LONG RAILWAY TUNNELS – COMPARISON OF MAJOR PROJECTS

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INTRODUCTION

The third railway corridor is planned to provide Trans European high-speed railway connection including Prague – Nurnberg (Germany) via Pilsen. Originally, a modernisation of the existing railway route between Prague and Beroun along the Berounka River was planned. Further studies proved that the existing railway route in this section can not be modernised to reach a required high-speed track parameters; area along the existing railway route is densely populated, moreover current route lies very close to the protected landscape area Czech Karst. Provided feasibility studies led to the decision to build about 24.7km long high-speed railway tunnel between Prague and Beroun (Krása et al. 2007). A preliminary design was completed in 2007, construction start is planned for 2011, and the project is expected to be completed in 2016.

The tunnel is expected to have two single-track tunnels connected with cross-passages with spacing of 400m. The tunnel diameter, now in verification process, would be around 8.3m, similar to the Alptransit size. Neither crossover chambers nor emergency stations are planned inside the tunnel at the moment. Turnout chambers (bifurcations) are proposed in both single-track tunnels close to Prague portals to provide possibility for trains to reach two different destinations in Prague, either Prague Smichov and Main Railway Station (passenger trains) or to Prague Krč (freight trains). Proposed design speed of the tunnel is over 200kph.

Straight connection of both defined portals would mean predominant excavation through limestone with karstic features under the protected landscape area (Czech Karst). Due to doubts about feasibility of effective and safe excavation in so far unknown geological conditions, a decision has been made to divert straight tunnel route northwards and reduce an excavation through the karst. Selected variant of the route is slightly longer in comparison with other alternatives, but it is supposed to reduce geological and environmental risks significantly. (karst is expected on significantly shorter sections). The tunnel will be excavated under the water table mainly through sedimentary rocks (shales, limestones) of ordovicien age, partly through volcanic rocks (basalts) with maximum overburden of about 100m. Majority of the tunnels will be excavated using TBMs, but significant excavations will also be realised using NATM (bifurcations, Prague approaches, cross-passages, access tunnels, etc.). All excavation in karst (close to Prague portals) are expected be realised using NATM.

The project is very unusual for the Czech Republic tunnelling industry due to tunnel length, TBM excavation, project preparation fast track schedule, and expected excavations in karst. D2 Consult is employed on the project by Client (Railway Infrastructure Administration) to provide a technical assistance, checking project preparation schedule, proving basic decisions and providing international expertise and experience. A preliminary design was carried out by the Czech consultants Metroprojekt a.s. and Sudop a.s.

THE LONGEST RAILWAY TUNNELS – CURRENT STATUS

Table 1 presents the world's longest, modern rail tunnels; older tunnels (e.g. the approximately 20km long Simplon tunnels from the beginning of the 20th century) are not shown. It is obvious from the table that the planned Prague – Beroun tunnel belongs among the longest rail tunnels in the world. There are not many longer tunnels worldwide. So far, only 5 tunnels longer than 25km have been opened (Seikan, Eurotunel and Iwate – Ichinohe, Lotschberg, Guadarrama). Other two tunnels with the length reaching 25km should be finished by 2010 (the Hakkoda and Pajares tunnels), and other three (the Gotthard, Koralm and Iyama) by 2016.

Table 1 - The longest modern railway tunnels

Tunnel	Location	Length (km)	Commis sioning	Status	Arrangement	Safety measures
Gotthard	Switzerland	57	2015	construction	Two single-track tunnels	2 multiple-function stations
Brenner	Austria - Italy	56		planning, surveys	Two single-track tunnels with a parallel escape gallery	3 multiple-function stations with an access to the surface
Seikan	Japan	54	1988	operation	One double-track tunnel with an escape gallery	2 emergency stations, service tunnel connected with the main tunnel every 600 - 1000m (shafts, galleries)
Lyon - Turin	France - Italy	53	2020	planning, surveys	Two single-track tunnels	4 emergency stations with an access to the surface
Eurotunnel	England - France	50	1994	operation	Two single-track tunnels and one service tunnel	2 crossover chambers
Gibraltar	Spain - Morocco	37.7		planning	Two single-track tunnels and one service tunnel in the middle	Parallel service tunnel throughout the length
Lotschberg	Switzerland	34.6	2007	operation	Two single-track tunnels (partially a single-track tunnel and a gallery)	2 stations – one service st. and one escape st.
Koralm	Austria	32.8	2016	planning, surveys	Two single-track tunnels	Emergency station in the middle of the tunnel length, without access to the surface
Guadarrama	Spain	28.4	2007	operation	Two single-track tunnels	500 m long rescue tunnel in the middle; cross passages every 50m, emergency chambers every 2250m
Hakkoda	Japan	26.5	2010	construction	One double-track tunnel	
Iwate-Ichinohe	Japan	25.8	2002	operation	One double-track tunnel	
Pajares	Spain	24.7	2010	construction	Two single-track tunnels	

Prague-Beroun	Czech Republic	24.7	2016	planning	Two single-track tunnels	Escape exit in the middle
Iyama	Japan	22.2	2013	construction	One double-track tunnel	
Wushaoling	China	22.05		operation	Two single-track tunnels	
Vereina	Switzerland	19	1999	operation	One single-track tunnel, partially one double-track tunnel	Without escape exit
CTRL (London)	England	19	2007	operation	Two single-track tunnels	Ventilation and escape shafts at max. spacing of 3km
Vaglia	Italy	18.7	2010	construction	One double-track tunnel	8km long service tunnel in the middle part, cross passages every 250m
Qingling	China	18.5	2002	operation	Two single-track tunnels	
Ceneri	Switzerland	15.4	2018	planning	Two single-track tunnels	Escape exit in the middle, branching off in the tunnel
Firenzuola	Italy	15.2	2010	construction	One double-track tunnel	Escape galleries 380m to 1500m long
Wienerwald	Austria	13.35	2012	construction	Two single-track – 10.75km One double-track – 2.37km	3 emergency exits and a smoke control cavern and vertical shaft
Bussoleno	France - Italy	12.5	2020	planning	Two single-track tunnels	
Lainzer	Austria	10.6	2012	construction	Two single-track – 2.3km One double-track – 8.3km	Emergency exits every 120 – 599m
Katzenberg	Germany	9.4	2012		Two single-track tunnels	Ventilation shafts
Zimmerberg	Switzerland	9.4	2003	operation	One double-track tunnel	
Perthus	Spain	8.3		construction	Two single-track tunnels	4 cross passages for equipment (1.6km spacing)
Storebaelt	Denmark	8		operation	Two single-track tunnels	Emergency ventilation, monitoring and control system
Marseille	France	7.8	2001	operation	One double-track tunnel	Without emergency exit, without ventilation
Abdalajis	Spain	7.3		construction	Two single-track tunnels	
Groene Hart	Netherlands	7.16		construction	One double-track tunnel, tracks separated by a wall with escape doors	3 escape shafts at 2.3km spacing

CONFIGURATION CONCEPTS

In the past, the double-track configuration was mostly designed for railway tunnels on double-track lines; two single-track tunnel tubes were used, first of all, in unfavourable geological conditions, where the smaller excavated area meant safer excavation processes. Today, with respect to higher design speeds and, above all, more demanding safety requirements, the configuration with two single-track tunnels connected by means of cross passages (see Table 3) is more and more often given preference. Existing tunnels have to cope with requirements for provision of additional of escape exits (parallel galleries with cross passages or escape shafts). Even further, some tunnels are designed as two railway tunnels with a parallel service or escape tunnel, which is, of course, the most convenient solution in terms of safety; on the other hand, this solution means the highest cost.

In all of the cases of European tunnels longer than 20km, opposing tracks are placed in two independent tunnel tubes, which are connected at regular intervals by cross passages. The third tunnel for services or escape services was implemented only in the case of the Eurotunnel (50km) and it is planned for the Brenner base tunnel (56km). The concept of a single, double-track tunnel longer than 20km is preferred only in Japan. The longest operating double-track tunnels are the Seikan (54km) and Iwate-Ichinohe (26km). In addition, the construction of the Hakkoda (26.5km) and Iyama (22km) double-track tunnels is currently underway in Japan. The concept of the Swiss tunnel Vereina (19km) is absolutely exceptional in terms of long tunnels. It is a single-track configuration throughout the major part of its length, without any escape exit. Although, this is a tunnel designed for low design speed, narrow-gauge trains. The longest double-track tunnels in Europe will be the Vaglia (19km) and Firenzuola (15km) tunnels in Italy, on the Bologna – Florence rail line. The lengths of all other double-track tunnels in Europe do not exceed 10km.

UNDERGROUND STATIONS

The safety concept of long railway tunnels very often incorporates underground stations. The reason is the intention to limit the length of travel of a passenger train to a safe place, in the case of a threat to passengers' life, to 20km. The safety stations are usually equipped with sufficient spaces and adequate ventilation, enabling passengers to wait for the arrival of a rescue train. The stations have usually the form of tunnels, parallel with the running tunnels, which are connected with the running tunnels by cross passages at about 50m intervals. Thanks to the necessity for the ventilation of the stations, the stations are usually connected with the surface through access tunnels and shafts.

The Gotthard base tunnel (57km) comprises 2 underground stations, i.e. the Sedrun and Faido. The Lotschberg base tunnel (34.6km) comprises one underground station, the Ferden station. The Brenner base tunnel (56km) will have 3 underground stations; the Lyon – Turin base tunnel (53km) will comprise 4 underground stations; the Koralm tunnel (32.8km) will have one station with a service tunnel in the middle of its length; similarly, the Guadarrama tunnel (32.8km) will have a 500m long area with a service tunnel, roughly in the middle of the tunnel length.

CROSSOVER CONNECTIONS AND TRACK BIFURCATIONS IN TUNNEL

Crossover connections between two single-track tunnels were designed for the majority of long rail tunnels. Long, double-track crossover chambers were built in the case of the Eurotunnel; in the other cases, the switching is solved through single-track tunnels running at an angle and connecting the main running tunnels (e.g. the Gotthard, Lotschberg, Brenner, Pajares and other tunnels). The cases where no crossovers were designed are infrequent (e.g. the Koralm tunnel).

Bifurcation of the track is usually designed to be outside the tunnel; the track bifurcation inside the tunnel is not a common configuration. This configuration, however, is impossible to avoid in some specific cases. The track bifurcation inside a tunnel configuration will be used, for example, within the cut and cover section of the Wienerwald tunnel; further it is planned for the Brenner base tunnel and the Ceneri base tunnel. As far as the Prague – Beroun tunnel is concerned, all hazards associated with the branching off from a high-speed railway tunnel and the influence of this solution on the operation will have to be examined.

INTERNAL DIAMETER OF SINGLE-TRACK TUNNELS

The inner diameter of single-track tunnels depends on many factors (the anticipated trains, the system of fixation of the contact line, design speed etc.). Owing to this fact, this parameter significantly varies for various tunnels. Table 2 presents inner diameters of some long single-track tunnels.

Tab.2 Internal diameters of long rail tunnels

Tunnel	Location	Length	Speed	Commissioning	Internal diameter
Gotthard	Switzerland	57 km	250 kph	2015	8.30 m
Eurotunel	France - England	50 km	160 kph	1994	7.60 m
Lotschberg	Switzerland	34.6 km	250 kph	2007	8.40 m
Guadarrama	Spain	28.4 km	350 kph	2007	8.50 m
Pajares	Spain	24.7 km		2010	8.50 m
CTRL	United Kingdom	19 km (36.8 km)	270 kph	2007	7.15 m
Katzenberg	Germany	9.4 km	250 kph	2012	9.40 m
Perthus	Spain - France	8.3 km		Construction	8.70 m
Storebaelt	Denmark	8 km	160 kph	Operation	7.70 m
Abdalajis	Spain	7.3 km	350 kph	Construction	8.80 m

The smallest of the above-mentioned inner diameters have the British tunnels –Channel Tunnel Rail Link (CTRL) – 7.15m and Channel Tunnel (Eurotunel) – 7.6m. Both tunnels are on one rail line between London and Paris. The reason for the minimisation of the profiles was an effort for the minimisation of the resultant cost. The Eurotunnel is used by both common UIC (International Union of Railways) trains and higher capacity freight trains. The CTRL is designed only for UIC trains, which is the reason why even a smaller profile could be achieved than that of the Eurotunnel. The ratio of the train cross-sectional area to the tunnel cross-sectional area (the so-called blockage ratio) which was designed for the Eurotunnel is high. The ratio for the UIC trains is 25%, whereas the ratio for freight trains is even 50%. Naturally, the higher ratio means higher resistance of air during the train travel. For that reason, pressure-relieving ducts were designed for the Eurotunnel. The ducts connecting the rail tunnels (running over the service tunnel) are installed at 250m spacing. This system allows the air which accumulates in front of the locomotive to be diverted to locations where the pressure is lower. Of course, all tunnel equipment had to be accommodated to the minimum space.

The dimensions of the inner profiles of the Swiss base tunnels Lotschberg and Gotthard were successfully reduced to 8.3m. Similarly to British tunnels, the reduction required many non-standard measures. Because of the high design speed, non-standard fixation of the contact line had to be designed to withstand the dynamical air pressure load. Of the above-mentioned examples, the Katzenberg tunnel in Germany has the largest profile, 9.4m diameter. The reason for the larger profile of this tunnel was the fact that design allowed the additional installation of an inner lining in the future.

LOCATION OF CROSS PASSAGES AND EMERGENCY EXITS

It is considered necessary that a long rail tunnel must give passengers the opportunity to escape to a safe space in the case of an emergency. The safe escape therefore depends, first of all, on the length of the escape route to a cross passage or a tunnel exit (portals, escape tunnels or shafts). Tunnel cross passages are a standard means of securing safety in the case of a twin-tube tunnel. The proper choice of the spacing of the cross passages is therefore of utmost importance. The choice of the spacing of cross passages depends on many factors (requirements of fire brigades, anticipated scenarios of emergencies, tunnel dimensions, properties of materials used in the tunnel and trains etc.). This is the reason why the spacing of cross passages significantly varies for different projects.

The overview of the spacing of cross passages or escape exits is presented in Table 3. In general, the spacing of cross passages in the cases of a pair of single-track tunnels varies between 250m (Guadarrama, Great Belt) and 500 m (Koralm, Katzenberg, Wienerwald; the planned spacing of 350m in the Channel Tunnel Rail Link (CTRL) was even increased to 750m. In the case of a double-track tunnel, the length of escape routes is in some cases even much greater. The Vereina tunnel (19km) and Marseille tunnel (7.8km) have no exit routes; the length of escape routes in the Firenzuola and Vaglia tunnels, which are currently under construction, will exceed 4km.

Tab.3 Spacing of cross passages and escape exits

Tunnel	Length	Commis sioning	Configuration	Spacing of cross passages / escape exits
Groene Hart	7.16km		One double-track tunnel with a dividing wall	Doors – 150 m
Perthus	8.3 km		Two single-track tunnels	200 m
Storebaelt	8 km		Two single-track tunnels	250 m
Guadarrama	28.4 km	2007	Two single-track tunnels	250 m
Ceneri Base Tunnel (CBT)	15.4 km	2018	Two single-track tunnels	320 m
Gotthard	57 km	2015	Two single-track tunnels	325 m
Lotschberg	34.6 km	2007	Two single-track tunnels (partly one single-track plus a gallery)	333 m
Brenner Base Tunnel (BBT)	56 km		Two single-track tunnels	333 m
Abdalajis	7.3 km		Two single-track tunnels	350 m
Eurotunel	50 km	1994	Two single-track tunnels plus one service tunnel	375 m
Lyon - Turin	53 km	2015	Two single-track tunnels	400 m
Bussoleno	12.5 km	2015	Two single-track tunnels	400 m
Koralm	32.8 km	2016	Two single-track tunnels	500 m
Katzenberg	9.4 km	2012	Two single-track tunnels	500 m
Wienerwald	13.35 km	2012	Two single tracks 10.75 km One double-track 2.37 km	500 m
Seikan	54 km	1988	One double-track tunnel	600 – 1000 m
CTRL	19 km (London)	2007	Two single-track tunnels	750 m (original plan: 350 m)
Lainzer	10.6 km	2012	Two single tracks 2.3 km One double-track 8.3 km	Spacing of escape exits: 120 – 599 m

Vaglia	18.7 km	2008	One double-track	Spacing of escape exits: up to 4500 m
Firenzuola	15.2 km	2008	One double-track	Spacing of escape exits: up to 5000 m
Marseille	7.8 km	2001	One double-track	Without escape exits
Vereina	19 km	1999	One single-track (6km double-track)	Without escape exits

CONCLUSION

The main purpose of a presented paper was to summary basic features of long railway tunnels and to compare proposed parameters of the tunnel Prague – Beroun to similar structures. The decisions about tunnel concept, tunnel diameter, and distance of emergency exits have to be done in early stages of the design process. These decisions are crucial and they have a mar-ginal impact on the final cost. It can be seen from the presented data that main features of very long tunnels vary very sig-nificantly. There are many reasons of this situation: missing standards (long tunnels have to be treated individually), amount of money available for the project, time available preparation and design, safety requirements in various countries, etc. In each case maximum effort should be made to optimise the design and to reduce final cost with retained safety. Currently prepared tunnel Prague – Beroun will be one of the longest railway tunnels after its completion. Presented data showed that proposed basic features of this tunnel generally com-ply with concepts of the similar tunnels.

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