THE ABDALAJIS TUNNEL (Malaga- Spain)

The new Double Shield Universal TBM challenge

Remo Grandori - SELI President

Paolo Romualdi – SELI Technical Office Director

S.E.L.I. Societa' Esecuzione Lavori Idraulici S.p.A., Viale America 93, 00144 Rome, Italy

Abstract

The new high speed railway lines under construction in Europe foreseen the execution of very long large diameter tunnels under the most variable rock conditions.
Standard Single Shield and Double Shield TBM are not always the right answer for the excavation of these tunnels, especially when adverse rock conditions are expected with rapid squeezing ground and/or face collapses.
The Abdalajis tunnel is a twin 7,1 km long 10 m diameter railway tunnel, part of the new high speed line connecting the city of Malaga with Cordoba, in the south of Spain.
The present article deals with the TBM excavation of the Abdalajis Tunnel East, where SELI is actively involved in the construction as partner of the Dragados-Tecsa-Seli-Jager Joint Venture. (The Abdalajis Tunnel West, that runs parallel to the East one, is executed by the Spanish Company SACIR with the same technologies)
A new type of TBM, named Double Shield Universal (DSU TBM) and manufactured by Mitsubishi, has been developed for the execution of the tunnel.
The DSU TBM has been designed as an evolution of the Double Shield TBM to cope with rapid squeezing ground, being able to treat and to stabilise the rock ahead of the tunnel face through the combination of piles and special grouting.
The ground conditions encountered in the first section of the tunnel excavated until September 2004 are below the today technical limits for TBM application especially for this range of tunnel diameters.
The argillite rock formations crossed in long sections of the tunnel are completely altered and faulted, with rapid convergence of the tunnel walls associated to large instabilities of the tunnel face (ravelling ground) and to methane gas inflows with pressures up to 11,5 bars.
The article, moreover, deals with the performances of the DSU TBM in extreme ground conditions and evaluates the possible improvements to this type of TBM to further extend its capacity to the most critical situations.

1 - THE PROJECT

The Abdalajis Tunnel East is one of the two 7,1 km long railways tunnels part of the new high speed railway line from Cordoba to Malaga and its alignment is shown in Figure 1.

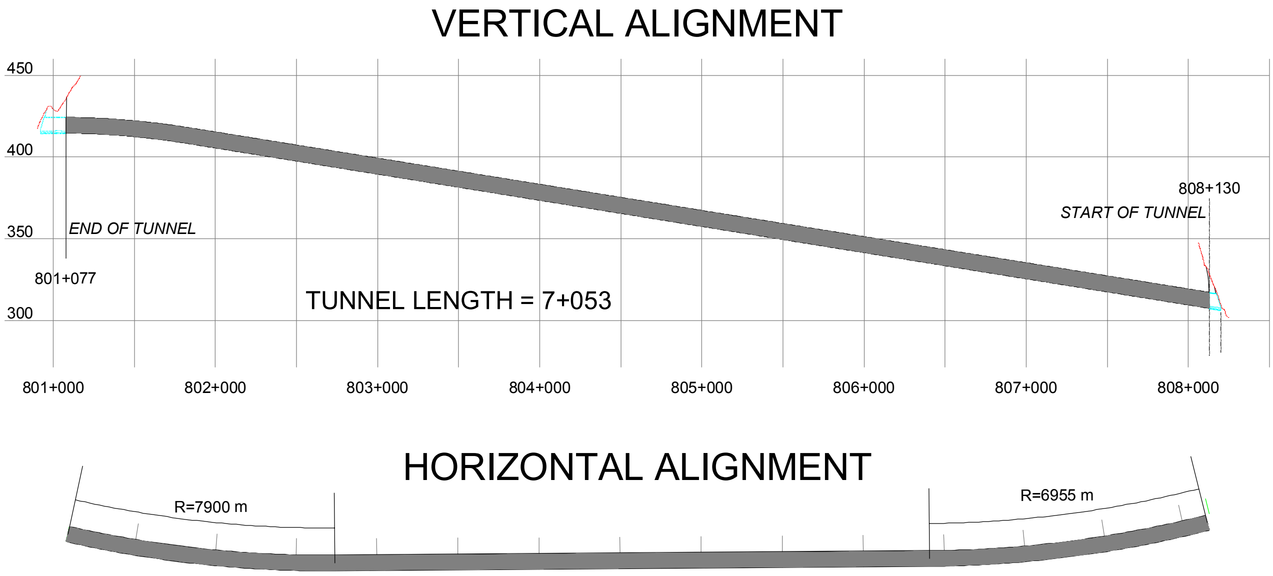

Figure 1 – TUNNEL ALIGNMENT

The excavation diameter is 10 meter and the lining is the tapered ring type made of 45 cm thick precast segments (Figure 2) with a final internal diameter of 8,80 m. The adjacent segments are connected with bolts and the adjacent rings with plastic connectors. An EPDM profile is used to seal the joints between segments. The gap between the segments and the rock surface is filled with pea-gravel and in a second stage the pea-gravel is grouted with a cement based mixture.

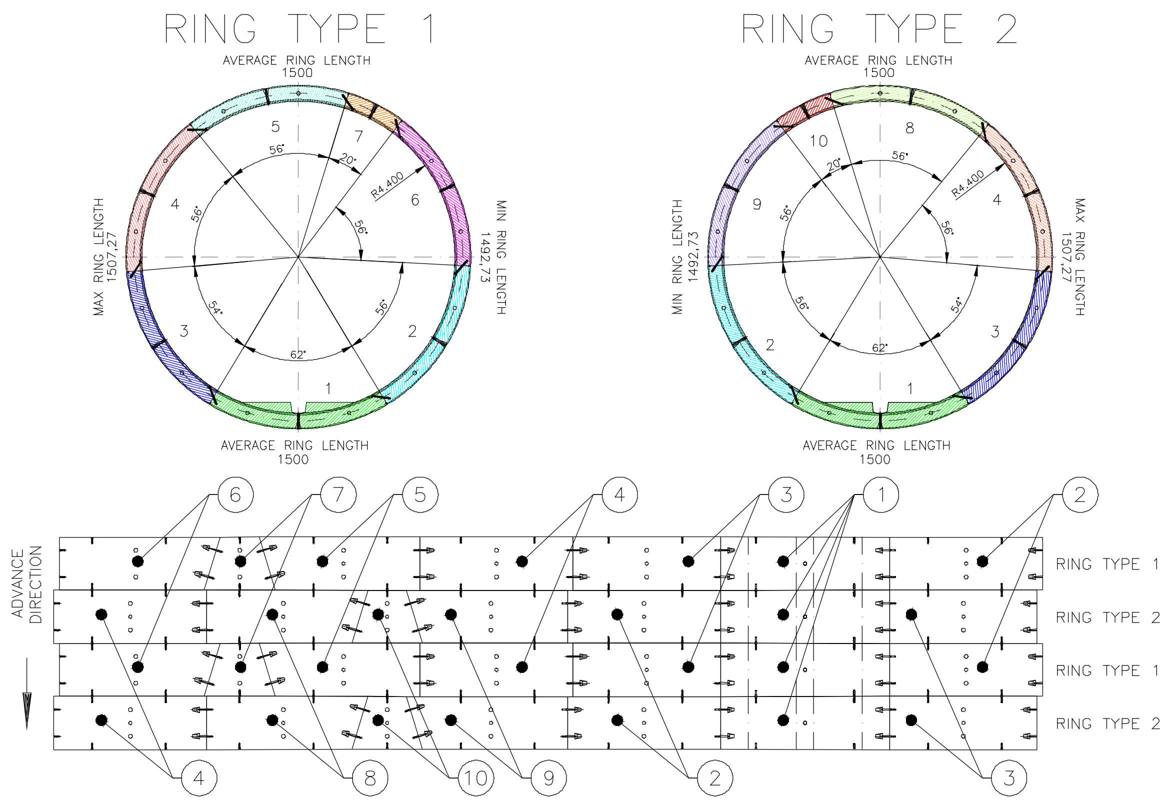

Figure 2 – TUNNEL TYPICAL SECTION

2 - THE GEOLOGY OF THE TUNNEL

The Abdalajis tunnel geology can be divided in two sections:

- the first section (Figure 3) in weak and very weak formations having a total length of about 2 km
- the second section in more competent sedimentary rocks under high overburden

The present article deals with the excavation of the first section, characterised by the following formations:

- phillade and quartzite - Formacion Tonosa
- slate and sandstone – Formation Morales
- conglomerate – Formacion Almogia
- argillite - Arcillas Variegadas

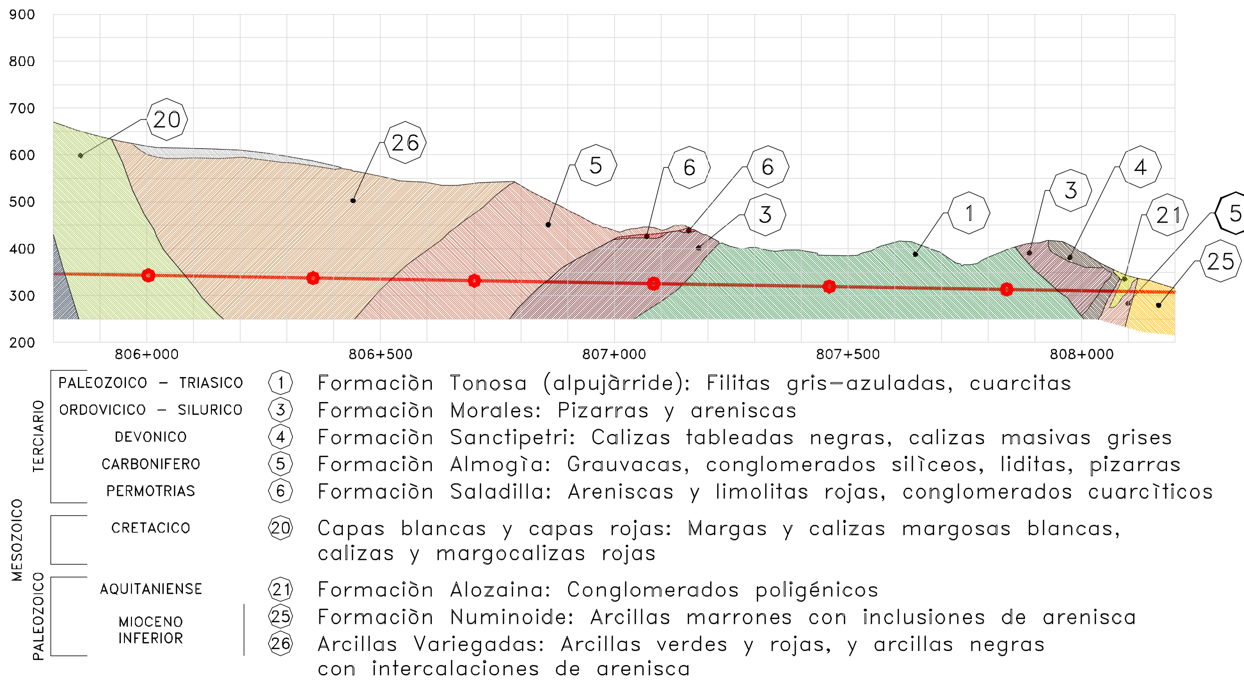

Figure 3 – FIRST SECTION OF TUNNEL - GEOLOGY

3 - THE DSU TBM DESIGN

The DSU design concepts and characteristics have been described in detail in the article " NEW DESIGN FOR A 10 M UNIVERSAL DOUBLE SHIELD TBM FOR LONG RAILWAY TUNNELS IN CRITICAL AND VARYING ROCK CONDITIONS" published in the RETC 2003 Proceedings by Wolfgang Gutter and Paolo Romualdi. This type of TBM have been developed to be able to cope with the adverse ground conditions and in particular with squeezing ground and face collapses even with large diameter. The capability of a TBM to face these adverse tunnelling conditions is in fact essential in large diameter tunnels in complex geologies, due to:

- the negative effects of poor ground conditions are enhanced by the bigger dimensions of the tunnel
- it is almost impossible to execute hand mining works to free the TBM and/or stabilise the ground around and in front of the machine.

To resume the main design and operational features of the DSU TBM are the following:

<u>Design Features</u>

- total TBM length in the range of 11 m, i.e. equal to the length of a single shield TBM of same diameter;
- rear shield diameter much smaller than front shield to allow the TBM advance also in squeezing ground;
- new telescopic articulation design to eliminate the problem of packing the joint in loose ground;
- overcutting facilities to increase the gap between the rock and the segments in squeezing ground.

<u>Operational Features</u>

- capability to advance in double shield mode even in the poor and instable ground conditions: since in large diameter tunnels the instability phenomena occur more frequently, this feature allows the DSU TBM to advance with maximum productivity in a wider range of ground conditions;
- capability to treat and to stabilise the ground ahead of the TBM through the execution of grouted piles all around the tunnel section.

4 – THE TBM PERFORMANCES IN THE FIRST 2 KM SECTIONS IN WEAK ROCK FORMATIONS

After an initial learning curve period, the TBM started to advance at high speed with daily advances over 20 m and a maximum peak of 34 m.

This despite the argillite formations proved to be in very poor conditions since the beginning of the tunnel.

Roughly at chainage 1600, however, the bad conditions of the argillite formations encountered in the first section of the tunnel negatively affected the TBM performances.

Figure 4 shows the tunnelling progress and the encountered geological difficulties in the first section of tunnel excavated.

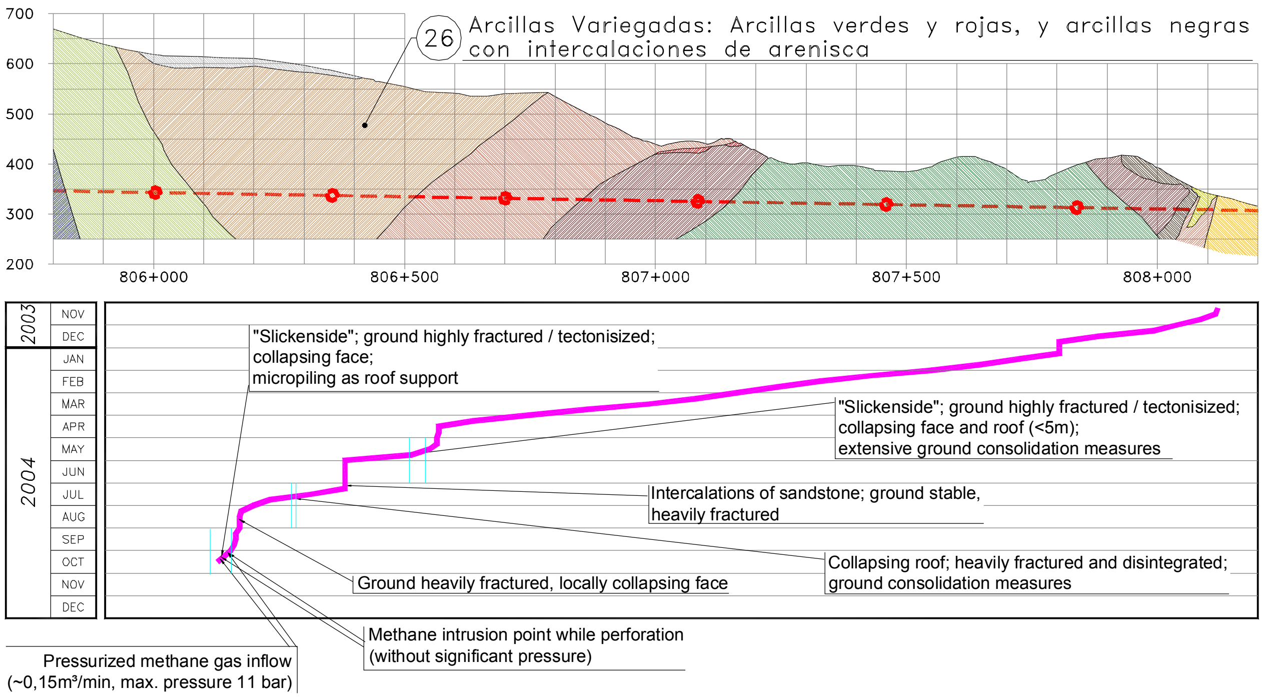

Figure 4 – TUNNELLING PROGRESS AND ENCOUNTERED GEOLOGICAL DIFFICULTIES

5 - TBM BEHAVIOUR IN SQUEEZING GROUND

Tunnel convergence was one of the biggest concerns in the project design phase since the large tunnel diameter and the presence of argillite rock formations under high cover.

The DSU TBM proved however to be able to cope with rapid convergences of the tunnel walls without any problem and without having to use the full overboring capability of the machine, thanks to the particular shield design of this new type of TBM.

This capability will allow the utilization of TBM in many projects under critical conditions that until now had to be executed with conventional methods with huge costs and very low advance rate.

6 - TREATMENT AND STABILISATION OF THE TUNNEL FACE AND AHEAD OF THE FACE RAVELLING GROUND SECTIONS

A long section of the tunnel in the argillite (Arcillas Variegadas formation) was characterised by large instabilities of the tunnel face.

In the most critical sections the ground was behaving like a non cohesive ravelling ground.

Under these conditions, without taking special measures, the over-excavations and face collapses would have buried the TBM in the tunnel.
For this reasons the following measures were implemented in several critical sections:

- <u>Face stabilization treatments</u> – (Figure 5) – when the over-excavation at the face was increasing above a couple of meters in front and above the cutterhead, the TBM advance was stopped, the voids filled with resin foams and the collapsed material in front of the face consolidated with chemical grout mix. Than the TBM was advanced for few strokes until the treatment had to be repeated.

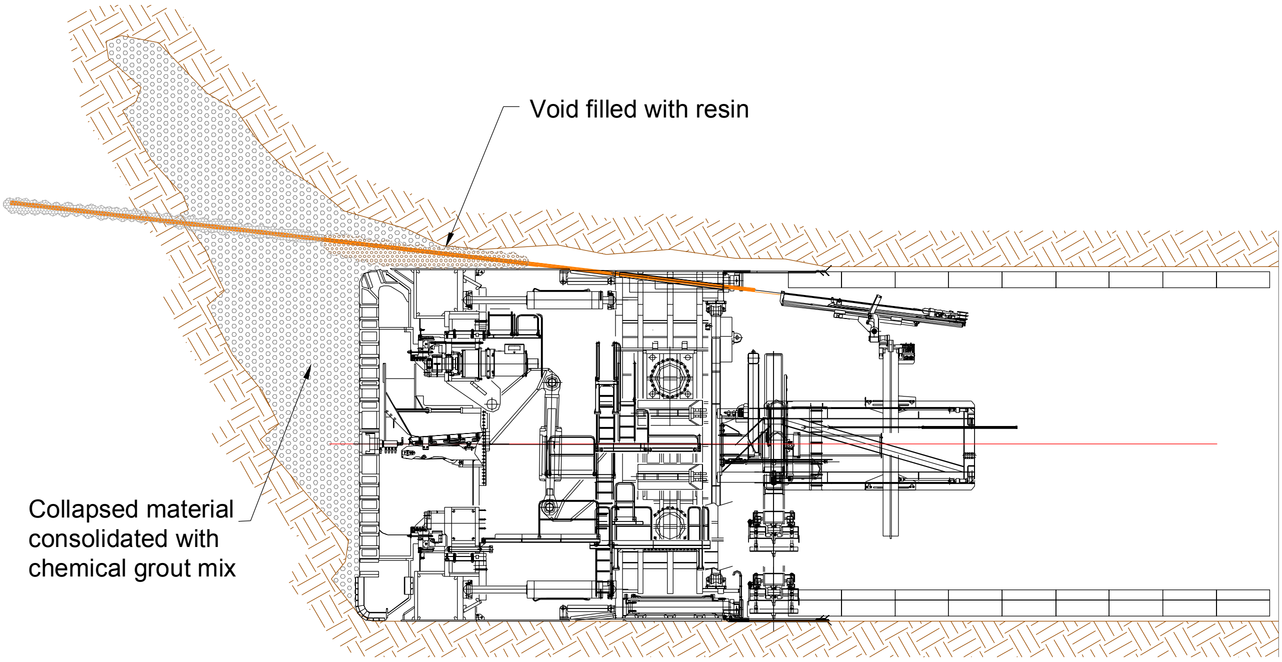

Figure 5 – FACE STABILIZATION TREATMENT

- <u>Pre-treatment of the ground ahead of the face</u> – (Figure 6) – in the most critical sections the weak argillite was behaving like a flowing gravel and even the above described face stabilization treatments were not sufficient to control the face collapses and the ground itself had to be treated in front of the TBM.
  A pattern of fiberglass pipes were executed through specific holes in the rear shield of the TBM in order to stabilise the crown of the tunnel. These piles were than grouted with chemical grouting mix (GEOFOAM or MEYCO), very successful in penetrating in the argillite formations and increase the cohesion of the ground enough to avoid face collapses.
  In the worst tunnel sections this treatments have been repeated each 3-5 m.

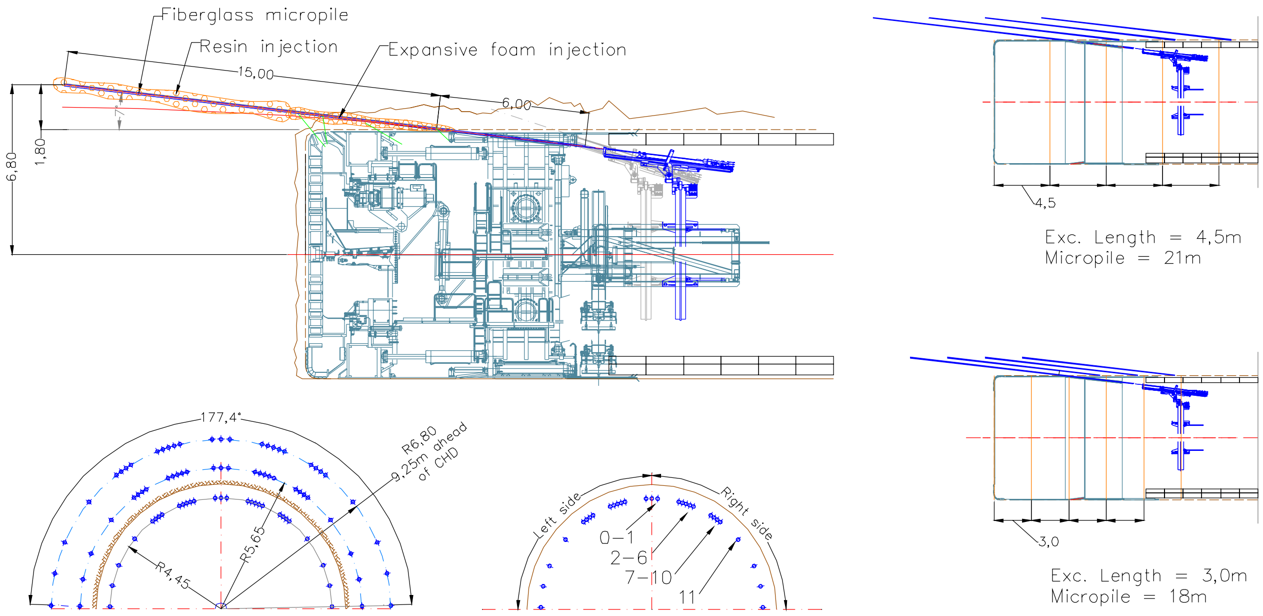

Figure 6 – PRETREATMENT OF THE GROUND AHEAD OF THE FACE

7 - THE INFLUENCE OF GAS INFLOWS ON THE TUNNELING OPERATIONS

The geological reports and investigations made before the project execution did not foreseen the presence of gas. Therefore the TBM was equipped with a standard gas monitoring system. Every time the concentration of gas overpasses a given percentage of the lower explosion limit, the system causes the automatic shut down of the electric supply to the TBM and Backup except for:

- the back-up ventilation booster fans
- the dust scrubber and related fans
- the gas monitoring system
- the communication system
- the emergency lighting system

The ventilation system installed on the TBM backup is designed for 37,5 m^3/s of air from the backup rear end to the TBM area. This amount of air maintains an air speed all along the backup of 0,61 m/s.

Despite the forecast, few minor gas inflows occurred already at chainage 1600 and important gas inflows occurred almost continuously between chainage 1850 and chainage 2050 in the argillite formation.

The gas was measured in a probe hole at a maximum pressure of 11 bar.

The exceptional volumes and the extraordinary pressure of the gas inflows, as well as the continuity of the inflows for long tunnel sections, caused big delays and disruption to the TBM advance and required additional installations to increase the air speed in some critical area in the TBM shield area.

To avoid the formations of gas pockets in the TBM shields several compressed air agitators were installed in critical locations (Figure 7) and at the same time several additional gas sensors were installed.

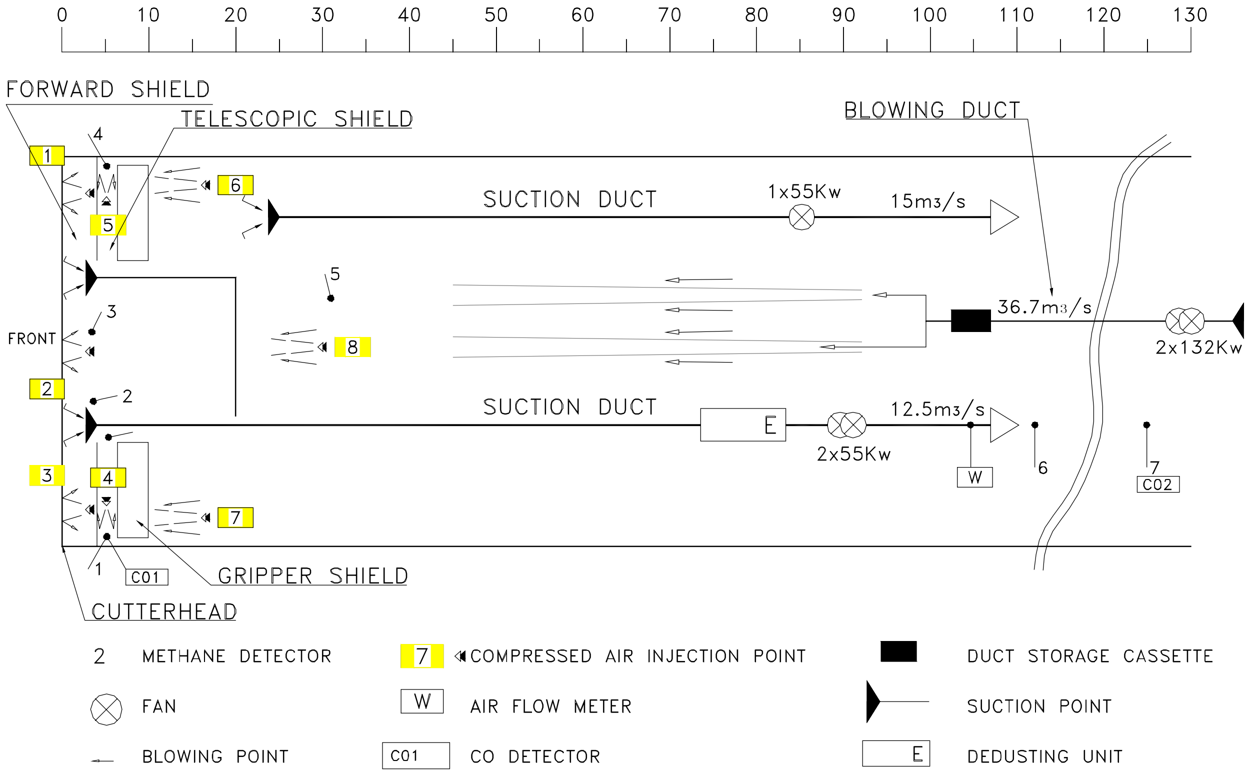

Figure 7 – MODIFIED VENTILATION SCHEME

Moreover, the upper limits of admitted gas concentration, initially set up at 20% of the lower explosion limit, was reduced to 10% in the attempt of increasing the level of safety in the tunnel.
These measures increased substantially the efficiency of the gas control and monitoring system.
However, despite the improvements, the power shut downs due to high gas concentrations were frequent and in some sections of the tunnel they were occurring every few revolutions of the cutterhead.
The stand by time of each shut down varied depending the volume and pressure of the gas inflow and was ranging from few minutes up to several weeks.
In total about 2000 hours of stand by have been caused by gas inflows; this despite the particular additional measures implemented on the TBM to increase the air flow in the critical area.
The presence of gas negatively influenced the TBM advance much more than the simple stand by time, this because:

- the TBM could not advance in the critical geological section with the required speed and continuity and the stand by time imposed by the gas presence caused the ground to develop the instabilities
- the frequent stops and restart of the cutterhead caused the ground at the face to be disturbed much more than under normal operating conditions
- the presence of gas delayed or even prevent the implementation of the special treatments at the face and of the ground ahead of the face
- the frequent stops and restarts of the tunnelling operations did not allow the tunnel shifts to reach the proper efficiency and every time such a complex industrial plant had to be put again in operation some problems occurred

8 -POSSIBLE IMPROVEMENTS OF DSU TECHNOLOGY FOR FUTURE APPLICATIONS

DSU TBM is an evolution of the traditional Double Shield TBM type and therefore many technical solutions and features were already of proved design and efficiency.

The main improvements that can be implemented to DSU TBM design in order to further increase their capability to cope with extremely adverse ground conditions can be resumed as follow:

- install on the cutterhead a copy cutter system designed for rock application. SELI has designed and tested in the Torino Metro Project a double copy cutter arrangement that proved to be able to work in soft rock and that could improve the overboring capability of the TBM in squeezing ground formations
- avoid the possibility of vertical displacements between the inner telescopic shield and the gripper shield
- further extend the possibility of the TBM to install piles (more positions for probe/piles around periphery) to treat and stabilise the ground ahead of the face.

Al the above improvements are relatively easy to be executed.

9 - CONCLUSION

The combination of the presence of high concentration of gas and of very bad rock encountered in this first 2 km long section until now excavated drastically reduced the advance speed of the TBM.

Despite these extreme tunnelling conditions the DSU TBM was able to advance without having to execute mining works like: by pass tunnels, caverns, etc.

In particular even rapid and important convergence of the tunnel proved not to be a problem for the TBM advance.

Ravelling ground could be treated ahead of the tunnel to an extent to avoid important face collapse.

Even in the weak ground conditions the DSU TBM can be operated in telescopic mode, erecting the segmental lining contemporary with the excavation. This type

of machine is therefore able to maintain very high advance speed even in unstable ground where traditional Double Shield TBM would have to advance in Single Shield Mode.
In good rock conditions DSU TBM is able to advance with a productivity that is basically limited by the segment erection time and by the efficiency of the backup system.
The DSU TBM technology can be further improved to increase its performance in the most extreme rock conditions.