15 Apr 2004, 7:00pm - 8:30pm

Case Histories of Jet Grouting for Canal Excavations

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Proceedings: Fifth International Conference on Case Histories in Geotechnical Engineering
New York, NY, April 13-17, 2004

CASE HISTORIES OF JET GROUTING FOR CANAL EXCAVATIONS

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ABSTRACT

This paper presents a several case histories of jet grouting for the slope protection on soft soil. The design concept and the method of analysis of jet grouting, the method of adopted installation and effectiveness of jet grouting are presented and discussed. The project site of this study is located at Nakornsrithamarat province, South of Thailand. The comparison of soil properties before and after improvement by the jet grouting is presented. The jet grouted was adopted to serve as firm foundations and increases the slope stability during the construction process. Finally, it can be concluded that this case study can be a case study adopted for the other's similar projects.

INTRODUCTION

This paper consists of the use of jet grouting for the slope protection on soft clay. The construction sequences and the basic design example of jet grouting for diversion channel works on soft clay are also given in this paper. The protection of an excavated slope on a thick layer of soft clay stabilized by the jet grouting has been investigated using the computer program. It was found that the factor of safety is increased by the jet grouting. Finally, this paper shows the concept for safety considerations which generally used to prevent the failure of the slope construction on soft clay.
An innovative use of jet grouting to improve soft soil foundation at Pak Phanang Diversion Dam project, Nakornsrithamarat, Thailand is presented. The design concept and method of analysis of jet grouting work using computer technique, results of the slope stability analysis, the installation adopted and effectiveness of jet grouting system are given and discussed. A total of approximately 92,770 m^3 (about 3,400 jet grouted columns) were installed. The jet grout diameter is about 1.6 m and the average depth 18.0 m. The jet grouted was adopted to serves as an excellent foundations, and resist stability during construction process. The benefits of the jet grouted piles, cost-effectiveness and time saving are highlighted.

Prior to the commencement of the jet grouted works, a test jetting has been carried out on site to finalise the optimum values of the grout mix and the operation parameters. The forming jet grouted columns should be used to achieve required effective diameter of 1.6 m and minimum undrained shear strength of 300 kPa at 28 days age. The cement consumption shall be at least 250 kgs OPC per m^3 of improved soil. Results from this test jetting would also be useful for refining the application procedure, in particular, the rod withdrawal rate and grout mix ratio to the other sites of the similar conditions. The two crucial factors affecting the strength and diameter of treated soil are withdrawal rate of rod and the grout mix. The operation parameters such as cement grout jetting pressure, compression air pressure, withdrawal rate, rotational speed of rod, and discharge rate of cement grout for the improvement of Pak Phanang Dam Development could be a reference for engineers to make appropriate design and to support the developing method of jet grouting. Finally, this study gives the most efficient of evaluating soil improvement. Further more this case study could be adopted to other similar projects as well.

SOIL INVESTIGATION

The site is located in the south of Thailand. Based on a compilation of soil investigation results, the topsoil was essentially a very soft to soft silty clay of low plasticity with standard penetration test (SPT) N-Value of 0 blows/30 cm and permeability value (k) of 0 cm/s until about 18 m from the existing ground (upper soil layer). Following this is the brownish gray silty clay with some gravel which was very stiff and of low plasticity (lower soil layer), with N-Values registered generally exceed 20 blows/30 cm.

For the simulation analysis, an idealized ground condition as stipulated in Table 1 was adopted. It is of interest noting that the idealized shear strength profile construed based on 5 times the N-value for the lower silty clay and 0.25 x effective overburden pressures for the upper silty clay assuming that it is normally consolidated, is generally consistent with the vane shear strength registered in the field. These soil parameters were used without soil improvement by jet grouting methods. Subsequent parts will discuss the effectiveness of jet grouting method in reducing the total settlement.

Table 1. Properties of soil

Type of soil	c (kPa)	ϕ (degree)	γ (t/m^3)
Very soft soil	7.5	0	1.40
Soft clay	11	0	1.50
Stiff clay	100	0	1.85

JET GROUTING

Introduction to jet grouting techniques

Jet grouting is a relatively new soil improvement method. It uses a high velocity jet stream to cut, remove and grout cement into the soil to form columns, panels or slabs. The method was developed in Japan in the 1960's before extending to Europe in the late 1970s. The method is applicable across the whole spectrum of soils from coarsest gravels to the finest clays. It can be conducted from a suitable access point, and can be terminated at any elevation, providing treatment only in the target zones. It can be conducted vertically or horizontally, above or below the water table. It has been successfully used in construction of seepage barriers and bottom seals, construction of tunnel support, structural underpinning, construction of soilcrete struts/slaps prior to excavation, stabilising slopes and containment of hazardous waste. Some of the published applications are summarised by Jaritngam, S. (1996, 2002). A similar technique using lime or cement, the so-called deep mixing method (DLM and DCM), has also been developed in Japan (Broms, 1983).

In this paper, an innovative use of jet grouting to create a subbase foundation in soft clay is used. The conventional method of road construction by driving concrete piles followed by stage of embankment construction is found to be less cost-effective. Moreover, the problem of pile movements would impose practical constraints to the pile driving works and hence slowed down the construction process.

Installation of jet grouting techniques

Jet grouting starts with drilling a borehole, usually 60 to 160 mm in diameter, to the required depth of treatment. The borehole can be pre-drilled or self-drilled depending on the equipment used. After drilling, the next process is to erode the ground with jetting under high pressure. The soil is mixed with the cement grout. Excess soil-grout mixture is removed as sludge through the borehole by airlifting action as the grout rod is being withdrawn slowly. The treated soil will harden into a cylindrical soil-cement mass. The system used in this project is also known as double tube or double fluid system. The grout is injected through a nozzle under air pressure. The air jet helps to increase the cutting distance. The key properties of treated grounds are strength and stiffness. These properties are affected mainly by the type of soil being treated, the water-cement ratio, the rate of rotation and withdrawal and the overlap pattern.

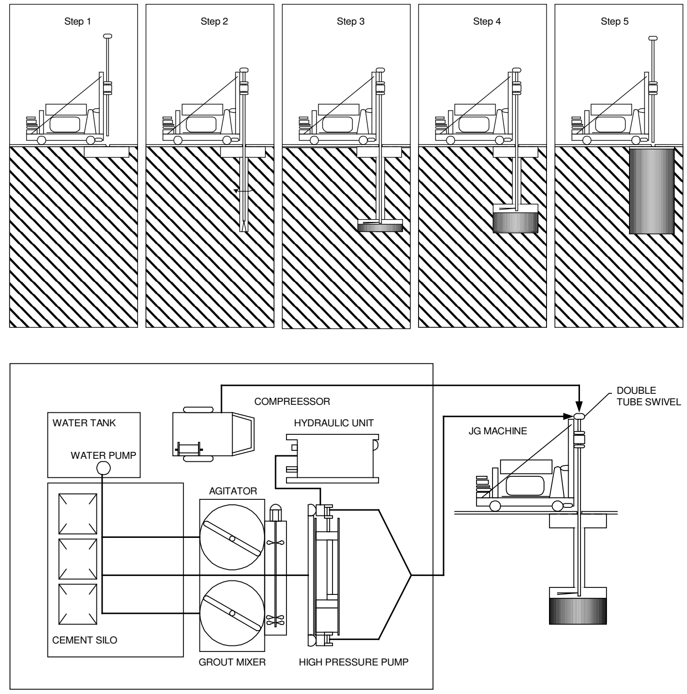

Fig.1. The installation of jet grouted piles.

The operation parameters used in this project were:

Jet grouting pressure	20 MPa
Grout flow rate	60 litre/min
Air pressure	700 kPa
Air flow rate	3 m^3/min
Withdrawal rate	18 min/m & 2 min/n
Rotation rate	10 rpm
Mix proportion	700 kg cement/ m^{3}grout

Jet grouting diameter 1600 mm was used to form continuous block and to fill gaps between jet grout piles. The overlab arrangement was applied for soil improvement as a conventional criterion. The proposed jet grout configuration for this project is 2.50 m spacing in equilateral grids.

METHOD OF ANALYSIS AND DESIGN

Introduction to slope stability analysis

There are many methods to compute the slope stability of jet grouted columns. In this paper, two concepts are given and discussed.
First concept for slope stability analysis will be conducted with equation 1. The improved soil can be considered as a composite foundation (Miki, 1997).

$$F.S. = \frac{R \cdot \left(l_1 \cdot \tau_1 + l_2 \cdot \tau_{av} + l_3 \cdot \tau_3 \right)}{W \cdot r} \qquad (1)$$

Where,
τ_{av} = Average shear strength of the composite soil

C_p = Shear strength of jet grouted columns

C_o = Shear strength of soft soil

α = Ratio of the strength of soft soil to the unconfined compressive strength of the jet grouted columns

W = The total weight of soil (see figure 2)

l_i = The slice length

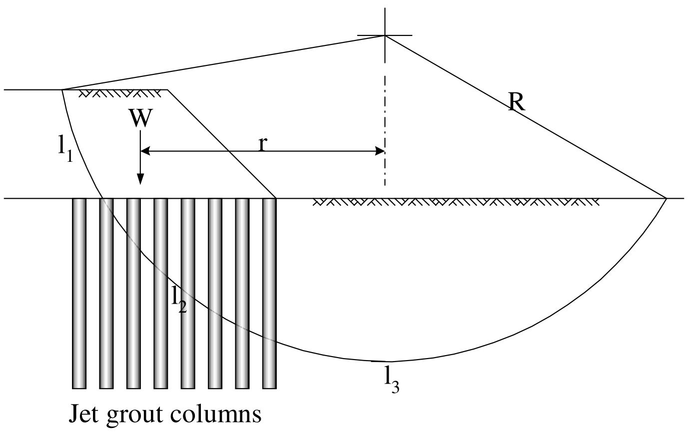

Fig. 2. The slope stability design for jet grouted columns.

The second concept for the factor of safety analysis can be calculated using modified Bishop method as shown in equation 2.

$$F.S. = \frac{\sum_{n=1}^{n=p} \left(cb_n + (W_n - U_n)\tan\phi\right)\frac{1}{m_{\alpha(n)}}}{\sum_{n=1}^{n=p} W_n \sin\alpha_n} \qquad (2)$$

Where

$$m_{\alpha(n)} = \cos\alpha_n + \frac{\tan\phi \sin\alpha_n}{F.S.}$$

b_n = the slice width

W_n = the total weight of the slice

c = the cohesion

ϕ = the angle of friction

α_n = the angle of the base of the slice to the horizontal

U_n = the water force

In this method, the trial failure arc was divided into a reasonable number of slices. The failure arc predicted by modified Bishop method has been found to compare well with the actual failure surface (Sevaldson, 1956). Either the total or effective stress parameters may be used in this equation, although the equation shows only the effective stress parameters.

The procedure for the both design concepts of jet grouted piles consist of the successive repetition of two steps. First step is to select the geometry of the jet grouted piles such as pile length, pile diameter and pile spacing. The next step is to compute the stability of the slope. If the results of the following calculations is unsatisfactory, the new geometry is altered and a new analysis is made.

<u>Computed slope stability analysis</u>

For this project, slope stability analysis was carried out using the modified Bishop method. The jet grouted piles design was conducted in a trial and error approach using a computer program for the slope stability analysis. The analysis was carried out by means of the conventional circular sliding calculation. A typical section for the new river section was considered as shown in figure 3. The final computer section for one-half of a typical section in this study was used. Both with and without jet grouting cases have been analysed. The strength and modulus parameters of the jet grouted columns assumed in the study are given in Table 2.

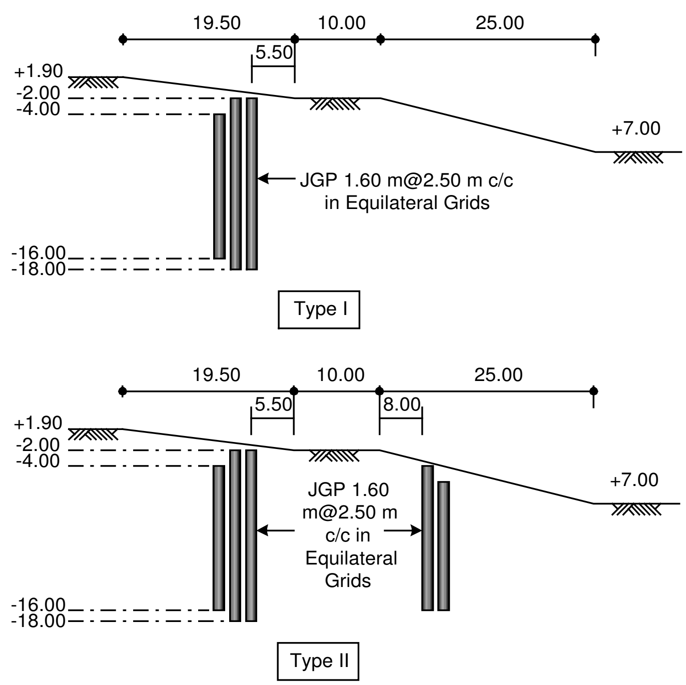

Fig. 3. The design configuration.

Table 2. The strength and modulus of the jet grout

	Specification	Ave. Measured
Shear strength (kPa)	300	950
Elastic modulus (MPa)	150	200

The shear strength and modulus of the jet grout composite adopted in this study are 300 kPa (300 kN/m^2), and 150 MPa (150,000 kN/m^2), respectively.

The objective of this part is to access the effect and sensitivity of various parameters in the design of jet grouted columns. The parameters considered the effect of with and without jet grouted columns. The variable adopted for comparison purpose are the factor of safety for each cases.

The three analyses compare the results of two systems with and without jet grouted columns. The design configuration is shown in figure 3. Results of the slope stability analysis to the stabilization work for both slope of berm and slope are summarised in Table 3. It is interesting to note that the factor of safety are all increased with the case of using jet grouted columns.

Table 3. Summary of results

Case	Slope	Factor of safety			
		Without jet grouted		With jet grouted	
		Slope	Slope of berm	Slope	Slope of berm
I	U/R	0.92	1.01	1.60	1.20
	L/R	1.01	0.96	1.61	1.20
II	U/R	1.93	-	2.52	-
	L/R	2.07	-	2.88	-
III	U/R	0.90	-	1.60	-
	L/R	1.05	-	2.01	-

Case I was used for the calculation during construction process and the end of construction (no water level). The analyses both upstream (U/R) and downstream (L/R) used the total stress analysis.
Case II was calculated by using maximum water level (M.W.L.) for slope analyses. The analyses both upstream (U/R) and downstream (L/R) used the effective stress analysis.
Case III was used for the case of rapid drawdown (M.W.L.-L.W.L.).

A surcharge was applied to represent a live load on the top of the slope. The study involves a slope with a factor of safety less than 1.2 using the computer analysis. The same analysis was repeated after jet grouting was used to strengthen the soil. The factor of safety became 1.2. Although there are many methods which can be used to stabilized the soil, there are special cases where jet grouting is the most appropriate method. Same as this case, if the surrounding area is developed and the facilities cannot be removed, then the most suitable technique may be jet grouting method. Jet grouting can be used to strengthen the soft soil as a stiff clay layer. It has been successfully used in this project. Jet grouting can bring the slope failure circle deeper down, so the factor of safety became increase.

CONSTRUCTION PROCESS

The jet grouted piles in the form of pile foundation is an effective way to prevent sliding of soft soil. If the conventional driven piles method was adopted, the pile length has to take into account the depth of 18.0 m and the problem of pile movement during installation process may be happened. The system was constructed with the jet grouted piles of diameter 1.6 m at centre-to-centre of 2.5 m at appropriate depth as shown in figure 4. A soil improvement scheme in the form of jet grouting was adopted to stabilize a 16.0-18.0 m depth of soft clay for this project. The jet grouted piles increased the factor of safety of the side slope, which allowed civil engineer to design and still meet safety requirements. It has been successfully used in several projects in Thailand.

The jet grouted piles at the site were installed using a jet grouted rig on the beam supported as shown in figure 4 and 5. The beams were connected together and sat on a support system at each end. The jet grouted piles could be installed easily and accurately. Figure 6 shows jet grouting works at the job site. The concept of the soil improvement using jet grouted piles beneath the soft soil with the light weight of the jet grouted rig was not only cost-effective but also safe, reliable and time-saving with the success of the project.

Fig. 4. Jet grouted installation at the site.

Fig. 5. Jet grouting method in construction site.

Fig. 6. Jet grouted machine during installation.

Our study indicates that the strength and modulus of the grouted soil mass were approaching that of a lean concrete.

A quality control is recommended to verify the installed jet grouted piles conform to the requirements. Core samples were taken for the purpose of obtaining and testing in-situ samples to confirm unconfined compressive strength under properly stored and cured in the laboratory.

RESULT OF WORK

In addition, the columns' diameter were visually checked after installation process. It is apparent from figure 7 that the jet grouted piles provides an excellent foundation. The 28 days unconfined compressive strength test results of core samples from the jet grouted piles exceeded the specified minimum limit of 600 kN/m^2 as shown in figure 8 and figure 9, respectively.

Fig. 7. Jet grouted piles after installation.

Fig. 8. Jet grouted coring.

Fig. 9. Unconfined compression test of jet grouted sample.

For the quality control of pile capacity, the pile load test was used for this propose as shown in figure 10. Pile load test of jet grouted columns have the minimum load capacity of 62.6 tons (more than the design load of 50.0 tons) and the total settlement of 4.75 mm.

Fig. 10. Pile load test for inspection of jet grouted piles.

CONCLUSIONS AND RECOMMENDATIONS

The application of jet grouting technique, as a soil stabilization method, was applied. Jet grouted piles have been proven to be a suitable choice under these conditions. Conventional methods are very time consuming, costly and may cause significant delay of the project. The concept of soil improvement using the jet grouted piles for slope protection purpose is not only cost-effective but also safe, reliable and time-saving with the success of the project. An advantage of using jet grouting as a foundation is a simplicity of slope construction works on soft clay.

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