

**JET GROUTING TO CONSTRUCT A SOILCRETE WALL  
USING A TWIN STEM SYSTEM**

By

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**ABSTRACT:**

An existing coal-loading pier located in Norfolk, Virginia was completed in 1961 for the purpose of loading ocean-going ships with coal for export throughout the world. The size of the ships that could be fully loaded at this facility was limited to the depth of the mud line adjacent to the loading pier. It was determined that dredging adjacent to the pier would provide an increase in loading capacity and productivity for pier operations.

Since the existing pier is supported by concrete piles, there was a concern that the lateral stability of these piles would be significantly reduced by the sloughing of surrounding support soils into the adjacent dredged areas. To prevent this, a wall of some kind would be required to retain these soils and ensure the integrity of the existing piles. After considering a number of options, the jet grouting technique was chosen as the method to be used to create a wall between the existing rows of concrete piles. At a contract value in excess of \$ 1,800,000.00, this project is the largest jet grouting application to date in the U.S.

Analysis of data obtained from the extensive project test program, verification section, and production work indicate that the twin stem jet grouting system, in what is believed to be its first U.S. application, yielded a more consistent, better quality end product than was produced with a single stem jet grouting system, in addition to substantial production rate increases.

**INTRODUCTION**

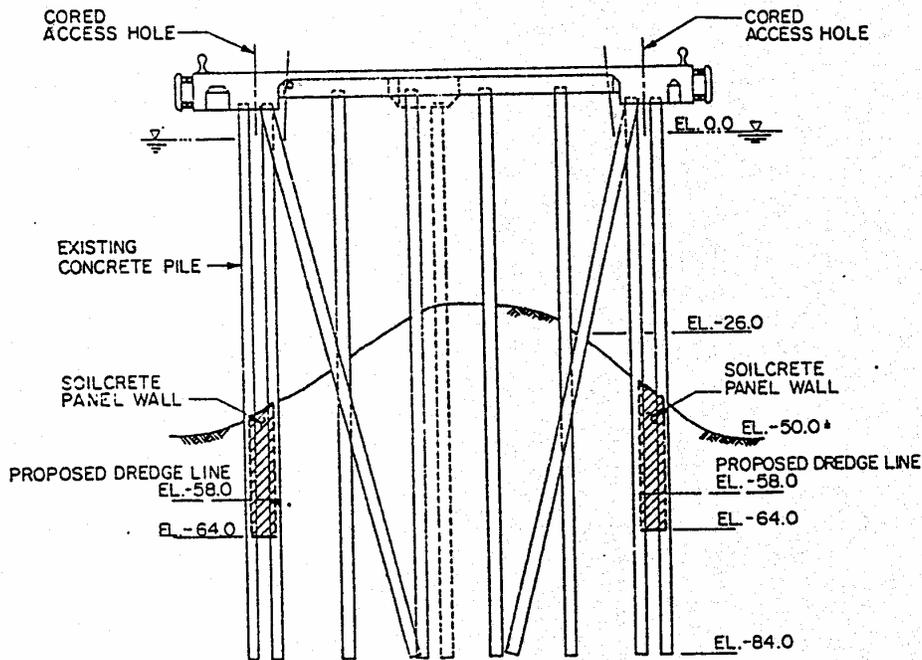
Jet grouting is a soil improvement technique which has only recently begun to gain acceptance in the U.S., even though it has been used for a number of years in Japan and Europe (2). While specific procedural and equipment details can vary greatly, most jet grouting performed to date can be generally categorized as either excavation and replacement (2), or jet mixing (1), with the primary differences being the jetting fluid and the degree of removal of existing materials. The resultant material has been referred to as "soilcrete" (1).

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1 - Group Mgr., Geo-Con, Inc., P.O. Box 17380, Pgh., PA 15235

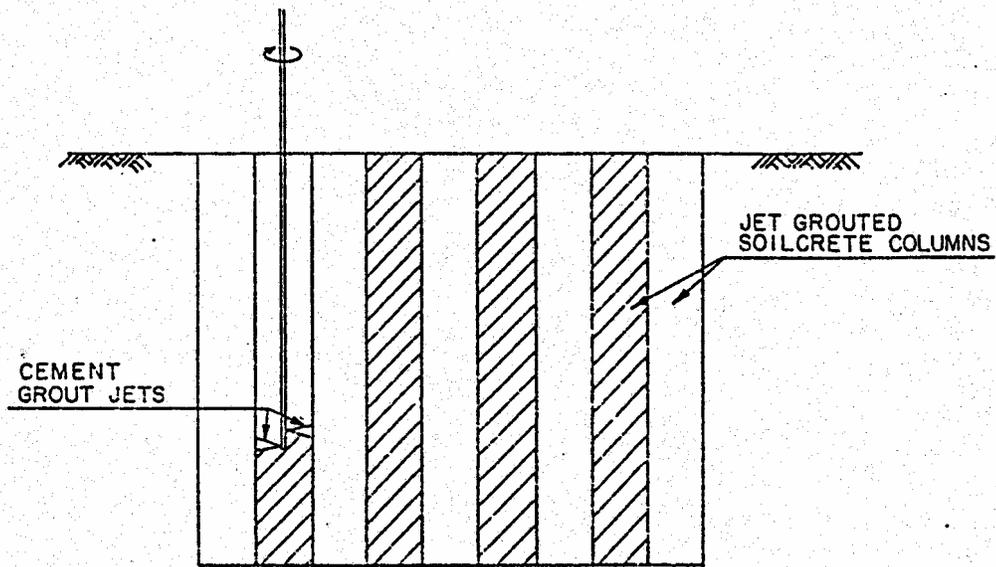
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This particular project required the installation of a wall beneath a six foot (1.8 meters) thick concrete pier and under approximately forty feet (12 meters) of water, sufficiently strong to retain existing soils beneath the pier after completion of planned dredging operations, while not interfering with continuing pier operations. The adaptability of the jet grouting process to these physical constraints, as are illustrated in Figure 1, was a primary factor in the selection of the jet grouting technique to install a soilcrete wall on this project. Environmental, schedule, economic, and other considerations led to the selection of the jet mixing method as the most appropriate for this application.

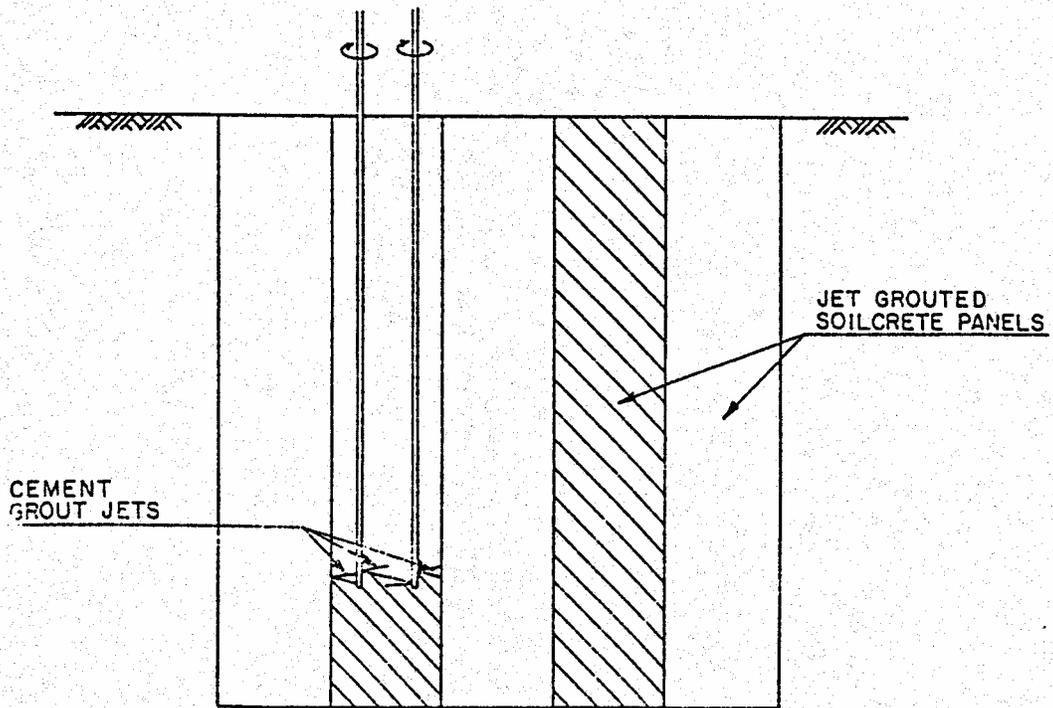


**Figure 1. Typical Project Cross-Section**

Prior practice in the U.S. for the construction of soilcrete walls by this method involved the installation of a series of individual, overlapping columns using a single rod, or stem (Figure 2). The size of this project, together with its constraints on equipment access led to the custom design and fabrication of a double stem jet grouting system wherein two adjacent holes were drilled and jet grouted simultaneously, forming elongated soilcrete wall segments, or panels. The resultant product, as shown in Figure 3, somewhat resembles a slurry panel wall.



**Figure 2. Soilcrete Wall Constructed by Single Stem Method**



**Figure 3. Soilcrete Wall Constructed by Double Stem Method**

## SOIL PROFILE

The soil profile on this project generally consisted of a loose to dense silty fine to medium sand with a trace to some gravel. Standard penetration blow counts were generally within the 10 to 40 blows per foot range.

## TEST PROGRAM

The first phase of the work was the design and completion of an extensive test program at the jobsite. This test program consisted of the formation of thirty test columns in the existing soil, on shore, in the vicinity of the project pier (Figure 4).



**Figure 4. Portion of Test Program Soilcrete Columns**

In this test program, a single stem jet grout system was utilized. Factors such as the number of jet nozzles; nozzle diameter; lifting, cement injection, and grout flow rates; pressure and grout mix were varied to determine correlations between the above factors and the quality and volume of the grouted material. One of the primary purposes of the initial test program was to optimize the soilcrete column diameter at the minimum cement injection rate. After each set of test columns was installed and allowed to set, the soil around each column was excavated and the minimum column diameter was determined (Figure 5).

Since the test program was conducted above the water table, several columns were installed in a compacted soil inside buried steel cylinders with a simulated head of water. These tests were performed in an effort to better correlate the test program data with anticipated actual soil conditions below the water table. A summary of the results of this test program are shown in Table 1.

Table 1: Summary of Test Program Results

Test No.	No. Jets	Jet Dia. mm	Injection Pressure		Grout Ratio w:c+	Avg. Flow (per min)		Lift Rate (per min)		Grout Qty. (bags)		Min. Dia.	
			psi	°MN/m <sup>2</sup>		gal	1	ft	m	/ft	/m	in	m
1	4	1.8	6.0	41	2:1	57	216	0.6	0.2	5.1	16.6	46	1.2
2	4	1.8	6.0	41	2:1	55	208	1.0	0.3	2.9	9.6	41	1.0
3	4	1.8	6.0	41	2:1	57	216	3.3	1.0	0.9	3.0	28	0.7
5	2	1.8	6.0	41	2:1	27	102	1.0	0.3	1.4	4.7	37	0.9
6	2	1.8	6.0	41	2:1	27	102	3.3	1.0	0.4	1.4	23	0.6
7	2	1.8	6.0	41	2:1	27	102	0.6	0.2	2.4	7.9	37	0.9
8	2	1.8	6.0	41	3:1	28	106	0.6	0.2	1.8	5.9	41	1.0
9	2	1.8	6.0	41	3:1	28	106	1.0	0.3	1.1	3.5	32	0.8
10	2	1.8	6.0	41	3:1	28	106	3.3	1.0	0.3	1.1	25	0.6
11	2	1.8	4.0	28	3:1	23	85	1.0	0.3	0.9	2.8	22	0.6
12	4	1.8	4.0	28	3:1	45	170	0.6	0.3	1.7	5.6	29	0.7
13*	4	1.8	4.0	28	2:1	50	189	0.6	0.1	3.2	10.4	40	1.0
14*	2	2.0	6.0	41	3:1	26	97	0.6	0.1	1.6	5.4	42	1.1
15*	4	1.8	6.0	41	3:1	51	193	0.6	0.1	3.2	10.6	60	1.5
16*	2	2.0	4.0	28	2:1	20	77	0.6	0.1	1.3	4.3	39	1.0
17*	2	2.0	4.0	28	3:1	21	80	0.6	0.1	1.3	4.4	39	1.0
18*	4	1.8	4.0	28	3:1	51	193	0.6	0.1	3.2	0.6	39	1.0
19*	2	1.8	6.0	41	3:1	29	108	1.0	0.3	1.1	3.6	38	1.0
20*	2	1.8	6.0	41	3:1	29	108	0.6	0.1	1.8	5.9	39	1.0
21*	2	2.0	6.0	41	3:1	26	97	1.0	0.3	1.0	3.2	42	1.1
22*	2	2.2	6.0	41	3:1	31	117	1.0	0.3	1.2	3.9	45	1.1
23*	2	2.0	6.0	41	3:1	31	117	0.6	0.1	2.0	6.5	44	1.1
24	4	1.8	6.0	41	3:1	52	197	1.0	0.3	2.0	6.5	51	1.3
25	2	2.0	6.0	41	3:1	25	95	1.0	0.3	1.0	3.1	41	1.0
26	2	2.2	6.0	41	3:1	31	117	1.0	0.3	1.2	3.9	49	1.3
27	2	2.2	6.0	41	3:1	32	121	0.6	0.1	2.0	6.7	35	0.9
28	2	2.0	6.0	41	3:1	25	95	0.6	0.1	1.6	5.2	36	0.9
29#	2	1.8	6.0	41	3:1	28	106	0.6	0.1	1.8	5.8	30	0.8
30#	2	2.2	6.0	41	3:1	31	117	1.0	0.3	1.2	3.9	49	1.3

NOTES:

Test Nos. 1 through 12 performed in moist, fine sand, above water table.

Test No. 4 invalid – not reported.

Values rounded for presentation.

+ By volume.

° x 1,00.

\* Test performed in 60" diameter cylinders with simulated water head.

# Set of four connecting columns in alternating sequence 2'0" O.C.



**Figure 5. Single Excavated Column from Test Program**

In addition to the installation of the test columns, the test program included laboratory testing of various grout mixes, and the installation of supplementary test borings at the test program site and beneath the pier at several locations, to establish the similarity of soil types.

Analysis of data obtained in the test program indicated that the optimum combination of jet grouting construction parameters for this project were as follows:

- Pressure: 6,000 p.s.i. (40 MN/m<sup>2</sup>)
  - Lift Rate: 0.6 to 1.0 foot per minute  
(0.18 to 0.30 meters per minute)
  - Number of Nozzles: 2
  - Nozzle Diameter: 2.0 to 2.2 mm
  - Grout Mixture: 2:1 water to cement ratio by volume  
(Type I Portland Cement)
  - Injection Rate: 2 bags cement per foot (6.56 bags per meter)
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## **VERIFICATION SECTION**

The jet grouting work on the verification section was also performed using a single stem jet system while the twin stem system was being assembled onsite. This work was performed with conventional equipment working from the top of the pier by first coring an access hole through the existing six-foot (1.8 meter) thick reinforced concrete pier. A steel casing was then set from the top of the pier, through the water and into the top of the underlying soils in order to maintain alignment of the jet stem.

The jet stem was lowered through this alignment casing and then drilled to plan depth using water flushing through the fishtail type bit attached at its base. The flushing ports in the bit were then closed and individual column formation begun by the injection of neat cement grout through the jet nozzles in accordance with the parameters established from the test program.

Starting seven days after the first group of columns was placed in this section, soilcrete coring operations began to obtain samples to verify soilcrete quality, continuity, and strength characteristics.

The initial sampling technique of NX wire line coring with water as the flushing medium proved to be ineffective in obtaining high quality, continuous soilcrete samples. Observations of the core samples indicated that the early strength characteristics of the soilcrete resembled those of a very stiff cemented soil or a very weak rock, which are not easily recovered by standard coring techniques. As a result, not only were modifications to the sampling technique required, but it had to be determined what technical variables had contributed to the soilcrete having lower initial strengths than had been originally anticipated.

After all jet grouting construction parameters had been reviewed and verified, it was speculated that depressed water and soil temperatures and organic content of the native soils may have had a significant impact on set time of the soilcrete. Sampling techniques were varied until the use of a polymer based drilling fluid used in conjunction with a modified Dennison Sampler with a special set diamond bit proved consistently effective in producing high percentage core recovery. In addition, the resultant core was of a larger diameter (approximately 2.5 in./63.5 mm) than the NX barrel (approximately 1.5 in./38 mm).

Evaluation of the above factors together with the results of laboratory testing of soilcrete samples, which will be discussed in a subsequent section, led to the determination that production work could proceed as originally planned.

## **PRODUCTION PROGRAM**

As in the verification section, the first step in the production program was the coring of access holes through the existing 6 foot (1.8 meter) thick heavily reinforced concrete pier. This work was accomplished using up to six standard concrete coring stands (Figure 6) to core over 1,400 holes. A drill template was

utilized to maintain the spacing of pairs of access holes at 22 inches (559 mm) on center.



**Figure 6. Coring of Access Holes Through Pier**

Since the existing pier facilities operated 24 hours per day, 7 days per week, all of the jet drilling and grouting equipment was mounted on a 40 feet (12 meters) by 120 feet (37 meters) barge for mobility (Figure 7). This allowed the equipment to be relocated at will winching or by tug so as not to interfere with pier operations.



**Figure 7. Barge Mounted Equipment**

The grout mixing equipment consisted of a custom built, high volume, and fully automated, high speed colloidal mixing plant (Figure 8). This plant provided sufficient quantity of grout, on demand, to supply both jet rods at a total flow of over 50 gallons (189 liters) per minute for an average of 45 minutes each hour, up to 24 hours per day (2 shifts), 5 to 6 days per week.



**Figure 8. Custom Built, Fully Automated Colloidal Mixing Plant**

Pumping equipment consisted of two (one standby) 350 HP high pressure triplex piston pumps, capable of working pressures up to 20,000 psi (138 MN/m<sup>2</sup>) (Figure 9).



**Figure 9. High Pressure Triplex Piston Pumps**

The drilling and extraction equipment consisted of a crane mounted system utilizing a tubular set of leads. This equipment supported two sets of jet rods, each 80 feet (24 meters) long. As an aid in maintaining alignment through the water and during drilling operations, 3.5 inch (9990mm) diameter jet rods with and approximate 1 inch (25 mm) wall thickness were used (Figure 10). Automated drill and extraction controls were mounted at the base of the leads, adjacent to the jet rods. These controls included: spotter alignment (two axis), spotter elevation, lead rotational alignment, drilling rate, jet stem rotation speed, jet stem center to center spacing, automated lifting controlled increments and set cutoff at predetermined elevation (Figure 11).



**Figure 10. Jet System and Control Panel**

## **LABORATORY TESTING**

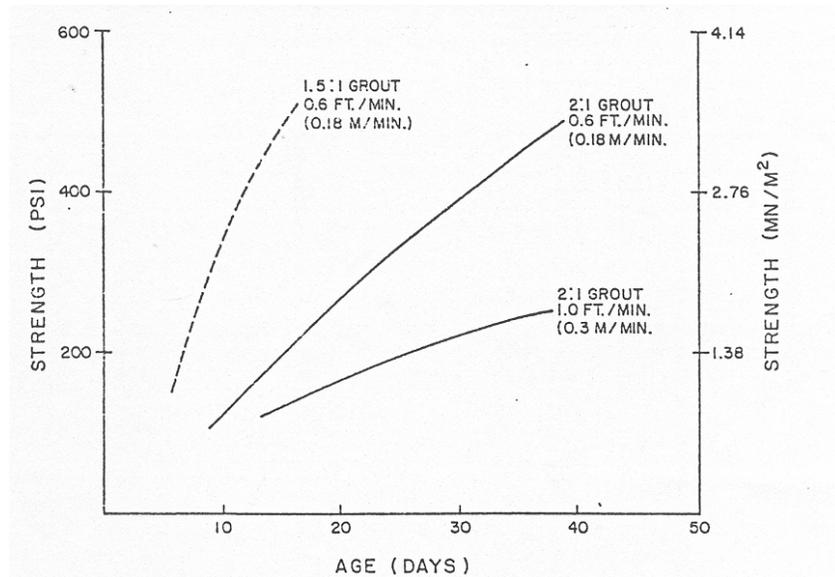
Initial laboratory testing of the soilcrete samples obtained in the test section and early phases of production work consisted primarily of unconfined compressive tests. Figure 12 shows a plot of unconfined compressive strength with time of some of the initial testing performed on verification section samples with a 2:1 grout as well as that from the limited injection of a 1.5:1 grout. As can be seen, the 2:1 grout at a lift rate of 0.6 foot (0.18 meter) per minute indicates a continuing upward trend, but project timing did not accommodate its verification. The 1.5:1 grout shows a much steeper curve and was much more readily acceptable from a technical standpoint, but the increased cement usage on a project of this size made the 1.5:1 grout unattractive financially. As a result, alternative verification testing methods were investigated.

Since the primary design consideration in this application was the shear strength of the soilcrete material, direct shear tests were performed to augment the previously performed unconfined compressive strength tests. While specific



**Figure 11. Automated Drill and Extraction Controls**

design details and results of long term testing are not available for publication, it is known that the results of direct shear tests performed verified that the soilcrete material installed with a 2:1 grout and a 0.6 foot (0.18 meter) per minute lift rate consistently satisfied minimum design criteria. Analysis of the above data also indicated that reliable test results could only consistently be obtained from samples that had attained an in-situ cure time of 30 days.



**Figure 12. Plot to Initial Soilcrete Strength Gain Trends**

As a result of the above observations and indications, construction verification procedures for the work were modified to allow 30 days in-situ cure time prior to sample retrieval, and the use of direct shear tests to determine the adequacy of the installed soilcrete panel wall.

## **CONCLUSIONS**

While the double stem jet grouting system that was custom designed and fabricated for use on this project more than satisfied the obvious production and cost advantages originally anticipated, a perhaps equally significant benefit in the continuing development of jet grouting technology is the apparent technical superiority of the soilcrete formed by the double stem system.

During verification coring of the soilcrete wall in which the double stem jet system was used, it was visually apparent that the soilcrete cores were more consistent and of better quality than the soilcrete cores obtained from the verification section in which the single stem system was utilized. As previously stated, specific results of long term testing are not available for publication, but it can be generalized that these visual observations were confirmed by a much higher percentage of core recovery with the double stem system and by results of testing which indicated that the double stem system yielded material of higher average strength than that obtained with the single stem system using otherwise equivalent construction parameters. It is believed that this improved quality is largely attributable to the greater turbulence of the two jet stems working simultaneously approximately 2 feet (0.61 meters) apart, resulting in a more thoroughly mixed end product.

As a result, the double stem system as used on this project not only provided overall decreases in labor and equipment production costs, but appears to have resulted in a reduction in material costs over what might have been required with a single stem system for the installation of an equivalent end product. It is believed that these developments will enhance the continuing acceptance of the jet grouting technique in the U.S. by strengthening its position as a technically and economically viable alternative to more conventional techniques.

## **REFERENCES**

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2. GA Munfakh, et al., In-Situ Ground Reinforcement, Soil Improvement – A Ten Year Update, Geotechnical Special Publication No. 12, ASCE Convention, Atlantic City, NJ, Apr 1987, 43-55.