LECTURE 40

GROUTING

The soil improvement techniques are effective for each of the allowed or required disturbance of existing structures. The following methods, which imply a low level of vibration, are useful to improve liquefiable ground by solidification:

(*a*) Compacting grouting ;

(*b*) Permeation grouting ;

(*c*) Jet grouting;

Compaction Grouting-

Compaction grouting is a soil injection with low workability cement paste that remains homogeneous without entering in the soil pores. The cement mass extends, soil is moved and finally compacted. The liquefaction improvement using compaction grouting divides into the following categories:

(a)Treatment under existing structures;

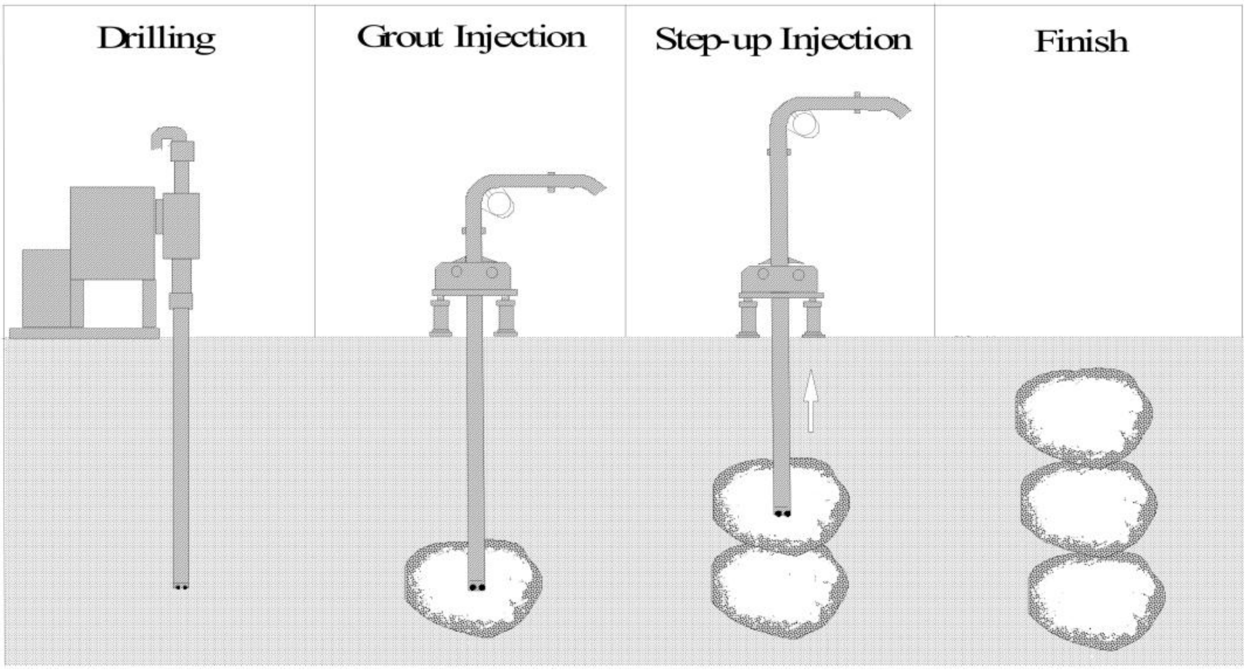
(*b*) Treatment in urban areas with low levels of vibration and noise;

(*c*) Treatment in narrow areas.

The execution of compaction by injection technology using bottom-up method takes place as follows. In the first stage, injection pipes set up on the foundation soil of the existing or future foundations using drilling machines. The injection process begins. Mixture injected through the pipes pushes the surrounding soil; then the injection pipes raises about 0.3-1.5 m and the process renews. The “in steps” injection process continues until the whole thickness of the soil layer is treated. Injection stabilizes soil layer by density and pressure increasing. The injection process is used when a controlled lifting of the soil surface or existing structures affected by local settlements are necessary (Plescan & Rotaru, 2010; Morales & Morales, 2003; Welsh et al, 2002).

Orense *et al.* (2010) reported that Compaction grouting involves the injection of a very stiff grout (soil-cement-water mixture with sufficient silt sizes to provide plasticity, together with sand and gravel sizes to develop internal friction) that does not permeate the native soil, but results in controlled growth of the grout bulb mass that displaces the surrounding soil. The primary purpose of compaction grouting is to increase the density of soft, loose or disturbed soil, typically for settlement control, structural re-leveling, increasing the soil’s bearing capacity, and mitigation of liquefaction potential.

Also Orense (2008) had a review of two case histories on the application of compaction grouting as liquefaction remediation was presented. One case involved the implementation in an open unrestricted space such as airport runways, while the second one was under an existing manufacturing plant. Based on the discussion, several important observations regarding the effectiveness of the technique were addressed. The post-treatment data suggested that compaction grouting was capable of producing the improvement in SPT resistance required to mitigate liquefaction risk. The method of construction, whether “bottom-up”, “top-down” or combination of the two, affected the level of effectiveness and the resulting ground heave. The method was most effective on sandy soil with fewer fines content. In addition, compaction grouting also increased the strength and the lateral earth pressure of the ground. This method is shown



Compaction grouting implementation (Orense, 2008).

Permeation Grouting-

Permeation grouting consists of the injection of a low-viscosity fluid in the soil pores without changes in the soil physical structure. The main goal of permeation grouting is both to strengthen soils through particle cementation (to stabilize the links between particles) and to waterproof ground by filling its pores with injected fluid. This method improves the soil physical and mechanical characteristics, successfully stabilizes the excavation walls in soft soils, controls the groundwater migration in order to implement the underpinnings at the existing foundations and prevents the effects of earthquakes – compaction and soil liquefaction. Permeation grouting is a technology used to mitigate liquefaction that is suitable for un-compacted soils solidification in order to reduce the risks of compaction and liquefaction that may occur as result of possible earthquakes (Plescan and Rotaru, 2010).

The process is quiet flexible and it can be designed with a minimal disruption at the surface and therefore, it is advantageous for use in urban areas or areas with limited access. During grouting process, injection pressures Based on the field trials and the soil conditions, the injection pressures and the grout volumes will be justified to meet the intended performance.

Particulate grouts (e.g. cement or bentonite) are generally used for medium to coarse grained sands, such that the particles in the grout easily percolate through the formation. Micro fine cement is also used for fine grained sands where Ordinary Portland Cement cannot percolate through the formation. Chemical grouts (e.g. silicates) are used in formations with smaller pore spaces, but are limited to soils coarser than fine grained sands. The process of permeation grouting is schematically shown in Figure 2. Quality Control & Quality Assurance Like any other grouting improvement process, the quality control during permeation grouting is very important to ascertain the effectiveness of the technique. As such, the process parameters such as grout are usually limited to prevent fracturing or volume change in the natural soil/rock formation. injection pressures and the grout volumes will be justified to meet the intended performance.

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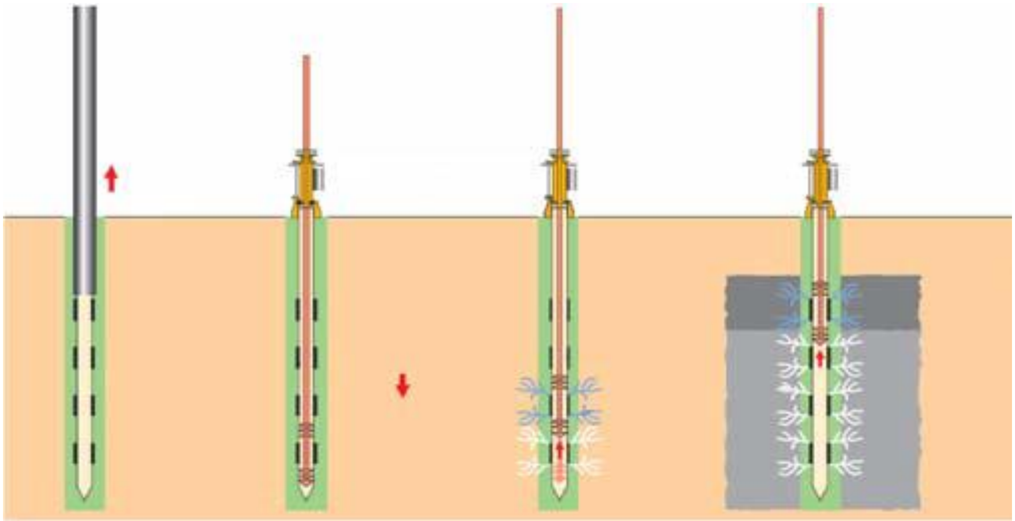
grouting improvement process, the quality control during permeation grouting is very important to ascertain the effectiveness of the technique. As such, the process parameters such as grout
pressure, flow rate, volume of grout for corresponding depth are monitored throughout the construction process. Post construction in-situ permeability tests are conducted after sufficient curing period to validate the effectiveness of permeation grouting (Raju & Valluri, 2010).



Schematic showing process of Permeation Grouting(Raju & Valluri, 2010).

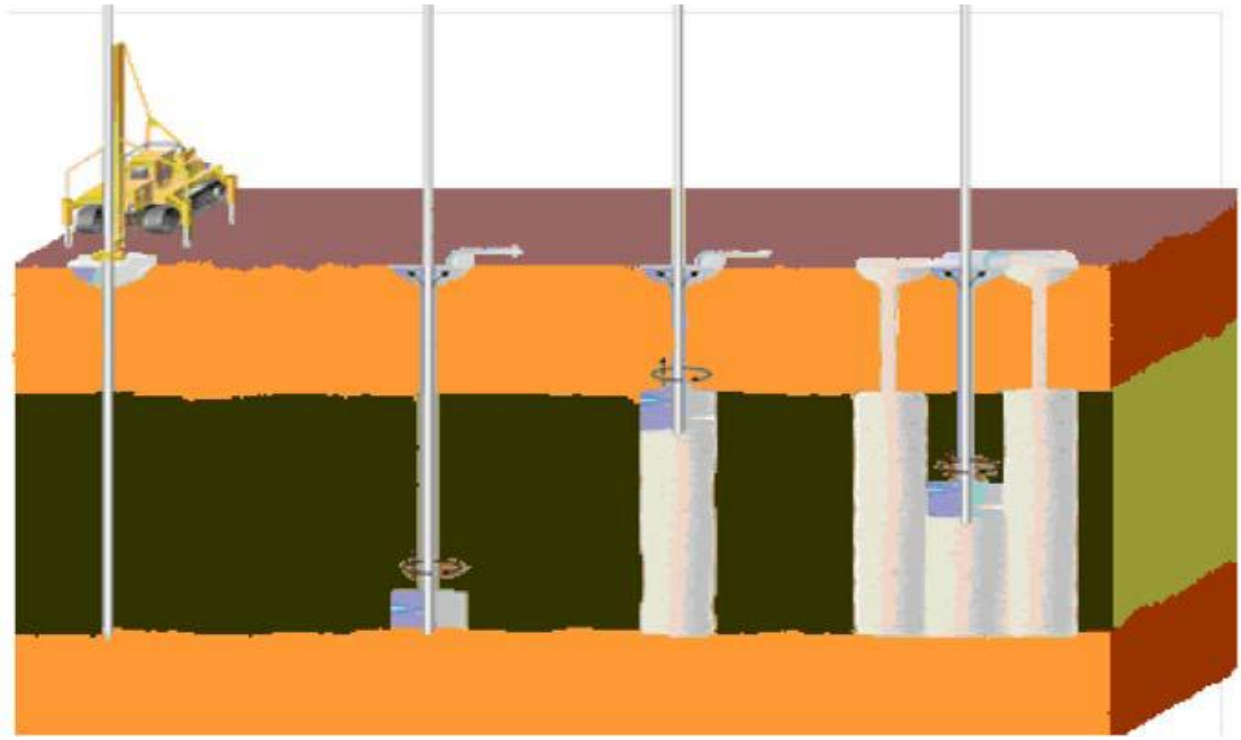
A newly permeation grouting technique using a colloidal silica has been developed to prevent the liquefaction of sandy ground beneath existing structures. In the case of cyclic torsional shear test with the treated sand, a relatively large strain is developed in the early stage of loading;
however, both the development of shear strain and the decrease of mean effective stress resulted without any collapse and liquefaction also the remarkable improvement of cyclic shear strength by the colloidal silica treatment can be exhibited. This phenomenon leads to the expansion of
dilation region across which it faced the phase transformation line and the failure line. (Ohno et al, 2005)

In order to study the deformation and the strength characteristics of the treated sand with the colloidal silica, a series of laboratory tests has been performed on the treated sand such as monotonic and cyclic torsional shear tests. In the case of cyclic torsional shear test with the
treated sand, a relatively large strain is developed in the early stage of loading; however, both the development of shear strain and the decrease of mean effective stress resulted without any collapse and liquefaction. As the results, the remarkable improvement of cyclic shear strength by
the colloidal silica treatment can be exhibited. This phenomenon leads to the expansion of dilation region across which it faced the phase transformation line and the failure line. When the performance based design for the silica-treated ground are carried out, it is necessary for the dynamic deformation analysis to produce the appropriate constitutive model for the treated sand
based on the test results (Oka et al. 2003). Their report indicates that the improved sand exhibited greater liquefaction strength curves. Based on the results of laboratory studies, a cyclic elastoplastic model has been proposed in order to describe the behavior of improved sand. Then, the cyclic elasto-plastic model has been implemented into the fully coupled effective stress based FEM program to perform numerical analysis of liquefaction of improved ground. It has been revealed that the improvement by permeating grouting method is very

effective in increasing the
resistance against liquefaction.

Jet Grouting-

Applications of the jet grouting system fall into three broad categories: underpinning or excavation support, stabilization of soft or liquefiable soils, groundwater or pollution control. The method consists of soil injection of a mixed fluid at high pressure forming jets that erode and
replace the existing soil with the injection mixture. In general this method begins by drilling
small-diameter holes (90-150 mm) up to the final injection depth. Cement mixture is injected into the soil with a metal rod that runs a rotational and withdrawal motion whilst. This technology is useful to underpinnings of existing foundations, to support excavations in cohesive less soils, to
control the groundwater migration and to improve the strength of liquefiable soil (plescan & rotaru, 2010; Geotechnical news, 2008). This method is shown in the Figure .



Jet grouting method (Plescan & Rotaru, 2010). Cooke (2000) studied the use of jet grouting under an embankment slope at existing highway
bridges to mitigate the risk of earthquake-induced liquefaction damage. The jet-grouted zone helped to limit movements of the abutment by containing and limiting the shear deformations that occurred in the liquefiable soils under the embankment that were softened due to the development
of excess pore water pressures during shaking. The limitation of the deformations was dependent on the strength and stiffness of the jet-grouted zone, which in the cases evaluated did not fail, and its ability to resist the increased overturning forces during shaking. The performance of a jetgrouted
zone is highly dependent on its strength. The strength assumed for the jet grouted material was high and resulted in no material failure during shaking (Geotechnical news, 2008).

Also Geotechnical News (2008) reported from Olgun (2003), the soils were improved to
increase bearing support for shallow foundations and to reduce liquefaction potential of the sand layers. Surcharge fills with wick drains were used to improve the soft clays, and jet-grouted columns were used to provide increased bearing support in the clays and prevent liquefaction of

the loose sands. Jet-grouted column spacing and diameters were selected on the basis of footing spacing, footing loads, floor slab loads, and judgment. A primary and secondary grid of columns was installed in a rectangular pattern to provide blanket treatment. In addition Olgun showed that

jet grouted columns do not stiffen the ground by attracting the seismic shear stresses. they do not reduce shear stresses on the soft ground. They may still act as vertical support if there is enough bearing capacity and side resistance from layers that did not liquefy. It is possible rely

on jet grouted columns to provide bearing support and reduce settlements if liquefaction is limited to a specific zone. It is clear that there could be liquefaction mitigation only if the entire liquefiable zone is treated. A total replacement of potentially liquefiable material by jet grouting,

will avoid the liquefaction likelihood.

Yilmaz *et al.* (2008) performed a study on the soil improvement in Beydag dam against liquefaction of alluvium at the dam site. Peak acceleration on rock was estimated to be 0.32 g for an earthquake having magnitude of 7. Liquefiable soils, which consisted of two separate layers of diatomaceous silt and one layer of volcanic ash beneath the downstream toe of Wick up Dam,

were stabilized using 4.3 m diameter jet grouting columns. These liquefiable strata extended to depths up to 26 m. The dam had a square grid of intersecting jet grout piles at the downstream side of upstream wall having an area replacement ratio of about 10%. Depending upon the shear

modulus ratio, G, between jet grouted column and soil, it was found that stress reduction coefficient changes with area replacement ratio. Cyclic stress ratio (CSR) after ground improvement is calculated by multiplying stress reduction coefficient with CSR before treatment. Thus, it was possible to calculate the area replacement ratio required to reach the intended factor of safety. It was found that 10% area replacement ratio may reduce CSR at least about 50%.