Productivity parameters from TBM excavations of "Pont Ventoux" hydroelectric power plant tunnels (AEM Torino S.p.A.)

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Summary – This article describes the performances and the the problems recorded during the tunnelling with open HR-TBM of 13 km of the Pont Ventoux Hydroelectric Plant (Italy) and aims to put in evidence the factors that caused the excavation driving decreasing. As far as the main tunnel is concerned (F2) it is put in evidence the influence of the angle of incidence between faults and direction of the excavation as a critical element in relation to the found problems.

INTRODUCTION

The Pont Ventoux hydroelectric plant is located in the Susa Valley (Western Alps, Italy) and has been built by the Pont Ventoux Consortium (JV Astaldi Spa, Roma and Effaiges SA, Paris) for the AEM Torino Spa.
The plant (Figure 1) is made up by an intake that diverts 35 mc/sec, a 14 km offtake tunnel between Pont Ventoux and Clarea Valley (PVDT) that feeds a surge tank, from which a 4 km pressure tunnel (F4) starts and leads to the penstock and, with a 500 meters waterfall, to the underground powerhouse. The PVDT is divided through an access window in an upstream part (Pont Ventoux – F2; named F2) and a downstream part (Clarea – F2, named CL).
The offtake tunnels (F2, CL e F4) were bored with 2 Atlas Copco – Robbins 147.210.5 and 148.212.3 open HR-TBM, (930Kw, 700 tons). A conveyor mucking system has been used.
The plant has been built since 1995; today only the F2 part of the PVDT is still to be built.
The data used to carry out this study were updated 30th october 2000.
These papers will show the excavation performances and the problems found in tunnelling with TBM (tunnels F4, CL e F2). This study was ordered by the ALPETUNNEL G.E.I.E. with regard to the planning of the monkey drift along the track of the basic tunnel Maurienne – Ambin (Italian side) of the new Turin –Lyons rail link .

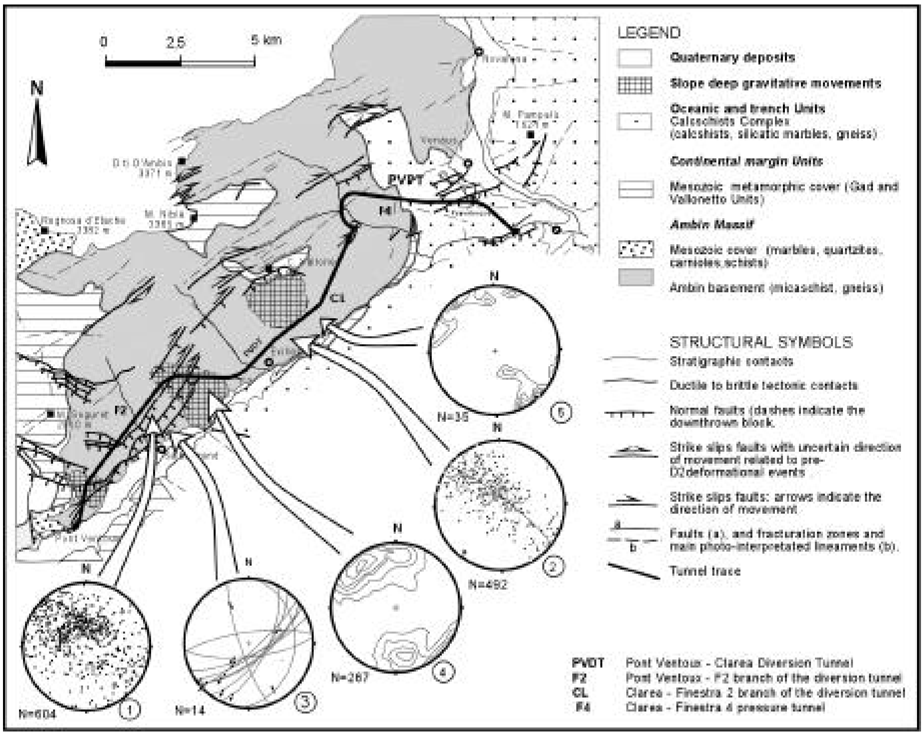

Figura 1: Geological-structural scheme with the location of the tunnels dealt with in this study. In the figure there are also stereographic projections of the schistosity and of the main joint systems of the area (modified after Alpetunnel GEIE, 1999)

GEOLOGY OF THE AREA

The Pont Ventoux plant developes in the Calcschists Complex and in the Ambin Basement, divided by some Cover Units (Lorenzoni, 1965; Gay, 1970, Polino, 1999) (Figure 1). The Calcschists Complex is built up by phyllitic calcschists with a few silicatic marbles and gneisses. In the studied area, in the calcschists, there are decametric layers of cataclastic breccias (carnioles l.s.). The Cover units located between the Calcschists Complex and the Ambin Basement are built up by quartzites, micaschists, dolomitic marbles, whereas the Ambin Basement is composed by micaschists and gneisses. The regional structure is due to the ductile deformation of alpine age that caused the formation of folding phases with axis about parallel to the examined tunnel direction and a SE average dip direction of the schistosity (Figure 1, plots 1-2). A brittle tectonics has recently imposed on the ductile tectonics causing the formation of important cataclastic deformation systems with transcurrent, transtensive and tensive features, with average direction N60-80°E and N110°E (Figure 1, plots 3-5). The first system (N60-80°E; Giardino & Polino, 1997) is parallel to the PVDT and played a main role in the excavation of the tunnels with TBM. Recently Giardino and Polino (1997) and Martinotti and Carraro (1997) correlated these important cataclastic systems to the slope deep gravitative deformations (DGPV) present in the area.

ANALYSIS METHODOLOGIES AND AIM OF THE STUDY

The elaboration of the data for this study tried to compare the excavation rates, i.e. daily and progressive tunnel excavation driving, and the various geological-structural, hydrogeological, anthropic or technical factors that are important to determinate its entity. The data refer to the pressure tunnel (F4) and to the two parts of the divertion tunnel (CL and F2), and they completely come form the documents placed at disposal by the Pont Ventoux Consortium, completed with the surveys and investigations carried out by SEA Consulting between 1996 and 2000 (Venturini et al., 1997; Perello et al., 1998).

In order to draw the excavation driving curves, a selective analysis was done, without considering the excavation driving interruptions due to days off, holidays, contractual, technical and planning causes. Average "refined" excavation driving speed referred to chainages of tunnel, that give better the potential excavation performances compared to the real geological, hydrogeological and geomechanical conditions found, were then obtained.

The excavation driving curves were then correlated to the lithology, the topographic cover , the intersected faults, the water inflows drained in tunnel and measured at portal, and the RMR indexes for the geomechanical determination of the rock mass.

As far as the faults are concerned the intersection angles between faults direction / tunnel direction and excavation driving curves were compared. The density and kind of the faults were determined for chainages of tunnel (100 mt), as well as a planimetric layout of their distribution, expressed as areas of frequence contour lines. The investigations for the geomechanical classification of the rock masses were carried out about every 100 meters of excavated tunnel, through the determination of the right RMR index (Bieniawski, 1989).

PRESENTATION OF THE RESULTS

Figure 2 shows the geological sections related to tunnels F4, CL and F2. Below each profile the excavation driving curves were placed with the indication of the average excavation driving speed obtained for chainages of tunnel, that resulted from the application of the analysis method described above.

The ***tunnel F4*** first intersected the Cover sequences between the Calcschists Complex and the Ambin Basement, inside which it was possible to obtain daily averages higher than 18 m/d. Afterwards the TBM dealt with the excavation of a sequence of aplitic gneisses that meant a decrease of the geomechanical class form II to III and a higher wear and tear of the cutters. The remaining 2000 meters of tunnel were excavated without problems inside micaschists and gneisses of the Ambin Basement, even though the performances suffered from the complex layout (that involved an about 180° bend), as well as from the downhill excavation of the last 500 meters. The tunnel F4 dealt with topographic cover of more than 600 meters in thickness.

The ***tunnel CL*** was excavated with the same TBM that finished the F4. This tunnel, 6500 meters long, entirely realized inside the micaschists of the Ambin Basement, was carried out without any problems in only 9 months of work, with real excavation driving average of 31 m/d, that decreased to 21 m/d in the second part of the layout not because of geological or technical problems but because the person who carried out the excavation was ahead of time. The tunnel dealt with an area with a topographic cover between 500 e 700 mt of thickness.

The excavation of the ***tunnel F2*** started in January 1997, inside the micaschists and gneisses of the Ambin Massif, under the cover that become thicker and thicker up to 800 meters. After a first part where the performances were more than satisfying (<24 m/d, with an excavation driving record of 71 m/d) the tunnel recorded a production decrease of 7 m/d, draining up to 300 l/s of water, and then further decreased to less than 3 m/d, also due to several TBM stops caused by extremely bad geomechanical condition of the rock mass. Figure 3 shows a direct comparison among the three face excavation driving curves, in which it is possible to notice the wide divergences of the curves obtained for F4, CL and F2.

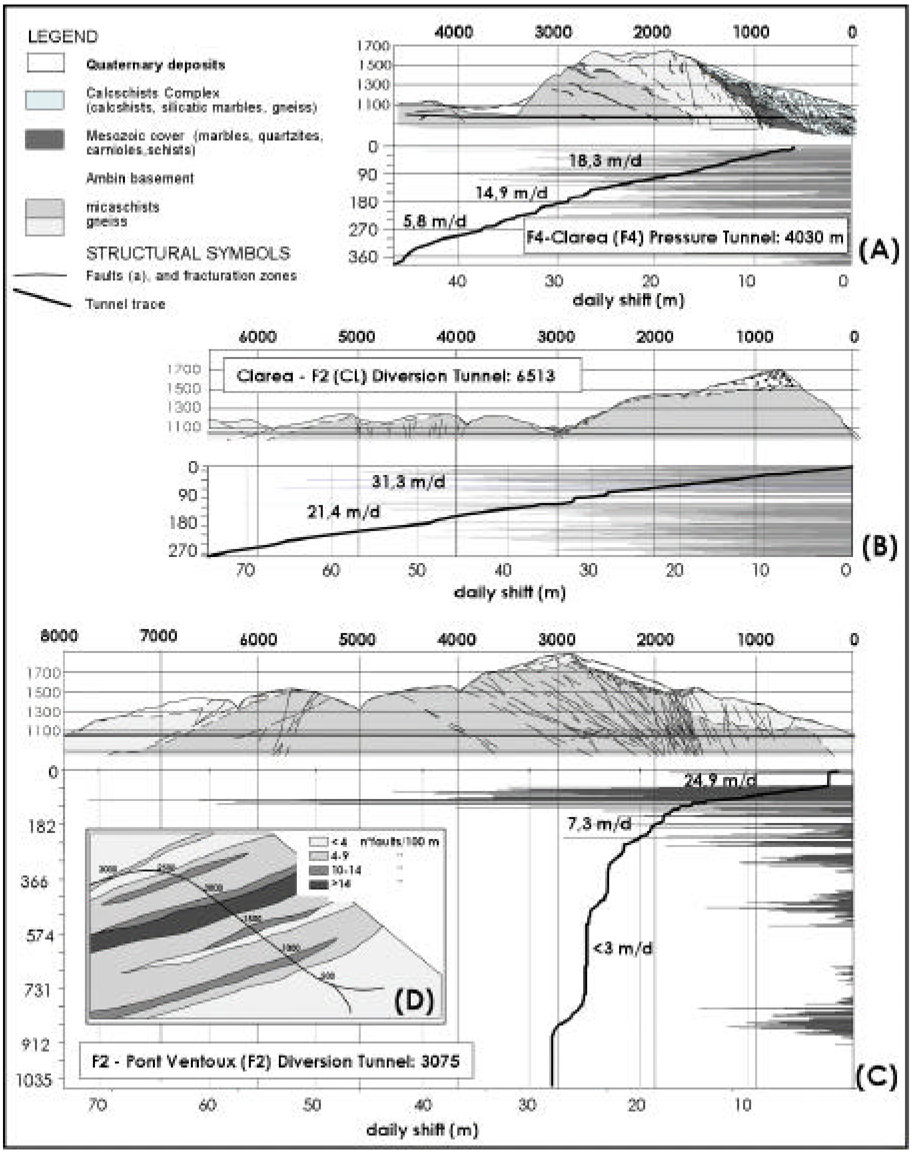

Figure 2: Geological sections of tunnels F4 (A), CL (B) and F2 (C) with graphics of the daily and progressive excavation drivings carried out with TBM. The sections show the geological setting found during the excavation. The average speeds calculated for chainages of tunnels are showed. For a better understanding of the geological setting found in the tunnel F2, a plan of the intersected discontinuities expressed as areas of density contour lines is also given (D).

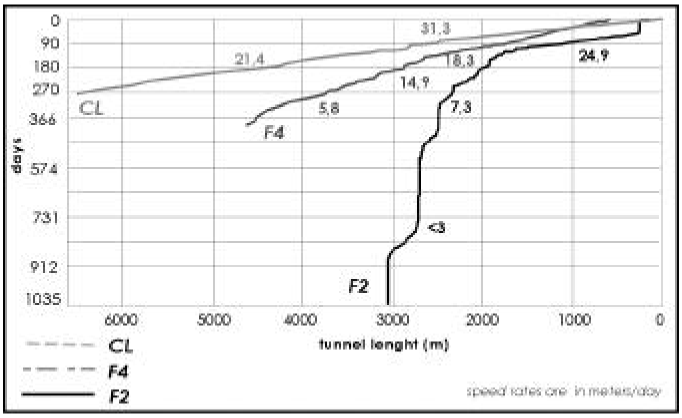

Figura 3: Comparison among excavation driving graphics of the tunnels F4, CL and F2. Notice how all the tunnels have comparable productivity indexes (Ip, m/d) in the first part, whereas they completely diverge, even though they were excavated in the same lithotypes.

ANALYSIS OF PROBLEMS IN THE TUNNEL F2

The tunnel F2 represents a perfect case of study for the understanding of excavation problems with TBM in bad conditions (Barla et al., 2000; Cesano et al., 2001). This fact is furthermore supported by data that come from excavation with the same TBM in adjacent tunnels, with same lithologies and similar geological setting. The tunnel F2 was in fact analysed by Barla & Barla (1999, 2000), and by Barla et al. (2000), who have recognized the cause of the problems that have been occurred till today in the situ stress conditins of the rock mass in which the tunnel has been excavated.

The rock mass in which the tunnel F2 has been excavated is characterized by the presence of a pervasive cataclastic deformation bundle, with regional direction N60°E, constituded by faults with direction between N30°E and N60°E (Figure 1 – plots 3-4-5, Figure 4A). More than 210 faults have been found till today in 3000 meters of tunnel. Analysing in details the excavation performances recorded in this tunnel and comparing them with the geological and hydrogeological conditions, it is possible to individuate three areas with different features (Fig. 4B). The graphic of the total number of intersected faults is showed in Figure 4C, followed by the pattern of the total drained water inflow (Figure 4D). The graphic 4E shows the distribution of the main faults for chainages of tunnel, whereas the foolowing one (4F) shows the α_{FT} intersection angle between the faults direction and the tunnel axis. The last Figure, 4G, shows the distribution of measured RMR indexes.

Basing on excavation driving performances, the tunnel F2, as it has been excavated till now, can be divided in 3 parts, characterized by the values given in the following table.

Settore	Ip (m/d)	TF (n°)	TW (l/s)	Fd (n°)	α_{FT}(°)	RMR_C	Topografic cover (m)
A	24.9	<50	<10	<2	40-80	II-III	<400
B	7,3	>140	>200	>8	35-80	III-V	400-700
C	<3	<30	<30	<4	<35	III-V	>700

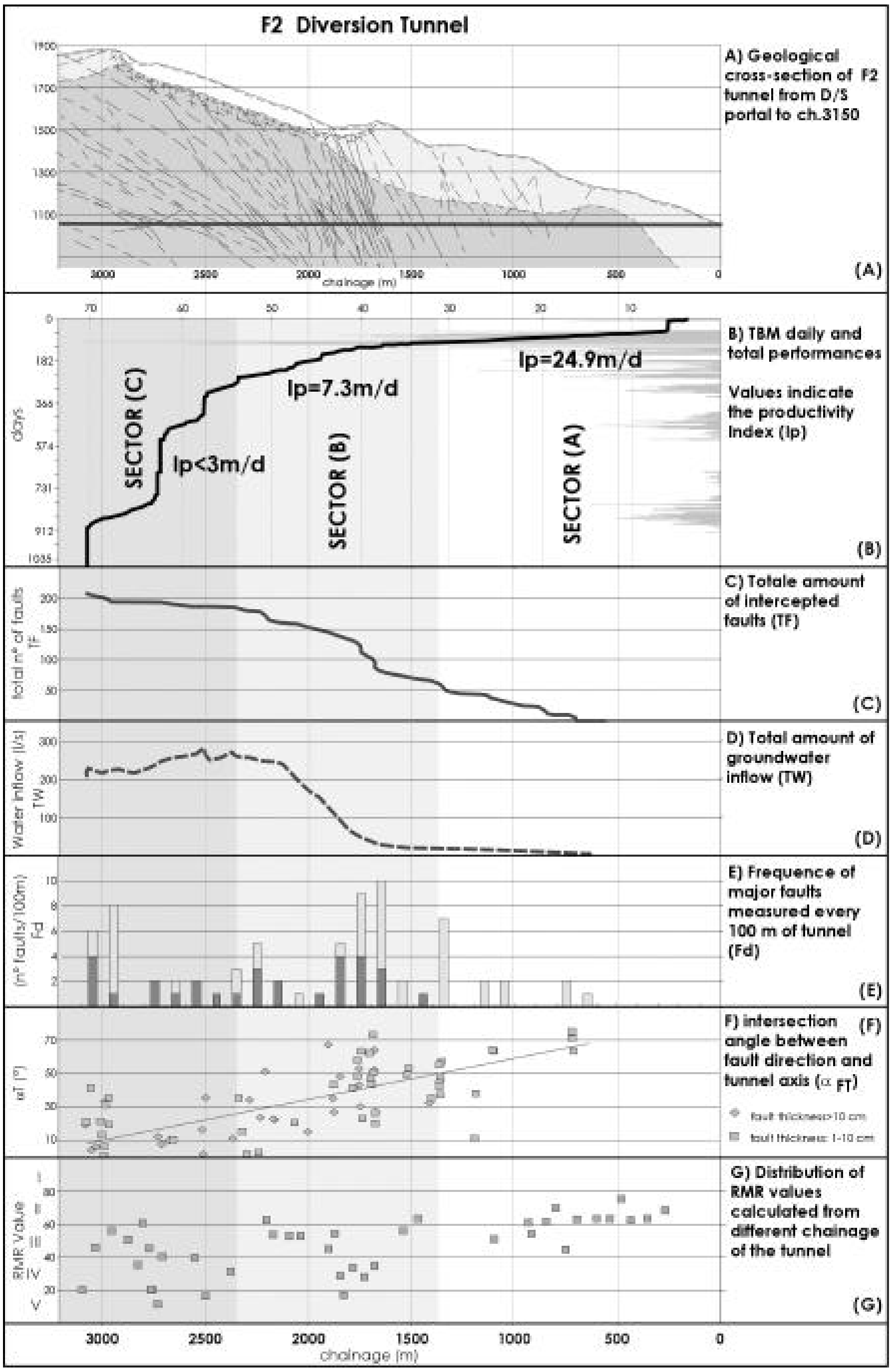

Figura 4: Analysis of different parameters that contributed to decrease the excavating rate with TBM in tunnel F2. See the text for deepenings.

Between part A and part B it is possible to notice a sharp decrease of the productivity indexes that from 24.9 m/d change into 7.3 m/d. That is caused by the intersection between the tunnel and the cataclastic bundle with consequent decrease of the rock mass quality (increase of faults from <50 to >190 in less than 1000 meters of tunnel) and above all by the presence of water (from 0 to more than 250 l/s).

Between part B and part C it was recorded a further decrease of the Ip index, particularly due to many extended stops of the TBM. But if the geological and hydrogeological parameters referred to these parts are analysed in details, it is possible to notice that there is not a further increase of the intersected faults (from 190 to 210) as well as there are not further increases of the drained water flow rates (settled to 220 l/s). As well, it possible to compare the quality indexes of the rock mass to those in the part B. The only parameters that change are the α_{FT} angle that becomes in general lower than 35° and the topographic cover that becomes thicker.

Many recent studies hold this parameter responsible for the high decrease of the Ip index and of the excavation driving problems. It is to be noticed that even though the other two tunnels (F4 and Cl) were excavated under a notable topographic cover (>600-700 m) did not recorded decreases of the Ip index due to cover increases (Figure 5). On the contrary, there would seem to be a direct relation between excavation driving speed and topographic cover.

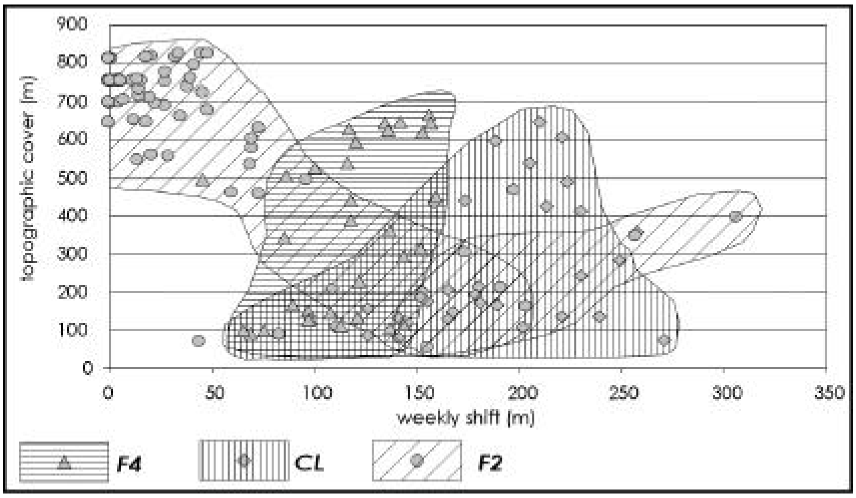

Figura 5: Relation between weekly excavation driving speed and topographic cover on the tunnel parts excavated in this week. Notice how data of tunnel F4 e Cl almost seem to show a direct relation between excavation driving and cover.

CONCLUSIONS

In the writer's opinion even though the increase of the lithostatic load and consequently of the in situ stress conditins of the mass in which the tunnel F2 has been excavated till today, is not a marginal factor, it does not represent the main cause of the excavation driving decrease. It is possible to identify the cause in the α_{FT} intersection angle between faults and tunnel axis, that, below a critical value of 35°, favours the formation of collapses at the intersection between the face and the walls, that occur near the TBM head. As well, this unfavourable angle involves that, once that the fault is intercepted by te excavaton and

before its complete intersection, it can intersect the tunnel for a lenght varying between 50 to 100 meters, slowly moving from a wall to another of the gallery and favouring the spalling phenomena, amplified by the in situ stress conditins. The decrease of the Ip index is lower in the part B, even in presence of water inflows of more than 250 l/s total, that strongly impeded the driving and the machine upkeep, and in presence of notable covers (up to 700 meters). It is possible to explain that, noticing that the faults were all intersected with medium-high angles.
Summarising, the data about tunnel F2 put in evidence the driving difficulties of the cutter in presence of cataclastic shear zones with unfavourable angle of incidence between the structures and the excavation axis. The elaboration of data about the tunnel CL, allows us to have reliable daily average driving parameters for open HR-TBM in intact rock masses with comparable lithologic – structural features. The analysis made for the tunnel F4 put in evidence the effect on the real driving speeds determined by the complex plan layout of the trace, related to a kind of excavation with TBM and conveyor mucking system.

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