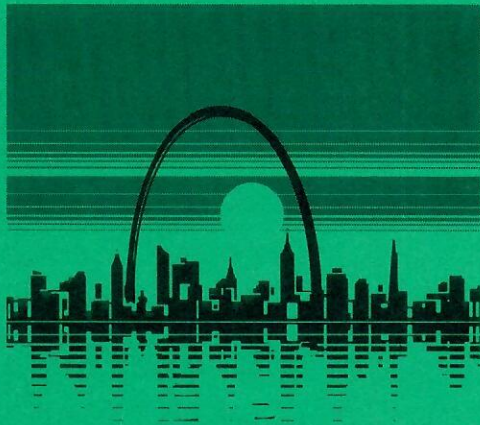


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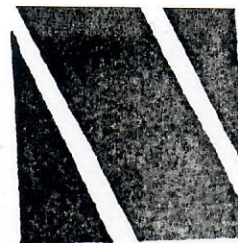
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**SPECIAL TUNNELING METHODS FOR SETTLEMENT CONTROL:
INFILAGGI AND PREMILLING**

by

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Special Tunnelling Methods for Settlement Control: Infilaggi and Premilling

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SYNOPSIS

This paper provides an introduction to two tunneling methods specially developed to optimize settlement control. This is particularly relevant in urban environments.

The concept of neither method may be regarded as novel: infilaggi is a development of the principles of forepoling, whilst the premilling idea has been considered for some years. However, recent trends in the nature of the tunnel market, and major advances in the equipment and systems involved have fostered a rapid growth in Western Europe. A description is provided of the major points of each method, and case history data are cited to illustrate their excellent performance.

1. INTRODUCTION

When tunneling in urban environments often at relatively shallow depths and in variable ground conditions, the development of surface settlements is an attendant reality. Depending on the local circumstances, such settlements may be deemed too small to be of significance. Alternatively some form of settlement mitigation or correction may be necessary, for example grouting (Bruce, 1987) or insitu reinforcement (Bruce et al., 1987). Such methods, and others, will also aid the progress and safety of the tunneling contractor and his personnel (Mongilardi and Tornaghi, 1986).

On the other hand it may be more practical or economic to attack the problem at source--to isolate the impact of the excavation method from the surrounding ground, which would thereby retain its virgin status, and not affect overlying structures.

This paper describes two particular techniques, infilaggi and premilling, which have been developed to minimize ground movements above tunnels. Although entirely different in execution, they share many common features, principally:

- they are executed from the face in advance of excavation, thereby minimizing subsequent decompression.
- they are not new ideas--infilaggi has been known as forepoling or spiling in the U.S. for decades, whilst the premilling system has taken some time to refine to its current status; however,
- given current trends of shallow tunneling in urban areas both have a revived potential rapidly being realized in Western Europe in particular.
- recent developments in equipment technology have broadened that potential with respect to speed, reliability and cost effectiveness.

Each technique is described below, illustrated by reference to recent applications by Ing. Giovanni Rodio & Co., in Italy.

2. INFILAGGI

The use of forepoling or spiling has long been common as a supplemental support method in U.S. tunneling practice. For example, Clough (1981) described how the array of steel rebars

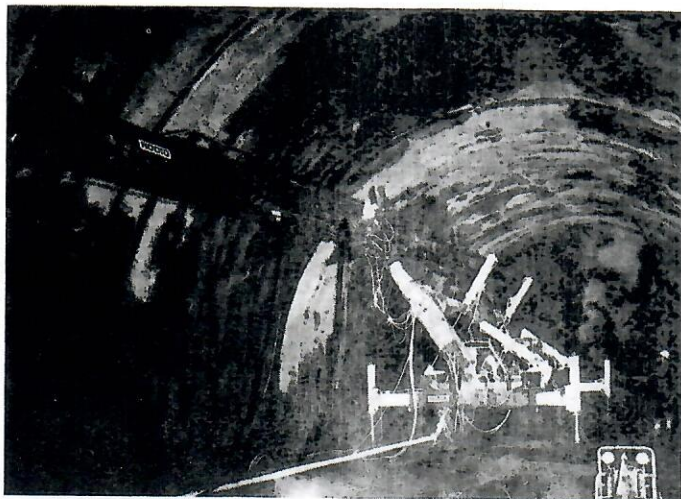
driven suprahorizontally around the crown forms an umbrella of reinforced ground above the subsequent excavation. However, within the last few years in Western Europe, the concept has been expanded upon, to the extent that horizontal insitu reinforcement or retention of this type (infilaggi) has become a primary tunnelling method. This has arisen for three main reasons:

- Demand - there is a vibrant phase of tunnel construction in certain countries in Western Europe--especially Italy, France, Germany and Austria--for new or upgraded transport networks. Much of the construction is in ground which can be classified as soil or rock of inferior mechanical characteristics.
- Equipment - recent advances in specialized drilling equipment (e.g., RODIO SR500 [Photograph 1] and SR510 diesel hydraulic machines) can allow up to 20m of protection to be installed in one pass, with very high productivities and with minimal demands on the facilities or assistance of the excavation contractor.
- Contractual - the contractual atmosphere fosters innovation and the principles of risk sharing. Thus individual companies, or groups of companies are encouraged to evolve new concepts to improve cost effectiveness and productivity. Equally, these ideas may allow contractors to minimize initial capital expenditure, by virtue of using or modifying existing equipment.

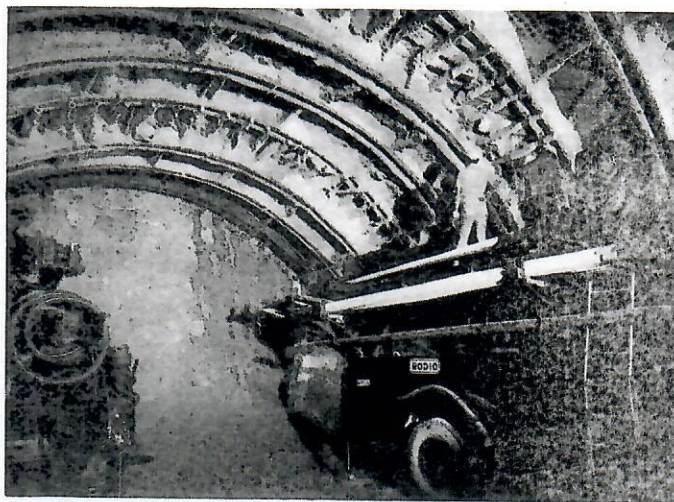
The length of each pass of infilaggi varies according to the ground conditions and the balance between the various aspects of the tunnel construction processes necessary to ensure efficient utilization of all resources by all parties. In certain instances, the steel pipes forming the reinforcement may also be used for grouting the surrounding ground, and the use of sleeved ports for example permits a range of cements and chemicals to be used, depending on ground conditions and the support requirements.

CASE HISTORY: LIMINA TUNNEL, MAMMOLA, ITALY

The Limina motorway tunnel is located in the south of Italy, near Mammola, approximately 20 Km northeast of Reggio Calabria. Typically, the 12m diameter tunnel has the profile in Figure 1, but at 250m intervals it opens out by 4m for a



Photograph 1 - SR500 diesel hydraulic tunnel drilling rig, installing 19m long, 140mm dia. infilaggi with sleeved ports to allow supplementary grouting of the morainic material. Up to 60 infilaggi per ring. For twin 12m dia. roadway tunnels. Dervio, Lake Como, Italy.



Photograph 2 - Drilling for installation of infilaggi (seen stored on drilling rig). Earlier phases of infilaggi, ribbing and shotcreting seen above the rig. Limina Motorway Tunnel, Mammola, Italy.

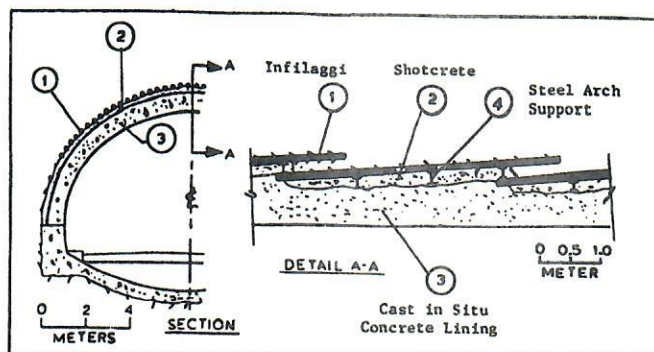


Figure 1 - Tunnel cross section and details of in situ support (Infilaggi). Limina Motorway, Mammola, Italy.

length to provide passing points. The tunnel runs east-west and is 3100m long.

The bedrock is extremely variable hornblende-biotite diorite, shattered and weathered irregularly. It trends oblique to the axis of the tunnel and so each face can exhibit both "good" and "bad" rock. Fissure water is tapped by groups of four or five 100 mm diameter drains 12m long drilled up from interim face locations as required.

In this instance, short infilaggi proved to be the safest and most cost effective solution, and a maximum installed length of 5.0m was determined (5.5m in enlargements). With the steel ribs being placed at 1.25m centers, this gave the option of excavating in steps from 1.25m (poorest ground) to 3.75m (best ground) long (Figure 2), depending on the rock conditions encountered. (To date the average has been 3.64m/drive.)

The long stroke SR500 or 510 rigs were not therefore required, and a purpose built truck-mounted diesel hydraulic rig

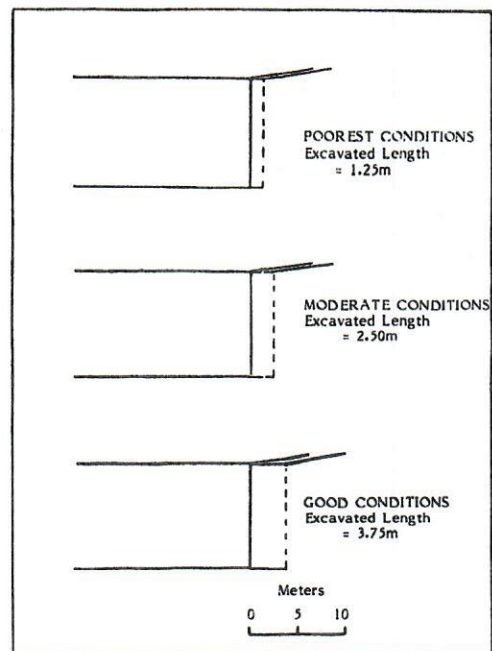
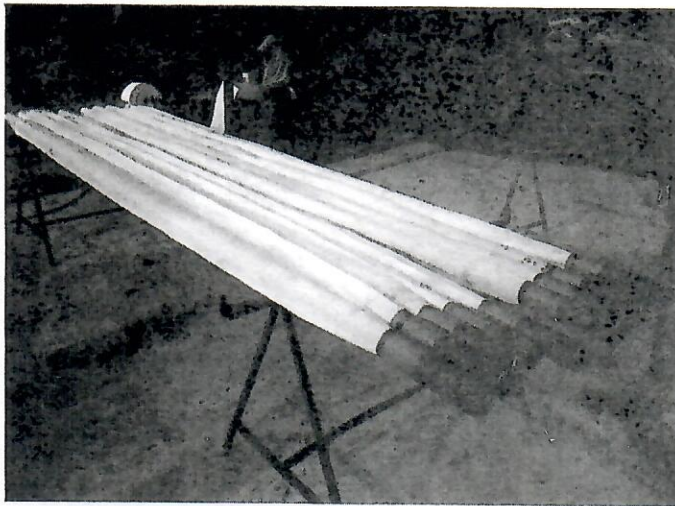


Figure 2 - Simplified elevation, showing variation in excavation length under infilaggi, related to rock quality. Limina Motorway Tunnel, Mammola, Italy.

was used (Photograph 2). This drilled holes of 120mm diameter using foam flush (to minimize water flush requirements) through a hydraulic roto-percussive top hammer. The 45mm drill rods were "sleeved" to 90mm o.d. to ensure hole straightness.



Photograph 3 - Infilaggi being assembled, showing fabric sleeve, sealed at top and bottom.

The holes in each umbrella were drilled at 300-400 mm centers (depending on rock quality) with an upwards inclination of 8%, but parallel to the tunnel axis. Drilling commenced in the poorest rock zones. In the normal section there were about 30 holes, with 40 in the enlarged sections.

Grouting the steel reinforcements into these holes required a novel solution, both to overcome the normal problem of grouting upwards, and to provide a high early strength performance. Each reinforcement consisted of a 76 mm o.d. steel pipe, sealed at the leading end. Rubber sleeves (manchettes) cover groups of four 6 mm diameter holes drilled in the pipe 1 m from either end. The entire length is encased in a continuous woven polypropylene geotextile jacket, closed against the steel at each end with steel clips and tape (**Photograph 3**). It is capable of unconfined expansion to 180 mm diameter.

The prefabricated reinforcement was placed in the borehole (**Photograph 4**) and a mechanical single packer introduced to just above the lower sleeve. A thick, neat cement grout was then injected through the packer to pass through the sleeve and so inflate the geotextile wrapping, forcing intimate contact with the borehole wall all along its length. In granular conditions (rock weathered to sand) injection was made with a silicate based grout, to permeate and consolidate the surrounding ground.

This system, permitting a very quick and clean installation and grouting operation, clearly solved the difficulties of "up grouting." In addition, the selected permeability of the geotextile material allowed cement grout water to be expressed during injection, thus leaving behind a grout of very low water-cement ratio, promoting fast set and very high early strength.

Following completion of each ring of holes, the drilling rig was withdrawn and excavation proceeded from the (lightly shotcreted) face. Steel arches were placed (as in **Photograph 4**), and the excavation then sprayed with up to 250 mm of shotcrete to ensure full contact of the structural elements and prevent local raveling or seepage (**Figure 1**).

With this system, the average (and very satisfactory) rate of face advance was almost 3 m per day, and excellent cooperation between the infilaggi and tunneling contractors was recorded. Typically each infilaggi phase took eight hours



Photograph 4 - Infilaggi being placed in predrilled holes, Limina Motorway Tunnel, Mammola, Italy.

followed by sixteen hours of excavation, arch placement and shotcreting. It has proved to be a particularly apposite solution given the flexibility it afforded in dealing with the major geological variations encountered.

3. PREMILL

Papers describing the successful development of "prédécoupage mécanique" (Premill) as a specialized tunneling technique in rock and soils have appeared sporadically in the French technical press over the last few years.

In essence, the system comprises a track-mounted frame, of shape corresponding to the tunnel extrados (**Figure 3**). Mounted on the frame and projecting out in front is a large band saw type milling machine about 3 m long (**Photograph 5**). This can be moved around the frame to cut a slot about 120-200 mm wide into the ground around the volume to be excavated. In competent rock this slot is left open, to optimize the subsequent blasting parameters and performance. In soft ground the slot is filled immediately with high strength, fast setting concrete, so forming an insitu arch to minimize decompression effects during subsequent excavation.

The system was evolved in response to the need to absolutely minimize construction-related effects in urban areas involving large diameter tunnels close to the surface under old and delicate structures. Under such conditions even the excellent performance afforded by the standard New Austrian Tunneling Method was not acceptable. The early examples for TGV and Metro construction in France have been followed by similar contracts for example in Lille (Belgium) and Roggiano (Italy), the last of which is described below.

In competent rock formations, of up to 2500 bar compressive strength, the premill is used only to provide a continuous slot around the volume to be excavated—usually with a drill and blast method (**Figure 4**). Premilling provides the following major benefits:

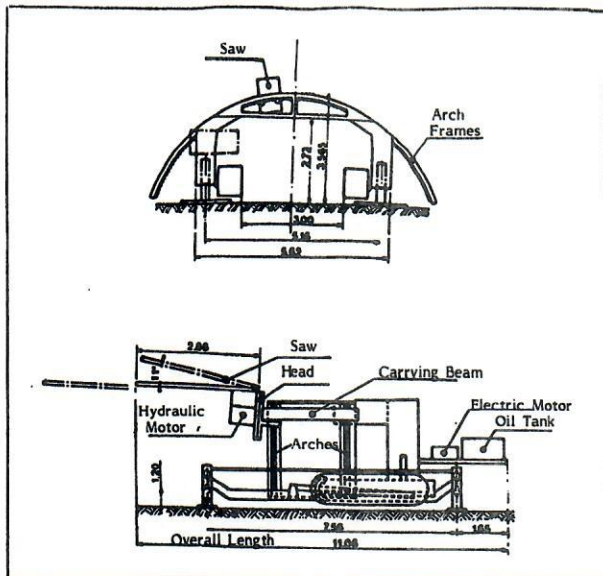


Figure 3 - General layout of typical premilling machine (Hydraulic arm for shotcreting not shown).

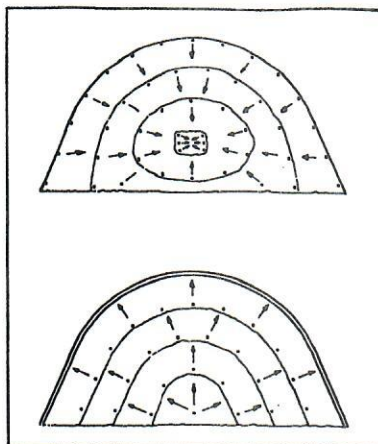
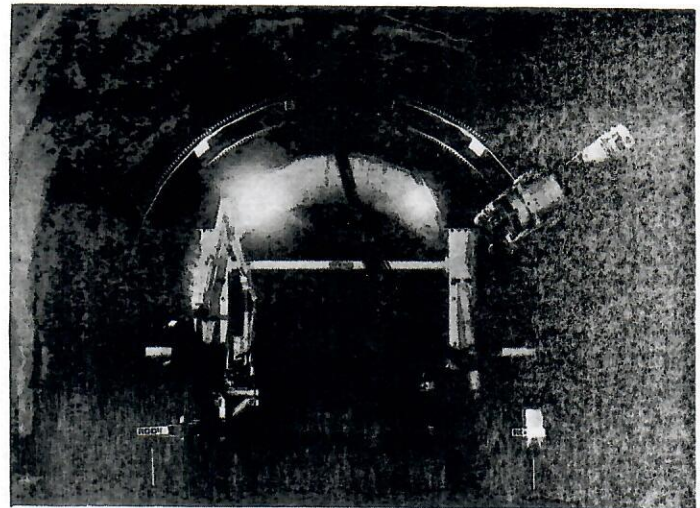


Figure 4 - Round blasting concepts - classical (upper) and with premilled slot (lower).

- less explosives (and blast holes) are required, rendering the entire blasting operation safer, faster and environmentally more acceptable.
- no fissuring or decompression occurs in the surrounding rock mass, thus preserving its virgin properties, and so reducing the demand for subsequent reinforcement, e.g., with bolts.
- there is no overbreak, and therefore associated cost savings in time, effort and materials.
- the smooth profile makes the placing and performance of arches more efficient.
- less contact or consolidation grouting is needed behind the final tunnel lining.
- following blasting there is a greatly reduced danger from rock falls due to chimneys of fractured ground developing above the excavation.



Photograph 5 - Premilling machine, seen from the front and showing premilling saw (upper right) and hydraulic arm (left) for shotcreting operations.

- the magnitude of vibrations transmitted upwards towards nearby surface structures is greatly attenuated.

Developments of the technique continue, for example, in special diamond tools, high pressure water jetting, and increased cutting power, to permit its use in harder rock formations, faster, and with increased safety.

In soft ground, as noted above, the major difference is that the cut slot is filled with a special concrete mix as early as possible. The advantages are as identified above for the rock prefill, although the prime target is the elimination of surface settlements induced by the tunnelling.

Each cover, up to 3.5m long, depending on the soil, is inclined slightly outwards and overlaps the preceding one by 300 to 500mm (Photograph 6). The cone is cut in discrete segments so that the concrete can be placed in each segment, as early as possible and without having to wait for the whole arch profile to be first completed. Cutting times for a typical 3m long segment may be as low as one minute.

The concrete may be placed by dry or wet shotcrete methods. A typical mix reported by Bougard et al (1979) comprises, per cubic meter of mix:

Cement	450Kg
Sand	560Kg
Fine gravel	650Kg
Coarse gravel	650Kg
Accelerator (Sigunite)	27Kg
Water, as appropriate, typically w/c = 0.25-0.30	

This gives a strength of up to 100 bar at eight hours. Replacement of the normal cement with 350Kg of cement fondu gave the minimum target strength of 80 bars in 4-5 hours. In addition, spraying the mix into the premilled slot ensures that none of the fine aggregate is lost, as is the case in conventional NATM applications of shotcrete on open faces. The concrete in place is, therefore, of superior quality, further enhancing the performance of the system.



Photograph 6 - Tunnel excavated under the pre-milled in situ arch, showing overlap of each cut, and placement of supporting steel ribs.

In comparison with the NATM, there are certain similarities, notably the overall concept of the support, and the common construction elements such as shotcrete, bolts, and arches. However, the major dissimilarity is that with premilling the primary lining is placed up to 3m ahead of the face before excavation, whereas in NATM the lining follows 1 or 2m behind the excavated face. This greatly impacts the generation and scale of tunnel deformations, and so the effect on overlying structures (Figure 5). Goër (1982) described a monitored case history of the relative performance of the two methods in the same material--Argenteuil marl (Figure 6). Typical properties of this material were listed as:

Density = 2
Effective ϕ = 20°
Effective cohesion = 0.5 - 1.0 bar
Undrained cohesion = 1.5 bar
Deformation modulus = 500 bar

Three times less settlement was achieved in the tunnel protected by premilling.

Most of the earlier applications have been carried out with the conservative "divided section" profile. However, excellent results with the "full section" profile (i.e., cutting a 270° arc, and excavation in one pass) in a shallow circular collector tunnel 3.50m diameter (Département de la Seine-Saint-Denis, France), in very difficult ground, encouraged its use in Lot 7 of the Lille Metro, Belgium. As evident in Figure 7 the performance of the full section profile was superior, with surface settlements no more than 1mm. Prefabricated base slabs were connected structurally to the premill cover by shotcrete, and the steel ribs then placed, bearing on the slabs. This system also proved faster than the divided section approach.

CASE HISTORY: RAILWAY TUNNELS FROM MONGRASSANO TO SAN MARCO ARGENTANO, NEAR ROGGIANO, ITALY

During 1986 and 1987, three tunnels totalling 2000m in length were formed by premilling. The soil was generally lightly indurated and variable sediments, typified by waterbearing silty claystones with fine sand lenses. The profile of the tunnel is shown in Figure 8, the 140mm wide slot extending 21m around the shape and 3.5m beyond the face. Each cover overlapped the

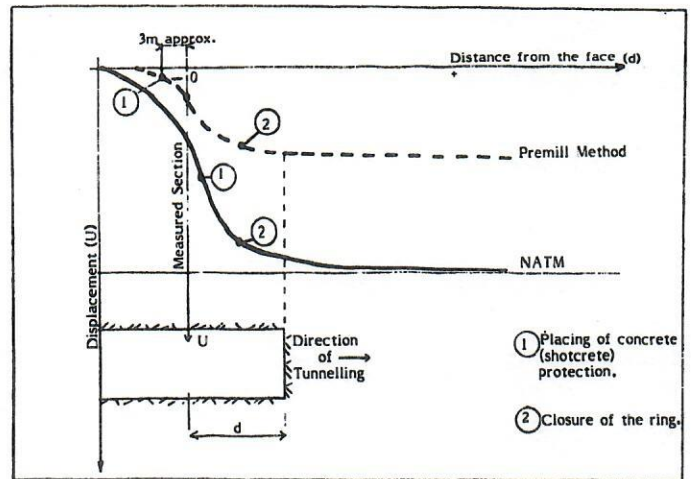


Figure 5 - Qualitative comparison of development of tunnel movements with Premill and NATM. (LeGoër, 1982).

earlier by 500mm, enabling the excavation to proceed full section in 3m drives, at an average rate of one advance per 24 hours, viz:

- Premill and shotcrete 8 hours
- Shotcrete stiffening period 6-8 hours
- Excavation and placing ribs 8-10 hours

The three faces were advanced simultaneously and laser guides used to ensure precise tunnel orientation.

The special dry shotcrete mix designed for this contract also incorporated steel fiber (about 30Kg/m³) to aid performance, and the mix reached 100 bar at 8 hours. Segments of 2-4m length were successively cut and filled.

During premilling in particularly poor conditions, the face (previously lightly shotcreted) was temporarily supported by simple mechanical props. Under these conditions, the spacing of the steel arches was halved. The final lining followed not more than 50m from the face.

4. SUMMARY AND CONCLUSIONS

The potential for the cost-effective use of infilaggi for soil and poor rock tunnelling has been greatly expanded by recent developments in drilling and grouting technologies. It is now realistic to anticipate single drives of over 15m, fully protected by the insitu reinforcement, and with or without complementary ground injection, using the new generation of purpose built drilling rigs.

In cases where surface settlements must be absolutely minimized then the premilling technique has been proved an excellent method, markedly superior in performance to the standard NATM. It can be carried out in both rock and soil.

The successful application of each technique, however, demands close and harmonious cooperation between the support specialist and the excavation/lining contractor. Once such links are forged in the U.S., the demands of the urban shallow tunnelling market will be more efficiently served.

ACKNOWLEDGEMENTS

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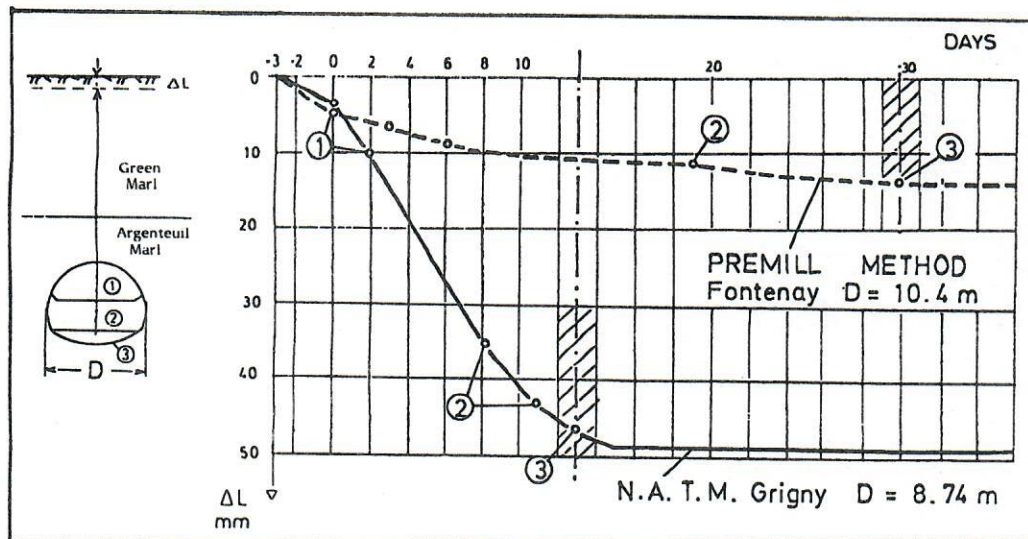


Figure 6 - Comparison of settlements generated with time in identical geological conditions, by Premill and NATM. (LeGoër, 1982).

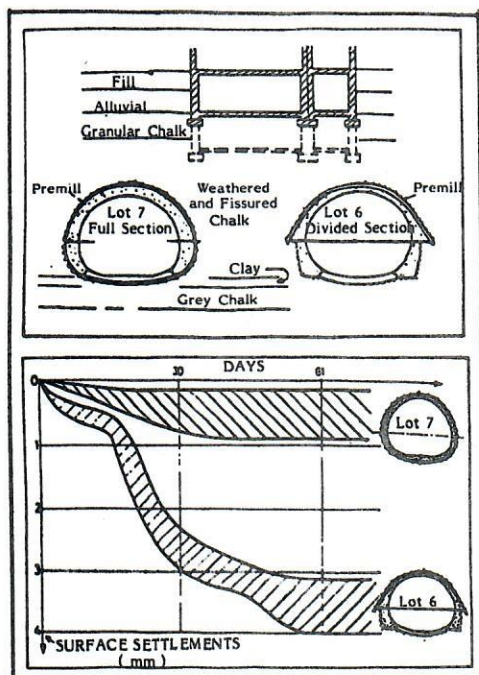


Figure 7 - Comparison of settlements generated by Premilling in Divided Section and Full Section, Lille, Belgium (LeGoër, 1982).

REFERENCES

Bougard, J.F., Francois, P., and Longelin, R. (1979), Le prédécoupage mécanique: un procédé nouveau pour le creusement des tunnels. *Tunnels et Ouvrages Souterrains*, 22 (July-August), pp 174-180, 23 (Sept.-Oct.), pp 202-210, 24 (Nov.-Dec.), pp 264-272.

Bruce, D.A. (1987), Tunnel grouting - an illustrated review of recent developments in ground treatment. *Proc. Int. Conf. on Foundations and Tunnels*, London, March 24-26, pp 156-173.

Bruce, D.A., Boley, D.L. and Gallavresi, F. (1987), New developments in ground reinforcement and treatment for tunnelling. *Proc. Rapid Excavation and Tunneling Conference*, New Orleans, June 14-17, Vol. 2, pp 811-835.

Clough, G.W. (1981), Innovations in tunnel construction and support techniques. *Bull. Assoc. Engrg. Geol.*, 18 (2), pp 151-167.

LeGoër, Y. (1982), Le creusement des tunnels en site urbain par prédécoupage mécanique. *Travaux*, December, pp 74-79.

Mongilardi, E. and Tornaghi, R. (1986), Construction of large underground openings and use of grouts. *Proc. Int. Conf. on Foundations*, Beijing, September, 19 pp.

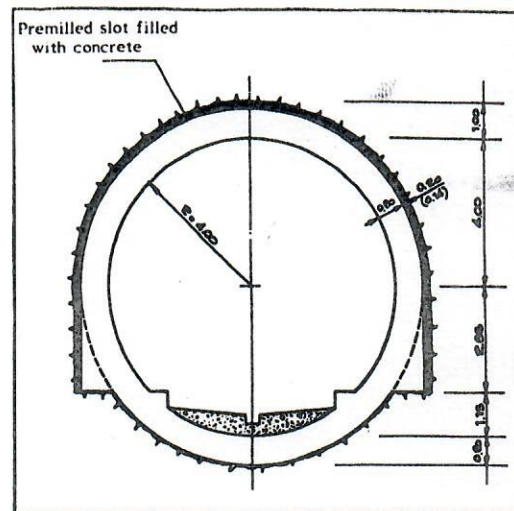


Figure 8 - Geometry of Roggiano Railway Tunnel, Italy, showing premilled protective arch.