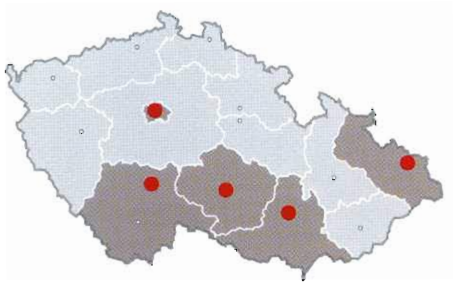
Mined utility tunnels



Construction of utility tunnels has roughly a 30-year history in the Czech Republic.

In central areas of larger towns, the placement of infrastructure services into tunnels is associated with the need for a comprehensive solution to the regeneration of technical infrastructure and boosting its capacity. These underground structures (in particular deep supply utility tunnels) have been incorporated into general extension plans for historic centres and large urban concentrations. Since its beginning in the 1970s, the development of utility tunnels reached farthest in Prague and Brno, with the recent addition of Ostrava. Another group comprises historic towns, namely Tábor and Jihlava, where the issues of refurbishment of utility networks are combined with the restoration of all other historic structures and their stabilisation. The group of those towns comprises above all Tábor and Jihlava.

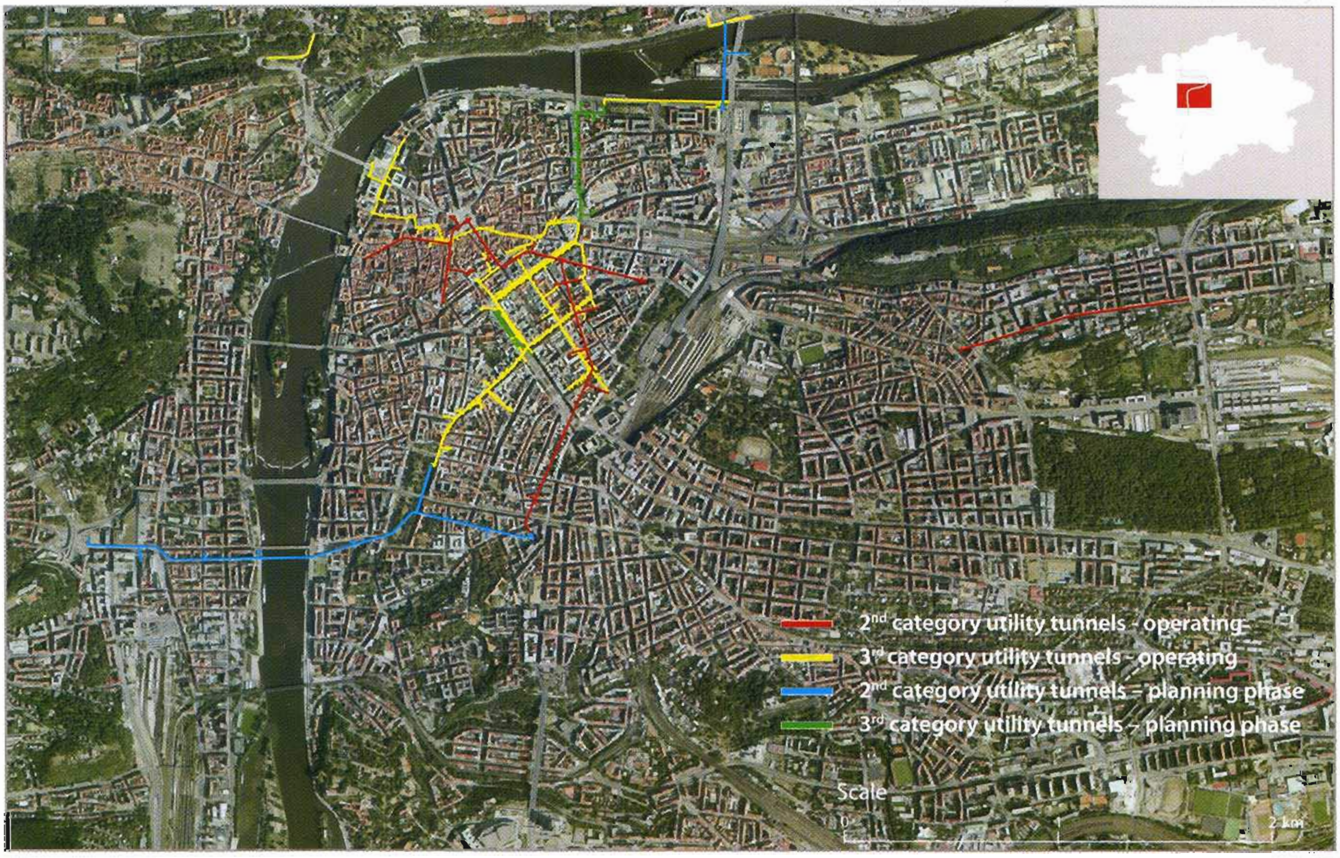
The utility tunnels house cable and pipe networks. The pipe networks comprise water pipelines of various pressure ranges and various systems, plus a medium-pressure gas pipeline. The cable networks comprise 110 kV, 22 kV and 0.4 kV heavy-current cables and traction mains, telecommunication, information and data distribution weak-current cables (both optical and metallic), as well as a tubular post distribution line. Utility networks serving the tunnel operation and management purposes are added to the above networks. In addition, other utilities, such as sewers and heat distribution lines, can be placed into the tunnels as required by the respective municipality.

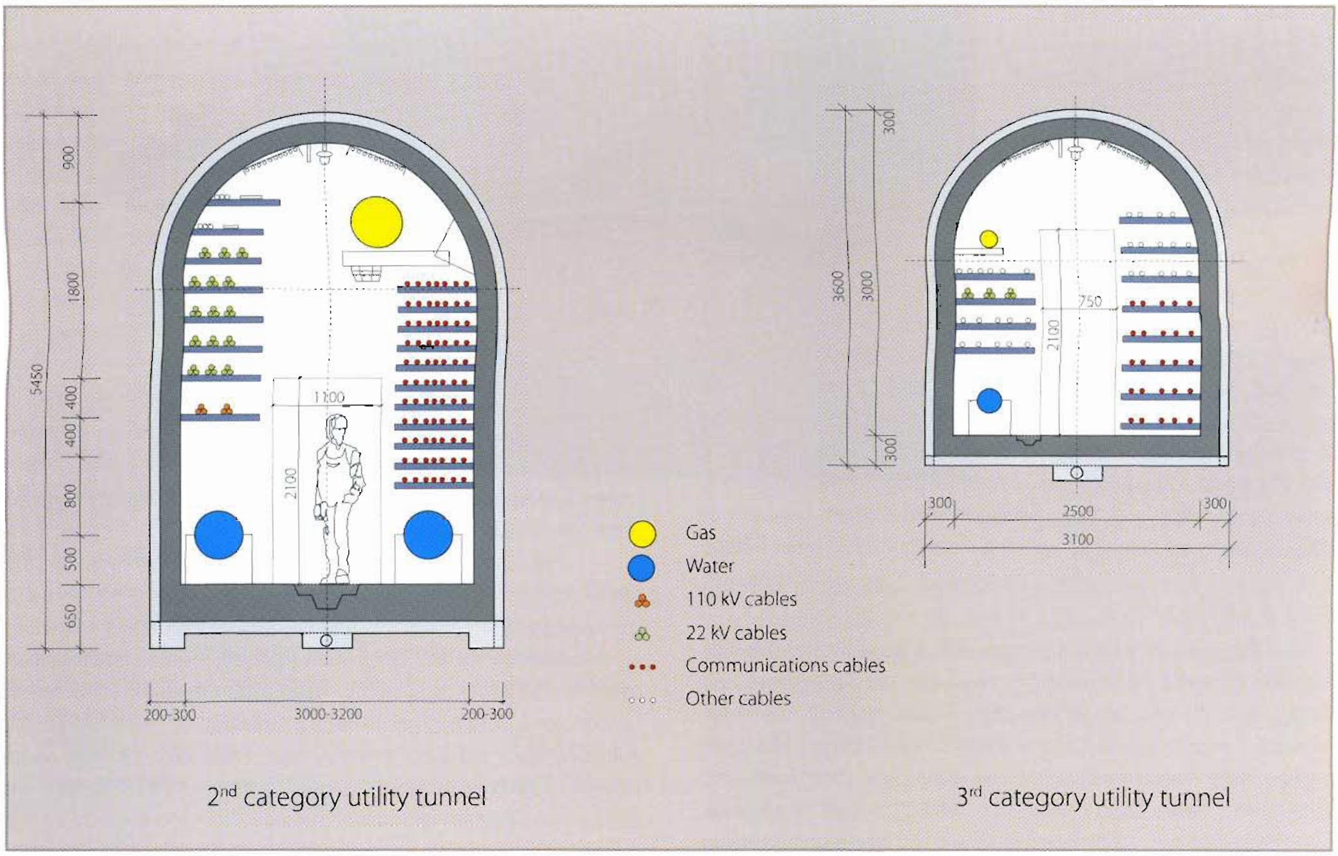
The placement of utility networks in tunnels is advantageous because it results in a well arranged system, centralised operational control, extended lifetime of utilities and enhanced safety, easy maintenance and repairs without requirements for digging, thus mitigating any negative impact on the environment.

The construction technique is closely dependent on the spatial conditions of the works, engineering geological conditions, and assessments of the impact of the construction on the surrounding area. Subsurface cut and cover routes prevail in residential suburban zones; prefabrication is utilised in larger extent there for utility tunnel construction. On the other hand, the possibility of constructing cut and cover linear structures in city centres is limited to the entry shafts because of the huge impact on services and the living environment. The underground galleries and tunnels for individual routes, which we will deal with in this chapter above all, are driven from these shafts, which are built in advance.

The planning and execution of these mined utility tunnel constructions is particular because of the large number of parties involved in the building permit process, which makes the negotiations difficult. The necessity for reducing the impact of the construction on the surface, in particular for minimisation of subsidence induced by

General layout of utility tunnels in the central part of Prague





Cross sections through 2nd and 3rd category utility tunnels in Prague

the excavation, is one of the problems. A part of the work is always detailed geotechnical monitoring comprising a comprehensive set of safety and check measurements, both on the surface and underground. Measured values are checked against the anticipated values of individual types of the deformations being monitored. Contingent corrections of the construction procedures and additional support measures are implemented operatively on the basis of the assessment. The excavation methods, which are today common, guarantee surface settlement values of less than 15 mm (20 mm on exception), unless anomalies occur in the overburden (e.g. leaking water mains, unknown underground spaces, insufficiently compacted zones, etc.). Advance exploration along the centre line of the mined structure is usually necessary to identify the anomalies.

Categorisation of utility tunnels

Utility tunnels are divided according to their function into two independent, but in terms of equipment, interconnected systems. Both systems differ from each other by the character of the routing of the networks, the position of their horizontal and vertical alignment, and the size of the cross sections. In different towns, the individual types are referred to in different ways. Nevertheless, their purpose characterises them unambiguously. In principle, these are the following two systems of utility tunnels:

- FEEDER/SUPPLY UTILITY TUNNELS (2ND CATEGORY UTILITY TUNNELS, also referred to as PRIMARY UTILITY TUNNELS) – these provide primary distribution routes significant for the whole city; they are built at greater depths, within a larger area, and with a limited number of exits to the surface provided in contact locations. Their alignment is as straight as possible, running through the bedrock when possible. In terms of their function, they are superior to distribution utility tunnels.
- CONSUMPTION/DISTRIBUTION UTILITY TUNNELS (3RD CATEGORY UTILITY TUNNELS, also referred to as SECONDARY UTILITY TUNNELS) – these provide direct supplies through individual lines in close relationship to the supply utility tunnels. In terms of the layout, they are situated as close to the points of consumption as possible, with their alignment as close to the surface as possible.
- For the sake of completeness, we state that dedicated civil engineering constructions significant in the whole-town scale, e.g. cable tunnels or water supply tunnels, are referred to as 1ST CATEGORY communal constructions.

Mined utility tunnels in Prague

The foundations for a systematic approach to the development of a utility tunnel network as a system for solving the problem of low-capacity utility networks in the central area of the capital were laid out in a territorial structure planning document called "The Master Plan For Development of the Network of Utility Tunnels In the Central Area of Prague". The first proposal was issued as long ago as 1982. It comprised a wider area of the centre with a prospective outlook of several decades. It was updated several times in the course of the years which followed, with the aim of adjusting it to new conditions existing in the concept of the development of the city as well as the development of utility networks. The extent of the area planned for the development of utility tunnels was partially reduced to cover the area known as the "Historic Prague Reserve". The final study, which refined the background materials for changes of the territorial structure plan, was finished in 2005.

The construction of the mined utility tunnels in the central part of Prague commenced in 1975, in advance of the completion of the "Master Plan for Development of the Network of Utility Tunnels", with the "Žižkov utility tunnel" construction (brought into service concurrently with a cable duct driven in 1984).

Today, an extensive network of utility tunnels, with a total length over 90 km, is in operation. Of this nearly 18 km of utility tunnels of both categories are found in the historic Centre, while other utility tunnels are under construction or at an advanced design stage. The remaining approximately 80 % comprise subsurface reinforced concrete utility tunnels in new residential areas in the city's periphery. Part of the system is the construction of the Supervisory Centre for Utility Tunnels, which is the only control and management centre continually monitoring the operation of the complex system in all of Prague.

GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS

The demands of the engineering geological conditions of the Prague centre follow not only from its historic development and morphologic diversity, but also from the lithological development of the rock environment and tectonic disturbances of the bedrock. The erosive action of the Vltava River also plays a role. In general, there are two characteristic units distinguished in the geological profile – the bedrock and Quaternary terrace sediments.

The bedrock is found at depths of 12 m to 15 m below ground level; this value drops to 6m under the terrace steps. The bedrock mostly consists of Ordovician shale of various composition (clay, sand, silt), which alternates with harder strata of quartzose shale and quartzite. Individual types are characterised by differing physical and mechanical properties as well as a varying degree of resistance against weathering processes. In addition, the Prague Fault crosses the centre of the city in the bedrock. The Fault is a variable zone of tectonically disturbed rock displaying significantly worsened properties compared to its surroundings.

The overlying layers of Quaternary terrace sediments consist of argillaceous sands and sands with gravel passing to gravel. The proportion of cohesive materials radically decreases toward the base. Non-cohesive materials found at the base are highly impermeable. The particularity of the 3–4 m thick overlaying layer of man-made ground is that its thickness and composition are variable owing to its anthropogenic origin. The water table creates a continuous horizon of gravel-sand and gravel in the permeable environment. It is found roughly 0–12.5 m below the ground surface, at a level differentiated according to the terrain morphology. The water table level is influenced by the water surface level in the Vltava River. Fluctuation of the water table level due to the variable level of water surface in the river is within a range of ± 0.5 m.

The water table level is significantly affected by underground structures built during the past decades (e.g. metro lines A and B, utility tunnels, basements deepened as part of the reconstruction of surface buildings) which, in many cases, prevent the natural flow of ground water.

The yield of ground water flow into underground structures depends on the composition of the environment and the level above the water surface in the river. It amounts to 5–10 l/s in the lower part of the flood-plain terrace and it drops to 3–5 l/s in the direction toward higher elevations. Minimum inflows are encountered in the rock environment with intrinsic permeability. These are mostly restricted to fractured zones and joint planes in the rock mass.

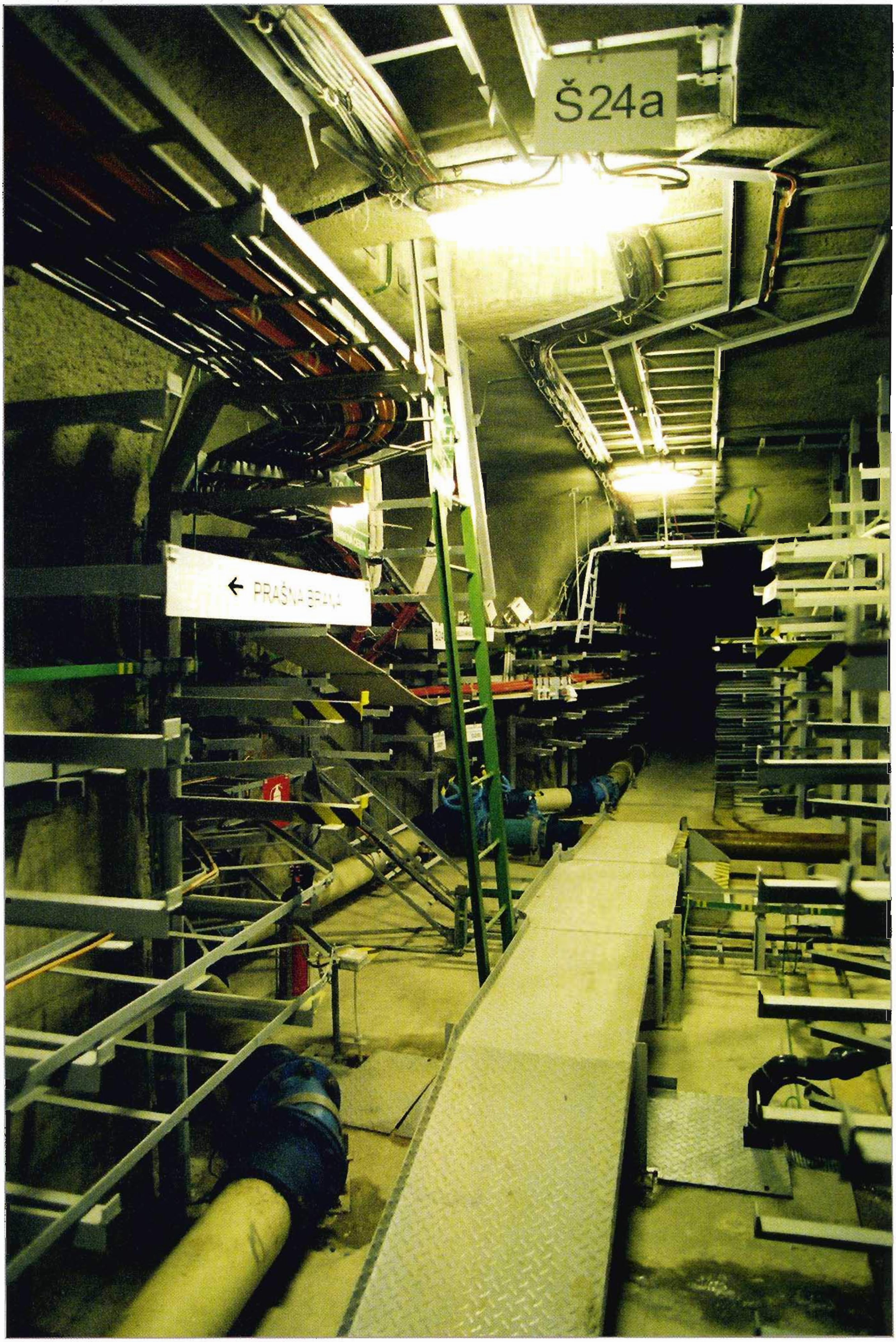
SECOND CATEGORY MINED UTILITY TUNNELS – SUPPLY PURPOSE

In the ground plan, the main route of the second category utility tunnels forms a by-pass of parts of the New Town and Old Town running on their eastern and northern sides. Branches terminating in shafts are connected to individual town sectors and to technical chambers built at crossings of individual routes. The third category consumption utility tunnels start from the shafts. The total length of these utility tunnels, including the branches, is 4.043 km.

The alignment of the routes is placed at a depth of 22 m to 30 m below the ground surface. This depth guarantees that the routes are found mostly in harder bedrock where the excavation operations are safer, and the effects on existing buildings and utility networks are

The Příkopy utility tunnel casting

The Příkopy utility tunnel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reduced. The deeper placement also allows a straighter connection between the points to be interconnected. The routes were designed so that a gravity-flow drainage system ending in selected collection spots could be applied.

The first utility tunnel, the 1.6 km long (including branches) Žižkov tunnel was built in 1975–1984. The circular cross-section was predetermined by the utilisation of a 3.98m-diameter PRIESTLEY tunnel boring machine. The 3.6m-diameter circular segmental lining of the tunnel consisted of five segments.

The excavation encountered very heterogeneous geological conditions, from nearly unconsolidated shale to quartzite layers. Because the maximum hardness of the rock locally exceeded the capacity of the TBM cutterhead of 240–300 MPa, it was necessary to refine the knowledge of the geology by horizontal probe drilling ahead of the excavation face. Maximum deformations of the surface never exceeded 5 mm. A total of 15 circular shafts were sunk along the route, either using traditional procedures or a CALWELD large-profile drilling set.

Another part of the development scheme, which was built in 1984 to 1988, was focused on the creation of a system of trunk routes passing beneath the central part of Prague. This period saw the construction of the Centre I utility tunnel, although its completion and the inception of service took place much later, in 1997. A total of 13 shafts, 4.2 m in diameter, were sunk for this construction. They were subsequently utilised as shafts allowing permanent contact of the underground with the ground surface. These shafts were the starting points for the excavation of individual sections of the horseshoe shape cross-section utility tunnel with vertical sidewalls and the excavated area of 19m². Each connection of the mined route of the utility tunnel to an open trench or a branching point was carried out through a mined technical chamber. The cross-section of these chambers necessary for the crossing of utility networks amounted to 55 m².

The tunnels were excavated using the New Austrian Tunnelling Method, with the rock disintegrated without blasting, using an Eickhoff roadheader. A horizontal excavation sequence with two benches was designed. The temporary lining consisted of colliery arches/lattice girders and sprayed concrete. Exposed locations, such as technical chambers and sections with deteriorated geological and hydrogeological conditions, required an additional measure – consolidation of the overburden.

The maximum subsidence of the surface experienced did not exceed 10 mm. The only failure experienced was an emergency during the excavation of a tunnel branch in a weakness zone where part of the overburden caved in due to water leaking from defective water mains in adjacent streets.

The secondary (final) lining is similar to the primary tunnel lining in that its cross-section of 16.5 m² consists of sprayed concrete containing waterproofing admixtures. In more exposed locations, cast-in-situ concrete lining with an intermediate waterproofing membrane is utilised.

Today, another extension of these utility tunnels is being prepared, namely on the northern and western side of the centre, each of them with a passage under the Vltava River (the Hlávkův Bridge utility tunnel – 0.540 km; the Centre – Smíchov utility tunnel – 2.580 km). Prospectively, the Centre II utility tunnel will join the "Centre I" utility tunnel, which will thus close the circuit on the western side of New Town.

THIRD CATEGORY MINED UTILITY TUNNELS – DISTRIBUTION PURPOSE

The third category (consumption) utility tunnels are built for the purpose of directly connecting buildings to the utility networks. Main utility tunnel routes are designed to run under selected exposed streets. The system is open, so that it allows for the incremental addition of utility tunnels under other streets, according to the particular needs of the city development and utility networks. Connecting to the basements proper is effected by a system of branches and boreholes carried out from the branches whereby individual pipelines and cables pass through the boreholes.

Centrum IA utility tunnel

Following the construction of the "Centre I" second-category utility tunnel system, the following third-category utility tunnels (named according to particular locations) have been built in the centre of Prague and brought into service since 1985:

- "The Royal Route" – Celetná Street utility tunnel – 0.686km
- "Rudolfinum" utility tunnel – 1.080 km
- "Tyl's Theatre" utility tunnel – 0.563 km
- "New Town Hall" utility tunnel – 0.603 km
- "RNLS" utility tunnel associated with the construction of the Těšnov road tunnel – 0.720 km

The Vodičkova utility tunnel excavation – a view of the heading

- "Centre IA" utility tunnel – a basic network of tunnels in four principal streets near Wenceslas Square – 2.684 km
- "Příkopy" utility tunnel – an integrated network of tunnels in four other streets, thus doubling the tunnel in Na Příkopě street – 1.971 km

The total length of these tertiary tunnels reaches 8.3 km. The cross section is that of a horseshoe with vertical sidewalls. The excavated cross-section area varies between 12 m² and 20 m²; the final net profile dimensions vary from 2.5 m × 3.0 m to 2.5 m × 3.6 m; the branches are designed with dimensions of 1.9 × 2.1 to 2.4 m. Due to the existing buried utility networks, the deciding factor in the tunnel design was the vertical alignment. Sewers, major pipelines, cableways, and other existing obstacles were considered untouchable or at least difficult to divert. A deeper alignment of the utility tunnel passing under sewers, i.e. at a depth of 10–14 m (locally up to 15 m), i.e. under a 7–10 m thick cover, was considered more advantageous. All of the routes lead through an environment consisting of Quaternary sediments, with the water table 0.5 m–3.0 m above the excavation floor. In addition, the excavation is carried out under the foundations of nearly all of the neighbouring buildings, which are therefore significantly affected by the construction. This is why the overburden had to be consolidated during the excavation and, depending on the position of the tunnel and structural condition of the particular building, the buildings had to be underpinned in advance.

The excavation technique utilised in the environment of non-cohesive ground experienced substantial development during the course of the construction of Prague's utility tunnels. The first sections were driven using a traditional subsurface system with the support provided by steel TH arches and forepoling. When the excavation was shifted to greater depths, a shield with a cutterhead (a TBM) was tried. The lining was produced behind the shield from cast-in-situ compressed concrete. The operations had to be suspended after the initial 220 m due to adverse geological conditions at the contact point between the existing gravel/boulders and weathered shale within the excavated cross section.

As a result, the remaining kilometres of utility tunnels were excavated using the traditional excavation technique, with the overburden improved by grouting. The temporary lining was subsequently constructed after the support of the overburden had been installed in advance of the excavation. The support consisted of spatial cones forming sub-horizontal jet grouted columns drilled from the excavation face. The operations were organised as cycles of excavation of approximately 8 m long modules, with the profile divided into two benches.

The primary lining consisted of steel TH arches or lattice girders, shotcrete and welded mesh. Forepoling was utilised in the lower part of the cross section. The primary lining was mostly 150 mm thick. The final support was designed with respect to the water table level. The cast in situ concrete lining (the invert, walls up to the top of the springing level) was performed using a single-sided formwork. The upper part (the vault) was lined with shotcrete. Measures improving its waterproofing properties were applied because the system has no waterproofing membrane insert. The thickness of the lining varies from 200 mm to 250 mm. Rubber waterbars are inserted into all expansion joints; construction joints were provided with bentonite-based hydrophilic waterstops. House service connections are driven in an uphill gradient toward the buildings façade; vertical cased boreholes were implemented for individual utilities from the end of the service connection drift to the connection points.

Currently, other utility tunnel routes are either under construction ("Vodičkova" utility tunnel – 1.263 km long), in the planning stages ("Wenceslas Square" utility tunnel – 2 routes 0.812 m long) or planned for the future ("Revoluční" – 0.905 km).

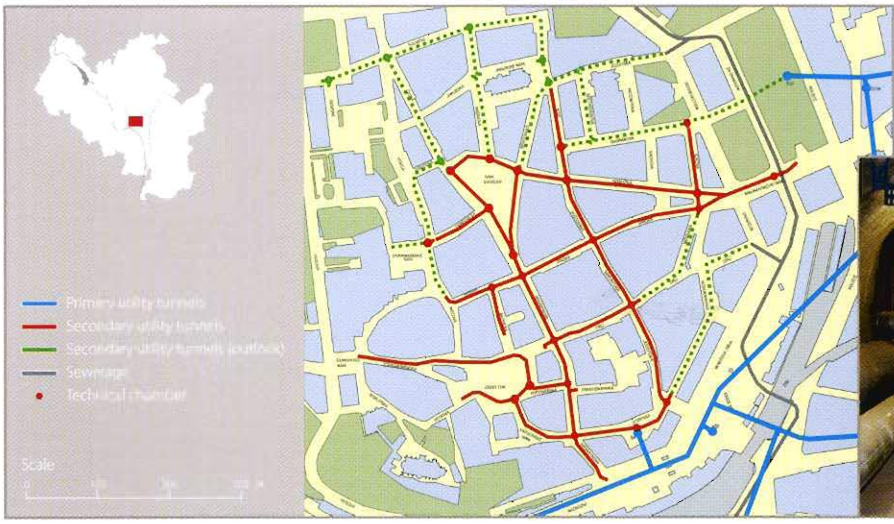
Mined utility tunnels in Brno

A two-stage system is proposed for Brno as well. The two systems differ in purpose, thus also in the placement in the rock environment. The deeper placed supply utility tunnels carrying media to the centre are referred to as primary tunnels; the closer-to-the-surface placed distribution utility tunnels connected to individual buildings are referred to as secondary tunnels.

The beginning of the construction of primary utility tunnels in 1971 was brought about by the need for solving the problem associated with the reconstruction of arterial roads and intersections in the centre of the city and the related refurbishment of main utility networks (the Křenová – Koliště – Dornych intersection where "Dornych – Křenová", the first utility tunnel, was built). The first "Master Plan for the Utility Tunnels Network" was developed in 1974. A revision carried out in 1978 defined two basic circles of primary utility tunnels: around the historic core and around the neighbouring industrial area, with a total length of 12 km.

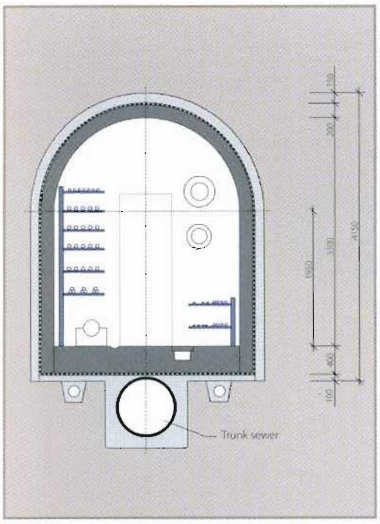
The first fulfilment of this intention took place in the 1970s and 1980s. A major part of the circle around the historic core of the city (at a length of 7 km) was built then, together with external branches leading to other residential zones, within the framework of a road reconstruction contract.

The second period of building utility tunnels in Brno is associated with the solution to functionality and with the process of increasing the capacity of utility networks in the historic core of the city, where one of the main problems had been a necessity for reconstruction of

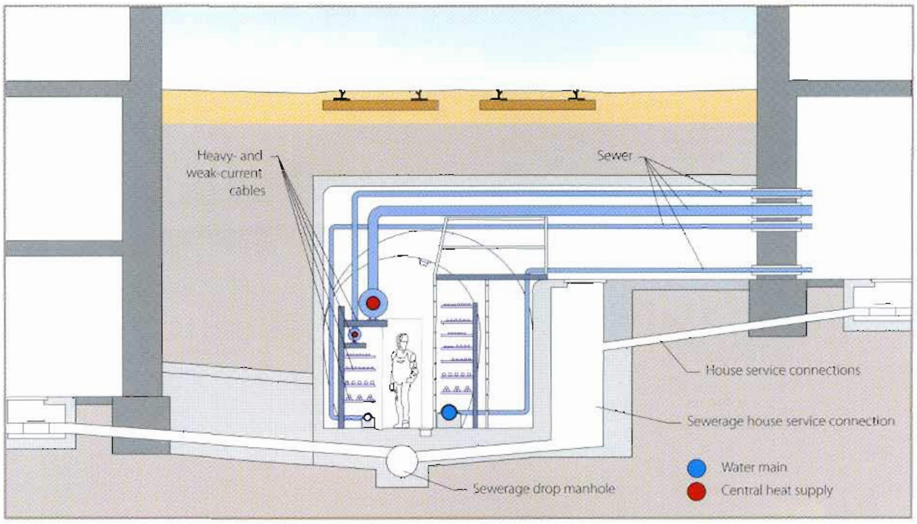


General layout of the utility tunnels in the central part of Brno

A primary utility tunnel



A cross section through
the secondary utility tunnel



Cross section through a connection utility tunnel

sewerage. For that reason, construction efforts since the end of the 1980s have been focused in particular on secondary utility tunnels, which are designed to supply surface buildings. The first study of the connection of individual blocks of buildings was developed in 1985; the master plan of the secondary utility tunnels proper followed in 1990. The length of the entire system being designed reaches 5.7 km. Prospective utilisation of secondary utility tunnels in Brno is also under consideration for the development area of Zvonařka, which connects to the southern part of the city centre. This comprehensively refurbished area allows construction of near-surface, cut-and-cover secondary utility tunnels. The 1994 territorial structure plan for the city of Brno solves the construction of utility tunnels conceptually and systematically from a longer-term perspective, in the context of the overall development of the city.

GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS

The composition of the geological profile in which the utility tunnels were built follows two basic formations:

- the upper layer of Quaternary sediments covered with man-made ground,
- the lower base layers of impervious Neogene calcareous clay (so-called "tégl").

Wherever the bedrock was encountered during the excavation, it consisted of layers of diabase and Devonian conglomerates.

The Quaternary base is mostly found at depths of 10 m–12 m under the surface. The two units can be distinguished in the horizons containing the Quaternary sediments. The underlying layers of sand, gravel-sand and gravel 2.5 m–4 m thick (significantly saturated at the base) are covered with layers of loess and secondary loess 5 m–10 m thick. Above these are mostly dense man-made deposits containing remnants of the original structures. The groundwater level is restricted to permeable gravel layers; it is found at a depth of 6m – 7m under the surface.

Neogene clay is stiff-to-hard when found at shallower depths and hard-to-very hard at greater depths. It is characterised by fissures and cracks with apertures which open due to deformations and then carry water both to the underlying layers and to the excavated opening. As a result, the clay at the bottom becomes muddy.

PRIMARY UTILITY TUNNELS

Apart from standard cable and pipe networks (e.g. 22–110 kV heavy-current cables and water mains DN 500–600), the primary utility tunnels built in Brno also contain pipelines allowing central heat supply (steam pipelines DN 700 and wet return pipelines DN 200, alternatively hot-water pipelines DN 400), as well as a compressed air line for future construction requirements. Gas distribution lines are not placed into the utility tunnel. The cross section of the utility tunnels is circular with a flat bottom and a net diameter of 3.4 m–5.1 m depending on the number of utilities housed in the tunnel (the maximum net height on the centre line is 4.8 m). The excavated cross section area varies from 10 m^2 to 26 m^2. Utility chambers are constructed at crossings and other route-branching points. Their horseshoe shape cross section has a net diameter of up to 7.8 m, the excavated cross section area is 75 m^2, and the chambers are 20 m–30 m long.

With respect to problems expected to emerge during the excavation through water-bearing gravel layers in the upper layers of sediments, the alignment of the primary utility tunnels was placed at a depth of 20 m–30 m below the surface, thus to the Neogene clay layers, with anticipated sufficient overburden consisting of impervious ground (7 m–27 m for utility tunnels, and 7 m–14 m for utility chambers). In reality, however, there was no guarantee that the clay would be impermeable due to the influence of the cracks in the clay. As a result, it was necessary to seal the lining.

The utility tunnels were driven from hoisting shafts sunk in advance. In the final state the shafts are utilised in particular for connection of networks placed into secondary utility tunnels or for connection of surface networks. A total of 40 shafts, 25 m deep on average, were built (including those used for ventilation and escape). A shaft-sinking method, utilising a cast-in-situ concrete ring lining provided with a cutting edge on the outside circumference, was used for the shafts found in the vicinity of streams and rivers (e.g. the Svratka, Svitava and Ponávka).

Traditional excavation, with the face divided into sequences, was carried out using the NATM. Individual faces were consistently supported with steel lagging anchored with rockbolts. The excavation was supported with steel TH frames and 150 mm of sprayed concrete and mesh. The final lining was also made of shotcrete with the thickness varying from 250 to 330 mm. Sealing of the rock behind the lining was solved by injecting grout into cracks. Deformations of the ground surface during the excavation reached 40 mm–120 mm; the extreme deformations originated due to anomalous inflows of ground water to the excavation.

A total length of seven kilometres of primary utility tunnels was completed till the end of the 1980s. The wealth of experience obtained during this construction, which was carried out in very difficult to predict environmental conditions, was further utilised at the construction of the secondary utility tunnels.


25 m
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SECONDARY UTILITY TUNNELS

These tunnels, designed in the Master Plan for the Utility Tunnels Network to be built in the historic centre of the city of Brno, were divided into 20 sections. At present, the following parts have been completed, at a total length of 5.7 km:

PHASE I – six sections at a total length of 1.790 km; completed in 2001.

PHASE II – five sections at a total length of 1.651 km; completed in 2005

The construction of the utility tunnels was co-funded by the ISPA fund of the European Union.

Together with cables, the secondary utility tunnels house water pipelines (with contingent differentiation according to pressure ranges), steam pipelines and wet return pipelines, and hot-water pipelines including return pipelines. As with primary utility tunnels, these were not used for the placement of gas pipelines.

On the other hand, sewers are a substantial part of secondary utility tunnels. The basic arrangement has sewerage placed under the tunnel floor. The sewer/sewers and the tunnel are one structural unit. The sewerage is separated from the tunnel space by tight covers. Where the original sewerage extended into the excavated cross section, it was continually connected to a substitute pipeline, without any interruption in operations.

The system of house-service connections was designed in Brno in a configuration based on the position of the tunnel branch, i.e. with the house service connection gallery connected in the upper part of the utility tunnel cross section, approximately 2.5 m above the tunnel floor. The advantage of this design is the invariable configuration of the placement of individual utilities along the utility tunnel, admittedly with the only access to the connection galleries being up a ladder. The direct connection to the surface buildings is carried out by drilling through façade walls. Depending on the difference between the elevation of the particular adjacent building and the gallery, a house sewer is connected either directly to the new sewer or via a drop manhole built next to the utility tunnel (in the case of shallower depth of the sewerage in the building).

The requirement for as short a length of the connection of the buildings being served as possible, combined with the condition for the excavation to lead above water-bearing sand and gravel layers, resulted in a necessity for as shallow a placement of the utility tunnel as possible. For that reason, the alignment was designed at a depth of 6 m–7 m below the surface, mainly in loess and secondary loess, locally even clay loam or dense man-made ground. A substantial part of the route passes above the foundation bases of adjacent buildings, which thus did not need underpinning. Specialised foundation techniques, such as jet-grouted curtains, were used only on an exception basis. Utility chambers for branching and crossing of the networks were the deciding factor in the design of the vertical alignment of the utility tunnel. According to the original concept, the chambers were to be built using the cut and cover method. However, this method was unacceptable with respect to its potential impact on the life of the city. Thus the chambers were mostly designed as mined structures with extremely shallow overburdens (locally only 0.8 m thick) where the operations were carried out without interruption to road traffic, although rail transit had to be suspended.

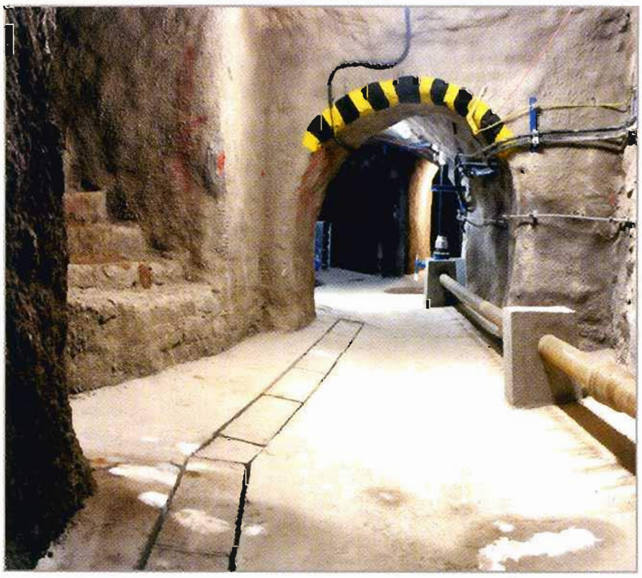
The secondary utility tunnels were excavated full-face; the excavated cross-section dimensions were of 3.4 x 3.8 m (about 10 m²). The horseshoe-shape cross section with basic net dimensions of 3.0 x 3.3 m was originally designed with curved and (later) straight sidewalls. The temporary lining consisted of steel TH arches or lattice girders, mesh, and a 100 mm thick layer of sprayed concrete. The subsequent final lining was built by attaching another layer of mesh and applying an additional layer of shotcrete up to a total thickness of 200–250 mm.

The mined technical chambers were built similarly. The sequentially excavated cross section was enlarged to net dimensions of 5.4 x 5.1 m (an area approximately 32 m²) along the length of the chambers. The temporary and final lining was similar to the lining of the common profile, although the thickness was increased to 100–250 mm.

Ground surface deformations never exceeded 20mm. In addition, successful load tests were carried out on the exposed structures of the chambers with a shallow cover, according to standards for load testing of civil engineering structures and load testing of bridges.

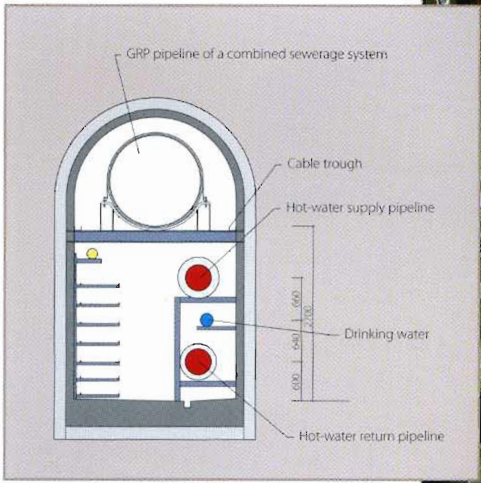
Mined utility tunnels in Ostrava

The intentions of building utility tunnels for combined routes of utilities in Ostrava were developed in the study "The Construction of utility tunnels in the extended historic core of Ostrava" in 1995. The commencement of the construction of utility tunnels in 1997 was an important event in the process of reconstructing Ostrava's networks. However, in a strict sense, it is not yet a systematic solution. The two structures which have been completed till now, despite the fact that they are closely connected, solve only local problems in the most critical localities of the centre. The main capital investment for both structures was the trunk sewers; the utility tunnels were only associated with them. Both the "Poděbradova" and "Centre" utility tunnels with a total length of 2.36 km were built in the years 1997–2005. The prospective length of the complete network of utility tunnels in Ostrava should amount to 8.270 km.



Connection of utility tunnels to the historic Brno underground

The composition of the geological profile in the centre of Ostrava is similar to the conditions existing in the other cities. Layers of Tertiary gravel and gravel-sand found in higher horizons are overlain with made-ground. The lower portion of the profile consists of a mighty series of measures of Miocene clay, which is referred to as the *Ostrava Marl*. The confined groundwater standing level fluctuates between 3.5 m to 4.5 m under the surface. Compared with the other cities, the urban concentration of Ostrava is unique because of the fact that the area is extensively undermined as a result of many years of coal mining in the past. For that reason, independent expansion blocks of the lining with a maximum length of 42 m had to be designed. In addition, pre-excavation cement grouting was carried out in the environment with worsened geological conditions, which resulted in a ground strength increase up to 1.5–2.0 MPa around the excavated space. Another complication to the construction was a possible occurrence of methane in the underground.



Cross section through "Centre" Ostrava utility tunnel


"Centre" Ostrava utility tunnel

THE PODĚBRADOVA CONSUMPTION UTILITY TUNNEL

Ostrava's first utility tunnel was built in 1997–1999. It is 0.7 km long. A uniform, circular cross section with a flat bottom was designed for the entire route of the tunnel, with a net area of 7.7 m², a net height of 2.6 m, and the width of the floor of 3.46 m. Individual services lead to the buildings through inclined cased boreholes. The overburden was 2 m to 3 m thick.

The underground excavation was carried out traditionally, divided into two phases comprising construction of the temporary and final linings with a total thickness of 200 mm. The lining was built from water-retaining concrete reinforced with lattice girders and welded mesh. The surface of the final sprayed layer was finished by trowelling to achieve a more economic application of the sprayed-on waterproofing. The tunnel floor was designed as an independent, 400mm-thick concrete slab anchored to the sub-base by means of grouted rock bolts to resist the buoyancy forces. The waterproofing of both the floor and vault was provided using a system based on crystallisation processes.

"CENTRE" CONSUMPTION UTILITY TUNNEL

The construction of the "Centre" consumption utility tunnel was carried out in 2002–2005. It was incorporated into the "Ostrava Sewerage System Extension" project, which was, thanks to the efforts of the municipality, co-financed in the European Union's ISPA fund. The utility tunnel is situated in the eastern and southern parts of the city. In the layout it is connected to the "Poděbradova" utility tunnel. The total length of the tunnel amounts to 1.658 km. The gallery housing the sewer connecting the sewerage system to the treatment plant is also part of the construction.

The specific character of this utility tunnel is based on the current reconstruction of the sewerage system by means of its incorporation into the utility tunnel structure. With respect to the gradient-related conditions in the centre of the city, the sewer is installed under the ceiling of the tunnel. This solution predetermined the necessity for a vertically elongated horseshoe shape profile with a net width of 2.5 m and a height of 2.9 m to 4.4 m. The tunnel excavation bottom is designed at a depth of 10 m below the surface; the overburden thickness varies from 2.7 m to 6.2 m. Thus the profile extends into the gravel, while the bottom is embedded in Miocene clay. The entire cross section is below the water table.

The centrifugally cast GRP sewerage pipes, with a maximum diameter of 1400 mm, are placed under the ceiling, on beams. The other lines are installed on composite brackets on the sidewalls.

Because of unfavourable and variable geological conditions, the excavation carried out using traditional mining procedures had to be protected by jet grouting, both above the vault and in the face. With respect to the high cross-section of the tunnel, the excavation had to be divided into two benches within a major part of the tunnel length.

"Centre" Ostrava utility tunnels with sewerage pipeline installed under the ceiling

The lining was built in the same way as the "Poděbradova" utility tunnel – in two phases, in combination of lattice girders, welded mesh and shotcrete applied in two stages. The waterproofing was also provided by a crystallising coat on the internal surface of the concrete lining.

Mined utility tunnels in centres of historic towns

The long-term development of many Czech historic towns gave rise to historic and architectural works of significant values in the core areas of the towns. Extensive development of towns on the outskirts led to stagnation of the historic centres, thus the infrastructure networks gradually wore out. For that reason, systematic activity commenced at the end of the 1960s and was focused on a comprehensive regeneration of historic town centres, including the rehabilitation of extensive underground spaces, underpinning of surface buildings, and regeneration of technical infrastructures.

The prime concern was the rehabilitation of historic underground spaces directly connected to historic basements of surface buildings, as well as structural surveys. This aim was closely associated with the necessity for a consistent drainage system allowing control of the water table level and stabilisation of surface buildings. This issue was solved, together with the overall renovation of utility networks (which had to be carried out as required by the care of historic monuments, i.e. with minimum interference with the most valuable cultural horizons). Integration of the networks in underground, near-surface tunnels was the only solution. The particularity of this solution is the narrow relationship with the stringent and often limiting conditions of the care of historic monuments, as well as the need for qualified underpinning and strengthening of structures of adjacent historic buildings. Detailed engineering, geological and other surveys, often carried out above and beyond what was required, formed a crucial basic documentation package.

The concept of placing utility networks in historic towns in tunnels resulted in the development of rehabilitation programs for the towns of Tábor, Jihlava, Český Krumlov, Kutná Hora, Brno, Nové Město nad Metují, and Žatec. The highest intensity of investment in the underground was in Tábor, Jihlava and Český Krumlov. For that reason, the design of utility tunnels in these towns is described in greater detail below. Regarding the other towns, the projects have remained in the planning stage. Only a minor part has been constructed, though not completed and therefore operating at a minimum. This poor condition of the infrastructure continues to deteriorate, and can only be resolved by limited rehabilitation of the worst spots and emergency repairs.

UTILITY TUNNELS IN TÁBOR

The historic centre around Žižkovo Square has been a listed national monument for a long time. An overall rehabilitation of the historic part of the town commenced in 1968. It consisted of three concurrent operations:

- Structural support of the historic underground
- Reconstruction of utility networks
- Rescue of the town's fortifications

Subsequent surveys discovered and documented historic underground galleries at a total length of 14km. The galleries had been successfully rehabilitated by 1980. Parts of the galleries were made accessible to the public as a sightseeing route through the town's medieval underground.

Interconnection of Tábor utility tunnels with the historic underground of the town

After the refurbishment, work began on the renovation of the infrastructure by placing utilities into tunnels driven under individual streets. The concept, developed in 1973, was based on a design comprising two levels – comparable to those of the utility tunnels, i.e. low placed tunnels for distribution purposes forming a closed circle around the centre, with branches extending to the peripheral zones, and even lower placed consumption-purpose tunnels, which are connected to individual buildings. The design of the utility tunnel system was adjusted to allow the gravitational drainage of all types of water (foul, rain and ground water) from the historic core of the town. The design requires that all 336 buildings within an area of 27.8 hectares be connected. The total length amounts to 7.9 km. Currently, only part of the excavation of the supply utility tunnel arterial circle, with part of the branches at a total length of 1.2 km, is complete. Unfortunately, the construction site is at a standstill and is still waiting to be utilised.

The completed excavation of the underground galleries so far was carried out using traditional methods. It passed through rock mass consisting of syenite weakened by numerous cracks, which conveyed water to the underground from the surface or from defective pipelines. Owing to the fact that the centre is situated on an elevated projection of rock, the thickness of superficial deposits is relatively small.

UTILITY TUNNELS IN JIHLAVA

The historic part of the urban conservation area in Jihlava occupies an area of 32.7 hectares. It comprises 526, of which 213 buildings are protected. Medieval galleries are found underneath, in slightly-weathered to weathered parts of the bedrock consisting of metamorphosed rock, at levels ranging from 4 m to 10 m. The total length of the galleries amounts to 25 km. The entire system, which consists of up to three levels, is a remnant of medieval fortification work. Apart from other purposes, this underground space was also utilised for drainage of sewage and rainwater underneath the ramparts outside the town.

Because the medieval galleries ceased to fulfil their role of drainage as a result of minimum maintenance and the development of the town, a priority task, which was brought about by the decision to build the utility tunnels, was to solve the need for the evacuation of excessive water found in the underground by using a gravity flow principle (analogous with Tábor's). The design and subsequent construction of the utility tunnels network took place in 1984, when the support of about 80 per cent of the underground galleries had been completed. The design concept was based on the following divisions of the utility tunnels, according to their functional utilisation:

- The main route of the supply utility tunnel – positioned at the lowest level, about 20 m under the surface, with a cross section area of 16 m^2, and the length of 2.9 km.
- Intermediate-level utility tunnels – in terms of their function, they are connected with the higher level, about 16 m under the surface; a cross section area of 10 m^2, and a length of 4.5 km.
- Distribution utility tunnels of the upper horizon – these originated

The Jihlava utility tunnel

by adaptating the existing historic galleries, or by excavating a new profiles with the cross section area of 9 m^2 approximately 8 m under the surface. The length of the entire system connecting the basements of the buildings amounts to 11.8 km.

The system was designed to have a length of approximately 19 km. The routes contain shafts which connect individual levels with each other, and utility chambers for junctions and branching of the networks. Also, road gullies are connected through the shafts at the highest level. The placement of combined sewers and drainage of the mined works was designed for all levels. Till now, however, only 1.7 km of the ambitious 19 km have been completed. This section houses a combined sewer and water main.