CONSTRUCTION OF AN UNDERPASS AT THE RAVONE RAILWAY YARD IN THE CITY OF BOLOGNA: ASPECTS OF THE DESIGN AND CONSTRUCTION

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SUMMARY: A description is given below of the design and construction of a completed underpass at the Ravone railway yard in Bologna. It connects up with existing roads and is the first lot of the works for extending the south and western roads designed to complete the Bologna ring road. The underpass passes with a very shallow overburden under the rail tracks of the Milan - Bologna, Verona - Bologna and Bologna - Padova High Speed Rail lines which were maintained in service during the works.

1. INTRODUCTION

The underpass (Fig. 1) consists of two tunnels running side by side, each with an internal diameter of 13 m, a length of approximately 400 m and a distance between centres of only 17 m. The very shallow overburdens vary from 7 to 13 m and, as is described in detail below, the ground concerned has poor mechanical qualities consisting basically of gravel and silty sands with very occasional clay interbedding. The tunnels were each driven from two portals with half of the length in “cut and cover” tunnel, and half in underground tunnel beneath the actual railway lines and sidings in the central part of the underpass.

Design of the works according to ADECO-RS [Lunardi, 2000] was conditioned from the very beginning by severe constraints imposed by the railway service, and possible movements of the track level and by the requirement to perform the excavation and construction works in complete safety for both tunnel workers and railway traffic, which was never interrupted during construction of the underpass.

The two “cut and cover” tunnels were built for about 130 m from the southern portal retaining the earth by means of anchored reinforced concrete diaphragm walls (Fig. 2); using a similar scheme but a different technique, bifluid 1200 mm diameter jet-grouting diaphragm walls were built at the northern portal for about a 70 m stretch (Fig. 3).

The central part of the underpass, which passes directly under the railway line, required greater attention for the design and much more rigorous care over construction because of both the geotechnical characteristics of the materials tunnelled and the extremely delicate situation regarding surface interference.

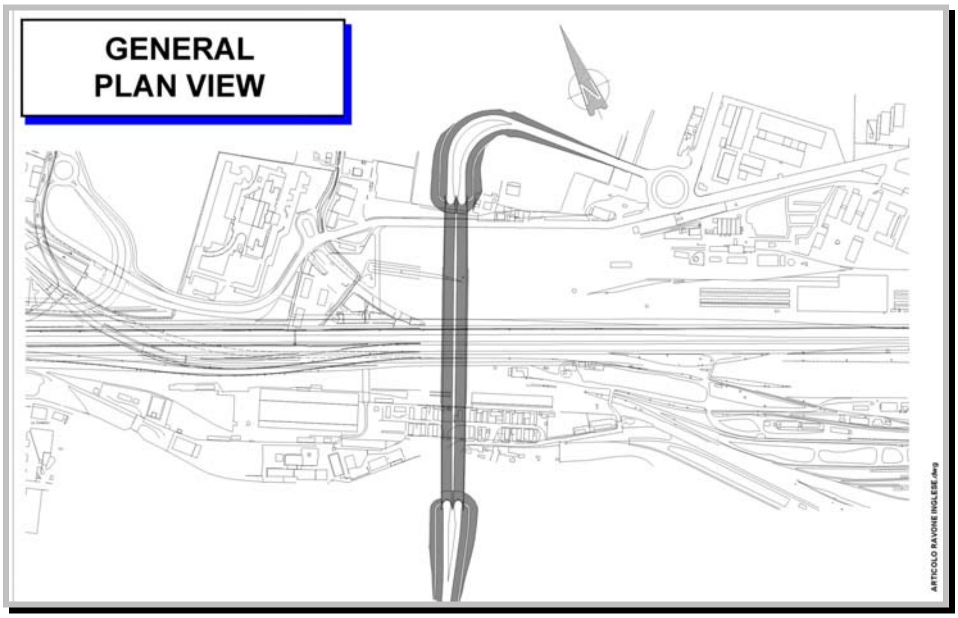


Figure 1 – GENERAL PLAN VIEW

The Ravone railway yard lies on the north western outskirts of Bologna between Via Zanardi and the River Reno in a few hectares of land, whose the geological and geomorphological characteristics are typical of the Bologna plain.

Anthropogenic action has nevertheless modified the original morphology considerably with excavation, movement of earth and levelling. This situation is particularly evident in the area of the underpass where the construction of the railway lines involved the creation of beds for the tracks consisting of fill material.

2. GEOLOGICAL-GEOTECHNICAL FRAMEWORK (SURVEY PHASE)

The stratigraphic sequence, ascertained by drilling a number of boreholes, was as follows (Fig. 4):

1) a surface stratum of fill material and debris less than 2 m thick consisting generally of gravel of varied granulometry with silty sand and fragments of bricks and tiles.
2) this is followed by a layer of clayey silts and silty clays weakly sandy, brown in colour with the presence of muscovite, with a slight to medium consistency that shows an increase in the silty and sandy fractions with depth. The thickness varies from a maximum of 4 m to a minimum of 2 m.
3) Further down a layer of silty sands is met, not particularly dense, with a mainly fine to medium granulometry, quartzy, angular with an abundant presence of muscovite, locally interbedded with more clearly silty lentils. The thickness varies from a maximum of 4 m to a minimum of 1.5 m.
4) The deepest layer identified consists of gravel with a varied granulometry in a sandy silty matrix, dense and light brown in colour. The sandy fraction has a varied granulometry, angular with a quartzy component. Within this body layers of less than one metre are found consisting of clay with silt, brown in colour. The thickness of the stratum is definitely greater that 16 m but its actual thickness is unknown

since no bore hole reached its bottom.

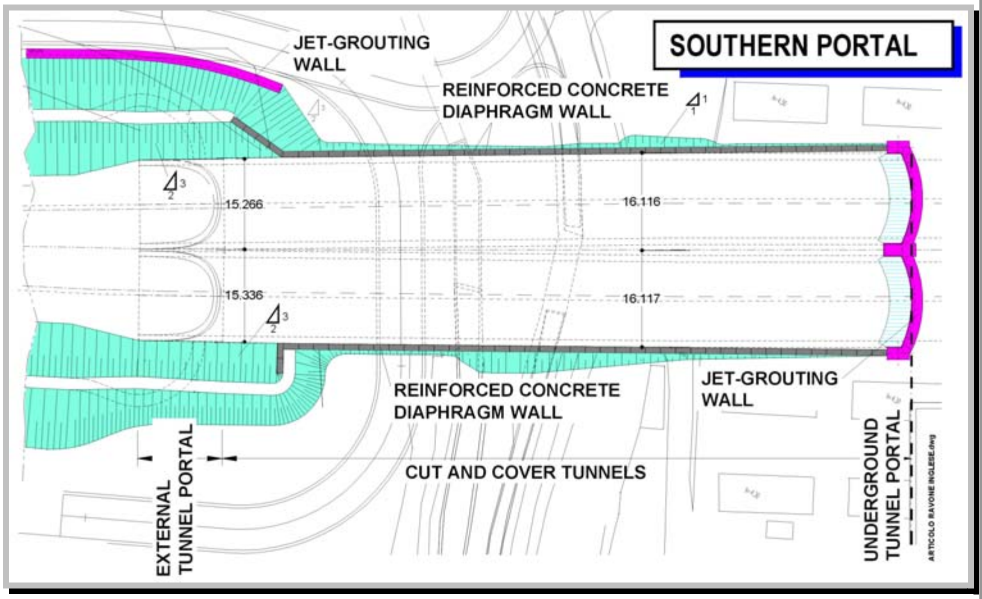


Figure 2 – SOTHERN PORTAL: diaphragm walls plan view.

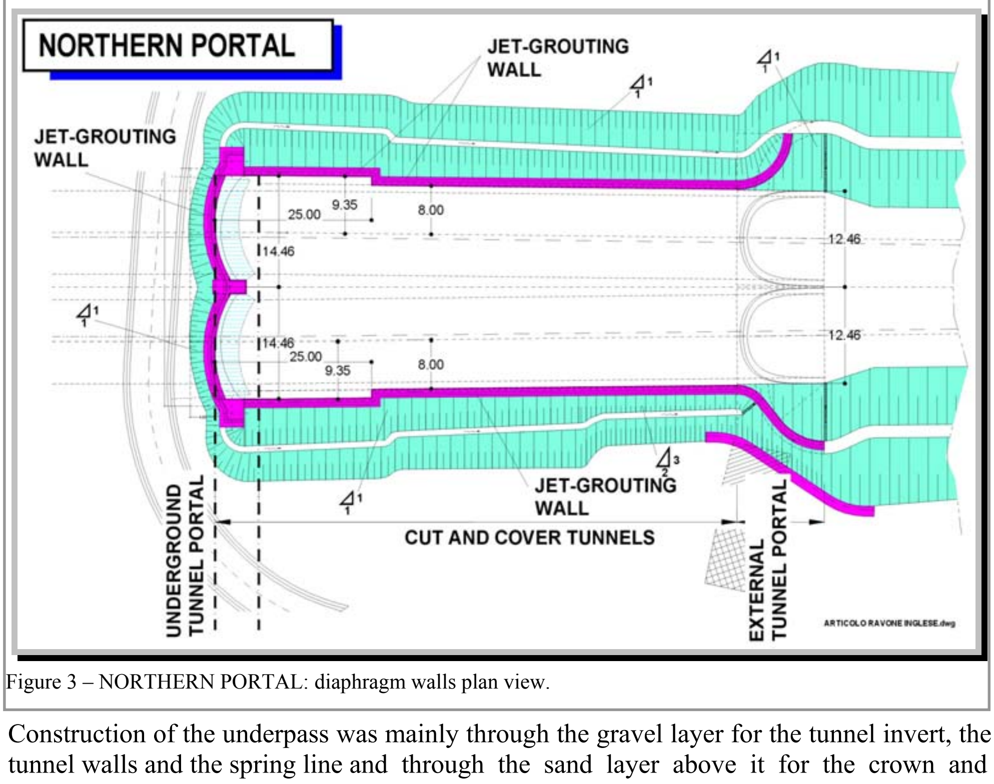
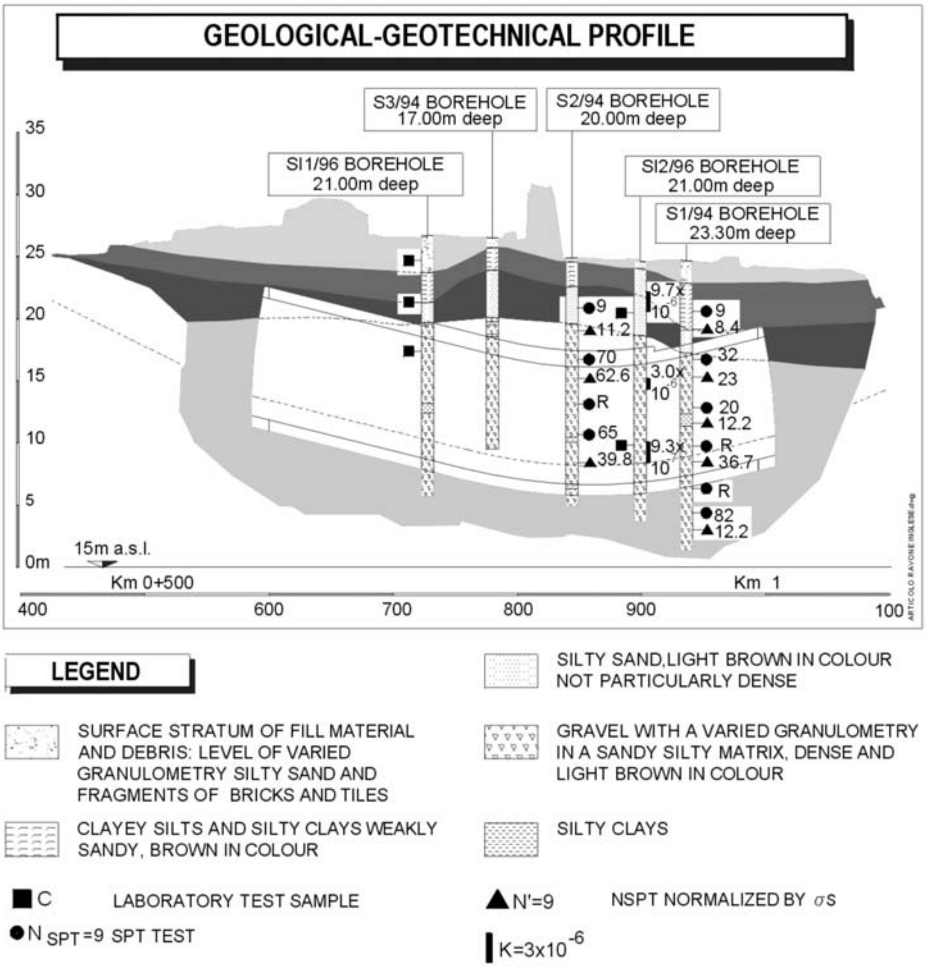


Figure 3 – NORTHERN PORTAL: diaphragm walls plan view.

Construction of the underpass was mainly through the gravel layer for the tunnel invert, the tunnel walls and the spring line and through the sand layer above it for the crown and spring line. Significant strata of silty clay were also frequently encountered.

Geotechnical characterisation of the ground to be tunnelled was performed by means of *in situ* mechanical tests and a series of laboratory analyses.



GEOTECHNICAL PARAMETERS							
	γ (KN/mc)	c(KPa)	φ (°)	Es(MPa)	μ	Dr(%)	K(m/SEC)
SILTY CLAYS	19.20	20-30	20-24	5-10	0.3	-	$< 1.0 \times 10^{-7}$
STILY SAND	20.00	10-20	26-30	50	0.4	30-35	1.0×10^{-7}
GRAVEL AND SAND	21.00	10	34-38	100	0.4	70-90	1.0×10^{-8} 3.0×10^{-8}

γ = UNIT WEIGHT
C = COHESION
φ = FRICTION ANGLE
Es = TANGENT YOUNG'S MODULUS
μ = POISSON'S RATIO
Dr = RELATIVE DENSITY
K = COEFFICIENT OF PERMEABILITY

Figure 4

The latter were aimed above all at classifying the material from a technical viewpoint.
Both the *in situ* and the laboratory tests showed similarities between the ground to be tunnelled and geotechnical data from numerous surveys on analogous ground conducted throughout the Bologna area and from data found in the literature.
The following table gives geotechnical parameters for the four levels identified.

	Unit weight (kN/m^3)	Cohesion (kPa)	Friction angle(°)	Elastic modulus (MPa)	Poisson's ratio	Relative density (%)	Permeability Coefficient (cm/s)
1) Fill	18 ÷ 20	20÷30	20÷24	5÷10	0.3	-	-
2) Clayey silt	19 ÷ 20	20÷30	20÷24	5÷10	0.3	-	$< 1\cdot10^{-5}$
3) Silty sand	20	10÷20	26÷30	50	0.4	30÷35	$\sim 1\cdot10^{-5}$
4)Sandy gravel	21	10	34÷38	100	0.4	70÷90	$1\cdot10^{-6}\div3\cdot10^{-6}$

3. DIAGNOSIS PHASE

An examination of the data above, with particular regard to the very shallow overburdens and to the modest thickness of the ground between the two tunnels (Fig. 5), and of the first calculations performed clearly shows the need to drive the tunnel carrying out preconfinement intervention around the cavity, in order to minimise the decompression of the ground and to reduce the effects of tunnel advance at the surface.

4. THERAPY PHASE

It was therefore decided to operate with tunnel advance sections that would reduce mechanisms producing decompression of the face and the cavity.
The advance core was in fact reinforced with cemented fibre glass structural elements or improved by jet-grouting depending on the consistency of the ground while that in advance around the tunnel was improved using jet-grouting only.
Thresholds for ground deformation at surface were set on the basis of the results of mathematical modelling conducted to simulate the sequence of the construction phases for the two tunnels and on the basis of the contract specifications for surface deformation and settlement of the track.
Italian State Railway specifications were consulted to obtain operating conditions for trains with a maximum speed of 80 Km/hr and the following thresholds for subsidence or raising of the surface were set during construction:

- sinking of the tracks (both rails) over a length of 40 m:
  alert threshold 2 cm
  alarm threshold 3 cm
- tilt - roll (lowering of one rail)
  alert threshold
  over a length of 3 m 2.5 ‰
  over a length of 7 m 2.0 ‰
  over a length of 10 m 1.0 ‰
  alarm threshold
  over a length of 3 m 5.0 ‰
  over a length of 7 m 4.0 ‰
  over a length of 10 m 3.0 ‰

5. OPERATIONAL AND MONITORING PHASE

Full face advance (average diameter of 15.65 m) permitted fast final lining completion times with the result that deformation was limited to within some tens of metres from the face.

Two different tunnel section advance and ground improvement types were employed (Fig. 6): for one stretch of tunnel a single layer of jet-grouting around the cavity was

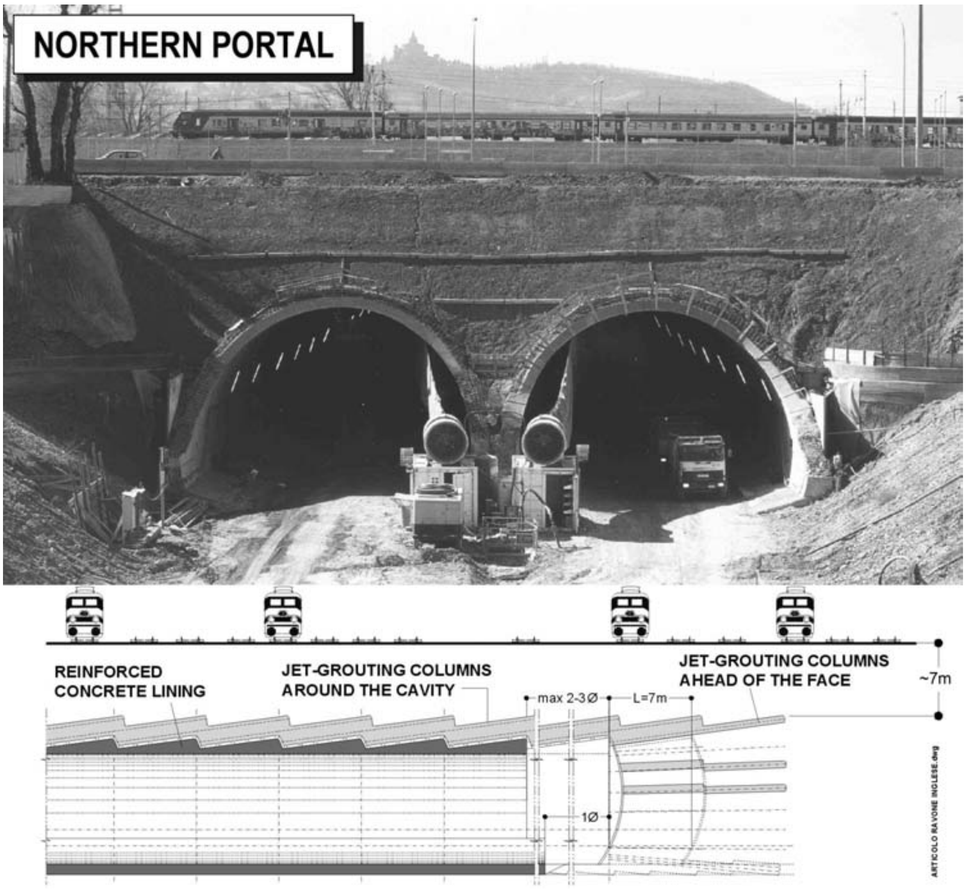


Figure 5 – Northern portal and underpass longitudinal section.

employed for the section with the shallower overburden (6-7 m) for a distance of around 90 m below the railway sidings and while for a second stretch of tunnel a double layer of jet-grouting around the cavity was employed for the part with the greater overburden (12-13 m) below the High Speed tracks. In both cases the following procedures were employed:

1) reinforcement of the ground ahead of the face with a minimum of 40 fibre glass structural elements each, 15 m in length with an overlap of 5 m into the subsequent advance step or with 30 columns of jet-grouting with a length of 10 m (single layer of jet-grouting around the cavity) or 7 m (double layer around the cavity);
2) creation of a layer of improved ground around the cavity employing 61 jet-grouting columns for a length of 13 m (single layer of jet-grouting around the cavity) or 15 m (double layer around the cavity) ahead of the face;
3) 3 + 3 sub-horizontal jet-grouting injections in advance at the foot of the steel ribs;
4) full face advance for at least 10 m (single layer of jet-grouting around the cavity) or 7 m (double layer around the cavity) in advance steps of 1.30 m followed by

immediate placing after each advance of steel ribs (type 2IPN/1.25 m) and a 25 cm layer of wire mesh reinforced shotcrete;

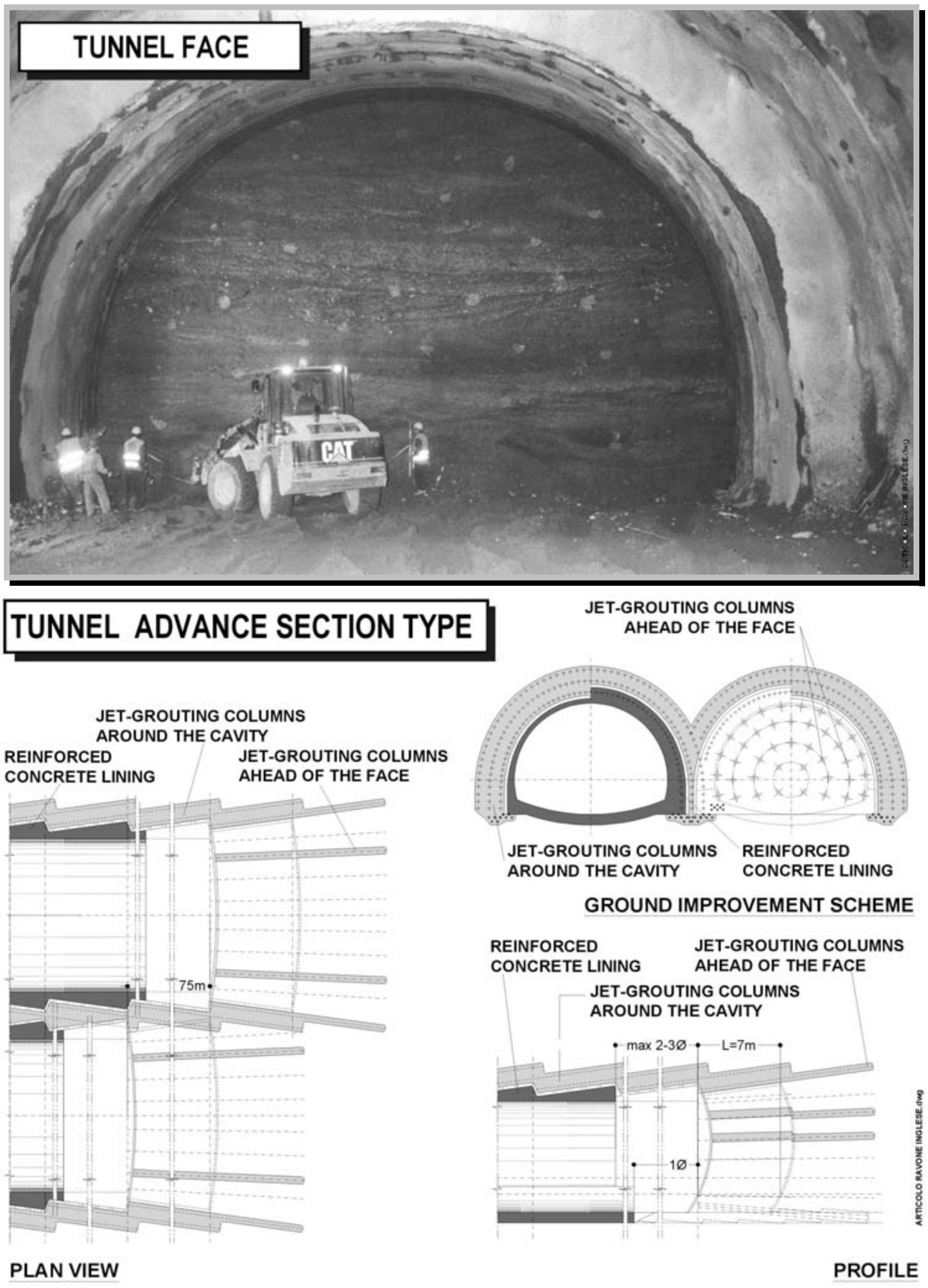


Figure 6- Reinforcement of ground ahead of tunnel face with jet-grouting columns and ground improvement and excavation advance section type

5) excavation and casting of the tunnel invert and kickers for the lining segments at a maximum distance of 10 m from the face, which may be reduced depending on the convergence of the cavity that is measured;

6) placing of water-proofing

7) completion of the final lining within 3 tunnel diameters from the face.

The faces of the two tunnels were always kept out of step as they advanced by a distance of 75 m and the face of the second tunnel always proceeded alongside the completed lining of the first tunnel.

The modest thickness of the ground between the two tunnels (around 1.0 m) practically resulted in the ground improvement of the first tunnel (from the side walls to the spring line) coincide with that of the second, which consequently had to be executed with extreme care to guarantee that the second treatment penetrated the first precisely without disturbing the lining already in place.

Given the delicacy of the situation around the tunnels and of the High Speed railway lines on the surface in particular, design and execution of systems for monitoring deformation at the surface and at depth was of considerable importance, if rail services were not to be interrupted.

The optical systems for measuring surface movements were particularly interesting. They furnished measurements of surface subsidence in real time within the railway sidings and on the track beds and compared these with the alarm thresholds that had been set (Fig. 7).

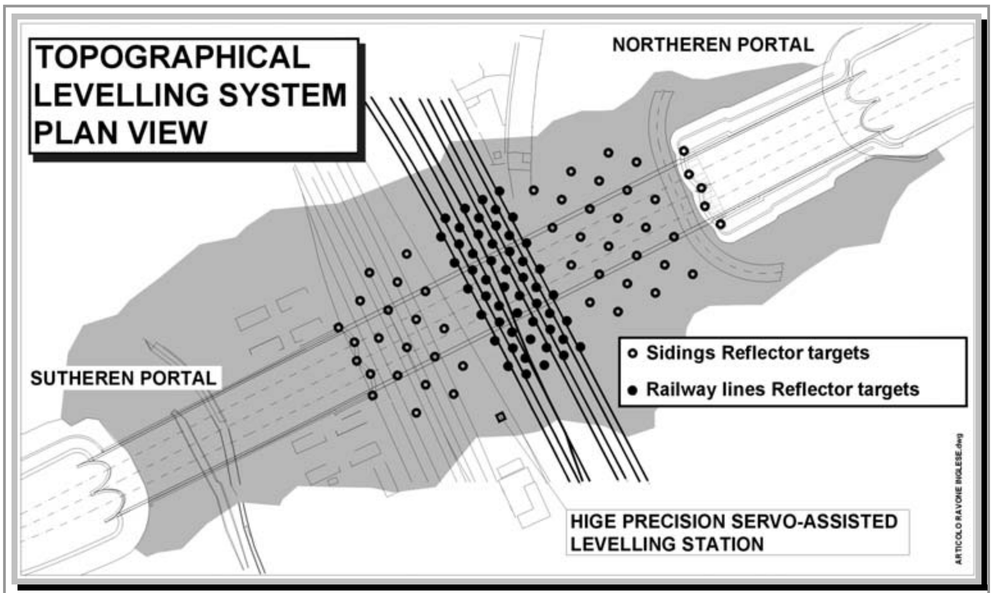


Figure 7- Topographical levelling target location plan view

The topographical instrumentation adopted consisted of a high precision servo assisted station with automatic targeting of the reflector target and measurement with a spacer and a series of micro prisms positioned at nodes on the topographical grid measured.

Deformation occurring underground as a result of tunnel advance and ground improvement was monitored by means of extenso-inclinometers and multi-base extensometers. The monitoring campaign was completed with convergence measurements taken in the tunnel.

The automatic topographical levelling system was employed to set parameters for jet-grouting injections since it registered the effects of these operations on the surface, essentially the raising of the ground, immediately. Subsequent advance of the two tunnels caused ground at the surface to subside.

The readings taken, suitably adjusted to iron out the effects of background noise, showed maximum raising of the ground of around 5-8 mm and maximum subsidence of around 8-10 mm (Fig. 8).

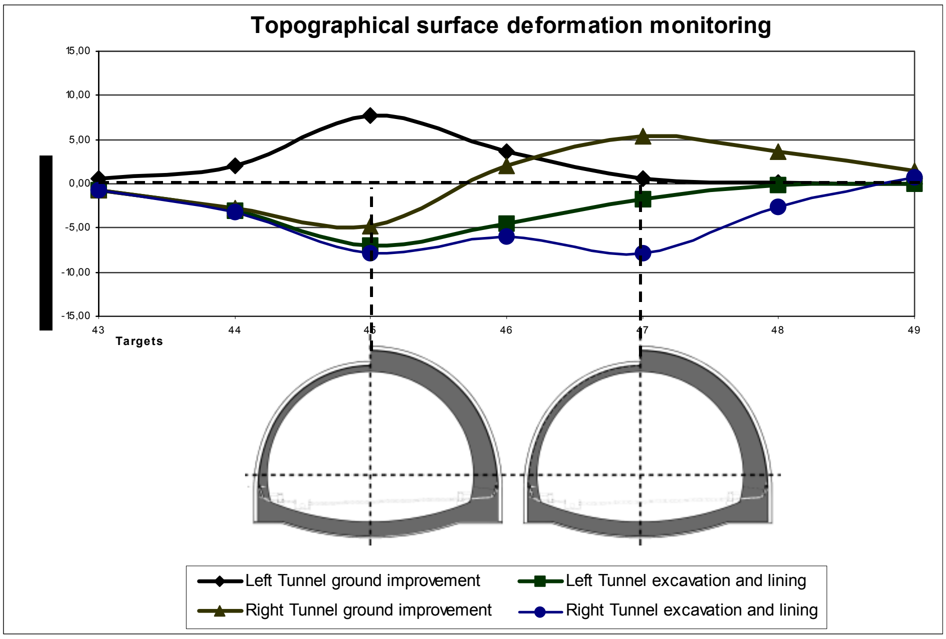


Figura 8- Surface deformation along a cross section across the railway lines

There were in any case no particular problems with surface subsidence or raising of the ground

Movements of ground both at the surface and below were kept within the admissible limits allowed by the track level.

Construction of the two tunnels, begun in July 1999, was completed in December 2000, with average advance rates of 25 m per month.

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Work: Underpass at the Ravone Railway Yard in the City of Bologna
Owner: Comune di Bologna
Main contractor: CMB
Design: ROCKSOIL S.p.A.
Monitoring: STONE S.r.l.