Doubling the tracks: the case of Arcisate-Stabio railway line
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ABSTRACT: The upgrading of the rail link between Arcisate (Italy) and Stabio (Switzerland) involves doubling of the existing single railway track. Trevi is involved in the project as foundation specialist sub-contractor. The project envisages the use of different soil improvement/deep foundation technologies such as jet grouting, grouting, diaphragm walls, anchors, micropiles and CFA / CAP piles. One of the most complicate tunnels to be built is the one across the small city of Induno Olona, that will run under the existing 19th century railway tunnel. Soil conditions are mainly a mix of sand, gravel and boulders with a slightly weathered limestone at the bottom. In order to allow excavation of the new tunnel under the existing one, the designer decided to install a tight grid of structural fiber glass elements injected via a tube-a-manchette (sleeved pipe) with cement and chemical grout. The installation of said fiberglass elements and all the grouting phases are mainly carried out from inside the old upper tunnel, while a small amount of improvement operations will be executed from open ground level. The small dimensions of the existing old upper tunnel require a special equipment and tools. Due to the reduced thickness between the top of the new tunnel and the floor of the old one, during the tunnel excavation phases an umbrella of micropiles will also be installed in order to create a “shield” around the roof of the new tunnel. Excavation of the tunnel will start in February, 2013.

Keywords: railway, tunnel, chemical grouting, fiberglass elements

1 INTRODUCTION

Very shallow depths and closely-spaced existing tunnels are two of the most challenging conditions when it comes to excavating new tunnels. The new Induno railway tunnel, that is going to be constructed within the Arcisate – Stabio railway line, is a perfect example of the difficulties that may be encountered when both problems occur simultaneously and of how to face them.

In the city of Induno Olona, the new Arcisate-Stabio railway line requires the construction of a double-track tunnel following the same path of the existing single track “Induno” tunnel. The new 330 m long tunnel will pass under the old one at such a depth as to ensure a minimum spacing of few decimeters between the existing invert and the crown of the new tunnel.

The excavation will be performed in various ground conditions: the upper tunnel runs through glacial deposits, mainly cohesionless, resting on fractured limestone. Part of the designed tunnel will be also driven through these fractured rocks. Obviously, due to the proximity of the two structures, excavation requires ground improvement, in order to ensure adequate safe working conditions, as well as to maintain the existing structural integrity. Because of this peculiar situation, ground improvement has been performed as a "preventive treatment", thus operating from the upper existing old tunnel. The whole volume around the designed tunnel has been treated through the installation of a tight grid of fiberglass (structural) elements and subsequent injection of cement-based and chemical grouts in order to create a continuous consolidated block where excavation can be safely performed.

The full treatment phases involved installation of some 120,000 linear meters of fiber glass elements and the injection of 5,800 cubic meter of cement-based grout and 4,700 cum of chemical grout.

2 SOIL CONDITIONS

Soil conditions were the following ones (from the working level):

- from 0 to max 15 m: glacial deposits (coarse gravel, sand and cobbles with fine particle content of about 20%, see Figure 1);
- from 15 m to the bottom: slightly weathered and fractured limestone.

In situ Lefranc tests have shown a permeability of $10^{-4}+10^{-5}$ m/s in the glacial deposit, while about $10^{-6}$ m/s was measured by Lugeon test in fractured limestone (approx 18 UL). Therefore, the new tunnel will be excavated in heterogeneous soil condition that required improvement of both portions (the upper layer of loose granular soil and the lower one with fractured rock); the contact between the two layers is strongly variable along the tunnel.

3 DESIGN

3.1 Original design

An earlier version of the tunnel project involved the use of closely-spaced 600 mm diam. jet grouting columns, aimed at improving strength and stiffness of the soil. The use of jet grouting is a typical solution, when adjacent or very shallow tunnels have to be built.

However, site and operating conditions, pushed designers to an alternative ground improvement technical solution. In this case, the major concerns arising with the use of jet grouting were the following ones:

- reduced operating space: jet grouting operations require the handling of a large amount of fluid drill and
treatment spoils that must be pumped away from the site and disposed with additional costs;

- controlling the interaction of the works with existing structure: if not perfectly managed, the high pressure typically used for the jet grouting (400 bars) may severely deform or damage the structure of the existing tunnel;
- variable ground conditions: it is very difficult to modulate jet grouting injections when operating simultaneously in gravels and fractured rocks. Most of the high-pressure grout could disperse in rock fractures, thus making it hard to control the cementing of the ground volume or, in the worst case, causing fractures to enlarge, thus deforming the rock mass.

3.2 Alternate design

In order to resolve such technical difficulties, jet grouting was replaced with cement and silica injections, reinforced with fiber glass elements. Injection points are very closely spaced, since the maximum distance at the far end is 90 cm: said distance ensures a continuous treatment of the ground around the tunnel (Figure 2 and 3).

Cement injections generate much less volume of spoil materials, and, above all, do not need high working pressures, since maximum injection pressures are around 15 bars, thus meeting the need to save the existing tunnel lining.

For this project, where the tunnel is in sand and gravel, cement injections have been carried out through manchette pipes with 33 cm spaced valves. This scheme was properly modified where encountering rocks in the lower part of involved soil volume (Figure 4).

The grouted section in rocks was in fact divided from the upper blind section by a single packer, and injection below the packer performed in one single step, without the need to form the grout sheath. At the end of the rock injection phase, the fiberglass structural element fitted with the manchette pipe was inserted for the full length of the hole and the sheath grout was injected via the manchettes' pipe lowest valve.

The interaction between the two tunnels and the improved soil has been checked by using 3D and 2D Finite Element Analysis (FEA). In fact, the complicated geometry prevents the use of simple analytical methods (i.e. convergence - confinement curves) to estimate pressure.
deconfinement after excavation. A 3D FEA model generated by the MIDAS GTS commercial code has been used (Figure 5a), faithfully reproducing the existing as well as the new tunnel geometry and the main construction stages. Three dimensional analysis results have provided clear indications on soil deconfinement and allowed to calculate deconfinement Panet parameter \( \lambda \) (Figure 5b), to be used in the 2D FEA analyses which were performed to calculate lining stresses (Figure 6).

One more important result of the analysis is that the two tunnels behave like a single tunnel, which means that arching effect occurs on the whole volume surrounding the two tunnels, thus generating vertical stress in the existing tunnel and lining. A steel armour has been therefore designed in order to prevent the existing structure from being damaged.

The design volume of grout (cement based plus Silacol®) to be injected was 26% of overall soil volume to be treated and the design percentage between cement based grout and Silacol® was 14% and 12% respectively.

3 EQUIPMENT

Up to five drilling rigs fitted with electric power pack and short mast have been used in order to guarantee a high production rate when drilling through the upper coarse soil layer and the lower limestone (Figure 7).

Two different types of batching plants have been used: one for the cement-based grout (Figure 8) and one for the chemical grout (Figure 9).

In order to maximize production and inject multiple sleeve pipes, two self-contained plants, fitted with eight pumps each, have been used (Figure 10).

Grout injection parameters - as far as delivery, volume and pressure were concerned - were properly managed by means of an electronic recording and controlling device.
Due to the poor stability during drilling of the upper cohesionless soil, the cased DTH system has been used to ensure the proper insertion of the structural elements.

4 MATERIALS

A twin-plate 40x6 mm fiberglass element fitted with a manchette pipe has been chosen by the designer as reinforcement of the holes (Figure 11).

Water-cement-bentonite ternary suspension has been used for the first stage of cement grouting. The proportion of the ternary grout was (on weight):
- water/cement ratio: 1.4
- bentonite/water ratio: 2.5%
- admixture: 5 lt per cum of grout

In order to improve the penetrability of the mixture, a CEM I 52.5 R type has been used. As for the second stage of chemical grouting, the Silacsol® system has been applied. The Silacsol® is a silicate-mineral-based grout which ensures good penetrability and excellent results both in terms of consolidation and of waterproofing. The grouting with Silacsol®, instead of only cement based grout, has been chosen for the high fines content in the glacial deposits.

5 EXECUTION PHASES

5.1 Drilling and weathered rock injection

Generally, drilling has been carried out by means of a cased DTH hammer up to the sound rock, as prescribed by design. After finishing the drilling phase, a single packer was placed and inflated at the top of the weathered rock. The full length of the weathered rock was then injected with a cement-based grout using a maximum pressure of 15 bars. After the rock injection phase, the packer was deflated and removed, and the fiberglass structural element with the sleeve pipe was inserted. The hole was subsequently filled with sheath grout via the deepest valve and the temporary casing retrieved.

5.2 Grouting of the glacial deposits

Grouting of the coarse glacial deposits was performed in two separate phases by means of the manchette pipe:
1. injection with cement grout;
2. soon after the setting of the cement grout, the second injection was carried out with Silacsol® grout.

The total volume injected has been the 18% of the total treated soil (instead of the 26% expected by the design) and the percentages between the two grouts (cement based and Silacsol®) have been 9.7% and 8.3% respectively.

6 SEISMIC SURVEY AFTER SOIL CONSOLIDATION

Approximately one month after the end of the injections phase, an overall survey of the treatment with a seismic method was carried out along the full length of the tunnel. The results show an overall good increase in shear and compression wave velocity (Figure 12 and Figure 13).

5 CONCLUSIONS

The execution of this work involved the design of an alternative solution jet grouting, to minimize the risk of damaging the existing tunnel from where the works have been conducted. During the drawing up of this paper, the overall consolidation phases and the envisaged controls were completed without heaves or damage of the existing tunnel. The seismic test has been performed and shows a good overall treatment with a general increase of seismic wave velocity due to the combination of fiberglass and grouting operation. The beginning of the tunnel excavation is expected on February 2013.

REFERENCES