GeoDrilling International

ESTABLISHED 1993

Geotechnical construction

The versatile jet-grouting method of ground improvement is widely used in the construction industry. *GDI* covers the basics

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A new task force is examining the UK ground-investigation industry. What can be done to improve the sector?

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TERRIER *Mk.2*

ISSN 0969-3769

June 2016 www.geodrillinginternational.com

The jet set

The construction industry has over the years introduced various methods for improving soil conditions and reinforcing foundations. Among these, jet grouting is nowadays in use worldwide. *GDI* looks into its applications, variations and recent innovations

Jet grouting, also known as high-pressure grouting, is an advanced construction method used for the strengthening of foundations. It involves the disaggregating of soil, and mixing it with cement admixtures by means of high-pressure jets.

Essentially, the high kinetic energy jet of fluid first loosens the ground and then mixes it with the cement slurry. It is known as a hydrodynamic mix-in-place technique that produces a soil-cement material, commonly referred to as jet crete.

Russell Deller, general manager of Mainmark New Zealand, goes into further detail: "Jet grouting uses high-pressure, high-velocity jets located in a grout monitor, which is attached to a drill stem. This is inserted to the project's required depth. As the grout monitor is withdrawn from the ground, it rotates to simultaneously water-jet and slurry-jet the ground."

Bauer Spezialtiefbau's Ulli Wiedenmann adds: "The soil is cut by the jet into thin spiral-like discs and by continuously turning and retracting the drill rods, a 'hollow' body is formed that is filled with cement suspension. This mixture hardens due to the cement, forming a jet-grout column, which can transfer loads."

The Soilmec SR-45 can use Turbojet technology, which relies on a tool combining jet grouting with mechanical mixing

The first jet-grouting contract in Germany, recounts Wiedenmann, was carried out at the end of the seventies. In 1983, Bauer performed underpinning by jet grouting for the first time in Munich and, since then, has gained extensive experience on numerous projects.

"By developing and improving the process in-house, it has progressively become a more controllable and more economical technique," he notes.

One of the key advantages of the technology is being able to use relatively small-diameter drilling rods to make the borehole in order to produce a much bigger consolidated composite mass in the ground.

Over the years, jet-grouting techniques have been used in a wide range of soils. "This is due to the capability of obtaining columns of consolidated soil with diameters ranging from 60cm to more than 200cm by using small-diameter drilled holes, in general not larger than 100-140mm," says Soilmec's Federico Pagliacci.

"With some imagination there seems to be almost no limit to the application of this technology," comments Wiedenmann.

Ground-engineering company Mainmark confirms that it has successfully used jet grouting beneath large multi-storey schools, apartment blocks and government buildings.

"Jet grouting is particularly effective for addressing ground-engineering challenges related to soil instability, liquefaction, large-scale structural support beneath existing structures and adjacent future excavation," Deller explains.

"When compared with traditional piling techniques, jet grouting is quick, clean and causes minimal disruption. The method leaves no mess as cement slurry is delivered by pipe from a mixing unit outside the building. Excess water and slurry extracted from the ground are automatically drawn off in large-diameter hoses and delivered directly to waste-disposal skips."

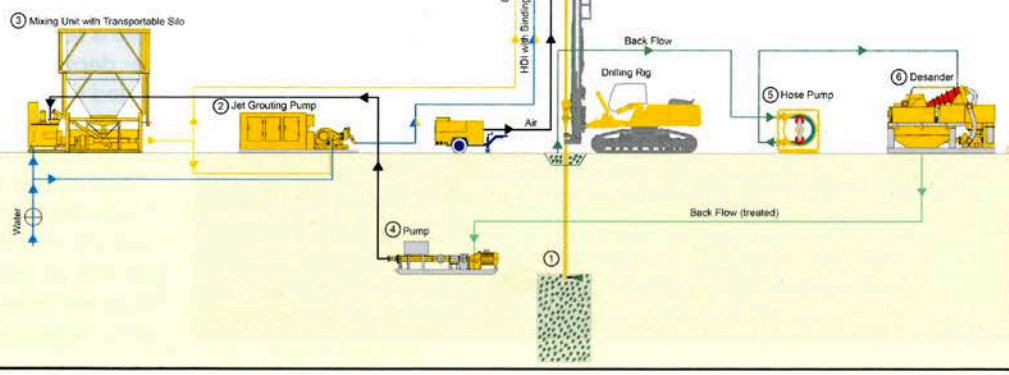
The drilling rigs used for jet grouting are typically lightweight and small; similar or the same machines can often also be used for micropile applications.

Bauer says its universal base carriers can be converted for most specialist foundation-construction techniques, including

Main applications

- Underpinning
- Base slabs as horizontal cut-offs
- Vertical cut-off walls
- Ground improvement
- Fissure grouting
- Gap grouting
- Protective hoods for tunnel drives
- Deep foundations

"When compared with traditional piling techniques, jet grouting is quick, clean and causes minimal disruption"



Jet-grouting equipment set-up

Main image: jet grouting was used below a cutter-soil-mixing wall to cut off possible seepage between the open-pit mine and its surrounding lake at Diavik diamond mine in Canada
Photo: Bauer

Inset: Mainmark's all-in-one jet-grout unit

jet grouting, and Klemm Bohrtechnik's compact rigs are also suitable for the application.

Mainmark, in turn, uses all-in-one jet grout units, which comprise a drill/jet head, power pack and controls. These are also lightweight (at between 100kg and 4,500kg) and can be managed in and out of limited-headroom environments.

"We also use a proprietary drill/jetting string adaptor to control artesian and high-water-table issues. The adaptor is bolted in place on the surface of the floor immediately after the drill has penetrated the ground, and balances the water head through a series of valves and pipes," says Deller. "Because each piece of equipment is an individual component, it can be placed in convenient locations determined by the site requirements."

360° 3-D view created with Bauer's ABG software for high-level quality control and assurance

METHODOLOGY

Jet-grouting techniques are often classified into three categories based on the number of injected fluids: a mono-fluid system, where cement grout is used as disaggregating and consolidating fluid; a bi-fluid system, where grout plus air are used as disaggregating and consolidating fluid; and a triple-fluid system, where water plus air are used as disaggregating fluid while grout is used as consolidating fluid.

Pagliacci explains: "All three methods are executed by drilling the soil and by mixing it during the extraction phase. For the mono-fluid system, a rotation and roto-percussion drilling system can be adopted by using the same jetting rods; the self-drilling monitor (the deeper string element) can be equipped with one or more jetting nozzles.

"For the bi-fluid system, nozzles are designed to allow an air-jet to create an 'envelope' around the grout jet. This allows the jet to reach a greater distance from the drilling axis than the mono-fluid system, i.e. a larger column diameter. A rotation and roto-percussion drilling system can be adopted by using the same jetting rods.

"For the triple-fluid system, rotary drilling systems can be adopted by using the same jetting rods; in case of difficult soils, drilling operations have to be performed with an auxiliary roto-percussion drilling string."

The choice of the method largely depends on the expected column diameter and prevailing soil conditions. According to Pagliacci, in coarse granular soils, bi-fluid and triple-fluid are preferred because of the use of air. The air helps in transporting the finer portion of the soil to the surface, with the spoil; the larger portion of the soil remains in-situ, and combined with the cement-based grout allows for higher resistance of the consolidated soil. In cohesive soil, the mono-fluid is the most-used technique.

Beside the basic rules on how to select the most suitable jet-grouting methodology, there are many details to be considered in jet grouting to avoid undesirable impacts on the ground during execution.

"On one hand, there is the constant high-energy jet stream to be applied; on the other hand, there is soil with varying resistance over depth, which should be eroded continuously to form a homogenous smooth column," says Wiedenmann.

"And exactly at that point a lot of experience and knowhow are required, enabling the experts to play with jet-grouting pressure, nozzle diameter, water-cement ratios, rounds per minute of the

Additional equipment

Bauer lists the additional equipment it uses for jet grouting:

- **Jet-grouting drill rods**
Depending on the jet-grouting application, different drill rods with diameters from 88.9mm to 133mm are available.

- **High-pressure jetting pump**
The high-pressure jetting pump has been specially tailored for the requirements of Bauer jet-grouting plant.

- **Mixing plant**
Bauer Maschinen subsidiary MAT Mischanlagentechnik supplies compact injection plant units for colloidal mixing and injection of suspensions for a range of applications.

- **Grout pump (eccentric screw pump)**
MAT's eccentric screw pumps are suited for the injection of cement suspension in the two- and three-phase processes with water jetting.

- **Backflow pump (hose pump)**
The backflow of excess water-soil-mixture resulting from the jet-grouting process can be removed by MAT's robust hose pump.

- **Desanding plants**
The range of Bauer's compact desanding plants facilitates the efficient separation of the backflow into its constituent parts, making partial recycling of cement suspension possible.

jetting rods, withdrawal time, etc. to create the desired jet-grouting product."

INNOVATIVE SOLUTIONS

Soilmec's Pagliacci says the company's research-and-development efforts in the last year have been focused on increasing the jetting efficiency by reducing energy losses when the fluid has to be diverted from the vertical direction inside the rods to the horizontal one through the nozzle.

Mainmark claims it is at the cutting-edge of lightweight jet-grouting technology. Its smallest machine weighs just 100kg and can produce a column that is 3.5m in diameter.

The company also offers JOG computer-controlled grouting, which uses computer-controlled equipment for multi-point, cementitious levelling of large and complex structures, such as multi-storey residential and commercial buildings. This method allows for level correction without the use of hydraulic jacks and temporary lifting platforms.

It also uses a proprietary high-pressure, low-volume grout pump controlled by a computer program that circulates cementitious grout to up to 128 injection points. The grout is circulated to each injection point in the quantity required at the moment it is required, raising the structure evenly and gradually without any undue stress on the building or equipment, Deller says.

In addition to many ongoing developments, Bauer, in turn, has established its 'As Built Generator' (ABG) as the quality-control and quality-assurance tool within its regular jetting process. Wiedenmann explains that difficult geometries, overlapping column structures as well as sequences can be shown online on demand, enabling the engineers to evaluate possible quality or sequencing issues.

Grout requirements

In general, only two materials are used to construct the jet-grouting columns: water and bonding agent (mostly cement). The mixture with locally available material has to meet the following requirements:

- Compressive strength < 1 to 15 MN/m²
- Density > 1 x 10^{-8}
- Stability against erosion
- Workability

The material consumption is influenced by the above-mentioned parameters. The dosage of the mixture is constantly controlled at the mixing plant.

In specific cases, the compatibility of the grout with the actual soil or groundwater is tested in advance in a laboratory. The achieved compressive strength of the jet-grouting body is tested on samples of the backflow or on undisturbed core samples recovered from the jet-grouting body.

"Jet grouting is an ever-evolving technology, with the depth, diameter and strength of columns being continuously challenged by the development of smaller machinery to deliver better and faster results," Deller concludes.