THE JET GROUTING
Jet grouting is an injection technique for soil consolidation; it is used to stabilize, reinforce or waterproof the soil directly in-situ through injection, at very high speed, of a binder mixture. The fields of application of Jet grouting extend to virtually all types of soil and certain types of soft rocks.

Developed in Japan in the late Sixties, it was introduced in Europe a few years later (early Seventies). Jet grouting technology soon spread widely throughout the world. It has many applications including construction and consolidation of deep foundations, slope stabilization (Ferles, 1990), consolidation prior to excavating tunnels in loose soil (Bienfait, 1994; Fredet, 1997; Richard, 1991), sealing of earth dams (Guastini, 2000; Nishi, 2000), ensuring the waterproof function of screens on old dams subject to liquefaction; construction of anchorages for high capacity tie rods with both active and passive action; bottom plugs between bulkheads and/or shafts for the excavation of underground rail lines, etc.

The versatility of Jet grouting, and the relatively small size of the equipment, make it the ideal choice for projects in urban areas and sites with difficult access.

This document discusses the following topics:

• the development of jet grouting from the origins to the present;
• the different techniques currently used in Jet Grouting;
• the operating procedures for Jet grouting;
• applications in theory and in practice (works performed).
HISTORY AND DEVELOPMENT OF THE METHOD
2. History and development of the method.

Jet Grouting technology was first used in the oil sector to consolidate the walls of deep wells (1954). One of the first companies to use the method was the British firm Cemmentation Company, which successfully built several dams in Pakistan.

The injection procedure used at that time consisted of drilling to the desired depth, injecting water through the drill rods to detach light particles of soil and float them up to the surface. The process took place during descent of the rod batteries. On reaching the desired depth, a cement mixture was injected in place of the water. This grout injection caused disintegration and leaching of the soil around the injection area, which effectively enlarged the perforation to three to four times the original diameter. During ascent of the injection rods, the cavity left was filled with a grout-soil mixture and formed a column to the surface (Fioravante, 1997; Kutzner, 1996; Lunardi, 1992; Tornaghi, 1989).

Later Yamakado, in attempting to overcome the ineffectiveness of traditional cement and chemicals injection in soils with low permeability and fine particle size, experimented with injection at very high power and controlled volume, and discovered that this method would disintegrate the soil which could then be treated with binders to improve its technical features.

The first applications in civil engineering go back in the early Seventies (Botto, 1985). The process used in Japan (Chemical Curning Pile) was based on three fundamental principles:

1. separation of soil particles by the dynamic effect of a jet at high kinetic energy;
2. partial soil extraction;
3. incorporation of a cement-based mixture.

The Chemical Curning Batteries method used to achieve these three functions was a high speed jet generated by a nozzle attached to drill/injection rods.

The uniform upward circular movement of rods caused disintegration of the soil which, under the influence of strong kinetic energy, was partially excavated and replaced by a soil-cement mix. The technique could only be applied on a limited scale however: the treatments were limited to 50 cm diameter in sand and just 30 cm in clay.

Also in Japan, to increase the radius of action of the cement jet, in 1972 experiments enclosed the cement jet in a jet of compressed air (Jumbo Special Batteries); this made it possible to reach diameters of about 2 meters. The treatment was not uniform, however, due to problems of hydraulic fracture or claquage caused by injecting the compressed air directly into the soil with the cement grout.

In 1975, following the experiments based on the techniques described above (monofluid, Chemical Curning Batteries, bifluid, and Jumbo Special Pile), the Japanese company Kajima Corporation developed a new method called the Trifluid-Kajima method. This new method injected air and water through 2 concentric nozzles from above, to break and partially excavate the soil. Simultaneously, at a lower level (30-40 cm), the cement mixture was injected for in-situ soil consolidation. The use of the Kajima was satisfactory to a diameter of about 2.5 metres, with acceptable uniformity.

At the same time, the first tests performed in Europe (CCP, Italy) under Japanese license and equipment made it clear that the jet technology was not applicable on a large scale due to the complexity and cost of the equipment which made it impossible to employ on a competitive basis at acceptable costs.

A number of European companies (Keller, Pacchiosi Drill, Rodio, Trevi, etc., 1975) and several engineering companies (C. Luis, France; P. Lunardi, Italy) perceived its potential, however, and began studying, testing and producing fully automated systems that could apply Jet Grouting technologies at competitive costs and performance.

The development of high performance equipment prompted the further development of Jet Grouting technologies (mono-fluid, bi-and tri-fluid) and its application spread worldwide, enabling Jet Grouting to resolve many of the problems in the field of civil engineering as well as complex problems connected with underground works and civil engineering.
BASIC PRINCIPLES OF JET GROUTING TECHNOLOGY
3. Basic principles of jet grouting technology.

Jet Grouting is essentially a process of controlled erosion achieved through the use of one or more jets of water or mixing cement, launched at very high speed against the wall of a small diameter hole in order to cut, break up and force to the surface part of the in-situ soil and, simultaneously, mix the remaining soil with a cement-based mixture.

The basic principle of Jet Grouting is that hydraulic power, transmitted by high-pressure pump to the injection grout, and “disintegration” water (Energy = Pressure x delivery), will be converted into kinetic energy (Ecin = m2/2) at the injection nozzles (Pacchiosi, 1998).

The normal stages of performance of Jet Grouting injections consist of boring a small-diameter hole (see fig.1), generally about 150 mm, to the required treatment level, followed by injection. This is done immediately after boring the hole, without necessarily withdrawing the rod battery. After enabling the injection jets, the rod battery is extracted slowly at controlled speed and rotation so that (see fig.2), in uniform soil, a column of soil mixed with cement grout will form, having regular diameter and uniform characteristics (see fig.3).

During the injection, a thick fluid (return flow) is constantly evacuated to the surface. It consists of cement mixed with water and fragmented soil, which flows between the external wall of the rod battery and the internal wall of the drilled hole and is an essential conditions for correct Jet Grouting, otherwise claquages (horizontal fractures of the soil caused by excess pressure) would be generated. When these conditions are effectively implemented, the hydrostatic in-situ pressure at the injection site is basically proportional to the column of liquid forming inside the hole. Properly done, Jet Grouting causes no risks to buildings and structures adjacent to the work site.
For some applications, the rods may be extracted without rotation or with partial rotation to obtain, as final result, the formation of thin panels or partial columns (see fig. 4, 5 and 6).

Recently, partial columns have been obtained with a radius of about 5 meters (see Figure 4) and panels with lengths up to 8 meters (see Figure 5 and 6) which are used instead of traditional bulkheads.

Figure 4: partial column

Figure 5: linear panel

Figure 6: linear panel
THE MAIN JET GROUTING SYSTEMS

- MONO-FLUID
- BI-FLUID
- TRI-FLUID
- CLOU-JET
4. The Main Jet Grouting systems.

The technologies mainly used worldwide are (Pacchiosi, 1998):

- Mono-fluid;
- Double-fluid;
- Triple-fluid;
- Clou-jet.

4.1. Mono-fluid.

The mono-fluid method is the most elementary Jet Grouting technology. A cement mixture is injected at high kinetic energy to perform three functions:

- break down the soil in situ by dynamic injection;
- extract of a portion of the soil;
- fill and mix cement grout with the soil remaining in situ.

Jet Grouting works performed with the mono-fluid technique are divided into several steps: First, a small diameter (60 to 200 mm) hole is drilled using a bit, blade or down-the-hole hammer. The diameter of the hole must be greater than the diameter of rod battery to allow the evacuation of the return flow generated during treatment. The drilling tools used should be able to deliver water or cement mixture to the bottom, while a sleeve is connected to the top with housing for a steel ball that is inserted when drilling is terminated, to close the axial channel of the drilling rod so that the cement mixture no longer exits from the bottom of the drilling tool, but only from the nozzles. The injection nozzles are located a few centimeters above the ball at different heights, so that the same area is always treated twice (see Figure 8). When the battery rod reaches the desired depth, the equipment begins an upward rotary motion, while the pump ensures the supply of the necessary grout at the required pressure. The jet breaks up the soil and mixes it with the grout. Ascent can be made in steps or continuously.

Application of this process is generally limited to columns of small diameter (about 1 meter) and granular soils.

The mono-fluid method is the only one possible for performance of horizontal injections, used in the construction of tunnels in loose soil.

Figure 9 shows a typical worksite with all the equipment necessary to perform Jet Grouting with mono-fluid. The equipment includes one or more hydraulic drill rigs supplied with cement grout by a high pressure pump which in turn is fed by a mixer, connected to one or more cement silos, which automatically prepares the necessary fluid.

The mono-fluid method is normally used in soils where no clay is found. However, it can also be used in soil containing clay particles if the soil is treated with a prewash process during drilling. The resistance (simple compression) and the diameter of the column will
be lower than those achieved in soils with no fine particles of clay. In fine sands, coarse sand and gravel, columns made with monofluid give good resistance and are produced fairly easily (they have regular form, large diameter, etc.). In soil of alluvial origin, the obtainable resistance is good even when the soil-grout mixture is made quickly. Although the mono-fluid method is suitable for alluvial soil, the bi-fluid or tri-fluid methods must be used, for example in cases where it is necessary to achieve large-diameter columns or if a part of land presents a clay matrix.

4.2. Bi-fluid

Conceptually, the bi-fluid method is similar to the mono-fluid method, with the addition of compressed air (from 6 to 20 bars) that encloses the jet grout (see in particular fig.11) making it more effective in disintegrating the soil so that greater diameters can be achieved, up to about 2 meters.

The bi-fluid method is effective even in weakly cemented soils, but there are a number of limitations:

- the bi-fluid process is not recommended for applications in buildings or other sensitive structures because this method is very susceptible to lifting phenomena caused the huge viscosity of wastewater injection, whose free evacuation to the surface is frequently difficult. The imperfect evacuation of return slurry flow, makes it possible the development of over pressure in the ground, raising the risk of hydraulic claquage, particularly in soils consistent;

- the quality of in-situ treatment generally will be less satisfactory and less uniform in soils fine and consistent, if compared to an hypothetical treatment performed with the mono-fluid, and especially in comparison to tri-fluid. Consequently, the bi-fluid will be used in applications where it is possible to tolerate considerable variations in the quality of treatment;

- the application of bi-fluid is particularly tricky at depths exceeding 15 meters, which is due to the increasing difficulty of effectively evacuate the wastewater injection to the surface; This is a necessary condition to achieve a good qua-
ility treatment. If this doesn’t happen it can be generated claquages (horizontal fractures of the soil) which could cause serious structural damage to buildings, infrastructures, etc.

Figure 12: view of a worksite with all the equipment necessary to carry out the bi-fluid Jet Grouting method.

Compared with the mono-fluid method, a worksite for bi-fluid Jet Grouting needs a powerful air compressor and, of course, two sets of drilling rods for the simultaneous and separate flow of the two fluids necessary for grouting.

4.3. Tri-fluid.

The tri-fluid Jet Grouting method is the most advanced method available at present. In this process, one or more jets of water surrounded by compressed air are used to break up the soil in-situ while, simultaneously, a cement mixture is injected through one or more nozzles located near the lower end of the rods (fig. 14).

This method requires the use of rods with triple walls for passage, in separate conduits, of the three fluids needed for Jet Grouting. The tri-fluid method requires very high pressures of the pump and compressor:

- 500-600 bars for disintegration water;
- 350-400 bars for the cement mixture;
- 6-20 bars for the air

Separation of the stage of soil disintegration from that of injection and mixing with cement grout ensures better control of the resulting features of the treated soil, through regulation of the control parameters (flow, pressure, composition of the mixture, ascent speed, etc.) for the two independently operating sequences. It is generally observed that the tri-fluid method makes the most significant soil replacements in situ, compared to the other methods described above.

Figure 13: columns produced with the tri-fluid method.

Figure 14: cross section view of ball housing, and circulation of fluids in the rod.
The tri-fluid method is the most flexible Jet grouting technique:

- it applies to all types of soil, including cemented and plastic clay soil;
- the results are excellent even at great depths (some applications over 100 meters);
- it ensures uniform treatment;
- it can be used in the vicinity of buildings and sensitive structures, because it is not particularly susceptible to lifting actions due to the continued dilution of return flow by disintegration water, facilitating the free evacuation of the return flow to the surface;
- large columns (over 4 meters) can be obtained, even in compact soil;
- in the same types of soils, the tri-fluid method is more economical of cement than the mono-and bi-fluid methods, due to the separate control which can be kept during disintegration and mixing with cement grout.

Figure 15 shows a diagram of a typical worksite with all the equipment necessary for tri-fluid Jet Grouting.

A few significant elements differentiate it from a worksite for mono- or bi-fluid Jet Grouting:

- the pumps must ensure the supply of cement mix (the same as for the mono- and bi-fluid methods) and simultaneously supply the water needed for the disintegration of the soil;
- the injection rods and drill rig are specially made for tri-fluid Jet Grouting (triple wall rods, head of the drill rig)
- the data recording systems for drilling and injection are more complex because they have to analyze multiple parameters.
4.4. A special application: Clou-Jet

Introduction.

The technique of soil consolidation by passive anchorage (“soil nailing”), is used to temporarily and permanently stabilize natural and artificial slopes, applying a fundamental principle in the field of geotechnical construction: mobilizing the intrinsic mechanical properties of the soil, such as cohesion and internal friction angle, so that the soil itself cooperates actively in the work of stabilization.

Developed between the Fifties and Sixties for use with hard, compact rock, the technique of soil nailing is now used on a wide range of soil, after the development of significant theoretical and technological innovations, including granular types, alluvial soils and more compact clay and marl. At the European level, the field of operations in which the technique is applied with success is expanding and can be applied for the containment of embankments and trenches, roadbeds, earth dams, riverbanks, the foundations of adjacent buildings and tunnels piers. Here below we shall illustrate operating procedures, benefits and applications of a particular technique of consolidation by means of the passive anchorage known as “Clou-Jet”.

Clou-Jet Technology:

Equipment and operating procedures.

Clou Jet technology, developed and marketed by C. Louis Ing. in Paris and by Pacchiosi Drill SpA company in Parma, Italy, consists of special types of anchors equipped with high-speed injection devices (Jet grouting), capable of producing large diameter bulbs of cement mortar. In this way, the blockage of anchors in the soil, and consequent improvement of the geotechnical characteristics are assured. High-pressure injection during drilling also helps the nail to penetrate by the gradual disintegration of the soil. The Clou-Jet technique enables the process of excavation and soil nailing to proceed in sequence, alternately (Fig. 16). After excavating to a depth that ensures the stability of the wall excavated, a row of Clou-jet nails is immediately inserted: the active forces generated in the volume of soil behind the surface of excavation are thus immediately counter-balanced. After this second step, the surface of excavation is coated with reinforced spritz-beton on a double-layer of wire mesh.

This creates a retaining layer about 20 cm thick which serves, by applying a light stabilizing pressure on the wall, to protect it temporarily from exogenous agents, as well as:

- To reinforce the action of the nails, ensuring stability between two rows of nails;
- To contain surface drainage created by draining textiles placed at the wall-soil interface parallel to the surface of soil excavation. Drainage is an integral part of the Clou-Jet method because the hydraulic system, considering the type of interstitial pressure normally applied to fracture areas, directly affects the characteristics of the system.

The water drained off, either through the textiles or through pipes sunk into the ground at a certain angle, flows to the foot of the slope where it is collected by a pipe parallel to the direction of the wall. The excavation thus progresses by separate steps or cycles, beginning with the excavation of a section of wall and ending with its complete stabilization. The originality of the technique is that the retaining wall and the nails are put in place immediately in the early stages of working, with a geometry of the wall (thickness, length, angle and density of nails) suitable to the final stage of the operation, so that the complete stability of the slope is ensured at all times.

The combined action of progressive excavation and placing of nails, anchored to the soil instantly by high pressure injection, minimizes turbulence so as to exploit the mechanical characteristics of the soil to the utmost. The gradual development of active lateral forces consequent to the increased vertical tension (\( \sigma_v \)), due to the weight of the soil is immediately balanced and then maintained within predetermined safety levels by the Clou-Jet nails, subject to tensile stress depending on the needs of the soil, so that they prevent accentuated decompression phenomena and consequent sliding along potential breakage surfaces. This tensile stress is transmitted from the ground to the nail through the bulb of cement mortar consolidated around it.

Benefits of the technology.

In loose soil, stabilized by the nailing technique, potential slides occur at soil-cement contact; for this reason, the less shearing resistance the soil has, the greater the outer surface of the bulb must be, especially in case of plastic soils. Clou-Jet technique, by means of the injection of cement at very high pressure, can involve considerable amounts of soil in order to produce large diameter bulbs of cement mortar; this ensures their ex-
cellent resistance to extraction (T) in comparison with resistance values obtained with traditional injection techniques.

Compared to traditional nailing methods, requiring time-consuming procedures and cumbersome equipment for the various phases (construction of the connecting rods, pouring reinforced concrete and filling behind the wall, with high risks of instability), the Clou Jet technique inserts the nails early in the process and therefore speeds up the whole project, as the duration of excavation depends on the time needed for stabilization of each step. The height of the excavation step, of course, depends on the type of soil: the better its mechanical properties, the higher the step can be.

It is clear that this technique is particularly advantageous in the case of loose, incoherent soil in which, because of the great instability, excavation is particularly problematic. Since the technique uses easily mobile machinery of reduced size and weight, it can be applied in those cases where other methods of consolidation cannot be used, such as cutting a slope whose top is not accessible to heavy equipment, stabilization of slopes with very irregular development of the elevation due to the presence of houses or vegetation, anchoring of underpinnings and wall supports in adjacent buildings. In addition, the teams engaged in excavation, placing of nails and casting of spritz-beton, work independently of each other, which also helps to increase productivity and save time.

In case of permanent works or in places where the esthetic factor is very important, the Clou-Jet technique provides various kinds of covering that completely hide the nails and allow the work to integrate, through appropriate architectural solutions, with the vegetation and rocks in the surrounding area. The technology offers a wide range of solutions for the design and construction of wall coverings, based largely on the use of precast reinforced concrete panels. The shape and size of the panels, the types of plants and natural or artificial materials that can be combined and associated, can vary to satisfy the most appropriate architectural solution for every type of job.

**Project scaling.**

A study of consolidation projects using Clou-Jet technology is based on ascertaining three conditions of stability (fig.17):

- **a.** the stability of the total volume of soil to be reinforced, viewed as a rigid parallelepiped structure; we have to analyze the risks of sliding related to the stresses and risks of side tilting due to the weight of the volume itself, according to the theory of earth pressure;

- **b.** the internal stability of the volume in which the nails are fixed; they should prevent the development of sliding surfaces represented by internal critical circles associated with specific safety factors: the length and density of the nails are functions of the results of this inspection;

- **c.** the overall stability of the volume of soil against potential slip surfaces outside the reinforced volume. The data for internal stability of reinforced volume analysis (fig.18), in order to determine the internal sliding surfaces are:
  - height and inclination of the wall;
  - number of excavation steps;
  - geotechnical characteristics of the soil;
  - position of the nails;
  - length, inclination and intrinsic properties of metal nails.

The graphic representation of results obtained with Tairen program, based on the Bishop calculation method, is shown in fig.18: the length of the nails (beyond the potential sliding surface), the tensile strength and resistance to shearing which can be mobilized in the soil by the nails, the radius of sliding circles and the location of their centers, the safety factors for each circle (calculated by considering the mass of soil without nails, the mass of soil with overload and without nails, and the soil with overload and Clou-Jet nails).

![Figure 17](image-url)
Figure 18: Analysis of stability

\[ T = \text{tensile strength mobilized by the nail} (= \sigma_e \times \text{nail section}) \text{ function of } L_u \]

\[ L_u = \text{effective length of the nail, beyond sliding surface} \]

\[ \alpha = \text{inclination of nail} \]

\[ h = \text{height of an excavation step} \]

\[ Q = \text{load of the mass of soil} \]

The final project is carried out on the basis of the results relative to the critical area corresponding to the lowest safety factor.
OPERATING PROCEDURES
5. Operating Procedures.

A program of quality control, appropriate for the project objectives, is a key element for successful organization of a Jet Grouting worksite. (Cicognani & Garassino, 1989; Pacchiosi, 1998; Tornaghi, 1993).

The program includes the following points:

- each Jet Grouting project must provide for the execution of a field test, before starting the effective works, during which the proper procedures are tested;
- it is normal, during the tests, to produce several columns, by varying the different injection parameters including, particularly, the ascent speed, to determine its influence on the diameter of the column obtained;
- if possible, test columns must be excavated and visually inspected and measured in diameter; if this is impossible due to extreme depth, for example, the verification is conducted by means of core samplings and, in some cases, permeability tests (Lugeon and/or Lefranc) are performed and a camera may be placed directly inside the core sample hole for a monitor view;
- laboratory tests on samples taken from field test columns enable us to determine the mechanical characteristics (compressive strength, elasticity modulus, etc.), and the permeability characteristics of in-situ treatments, to verify their compliance with the project specifications.
- a normal control during production consists of verifying the correctness of the cement mixture used for injection (density, viscosity, etc.);
- for some projects, where the uniformity of the Jet Grouting treatment is an important requirement for correct performance of the works, the verticality of drilled holes is systematically controlled; some companies have developed inclinometers that can be inserted directly into the rods, after drilling, to measure the deviation before injection; other inclinometric systems can be mounted directly at the bottom of drill rig, but the reading of the data, at present, requires the extraction of the rods, causing losses of time and adding to costs;
- the methods of verification of Jet Grouting works will be essentially the same as those used for the field test, but applied generally and with lower frequency;
- for some applications, we can perform further checks (pumping tests, horizontal or sub-horizontal control holes, etc.);
- the use of real time systems to record the main drilling and injection parameters (depth, pressure, delivery, ascent speed, etc.), has become standard practice for all qualified firms that execute Jet Grouting; these systems produce detailed reports, which describe the performance of each column, greatly facilitating the continuation of working and providing efficient control of the correct performance of injections, according to the parameters defined in the study of the results obtained in field test (see fig. 19, 20 and 21).

The parameters recorded during drilling are shown in blue, for example:

- Drilling Rate: the speed of the rods is inversely proportionate to the consistency of the soil;
- Rotary Speed: it depends mainly on the type of tool used for drilling;
- Tool Pressure: it is the pressure applied on the tool and is directly proportional to the consistency of the soil;
- Rotary Pressure: it indicates the force necessary to turn to the rod battery during drilling;
- Drilling Fluid Pressure;
- Drilling Fluid Rate.

In the graph, the red line represents the progress in relation to the time. The angle of line inclination of the red line indicates increased consistency of the soil.

![Figure 19. Graph of drilling procedure: the red line shows the progress in relation to the time.](image-url)
Figure 20 illustrates charts related to the injection parameters (trifluid method):

- Water Pressure;
- Water Flow Rate;
- Slurry Density: this is calculated automatically at the pumping station by an electronic system installed directly on the mixer;
- Slurry Pressure;
- Slurry Flow Rate;
- Air Pressure.

Figure 20. Injection Graph: the red line indicates the ascent in relation to time.

Figure 21 illustrates graphs of other parameters measurable during injection, such as:

- Air Flow Rate;
- Rotary Speed.

Figure 21. Injection Graph (Continued from fig. 20).

Recordings of drilling and injection parameters are used by companies that perform Jet Grouting to control the proper performance of the work. In case of imperfections shown during the monitoring phase, or better, already during the injection stage, with the support of these graphs it is possible to trace the cause and take the necessary steps to eliminate the problems.
CONCLUSIONS
Conclusions

We can draw the following conclusions from our analysis of the documents:

• The developments in Jet Grouting equipment and techniques (monofluid, bi-fluid, tri-fluid) provide engineers with innovative, refined, competitive solutions for many of the problems of civil engineering.

• The use of the various Jet Grouting technologies available can serve for consolidation and/or waterproofing of all types of soil and some types of soft rocks.

• The Jet Grouting methods are sufficiently flexible to allow them to prioritize resistance and/or permeability of treated soils, as needed.

• The technique makes it possible to predict, with good accuracy, the geometric and geotechnical characteristics obtainable in terms of columns of consolidated soil.

• The versatility of Jet Grouting and the rather small size of the equipment necessary for its performance make it possible to operate in areas with difficult access (cellars, urban contexts, etc.), with non-invasive methods, even through existing structures for conservation and/or restoration (underpinning).

• There are many fields of application, and including:
  • construction and restoration of deep foundations
  • stabilization of slopes
  • consolidation before excavation of tunnels in difficult soil
  • sealing of earth dams and/or dikes
  • realization of bulbs for high-capacity anchors
  • execution of bottom plugs between concrete diaphragm walls for the construction of underground metro lines and/or the excavation of shafts below the water table
  • massive consolidations to prevent differential and/or delayed settlement
  • pre-consolidation to protect excavations near buildings for the construction of subways, underground parking lots, etc.
  • protection against erosion for the piers of bridges in riverbeds.

Current research, development and testing make it possible to predict which areas of application of the Jet Grouting methodology will expand in the future. For example, the development of more powerful pumps (initially 200-300 Hp currently Hp 800-1000), the continuous improvement of rod batteries, heads and injection nozzles (decrease of pressure drop with increased performance), will reduce time and costs of the work while maintaining the same high quality of the final product.

Finally, we can conclude that the Jet grouting method, 50 years after its first application, thanks to a good initial idea and all the subsequent experimentation and testing, is a constantly evolving technology that is innovative, flexible and competitive (from a costs/benefits viewpoint), now used successfully throughout the world.
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