Tunnel Holstein on the A44 Motorway: Excavation in Complex Geological Conditions

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ABSTRACT: The Holstein Tunnel, forming a bypass of the town of Sontra in Hesse, is part of the construction of the A44 motorway between Kassel and Eisenach. The project belongs to the "Verkehrsprojekt Deutsche Einheit" programme, aimed at connecting the former eastern and western federal states of Germany. The Holstein Tunnel is a twin-tube, conventionally excavated road tunnel with a length of 1,664 metres. The construction is carried out by the joint venture ARGE Tunnel Holstein, consisting of BeMo Tunnelling GmbH and Subterra a.s. Other members of the consortium include Josef Rädlinger Bauunternehmen GmbH and Stutz GmbH, responsible for earthworks and pavement construction. The investor is DEGES GmbH; the design was prepared by BUNG Gruppe using BIM methodology at LOD 300/400 level, including 4D and 5D modelling for time and cost management. Tunnel excavation began in March 2025. The applied technology complies with the principles of NATM, using lattice girders and shotcrete for excavation support. Completion of tunnelling works is expected in mid-2026, and concreting of the final lining commenced in both tunnel tubes already during the excavation phase. Hydrogeological conditions along the alignment are extremely challenging because the tunnel crosses the regionally significant Sontra Graben with numerous fault zones, karst features, sinkholes, water inflows and erosion phenomena. The rock mass is highly variable, ranging from tilted Buntsandstein layers at the portals through compact dolomite and limestone in the central section to Zechstein sediments at the boundaries of these units. From a geomechanical standpoint, Zechstein formations are extremely unstable with rapidly changing, difficult-to-predict properties, and high-water saturation with strong local inflows play a significant role. Excavation of both the east and west tunnel tubes proceeds in a downhill direction from the southern portal. The northern portal lacks sufficient space for site facilities, and the access road does not allow transport of excavation materials. Efficient reuse of excavated material is also a key factor, as the spoil is processed directly into embankments and parking areas adjacent to the south portal. The project exemplifies a modern approach to conventionally excavated tunnel construction in Germany in terms of both technical solutions and project management.

1. BASIC INFORMATION AND PROJECT CONTEXT

The Holstein Tunnel forms part of the new A44 motorway section linking the A7 and A4 motorways, specifically between Kassel and Eisenach, and it represents an important transport connection between the former eastern and western federal states of Germany with the aim of relieving the regional road network of transit traffic. The Holstein Tunnel is one of the key structures of section BA 4.1 which, together with other structures, connects the already completed segment between the interchanges AS Sontra-West and AS Sontra-Mitte with the subsequent section BA 4.2. The tunnel consists of two unidirectional tubes, east and west, each approximately 1.65 km long, excavated using the conventional NATM method. The project investor is DEGES – Deutsche Einheit Fernstraßenplanungs- und bau GmbH, responsible for major infrastructure projects throughout Germany. Construction is carried out by the joint venture ARGE A 44 Tunnel Holstein. The tunnel itself is executed by ARGE Tunnel Holstein, which includes BEMO Tunnelling GmbH, NLW and Subterra a.s. The remaining motorway structures are executed by ARGE A 44 Streckenbau Holstein consisting of JR Bauunternehmen GmbH and Stutz GmbH. The design was prepared by BUNG Gruppe using BIM at LOD 300/400, including 4D and 5D modelling for time and cost control, and the execution design was prepared by the technical department of BeMo Tunnelling GmbH in Innsbruck. Subterra a.s. has previous experience with the A44 corridor, having executed the nearby Spitzenberg Tunnel and adjacent motorway sections between 2017 and 2022 together with BeMo Tunnelling GmbH and Stutz GmbH.

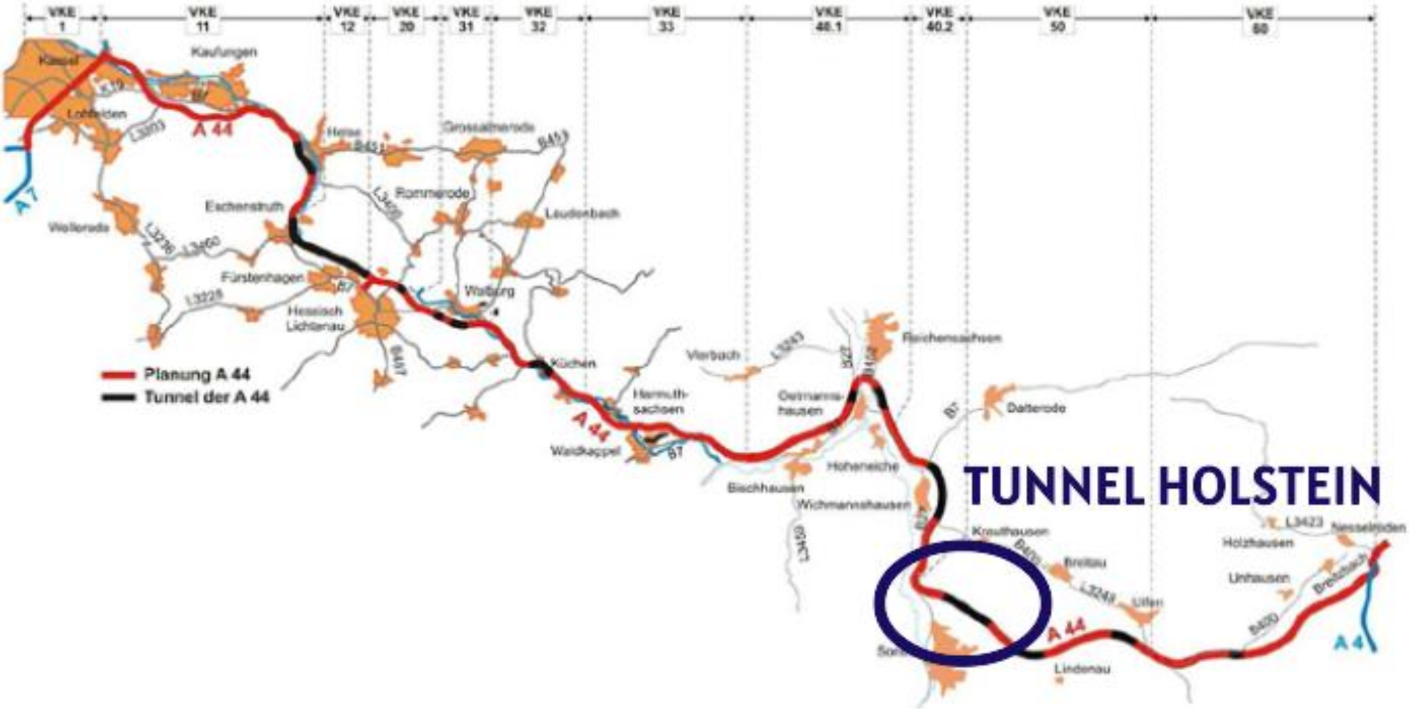

Figure 1: Overview of the entire A44 route.

1.1 PROJECT HISTORY

The concept of constructing a motorway connection between Kassel and Eisenach dates back to the 1920s. Certain structures were already initiated in 1940; however, due to insufficient funding, construction works were discontinued. Because the planned route was intended to link two federal states located on opposite sides of the former East–West German border, its strategic relevance diminished after the Second World War and no further construction activities were undertaken. Only after the reunification of Germany in 1990 did the traffic intensity on the regional road network increase significantly, resulting in high traffic loads in municipalities across this region. For this reason, the new construction of the A44 motorway Kassel (A7) – Herleshausen (A4) was included among the priority projects under the national programme Verkehrsprojekt Deutsche Einheit (VDE). The VDE comprises seventeen major infrastructure projects designed to modernise and strengthen long-term transport links between the former eastern and western parts of Germany, and the A44 is also integrated into the Trans-European Transport Network (TEN-T). In the 1990s, the routing of the motorway was confirmed and design works commenced. From the year 2000 onwards, the corridor has been gradually implemented from the Kassel side in the direction of the A4 motorway. Most sections of the A44 are already in operation while the remaining parts are under construction, and the tender for the final several-kilometre section, including the Bubenrad and Dachsloch tunnels which directly follow the Holstein Tunnel section, is expected to be launched in 2026.

1.2 CONSTRUCTION OF THE A44 MOTORWAY

The A44 route traverses the hilly landscape within the Meißner–Kaufunger Wald Nature Park in the foothills of the Harz Mountains, and the immediate surroundings of the Holstein Tunnel form part of the Frau-Holle-Land Geopark. Routing the motorway through the valley was not feasible due to the presence of extensive residential areas. Projected future traffic loads, stringent safety requirements and the environmental constraints of this protected landscape led to an alignment characterised by a high density of tunnels and bridges that enable passage along the mountain slopes rather than through populated valleys. Along the 64.3 km long section of the A44, the construction includes fifteen major bridge structures with a combined length of approximately four kilometres and thirteen tunnel structures with a cumulative length exceeding fourteen kilometres, together with numerous additional overpasses, culverts, retaining and revetment walls, extensive slope stabilisation measures and multiple noise protection walls. Combined with the geological complexity of the region, this corridor represents one of the technically most demanding motorway projects in Germany.

2. BASIC PROJECT DATA

Project name:	Tunnel Holstein, AS Sontra West – TB Riedmühle VKE C231
Client:	DEGES GmbH
Contractor:	ARGE A 44 Tunnel Holstein
Tunnel Works Contractor:	ARGE Tunnel Holstein – BEMO Tunnelling GmbH, NLW and Subterra a.s.
Project Location:	A44 Kassel – Herleshausen, Sontra, Northern Hesse, Germany
Planned Construction Period:	11/2024 – 05/2027
Tunnel Length:	ETT 1667 m, WTT 1659 m
Estimated Construction Costs:	EUR 219,252,043.75, of which tunnel works: EUR 114,934,842.55

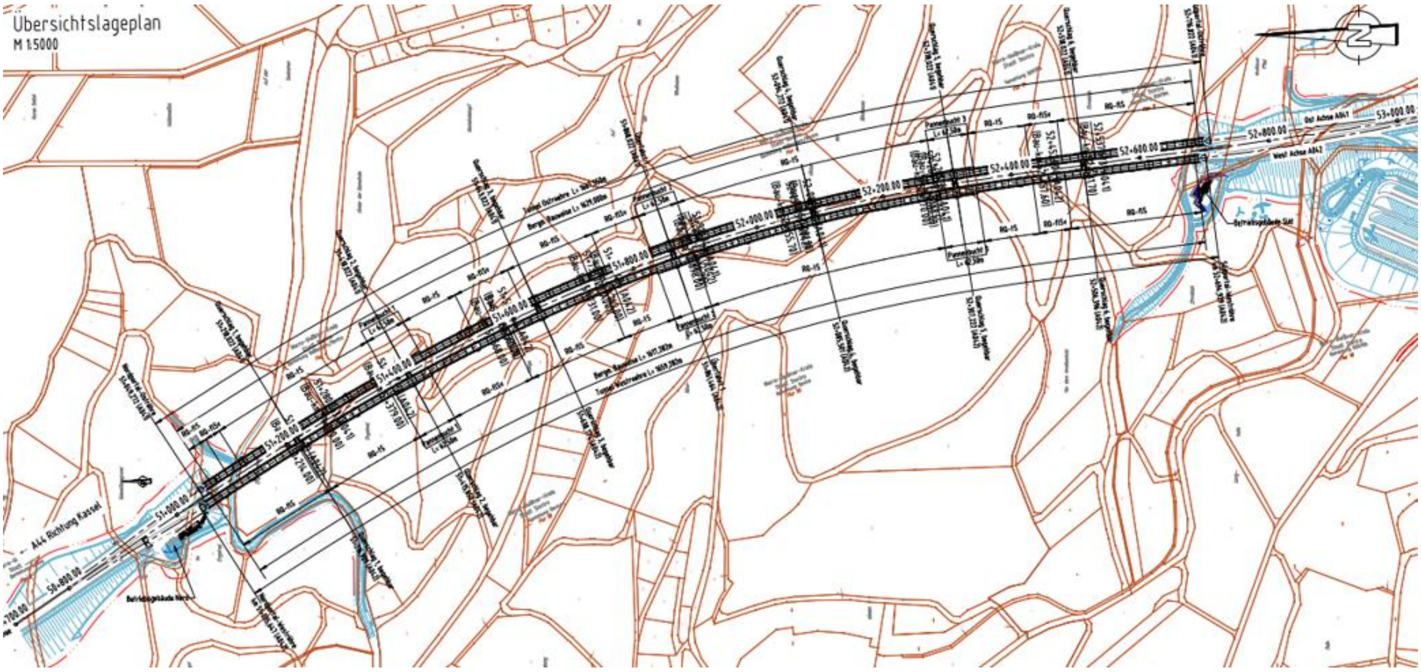

Figure 2: Situational alignment of the tunnel.

The construction section BA 4.1 begins at the existing grade-separated interchange Sontra–West, located north of the historic mining town of Sontra in northern Hesse, near the borders with Thuringia and Lower Saxony. From there, the route leads southeast towards the foot of Mount Holstein (462 m a.s.l.) and continues in a right-hand curve through a 1,659/1,667 m long tunnel. The route then proceeds eastwards to the Sontra–Mitte interchange, where the A44 motorway is connected to the road network by means of an approximately 1 km long motorway feeder road.

In this area, a large single-sided motorway rest area with toilets (PWC) will also be constructed, together with an operations building and an overpass. Extensive slope-stabilisation works will likewise be required.

The structural design of the tunnels consists of two two-lane, unidirectional tubes connected by seven cross passages. The central cross passage is driveable. The remaining cross passages are pedestrian-only, and every second one is supplemented by emergency bays in both tunnel tubes.

The tunnel is being constructed in accordance with the ZTV-ING (Zusätzliche Technische Vertragsbedingungen und Richtlinien für Ingenieurbauten – Additional Technical Contract Conditions and Guidelines for Civil Engineering Structures). These are the generally applicable and binding technical and quality standards for construction in Germany; in our case, the relevant section is primarily Part 5 –

Tunnel Construction. Tunnel construction projects in Germany are implemented almost exclusively in line with these standards, which apply uniformly to all clients, who therefore do not impose their own or supplementary technical or quality requirements.

3. GEOLOGICAL CONDITIONS

The Holstein Tunnel passes through a geologically diverse and complex area within the regionally significant Sontra Graben, where the stratigraphic sequence has been severely tectonically deformed and fractured resulting in numerous fault zones, karst features, sinkholes, water inflows and significant erosion phenomena occurring along the alignment. Because the tunnel encounters the most difficult geological conditions of all tunnels along the A44 corridor, it was clear from the outset that these conditions would pose exceptional challenges for the project team.

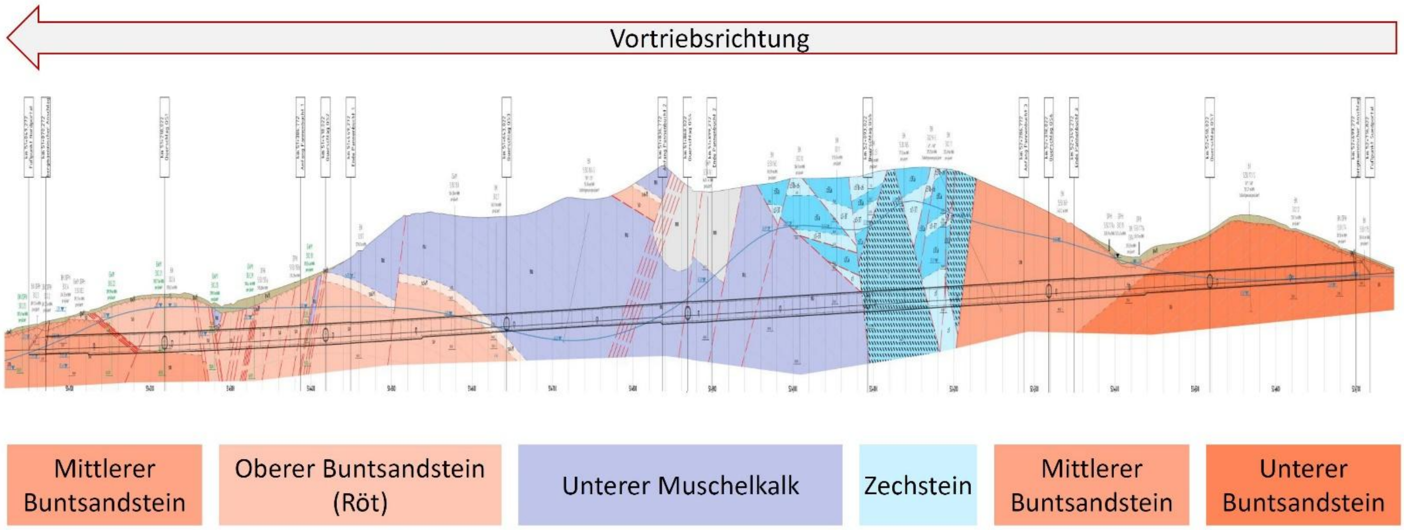

Figure 3: Geological cross-section of the tunnel.

The geological environment of the tunnel is classified as highly variable, with Buntsandstein formations encountered at the portals and compact limestone and dolomite blocks of the Muschelkalk in the central section. At the transition between these two zones, sequences of the Zechstein formation are tectonically wedged in.

Buntsandstein (literally “variegated sandstone”) is a Lower Triassic sediment found in the region of the Germanic Basin. In this locality, it is distinctly reddish in colour and deposited in relatively thin layers. It is composed primarily of sandstones, claystones and siltstones. Thin interlayers of limestone, anhydrite and gypsum also occur locally. In the area of the Holstein Tunnel, the layer thickness ranges from a few millimetres to the lower tens of centimetres and the layer boundaries are often interbedded with remnants of clay, which makes them relatively prone to degradation. The layers dip alternately to the east and west, but always with a slight inclination to the north. The properties of this rock vary significantly: very compact formations requiring blasting have been encountered, as well as disturbed formations with a fissile character and a highly developed joint system that are susceptible to further disintegration, and also very weathered, crumbly formations with a cohesion closer to that of soils. Hydrogeological conditions are relatively favourable in the more competent sandstones, as the joint system provides good drainage of groundwater. At the contact between Buntsandstein and Zechstein, a layer of copper shale (Kupferschiefer) is common. In Sontra and the surrounding area, these copper ores were intensively mined from the 15th century until the 1970s.

Muschelkalk is a carbonate- and sulphate-rich sediment of the Middle Triassic occurring north of the Alps. This rock consists mainly of limestone and dolomite, with lesser amounts of anhydrite and gypsum. From a tunnelling perspective, it represented a relatively favourable, compact rock mass, although often tectonic fractures. Blasting was always required for excavation. Higher groundwater inflows occurred in this section and karst development was expected; therefore, exploratory drilling had to be carried out regularly. At the boundary of this geological zone, Zechstein layers were wedged into the limestone from the south, and sandstone formations from the north.

Zechstein is a heterogeneous sediment of Permian age. It is composed mainly of magnesium- and potassium-rich salts combined with anhydrite, gypsum, limestone, dolomite and residual clays and claystones. From a geomechanical point of view, it represents a very unstable rock environment, with properties that change rapidly and are difficult to predict. The degree of water saturation plays a major role here. In some sections, the Zechstein behaved relatively stable; however, its properties generally changed very quickly, even within a single tunnel face. In some layers with high water content, its consistency resembled a saturated slurry. Localised massive water inflows also occurred. This type of rock mass is highly unfavourable and risky for conventional tunnelling, with unpredictable behaviour. It therefore places high demands on both the technical team and the excavation crews.

From a geomorphological perspective, the area is also challenging. Numerous tectonic faults occur along the entire tunnel alignment. The maximum overburden is approximately 75 m. Roughly 250 m from the southern portal, the tunnel passes through a critical depression where the overburden decreases to only 3–4 m. In the section 280–150 m before reaching the north portal, another significant fault zone is encountered, again with an area of low overburden, at its minimum only 5 m.

Figure 4: Face of the crown heading (ETT) at chainage TM 1051, Figure 5: Face of the crown heading (WTT) at chainage TM 455.

4. CONSTRUCTION SITE FACILITIES AND TUNNEL PORTALS

The construction site facilities were handed over to the contractors in November 2024. Work immediately began on preparing the south portal and on laying out and improving the areas for the site facilities. The priority was to commence excavation at the earliest possible date with the complete supporting infrastructure in place.

Construction of the south portal, from which the excavation proceeds, was carried out in parallel with the preparation of the areas for the future motorway embankment and the motorway rest area. Earthworks at the portals were executed in stages in accordance with the design, with the slopes being secured continuously. The excavated material was used directly in the motorway embankments and in the areas needed for the site installation. Measures were implemented in the portal area to manage surface water drainage.

Preparation of the north portal took place from November to December 2024, concurrently with other earthworks for the motorway formation in this locality. The cutting has currently been excavated down to the first anchoring level; completion is scheduled for immediately before breakthrough. Work at the north portal is constrained by access via a narrow local road with a steep longitudinal gradient passing through residential areas on the edge of the town of Sontra. Deliveries of material and equipment, and especially muck disposal, are very limited, above all in view of traffic-load constraints in the surrounding area. For these reasons the north portal is not suitable as an excavation face; both tunnel tubes will only be broken through at this portal.

Figure 6: South portal including the construction site facilities.

Within the south-portal area it was necessary to construct the site facilities. These are arranged partly in additional cuttings on the slope and partly on newly formed embankments. A materials depot was set up in the immediate vicinity of the portal. On the opposite side of the site there is a small container compound for operational shift personnel, sanitary facilities, a workshop for equipment maintenance, a fuel store, a store for pumpable explosives, a store for accelerator, a helipad, and, at the far end, an additional explosives store.

Direct processing of the excavated material into the newly constructed embankments makes it possible to expand, on a rolling basis, the working platform in front of the portal, which is needed in particular for the assembly of the concreting systems and for storage of reinforcement for the final inner lining.

The water-management facilities for the works are located in the valley below the portal near a local watercourse into which the wastewater is discharged. They consist of a chain of settlement tanks and a high-capacity neutralisation plant. Although the project is not situated in a designated water-protection area, very strict discharge-quality limits traditionally have to be met in Germany.

A larger container compound for the project management, together with parking areas and changing rooms, was established on the opposite side of the valley near the access road (the future motorway feeder). Two mobile batching plants were also erected here, with aggregate and sand storage areas. Because this area lies outside the future motorway corridor and is independently accessible, the installed facilities can remain in operation until the entire project is completed.

To ensure full service access to the tunnel in parallel with the execution of earthworks in broken terrain and irrespective of weather conditions, service roads with asphalt surfacing were constructed throughout the site-installation area, and the necessary parking areas were likewise asphalted.

5. EXCAVATION WORKS

Excavation began in mid-March 2025 in the eastern tunnel tube (ETT), starting with the top heading. In the western tunnel tube (WTT), excavation commenced approximately one month later after a lead of 208 metres had been achieved in the eastern tube. From that moment onward, the top-heading excavation in both tubes proceeded in parallel. From July onward, excavation of the bench and subsequently of the invert began. These operations were initially performed alternately in the eastern and western tubes, and from January 2026 excavation of the bench and the invert was also carried out at a second workplace. Since January 2026, work has therefore been progressing simultaneously at four partial faces.

The designed total lengths of the tunnel tubes are 1,667 metres for the eastern tube and 1,659 metres for the western tube. The conventionally excavated sections have lengths of 1,629 metres and 1,617 metres respectively, and a full-length invert arch is planned in both tubes.

The excavation is conducted in accordance with the principles of the New Austrian Tunnelling Method (NATM) and proceeds in a downhill direction from the south portal at a gradient of 2.74%. Approximately half of the excavation is executed by mechanical means and the remaining half by blasting. The face is divided horizontally into the top heading, the bench and the invert. The excavation area in the standard profile is approximately 95 square metres, and in the profile of the emergency bays it is approximately 120 square metres.

The first approximately 450 metres were excavated in Buntsandstein formations exhibiting very diverse strength and cohesion. This was followed by about 150 metres in Zechstein, which was then replaced by a Muschelkalk. After a further 500 metres in limestone, Buntsandstein was encountered again, locally with geomechanical properties even less favourable than in the initial portal section..

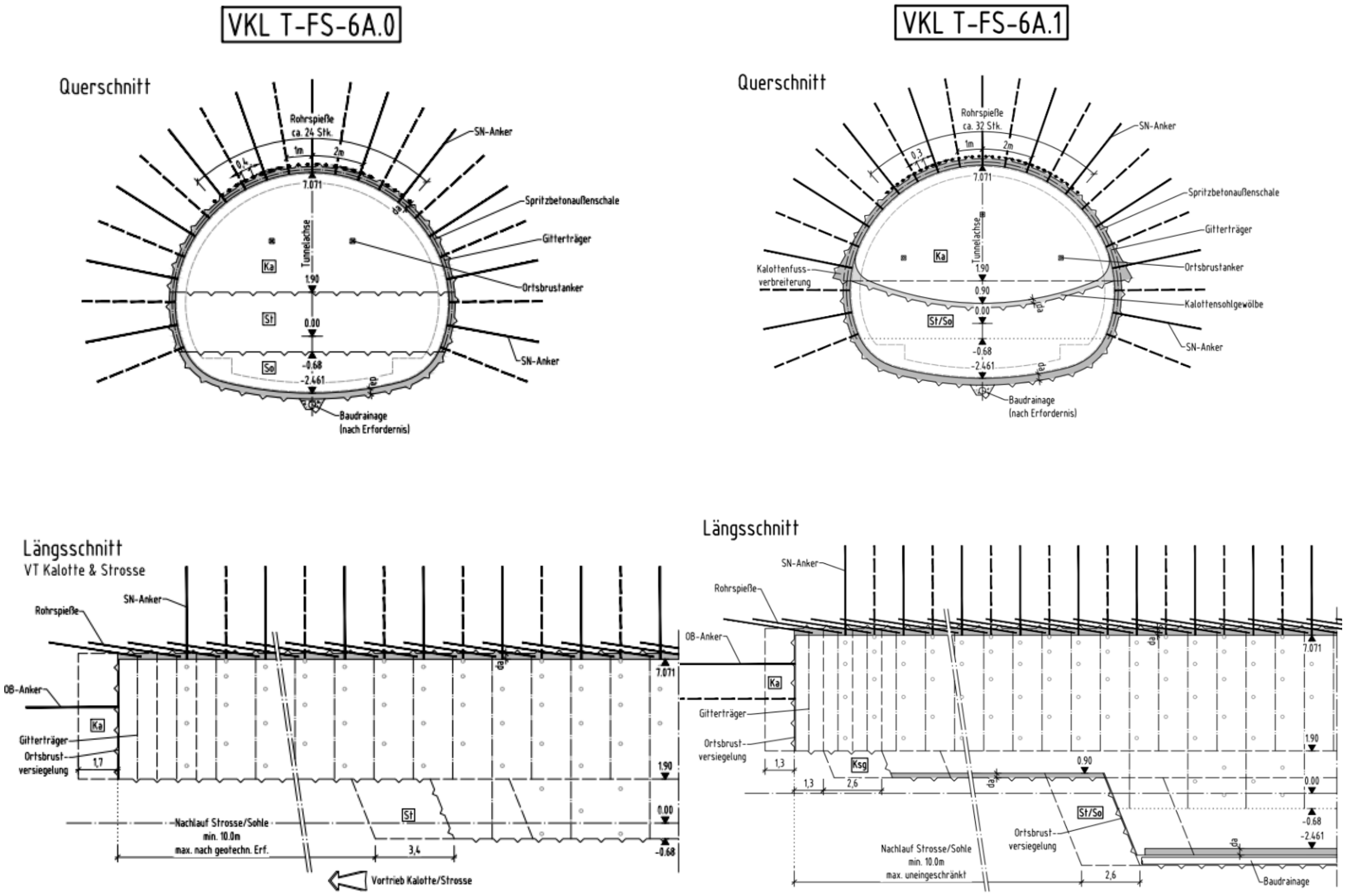

Figure 7: Excavation support classes 6A.0 and 6A.1.

The excavation has primarily used support classes 6A.0 and 6A.1. Class 6A.0 employs a 25-centimetre shotcrete lining with advance lengths of 1.0, 1.3 or 1.5 metres. Class 6A.1 employs a 30-centimetre shotcrete lining with a round length of 1.3 metres, and of 1.0 metre in poorer geological conditions. In Class 6A.1, the top heading foot is additionally closed with an offset of two rounds, with two rounds being closed at a time. The support scheme is standardised and varies by class; it includes shotcreting of the face and of the excavation profile, installation of lattice girders, two layers of welded mesh, radial anchors and forepoling. Face anchors and a higher bolt density are installed where required on the basis of the on-site geological assessment. For forepoling, ungrouted steel tubes with an external diameter of 51 millimetres and a minimum wall thickness of 3 millimetres are used; owing to their greater cross-section they provide improved static support, while their lower weight facilitates handling. Excavation classes with pipe umbrellasor with vertical subdivision of the top heading have not yet been used.

In areas with potential karst, the design prescribed a karst investigation programme in order to minimise the risks arising from karst cavities—either open or filled with water or sludge—both for excavation and for the future operation of the tunnel. The measures in carbonate rocks susceptible to karst, specifically the Muschelkalk and in part the Zechstein, are divided into two stages. The first stage consists of exploratory probe holesdrilled from the face in a fan pattern so as to investigate both the excavation envelope and the surrounding rock mass with sufficient advance and coverage; the type and extent of the boreholes depend on the excavation class and on the advance-support elements employed, and boreholes for spiling may partly replace those prescribed for karst investigation. The second stage comprises geophysical surveys performed after completion of excavation, using a combination of microgravimetry and seismic reflection.

In total, karst investigation was carried out in five sections over a combined length of 1,400 metres in both tubes. The first-stage probe holes are full-profile, non-core holes 12 metres in length and 55 to 70 millimetres in external diameter, drilled using the drill jumbo. The standard scheme for drilling—excavation with forepoling, without micropiles and without face anchors—consists of eleven investigation boreholes in various positions in the face. Eight boreholes in the face are drilled with an upward inclination of approximately 10 to 13 degrees, and three boreholes near the top heading foot are drilled with a downward inclination of approximately 10 and 20 degrees. In the springline, sidewall and crown zones, the boreholes are alternately deflected so as to improve the coverage of the rock mass. From the bench, three boreholes are drilled with downward inclinations of 20 and 30 degrees to investigate the invert.

5.1 TOP HEADING

The top-heading excavation in the eastern tube is maintaining an advance of approximately 200 metres, and breakthrough is expected in April 2026. Up to now there have been no significant interruptions, except at two locations at stationing TM 512 and TM 583 in the Zechstein zone where temporary water inflows of up to 50 litres per second required a suspension of excavation for several days. In the eastern side of the top heading it was necessary to drill drainage holes and to implement other indispensable measures, including the installation of an additional drainage pipe and the installation of pumping stations. Vacuum trucks supplied by the partner in the consortium were also deployed for the removal of ingress water. During further progress, pressure relief drillingproved highly effective.

Figure 8 and 9: Water breakthrough in Zechstein formations.

In unfavourable geological conditions, particularly within the Zechstein, measures were applied to improve stability. These included shortening the round length to 1 metre, increasing the shotcrete thickness to up to 40 centimetres and, in particularly demanding sections, closing the top heading by means of a counter-arch. Locally, on short sections with an unstable face, the top heading was opened in eight partial faces; in each, a 12-metre face anchor was installed with overlap, and the face was additionally loaded by a central face wedge. The decision to adopt such measures was taken operationally in accordance with the situation at the top-heading face. Excavation of the top heading in the western tube is proceeding under slightly more favourable conditions. The area is already partially dewatered by the eastern tube and, according to the geological investigation, lies in part beyond the boundary of a fault zone, so that more favourable rock conditions are encountered in some sections. Figures 8 and 9 show a water inflow at the top heading within the Zechstein.

5.2 BENCH AND INVERT

Excavation of the bench and the invert follows at a distance of several hundred metres behind the top heading. The design documentation prescribes a minimum spacing of 10 metres in order to allow the rock mass to stabilise after excavation of the top heading. The bench and the invert are excavated full-profile within the section between two adjacent cross passages. As a rule, the bench is excavated in the direction of advance of the top heading and the invert is excavated in the opposite direction, alternating between the eastern and western tubes. From January 2026, a second workplace was established for excavation of the bench and the invert, so that parallel progress in both tubes is possible, offset by one cross passage and synchronised with the excavation of both top headings.

Figure 10: Bench excavation, Figure 11: Invert excavation with shotcrete application.

In sections with unfavourable geological conditions, excavation of the bench and the invert is carried out simultaneously. The invert is always closed after two rounds behind the bench, with a spacing of two rounds between the invert face and the bench face. The round length of the bench is approximately double that of the top heading. The round length of the invert depends on the geological conditions and on the execution technology; it usually corresponds to the round length of the bench and is limited to a maximum of 3.4 metres.

The support system corresponds generally to that in the top heading, except that only one lattice girder is installed per round, which means that every second top-heading girder is supported; radial anchors are retained. In the invert, only welded mesh is installed, without lattice girders. Face anchors are not used for excavation of the bench and the invert. A construction drainage system with manholes is laid in the invert at regular spacing.

The design defines sections with an unstable geological environment in which excavation with a deep invert is adopted. In the eastern tube these are TM 250 to TM 862 and TM 1162 to TM 1575, and in the western tube they are TM 250 to TM 932 and TM 1231 to TM 1467.

A necessary condition for full-profile excavation of the bench and the invert is the diversion of construction traffic into the other tunnel tube through a cross passage and, where two workplaces are occupied, back again through another cross passage. Figure 12 shows excavation of a niche at the boundary of the Zechstein zone, and Figure 13 shows bench excavation in the vicinity of a cross passage.

Figure 12: Excavation niche at geological transition zone, Figure 13: Bench excavation near cross-passage zone.

5.3 TUNNEL CROSS PASSAGES

Both tunnel tubes are connected by a total of seven safety cross passages. The central cross passage, designated UF1, is accessible for emergency vehicles. The remaining cross passages, designated QR1 to QR6, are pedestrian-only and will be partially equipped with systems and operational technology. Opposite QR2, UF1 and QR5, the profile of both tunnel tubes is widened on one side to form emergency bays.

Excavation of the cross passages is carried out in parallel with the excavation of the top headings so that material and muck haulage from the top heading can be routed through them when the bench and the invert are being excavated simultaneously. Before excavation of a cross passage begins, the bench and the invert must already be excavated and stabilised in the immediate vicinity. Access ramps are built from the top heading. In the eastern tube, a break-out niche is first driven for each cross passage, and the cross passage is then broken through with a time offset from the western tube. The cross passages are also driven with an invert arch.

6. FINAL LINING

The concept of the final lining reflects the complex geological environment. Two principal structural types have been designed. In addition to a standard lining, a special type referred to as WUBKO, short for WasserUndurchlässige BetonKOnstruktion, is provided for sections with higher expected groundwater inflows. This solution offers increased resistance to water ingress, including water under pressure up to 5 bar. WUBKO is designed for a section 500 metres in length within the Zechstein zone and the adjacent parts. Independently of the WUBKO concept, various invert configurations are adopted according to the excavation class, namely a flat invert in favourable geological conditions and in cut-and-cover sections, a deep invert in unfavourable geological conditions and within cross-passage blocks and emergency bays, and a reinforced flat invert in transition zones.

Over the entire length of the tunnel, including the cut-and-cover sections, the invert and the vault are formed from watertight reinforced concrete. For the invert, concrete class C30/37, XC3, XF2, XD2, WA, GK16 is specified, and for the vault, concrete class C30/37, XC3, XF2, XD2, WA, GK16, SB2 with polypropylene fibres is used to improve fire resistance. The minimum required cover to the reinforcement is 70 millimetres. In accordance with ZTV-ING, the minimum strength required for striking the formwork is 2 MPa.

The standard block length is 12.5 metres, and in the WUBKO section it is 10 metres. The lining thickness varies significantly with structural type and excavation class. In the vault, the thickness is 40 centimetres in standard blocks, 60 centimetres in blocks with a reinforced flat invert or a deep invert, 80 centimetres in cross-passage blocks and 60 centimetres in cut-and-cover sections. In the invert, the thickness is 40 centimetres in standard blocks, 60 centimetres in reinforced flat-invert blocks, 80 centimetres in deep-invert blocks, 100 centimetres in cross-passage blocks and 60 centimetres in cut-and-cover sections.

Concreting of the lower vault and of the side benching employs a formwork traveller with a walking mechanism, while concreting of the upper vault uses a heavy steel mobile formwork carriage capable of widening to the emergency-bay profile. To allow curing of each block in accordance with ZTV-ING during the first three days, each concreting set is equipped with three climate-control trolleys that regulate the temperature and humidity of the freshly cast block. This ensures controlled early-age curing and reduces shrinkage and cracking. One concreting set is used per tunnel tube. Parallel concreting of the invert and the vault is planned in both tubes in a one-day cycle and takes place in parallel with the ongoing excavation works.

6.1 WATERPROOFING AND DRAINAGE

The tunnel is designed as a watertight structure with a pressure-resistant waterproofing system. The primary waterproofing element is a 3-millimetre thick plastic waterproofing membrane made of flexible polyolefin backed by a geotextile of at least 900/1000 grams per square metre. This continuous membrane is supplemented by system sealing strips, the so-called fugenbands.

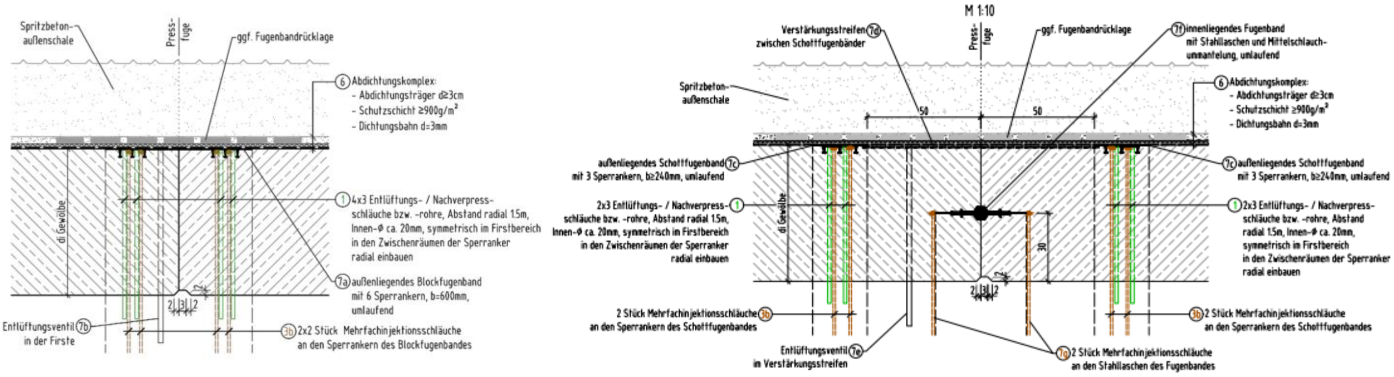

Figure 14: Waterproofing system details – standard block and WUBKO block.

In standard blocks, one waterstop 240 millimetres in width is welded onto the membrane on each side of the construction joint. In the WUBKO section, the joint zone is reinforced by an additional KDB strip 1 metre wide; on each side of this, a 600-millimetre strip is welded onto the membrane, and at the mid-thickness of the lining a third, intermediate strip 350 millimetres wide is added. The transition between mined and cut-and-cover sections is designed analogously to the WUBKO solution. All welded waterstops are equipped with perforated injection hoses.

To ensure the correct functioning of the waterstops, several venting and initial injection hoses are installed in each strip and injected immediately after concreting with cement grout according to the ‘wet-on-wet’ principle. These are supplemented by hoses of a secondary re-injectable system for subsequent injections in case of leakage during operation. The intermediate strips are fitted solely with re-injectable hoses. The joint between the invert and the vault is sealed by a metal waterstop, which is sandblasted prior to concreting to a depth equal to one half of the maximum aggregate size in the concrete mix.

Because the tunnel is waterproofed against water under pressure, the primary drainage element comprises slotted gutters for roadway drainage. Water from the slotted gutters is conveyed to a DN 300 central drainage pipe and then flows by gravity to the lower portal into a retention tank. For the removal of groundwater from the rock mass during construction, a DN 300 working drainage pipe is installed outside the primary shotcrete lining, beneath the invert and behind the waterproofing membrane; after completion of concreting it is backfilled with grout.

Figure 15: Sealing bands at transition between mined and cut-and-cover section, Figure 16: Invert concreting operations.

7. CONCLUSION

The Holstein Tunnel is in many respects a demanding project. It is technically complex, executed in difficult geology and highly constrained in terms of schedule and organisation. In order to meet the construction programme it is necessary to minimise construction time while at the same time complying with very stringent quality requirements. From the rapid phase of site establishment through the parallel execution of the works to managing changes in the various rock formations, the close cooperation of all parties is evident throughout. The processes and collaboration between the client, the construction supervision, the contractor and the designer have been successfully established, enabling the project to proceed in line with the defined schedule. Active cooperation within the consortium also helps to successfully navigate the most difficult sections encountered during excavation.

In the geologically demanding and highly variable conditions of the excavation works, the permanent presence of the contractor's site geologists has proved highly effective. Through systematic face mapping and continuous monitoring, they help to anticipate changes in the rock mass and contribute to the design of adaptive support measures during excavation.

A key factor in a successful tunnelling contract is the advance rate and the timely start of concreting of the final lining. The constraints imposed by the geological situation were considerable, which makes the organisation of activities and a collision-free parallel workflow all the more important. Progressive excavation at four workplaces in parallel with concreting at four workplaces imposes extreme demands on the site team. It is necessary not only to organise progress efficiently, but also to optimise the deployment of personnel and to master the project logistics. Despite the demanding geological conditions, good advance rates are achieved. In favourable conditions the rate in the top heading reaches up to seven rounds of 1.3 metres per day (9.1 metres per day), and in the bench and the invert up to eight rounds of 3.4 metres (27.2 metres per day).

A decisive factor for the quality of the final lining is the creation of sufficient time for its preparation and the timely completion of the primary shotcrete layers beneath the waterproofing, with the required parameters and geometric accuracy.

Direct placement of the excavated material into the future embankments shortens transport times and thereby increases the efficiency of muck haulage, while at the same time creating space for the assembly of the concreting formwork sets and for material storage thanks to good cooperation with the partners responsible for earthworks.

The use of on-site concrete batching plants minimises waiting times between operations, provides great flexibility in scheduling during excavation, and allows better quality control of the delivered concrete mix.

In spite of the tight schedule, there has still been scope for the implementation of innovation. In cooperation with BeMo's equipment division (MTA BeMo), the robotic shotcrete spraying system Meyco Logica has been introduced into regular operation and is being further developed so that its use is fully functional and effective in day-to-day site operations.

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