Jet Grouting in Contaminated Soils

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Abstract

The jet grouting technique has gained wider acceptance in the U.S. over the past few years as a viable tool for such geotechnical applications as the improvement of foundation soils, slope stabilization, and underpinning (Welsh and Burke, 1991). Jet grouting; however, has recently been used as a method of performing block stabilization of contaminated soils as well as for the formation of barriers for the control of contaminant migration in the environmental field. The two case studies given herein will illustrate these recent engineering applications.

Introduction

In one application, jet grouting was used to close gaps in a slurry cutoff wall created by high concentrations of utility lines which could not be taken out of service. In the second application, a block stabilization was performed in order to fix small concentrations of contaminants in place, while at the same time creating a plug, or horizontal barrier to prevent future contaminant migrations into an underlying aquifer. In both instances, a cement-bentonite grout mixture was used which yielded excellent permeability test results.

Case Study One – Northern Michigan

An area within a chemical plant required the construction of a vertical containment barrier up to twenty-four feet (7.3 m) deep to stop the lateral movement of phenols in the groundwater. The site is bordered by an existing slurry trench cutoff on one side and a clay cutoff on the other. The project required joining the two existing vertical barriers with an impervious wall to complete a permanent cutoff through the primarily granular soils. Several underground utility crossings consisting of numerous pipelines at depths of as much as seventeen feet (5.2 m) complicated the normal trenching procedure. A typical section is shown in Figure 1.

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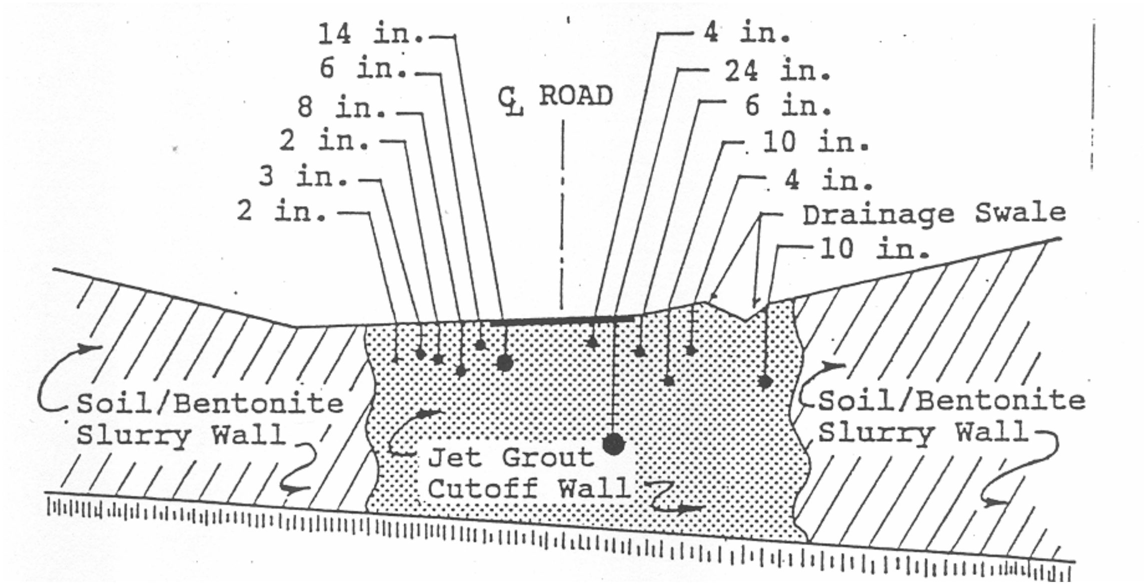

Figure1. Typical Utility Crossings

The first phase of the project involved the installation of soil-bentonite slurry trench sections, terminating at each utility crossing. A jet grouted cutoff wall at each crossing then had to be installed and keyed into the new slurry trench and meet the required 1 x 10^{-6} cm/sec permeability, without removing or disturbing the existing utilities.

At this site, a preliminary test program was performed in order to verify grouting parameters (pressure, flow rate, jet nozzle diameters, rotation rate, lift rate, etc.) that had been anticipated during conceptual design. This was critical since closure of the cutoff wall below the utilities had to be assured while not damaging the conduits themselves during the jetting process. In addition to rigorous testing of the conduit materials to determine pressure and distance thresholds to prevent damage, several test columns were also installed and later excavated to confirm the column diameters that could be achieved. In this test program, column diameters of as much as 4 to 5 ft (1.2 to 1.5 m) were achieved, with the optimum (in terms of time involved and grout refusal, or waste) being just over three feet (approx. 1.0 m), as is illustrated in Figure 2.

Figure 2. Representative Jet Grout Test Column

On the basis of the results of the test program, a conservative two-foot (0.6 m) center-to-center spacing for the jet grout columns was decided upon. With typical grout pressures approaching 6,000 psi (41.4 MN/m^2) and rotation and lift rates of approximately 1.3 rpm and 1.3 feet per min (0.4 m/min.) would be acceptable for the majority of the work while allowing for isolated soil type variations which could reduce the effective area of influence of the jetting operation.

Much slower rotation and lift rates were utilized adjacent to the larger diameter pipes, some as much as four feet (1.2 m) in diameter, in order to assure closure beneath them. In areas of close proximity to some of the smaller and more fragile conduits, column spacings were tightened and rotation and lift rates increased in order to optimize closure while preventing damage. In rare instances, the pressures were also decreased to as little as 4,000 psi (34.5 MN/m^2) for short periods in the immediate vicinity of the particularly sensitive conduits to further reduce the likelihood of damage.

In total, over 5,700 square feet (approx. 530 m^2) of cutoff wall was satisfactorily installed by the jet grouting technique in some three and one-half weeks time with no detectable damage to any of the subsurface conduits from the effects of the jetting action.

Case Study Two – Northern New Jersey

While not as procedurally difficult in terms of providing closure around utilities while preventing damage as the previously described case, this application was equally sensitive from an environmental standpoint.

On this site, a storage tank had been removed and the excavation backfilled with silty sand fill. It was later discovered that chlorinated hydrocarbon contaminants from the surrounding undisturbed soils were migrating into the clean fill and seeping downward through the previously excavated area, thus posing a threat to groundwater in the underlying rock formation. Block stabilization of the entire excavated area by the jet grouting technique was determined to be the most cost effective solution to this problem. This design not only provided a vertical barrier to prevent the further migration of contaminants into the clean fill, but also provided a bottom "plug" to prevent vertical migration of contaminants into the underlying aquifer.

The area to be treated measured approximately 20 ft (6.0 m) by 12 ft (3.6 m) in plan and was some 10 ft (3.0 m) in depth. A series of columns were installed in a basic 5 ft (1.5 m) primary grid pattern with additional primary columns installed in the centroid of each grid block. A similar, overlapping grid of secondary columns was installed to complete the coverage of the entire area and effect the block stabilization, with a resultant nominal center-to-center spacing of 2.5 feet (0.8 m) between any two jet grout columns. Pattern geometry is illustrated schematically in Figure 3.

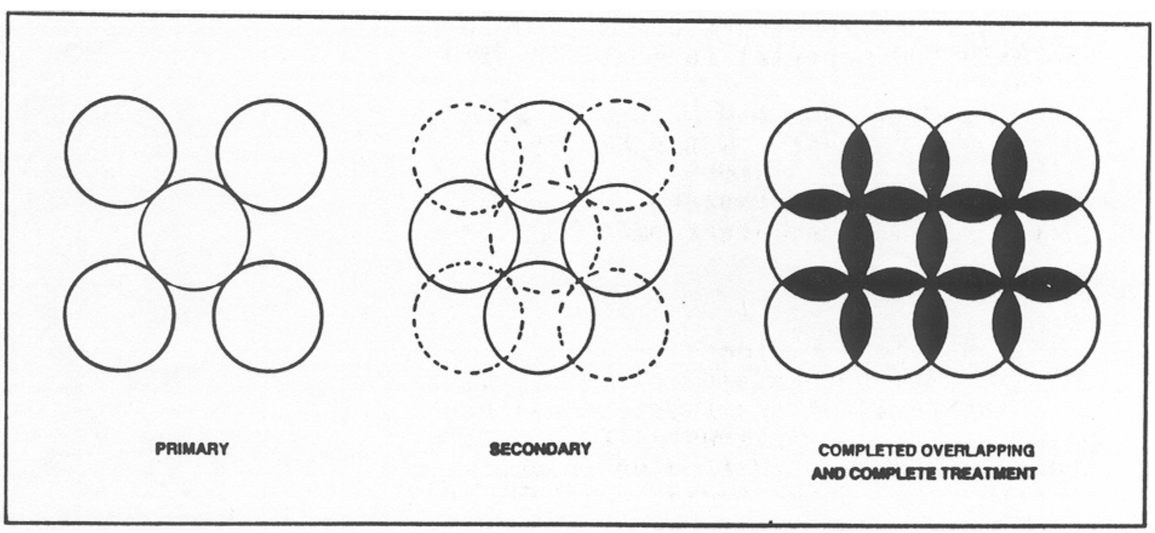

Figure 3. Typical Block Treatment Pattern

While prudence normally dictates that a test program should be performed on all jet grouting projects, the relative straightforwardness of the project together with the limited scope of work simply made the performance of a sophisticated test program economically unattractive for the owner. As a result of this, a conservative design approach, based on prior experience, yielded the treatment pattern as described above, together with grouting parameters as follows:

•Jet nozzle diameter (range)	1.8 to 2.2 m
•Grout pressure	6,000 psi (41.4MN/m^2
•Rotation Rate	1 rpm
•Lift Rate	1 foot per minute (0.3 m/min)

This design proved very effective for the completion of the block stabilization desired. Descriptions of quality control and testing procedures and results are provided in more detail in a later section.

Process and Equipment

Of the three commonly accepted jet grouting processes (Burke, et al, 1989), the single-phase process was selected for use at both sites for various reasons; soil characteristics, engineering application, and contractor option among them. In this process, the mixed grout is pumped under high pressure in order to concurrently cut through the surrounding soils and mix with them in place.

Equipment utilized at these sites consisted of a high speed mixer feeding a 350 HP triplex piston pump capable of working pressures in excess of 12,000 psi (83 MN/m^2). The high-pressure pump is shown in Figure 4. The grout exited through as many as four jet nozzles within the 1.8 mm to 2.2 mm diameter range (Figure 5.), with jet rod advancement and jetting control accomplished by a track mounted hydraulic drill fitted with a hollow chuck rotary drill head (Figure 6.)

Figure 4. High Pressure Pump

Figure 5. Grout Exiting Jet Nozzles Under High Pressure

Figure 6. Jet Grout Drill

Grout Mix Design and Materials

The grout mix design used on these projects was resultant from evaluation of information obtained from a bench scale study performed for this purpose. The optimum mix selected for use consisted of approximately 17% cement and 9% bentonite, by weight of slurry. Cement materials were in accordance with ASTM C 150, Portland, Type I. Bentonite was premium grade Wyoming sodium bentonite manufactured in accordance wit API Std. 13A.

Quality Assurance, Testing, and Results

During the course of the work, various physical and visual tests were performed for quality assurance. These included the following:

- Each batch of mixed grout was tested in accordance with API Std. 13B for bentonite content and cement content. At least twice per day, these were augmented by measurement of total grout unit weight.

- During grout injection, grout pressures and flow rates, and rod rotation and lift rates were continuously monitored, and recorded.

- Visual observations were performed continuously regarding the following:

  - existence and nature of grout refusal (waste).

  - changes in system behavior, especially when working adjacent to utility lines.

In these two cases, the visual observations were used as initial confirmation that the pattern geometry, together with the grouting parameters chosen appeared effective. Slight disturbances to previously placed columns and/or grout refusal exiting from adjacent columns was quite often the case, providing preliminary evidence that closure had been achieved.

Closure and in-place grout effectiveness was further verified from the testing of undistributed samples taken from various depths at column overlap points. Permeability testing of these samples was performed in accordance with US Army Corps. of Engineers EM-1110-2-1906, Appendix VII. Results of these tests were very uniform and all yielded permeabilities of less than 1 x 10^{-7}cm/sec, with the average being 2.9 x 10^{-8}cm/sec. These results were consistent with those obtained during the bench scale testing. While permeabilities of this magnitude are lower than one might expect from a cement-bentonite grout, it can be hypothesized that the finer fraction (silts and clays) of the soils at these sites may have aided in the achievement of these values. Another possible contributing factor may have been the observed homogeneity of the soil/grout mixture as noted in the grout refusal and the test specimens.

Further visual observations indicated that the upper one to two feet (0.3 to 0.6 m) of the jet grouted mass did suffer some ill effects due to “overbreak” of the soil mass resulting in less than satisfactory mixing at the surface, together with exposure to the elements and day to day construction activities and traffic. In both cases, the surficial grout was removed and replaced manually with a low permeability fill to maintain the integrity of the completed unit.

Conclusion

As mentioned earlier, jet grouting has finally begun to be accepted as a viable method of soil treatment in a wide variety of geotechnical applications. On the two projects discussed herein, jet grouting proved to be a cost effective and technically successful method for the control of both lateral and vertical migration of subsurface contaminants.

It should be remembered, however, that the information provided above represents two specific case histories of successful jet grouting applications. As care and sound engineering practice must be observed in the selection of techniques to address specific geotechnical problems, the application of even closer scrutiny becomes prudent when dealing with environmental applications. With the application of such scrutiny and prudence, jet grouting should become an even more valuable tool for use in the environmental field.

Appendix. References

1. Burke, J.K. , Johnsen, L.F. and Heller, R.A. (1989), "Jet /Grouting for Under pinning and Excavation Support", Proc. 1989 ASCE Foundation Engineering Congress, Evanston, IL pp. 291-300.

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