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- Case History -
8 M Diameter 7 Km Long Beles Tailrace Tunnel (Ethiopia) Bored And Lined In Basaltic Formations In Less Than 12 Months

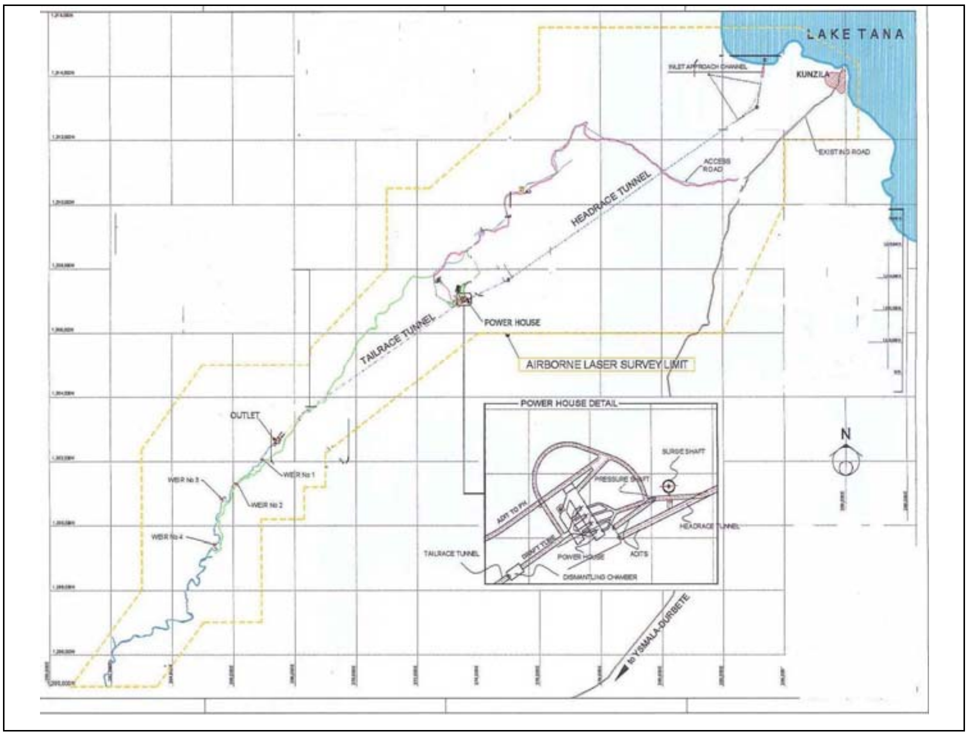
Antonio Raschillà, Site Manager, S.E.L.I. Spa
Francesco Bartimoccia, Project Manager, S.E.L.I. Spa

ABSTRACT

On the 2nd of June 2007 SELI S.p.A. started the excavation of Beles Tailrace Tunnel (Ethiopia). The new 8,07 m diameter DS Universal TBM utilized for the tunnel excavation was manufactured by SELI S.p.A. and allowed the installation of 30 cm thick concrete lining, contemporaneously with the excavation of 7,200 m of tunnel.
The greatest part of the tunnel alignment was excavated in hard and sound basaltic rocks.
The paper describes the main steps of the tunnelling operations which led to a remarkably rapid excavation, with a peak production of 36 m / day and a final breakthrough achieved 46 days ahead of the contractual deadline.
Furthermore the paper describes the work and logistic organization that was set up to efficiently perform the mechanized excavation in the very remote area of the project.

THE PROJECT

Beles project is one the multi-purpose projects, currently underway, to develop the resources in Ethiopia.
The project area is located in the Amhara Region (north western of Ethiopia), about 150 Km to the Bahir Dar town (see figure 1). The Beles Multipurpose Project, committed to Salini Costruttori S.p.A., will be a single stage power plant with a total installed capacity of 460 MW.



<Figure 1. General map of the project>

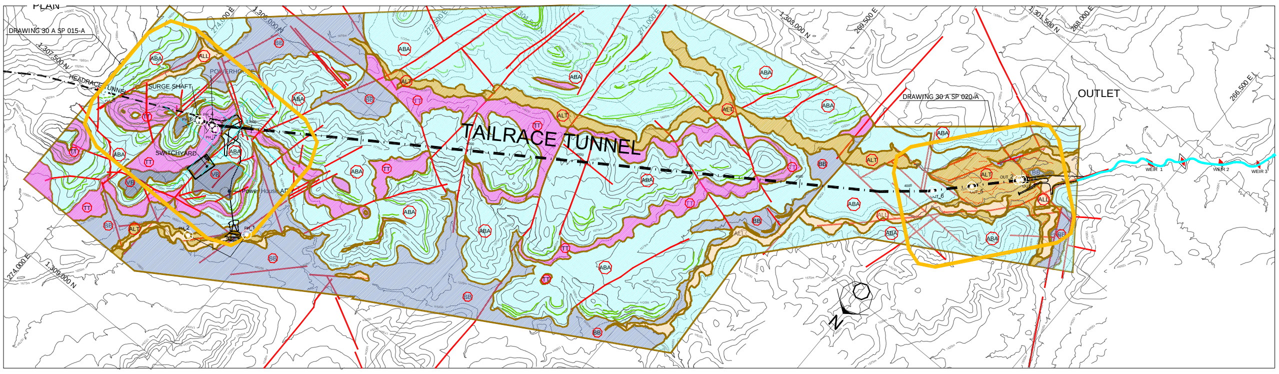
The project, located in the South-Western bank of the Lake Tana, develops completely underground for a total length of about 20 Km, and consists of mainly:

- 12 Km Headrace Tunnel (which will conveys water from Lake Tana into the penstock of the underground powerhouse)
- **7,2 Km Tailrace Tunnel** (which will discharges water into the Jehana River, a small tributary of the Beles River)
- Underground Powerhouse with n. 4 Francis type turbines of 115 MW each and Transformer system
- 270 m Penstock shaft
- 90 m Surge Shaft

THE TRACING AND GEOLOGY

The SE-NW running tunnel is divided in a Tailrace Tunnel and Headrace Tunnel, with a total excavation length of nearly 19 Km.

The Tailrace Tunnel runs from the Powerhouse to the outlet portal for 7200 m with a slope of 0,15%, conveying the discharge water to the Jehana River (see figure 2).



<Figure 2. Tracing of Tailrace Tunnel>

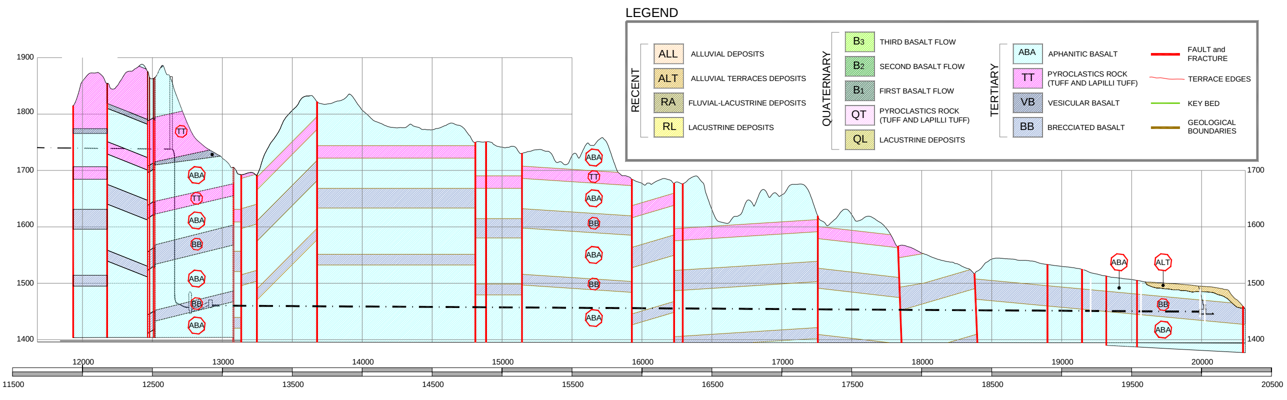
Excavation started from the outlet towards the Power House. The geological conditions are described in TBM advance direction, as follows:

From chainage 7200 to 5000 the tunnel penetrated a brecciated Basalt formation, which was composed of plateau flow basalt and pyroclastica (agglomerates and tuffites). The overburden in that range extended up to 120 m. Excavation conditions was good to fair for most of this TBM section, depending on the fracture intensity.

From chainage 5000 to 0 the tunnel section contained a series of aphanitic Basalt layers with some intercalations of brecciated basalt layers at an overburden from 250-370 m. The rock mass crossed was good and favourable tunnelling conditions (see figure 3).

<Figure 3. Front Face>

The complete Tailrace tunnel was expected to intersect about 17 major lineaments; these zones were described with locally poor tunnelling conditions. The lineaments intersect the alignment most of the times at obtuse angle and almost vertically (see graph 1).



<Graph 1. Geologic profile>

THE WORK AND METHOD OF EXCAVATION

For the excavation and lining of the about 7,2 Km of Tailrace Tunnel was utilized a Double Shield TBM system designed and built by SELI Tecnologie. The tunnelling system executed all the following operations:

- boring
- erection of the precast lining
- filling of the annular gap between the excavation and the precast lining by pea-gravel.
- grouting of the rock around the lining

TBM And Back-Up System Description

TBM, back-up system and rolling stock were designed and manufactured by **SELI Tecnologie** (see figure 4) in the Italian factory of Aprilia (Rome) to ensure the maximum advance rates under variable ground condition through the complete mechanisation of all operations related to handling and installing precast segment, loading and exchanging muck trains and servicing the various TBM power units mounted on the rolling platforms. The table below resumes TBM specifications.

TBM TYPE	Double Shield Universal
Cutterhead excavation diameter	8,070 mm (new cutters)
TBM Shield Length (Including tail shield)	11,87 mt (TBM closed)
TBM & Back-Up Length	approx. 125 mt
CUTTERHEAD AND CUTTERS	
Cutterhead structure	No. 6 parts – heavy structure bolted
Number of cutting tools	52
Cutter type	17 inch disc – backloading and recessed
CUTTERHEAD THRUST	
Thrust Cylinders	n. 12 – 345 bar max pressure
Auxiliary Thrust Cylinders	n. 14 – 345 bar max pressure
Maximum advance speed	6 m/h
CUTTERHEAD DRIVE	
Type	Electric
Cutterhead Power System	8 x 315 kw Electric water cooled motors
Maximum Torque	5,250 kNm
Cutterhead Speed	0 to 6 rpm
SEGMENT ERECTOR	6 movements radio controlled
CONVEYOR SYSTEM	
Width	1,000 mm
Capacity	550 t/h
MACHINE WEIGHT	Approx. 600 t
BACK-UP COMPONENTS – AUXILIARY EQUIPMENT	- ZED system - Gas monitoring and alarm system - Pea gravel storing and pumping system - cement grouting storing, mixing and grouting system - emergency diesel generator - close circuit TV camera system - rock drilling equipment - PLC system (see figure 5)

TBM was also equipped with a special Rock Drilling Equipment to probe in front of the Cutterhead and from the Gripper shield, which has 18 different holes (internal diameter 102 mm) where, by using a special support mounted on the erector, probe drilling can be carried out.

An automatic recording device of the latest generation was installed on the TBM. Excavation parameters were visualized on a monitor in the operator cabin. The computer mounted in the operator cabin recorded and stored all the data by means of datalogging system.

The recorded parameters were:

- TBM total thrust and pressure thrust on each thrust cylinder
- Penetration rate
- Cutterhead torque
- Cutterhead revolution per minutes
- Electric power consumption for each electric motor
- Stroke advance
- Steering parameters

<Figure 4.TBM (called Hiwot) in Aprilia Factory (Rome)>


<Figure 5. PLC System>

Tunnel Transport System

Tunnel excavation and segments installation, in DS Mode, are performed concurrently, except under unfavourable geological conditions.
The rolling stock followed SELI philosophy and design tradition, that has proved to be successful in more than 500 Km of tunnels built.
The choice of muck cars (fix body type) allowed the highest ratio among the transported weight and the own weight of the muck car. Furthermore, all lateral internal surface was smooth and didn't create any obstacle to the operations of unload of the muck.
The wheels had large diameter and high capacity bearing for long life and low rolling friction.
Each Tailrace tunnel trains included:

- 13 fixed-body muck cars for a total capacity of 156 m^3 of muck (see figure 6)
- 1 pea-gravel car transporting a silos of 5,3 m^3 of capacity
- 3 flatbed cars for the transportation of precast segments
- 1 personnel car having 16 seats capacity

The number of trains utilized was 2/3 up to chainage 3500 and n° 4 from chainage 3500 to the end of the tunnel.

A fully automatic hydraulic muck car tippler (able to unload one muck car each 2 minutes and full train in 26 minutes) was located outside the tunnel portal. The tippler was complete with pusher for the train shunting and therefore there was no need of the locomotive to unload the train.

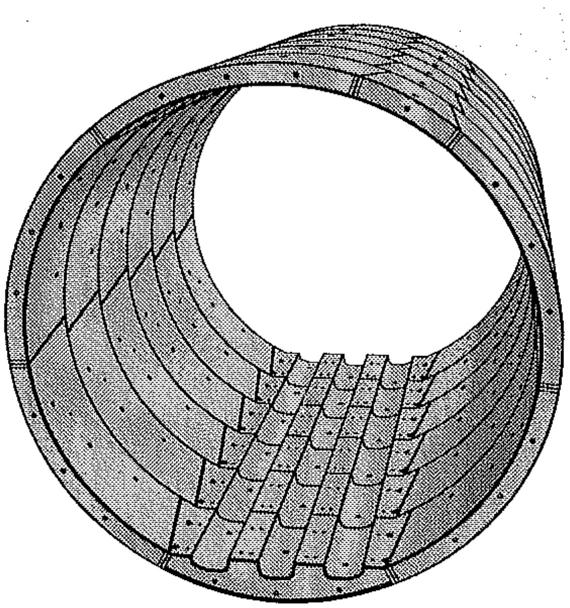
<Figure 6. Tunnel portal>

Lining

The lining was an open type parallel ring rhomboidal segmental system, with the following characteristics:

- External diam. 7800 mm
- Internal diam. 7200 mm
- Lining thickness 300 mm
- Segment ring width 1500m
- N.6 segments + n.1 key stone
- Invert with flat tracks and 3 central trenches
- Dowel connectors in the circumferential joints
- Grouting holes

For assembling of the segment ring, the invert was installed first with the opportune dowels of the circumferential joint. Next step, the both left and right bottom sidewall segments was installed and kept in position by means of the auxiliary thrust cylinders. Afterward the both left and right top sidewall and as the last elements of the ring the roof segment and key stone were installed (see figure 7).
Dowel connectors (three for each segment made by extruded polyetilene) had no structural function, but were installed just like simple connecting and centring devices.



<Figure 7. Lining System>

Pea Gravel Injection

During excavation “pea gravel” was injected into the annular gap between rock mass and the lining. The size range of the pea-gravel was 8-12 mm and it has been dimensioned to allow its injection by using n° 2 air pumps mounted on the deck n° 3. A dedicated line arrived to the deck n° 1 where, using flexible pipes, pea-gravel was injected behind the second-last completely assembled ring.
Immediately after the injection the grouting holes was plugged with suitable wooden plugs to prevent escaping of pea-gravel.

Contact Grouting

Contact grouting was performed all along the tunnel (see figure 8) to grout the pea-gravel in the annular gap, following the excavation behind the back-up (see figure 9).
Grouting was filled up also the small space between segment and segment along the joint where was present any opening.
Grouting plant was installed at the Tunnel Portal and the grout mixture was pumped inside the tunnel by using n° 2 lines of galvanized steel pipes.
Grout equipment was composed by:

- turbomixer having capacity of 1500 lt and production rate of 15 mc/h
- agitator having capacity of 4000 lt
- automatic dosing system for additives
- automatic dosing system for bentonite
- n° 2 pumps, maximum flow rate of 100 lt/min and maximum pressure of 200 bar

During the normal activities (excavation and regripping), in the range of the back-up decks, the chalking grooves was closed with mortar and all necessary repairs were done.

<Figure 8. Tunnel inside sight>

<Figure 9. Core drilling example>

LOGYSTIC AND WORK ORGANIZATION

Due to remote location of the project, it was necessary to overcome several logistic difficulties.
The shipment of the TBM, back-up, rolling stock and all the other spare parts and materials was carried on from Italy to Gibuti and from Gibuti to the job site (in Bahir Dar area) through about 1000 Kms of difficult roads (see figures 10,11,12), especially during the rainy periods.
Particular attention was done in the Nile Bridge (see figure 13) crossing where all necessary checks of the structure took place before the passage of the main TBM components.
The waiting to receive any shipment on site was about 4-5 months from purchase order.
For this reason it was indispensable to plan possible spare parts as providently as possible, with considerable advance.

<Figure 10. Portal area>

<Figure 11. Road from Gibuti to site>

It was also necessary to face low level of specialization of local manpower; a specialized SELI staff with adequate experience supervised all tunnel boring operations training local workers to assure the level of reached quality and productivity.

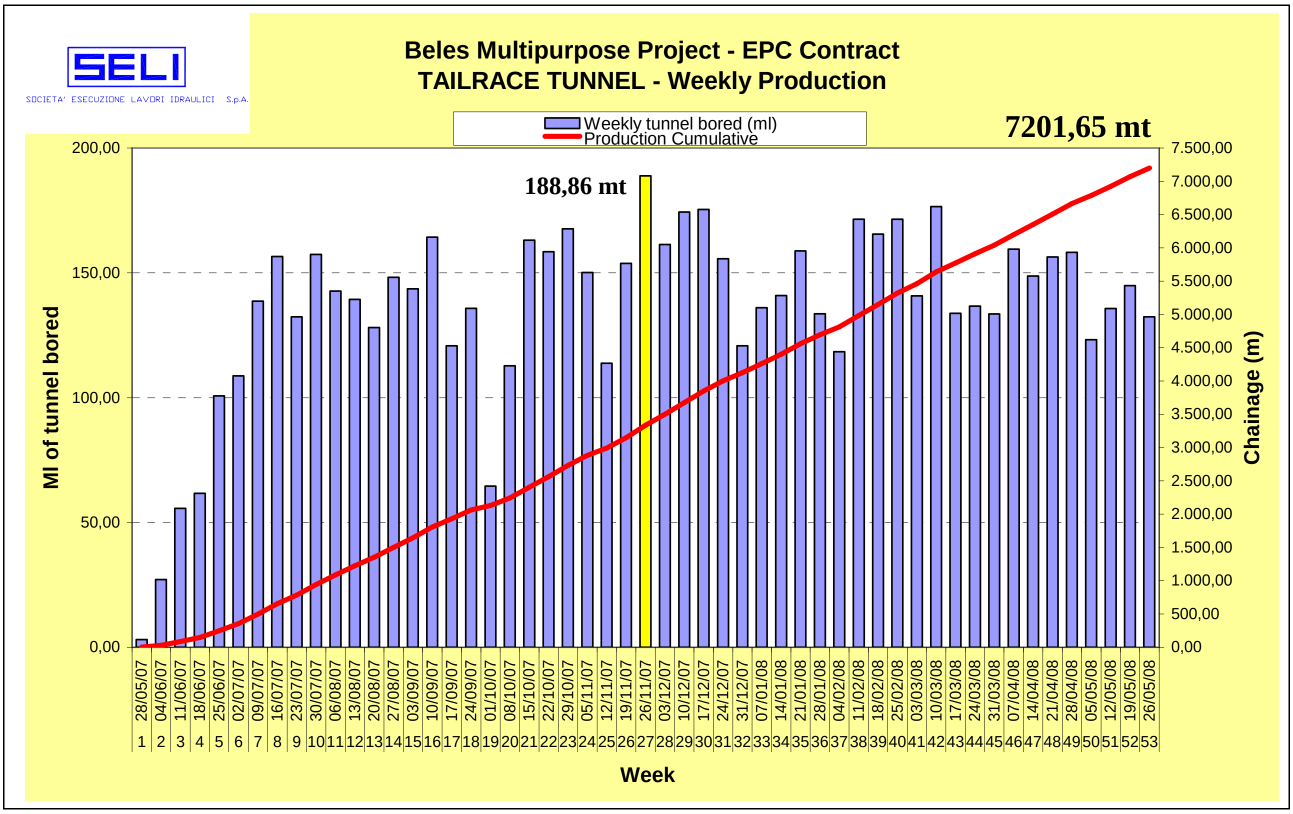
<Figure 12. Road from Gibuti to site>

<Figure 13. Nile Bridge crossing>

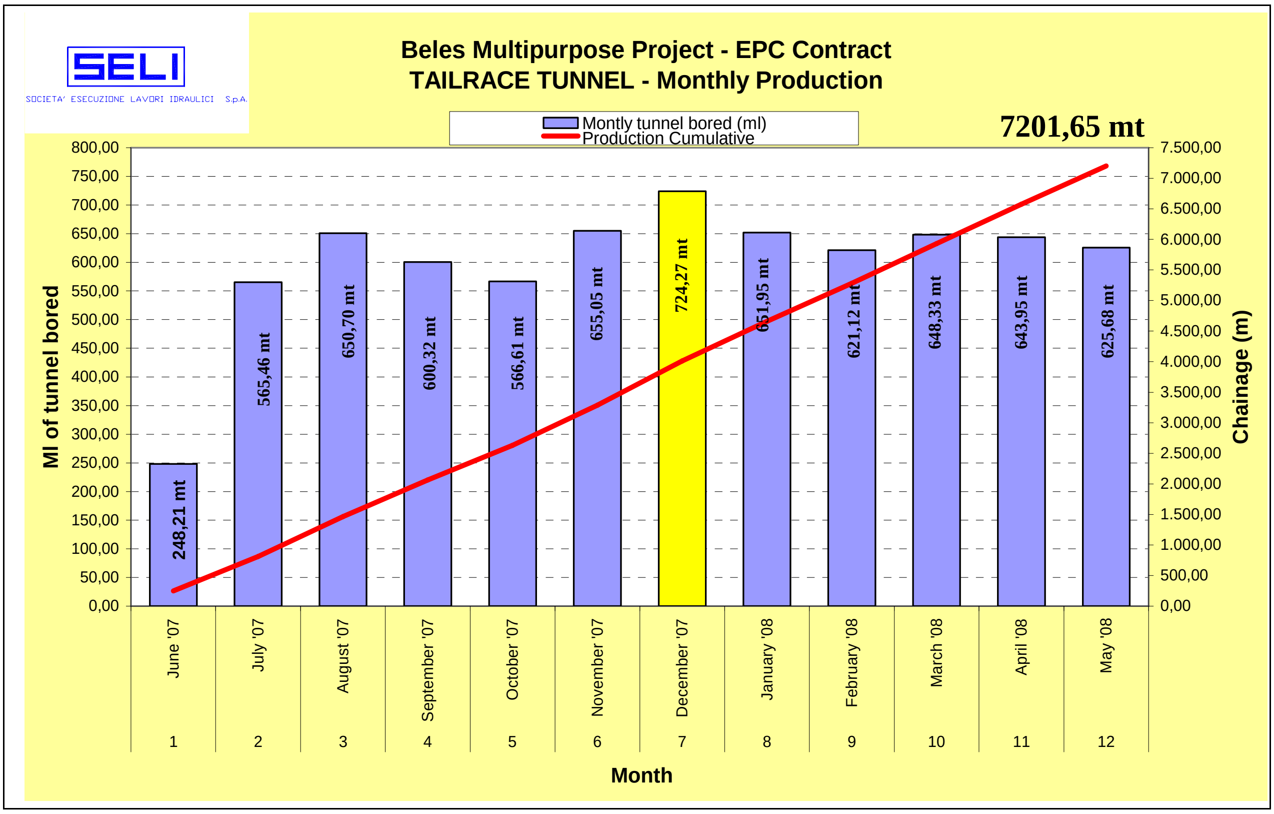
Tunnelling operations was carried out 7 days/week in 3 shifts of 8 hours each, with shift changing at the front and a scheduled maintenance shift inside the tunnel of about 4 hours in the morning. The maintenance operations consisted mainly in cutterhead inspection and cutter changes as required, supply and extension of tunnel services, eventual probe drilling operations, maintenance pea-gravel lines. When special maintenance, repairs or probe drilling was required, the maintenance duration was extended beyond the normal 4 hours time.

TBM PERFORMANCE

The excavation of the tunnel started on the 2nd June 2007 and was completed the 31st May 2008, after less then one year at an average advance rate of about 20 metres per days.
The maximum daily advance rate of 36 metres (24 rings) was achieved in January '08, while the best weekly advance rate was 189 metres achieved on the 27th week of excavation (see graph 2).
The best month, as shown in the graph 3, was December '07 with 724 metres of excavation during 29 days of work (excluding 25th and 31st of December) at an average rate of 25 metres per day.



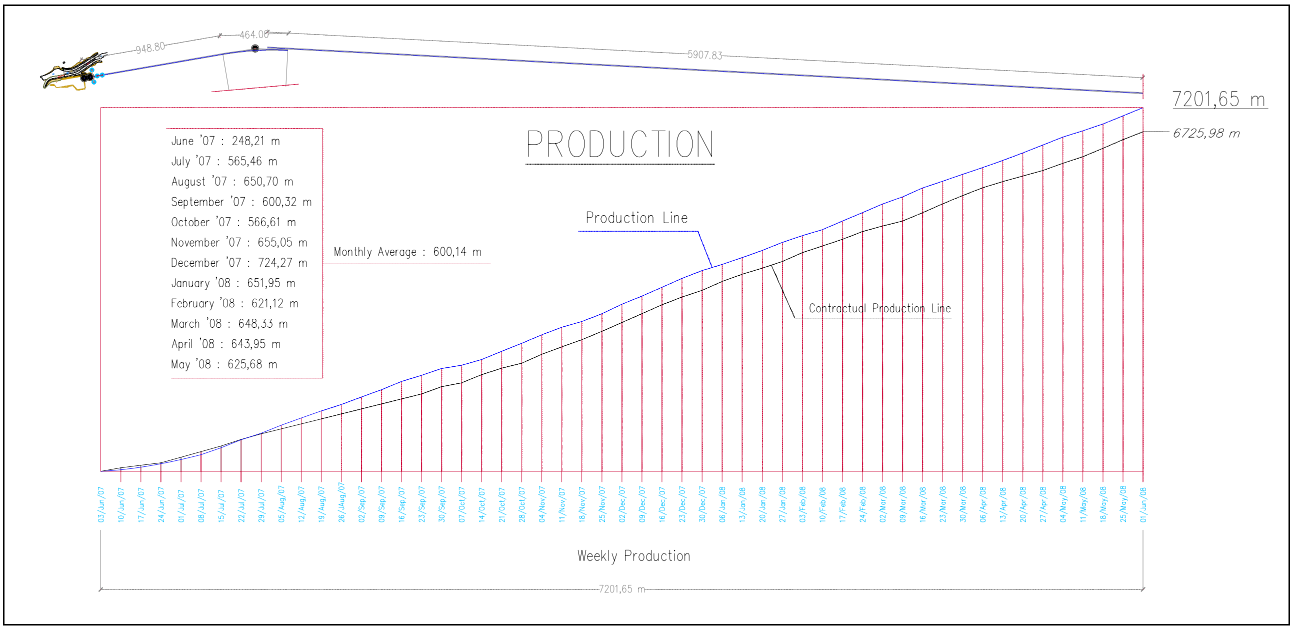
<Graph 2. Weekly productions of the TBM DS 0807 114 SELI>



<Graph 3. Monthly productions of the TBM DS 0807 114 SELI>

Graph 2 shows the very short period of the learning phase.

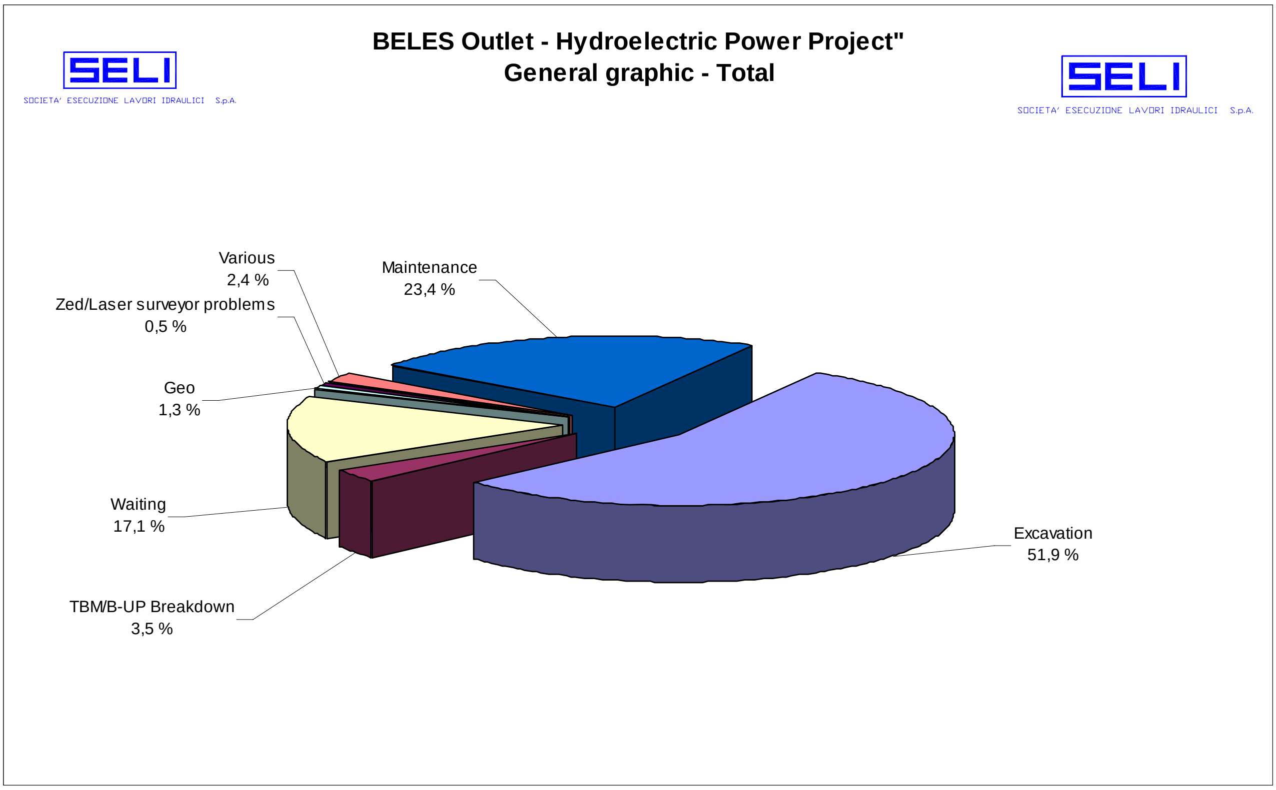
Learning curve, usually long 2-3 months, was limited at less that one month. This important target was obtained through an easy and rapid interaction expatriate – local personnel and an optimization of the necessary equipments.



<Graph 4. Production lines of the TBM DS 0807 114 SELI>

The graph 4 shows the constant advance of the excavation production (upper line) related with the contractual production (lower line) calculated on the basis of the RMR (Bieniawski) of the rock mass encountered. TBM completed the tunnel with 46 days of advance on contractual time.

TIMING ANALYSIS



<Graph 5. TBM DS 0807 114 SELI – timing analysis>

Graph 5 above shows the good efficiency reached from the TBM (51,9 % included regripping time and ordinary waiting train).
It was the result of a punctual daily maintenance (23%).
In the “Maintenance” and “Waiting” items, particularly main point was time lost for Pea-gravel injection lines. Substantial delays were imputable to the necessary daily maintenance of the injection lines (to guarantee the good operation of the system) due to the characteristics of the material. Non available fluvial gravel in situ has imposed a sharpy material from quarry with consequent easy deterioration of the lines.
Other important parameter was “TBM breakdown” (3,5 %), a low value considering the rock hardness (with the consequent problems relative to the vibrations) and TBM adjustment during learning phase.

CONCLUSIONS

Main problems encountered during the project were difficult logistic situation, especially for supplying materials and a local manpower with lack of specialization.
It was possible to obtain good results through a sharp design and planning of all the activities, with the employment of specialized SELI human resources, who has organized in the better way all the work and has instructed the local manpower.
Key factor was a careful planning and equipments employment, with consequent optimization of the work phases during the whole work.

<Figure 14. Breakthrough of the TBM>