The Role of Ita-Aites in Promoting Research and the Case of Study of the Fréjus Motorway Tunnel Built in the 70's

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1. The Role of Ita-Aites in Promoting Research and Guidance in Tunnelling and Underground Space Works

Founded in 1974 by the initiative of nineteen Nations, the International Tunnelling and Underground Space Association (ITA) aims are: to encourage the use of the subsurface for the benefit of public, environment and sustainable development and to promote advances in planning, design, construction, maintenance and safety of tunnels and underground space, by bringing together information thereon and by studying questions related thereto.

Since then, ITA has considerably developed. Any independent nation, may through the medium of a National Organization become an ITA «Member Nation». Presently, ITA gathers 78 Member Nations.

Corporations and individuals (as far as they fulfill the conditions) can participate in the activities of the Association by becoming an «Affiliate member». ITA gathers 300 Corporate or Individual Affiliate Members.

Among the Corporate members some are more involved inside ITA being Prime Sponsors or Supporters.

The General Assembly, which met annually, resolves all questions concerning the organisation and conducts of the affairs of the Association; it shall approve the budget of receipts and expenditure, and appoint and organise all Committees of the Association; it shall decide on the admission of new adhering national Organisation and of the new affiliate member. The General Assembly is host by a Member Nation at the occasion of the yearly World Tunnel Congress.

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For further information see: ITA-AITES website: https://about.ita-aites.org/; P. Lunardi, *Applicazions de la Mecanique des Roches aux Tunnels Autoroutiers. Example des tunnels du Frèjus (côte Italie) et du Gran Sasso*, in «Revue Francaise de Geotechnique», 12, 1979; Id., *Design and construction of tunnels. Analysis of Controlled Deformation in Rock and Soils (ADECO-RS*), Springer, 2008, 576 pp.; Id., *Extrusion control of the ground core at the tunnel excavation face as a stabilisation instrument for the cavity*, Muir Wood Lecture, World Tunnel Congress 2015 (WTC2015), Duborvnick, Croatia.

The main objectives of the ITA are:

- To encourage new uses of underground space for the benefit of the public, environment, and sustainable development.
- To encourage studies of underground alternatives to surface construction, not only considering construction costs but also indirect life-cycle costs and savings as well as social and environmental advantages.
- To stimulate the development of guidelines for a positive public strategy to take advantage of subsurface potential.
- To encourage the development of better and cheaper methods for planning, geo-investigation, design, construction, operation, maintenance and safety of underground structures by using improved methods such as new technical developments and risk management principles.
- To improve training of everyone, especially young professionals, by conducting workshops, by improving and coordinating academic programs worldwide, and by improved on-the-job training.
- To bring together engineers, owners and others involved in the development of underground space, such as architects, planners, authorities, economists, lawyers, insurers, financers and politicians.
- To arrange international exchange on developments in underground technology and experience from its use.

To reach its objectives, ITA has set up 4 Committees and several international Working Groups (WG) to study and report on specific topics.

Committees

ITA has 4 Committees:

- *ITA-COSUF*
- *ITA-CET*
- *ITA-CUS*
- *ITAtech*

Each Committee has a specific identity with related scope and in the following they will be briefly described.

ITA-COSUF, Committee on Operational Safety in Underground Facilities with the cooperation of the World Road Association-PIARC and all the major

European fire research organizations. It was founded at the 33rd ITA-AITES World Tunnel Congress (WTC) 2005 in Istanbul, following a joint initiative of eight European research projects which all aimed at an improved tunnel safety. This Committee is the centre of excellence for world-wide exchange of information and know-how regarding safety and security of underground facilities in operation.

ITA-CET, Committee on Education and Training, nicknamed «University Network». Since the year 2000, the ITA has identified education and training as one of the most important challenges and needs of the Association. ITA-CET as been officially established in 2007 in order to promote education and training throughout the Tunnelling and Underground Space Association and assist its coordination. The importance of knowledge sharing through education and training has been reaffirmed over the years in the ITA's Strategic Plans and remains a priority of the current Strategic Plan. A certain number have been identified by ITA in relation to this goal:

– Support Member Nations through the organization of training sessions and workshops.
– Develop a training offer for professionals and industry.
– Implement e-learning / webinars.
– Create and develop a university network as well as a regional correspondents network.
– Involve Working Groups and Committees in the preparation of didactic documents and ITA-CET courses, based on their publications.
– Organize specific training sessions on the use of underground space in developing countries.

ITA-CUS, Committee on Underground Space, believing in an urban underground future. The urban underground space is an often-overlooked asset of cities. As such underground space should play a vital role in the quest, many cities are undertaking to combat lack of space. Cities need space for housing, for infrastructure and public spaces. As demands on cities grow in terms of spatial requirements, they also must cope with climate change. They need to become more resilient against natural disasters. Cities need to mitigate and above all, adapt. The urban underground can provide solutions for helping cities achieve this. ITA-CUS has launched activity groups dealing with relevant topics, such as urban adaptability, urban sustainability, urban integration, and the circular economy, and is thus contributing to the further development of this important field. The *Next Level Up is Down* is the core of the Committee's vision and strategy. As cities have grown denser, it seemed only natural to extend skywards. However, the sky is not the limit: cities need to start looking downwards to adapt to new circumstances and reach the next level of existence. ITA-CUS believes this should not just be for new spaces but also for renewable energy and to achieve food security. Last but not least ITA-CUS has the mandate to reach out to policy leaders, NGOs and interrelated disciplines. ITA-CUS presents at worldwide congresses, seminar and workshops to create awareness of the undergrounds potential but also to foster the integration into the urban fabric through planning and applied uses.

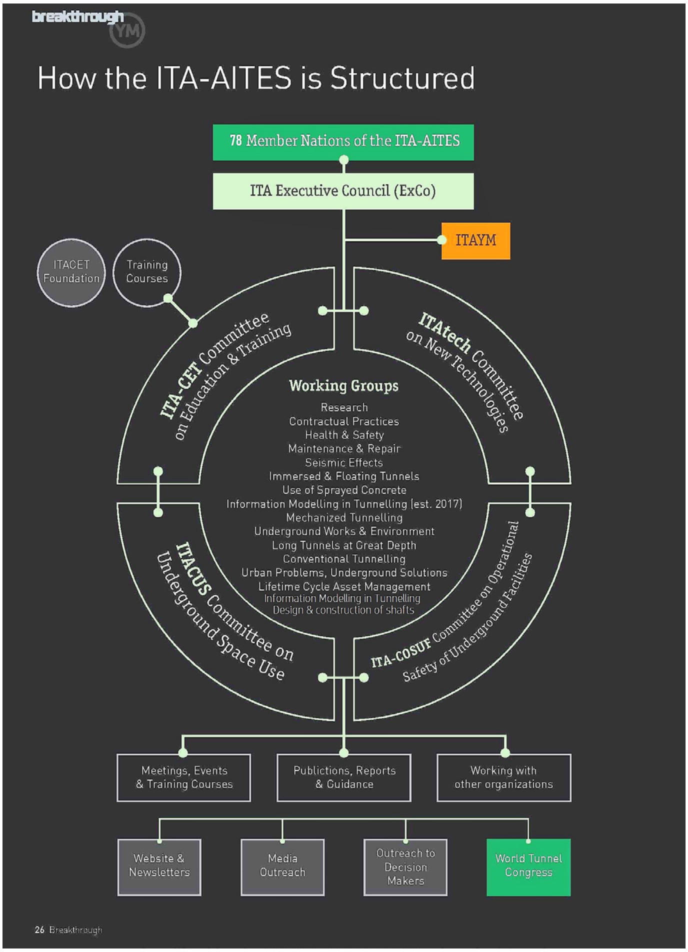


Fig. 1. ITA-AITES Structure.

ITAtech, Committee on New Technologies. The ITAtech has been founded in 2010 with the aim to provide a platform for engineers, manufacturers, contractors and suppliers to draw global experience and expertise together for the benefit of the whole industry, and to find ways of supporting the introduction of new techniques and products by collaborating on the development of design and performance criteria and preparing application of best-practice guidelines.

The ITAtech activity groups (AG) include all processes related to underground construction such as Data Management, Excavation, Linning, Support &Waterproofing and Design. ITAtech members participate inside various activity groups and work as well propose topics for studying new technologies with the final goal to review them and when approved promote them into the tunnelling market.

Working Groups

Today, fifteen working groups (WG) are active (fig. 2). Each WG works on a specific topic carrying out tasks with the purpose of promoting information exchange between National Groups and planning, coordinating and releasing the development in order to advance the state-of-the-art of different topics belonging to the tunnelling world, improving possibilities for design and construction of new underground works. The main scope of each WG is defining guidelines on particular subject that could be use as a standard reference during design and construction of tunnels. All the publications of ITA-AITES are free available through association website (https://about.ita-aites.org/). The missing number in Fig. 2 are the ones of the WG not active at the moment, but their publications are available as an integral part of the state of art of tunnelling industry.

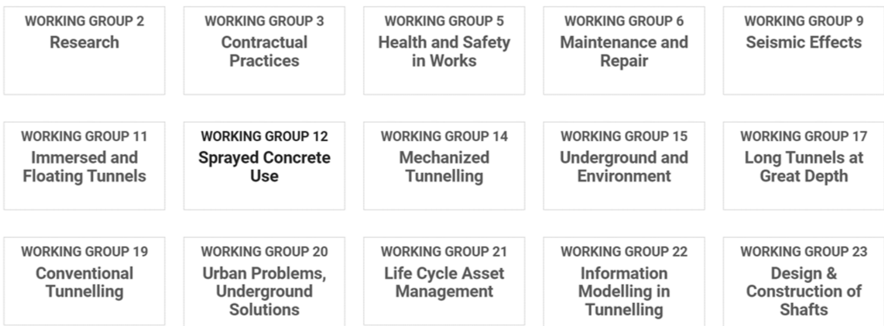


Fig. 2. ITA-AITES active working group.

Remarks

The International Tunnelling Association is daily working with the goal of promoting the research through the work of its Committees and Working Groups. Corporations and individuals (if affiliated) can participate to the activity of the association, this lead to information exchange between the different stakeholders (clients, designers, contractors, suppliers) involved in tunnelling industry. The Association works constantly for the information exchange and update which considers the last development and not only in terms of new technologies but also in terms of new planning and design approach, such as the use of the underground space not only in the way it is usually known.

Increasing the number of underground structures to be excavated also the number of technical challenges to be overcome is increasing and for this reason the Association is promoting innovative researches focused in exploring technologies that can improve the quality and the safety during the construction of underground structures.

2. Fréjus Motorway Tunnel

The considerable increase in heavy road traffic between the countries of the European Community had made necessary improving the connections between North-Western Italy and the industrial area of the Rhone, France, by creating a direct highway route than the one crossing the Alps through the Mont Blanc.

The most suitable route for this purpose is the ones linking Turin to Lyon via the Susa and Arc-Isere valleys. This had been understood over a century ago by the promotors of the first big alpine railway tunnel.

The unquestionable economic and commercial advantages deriving from the easier communication between the two countries was the proof of the right geographical position of the tunnel, which was reaffirmed after World War II, when the continuous increase in road transport gave rise to the need of studying new highways. The Mont Blanc Tunnel, built in the 60's, attracted most of the traffic to and from France, it appearing easier to cover a large distance than using shorter but uncomfortable routes along the Susa valley, crossing the Alps through Moncenisio and Monginevro passes. The need of a shorter route was deeply felt. This problem, together with the possibility of using the experience developed over a century ago, led to the choice of a route in the immediate vicinity of the railway tunnel with such features as to maker it possible to avoid the least favourable zones.

The Fréjus Railway Tunnel is about 13,5 km long, it was opened in 1871 (construction began in 1857), marking the beginning of tunnelling in Italy and it is the oldest among the Alpine tunnels. Since 1980, near the Frejus railway tunnel there's also a highway one. Construction works began in 1974, almost a century from when the railway tunnel, located alongside, was first opened. The Fréjus Highway Tunnel is 12.895 km long, and is managed by two different companies: in France by SFTR, while in Italy it is managed by SITAF.

The Project

The Fréjus Motorway Tunnel connects Bardonecchia (Piedmont) with Modane (Savoie), and represents an important link between Italy and France, along the Turin-Lyon axis (fig. 3). The excavation works started in 1975 and the tunnel was opened to traffic in 1980. The Fréjus tunnel is designed for heavy goods traffic with a maximum height of 4,3 metres. A single tube accommodates two 3,55-metre lanes of traffic. The French and Italian portals of the tunnel are at similar altitudes, respectively 1.228 and 1.297 metres. The longitudinal profile has a slight slope of 0.54% in the direction France-Italy. The design features of the project are listed in Table 1.

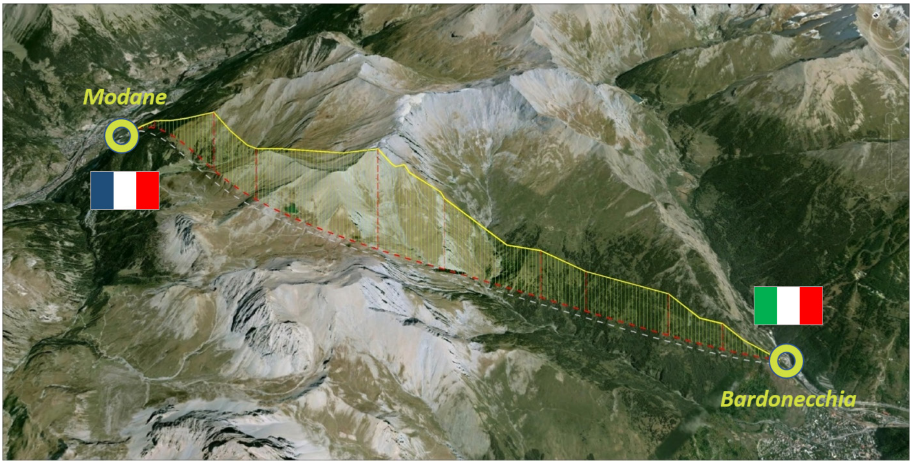


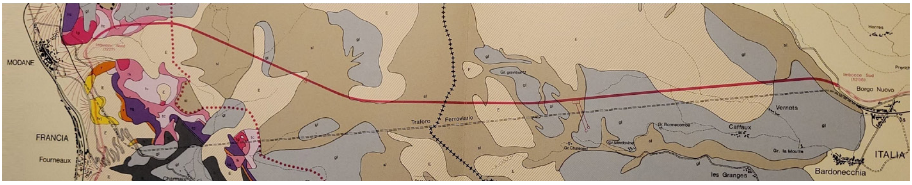
Fig. 3. Fréjus highway tunnel layout.

Geological & Geomechanical conditions of the tunnel

The Italian stretch of the highway tunnel, runs 130 m through a glacial deposit at the portal, than it runs essentially through a calcareous schist formation composed of calcareous paraschists composed of 80 to 90% calcite and quarz, as well as by muscovite and chlorite. In addition, occasional lenticular intrusions of green stones, also methamorfic, and in smaller amounts, other sialic rocks are present (fig. 4).

Total Length	
including cut&cover stretches at the portals	12.895 m
Entrance Elevation	
Bardonecchia	1.297 m m.s.l.
Modane	1.228 m m.s.l.
Grade	
from Bardonecchia to Modane	0,54 %
Overburden	
Minimum value	50 m
Maximum value	1’750 m
Excavation	
Average design section	90 m^2
Average height at the crown	8,50 m
Average width between walls	11,50 m
Cross section	
Clear roadside section	67 m^2
Vertical clearance	4.54 m
Total lateral clearance	9 m
Section widenings – n.5 every 2100 m	
Lenght	40 m
Width	2 m
U-turn tunnels – n.5 every 2100 m	
Lenght	15 m
Width	8 m
Ventilation plants	
Above ground	n. 2
Underground	n. 2
Ventilation shaft	
French side	n. 1
Italian side	n. 2

Tab. 1. Design features of the project.



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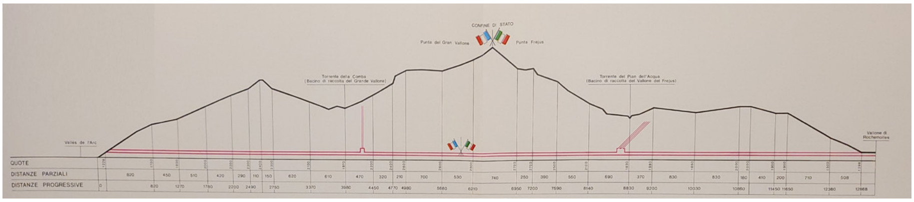

b

c

Fig. 4. Fréjus highway tunnel: a) Geological map; b) profile; c) alignment.

This was one of the most important and complex tunnelling works of its time (around 13 km in length), and also a once in a lifetime opportunity to monitor and to study the stress-strain behaviour of the rock mass as the overburden varies (between 50 and 1.750 m). Indeed, it was necessary to advance for about 6.400 metres (this was the length of the Italian side) through a calceschistic formation, which for 95% of the underground path remained lithologically and structurally homogeneous with joints of schistosity constantly tangent to the left haunch of the tunnel.

Despite the fact that at the time it wasn't common practice to make predictions on the deformation response of the rock mass to the action of excavation, in this particular case in-depth geological and geomechanic campaigns were carried out on the base of reports collected while excavating the adjacent railway tunnel (almost a century before).

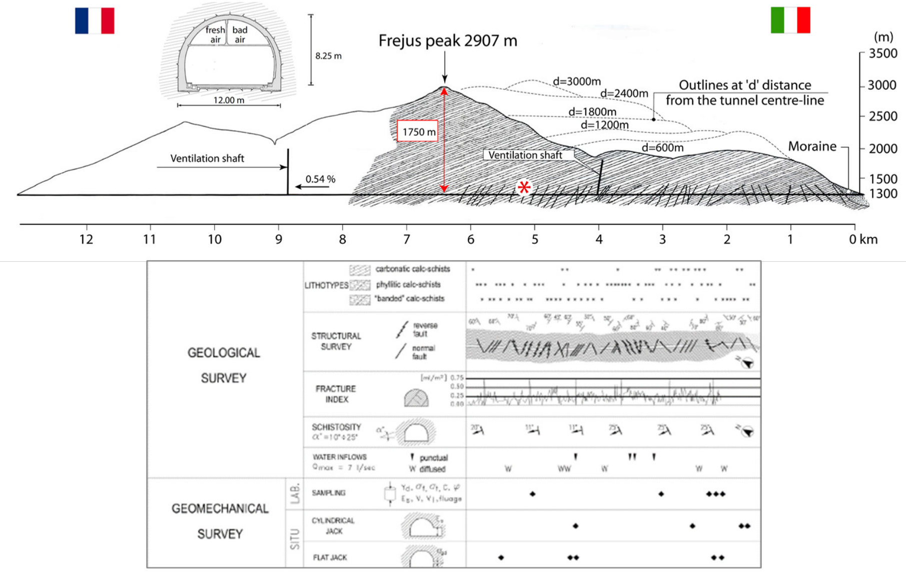

Fig. 5. Fréjus highway tunnel: geological & geomechanical survey.

The resistance and deformation tests carried out on the calceschistic samples indicated the following medium values for the main geomechanic parameters:

– σ_{gd} = strength of the rockmass = 20 MPa (≅ 200 kg/cm^2)
– σ_f = unconfined compression strength = 86 ÷ 108 MPa (≅ 860 ÷ 1080 kg/cm^2)
– E = elastic module = 10000 MPa (≅ 100000 kg/cm^2).

Construction approach & monitoring

The Fréjus tunnel is an Alpine motorway tunnel between Italy and France. It is a unique case: a metamorphic formation of calcareous schist lithologically and structurally homogeneous along the 95% of the underground route, with overburden varying from 10 to 1.750 m.

When the excavation method was selected the particular geological-lithological conditions represented by the constancy of the rock type on the Italian section led to consideration of the adoption of a TBM, but the choice was uneconomic at that time, by this way, the excavation has been performed with conventional excavation method (fig. 6a).

Fig. 6. Fréjus motorway Tunnel (1975) – Conventional excavation method: A) Drill carriage; B) Confinement operations by ancral roof bolts (Steel quality: Aq 60-Aq 70; Roof bolts length: 3,5 – 5 m; Intensity: 1 – 1,5 bolt/m²).

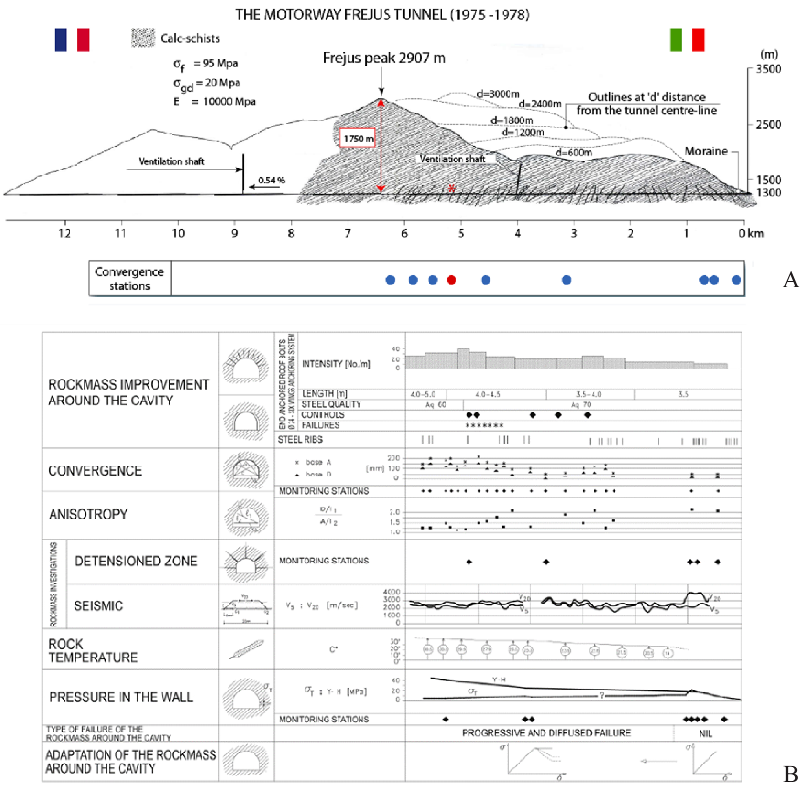

Fig. 7. Fréjus motorway tunnel (1975). A) Longitudinal profile and location of the most significant convergence stations; B) Monitoring results.

The advancement was carried out in full face (~90 m^2) by blasting, using rounds between 1 and 4.5 m and immediately stabilizing the rock cavity with end-anchored steel bolts Ø 24 (3.5 ÷ 5 m in length) that were radially positioned around the perimeter of the cavity (fig. 6b).

Density varied according to the stability situations, acting on the interaxis, length and quality of steel. The final lining in concrete – 70 cm thick on average – was cast at around 400 m from the excavation face. Average production using this method was around 7.5 m/day.

In order to keep behavior of the rock mass under control, an accurate and systematic monitoring of the diametrical convergences was carried out by installing – always at the face – a six-base convergence measurement station (fig. 7) each 50 m of advancement. This made it possible to thoroughly monitor the deformation response of the cavity as the overburden varied. Each of these stations was constantly read for 120 days from the moment of installation.

From the examination and comparison of the convergence curves (mm/day) of the most relevant measurement stations, the following became clear as the overburden increased (Figg. 8-9):

– a) convergence was generally influenced by increased overburden.
– b) for overburden below 550 metres the values reported on the convergence curves were equal to tens of millimetres; but for overburden between 600 and 1.700 m, these same values went up to 150 ÷ 200 mm.
– c) the strongest convergences were recorded between the chainages 4.500 ÷ 5.800 m and not at the maximum overburden (1.700 m).
– d) the maximum convergence values were recorded for the base D (perpendicular to the schistosity joints).

Examination of the convergence curves of these bases immediately revealed an anomaly at chainage 5.172 m [red dot in Fig. 5], with an overburden of 1.200 m, where in a station [n. 6, Fig. 6] in no way different than the others, without particular geological accidents, on 7 August 1977 advancement had been suspended for the summer holidays and had recommenced 15 days later.

It's important to note at this point that, before interrupting the works, the rockmass around the cavity had been regularly reinforced up to one metre from the face with around 30 radial bolts per metre of tunnel (without taking any particular actions on the face itself) and that, once excavation had recommenced, rockmass reinforcement around the cavity had also resumed with the same method, continuity and rhythm in terms of 4 m rounds.

The anomaly recorded at station n. 6 installed at ch. 5.172 m at the un-advancing face, with an overburden of 1.200 m, showed a convergence of around 100 mm during the 15 days of holiday. As soon as excavation started again,

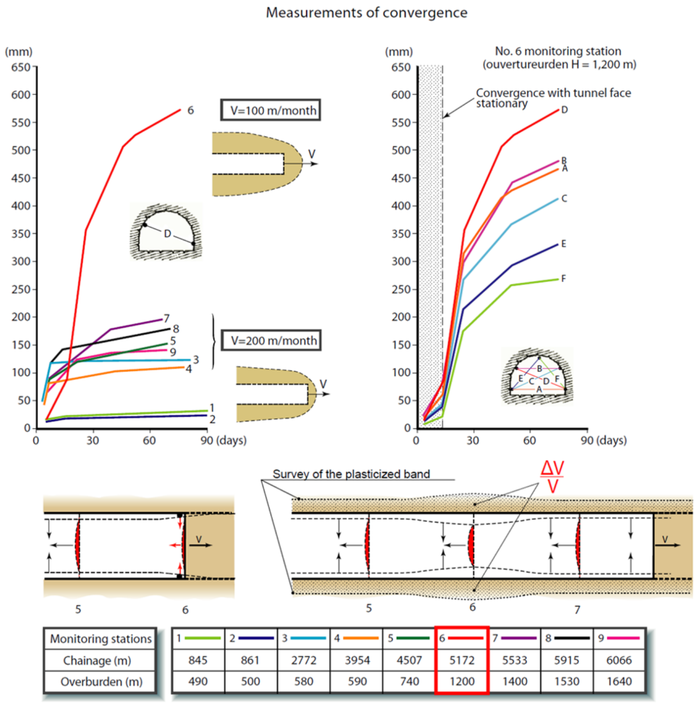

Fig. 8. Fréjus Motorway Tunnel (1975): convergence measurements.

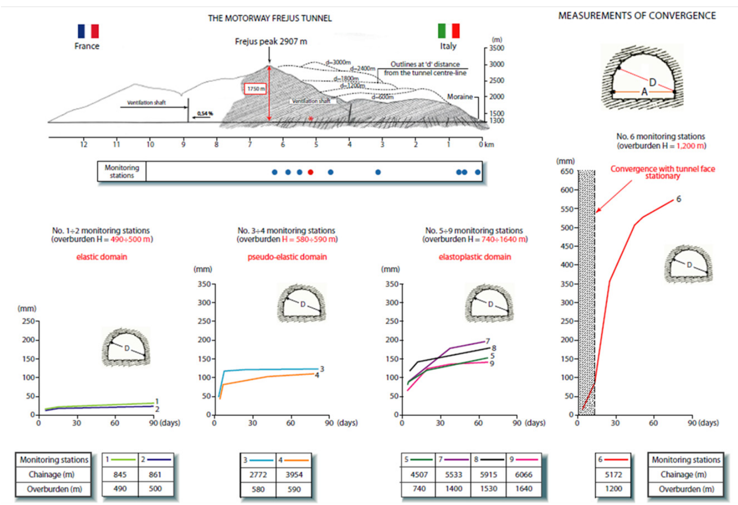

Fig. 9. Fréjus Motorway Tunnel (1975): convergence measurements.

the convergence recorded a sharp jump to values of 600 mm after about 3 months of measurement.

In an elastic-plastic regime a mass experiences, during the advancement phase, plasticization phenomena of rock surrounding the cavity with a Radius of Plasticization Rp which varies according to the overburden and advance speed respect to the profile of excavation. However, the plasticization phenomenon produces an increase of the rock's ΔV/V volume in the plasticized band.

While downstream the excavation face this increase of ΔV/V volume translates into a convergence of the cavity (which can be kept under control to a certain limit with radial operations), upstream the face ΔV/V can only vent underneath the surface of this, as an «extrusion», which upstream the face automatically produces a form of convergence of the theoretical excavation profile that can be defined as «pre-convergence».

In the case of measurement station n. 6, the 15-day pause of the advance face certainly produced an increase of the plasticized band both surrounding the cavity and upstream the face. This caused extrusive movement of the ground through the face and resulting pre-convergence, which – when advancement recommenced after the 15-day break – brought about the exceptional convergence of the cavity that could not be controlled only by radial operation (the calceschist under high overburden showed a similar creep behaviour to that of a soft ground such as clay).

Definitively, it appeared from the analysis of the measurements recorded at station n. 6 at ch. 5.172 that the deformation response of the cavity (convergence) could be interpreted as the final stage of a deformation phenomenon which originated upstream the excavation face as a consequence of the extrusive behaviour of the face. This phenomenon then evolved – always upstream the excavation face – into a «pre-convergence», which can increase and amplify the convergence of the cavity downstream the face itself.

The following points appeared clearly from the Frejus study:

– when advancing through ground in elasto-plastic conditions it is very important to keep excavations rates high and constant in order to avoid giving the core time to deform. This prevents extrusion and preconvergence, which constitute the starting point of subsequent convergence of the cavity, from being triggered.

What also emerged from the other experiences cited and similar cases was that:

– the failure of the core is generally followed by the collapse of the cavity and it is very rare for the latter to be preceded by the former.

In addition, Fréjus case underlined the following issues (fig. 10):

– 1) there is a close connection between extrusion of the advance core at the face and preconvergence and convergence of the cavity.

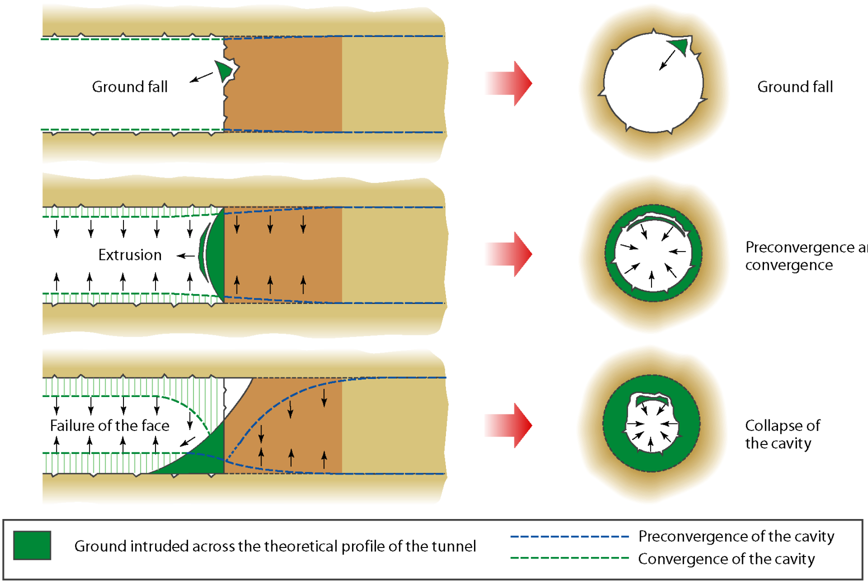

Fig. 10. Correlation between the behavior of core face and cavity.

- 2) there are close connections between the failure of the core-face and the collapse of the cavity even if it has already been stabilised;
- 3) chronologically deformation in the cavity normally follows and is dependent on deformation in the core of ground at the face.

It was also clear that it was necessary for an arch effect, which as we know conditions the stability of a tunnel, to have already been triggered ahead of the face in order to be able to continue to function in a determined cross section after the face has already passed ahead of it.

Remarks

The Fréjus Motorway Tunnel was built in the years 1975-1978, the geomechanical and structural features of the rock mass were homogeneous all along the underground alignment, having as a variable only the overburden and the advancing rete speed. The problems and the consideration studied in that unique job-site has become the pillar of the modern tunnelling design approaches.

Long and deep tunnels, such as the «Fréjus Tunnel», are for sure among the most challenging underground infrastructures and for this reason the excavation and the studies on this type of structures have to be considered as a sort of «full scale laboratory» where to develop new design approaches and construction technologies that will become the «state of the art» in the future excavations.

Plasticization phenomenon of rock surrounding the excavated cavity, which varies according to the overburden and advance speed, produces an increase of the rock's $\Delta V/V$ volume in the plasticized band.

The observation of the particular deformation phenomenon which occurred while tunnelling through Fréjus inspired the path led to the formulation of the Analysis of Controlled Deformation in Rocks and Soils an approach for planning and constructing underground works which has become universally valid for both conventional and TBM excavation in any type of ground or stress-strain condition.