

TUNNELS: CHALLENGES OF TODAY AND TOMORROW

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ABSTRACT

The use of underground space is winning more and more importance all over the world. This development is justified by the proven positive impact of subsurface construction especially to densely built-up areas. Those activities contribute as one of the key tools for getting our cities more worthwhile to live in as well as more loveable and to form the social and hygienic basis for the increasing number of megalopolises.

1. STARTING SITUATION

Modern industrial societies require an efficient and reliable transportation infrastructure. This applies to roads as well as railways and mass transit systems. Against this background it cannot surprise that at present, the overall length for operational transportation tunnels throughout all of Europe is well in excess of 15,000 km.

Tunnelling and transport tunnel construction in particular has gained increasing importance both in Europe and internationally during the past 10 to 15 years. This development seems bound to continue over the years ahead. The reason is provided by the results of a recently completed study by the Viennese Academy of Sciences. It carried out an extensive survey on behalf of the Austrian Automobile and Touring Club on how **passenger and goods traffic** has developed in Europe. It reveals according to Haack¹ that private motoring in Europe will rise by around 20 % by the year 2010 compared with 1997, and by as much as about 40 % by 2030.

Forecasts by more than 100 internationally recognized scientists, who estimate that freight traffic in Europe will rise by about 60 % during the next 30 years, follow a similar pattern. This means that Europe's highways will come ever closer to reaching their capacity in the near future thus introducing more stop than go for traffic than ever (Fig. 1).

Other surveys are no less pessimistic. The OECD (Organisation for Economic Cooperation and Development) for instance, reckons that by the year 2020, there will be roughly a 50 % rise in the number of vehicles on Europe's roads compared with today.

There is a further aspect that gives rise to an increasing need for underground transportation facilities. It derives from the **growth in the world's population and ever increasing urbanisation**. In 1995, roughly 45 % of the world's population lived in cities. By 2015, this proportion will have risen to some 55 %. The following scenario is provided by considering the developing nations alone: In 1995, around 39 % of the population there lived in cities. However, by 2015, the figure will probably have grown to no less than 50 %. As far as the

industrialised countries are concerned, as much as 75 % of the population lived in cities in 1995. This figure is due to rise to around 80 % by 2015. All in all, it can be assumed that on a worldwide scale at present, the urban population is growing by some 60 million inhabitants annually.



Figure 1 Traffic jam on a highway in Germany

Further predictions indicate that by the year 2015, around 10 % of the urban population will be living in so-called mega cities with more than 15 million inhabitants. Of this kind 26 mega cities are anticipated, distributed all over the globe, with no less than 18 of them located in Asia (Fig. 2). The use of underground space will be required to a high degree to make sure that such mega cities and expansive urban regions in general are capable of functioning so that the quality of life is assured. This applies to transport tunnels as well as to supply and disposal facilities and the storage of goods.



Figure 2 Shanghai, Metropolis in China

In view of such developments, it is imperative that new logistics concepts, new ways to secure mobility and also new supplementary measures to improve the infrastructure are found. One solution is certainly to be found in exploiting the chances afforded by tunnelling pertaining to the overall securing of mobility, speeding up transportation processes and essentially for protecting the environment and countryside as well. As a consequence, the latest statistical data give rise to the **expectation of substantial tunnelling activities** on a worldwide scale over the next 10 to 15 years (Fig. 3).

The following figures relate to transport tunnel construction for Europe alone:

- approx. 465 km in Germany (according to Haack²)
- approx. 260 km in Austria
- approx. 300 km on the Iberian Peninsula (Spain and Portugal)
- approx. 150 km in France
- approx. 200 km in Italy and
- approx. 500 km in Scandinavia.



Figure 3 Constructing a traffic tunnel by using the sequential excavation method

In summing up, the European tunnelling market can expect a total construction volume of around 2,100 km in the years to come. Immense efforts designed to improve the infrastructure are being planned in other parts of the world as well. Statistics relating to the Asian market indicate a volume of around 2,350 km for future transport tunnel projects. Roughly 650 km of transport tunnels are scheduled for construction in South America within the next 10 to 15 years and at least the same magnitude on the North American continent. Australia and northern and southern Africa are also planning tunnelling projects, but to a considerably less degree.

The current and future **major tunnel projects** undoubtedly represent particular challenges. In this connection, the Gotthard Base Tunnel (Fig. 4), the Lötschberg Base Tunnel, the Brenner Base Tunnel and the tunnel between Lyon and Turin should be mentioned here, some of which are already being built or are very far advanced in terms of the design and decision-making process. Further projects of this size have already been envisaged in various regions of the world. These include passing under the Straits of Gibraltar between Morocco and Spain or under the Tartar Strait between Russia and the Russian peninsula of Sachalin with a further link to Japan or under the Bering Strait between Russia and Alaska (USA). All these projects represent driven lengths of between 30 and 60 km or even more. They call for special consideration relating to the driving technology, their subsequent operation and thus in turn, the safety concept.

2. SIGNIFICANCE OF SUBSURFACE CONSTRUCTION

Generally speaking, we experience our cities from the surface. We can find our way around here, can recall certain groups of buildings and are thus aware at any time just where we are.

In cities with which we are unfamiliar, we can obtain decisive initial impressions when encountering it for the first time and compare and evaluate the character of the place we are visiting with towns we have got to know before. This normal pattern of behaviour also explains why so many of our fellow human beings prefer transportation systems which are on the surface.



Figure 4 Tunnel excavation for the Gotthard Base Tunnel, Switzerland, section Bodio-Faido, using a TBM

Most inhabitants of a city as well as its visitors are far more familiar with the structure above ground than the multifarious infrastructure below the surface of the earth. Supply lines for gas, water, electricity, telecommunications and distance heating are located here along with a diversified network of disposal lines (Fig. 5). In large cities, there are also transport tunnels for rail commuter traffic, long-distance trains, motor vehicles and pedestrians. In many cases, this subsurface urban landscape is rounded off in built-up areas by private transport tunnels, underground garages, with as many as four or five storeys in the case of large administrative buildings, subterranean shopping malls and storage rooms, covered watercourses and many other special facilities.

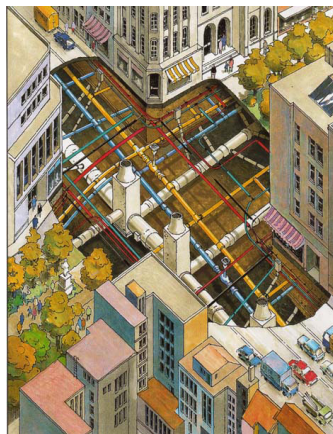


Figure 5 Variety of the underground infrastructure of a city

Should local conditions demand and facilitate this, even production halls, offices, sports facilities and churches are set up underground. In this connection, especially impressive examples are to be found in North America, Japan and Scandinavia.

Our modern cities are almost incapable of sustaining themselves without this subsurface infrastructure, which is not identifiable at first glance. This very soon becomes evident when the chaotic conditions prevailing in some cases in the multimillion cities on the African, Asian and South American continents are taken into consideration. This does not simply apply to the hopelessly congested streets in the downtown areas. If anything, it is shown here too that a subsurface infrastructure represents an important prerequisite for public health right up to banishing the danger of disease. Even during the 1990s of the last century, this has been clearly underlined through examples of cholera and plague epidemics in parts of Central and South America as well as on the Indian sub-continent.

The overriding significance of an inner urban subsurface infrastructure in order to create decent conditions in the major built-up areas was once again emphasised not all that long ago at the United Nations HABITAT-II Conference in Istanbul, Turkey, in June 1996. More than 15,000 delegates from all over the world mulled over and discussed the prerequisites for humane living conditions in human settlements taking the varying climatic, topographical and cultural marginal conditions in different regions of the globe into account.

Apart from the built-up areas themselves, the utilisation of underground space is experiencing high and ever increasing significance in less densely populated regions. Attractive and fast transport links between industrial centres call for high-performance transport arteries for the economic, speedy and unhampered carriage of people and goods. Important impulses for the economic power of a region or nation are provided by transport development and links. As a consequence, tunnels for roads and railways are being built or planned to a great degree for crossing mountain ranges, rivers and straits.

Let us briefly mention at this point that apart from the use of underground space for civil purposes, there is in some cases, exploitation world-wide for all kinds of military facilities. The construction and maintenance of these facilities possess a not inconsiderable economic importance.

There is no doubt that the construction of transport tunnels and subsurface construction in general has reached a high standard in many countries.

In more than 100 cities with populations in excess of 500,000, metros, urban railways or rapid transport systems travelling beneath the surface in inner urban areas have been built or further developed during the last 30 to 40 years. In Europe, Berlin, Budapest, Hamburg, London and Paris are numbered among the first cities starting with such modern rail commuter systems at the end of 19th, beginning of 20th century.

In conjunction with building tunnels for long-distance road and rail links, in Europe, first and foremost, the efforts which started in the early 1980s to develop high-speed rail traffic deserve mention (Fig. 6). A number of these new lines possess a very high proportion of tunnels between say 30 and 40 per cent with overall section lengths of 100 to 350 km. Basically, the situation world-wide is similar as e.g. in Japan, or plans drawn up in Taiwan, South Korea as well as other countries.

In summing up, it can be established that currently there are a number of countries which are extremely active in tunnelling (Fig. 3). In Germany for instance, contracts were awarded for roughly 25 km of transport tunnels annually on average during the last ten years, which were then completed following a commensurate length of time. 10 to 12 km of this total is accounted for by metro, urban and rapid transit system tunnels, some 5 km by long-distance rail tunnels and around 10 km by road tunnels. For the years to come, an increase especially with respect to long-distance rail tunnels can be anticipated. Mining has not been included in this study.



Figure 6 Fast train in a tunnel (example of TGV)

Currently, the overall length of operational transport tunnels in Germany alone can be accepted to amount to roughly 1,200 km. Throughout Europe, the figure is well in excess of 15,000 km, in other words, far more than from Lisbon to Moscow and back! The situation elsewhere in the world, for instance in North America or in South-East Asia is similar.

3. EFFECTS OF SUBSURFACE CONSTRUCTION ON THE ENVIRONMENT

"Till the earth and subdue it!" This biblical saying from the First Book of Moses (Genesis), Chapter 1, Verse 28 calls for a high degree of responsibility not only vis-a-vis one's fellow human beings but also with regard to dealing with nature and the world around us in a responsible fashion. Tunnelling and underground construction in general can afford a considerable contribution in this respect. Many examples from all over the world have been able to underline this, particularly over the past years.

Thus the financial efforts which have gone on in Europe, North America and Japan for some three to four decades now in conjunction with constructing metros, the relocating of especially busy roads in inner urban areas at greater depths, the conversion of railway lines into high-speed routes, and finally the expansion or renovation of many main collectors for sewage in the core areas of major cities have considerably enhanced their vitality and their acceptance by the citizen.

As outstanding recent examples in this connection, let us mention: the subterranean shopping centres in Toronto and Montreal, the Washington and San Francisco metro systems as well as those in Seoul, Beijing and Shanghai, expansion of the rail networks in Berlin, London, Paris and Tokyo. At present, enormous efforts are being undertaken in the densely populated cities of Asia, Africa and Latin America aimed at establishing properly functioning sewage disposal systems. Examples of this are New Delhi, Calcutta, Cairo, Mexico City, Sao Paulo, and Singapore.

Apart from the direct positive effects for coming to grips with traffic flows, tunnels also generally have considerable effects with regard to reducing loads on the environment caused by traffic. This immediately becomes evident in downtown areas with underground rail systems, in which extensive pedestrian zones could be set up on the surface. Indeed, the effects are so far-reaching that complete regions have been freed from the loads imposed by road traffic. This is for example, an important objective for the major arteries crossing through the Alps, by means of which in Austria and in Switzerland, through lorry traffic between central and southern Europe is to be transferred to rail.

In conjunction with the construction of tunnels on new long-distance connections for road and rail, **protection of landscape and environment** has gained special and ever increasing significance. Engineers are called on to pull out all the stops here. For the ICE new route between Frankfurt and Cologne for instance, some 33 hectares of woodland had to be destroyed in the Greater Frankfurt area; however, in order to compensate for this, the Deutsche Bahn AG planted 142,500 new trees on a similarly large area. This represents one of the largest compensatory projects ever undertaken in the German federal state of Hessen and at the same time is the biggest reforestation undertaking in this region for centuries. Alongside such highly positive effects, unfortunately, mistakes are also made. Thus it should not happen - as it did in Europe a few years ago - that in conjunction with the constructing of a two tube rail tunnel several km in length grouting materials were used for closing the fissures in the rock, which to a large degree contaminated surrounding springs and brooks. As a consequence, cattle grazing there died of poisoning when they used their customary watering places. The population of that area had to be supplied with drinking water transported there in tanks for months on end. In another case, a number of lakes above a tunnel route discharged into the tunnel tube that had been headed because fissures were either closed insufficiently or too late. These examples reveal the balancing act between what is strived for and what is actually achieved that is encountered in some places. Also as far as tunnelling is concerned, in the end, you must depend on the individual and the care he takes in planning and executing a project.

4. CONSTRUCTION METHODS – SAFETY ASPECTS AND RESPONSIBILITIES

The geology and topography which are encountered decisively influence the construction methods chosen to build a tunnel. In this connection, we have to distinguish between tunnelling in soft ground and in solid rock.

For soft ground tunnelling, there are typical methods which are applied.

These include all kinds of variants of cut-and-cover construction methods (Fig. 7), shotcreting in combination with additional supporting measures geared to improve the bearing capabilities in the surrounding ground as well as mechanised, shield-supported tunnelling. In such cases, the ground is removed by excavators, in special cases, possibly by means of roadheaders, whereas tunnel boring machines are generally applied in the event of a shield-supported heading. The latest most spectacular examples for the application of shield-supported tunnel boring machines are the drives for the Trans Tokyo Bay Tunnel in Japan as well as the 4th Elbe Tunnel Tube in Hamburg. The last-mentioned project is being headed over a distance of 2.6 km with one of the biggest shield diameter ever used amounting to 14.2 m (Fig. 8).



Figure 7 Typical situation using the cut-and-cover construction method



Figure 8 Mounting the TBM for the 4th Elbe Tunnel Tube in Hamburg, Germany with an outside diameter of 14.2 m

Tunnels in solid rock are usually driven as drill and blast projects making use of the shotcreting method. For long-distance links, the cross-sections amount to maximum excavated areas of 100 to 150 m². The heading is undertaken in a number of sections depending on the strengths of the rock encountered, should the conditions be especially tricky, then divided up into several wall, roof and base tunnels (Fig. 3). However, mechanised tunnelling with boring machines is being increasingly applied for tunnels through rock as well. Alongside high rates of advance, it, above all, caters for improved safety for the tunnelling crews.

An important aspect in the construction of transport tunnels is ensuring that they function properly. Alongside the technical installations which are required and optimised routing and alignment, these, above all, include adequate sealing. Various methods are necessary to achieve this goal depending on the construction method applied. With regard to inner urban tunnels, watertight concrete in conjunction with joint strips and joint plates is mainly utilised. In the case of shield-driven tunnels, the joints between the prefabricated reinforced concrete elements are sealed by means of special elastomer profiles. Underground tunnels which are not shield-driven for commuter and long-distance links are, by and large, provided with membrane seals on the basis of plastic sealing materials (Fig. 9). These are created in the form of so-called umbrella seals if they are only required to ward off seepage water. On the other hand, if groundwater has to be contended with, then the membrane seal must completely encase the tunnel cross-section. During the last 20 to 30 years, the processing technology for such membrane seals has achieved a high standard of development.

It goes without saying that underground construction measures pose high demands on technological experience as well as call for a highly responsible approach. Considerable differences exist in this respect compared with building activities on the surface. The geologists, geo-technicians and engineers, involved in planning and execution, must on no account succumb to the temptation of constantly further extending the limits of what is possible or supposedly possible. Over-assessment of one's own capabilities, cost and time pressure can then easily lead to setbacks. Such experiences have been made repeatedly of late (Fig. 10). In this conjunction, let us recall also the tragic tunnel cave-in in Munich as a result of which an articulated bus fell into the ensuing crater as well as the major earth collapses at London's Heathrow Airport or during the building of the Sao Paulo metro in Brazil.

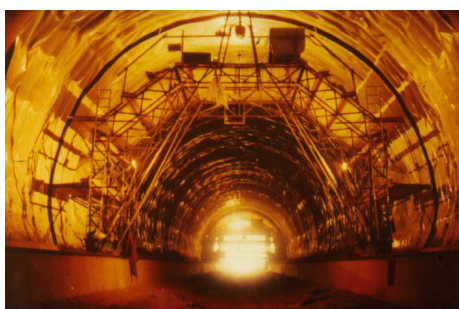


Figure 9 Installing a membrane seal on the basis of plastic material

Against this background, tunnellers must recognise their limits well in time and keep their sights trained on the high degree of responsibility they bear for the crews working underground as well as for the residents and road-users above the tunnel route.

Accidents, such as those that were mentioned, can all too easily result in tunnelling, which from its very nature represents an effective and beneficial tool designed to improve traffic and living conditions in our cities, receiving a bad reputation, as Haack³ states. Such a state of affairs can occur very rapidly even if no tunnelling accidents worth mentioning have taken place for years or decades on end. One of the main tasks in the years ahead will thus be directed at - in addition to technical improvements - bettering the image of subsurface construction for the general public and consolidating confidence in tunnelling techniques and their application.



Figure 10 Collapse Munich-Trudering, September 1994

5. SUMMARY AND FUTURE PROSPECTS

Cities which are capable of functioning both in social and hygienic terms form the prerequisite for a decent life in built-up areas. This also necessitates the utilisation of underground space to an ever increasing extent, as clearly demonstrated by ITA⁴. The optimised translation of systematic underground development planning in our cities is only possible through applying the means presented by modern tunnel and line construction.

All in all, it can thus be determined that subsurface construction has lost none of its topicality world-wide, indeed it is actually gaining in significance. In economic terms, it represents a growth branch of industry, which is orientated to the future.

In order to avoid possible misunderstandings, it must be clearly stated at this point that we are not concerned with building tunnels at all cost. However, there is no real alternative to constructing tunnel in most cases when it comes to traffic links and the safe use of congested areas in large cities. This is impressively reflected by the extremely positive examples of a large number of downtown areas in European, Asian and North and Latin American built-up areas. However, it is not at all essential to set up straddling rapid transport systems underground in medium-size cities. Instead considerable improvements can already be achieved by ensuring that public transportation is operated underground along central lines in the core of a city only.

In a nutshell, it can thus be said that the development of core areas in many big cities through the routing of public commuter traffic as well as important road links via underground facilities clearly reflects the positive effects of subsurface construction. In a well considered fashion and taking cost-benefit aspects into account, these opportunities should therefore also be exploited free of ideologies in future so that our cities become more worthwhile to live in and more loveable.

Often tunnels represent the sole alternative for crossing mountain ranges and waterways if large-scale transport links have to be established. In many cases, cross-border projects are at stake.

As a consequence, effective co-operation on a technical and a political level as well is thus of decisive importance. This is valid against the background that tunnels form a part of our traffic infrastructure, which cannot be disclaimed and contributes significantly to ensure the politically high-profiled mobility in our modern societies.

6. REFERENCES

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