INTERNATIONAL SCIENTIFIC CONFERENCE

CIBv 2010

12 – 13 November 2010, Braşov

IMPORTANCE OF EXECUTION TECHNOLOGIES IN TUNNELS CONSTRUCTION

Mihai DOBROVOLSCHI* , Christiana CAZACU**

* S.C. BETA COPS SRL Bucureşti
** Transilvania University of Braşov, Faculty of Civil Engineering, Civil Engineering Department

Corresponding author: Mihai DOBROVOLSCHI, E-mail: dobrovmihai@yahoo.com

Abstract: Technology implementation is a key factor in the underground constructions success of the completion of the work safely, economically and in a short time. It is determined by many factors and, in turn, determines some features of the work. Choice of technology is a major decision to tunnel construction. The work has shown the condition, how to choose and the consequences of wrong choices.

Key words: tunnel, the method of execution, technology.

1. INTRODUCTION: HISTORY, KEY POINTS IN THE HISTORY OF UNDERGROUND CONSTRUCTION

To emphasize the place that *technology* has to create a tunnel, the dictionary will quote the definition of this term: "The whole process, methods, processes, operations, etc., used for obtaining a product, from the Greek τέχνη (techno) = **art** , **craft** and λόγος (logos) = **study**. "So, a complex and not a mere name. Technology of the underground tunnels works in particular, has been crystallized over the history of human society development in tandem to influence one another. The craft was passed by word of mouth and we have few written records. We could say that compared to other technical fields even today bibliography is poor. **The first mention of a new technology** applied was carved in the wall of a tunnel between Lake Siloam aqueduct and Jerusalem. (727-699î.e.n.). **First vault** (essential for use of materials resistant to efforts to compression) is determined by archaeologists on year 320 BC. It was used to access a gallery of athletes at a stadium in Nemeea (Greece). **The methods of excavation** occur during Roman times, the method fires. Lighting is switched from wood chips to the lamps. **The first carriage and the first switch** were used in gold mines of Transylvania. They are found in the Technical Museum in Berlin.**The first book** about the technology of underground, "Die Re Metallica", is written only in 1554 and printed in Switzerland in 1556 at Basell. The author, Georg Agricola (Georg Bauer) wrote in Latin. Romania was the 14th language to translate this book (Professor Univ. Bradeanu Nicholas eng). It was over 200 years the only book in the field. **Triangulated steadiness** was another big step in the development of underground construction (beginning of sec. XVII). The first use of gunpowder in the tunnel is known at Malpasse (1678-1681). The Languedoc waterway witch link the Rhone to Garon. **The first mechanized works** dating from 1683 without significant results, but have the merit that have paved the way for a new concept in field productivity, so the involvement factor "time" existential factor, particularly important in underground works. Only in 1851 with the advent of compressed air and rotary punch mechanization we consider indispensable in implementing technology. In 1823 Brunel Thames Undercrossing inserted in a rudimentary form of a shield (a wooden box without two opposite sides). Today a universal technology, a plant product tunnels.

Fig.1 The biggest shield with total mill. Ø 14.2 meters in diameter.
Subway in Berlin

In 1866 the Swede Alfred Nobel invented dynamite in 1867 and mercury fulminate caps. It took 125 years Rabcewicz L. Von, 1948, to patent the new Austrian method (NATM international name). Today this method, with the shield method is most commonly used method in the world.

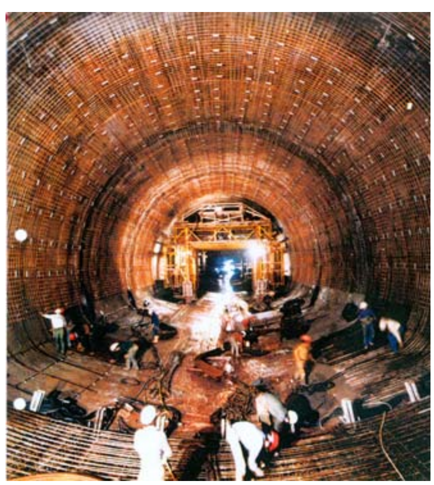


Fig. 2 Tunnel NATM method executed.
Waterproofing operation (in the envelope system) and the casing interior outfitting operation

Of course, research is ongoing (jet cutting 4,000 atmospheres, klincherisated rock contour, etc.) and will not be long before a new method generalizing safe, fast, economical, easy to apply.

2. GENERAL CONSIDERATIONS

A tunnel is made in an environment, we might say, unknown and often hostile. As evidence, we have the fact that, till our time it has not been established a universal method for calculating the thrust. For this reason the technologies used are very diverse and adapted to each case. There are over 25 different methods (technologies) for execution. To all these we can also add the methods for implementation of the caves (with an opening goal from 15 to 30 m, heights of 30-40 m.), the under-crossing and sinks. The structure of an underground work includes the excavated hole, the support works and the shirt that ensures the stability of the rock mass surrounding the excavation.

Excavation is a process that takes place in space and time, and the redistribution of the initial efforts from massive and the interaction between the rock mass (which undergoes deformation) and the support works (which tend to limit these deformations and they load with their deflection) are also phenomena that evolve with the excavation progress.

In the diagram below you can see how many adjustments it should be made because of technology. Choosing a construction method involved several factors. They are deterministic, statistical and strategic type. The eternal antagonistic duality, technical – economical insurance does not act mathematically rigorous at the three types of factors given above. It will be more simply that all factors to be deterministic. The results should be mathematical. We could estimate the cost of technology applied, also the safest construction method. The work would be done in a specified time.

In reality, occur, some influence factors known statistic from the previous activity. For example, the estimates costs of all large and medium-sized tunnels has been exceeded (Simlon tunnels - L = 19.802 km., Eurotunnel Channel Tunnel - L = 53.30 km., Tunnel under the agitated Tsugaru Strait - L = 53, 85 km).

The greatest influence, however, are the strategic factors. For example, time. Employer wants to make a tunnel in a time, which is usually very short due to various reasons (for example to get a quick high profit). In this case choosing the execution technology, form a simple problem becomes a complex problem, or at bests a complicated one.

The makers have a key role. But only the engineer can discern and decide ultimately. He is the only one who takes a risk, risk that may cost him his career and life.

The characteristics of underground works, unlike the above-ground buildings have special features:

• It moves along with the environment that surrounds the building. The environment is also the principal action for the construction. These movements are due to the tectonics factors. Underground each second take place crust movements, and underground tension. When these movements exceed certain limits that will make the building unusable? Can we predict that?

• The underground water migrates faster or slower. In time dry areas get wet and vice versa. How long will this phenomenon take? And if we take protective measures (such as. Isolations) how long they will protect the tunnel? How we design the system to be rehabilitated over time? What is the optimal time to act?

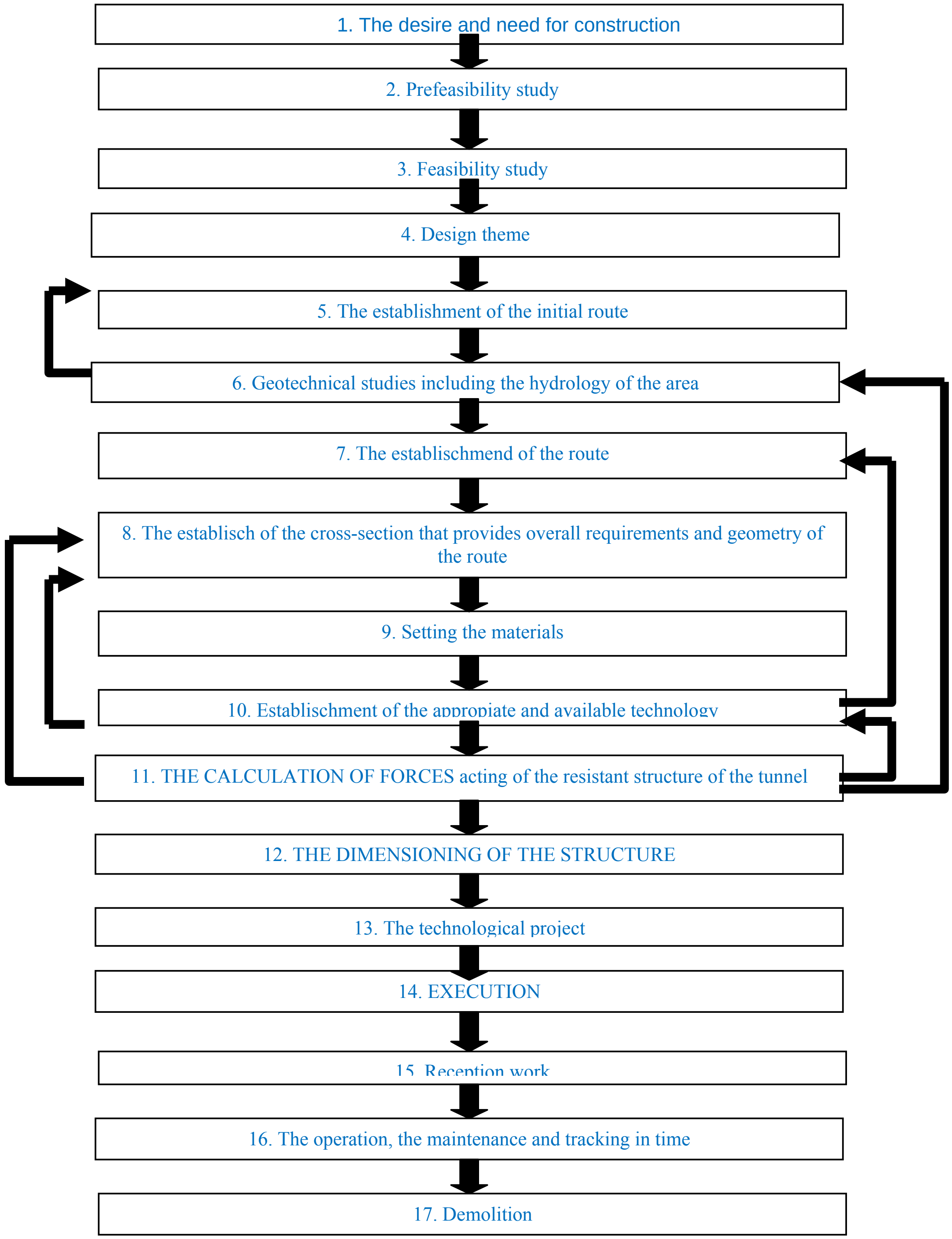
• In general, each meter of a tunnel is an entity. What do we act in a case of a very large tunnel? The longest railway tunnel, standard gauge, has already reached 57,000 m. For such dimension, at present there is not special equipment for a satisfactorily geo-hydrological study.

•The actions of a tunnel may be due to other causes even more distant in space. For example, landslides or heavy water (seas, oceans);

•On the tunneling effect can be positioned at considerable distances antefacte

The implementation technology of a tunnel several times, at first side, borders the logic with which we are accustomed. Attacking the cross-section from top to bottom, or sometimes bottom-up. We start to attack the tunnel from one end when time is pressing us, when we should attack from two sides the tunnel (in the longitudinal direction in tunnels with strong infiltration of water).

THE LOGIC SCHEME OF THE CONSTRUCTION FOR TUNNELS.



Choosing the implementation technologies for underground we should be considered two distinct stages of construction:

- Stage construction;
- The level of service.

We have common features and operations of the two stages, but in different proportions. The first stage will prevail taking massive thrust, over a relatively short period of time and the operation to achieve the proper construction. In the background, but at the same time, the operation of the completed portions of the tunnel.

In stage two, the operation of the tunnel will prevail, and the massive pressures will be taken over permanently by the resistance structure and the maintenance of the building will have some similar operations, such as injections.

Choosing the proper execution method has also a big influence and an important argument for implementing agreement negotiations of execution.

3. CRITERIA INVOLVED IN TECHNOLOGY SELECTION

The main criterion for choosing the technology is the nature of the rock used for construction and hydro geological conditions. These are not the only criteria. Multitude of criteria and their correlation requires a systematic inventory. The table below illustrates such systematization. Before each case is necessary to update this table, eventual additions and improvements.

In case of rocks in homogenous massive the choosing of technology is much easier.

But in case of a crumbled massive, only experience in developing underground works of all participants (geologists, engineers, experts, builders) may lead to a positive result. In this case we choose a very flexible technology.

Let's illustrate the influence of some criteria:

The length of a tunnel often requires choosing a classical method. In a short tunnel, of tens or hundreds of meters, it is not practical to bring a shield (with annexes, energy supply, precast, etc.) with a yield exceeding 100 m / month. Certainly, the effort would be too high. Including the financial side.

Cross-section, not just for one strand but on the whole, is also important. As an example, we can give choosing the cross section with double track for the longest tunnel in the world (until few days ago) 53.85 km. Costs have nearly doubled and construction period has been greatly exceeded. Europeans used Japanese experience for Eurotunnel (53.3 km.) choosing two parallel galleries. In this way they could use four shields, two for each side (France and UK).

Profile in long can determine deterioration from one end, especially if groundwater has high flows. In plan, small radius curves will require technology.

Type of waterproofing imposed by moisture conditions from the design theme can dictate the type of waterproofing, "in envelope" or "umbrella". We will choose a technology that can ensure implementation of appropriate waterproofing.

The nature of rock is, as we reported, the most important criterion. For example, choosing the shield method for rocks with $f > 6$, we will choose a shield with mill and supported by walls (Fig. 1). For $f = 2$ to 5, we will choose a mechanical shield with support on the back and for a rock with $f = 0.3 \div 2$, we will choose a shield with compressed air.

Water requires special measures if is highly aggressive, but will require using compressed air if Q is very high or there are water clusters nearby (caves, seas, lakes).

Gases claim their right. In case of explosive gases we will choose enclosed, antigases equipments or other specific measures.

Availability of equipment is an easier criterion to exemplify. In the present, owners of shields are offering their equipment on the Internet. But some difficulties may occur such as transport distance and time availability. In Australia we were offered a shield with a diameter of 9.5 m, but only in March 2011. Adding transportation time we found a delay of six months and the offer became useless.

Assembly and disassembly time have an important share. In many cases, the shield is not removed, but abandoned in underground. In case of Eurotunnel, the French side preferred to divert the shield on the side and the English part to stick it under the tunnel. Obviously, for the diverted sections traditional methods were used.

Nr. crt	Group criteria	Caractristica, specification		Quantities and units of measure	Execution method											
					Modern*			Classic**			Special***			Other methods ****		
					CF	S	Etc.	MA	MB	Etc.	MC	MIj	Etc.			Etc.
0	1	2		3	4	5	7	8	9	10	11	12	13	14	15	16
1.	Characteristics elements of tunnel	Length														
2.		Transversal section														
3.		In long														
4.		In plan														
5.		Type of hydroisolation														
6.		Location, topographic data, access, organization of site														
7.	Hydrologic criterion	Nature of the rock	Extremely strong	f=20; $\varphi=87^{0}08'$												
8.			Very strong	f=15; $\varphi=86^{0}11'$												
9.			…													
10.			Earth	f=0,6; $\varphi=35^{0}00'$												
11.			Running	f=0,3; $\varphi=16^{0}42'$												
12.			Surprises	Geo accid., falii												
13.			Coverage													
14.		Water	Aggressive water													
15.			Underground hydro scheme													
16.			Waters near													
17.		The possibility of attack from several points														
18.	Existing gas	Probability of gas		Explosive												
19.				Harmful												
20.	Materials	Building materials from a priority area														
21.	Equipment	Availability of the equipment in time														
22.		Instalation time														
23.		Removal time														
24.		Estimated time of construction														
25.		Energy														
26.	Productivity	Degree of industrialization														
27.	Design	Accuracy in predicting the outcome of pressures														
28.	Subjective criteria of choice	The experience of the constructor														
29.		The experience of the designer														
30.	Economy	Cost estimates														
31.	Experts	Findings of the tunnels expert group														
32.	**FINAL ASSESSMENT**															

Construction period involves, in addition to advancing speed, efficiency calculations of labor productivity. A shield will total bit will require fewer workers than, for example, the German method.

The degree of industrialization. Especially for long tunnels the degree of industrialization should be very high. The secret to a successful application of one technology is also the operations' division in distinct parts with rhythmic application. Example for shield: excavation, advance, presses withdrawal, installing advance.

Energy consumption for each method. A shield requires a transformer higher than 630 KVA. If the work is in remote locations will be built a high-voltage line. Costs increase.

Cost estimations. Cost is divided into direct costs for construction and operating, plus interest at the banks, plus costs for maintaining security at the end of exploitation period.

Very interesting is to compare the *total energy embodied in the implementation of one meter tunnel*. We calculated for a second-generation mechanized shield, normal track, the energy embodied in the manufacture of the shield, the concrete blocks, of all materials, the energy spent by people, other expenses converted into energy. On the other hand, according to some studies regarding tracks, the consumption of a diesel locomotive, from level ground to a ramp of 6 ‰ increases with 175%. Hypothetically, the reduction of the slope of a tunnel from 6 ‰ to 0 ‰ would lengths the tunnel with 100 meters. For each side of the tunnel, the energy consumed to build the additional 200 meters, would be recovered in service, in conditions of medium traffic, in two years.

Fig. 3 Consequences of choosing the wrong technology or non-compliance.
Tunnel in Munich-Germany 1994

Comparison between methods is made assessing each criterion, by giving a share. Where appropriate, certain criteria can be labeled "0" and removed from the beginning; others noted with maximum grade "10" remain in competition. Some may be first processed and then introduced in competition or not take them into account. For example: criterion nearby waters. If there is no water nearby or their influence is insignificantly, we can eliminate this criterion. Instead, if it is possible to flood the tunnel, we take this criterion into consideration.

The people who analyze the table can make their own value system which ultimately leads to the optimal choice.

4. CONCLUSIONS

- Since the construction of a tunnel requires huge financial values and involves numerous selection criteria, the action requires a systematic approach.
- Achieving the requirements of the design theme is the main purpose for establishing technology.
- The choice must be well documented and endorsed by all stakeholders involved in development: geologist, designer, builder, expert, recipient (with his specialized consultant in tunnel construction).
- Particular attention must be given in cases when one of the basic criterions is at the satisfaction limit due to application of that technology.
- Any situations that may disrupt the rhythm must be predicted, and provided with “emergency repair” methods for those cases.
- The choice of a technology is better to be verified through the amount of energy embodied in the construction of one meter tunnel, check which I named ”energy verification”.

REFERENCES

1. ALMĂŞAN, B., PAVEL, GH., *Perfecţionarea tehnologiilor de săpare a lucrărilor miniere,* Editura Tehnică, Bucureşti,1983.
2. BENEA, Ş. & all, *Susţinerea cu ancore şi torcret,* Editura Tehnică, Bucureşti, 1967.
3. BOB, C., *Strategii pe plan internaţional privind asigurarea durabilităţii construcţiilor din beton*, Revista „Materiale de Construcţii”, **Vol. XXII**, nr.3, 1992, Timişoara,1992.
4. BOŢI, N. & all, *Tuneluri ţi metropolitane*, Institutul Politehnic Iaşi, Iaşi,1989
5. CHIFANE-DRĂGUŞANI, C., *50 de metropole şi metrourile lor*, Fundaţia Culturală Marco Polo, 2004 , Bucureşti,2004.
6. DIMA, A., IFTIMIE, T., *Tuneluri şi metropolitane – Aplicaţii,*Institutul de Construcţii Bucureşti, Bucureşti,1984.
7. DOBROVOLSCHI, M., *Viitorul tunelelor pentru viteze mari,* ART – Conferinţa naţională de construcţii subterane, Braşov,1996.
8. DOBROVOLSCHI, M., ŞUHANE, S., *Tendinţe privind hidroizolarea tunelelor,* ART – Lucrările primei conferinţe naţionale de construcţii subterane cu participare internaţională, 7-8 octombrie1993, Iaşi,1993.
9. HOBST, L., YAJIC, J., *Ancorarea în roci* [Trad. Sima N., Hârsulescu A.], Editura Tehnică, Bucureşti,1981.
10. IFTIMIE, T., *Întreţinerea, reabilitarea şi reconstrucţia tunelelor,*Editura ASAB, Bucureşti, 2002.
11. IOANIDI, A., *Contribuţii la perfecţionarea concepţiei şi a tehnologiilor de execuţie a tunelurilor pentru căi de comunicaţie*, Editura Matrix Rom, Bucureşti,2002.
12. LEVY, M., SALVADORI, M., *De ce cad construcţiile. Cum se distrug structurile*, Editura Tehnică, Bucureşti,1987.
13. NEAGU, F., *Îngheţarea rocilor la construcţiile subterane*, Editura Tehnică, Bucureşti,1982.
14. SIMIONESCU, A., *Tehnologii pentru excavarea lucrărilor de construcţii subterane*, Editura Tehnică, Bucureşti,1985.
15. SIMIONESCU, A., *Istoria tunelurilor din antichitate şi până azi*, Editura Niculescu, Bucureşti,1997.
16. STEMATIU, D., *Mecanica rocilor pentru construcţii subterane,* Editura Matrix Rom, Bucureşti, 2003
17. TEODORESCU, P., *Întreţinerea tunelelor*, Editura Transporturilor şi Telecomunicaţiilor, Bucureşti,1963.
18. TEODORESCU, P., *Construcţia tunelelor*, Editura Căilor Ferate, Bucureşti,1958.
19. TEODORESCU, P., *Tuneluri*, Editura Tehnică, Bucureşti,1977.
20. TOLOGEA, S., *Accidente şi avarii în construcţii,* Editura Tehnică, Bucureşti,1980.