BOTTOM BARRIER BY NEW SOIL IMPROVEMENT METHOD, SUPERJET™, TO CONFINE VERTICAL PLUME OF CONTAMINATION

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ABSTRACT

The first task for remediation actions against underground contamination should be an effective confinement of contamination plumes. Some conventional barrier techniques have been already proved to have sufficient features to prevent such plumes from extending horizontally, but further technical development is required to construct a bottom barrier to stop plumes going deeper.

Superjet™ is a powerful version of the jet grouting method (1) and is characterized by prompt construction of an underground cement pile which exceeds 5 meter in diameter. Its application to a case of construction of underground lapping beams has shown satisfactory completion to sustain underground open space. The results and some basic experiments indicate that this method is technically feasible to build a bottom barrier with a certain mechanical strength.

INTRODUCTION

Underground contamination has been quietly but steadily spreading out in Japan. It is rather difficult to assess the matter and to stop its migration into water supply system because of complicated geological structure in Japan, especially in alluvial plane area. The first task for remediation actions against underground contamination should be an effective confinement of contamination plumes. The objective of this paper is to outline the soil improvement method, Superjet™, and to discuss the feasibility when it would be used in constructing a subsurface horizontal barrier.

Superjet™ has been jointly developed by Kajima Corporation and Chemical Grouting Co. LTD., Japan since 1985. The original target of the method is to reinforce the ground by mixing and/or replacing soft ground with cement slurry, which will act as a rigid column after solidification. The method can make piles whose diameter is up to about 5 m and whose length is basically unrestricted at any depth. Thus, a pile with 5m in diameter and a few meters in length, which could be called a plate, and its multiple arrangement can be utilized as a bottom barrier.

Superjet™ was applied in recent construction works to make subsurface beams which are formed by lapping piles in a straight line. Soil over the beams was, in the course of the construction, excavated to create underground open space, which gave us a chance to access lapping characteristics of piles, to investigate it with eyes and to sample cores from it.

SUPERJET™

Superjet™ originally aims reinforcement of soft ground to prevent damage caused by liquefaction on the occasion of earthquake. Figure 1 shows a conceptual view of the method and pile construction. The first thing to do is drill a borehole of 15 cm in diameter and insert a triple-wall pipe to a designated depth. Cement slurry, air and water flows in the pipe. Two nozzles are installed in the triple-wall pipe in order to blow the jets in opposite direction each other. Cement slurry is jetted into the ground and compressed air is blown at the same time so as to shroud the slurry one. The air jet protects the slurry jet from dissipating its energy. The pipe is withdrawn upward with rotation, thus a cement pile is constructed in the subsurface after solidification of cement slurry. Excavated soil and slime are pushed up through between the borehole and the pipe before they are treated by a screen and

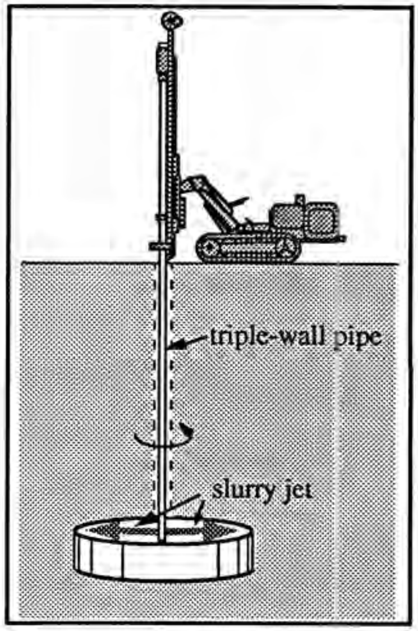

Fig. 1. Conceptual view of Superjet™ method.

a centrifuge, SWACO headquartered in Scotland, to minimize industrial waste. Construction machines which can resist high pressure and tough working environment are introduced from oil industry.

Lapping piles will be served as a horizontal barrier. Fig. 2 illustrates the idea of lapping piles. Before introducing the method to real construction works, it is necessary to verify its reliability in terms of contamination confinement. Subjects which should be examined and resolved are:

- a jet-reach range in a geological media,
- properties of wrapping zone, and
- management of secondary waste.

JET RANGE

On blowing of slurry or water jet in the ground, several factors affect the range the jet will reach. Pressure or flow rate of the jet, rotation rate or withdrawal rate of the triple-wall pipe or number of passage and geological formation are the main factors of them. (2)

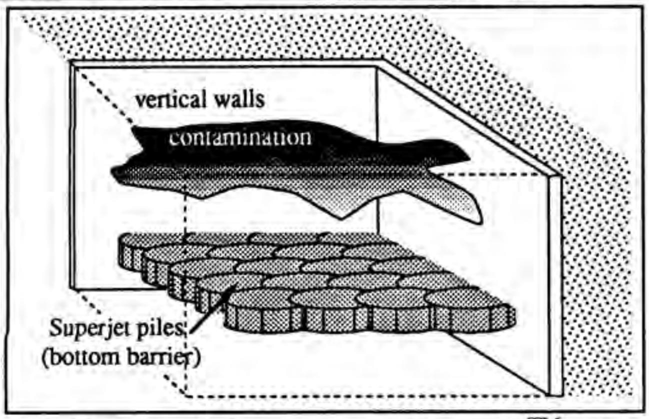

Fig. 2. Idea of multiple arrangement of Superjet™ piles for subsurface horizontal barrier.

Pressure or Flow Rate of the Jet

In order to attain a pile with a larger diameter, the easiest way to think of is to supply higher pressure and/or more flow rate on the jet. Though, there is a limit to gain these parameters because of the performance of available machines such as a pump or other supply lines. It costs considerable investment and time to develop high-performance appliances, which is not an object of the technological development.

Figure 3 summarizes the result of a basic experiment, which was conducted to know what parameter is more effective to get farther excavation. The figure explains the waterjet-reach range after 0.1-second blowing in a sand bath. The geological strength of sand body corresponds to that of alluvial sand layer around Tokyo bay area. Conditions of pressure and flow rate varied in each test. Given the jet-reach range of 250 cm, the operation time t(s) can be expressed by the following equation.

$$t = 1x10^{-3} P^{-1.7} Q^{-1.9} \quad (1)$$

Where:

p = pressure of the jet (MPa)
Q = flow rate of the jet (m^3/s)

From the viewpoint of waste minimization, it is preferable to shorten operation time. The equation tells that an increase of flow rate has more effect on reducing the operation time than that of pressure. Also, modification of the apparatus to achieve higher flow rate does not demand so much effort as to achieve higher pressure. Taking another factor such as past experience into consideration, an optimal setting for the jet is determined; 30MPa of pressure and $5x10^{-3}$ m^3/s of flow rate.

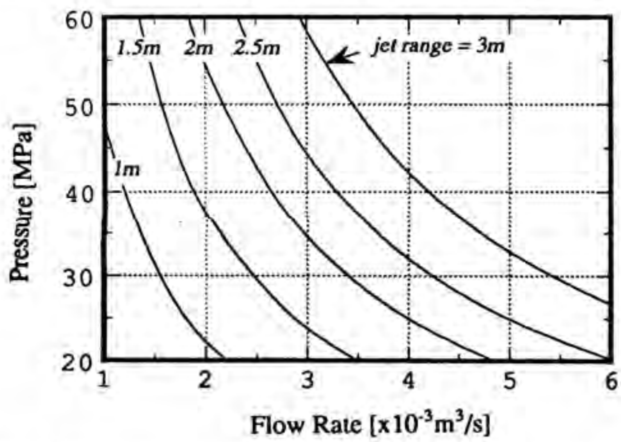

Fig. 3. Map of range waterjet reaches under varied pressure and flow rate.

Rotation Rate, Withdrawal Rate and Number of Passage

These three parameters could be optimized by following basic experiments, but other conditions such as volume of discharged mud should be taken into account.

The number of passage means the repetitive operation times before solidification of cement slurry. The experiment was carried out in the same sand bath as the previous experiment. Figure 4 shows the jet range with varied rotation rate and number of passage at 30MPa of pressure and $5x10^{-3}$ m^3/s of flow rate. An increase of rotation rate decreases the range waterjet can reach. The excavation reaches farther with more repetition times. The results mentioned above are quite natural, because less rotation rate and more number of passage give the jet more frequent attack against geological formation in the same direction. However, the effects are significant when the rotation rate is less than 10 rounds per minute (rpm) and when the number of passage is less than 5. Furthermore, these parameters are to be adjusted by soil conditions, that is to say; more homogeneous piles are completed with slow withdrawal rate for cohesive soil.

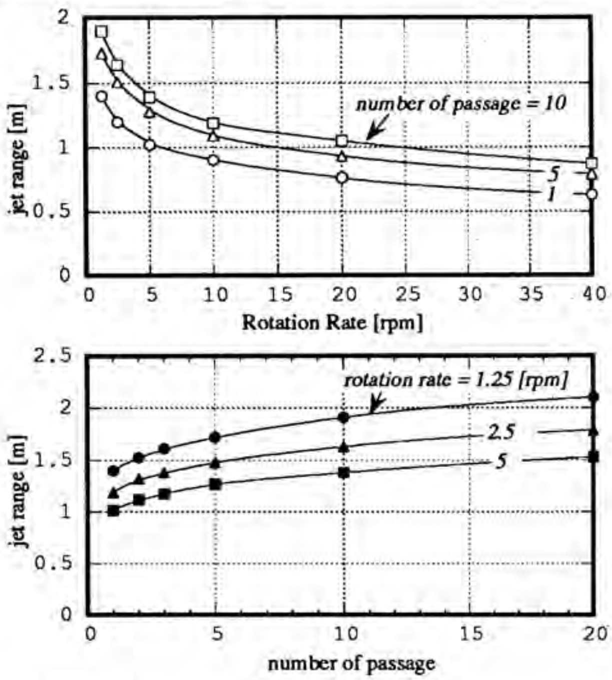

Fig. 4. Effect of rotation rate (above) and number of passage (below) on waterjet range.

Geological Formation

Demonstration experiments were conducted at two sites in Japan, where cohesive soil or sandy soil is major geological composition respectively. Pressure and flow rate of the jet in both experiments were 30MPa and $5x10^{-3}$ m^3/s.

One site is located in Shizuoka Prefecture and had been a rice field whose main geological composition is sticky clay with humus (10-14 % in volume). Figure 5 shows unearthed piles. Each pile has more than 5 m in diameter and about 3MPa in unconfined compressive strength. For one pile with 1 m in length, it took 16 minutes to complete and produced about 15 m^3 of mud, which is a little more than a slurry volume

Fig. 5. Unearthed piles constructed in cohesive soil.

injected during operation. It should be noted that the lower withdrawal rate gave preferable mixture of cement slurry with inherent clay, which resulted in homogeneity in piles.

Another site is located near Tokyo International Airport, where sandy soil is major component. A comparable diameter and unconfined compressive strength was obtained for this case as well.

It was concluded by the demonstration experiments that if an operation was implemented with optimized parameters, it is technically possible to build piles with diameter of 5 meter.

LAPPING BEAMS

The first application of Superjet™ to a real construction works enabled us to build subsurface beams with least influence to surroundings. Figure 6 illustrates the plane and the profile of the site located in Shinagawa Ward, Tokyo. An ordinal method to support vertical walls, soil mixing wall in the figure, is metal bracing. Though, the construction site faces a busy street and neighboring houses, then special efforts should be paid to avoid noise and vibration.

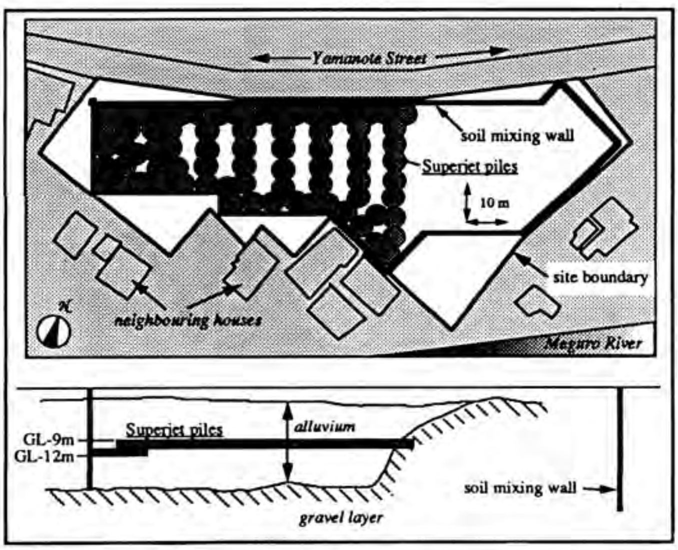

Fig. 6. Plane and profile of the site located in Shinagawa Ward, Tokyo.

Figure 7 is a photograph which visually explains the completion of lapping beams. The performance of the beams was evaluated with respect to mechanical behavior. Unconfined compressive strength of cores was above the criterion, 10MPa and the inclining deformation of walls is minimal. Hydraulic characteristics of the beams was not measured experimentally, but the connection between one pile and another is witnessed to be tight. The slurry jet probably washes away the disturbing soil surrounding the next pile which has already solidified. The underground open space will be utilized as a parking lot and a public theater.

WASTE MANAGEMENT

Superjet™ will be used to improve non-contaminated soil to contain inner harmful soil, but it consequently produces secondary waste whose volume is estimated more than multiplication of flow rate by operation time. In order to reduce cost for waste management, the screen and the centrifuge were introduced. The screen separates coarser component

Fig. 7. Underground open space surrounded by vertical walls and lapping Superjet™ piles.

such as sand from original mud, and the centrifuge squeezes water out of residual mud. The performance was checked by using reference mud which consisted of sand(42% in weight), fly ash (37%), bentonite (2%) and water (19%). As a result, industrial waste to be disposed of was reduced to about 40% in weight or 50% in volume.

CONCLUSION

Superjet^{TM} will be potentially used in constructing sub-surface horizontal barrier. This method assures a prompt installation of piles whose diameter is above 5 meter, in the soft ground. Wrapping characteristics were verified through construction works.

As it is diversified how a site is contaminated, it would be necessary to add some options to Superjet^{TM}. For example, the method would be used in immobilizing or neutralizing contamination if chemical component of a slurry jet is adequately arranged. Powerful injection of air jet might promote a discharge of gaseous contamination.

It is an important question whether the site is reused after remediation actions. If there is a plan to build facilities in future, there is a good reason to adopt this method which provides an optimized plan for structural foundation for the facilities.

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