and South troughs)
- Repairing of corrosion protection of the steel sheet pile walls in the southern trough section according to ZTV-ING.
- New construction of concrete protection walls
- Expansion of openings in the areas of emergency exits and fitting of new doors
- Installation of emergency telephones including collision protection
- Partial renewal of existing road drainage and adaptation of the new road gradient
- Adaptation and expansion of already existing emergency paths according to RABT 2006 (German guideline for road tunnel construction and operation

Picture credits: SSF Ingenieure GmbH

Technical equipment

The renovation prioritized by the German Ministry of Transport was an expression of the unacceptable state of the existing technical equipment. The operation, traffic and especially security technical equipment of both tunnel shafts as well as the trough and the transition areas did not correspond neither to the requirements of the updated European regulations nor to the revised RABT 2006. This was the case of the complete ventilation and lighting installations, measurement technique, video surveillance, BOS radio system (for authorities and organizations responsible for safety) and fire alarm system as well as escape route marking, traffic management systems and tunnel portal barriers.

Non-existent or non-functional were the fire emergency lighting, the PA-installation, the fire-fighting line, fire-fighter control panel and emergency telephone cabins. Doors of the emergency exits in the middle wall did not correspond to the actual state-of-the-art of cross-section dimensioning nor to the fire protection and smoke control regulations. The preparatory planning and the following works were marked by comprehensive renewal and retrofitting of the operation technique.

Security technical equipment

In the tunnel, during renovation and conversion works, 5 closed emergency telephone cabins were built in the area of the emergency lay-bys and 28 emergency telephones were renewed which were for the most part placed next to the converted emergency doors. For automatic fire calls, linear fire detection cables were mounted on the ceilings of both tunnel shafts. These cables detect the fire with an accuracy of 3 meters within 60 second after fire break-out. Each fire call is processed in the automatic control of the ventilation, the lighting and traffic management. Manual fire call installations were mounted to the emergency call stations and telephone cabins as well as the operation rooms. At the entries and exits of the tunnel, control boxes were installed in order to enable fire-fighters to intervene in the tunnel ventilation and to have direct contact with the tunnel control centre. A tunnel radio allows police, fire-fighters, rescue services and the control centre in Berlin direct communication by voiceover messages (separately in each shafts) on 21 radio stations to immediately inform tunnel users. To obtain a distortion-free reception of cellular radio, signal amplifiers are utilized. Direct communication with the tunnel users in case of emergency is transmitted over a new loud speaker system.

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1 Old operation and traffic technical installations, emergency doors
2 Widening of emergency doors
3 New emergency doors in the middle wall between tunnel shafts

Picture credits: Senatsverwaltung für Stadtentwicklung Berlin

1 Initial situation trough and tunnel portals, area south
2 Emergency route north 1 during construction, width 1.5 m, wall lining left F 90
3 Final state

Marking of emergency paths and escape routes

Emergency paths and escape routes were marked at a distance of 24 m on the tunnel middle wall by 50 special escape route lights. In addition, 90 lights for orientation were assembled to the walls, which are automatically switched on in case of fire alarm. Further marking devices are installed on the carriageway ledges of both tunnel shafts as well as the turnoff routes in form of visual guiding installations consisting of 200 white self-luminous LED-elements. All of these lighting devices facilitate orientation in case of smoke, thus, supporting self-rescue of tunnel users who are enabled to get themselves to safety. During normal operation, the visual guiding devices are only switched on on the right side of the road.

Remote monitoring by the control centre is assured by 50 individually controllable video cameras in the tunnel walls. The existing 12 escape doors, at a distance of 130 m in the outer wall and in the middle wall, were enlarged during conversion works and provided with F90-equipment. The already mentioned escape route markings with distance indications in both possible escape directions were fixed to these doors. Above the escape doors flash-lights were installed who indicate a dangerous situation to the traffic when opened. What is more, in this case the closest video camera is activated and the control centre in Berlin is automatically informed. Next to the escape doors two 6-kg-fire extinguishers are at disposition. Along the middle wall in northern direction, an emergency path was isolated and heated fire-fighting lines DN150 are laid as wet pipes.

The tapping for extinguishing water is situated next to the escape doors in the middle wall as fire hydrant with separate connections and shut-down valves for both tunnel shafts.

Operation and ventilation equipment

The existing power installation and energy distribution was completely exchanged including all cables, ducts (total length ca. 125 kilometres) and cable support systems (ca. 20 kilometres) in the tunnel and the operation rooms. Energy and cab cables in the tunnel run along cable routes in cable ducts in the walls and the tunnel ceiling.

The UPS-system (uninterruptible power supply) was also completely removed and modernized. This system assures operation of all safety-relevant elements of the tunnel in case of power outage.

Tunnel lighting/ controlling

In the entry and transition areas of the tunnel, counter-beam lighting is used for economic reasons. The chosen lights distinguish themselves by high efficiency and optimum light-technical characteristics.

The basic lighting is symmetrical and will be used as emergency lighting in case of an incident. The increased requirements to safety in road tunnels and the necessity of an energy-optimized operation of the lighting resulted in the installation of a lighting control system. Control is carried out continuously by light controllers depending on the outside lightness.

570 high-power projectors including the necessary light control (16-field switchgear with control panel and PLC-panel) contribute to the tunnel's lighting.

Exterior lighting

The lighting system on the outside, in the troughs before the northern and southern tunnel portals and in the area of the uncovered route up to the Hinkeldey-bridge, was completely renewed.

Ventilation

In the tunnel, in addition to the longitudinal ventilation, 28 jet fans type TAS were mounted to the tunnel ceiling in pairs. Ventilation can be controlled automatically and manually by section in adaptation to the individual incident. The existing escape routes were equipped with positive pressure ventilation.

Traffic management installation Tunnel Tegel Airport

Induction loop, TLS Type 1	Flasher unit	Road outstation	Height control collectors	Height control indicators
Radar detector	Flash lights	Lane signalling	Variable message signs	Variable traffic guiding signs
Variable traffic signs	Visibility sensors	Traffic management facilities, Type B	Routing and blocking barriers	

Traffic technical equipment

- Refitting of the old traffic management installations with display units, lane direction control, traffic data collection, height control and outstations.
- Refitting of the sub-centre in the tunnel control room and of the control centre at the Berlin police station.

The tunnel at Tegel Airport Berlin was furnished with a comprehensive tunnel control system with lane signalling, network and junction management as well as section control which were then integrated into the overall control system. Four sign gantries with signposts in the trough and transition areas were part of this concept. Section control serves to alert danger and adapt speed limits, congestion warnings, harmonization of traffic flow and sectional close-off of lanes for construction or in case of accidents. Tunnel control reacts to requirements of central building control (e.g. disturbances of the operational technique, fire alarm), of users (maintenance, accidents, particular traffic situations in the tunnel environment) and of automatic traffic control (e.g. congestions in the tunnel).

In case of danger, traffic is stopped already at the tunnel portal and safety barriers at the tunnel entries are closed. In case of fire, this procedure is brought about within 3 seconds after detection by the fire detection system. In total 44 measurement cross-sections and 68 display cross-sections with 153 LED-variable road signs and 34 dynamic message signs are part of the renewed tunnel. Traffic data collection at the tunnel of Tegel Airport is done automatically by a local data collection system with 107 radar detectors (42 in the tunnel) separated by lanes mounted to the tunnel ceiling and on sign gantries above the lanes. In total 26 outstations are connected to a redundant optical fibre network. A TCP/IP-connection with TLS-over-IP protocols ensures communication. Traffic computers calculate an optimized state of the whole system on the basis of traffic and environment data as well as the manually input data and requirements of the central control. Interface between all operators in both round-the-clock control centres of the tunnel and the traffic management centre is a web visualization.

It graphically shows the whole route in all possible traffic situations, control systems and switching situations and serves as user interface. A matrix links every potential necessity of all possible situations so that at all times a pre-defined, automatically running, traffic-secure reaction of the whole tunnel system is ready for every situation occurring in the tunnel.

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