# Application of Ground Improvement: Jet Grouting

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Application of Ground Improvement: Jet Grouting

1 Introduction

Ground improvement is becoming an increasingly common technique for solving a number of temporary and permanent problems in the field of civil engineering.

The aim of this document is to provide a basic understanding to the engineer such that:

i) There is a recognition when and how ground improvement can be applied*

ii) There is equally a knowledge of the limits and risks involved

The success of ground improvement is due to good design, appropriate techniques and most importantly experience and skill on site.

2 Application of Ground Improvement

The successful application of ground improvement requires both a correct design concept and also correct execution. It can therefore be regarded as a design and construct method. The use of the systems described below is intended to be taken as a guide, so it is important to recognise that some ground conditions may be complex leading to difficult solutions. Consultation with engineers experienced in the design and execution of jetgrouting is always recommended.

2.1 Jet Grouting

Jet grouting differs from permeation grouting in that the intent with the latter is not to disturb the fabric/structure of the soil whereas with the former this has to be the case for successful application.

Typical Uses

Because the product of jet grouting tends to be more structural in nature, it has a great range of application.

When installed beneath buildings it can extend foundations through poor ground or support them while excavations, often unsupported, are carried out next to them.

It can provide support underground where openings are necessary such as for TBM break out or break in or cross passages or equally to support tunnel faces. Because it does not rely on passage through the ground its product usually is more predictable and significantly less dependent on ground strength or composition.

It can provide ground water control at the base of excavation and prop retaining walls at the same time. It can truly be a multi-application tool dealing with support, groundwater control and increasing efficiency of site usage simultaneously.
Technique

Jet grouting consists of drilling down with a small diameter rod system, typically 90-130mm in diameter and then injecting a high pressure fluid while rotating and withdrawing the rod.

There are three basic systems available:-
(a) Single System
(b) Double system
(c) Triple System

The single system as the name implies, is the injection of grout only at high pressure. This was the first system to be used and gives limited column diameter and the borehole has a tendency to become blocked often resulting in ground heave. Column sizes are small usually up to 1m in diameter.

The double system is effectively the single system with the addition of an air shroud to the nozzle. The addition of the air shroud increases jetting efficiency dramatically giving typically 30% or more increase in diameter for the same jetting energy. This system is very common currently and a number of specialists operate similar systems of variable power. Typically column diameters being designed and used with the double system are now approaching 3m due to the advent of more powerful high pressure pumps.

There are other company specific systems. These are very versatile and powerful systems with column diameter capability of up to 4-5m in most soils.

The triple system differs from the single and double systems in that the erosion of the ground is carried out by a high pressure water jet shrouded with air with an additional low pressure grout line. The column diameters achieved with this system are greater than those of the single system but the energy is relatively low compared to the double systems. Columns are usually only up to 1.7m to 2m (in exceptional ground) in diameter. Some companies have recently increased the power of the triple system to match that of the double system giving diameter capabilities of 2-3m.

The Xjet system is unique in that it consists of a pair of intersecting air-shrouded water jets with separate grout jets and is designed to cut a nominal 2m diameter column in any ground. The figure below shows the concept.
It is most applicable in variable weak ground such as soft clays and peat where overcutting of the design diameter can be a problem.

The ranges of applications for the systems are similar and the selection is a site specific requirement. The single system is rarely used unless there are concerns about the air usage and loss of strength so the choice normally rests between the use of the double or triple system.

Generally the triple system can produce more spoil but is it usually less viscous and hence offers less risk for blockage and potential structural or ground movement.

Risk

Jet grouting historically has been considered as a risky ground improvement process due to the high pressures involved and the spoil generation. With good experience, site operatives, site control and proper design the system can be no risky than other processes.

The main risks associated with the process are the use of high pressures and the potential generation of movement. When jet grouting is carried out beneath buildings care must be taken to ensure that heave of the walls or floors is maintained within agreed limits. It is absolutely critical that the construction of the floors and walls can withstand the potential effect of jet grouting. Where floor construction is poor and non sealed then it is advisable to maintain a visual inspection and potentially monitoring during jet grouting. Wall movement during jet grouting can be controlled in the long term by precise levelling and in the short term by the use of rotating laser targets fixed to the wall.

Sequence is extremely important during underpinning operations as there is the possibility of loss of support if too large an area is jetted at the same time. Where structural foundation condition is poor i.e. poorly cemented masonry or brick then a pregrouting exercise using lancing or end of casing can be considered with the intent to reinforce the available bonding and reduce the risk of partial wall collapse into a freshly completed column. For underpinning work it is usual to restrict the jetting of adjacent columns to intervals of at least 12 hours. For isolated foundations, the sequence must be designed to prevent loss of support and in extreme cases temporary load transfer should be provided during the jet grouting operation.

There is usually excellent bonding between the foundation and the jet grout columns as subsequent adjacent columns always treat this zone and ensure perfect contact.

Careful attention to the location of any service or underground structure is needed as grout can end up in services, especially old sewers where the lining is not competent. It is essential to identify such services prior to grouting and consider the effects of the scheme on the service. In particular for sensitive services (i.e. gas or chemical pipelines) additional monitoring and control will be required. For grouting adjacent to tunnels, due consideration to the effects of the injection pressure needs to be taken especially in the case of segmental construction.
When jet grouting, care must be taken to control the spoil return as any blockages are detrimental and can cause ground movements if uncontrolled.

Health and Safety Issues

Apart from the H&S issues arising out of adopting this solution in situations where failure could impact on safety, the technique requires grout to be pumped at high pressure. Potential failure of grout hoses in this situation needs to be addressed as escaping grout can impact on a wide area and cause serious injuries through the high pressure fluid or whiplash of hoses.

Grouting close to underground structures needs careful consideration and any grouting carried out within 3-5m of any underground structure will require a specific risk assessment. Wherever possible, consultation with the original designer is advisable to understand the specifics of the ground improvement.

The use of jet grouting for remedial ground improvement for dams or other water retaining structures needs careful consideration due to the additional risk of spoil blockage and subsequent ground fracture creating leakage paths which could ultimately cause serious problems with the safety of the structure.

Design Considerations

Because of the ability of jet grouting to bond soil particles and create relatively strong bodies (UCS range 2-10Mpa), the design process is similar to the design of brick or masonry.

Strength of treated ground is usually assessed on the basis of unconfined compressive strength tests of samples obtained by in situ wet sampling or coring. The histograms shown in the Figure below demonstrate experimental unconfined compressive strengths in sandy and cohesive soils. The Japan Jet Grouting Association has adopted these distribution charts, defining the unconfined compressive strength used for design to be the minimum safe values which range between 1 to 5 percent from the least values in the whole group.

This definition gives the standard unconfined compressive strengths as follows (where the Water/Cement ratio of the grout is typically 1)
Table 1. Standard strengths in designing

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Qu: Unconfined Compressive strength (MN/m²)</th>
<th>C : Cohesive strength (MN/m²)</th>
<th>f : Bond strength (MN/m²)</th>
<th>σ₁ : Bending tensile strength (MN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cohesive</td>
<td>1</td>
<td>0.3</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Granular</td>
<td>1-3</td>
<td>0.2-0.5*</td>
<td>1/3C</td>
<td>2/3C</td>
</tr>
</tbody>
</table>

* depending on grout type according to the JGA

Strength is usually only an issue for base slabs and shaft break out or in. In these cases the strength can influence the design as the jet grouting is required to span across openings and hence has to be designed with a minimum structural integrity.

Jet grout column layout is designed based upon the two factors:-

(a) Hole Deviation
(b) Column Diameter

When drilling holes for most operations, hole verticality tolerance is unlikely to be better than 1 in 100 and is typically specified at 1 in 75. For shallow holes this does not create an issue but as depth increases it becomes a more important influence on the design of the jet grout layout.

When creating a jet grout base slab, the design is normally based on a triangular grid.

![Diagram showing effect of deviation](image)

This figure shows the effect when a single column deviates from the design position. The solution is to reduce the column spacing. This has a significant influence on cost as column diameter and spacing determine the quantity of columns.

Validation

Validation is as described above. Because jet grouting generally is structurally more sound, coring can be more successful if care is taken. In addition the process lends itself to trial exposure whereby a number of initial columns are jetted on site and then exposed after 24-48 hours to determine size and uniformity. With jet grouting, the column diameter tends to be the more important parameter for validation as this is
fundamental in the construction of gravity or underpinning blocks. In granular soils, strength is not usually an issue.

New techniques being used by a number of jetgrouting specialists include the use of microphones installed in boreholes close to the columns to assess whether the diameter is achieved by detecting the noise as the grout/water jet strikes the microphone tube. Also in-column calliper systems have been used to measure diameter directly by extending calliper arms till they touch the sides of the columns.

Interpretation of the results can be problematic but it shows promise in providing a usable system to demonstrate the column diameter.

REFERENCES

1. Xanthakos, Abramson and Bruce, Ground Control and Improvement, Chapter 8, 1994, published by Wiley (An excellent guide to jet grouting covering both design and execution)
2. RD Essler, Shibazaki, Jet grouting Chapter, Ground Improvement 2nd Edition 2005 published Taylor & Francis (Covers design and case histories)