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A Review on Ground Improvement Techniques to Improve Soil Stability against Liquefaction

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Abstract- Liquefaction is one of the cardinal concern to the geotechnical engineers as well as those involved in the building and development of structural foundations. To strengthen the subsoil properties in terms of its bearing capacity, shear strength, and settlement; ground improvement techniques are often used. This paper reviews three ground improvement techniques suitable for remedial work near existing structures. Three techniques includes- compaction grouting, permeation grouting, and jet grouting. Suitable method can be selected according to loading conditions, characteristics of soil, project type and cost. The factors which influence the efficacy of a particular technique are identified. From the advantages and drawbacks stated, a combination of techniques may provide the most cost-effective ground improvement solution for preventing damage to existing lives resulting from liquefaction-induced settlement and uplift.

Keywords- *Ground Improvement, Compaction Grouting, Permeation Grouting, Jet Grouting, Liquefaction.*

I. INTRODUCTION

The One of the major factors of lifeline damage in earthquakes is horizontal ground displacement caused by liquefaction of loose cohesionless soils, which is described in the case studies for many past earthquakes. Soil liquefaction is a phenomenon when a soil loses its strength in response to an applied stress due to earthquakes or significant horizontal shearing and excitation of the loose soils. The cyclic disturbance causes a significant loss in shear strength in sensitive soils which causes bearing capacity failure. Ground shaking is accompanied by rapid increases in pore water pressure. When superimposed load on the ground is transferred to the pore water the effective stress becomes zero. Soil structure does not possess any shear strength or load carrying capacity and the buoyancy causes the total collapse [2, 6].

Many lifeline structures lie in regions of high liquefaction and ground displacement potential. Ground improvement is the economical solution to avoid risks. Liquefaction and soil deformation risk mitigation are based on the following improvement methods: densification, solidification, drainage, dewatering and consolidation. Densification can reduce the volume deformation potential that cause liquefaction. Deformation resistance caused by shear forces increases with density. Solidification prevents soils subsidence and can give a higher cohesive force. Drainage method can accelerate interstitial water pressure dissipation limiting the loss of cohesion and reducing pressures on underground construction. Dewatering method is used to decline the groundwater level which reduces the degree of saturation preventing the formation of the interstitial water pressure in excess that could cause liquefaction. Commonly available techniques applied for soil liquefaction correction in Bangladesh are: vibro-compaction, dynamic compaction, and sand pile. These techniques improve soil by densification and less expensive but they can cause unwanted vibration and may not be applicable for long term scenario. On the other hand, Grouting method is sort of solidification techniques that are considered as an effective method to strengthen weak soil again liquefaction [1].

II. DIFFERENT GROUTING TECHNIQUES

The soil at a construction site may not always totally suitable for supporting structures such as buildings, bridges, highways, and dams. Soil improvement techniques are effective for each of the allowed disturbance of existing structures. The following three methods are useful to improve liquefiable ground:

(a) Compaction Grouting
(b) Permeation Grouting
(c) Jet Grouting

A. *Compaction Grouting*

A Compaction grouting is a soil injection with low workability cement paste that remains homogeneous without entering in the soil pores. The process follows as - cement mass extends, soil is moved out and finally compacted. Ground improvement against liquefaction by using compaction grouting can be categorized as-

(a) Treatment under existing structures;
(b) Treatment in urban areas with low levels of vibration and noise;
(c) Treatment in narrow areas.

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 to control settlement control, increase bearing capacity, and decrease potential of liquefaction [4].

Orense (2008) had a review based upon two case histories on the application of compaction grouting as liquefaction remediation. Airport runways and an existing manufacturing plant were considered for the experimentation. The review suggested that the techniques subsequently increase the Standard Penetration Test (SPT) N-values. 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 little fines content. Some important observations regarding the effectiveness of this technique are – increase in soil shear strength and lateral earth pressure of the ground [3]. This method is shown in the Figure 1.

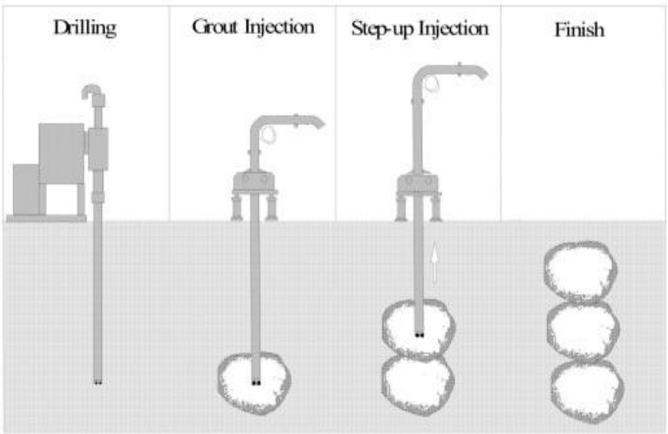

Figure 1. Implementation of Compaction Grouting.

B. Permeation Grouting

Permeation grouting consists of the injection of a low-viscosity fluid in the soil pores without changes in the soil physical structure. One objective of permeation grouting is to strengthen soil by particle cementation. Another goal is to waterproof ground by filling its pores with injected fluid. This method stabilizes the excavation walls in soft and weak soils, prevents from the liquefaction-induced damages and also controls the groundwater migration. Permeation grouting is a technology to improve physical and mechanical characteristics of soils, which 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 earthquakes. The process is very flexible and can be used in urban areas or areas with limited access in resources. During grouting process, injection pressures are usually limited to prevent fracturing or volume change in the natural soil formation. The injection pressure and grout volume is dependent upon the performance required for the project.

Cement or bentonite grout is 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 permeation grouting process is shown in Figure 2. To control the appropriate quality, 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 [5].

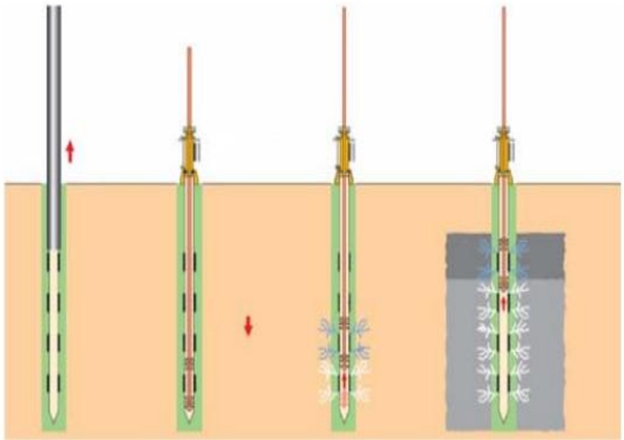

Figure 2. Diagram Showing Permeation Grouting.

C. Jet Grouting

High pressure fluid jets are used in jet grouting to erode and mix/replace soil with grout. At first, a small bore hole of 90 to 150 mm diameter is drilled till the required depth. The procedure is shown in Figure 3. Grout is jetted into the soil through small nozzles as the drill rod is rotated and withdrawn. A continuous flow of cuttings from the jet points to the ground surface is required to prevent ground pressures from building up to the jet pressure, leading to ground deformation. The cuttings accumulate at the surface to form large spoil piles [1].

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% [7].

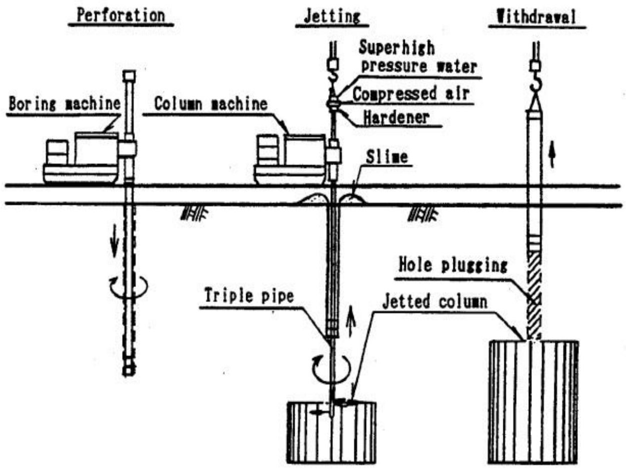

Figure 3. A procedure for Jet Grouting

III. CONCLUSION

Three very important grouting methods reviewed in this paper can increase shear strength of weak soil thus reducing the potential of liquefaction. Compaction grouting is useful for densification of a thick loose sand layer in urban environment but gives a marginal safety against liquefaction. It may not sufficiently compact soils immediately. Jet grouting is preferable for the prevention against liquefaction-induced ground failure. On the other hand, permeation grouting is very effective in increasing the resistance of un-compacted soils against liquefaction by injection in the soil pores without changing its physical structure. With great care and depending on their nature and condition, permeation and jet grouting could improve soil conditions immediately. A combination of techniques based on project type may provide the most cost-effective ground improvement solution.

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