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# ON THE DIVERSE GEOTECHNICAL AND TUNNEL CONSTRUCTION PROBLEMS IN THE LA SPEZIA-PARMA RAIL LINK IN ITALY.

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## ABSTRACT

The railway connecting the important harbor at La Spezia to the industrial North of Italy via Parma includes several shallow and deep tunnels. The type of geotechnical and construction problems encountered while driving these tunnels are discussed together with the procedures adopted for solving these problems.

## INTRODUCTION

This paper discusses some significant geotechnical and construction problems which arose during the design and construction of the tunnels along the new railway link between La Spezia, an important harbor in the Ligurian Sea, and Parma, located in the industrial North of Italy. Four principal tunnels along the link (see Fig.1) proceeding from La Spezia to Parma are: Termo, Serena, Ossella, and Scorza. A summary description of the geometry of the tunnels, the overbuden, and the typical geologic formations, is given in Table 1.

### Geologic setting

The tunnels generally pass through geologically complex formations and geomechanically poor rock (typical of the Appennini mountains) consisting of flysch (an alternating sequence of limestone with intercalation of marl and shale), polygenetic breccias, and recent sedimentary cover of alluvial-colluvial origin. Some of these formations have been subjected to tectonic cycles which have frequently transformed the original stratigraphy and, have on occasion, produced a chaotic structure. Intense lamination with preferred orientation (dipping NW) has developed due to tectonic folding. Faults and tectonic contact zones are often associated with diffused inclusions of water. The lithological profile consists of marl, sandy limestone, and shale. In the case of a chaotic structure, rock blocks of substantial size may be included in a matrix of blackish, clay and shale, see Fig.2.

### Geotechnical considerations

The geotechnical characteristics of the rock mass along the various tunnels were determined by core logging of exploratory boreholes (about 9500m), penetrometric tests with their locations identified through aerial photography, laboratory tests on core specimens, in-situ index tests, and literature survey to identify the characteristics of rock mass in other, similar site conditions. The results are presented in Table 2 which is adapted from the geomechanical classification system, RMR, of Bieniawski (1), except that a further subdivision of classes IV and V is made into subclasses IVa, IVb, and Va, Vb for a more detailed

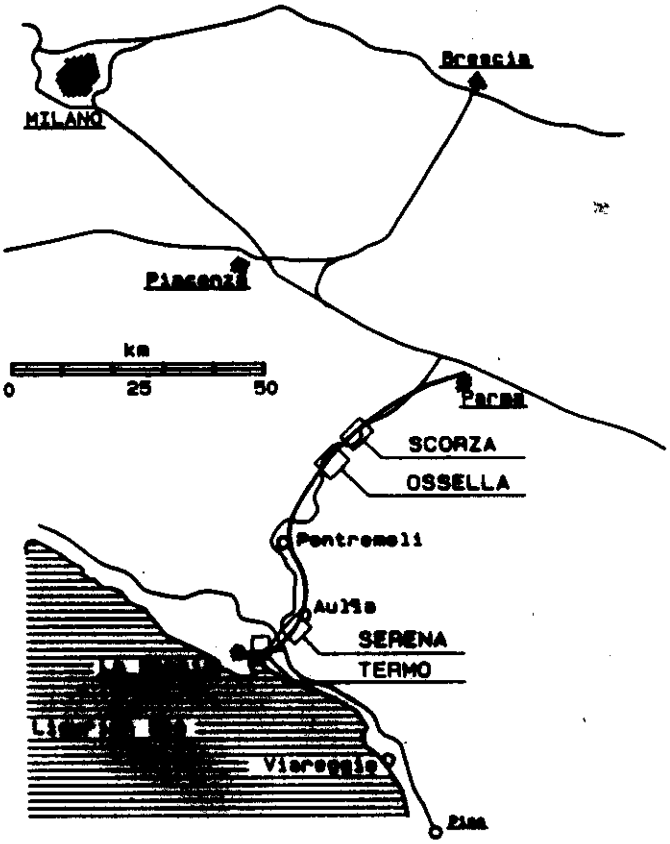


FIGURE 1 - Location map showing the La Spezia-Parma railway link and the major tunnels under construction: TERMO, SERENA, OSSELLA, SCORZA

TABLE 1. Tunnel characteristics

| Tunnel Name | Area of cross-section (sq.m) | Length (m) | Maximum cover (m) | Geology |
|---|---|---|---|---|
| Termo | 60 | 450 | 25 | Thinly-bedded limestone & alternation of highly tectonized marl & shale |
| Serena | 100 | 6900 | 450 | Alluvial deposit & fly-schoid sequence of marly limestone & shale, tecto-nized; alternation of silt & sand-stone; & poligenetic, shaley breccia |
| Ossella | 100 | 1400 | 100 | Flyschoid sequence of marly shale, tectonized |
| Scorza | 100 | 800 | 100 | Flyschoid, tectonized marly shale & shaley, poligenetic breccia |

Table 2: Average geotechnical characteristics of rock mass encountered in the tunnel

| Rock class (after Bieniawski, 1984) | IVa | IVb | Va | Vb |
|---|---|---|---|---|
| Rock condition | fractured | crumbly friable | squeezing | highly squeezing swelling |
| Rock formation | Flysch marly-limestone to marl | | "Caotic" structure tectonized, marl-shaley flysch | |
| Angle of friction | 30° | 25° | 20° | 20° |
| Cohesion (KPa) | 100 | 100 | 50 | 20 |
| Modulus of deformation (MPa) | 4000 | 2000 | 1000 | 500 |
| Density (kN/m3) | 26 | 26 | 24 | 22 |

FIGURE 2 - Caotic structure with rock blocks of substantial size embeded in a matrix of clay and shale.

## Contractual constraints

Before discussing the geotechnical and construction problems, it may be useful to examine the following list of contractual constraints which are typical of the railway tunnel construction discussed here.

(a) The client requires (and recognizes) the final, concrete lining only. The cost of a temporary support, if provided, is not paid.
(b) The excavation must, however, remain open to allow concreting of the entire section in a single cast and without loading the concrete during setting.
(c) The contractor must determine the (minimum) amount of pre-reinforcement of the rock or temporary (primary) support to achieve (b).
(d) Two different approaches would be required for the two types of tunnel (shallow and deep tunnels). In the case of a shallow tunnel, the integrity of the overburden may have to be insured. For the deep tunnel, control of convergence and the extent of the plastic zone will be more important.

## DISCUSSION OF PROBLEMS AND THEIR SOLUTIONS

The excavation of the tunnel section is done in stages except in the case of a single-track tunnel (if conditions are favorable) when a heavy hydraulic hammer is used. The conventional drill-and-blast method is limited to certain segments of the tunnels having strong sandstones or limestones, such as those mainly associated with the Macigno formation. In such a case it is normal to support the excavation with steel ribs, with the rib spacing varied according to the quality of the rock mass and the imposed load.
The primary support consists of wire mesh and shotcrete with an average thickness of 20cm and reinforced with steel fibre. The rock around the bottom part of the excavation (around the feet of the ribs) is reinforced with conventional and swellex type of rock bolts.
The principal problems encountered while tunneling in the La Spezia-Parma link are briefly discussed in the following subsections. The characteristics of the four tunnels are given in Table 1.

### Shallow tunnels

In shallow tunnels, where the cover is only a few times the size of the tunnel, it is generally difficult to maintain the face and the excavation boundary. At times it is necessary to use special techniques for advancement both for improving the quality of the overburden and for maintaining the integrity of the urban structures above ground.

### The Scorza tunnel

The construction and stability problems in the Scorza tunnel relate to the shallow unsymmetrical cover and a rapid variation in the geotechnical characteristics of the rock mass. For example, the tectonically disturbed zone (see Fig.3) in one section of the tunnel caused a sloughing or caving of the material to the ground surface and, as shown by convergence measurements, mobilized the material in the unsymmetrical cover thereby threatening the stability of the slope itself.
The problem was solved by providing an integrated system of support and reinforcement which included: (1) steel ribs for support of the tunnel, (2) grout injection into the cover through a set of inclined steel tubes, and (3) an umbrella arch to provide a pre-reinforcement roof of

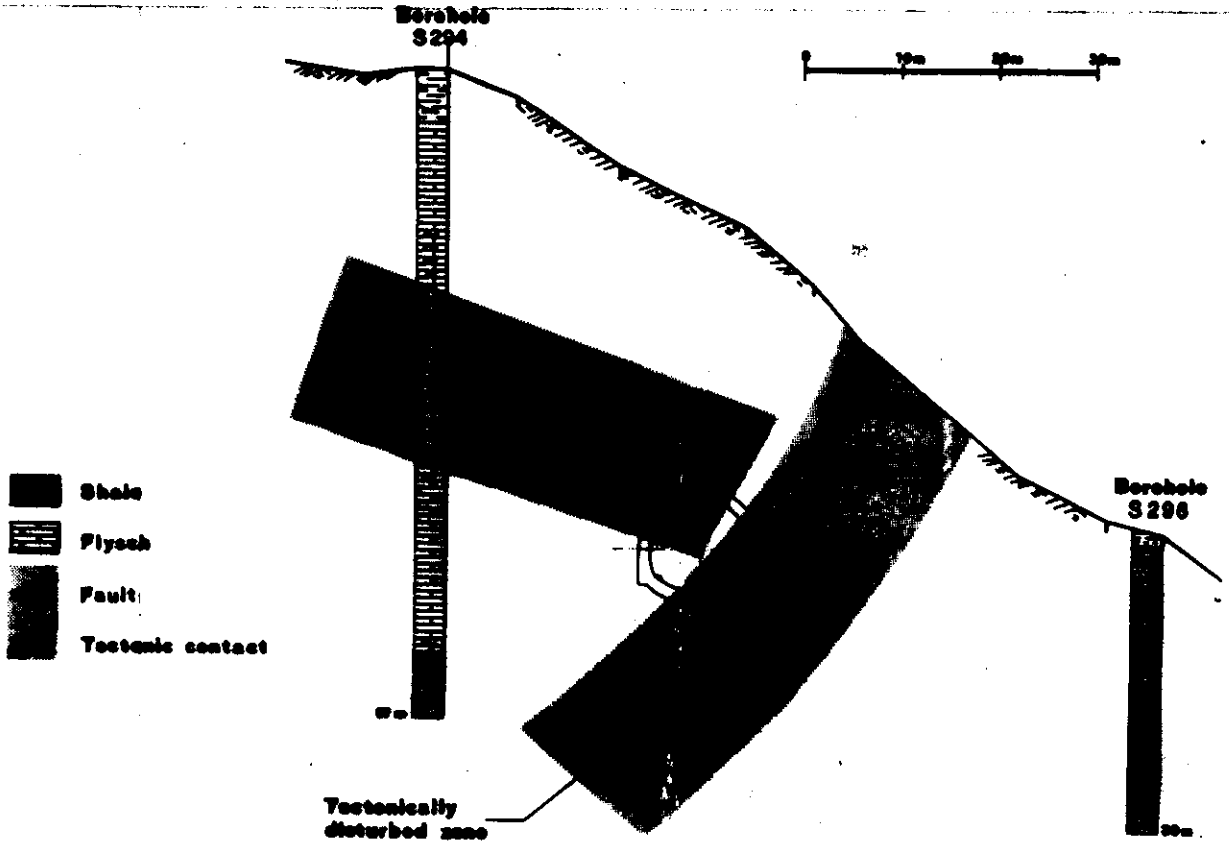


FIGURE 3 . Geologic section of Scorza tunnel
showing tectonically disturbed zone

FIGURE 4 - Problem of sloughing of material into the Termo tunnel near

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### The Termo tunnel

The Termo tunnel constitutes a good example of the need to excavate a single-track tunnel in difficult geologic conditions, under a thin cover, and below urban development. The construction problem (sloughing of material, see Fig.4) began within a short distance from the portal, near a tectonic contact between the shaley limestone and the highly tectonized shaley-marl.
The following operations were used to solve the construction problems:

- Pre-reinforcement of the rock mass in the roof of the tunnel by the umbrella-arch technique.
- Drainage of the cover.
- Advancement of the tunnel in 2 sections.
- Providing a wide footing for the support ribs.
- Anchoring the feet of the ribs to the rock mass through rock bolts, micropiles, or struts.

### Deep tunnels

The problems in tunnels whose depth is greater than several times their size generally result from the reduced strength of the rock mass surrounding the opening. The problems are, at times, evidenced in significant convergence. In the following discussion, we include an example from one of the two deep tunnels listed in Table 1.

### The Serena tunnel

A notable problem occurred in the Serena tunnel near station 6+828 (see Fig.5) around the contact between the Macigno formation and the marl-shale unit. A high rate of convergence (3cm/day) was measured at this station where the rock mass was assigned class Va (see Table 2). The (primary) support, consisting of steel arches of size 2NP160 (36kg/m; W=234cm3), placed at 1m spacing, were clearly insufficient to control the convergence.
The solution to the problem of high convergence was to modify the properties of the rock by reinforcing it with a pattern of grouted rebars (Fig.6) at some stage of convergence (selected on the basis of parametric analyses). As detailed elsewhere (2), the grouted rebars pick up tension following deformation of the rock mass and provide a confining pressure to the rock around the opening. The net result is the introduction of an "effective" cohesion in the rock mass which, in turn, allows a reduction in the extent of the plastic zone and the convergence. The significant decrease in convergence occurred after reinforcement (see Fig.5 for comparison of expected convergence, without reinforcement, and measured convergence, after reinforcement).
The tunnel is excavated in two stages. The first and the more important stage consists in driving the heading which is the upper half of the tunnel. The general procedure is to advance 6m in 1m step. The ribs and shotcrete are installed after each step while the reinforcing rock bolts are installed after the complete, 6m advance. There are 16 bolts per meter and each bolt is 8m long. The following are approximate averages of the time for the various operations for the 6m advance:

| | |
|---|---|
| Excavation and mucking | 3hrs/m x 6 = 18 hrs |
| Installation of rib and shotcrete | 4hrs/m x 6 = 24 hrs |
| Installation of rock bolts | 8hrs/m x 6 = 48 hrs |

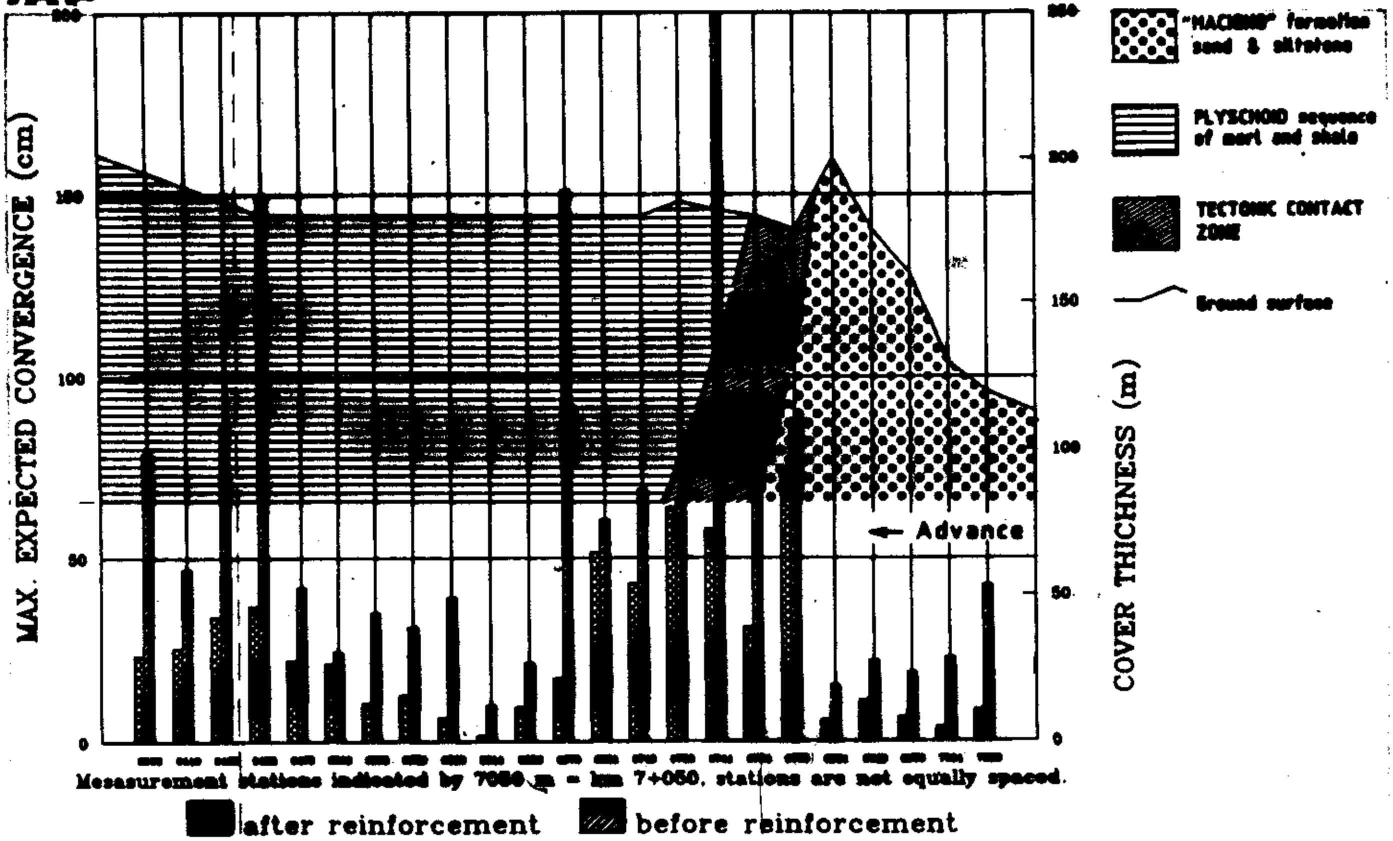
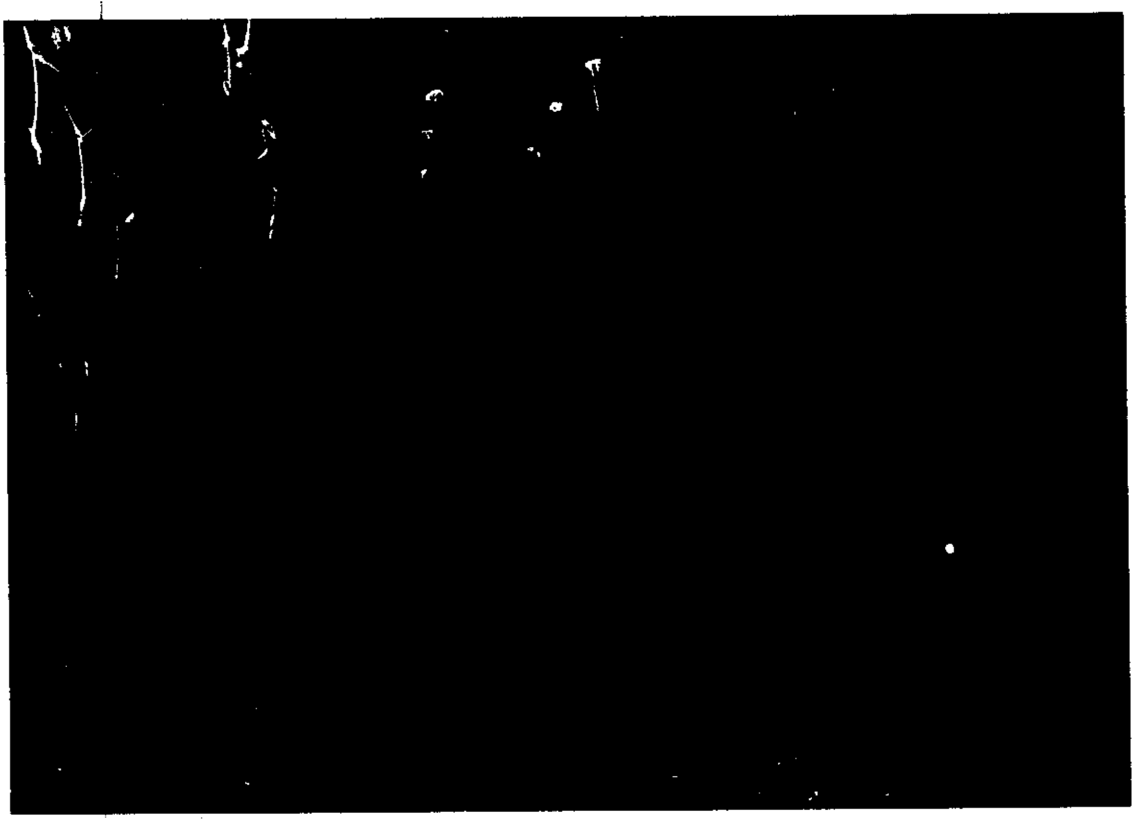



**FIGURE 5. Maximum expected convergence with progression of excavation of SERENA tunnel with superimposed geology.**



## CONCLUSION

The geotechnical and construction problems discussed here may be expected to arise in other parts of the world where tunnels must be driven through geologically complex formations, in weak rock, at shallow depth, or below urban development. The solution techniques described here may also be applicable in these situations. If the contractual constraints are not so rigid as for the railway tunnels discussed here, reinforcement of the rock mass in advance of excavation may be used to increase economy and efficiency.

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