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Overture
47th episode of the Grout Line and for this issue a European experience with the use of Multiple Port Sleeved Pipes (or TAM) in soil grouting. The authors Ing. Andrea Pettinaroli (a.pettinaroli@stap-engineering.eu), Dr. Mario Ruggiero (m.ruggiero@sireg.it) and Ing. Gabriele Balconi (g.balconi@sireg.it) prepared this article about a successful compensation grouting project carried out in Warsaw, Poland.

A case history of compensation grouting with the TAM application in an urban area in Warsaw, Poland

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Grouting is a technique used for modifying the behaviour of a mass of soil or rock by injecting cementitious or chemical mixes. Different processes of execution may lead to different results, and the choice is a function of the objective of the treatment and of the type of ground. More than fifty years ago, the introduction of sleeved pipes also known as TAM (Tube A Manchette) brought a lot of advantages to this technology; it allowed for widening of the use of the grouting, leading in many cases to more easily reach the purpose and to savings in time and cost. The use of non-metallic pipes is nowadays highly diffused because the variety of pipe materials available, such as plastics and composites, allows for optimization of the costs of the tubes as a function of the kind and importance of the work. The TAM pipe technology is used both in soil and rock.

The TAM pipe is a tube, normally made of plastic, perforated at a regular distance, with rubber sleeves mounted on the holes to prevent the flow-back of the mixtures inside the pipe. For standard applications the pipe’s outer diameter ranges usually from one to two inches (Fig.1).

After identifying the area to be treated and method of treatment required it is necessary to proceed with the realization of the pre-drilled and cased holes where the pipe will be inserted, by a conventional drilling rig. The sleeved pipe is installed and sealed into the hole by means of a suitable plastic cement mixture (sheath) in granular soils, or alternatively through the use of geotextile bags in rocky soil acting as packers. The sealing prevents the injection mixture from raising up along the borehole and penetrating in the area of influence of the single sleeve.

Once the annular space around the pipe is sealed, the pressure injection is carried out through a single valve with a double packer (mechanical or...
The injection mixture opens the valve and spreads the grout into the surrounding soil. After grouting, the valve closes, preventing the injected material from returning into the pipe. Once the pipe has been washed inside, the valves are ready to be used eventually for other subsequent grouting operations.

There are many advantages to this method. One of them is that the injection can be carried out in more than one stage and, if necessary, using different cement based mixes.

One of the typically employed grouting processes is **Permeation grouting**, which consists of filling the natural voids in the soil with a mixture, substituting the in-situ fluid (normally air or water). The result is a reduction of the hydraulic conductivity and an increase in the mechanical characteristic of the soil. Cements, chemical mixtures and resins reinforce the soil structure, improving the strength and the elastic modulus of the treated ground. The granular composition of the soil also plays a fundamental role in the success of the permeation grouting: the finer the dimension of the soil grains and the higher the dis-uniformity degree ($U = D_{90}/D_{10}$), the lower the volume of the voids. So basically it is important that in the first phase of the grouting design, a detailed investigation campaign including soil coring is planned, in order to obtain the granulometric sieve from samples of the soil layers where the treatment shall be carried out.

On the other hand, the capability of a grout mix to permeate the soil is a function of its composition. The rheology study of the mixtures allows for definition of this parameter.

In order to achieve a good permeation grouting homogeneity, cement mixes are stabilized by adding a filler (for example bentonite) that helps to maintain in suspension the cement grains. The use of fillers normally increases the viscosity of the mixture; the use of polymeric-based additives allows viscosity and stability to reach optimal values.

As a matter of fact, an accurate set of preliminary tests has to be foreseen before starting permeation grouting work, in order to define the correct mixture to be used for the grout and to provide the benchmark values of its rheological parameters. The latter will be considered during the on-site work in progress controls. The use of sleeved pipes brings a series of advantages to permeation grouting:

- it allows for the injection of the proper grout quantities, in a controlled way, in the different zones of the soil mass to be treated;
- for each sleeve it is possible to record the operative parameters (pressure and flow rate) during the injection process, obtaining the “story” of each grouting and allowing the evaluation of the parameters for the following steps;
- it is possible, if necessary, to inject additional quantities of grout in further stages;
- it allows for the injection of different kinds of mixtures from the same sleeve, for example following an order of growing penetrability.

The use of sleeved pipes, often coupled with a polypropylene bag (Fig.3), allows for the reduction of the number of drillings required. This way the injection process is faster, without any influence on the type of mixture to be injected and/or on the parameters to be used.

Grouting is not only required to improve the mechanical characteristics. It has also been used in the reduction of the mechanical prop-

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**Figure 2. Grouting injection through a sleeved grouting pipe.**

**Figure 3. High tenacity polypropylene bags.**
properties of the rock/soil for specific purposes: for example a treatment of fissured rock with highly deformable resin using sleeved pipes allowed for excavation with blasting of a highway tunnel close to a rock mass containing inflammable gas. The energy of the blast was dissipated by the shell of deformable treated rock that surrounded the tunnel excavation profile, avoiding the propagation of the vibration waves and the upsetting of the dangerous zone in proximity to the site (Wolf E., Collini R., Balossi Restelli A. – Attraversamento di una tratta della galleria Capo Calavà (Autostrada Messina Palermo) in presenza di gas tossici in pressione – Gallerie e grandi opere sotterranee n.°8, March 1979).

Warsaw Metro compensation grouting
The new Warsaw Metro Line 2 ends east of Vistula river. The last station C15 is near a shopping center. The latter is connected to the Metro Station by an underground pedestrian passage that runs very close to the shallow foundation of one of the building’s façades. During the execution of the provisional lateral sheet wall diaphragm, the vibration de-tensioned the sandy layer under the foundation of the structure, causing remarkable settlements on some pillars, up to about 50 mm (Fig. 4).

The investigation showed the presence of a superficial layer composed of an almost monogranular sand in the foundation level, from 3 m to 12 m of depth under the campaign level (see res curves in the chart of the following fig. 5), followed by a stiff clay layer at -12 m u.c.l. (blue curves).

CPT tests were carried out both in the area of the disturbance and in the sector of the building façade where the diaphragm wall was not constructed, putting in evidence the weakening caused by the works.

It was then necessary to re-compact the soil under the building foundations in the zone of the damage, and to uplift the involved plinths in order to reduce the differential settlements between the adjacent parts of the structure. Moreover, preventive treatment was necessary in order to reinforce the soil foundation of the plinths in the sectors where the sheet wall was yet to be executed.

The treatment was carried out injecting in the first stage a cement grout, with ratio C/W=0.4 stabilized with bentonite and the aid of a stabilizer additive, and in the second stage silica grout. The consumption of cement mix has been prevalent in the decompressed zone for achieving the re-compaction effect. In the natural sandy soil a lower quantity of cement was integrated by the silica grout that achieved the requested improvement of the ground by permeating the latter with a smooth effect on the structures, as hereafter described.

The treatments were carried out by grouting the sands for a thickness of about 9 meters (down to the clayey layer) under the foundations, composed by concrete plinths at the base of the pillars, connected by beams. Two lines of PVC sleeved pipes were installed along the external alignment of the building (fig.6), while two other rows were installed working from the...
underground floor, in narrow spaces (the average height was 2.30 m) (Fig. 7).

The structures were controlled by an automatic topographic monitoring system (Fig. 8); optical prisms were placed in correspondence of each pillar.

The grouting scheme was studied in order to gradually uplift the structure’s pillars; in some cases even the specific order of the sleeves to be injected was indicated. On the first day, a set of holes was drilled and the sheath injection executed. On the following day, the first stage of the injection, using cement grout, was carried out. The monitored points were regularly checked. The operative parameters were recorded in real time and the pressure and volumes evaluated at the end of each working day. In some cases, the data analysis involved rescheduling the grouting sequence of the following days. The continuous and constant monitoring and recording of the grouting parameters influenced the timing and scheduling of the project. On several occasions the weekly scheduling was modified based on the results obtained day by day. In some cases, the weekly programming was modified based on the data and results obtained on a specific day.

The chart of figure 9 shows the evolution of the vertical displacements measured during the works. Firstly the grouting with cement mix gradually uplifted the pillars nr. 8 and 9.
Few holes required an additional second stage of cement grouting. When the differential settlements between the pillars were strongly reduced, the silica grout was injected, working gradually along the area to be treated. The effect of this injection stage is shown by the yellow line in (Fig.10); an average uplift of about 5 mm was induced.

At the end of the treatment, the sheet wall execution was also completed in the area in front of pillars nr. 6 to nr. 3. The sheet elements were now driven into the ground without vibration. The green curve in the following figure 11 evidences the effect of this work on the structure. Settlements of about 5 mm were measured in the zone besides the activities, while pillars nr. 8 and 9, showed a very reduced settlement (less than 1.5 mm) after the compaction grouting works.

Finally, the excavation between the driven sheet walls and the following reinforced concrete lining cast was carried out in the following 4 months. Low residual settlements were measured, varying from 1.5 mm to 3 mm, in the range expected by the structural designers. The effect of the treatment, together with the different execution methods used, definitely allowed for reduction of the sensitivity.
of the structure during the driving of the sheet piles. This was confirmed by the very slight displacement produced during the final excavation stage.

The success of this project confirms once more the flexibility of the TAM grouting technology that, along with the use of real time monitoring and recording, allows the technical optimization of the scheduling.

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In conclusion, a final reminder, only a few weeks away:

- **5 short courses:**  
  - Compaction Grouting  
  - Jet-grouting (1/2 day)  
  - Compensation Grouting  
  - Diaphragm wall  
  - Deep mixing (1/2 day)

- **5 Key Note Lectures:**  
  - Jim Warner P.E. Fellow and Life Member ASCE- Reflections from 65 years in the grouting industry.  
  - Dave Paul, USACE – Mosul Dam, International cooperation for remediation of dam safety issues.  
  - Prof. Alessandro Flora- The future of Jet-grouting- A European perspective.  
  - Donald Bruce, PhD, C.Eng.- Remedial cutoff walls for dams: great leap and Wolf Creek.

- **130 technical presentations**


An opportunity not to be missed, to stay updated on Grouting, Deep Mixing and Diaphragm Walls, to network with colleagues and friends and, why not, enjoy the beauty of Hawaii!

**Aloha!**

And see you there, I hope!

As usual, I make the same request, asking you to send me your grouting comments or grouting stories or case histories. My coordinates remain:

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Ciao! Cheers!