# INDUSTRIALISATION AND TUNNELLING: THE ITALIAN EXPERIENCE

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## ABSTRACT

Italy, which as is well known, competes with Japan for the largest number of tunnels in the country, has been making exclusive use of the ADECO-RS approach to tunnelling for more than twenty years now. The results achieved, illustrated in this paper, confirm the soundness of this choice and they demonstrate that this approach can be used to industrialise tunnel excavation even under the most difficult stress-strain conditions.

## 1. INTRODUCTION

The invitation to prepare this conference for the 25th National Civil Engineering Congress in Mexico City gives me the opportunity to illustrate the results we have achieved in Italy in the difficult field of tunnel excavation. I have therefore decided to take the example of the tunnelling projects completed on the Apennine section of the new High Speed/High Capacity Milan-Rome-Naples railway line: more than 73 km of twin track tunnels with a 140 sq m. cross section all fully excavated in less than six years since the start of the first tunnelling work.

This was a pilot experience for the whole of the major infrastructure sector and not just because the project was awarded to a single general contractor for the first time in Italy, but also because of the technical difficulties that had to be overcome. The geological and geotechnical context appeared to be and in fact was one of the most difficult and complex in the world. A broad and heterogeneous variety of grounds had to be tunnelled, affected by groundwater and gas at times and under overburdens ranging from nil to very deep.

A new design and construction approach was selected to tackle the heterogeneity of the materials and conditions, which is based on the "Analysis of the COntrolled DEformation in Rocks and Soils" (ADECO-RS). By using this approach, which is based on a clear distinction between the design stage and the construction stage of tunnels, it was possible to reliably estimate construction costs and times for the project in advance and this in turn made it possible to award contracts for the work on a lump sum "turnkey" basis for the first time in the history of underground works for projects of these dimensions and difficulty.

Other important characteristics of the ADECO-RS approach are the centrality of the deformation response of the ground to the action of excavation and the use of full face advance employed even under the most difficult conditions after first using the core of ground ahead of the face (appropriately protected or reinforced) as a structural element capable of guaranteeing the formation of an "arch effect" close to the walls of an excavation and therefore also the long and short term stability of a tunnel.

On conclusion of any pilot experience, whether large or small, it is important and necessary to examine the results achieved at the end of the day to assess the effectiveness and the real potential of the innovations introduced.

The length of the alignment that runs underground, the heterogeneity of the ground tunnelled and the extremely difficult stress-strain conditions to be overcome on the section between Bologna and Florence of the new high speed/capacity Milan-Rome-Naples railway line, certainly constituted a severe test of the actual capacity of this new design and construction approach to come up to expectations. This paper furnishes an illustration of what emerged and the results that were achieved.

## 2. GENERAL BACKGROUND OF THE PROJECT

The new railway line between Bologna and Florence is part of the Italian Milan-Rome-Naples route of the High Speed/Capacity Train which constitutes the southern terminal of the European rail network (Fig. 1).

the total length of the alignment is more than 78.5 km. of which 70.6 km. (approximately 90% of the total length) is in twin track underground tunnel.

the project involved the construction of:

- 9 nine line tunnels with a cross section of 140 sq m. and lengths of between 528 m. and 16,775 m.;
- 14 access tunnels for a total of 9,255 m.;
- 1 service tunnel for a total of 10,647 m.;
- 2 interconnecting tunnels for a total of 2,160 m.


Figure 1. Location of the work

As already mentioned, the detailed and construction designs for all these works were performed using the ADECO-RS approach. the design and construction therefore took place in two distinctly different stages from a chronological viewpoint and more precisely by means of:

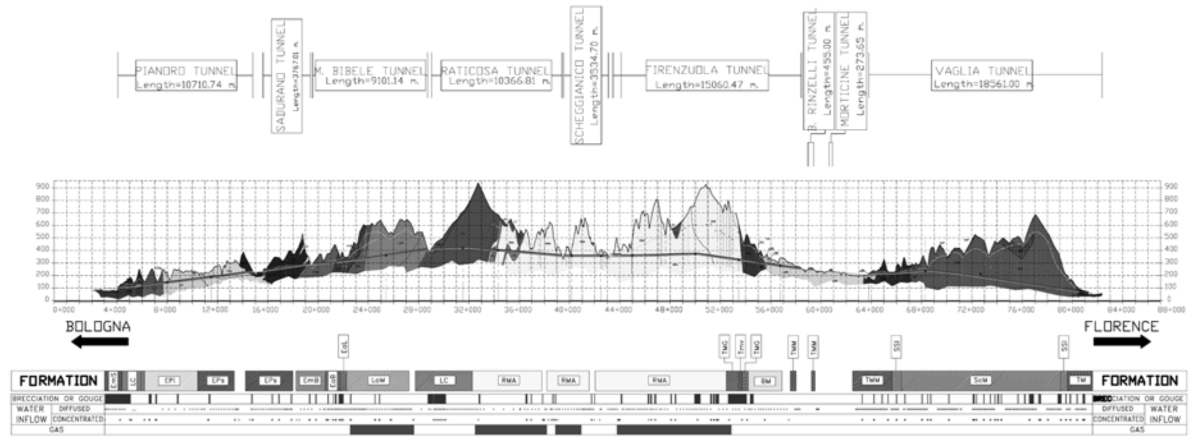
- a survey phase, a diagnosis phase and a therapy phase at the design stage;
- an operational phase and a construction monitoring phase at the construction stage.

## 3. DESIGN

### *3.1 The geological-geotechnical context (survey phase)*

The exceptional complexity of the ground involved was well known. It had already been tackled with great difficulty for the construction of the "*Direttissima*" railway line inaugurated in 1934 and currently in service. Consequently it was decided to invest a sum of € 84 million, 2% of the total cost of the project in the geological survey campaigns required for detailed design of the new high speed/capacity railway line. This provided a geological-geomechanical characterisation of the ground to be tunnelled that was very detailed and above all accurate.

As is shown in Fig. 2, the formations are primarily of flyschoid, clay and argillite formations and loose grounds, at times with substantial water tables, accounting for more than 70% of the underground alignment, with overburdens varying between 0 and 600 m. Some of the formations also presented the problem of gas, always insidious and delicate to deal with. During the survey phase, the route was subdivided into sections with similar geological and geomechanical characteristics on the basis of the information acquired. Strength and deformation parameters were attributed to these as assumptions for the subsequent phases of diagnosis and therapy.




| FORMATION | | LENGTH [m] to be tunnelled | LENGTH [m] already tunnelled | OVERBURDEN [m] | Cohesion [Mpa] Angle of friction [°] | Modulus of elasticity [Gpa] |
|---|---|---|---|---|---|---|
| Marne in facies di Schlier (EmS) | | 0 | 2012 | 0 -120 (Pianoro Tunnel) | c = 0.25-0.3 φ = 28 - 30 | E = 2.9 - 3.4 |
| Pliocene Intrappenninico Superiore (EpS) | | 0 | 11445 | 0 - 245 (Sadurano Tunnel) | c = 0.5-0.7 φ = 28 - 30 | E = 3.0 - 6.0 |
| Marne di Bismantova | | 0 | 7055 | 0 -140 (Monte Bibele Tunnel) | c = 0.8-1.35 φ = 29 - 33 | E = 4.0 - 6.0 |
| Flysch di Monghidoro (LaM) | | 500 | 8615 | 0 - 290 (Monte Bibele Tunnel) | c = 0.12-0.5 φ = 23 - 35 | E = 3.0 - 8.5 |
| Complesso Caotico (LC) | | 0 | 11187 | 0 - 520 (Raticosa Tunnel) | c = 0.03-0.7 φ = 10 - 25 | E = 0.1 - 1.8 |
| Marnoso-Arenacea (RMA) | | 400 | 39561 | 0 - 550 (Firenzuola Tunnel) | c = 2.0-2.2 φ = 24 - 38 | E = 15 - 20 |
| Clays of Mugello Basin (aBM) | | 0 | 7404 | 0 - 80 (Firenzuola Tunnel) | $c'_p$= 0.03 $\varphi'_p$= 26 - 28 | E = 0.01 - 0.3 |
| Monte Morello (ScM) | limestones | 2500 | 11361 | 25 - 560 (Vaglia Tunnel) | c = 1.0-1.4 φ = 42 - 45 | E = 7 - 15 |
| | clays and marls | | | | c = 0.18-0.24 φ = 28 - 33 | E = 2 - 8 |

Figure 2. Survey phase: variability of strength and deformation parameters for the main formations

*3.2 Predicting the behaviour of the rock and soil masses in response to excavation (diagnosis phase)*

It became immediately clear in the diagnosis phase that the tunnels to be constructed whether because of the different geotechnical characteristics of the ground or the widely differing overburdens would be driven under extremely different stress-strain conditions.

The underground alignment was therefore divided into sections with uniform stress-strain behaviour as a function of the predicted stability of the core-face in the absence of stabilisation measures. This was performed on the basis of the geological, geotechnical, geomechanical and hydrogeological information acquired and of the results of the analytical and/or numerical calculations of stability performed. The sections were as follows:

- stable core-face (behaviour category A; deformation phenomena in the elastic range, prevailing manifestations of instability: falling ground at the face and around the cavity);
- core-face stable in the short term (behaviour category B; deformation in the elastic-plastic range; prevailing manifestations of instability: spalling at the face and around the cavity);
- core-face unstable (behaviour category C; deformation phenomena in the failure range: consequent manifestations of instability: failure of the face and collapse of the cavity).

It was found from this analysis that 17% of the alignment would pass through ground which would have reacted to excavation with behaviour in category A, 57%, it was predicted would be affected by deformation phenomena in the elastic-plastic range of behaviour category B and finally approximately 26% would have been characterised, in the absence of appropriate intervention, by serious instability of the core-face typical of behaviour category C.

*3.3 Definition of excavation methods and stabilisation measures (therapy phase)*

Once reliable predictions of the stress-strain behaviour of the ground when excavated had been formulated, the action required (preconfinement and/or ordinary confinement) to guarantee the formation of an arch effect as close to the profile of the excavation as possible, in each situation hypothesised, was identified for

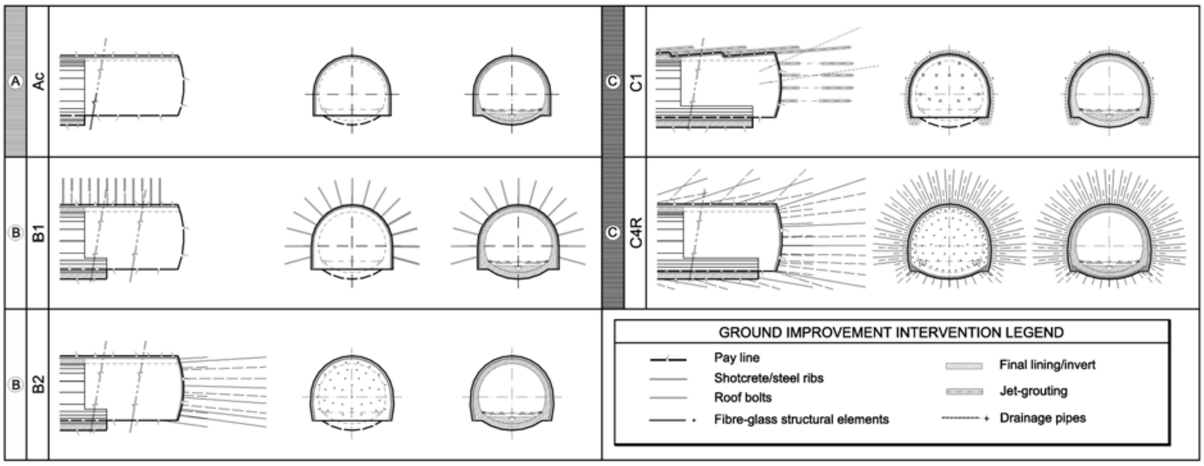
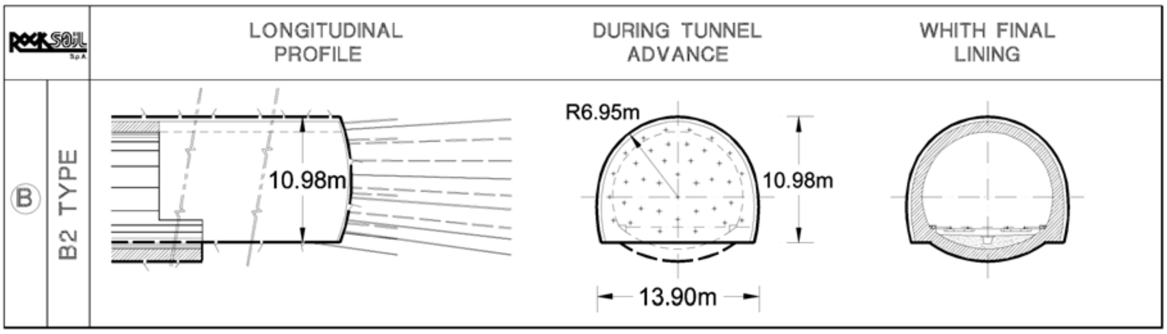



Figure 3. Mail design section types

each section of tunnel with uniform stress-strain behaviour. The advance methods (method of actual excavation, length of tunnel advance steps) and the most appropriate techniques for producing that action and guaranteeing, as a consequence, the long and short term stability of the excavation were then designed.
The variable character of the ground, present to a greater or lesser extent in all the tunnels, meant that totally mechanised technologies were not advisable with the exception of the service tunnel of the Vaglia tunnel. The basic concepts on which the design of the tunnel section types were based were therefore as follows:

1. full face tunnel advance always, especially under difficult stress-strain conditions: due to its peculiar static advantages and because large and powerful machines can be profitably used in the wide spaces available, it is in fact possible to advance in safety with excellent and above all constant advance rates even through the most complex ground by using full face advance after core-face reinforcement, when necessary;
2. containment, where necessary, of the alteration and decompression of the ground that excavation causes by the immediate application of pre-confinement and/or confinement of the cavity (sub-horizontal jet-grouting, fibre glass structural elements in the core and/or in advance around the cavity, fitted, if necessary, with valves for pressure cement injections, shotcrete, etc.) of dimensions sufficient, according to the different cases, to absorb a significant proportion of the deformation without collapsing or to anticipate and neutralise all movement of the ground at the outset;
3. placing a final lining in concrete, reinforced if necessary, complete with the casting of a tunnel invert in short steps immediately behind the face where the need to halt deformation phenomena promptly was recognised.

The most appropriate longitudinal and cross section types were therefore identified to deal with the different ground conditions. The range of geological and geomechanical and stress-strain (extrusion and convergence) conditions within which they were to be applied was clearly defined for each type as well as the position in relation to the face, the intensity and the phases and intervals for placing the various types of intervention (advance ground improvement, preliminary lining, tunnel invert etc). Very reliable work cycles based on a considerable number of previous experiences were drawn up from which precise predictions of daily advance rates could be made. Figure 3 shows the main section types adopted (there were 14 in all), grouped according to the type of behaviour category, A, B and C. Variations to be applied were designed for each section type for statistically probable conditions, the location of which could not, however be predicted on the basis of the available data (see example in Fig. 4).
The identification of admissible variability in advance for each section as a function of the actual response of the ground to excavation, always and in any case, within the deformation ranges predicted, is a fundamental part of the ADECO-RS approach. It allows highly detailed definition of the design and at the same time the flexibility required for the useful application of ISO 9002 quality assurance systems during construction without impairment of the basic principles of such systems. By employing




| GEOLOGY | GEOMECHANICS | OVERBURDEN (m) | | DESIGN SECTION TYPES | | | FORECAST DEFORMATION RESPONSE | | VARIABILITY | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | INTERVENTION | | | | | INTERVENTION | |
| | Intrinsic band | From | To | Type | Primary | Final | | | Primary | Final |
| Sandy-silty complexes in massive or not well stratified from slightly to moderately cemented facies. Low permeability at the mass scale. | $\varphi$=14÷32 c=0.25÷0.5 MPa E=0.5÷3.0 GPa | 50 | 100 | B2 | 45 fibre glass structural elements in the advance core Overlapping >5.00m Lattice steel ribs every 1.20 m Shotcrete >30cm | 90 cm concrete lining 100cm invert | <10cm | 5÷18cm | 35÷55 fibre glass structural elements in the advance core Overlapping 5÷7m Lattice steel ribs every 1÷1.4 m Shotcrete 25÷30cm | 90 cm concrete lining 100cm invert |

Figure 4. Section type variability as a function of the actual response of the ground to excavation

this method Non Conformities (i.e. differences between as built and design) are avoided which oblige partial redesign each time a change in conditions is encountered even if it involves only a minor change to the design.
Each section type was analysed as a function of the loads mobilised by excavation as determined in the diagnosis phase, with regard to both the different construction phases and the final service phase by employing a series of calculations on plane and three dimensional finite element models in the elastic-plastic range.
Finally, precise specifications were formulated for the implementation of a proper monitoring campaign, which, according to the different types of ground tunnelled, would both guarantee the safety of tunnel advance and verify the appropriateness of the design and allow it to be optimized in relation to the actual conditions encountered.
Detailed design also obviously concerned indispensable accessory works, such as portals, large chambers and access and service tunnels, which for the sake of brevity we will not dwell on here.

## 4. TUNNEL CONSTRUCTION

### *4.1 Type of contract*

The contract for the entire section of the railway between Bologna and Florence was awarded on a rigorous lump sum basis (€ 4,209 million) by FIAT S.p.A., the general contractor, which accepted responsibility for all unforeseen events, including geological risks on the basis of the final design as illustrated above. It subcontracted all the various activities out to the CAVET consortium (land expropriation, design, construction, testing, etc.).

### *4.2 Operational phase*

Immediately after the contract was awarded, the construction design of works began at the same time as excavation work (July 1996).
Additional survey data and direct observation in the field generally confirmed the validity of the detailed design specifications, while the following minor refinements were made in the construction design phase:

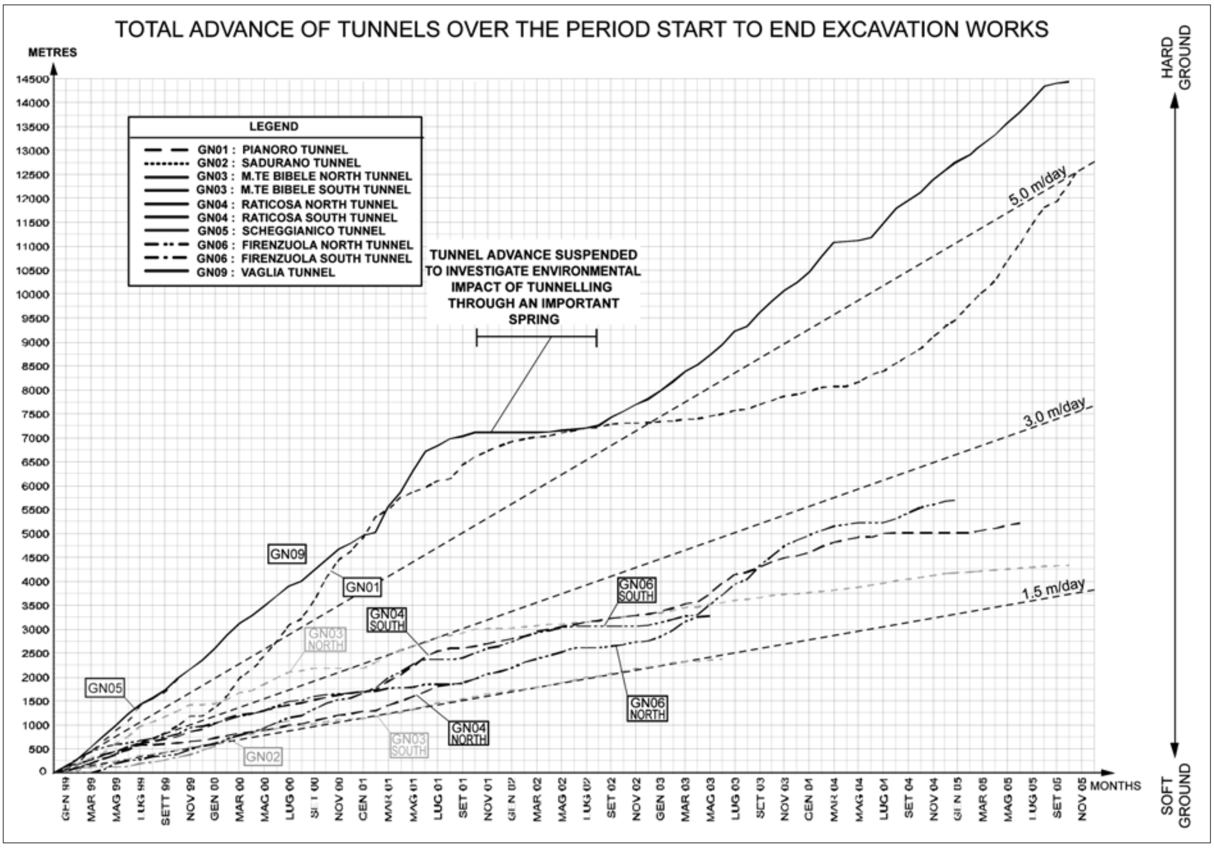



Figure 5. Advance rates obtained in the different stress-strain conditions found

- to deal specifically with particularly delicate stress-strain conditions a steel strut was introduced as a variation to section types B2 and C4 in the tunnel invert to produce much more rapid confinement of deformation. This modification of the B2 section type was found to be much more versatile and appropriate even for many situations where the core-face was unstable. Use of the heavier C section types was thus limited to the more extreme stress-strain conditions.
- the effectiveness of core-face ground improvement using fibre glass structural elements was increased considerably by introducing an expansive cement mix to cement the fibre glass nails;
- as a consequence of positive results acquired during the construction of tunnels on the Rome-Naples section of the same railway line, a section type B2pr was designed for underground construction of the Sadurano, Borgo Rinzelli and Morticine tunnels originally designed as artificial tunnels;
- finally it was decided to replace section types B3 and C3, which involved the use of mechanical pre-cutting with section C2 (ground improvement in the core-face and around it with fibre glass structural elements) better suited to the ground to be tunnelled.

The final result of construction design was the definition of the following percentages of tunnel section type:

- section type A: 20.5 %; section type B: 57.5 %; section type C: 22.1 %.

In less than six years approximately 70.6 km. of running tunnel have been driven and lined, 100% of the total. Average monthly advance rates of finished tunnel were around 1,000 m. of finished tunnel with peaks of 2,000 m reached in March 2001, working simultaneously on 30 faces.

Fig. 5 gives the production graphs for the different tunnels constructed. It can be seen that not only were the advance rates very high in relation to the type of ground tunnelled, but above all they were very constant, a sign of the excellent match between design and the actual reality encountered. Even for the Raticosa tunnel, driven under extremely difficult stress-strain conditions in the *Caotic Complex* formation consisting of the much feared scaley clays, average advance rates were never less than 1.5 m per day. Table 1 gives a comparison of daily advance rates forecast by the detailed design specifications for some section types and the actual advance rates achieved.


Figure 6. Borgo Rinzelli tunnel: the face during the advance under artificial ground overburden

Figure 6. Firenzuola tunnel: the face reinforced with fibre glass structural elements inserted into micro jet-grouted columns

Table 2 on the other hand gives the distribution of differences in section types between the detailed design specifications and the tunnel as built. Even if account is taken of the increased rigidity introduced to the B2 section type, which made it possible to employ the type in many situations typical of behaviour category C, there was nevertheless a significant reduction in the use of the more costly section types in favour of more economical solutions.

This result was to a large extent due to the exceptional effectiveness of the preconfinement methods employed even under large overburdens. It was the first time they had been used with overburdens greater than 500 m.. Some consider tunnel advance after first making the face-core more rigid as counter productive under large overburdens. However, if it is properly performed and the continuity of the action from ahead of the face back down into the tunnel is ensured, with the placing of a steel strut in the tunnel invert it is, as was demonstrated, extremely effective even with large overburdens and resort to the heavier section types was only necessary in the most extreme situations. Another reason for the greater use of section type A was that there are only minor differences between it and the B0 sections types such as the thickness of the final lining or the distance from the face at which the tunnel invert is cast. As a consequence, section type A was adopted in place of section types B0 or B0V, whenever the ground conditions allowed this to be done without risk (e.g. in long sections of the Vaglia tunnel where the presence of the adjacent service tunnel already built made the situation particularly clear). The differences found between the detailed design specifications and the tunnel as built did not reveal any sensational discrepancies, neither in terms of the overall cost of the works, which was a little less than budgeted under the detailed design specifications (~ -5%) nor with regard to construction times. While the contractor will benefit from the lower cost, a reward for the greater risk run by agreeing to sign a rigorously lump sum, all-in contract, the client and citizens will benefit from the punctual observance of time schedules because they will be able to use the new transport services without intolerable delays.

TABLE 1.

| Section type | Tender forecast advance rates [m. per day of finished tunnel] | Actual advance rates [m. per day of finished tunnel] |
|---|---|---|
| A | 5.40 | 5 – 6 |
| B0 | 4.30 | 5 – 5.5 |
| B2 | 2.25 | 2.10 – 2.2 |
| C1 | 1.40 | 1.40 |
| C2 | 1.25 | 0.85 |
| C4V | 1.25 | 1.63 |

Table 2

HIGH SPEED/CAPACITY TRAIN - Milan to Naples Line beetween Bologna and Florence - SECTION TYPES DISTRIBUTION

DETAILED DESIGN

| TUNNEL | Length [m] | SECTION TYPES DISTRIBUTION [m] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B0 | B0V | B1 | B2 | B3 | B4 | C1 | C2 | C3 | C4 | C4V | C5 |
| Pianoro | 10293,4 | | 951,8 | | | 3886,4 | 3036 | | 62,0 | 948,8 | 1083 | 310 | | 15,5 |
| Sadurano | 3778,0 | 64,0 | 2580,8 | | | 875,0 | | | 68,0 | 190,3 | | | | |
| M. Bibele | 9118,5 | 978,2 | 1094,6 | | 4529,1 | 1212,2 | | | 76,0 | 1112,8 | | 115,6 | | |
| Raticosa | 10381,0 | 3043,0 | | | 972,2 | 758,4 | | | 40,0 | 786,7 | | 4465,1 | | 315,67 |
| Scheggianico | 3530,6 | 2089,9 | | | 1404,7 | | | | | 36,0 | | | | |
| Firenzuola | 14311,5 | 3528,7 | | | 5950,4 | 716 | 412,2 | | 227,5 | 511,9 | 2226,8 | 738,1 | | |
| B. Rinzelli | 455,0 | | | | | | | | 160 | | 295 | | | |
| Morticine | 273,7 | | | | | | | | 80 | 193,7 | | | | |
| Vaglia | 16757,0 | 2017,2 | 3104,3 | 1129,8 | 5629,0 | | | 1151,2 | 692 | 708,5 | | | 2325,2 | |
| TOTAL LENGTH [m] | 68898,6 | 11721,0 | 7731,5 | 1129,8 | 18485,2 | 7447,9 | 3448,2 | 1151,2 | 1405,4 | 4488,6 | 3604,8 | 5628,8 | 2325,2 | 331,2 |

AS BUILT

| TUNNEL | Length [m] | Tunnelled length [%] | Tunnelled length [m] | SECTION TYPES DISTRIBUTION [m] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | B0 | B0V | B2 | B2pr | B2V | C1 | C2 | C4 | C4V | C6 |
| Pianoro | 10710 | 100,0 | 10710,0 | | 8167,0 | | 682,5 | | 63,0 | 3,5 | | | 1794,3 | |
| Sadurano | 3767,0 | 100,0 | 3767,0 | 2213,1 | 1408,0 | | 85 | 53 | | | 8 | | | |
| M. Bibele | 9101,0 | 100,0 | 9101,1 | 2935,5 | 2015,7 | | 3965,8 | | 97,9 | 41 | 45 | | | |
| Raticosa | 10367,0 | 100,0 | 10367,2 | 3680,0 | 786,0 | | 857 | | 25 | 85 | | 1468 | 673,4 | 2792,6 |
| Scheggianico | 3535,0 | 100,0 | 3535,0 | 3517,0 | 18,0 | | | | | | | | | |
| Firenzuola | 15211,0 | 100,0 | 15211,0 | 6833,1 | 3556,3 | | 3081,8 | | 263,5 | 577,1 | 9 | | 125,83 | 43,46 |
| B. Rinzelli | 528,5 | 100,0 | 528,5 | | | | | 303,5 | | | 225,1 | | | |
| Morticine | 565,5 | 100,0 | 565,5 | | | | | 537,0 | | | 28,5 | | | |
| Vaglia | 16757,0 | 100,0 | 16757,7 | 5287,60 | 9299,50 | 96,60 | 1547,0 | | 296,70 | 128,25 | 101,4 | | | |
| TOTAL LENGTH [m] | 70542,3 | 100,0 | 70542,4 | 24466,2 | 25250,5 | 96,6 | 10219,1 | 893,5 | 746,1 | 834,8 | 417,0 | 1468,0 | 2593,5 | 2836,1 |

| | A | B0 | B0V | B1 | B2 | B3 | B4 | C1 | C2 | C3 | C4 | C4V | C5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SECTION TYPES DISTRIBUTION [%] | 17,0 | 11,2 | 1,6 | 26,8 | 10,8 | 5,0 | 1,7 | 2,0 | 6,5 | 5,2 | 8,2 | 3,4 | 0,5 |

| A | B0 | B0V | B2 | B2pr | B2V | C1 | C2 | C4 | C4V | C6 |
|---|---|---|---|---|---|---|---|---|---|---|
| 34,7 | 35,7 | 0,1 | 14,5 | 1,3 | 1,1 | 1,2 | 0,6 | 2,1 | 3,7 | 4,0 |

*4.3 The monitoring phase*

*4.3.1 Monitoring during construction*

The particular nature and the importance of the project required a thorough monitoring programme both during construction and for the completed tunnel in service.
The following was monitored during construction:

- the tunnel faces by means of systematic geomechanical surveying of the ground at the face. The surveys were conducted to I.S.R.M. (International Society of Rock Mechanics) standards and gave an initial indication of the characteristics of the ground to be compared with design forecasts;
- the deformation behaviour of the core-face by measuring both surface and deep core-face extrusion, with measurements carried out taken as a function of the different behaviour categories. Systematic measurements of this kind under difficult stress-strain conditions are crucial: in fact monitoring convergence alone, which is the last stage of the deformation process, under these conditions is not sufficient to prevent tunnel collapse. Extrusion, on the other hand is the first stage in the deformation process and if it is kept properly under control will allow time for effective action to be taken.
- the deformation behaviour of the cavity by means of systematic convergence measurements;
- the stress behaviour of the ground-lining system by placing pressure cells at the ground-lining interface and inside the lining itself, both in the preliminary and the final lining.

The results of monitoring activity during construction guided design engineer and the project management in deciding whether to continue with the specified section type or to modify it according to the criteria already indicated in the design, by adopting the "variabilities" contained in it. Obviously, in the presence of particular conditions that were not detected at the survey phase and therefore not provided for in the design, which can occur, it is always possible to design a new section type. This method of proceeding allowed the uncertainty connected with underground works to be managed satisfactorily even with a rigorously lump sum contract like that between CAVET and TAV.
Most of the instrumentation already used during construction, and connected to automatic data acquisition systems will continue to be employed for monitoring when the tunnel is in service. The automatic data acquisition system can be interrogated at any moment in the life of the works to obtain data and verify the real behaviour of the tunnels and compare it with design predictions.

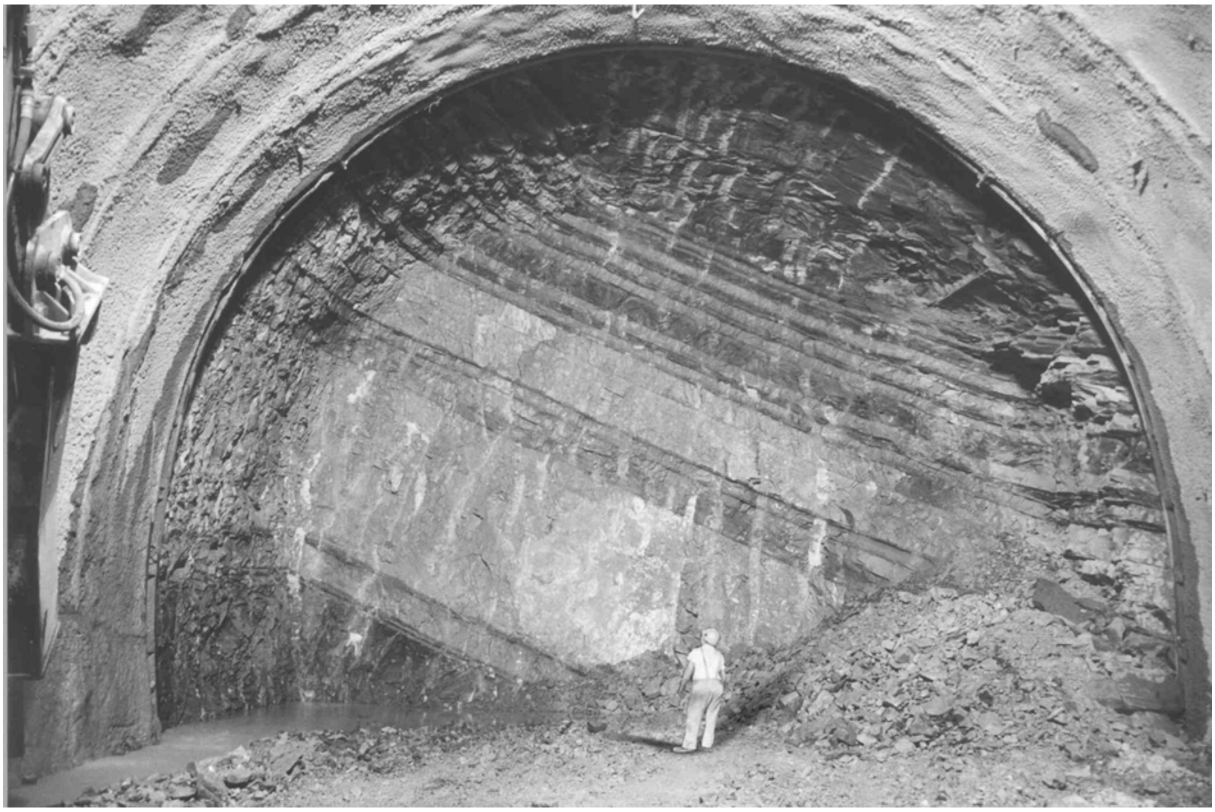


Figure 7. The face of the Vaglia tunnel in the Monte Morello Formation (limestones, marls and sandstones )

## 5. CONCLUSIONS

New pre-confinement techniques such as horizontal jet-grouting, full face mechanical pre-cutting, advance core reinforcement using fibre glass structural elements have certainly produced a technological leap ahead in the tunnelling field similar to that which occurred at the beginning of the twentieth century with the introduction of cavity confinement techniques such as shotcrete, steel ribs and steel anchors, allowing previously impossible conditions to be tunnelled with success.

Nevertheless, as in the last century, when design and construction engineers had to make an effort to abandon old theories and practices in favour of more efficient and more adequate methods in order to reap the full benefit of the potential offered by the new technologies, they must again make the same effort.

The experience acquired in the construction on time and to budget of this project to cross the Apennines with a new high speed/capacity railway line, which was exceptional in terms of its size and the heterogeneity and difficulty of the ground demonstrates that a more aware and more correct use of new technologies can open up exceptional new prospects for tunnelling and make it finally possible to fully industrialise it and thereby produce that certainty over construction times and costs which until only recently had been lacking. This is, however, on condition that the technologies are employed in an integrated manner, in the framework of design and construction approaches like ADECO-RS and consistently with the principles that generated them.

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