JETGROUTING FOR FOUNDATION REINFORCEMENT - A STEP TOWARD A MORE SUSTAINABLE SOLUTION

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ABSTRACT

Jet grouting (JG) is a well-known and often used geotechnical technique suitable for various applications, such as underpinnings and foundation reinforcement. The downsides are its comparatively high CO2 footprint, caused by the high amount of cement used, and accumulating waste, i.e., backflow slurry. The former, cement, is recognized for its CO2 emission potential and we are seeing new binders being introduced as surrogates, a process driven by the cement industry. The latter, spoil, must be taken care of on site. Here, the use of centrifuges is a promising approach to reduce waste. Centrifuges offer a high throughput in relation to space requirements when compared with other systems, e.g., chamber filter presses (CFP). This paper presents exemplary projects which used jet grouting for foundation reinforcement. For our analysis we are using data from a construction site that worked both with and without a centrifuge during different stages of its production time. This allowed a more precise analysis than comparing two different sites. Using the calculated CO2 footprint and other parameters, the operation of the centrifuge is evaluated regarding its environmental and economic impact.

Keywords: jet grouting, foundation strengthening, spoil, dewatering, recycling

JET GROUTING IN URBAN AREAS

Space is a scarce good. This is especially true in urban areas like Vienna. Other communities are still able to use virgin lands to satisfy the need for building sites, but here construction tends to go either higher up or add basement floors. Combined with more demanding legislation on monument conservation, we see an increasing demand for the reuse and strengthening of existing foundations.

For strengthening of existing foundations, jet grouting is of particular interest. In principle, a rod is drilled down into the subsoil until it reaches the defined lower boundary of the element to be installed. During the slow, rotating retraction of the drill stem, a perpendicular emerging, high velocity, grout jet of up to 400 bar pressure erodes and mixes the *in-situ* soil with grout. As this grout contains some sort of binder it hardens over time. This way load bearing elements can be installed directly below already existing footings. For an in-depth description see, for example, Croce et al. (2014). For examples of applied research, with the aim on optimization and quality control see among others Kummerer et al. (2016).

A drawback of this technique is the quantity of spoil inherently caused during the production. The treatment of this spoil is space and time-consuming. And as landfill volumes become scarce too, the costs are increasing rapidly.

DESIGN AND PREREQUISITIES

Design

The external bearing capacity of jet grouting elements used for foundation strengthening can be calculated according to EN 1997-1-3, which covers bored piles. This way, it is possible to use the tabled values for skin friction and base resistance, as well as the safety factors found therein, allowing a comparatively easy dimensioning.

Regarding the internal bearing capacity, EN 12716 is the valid standard. Here, an admissible compressive strength, across the horizontal cross section of the jet grouting body, is assumed and verified during execution. Note, however, that annex A, which gives the formula for the calculation of JG-compressive strength, is only informative. Depending on the soil in place, characteristic uniaxial compressive strengths of up to 10MPa can be achieved.

Special emphasis must be put on the contact surface between jet grouting elements and foundations. As older buildings and foundations often consist of masonry, its structural condition must be assessed. The admissible compressive stress, i.e., design resistance, is an important factor for the strengthening design. It influences the distance between neighboring elements as well as the required column diameter. It often turns out to be the limiting factor of such a design.

Space requirements

Jet grouting is executed using comparatively small machines. Openings of 80 cm are sufficient to operate inside of existing buildings. The required minimum height of 2.80 m can also be guaranteed in most cases. One specialty of jet grouting is the need of an overburden of roughly 50 cm. In some cases, e.g., very shallow foundations, this might require an additional embankment.

Soil conditions / contaminations

Soil parameters govern all aspects of jet grouting. However, experts usually only consider the mechanical and strength parameters. Often neglected, but equally important, is the chemical condition of the soil. All aggressive substances or contaminants which have a negative impact on the strength and durability of cement and concrete according to EN 207, are equally applicable to jet grouting bodies. The fact that during the jet grouting process these substances – if present – are mixed into the element causes additional problems. Sugars, acids, oils, and fats are all known to retard or inhibit cement stiffening (Aitcin and Flatt, 2016). Water-rich organic soils might also increase the water content up to a level where hardening is delayed. Fine-grained soils, especially clays, can necessitate precutting. All these factors might lead to logistical or time problems, if not halting the site. These soil conditions also influence the quality of the spoil, as often a classification as “excavated soil” is required by local rendering plants.

At this point it must be noted that jet grouting can be used as a means of remediation for heavily contaminated soils. But such an application differs strongly in logistical and legal requirements (Freitag and Reichenauer, 2022).

Spoil and waste

The root cause for spoil is the volume consistency of soil. It varies by soil type, but generally one can assume that volumes of neat grout and spoil (backflow) are equal. The composition as well as the amount is defined by the site-specific subsoil, pore volume being an important parameter. Washed out soil compounds can constitute up to 90% of the spoil (Lesnik, 2003). In order to process, i.e., pump, the backwash, it is often necessary to water it down. This leads to an increasing amount of spoil in liquid form.

Normally this liquid waste is stored in large lagoons until it has solidified, can be excavated, and transported to a landfill site. This of course is only possible if space limitations are of no concern. In Vienna, especially in its inner districts, this is not possible. Here the spoil must be transported from site in a liquid state, using vacuum trucks and has to be prepared for deposition off-site.

Based on all the conditions listed above the authors would like to present two sites from Vienna. The first being a typical example of the strengthening and reuse of an existing foundation. The second covers a relatively new approach to the topic of spoil and waste management. The site "Z" saw the employment of a new automatic separation plant.

A TYPICAL EXAMPLE: THE SITE "S"

Additional load due to overbuilding or usage change of a building is often the reason for foundation strengthening. At the site "S", the possibilities to construct a new building were restricted by the presence of a small, landmarked historical building (Fig. 1). As demolition was not an option, the decision was made to include it in the overall concept, overbuild it, and only change the internal design. The load caused by the new superstructure required a strengthening of existing foundations (Fig. 2).

Soil conditions encountered on site were typical for Vienna. Under around 2.00m of anthropogenic filling, coarse grained material, lies atop the "Wiener Tegel" which is a stiff clay. The Tegel was not reached on this site. The coarse materials are sands ("Deckschichten") and medium dense to dense fluvial gravels, deposited by the river Danube. The site investigation consisted of dynamic probing and trenches.

Fig. 1. The historical building to be overbuilt

All external walls had to be strengthened. All elements had a defined minimum length to reach layers with sufficient bearing capacity. Due to inclined drilling axes, because of existing walls, a utilization of 45% of column cross section in the contact surface to the strip foundation was considered. The inclined drilling axis is required because of existing walls. Characteristic loads reached 1600kN per element. As an additional positive side effect, the foundation loads were not acting as a horizontal force on the neighboring retaining structure consisting of drilled piles.

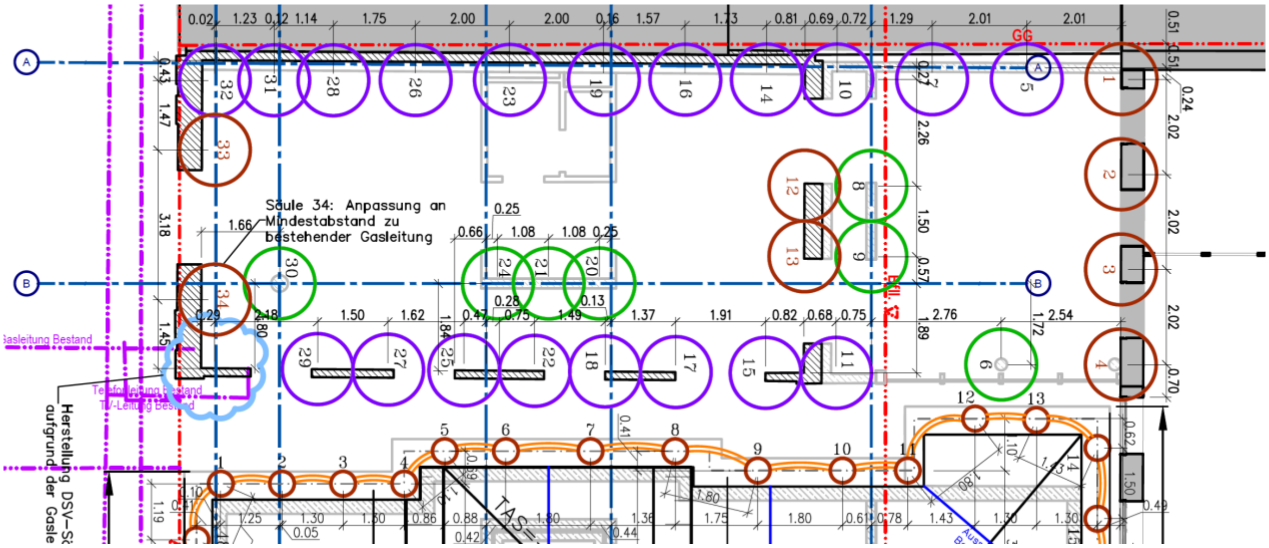

Fig. 2. Plan view (ground floor) of the reinforcement works. Green, brown, and purple circles depict JG columns. The actual strip foundation is not shown.

Noteworthy are high concentrations of sulphate in other parts of the site, which might have caused difficulties during the jet grouting works. The spoil was handled in liquid form.

DEWATERING: SITE "Z"

A wide range of dewatering techniques are available commercially. Various plants are in use, chosen site-specifically and based on expected spoil volumes and available space. For example, chamber filter presses are a good choice if space is not the limiting factor. CFPs can cope with large amounts of slurry but require large excavators for handling accumulating solids. In built-up areas this is not feasible. Centrifuges as a compromise between size and throughput are the method of choice.

Decanter

Decanters are a special type of centrifuges where the separation takes place inside a bowl. Fig. 3 shows the cross section of a system during operation. Centrifugal forces acting on the loaded slurry lead to the collection of solids at the wall of this bowl. A screw conveyor rotating inside the bowl then transports them inside the cylindrical part toward the conical end of the bowl. There they leave the decanter. The clarified water leaves through a pairing disc at the other end.

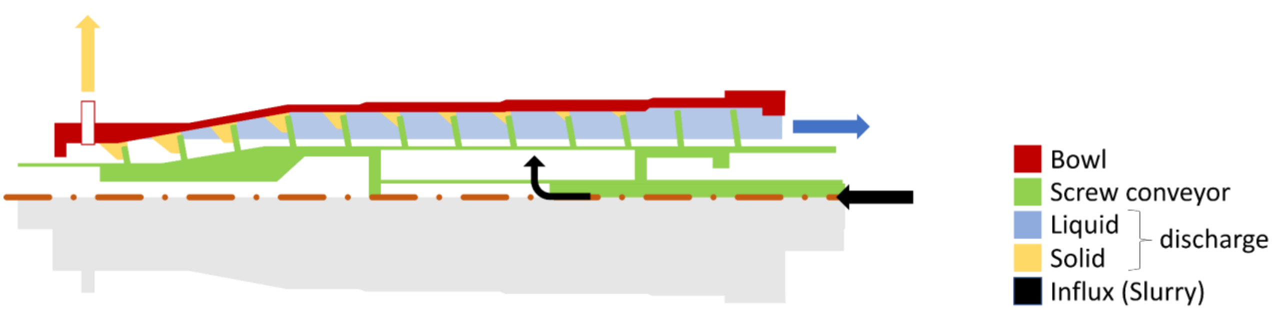

Fig. 3. Decanter schematic, upper half cut away along symmetry/rotation axis

The rotating speed of the drum and the differential speed between screw conveyor and bowl are two important system parameters used for the regulation of the system. A decanter can reach acceleration levels of up to 4000g at rotation speeds of up to 2600rpm.

Automatic separation plant

The automatic separation plant used on the site is based on a decanter as described above. The whole plant consists of three 20' containers (Fig. 4). A shale shaker is situated on top of the first and utilized to separate all particles larger than the silt fraction. The container itself is a 22m³ storage and agitator tank. It is required to guarantee a continuous influx to the decanter, and it also homogenizes the slurry to a degree.

The next container includes all the equipment needed to treat the slurry in such a way that the decanter can work at optimum levels. First iron-III-chloride or iron-III-sulphate is used as a flocculation agent. Further addition of sulphuric acid helps to bring down the pH value to approx. 8-10, where polymers, used as coagulation aids, work best. The polymers station can handle liquid as well as solid polymers.

The decanter is the only system component that is installed in the third container. The solid discharge is collected and transported outside via a conveyor, either directly into troughs, or free falling to form heaps. The decision on the suiting method is based on available space.

The plant can cope with 150m³ backwash slurry in an 8-hour shift. This throughput can be reached even with varying density of the backwash.

Fig. 4. Site installation at site "Z", from right to left: storage tank with shale shaker, decanter (open doors) over slurry conditioning. The blue basins are used for final pH regulation

The liquid discharge can be recycled and used for drilling or disposed into the sewage system. For the latter it often must be treated to reach legally permitted levels of pH and electric conductivity. In Austria this step is further complicated by legal responsibilities being divided between the federal level and the state level.

At “Z” the Austrian Ministry of Education, Science and Research is expanding one of Vienna's schools and is erecting an adjoining new gym, close to other existing buildings. The excavation support consists of bored piles with jet grouted water sealing between the piles. Inside the existing school JG is used to enable the construction of a staircase. For that, long columns have to be installed, leading to a considerable amount of spoil during a single shift. Soil conditions were similar to that at site “S”, but this time the Tegel was also reached, necessitating precutting in this layer. Again, the site was investigated using trenches and dynamic probing, but this time core drillings were also done. Soil parameters, which are typical for Vienna can be found in Table 1.

Table 1 (Viennese) Soil parameters

Layer	γ [kN/m³]	γ’ [kn/m³]	φ [°]	c | kN/m²	E_s [MN/m²]
Anthropogenic filling	Not parameters assigned, normally excavated,				
Sands	18	9	25	0	
Gravels	22	13	35	0	50-70
“Tegel”	20	10	20	15	30

As can be seen in Fig. 5, space was very limited. Two drilling rigs were working on the site. Reinforcement cages had to be readily available, so due to their required storage areas, no place was available for spoil lagoons.

A plan was devised to introduce a new dewatering plant at this site. As the sited started later than originally planned, the plant had been used on a site in Vorarlberg before. A week of delay in Vorarlberg lead to the necessity of handling the backwash in its liquid form, allowing a comparison with the dewatering plant working later. On the commercial side, the project was successful, because, after starting operation on site, a decrease in costs and an increase in production could be observed. The first can be explained by removal cost alone. The second is due to the independence from vacuum trucks. On the technical side it was equally successful, as the plant could cope with the most unfavorable production conditions, i.e., long columns in connection precutting. The only question left to address was that of sustainability, i.e., environmental impact.

Fig. 5. Birds eye view of the site. Plant is located to the right (compare Fig. 4).

Calculation of CO2 emissions

To get an understanding of the environmental impact of the new plant, the CO2 equivalents evolving during its operation were calculated. In principle this is straightforward, as the consumption of energy or materials must only be multiplied with an emission factor. In detail there are two challenges to face. First, the consumption on site can't always be attributed to a specific production step. For example, the electricity generated on site, using diesel, is used for various tools and tasks and can't be attributed to the decanter alone. The second challenge is to get emission factors. They were either taken from suppliers directly, available standardized values, or derived from publicly available information (Table 1). Unfortunately, not all suppliers had the CO2 footprint of their products readily available.

Table 2. Selected emission factors used and their origin.

Material	Emission factor	Source
Transport (lorries)	70 gCO2e/t/km	Reported by the Austrian federal environmental agency (UBA) (Loessl, 2022)
Polymers	341 kg CO2e/t	From the supplier, SEPAR Chemie
Wastewater	0.174 kg CO2/m³	Derived from Müller-Rechberger et al. (2022)
Diesel	3,134 kg CO2e/l	UBA, online calculator (UBA 2020)

For the comparison, an interconnection point was defined right after the bore hole. From here the handling of the slurry and related emissions were considered for further calculation and comparison.

For the conventional approach, only the transport of waste away from the site had to be taken into consideration. As waste generated during jet grouting is deemed to be chemically inactive, it causes no further gaseous emissions at the landfill site.

With the decanter we had to include power generation, required chemistry, and sewage and waste disposal among others. Figure 6 shows the distribution of the CO2e sources. It does not include the transport of equipment to the site. This would distort the results, as its impact depends on the duration of the site. As for solid waste transports shown in Fig. 6, the distance between construction and landfill sites is representative for Vienna.

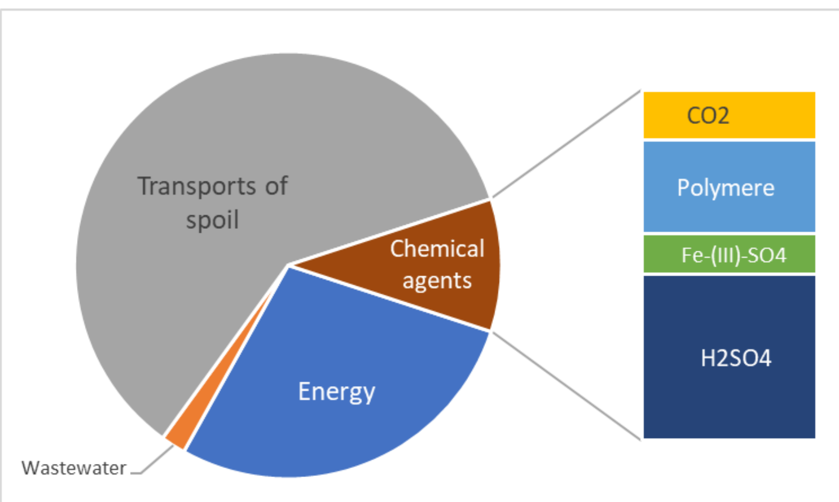

Fig. 6. Distribution of CO2 emissions for decanter operation.

Figure 7 shows the results of a comparison of four characteristic numbers for the site. It compares conventional treatment with the decanter operation. The distribution of sources for the latter is according to

Fig 6. Also added was an additional graph depicting decanter operations taking into account the transport of the equipment to the site. All values are related to 1 m³ of planned jet-grouting body.

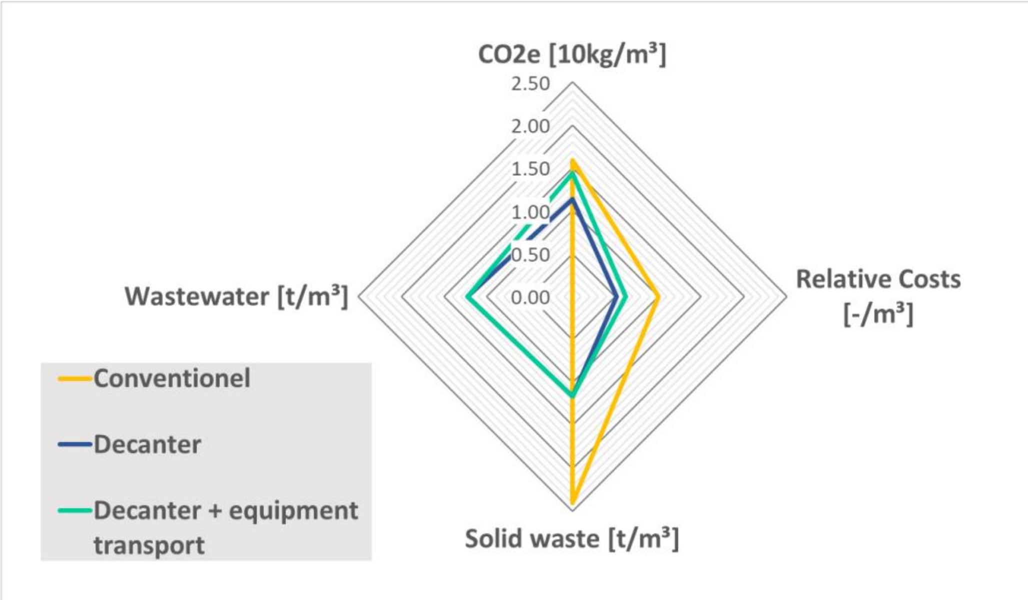

Fig. 7 Comparison of operation modes for spoil treatment

Overall, the employment at "Z" was a success. While not reducing the tonnage of waste accumulating at the site, the separation into solid compounds and wastewater is an improvement of the situation. Where liquid slurry can only be deposited, the wastewater generated by a separation plant can be treated in an existing wastewater treatment plant. The solids still must be deposited, but the amount is less, contributing to a relief of the situation in landfill sites. There are also some considerations of recycling slurry material (Li et al., 2021), some of them benefitting from separated, solid material.

In terms of CO2 balance, the improvement is not as significant as expected, but there is potential for improvement. First, the transport from Vorarlberg to Vienna is one of the longest possible in Austria. Second, the power generator worked with conventional fuel. Switching to biodiesel or electricity directly from the power the grid will lead to huge improvements there.

RESULTS AND CONCLUSION

The information presented in this paper gives some insights into a relatively new service that is now available on sites. Using jet grouting it is already possible to reinforce the foundations of existing structures to levels where they are able to take the load of additional floors. Now, the spoil can be treated in a way that handling liquid wastes is not necessary anymore and reducing required landfill site volume. All of this can be achieved with reduced costs and reduced CO2 emissions at this particular site.

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