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Countermeasure Construction Using Jet Grouting Methods to Combat Foundation Scour

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Abstract

There is substantial information on the prediction and performance of bridges and other coastal construction due to the damaging effects of scour. Currently, predictions are formulated by using numerical modeling software. In general this software is based upon historical data of stream flows or coastal storms and does not take into account unusual extremes in precipitation causing inaccuracies. When unpredicted extreme weather events do take place, calculated scour patterns can change resulting in serious foundation damage to structures. Countermeasure construction must be employed to repair damage and the compromise of crucial foundations. Jet grouting has been successfully used for many years to repair foundations damaged by scour as well as to construct scour protection in situ. Four projects are described in this paper, to demonstrate the value and acceptance of jet grouting as a countermeasure construction for combating scour for both bridge and coastal structures.

Introduction

Many structures adjacent to and across waterways have suffered the effects of scour on foundations. According to documented information, in the United States alone more than 500 bridges have suffered significant damage on their foundation elements in just the past 30 years (Shirole and Holt 1991). The number of coastal structure collapses directly caused by large coastal storms is not as well documented.

There is substantial information that indicates that maximum scour depth in coarse-grained soils usually occurs during the first major flood event. However in fine-grained soils the process may take years and is not as predictable.

The current practice for predicting scour is to use the numerical modeling technique provided in HEC-18 and HEC-20. The use of this water-flow modeling

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software usually makes it possible to design structures to proper depths to prevent the detrimental effects of scour. But the impact of unusual storm patterns cannot be predicted by using hydraulic models. As a result, in spite of the use of water-flow modeling, structures can be undermined or damaged. In such cases, jet grouting can be used to prevent further scour of the foundation soils and ultimately extend the life of the structure. With coastal structures, jet grouting can be used to decrease the susceptibility of the structure to the effects of scour.

Because jet grouting has been used successfully in many ground improvement projects, it has gained wide acceptance throughout the world. In the United States, this acceptance began during the late 1980's, and since then it has become more than just an underpinning tool. Jet grouting has been defined by the ASCE Geotechnical Engineering Division Committee on Grouting (1980) as a "technique utilizing a special drill bit with horizontal and vertical high speed water jets to excavate alluvial soils and produce hard impervious columns by pumping grouts through the horizontal nozzles that jets and mixes the foundation material as the drill bit is withdrawn." Figure 1 shows how the jet grouting process is carried out in sequence, while Figure 2 depicts the three methods of jet grouting currently practiced in the United States.

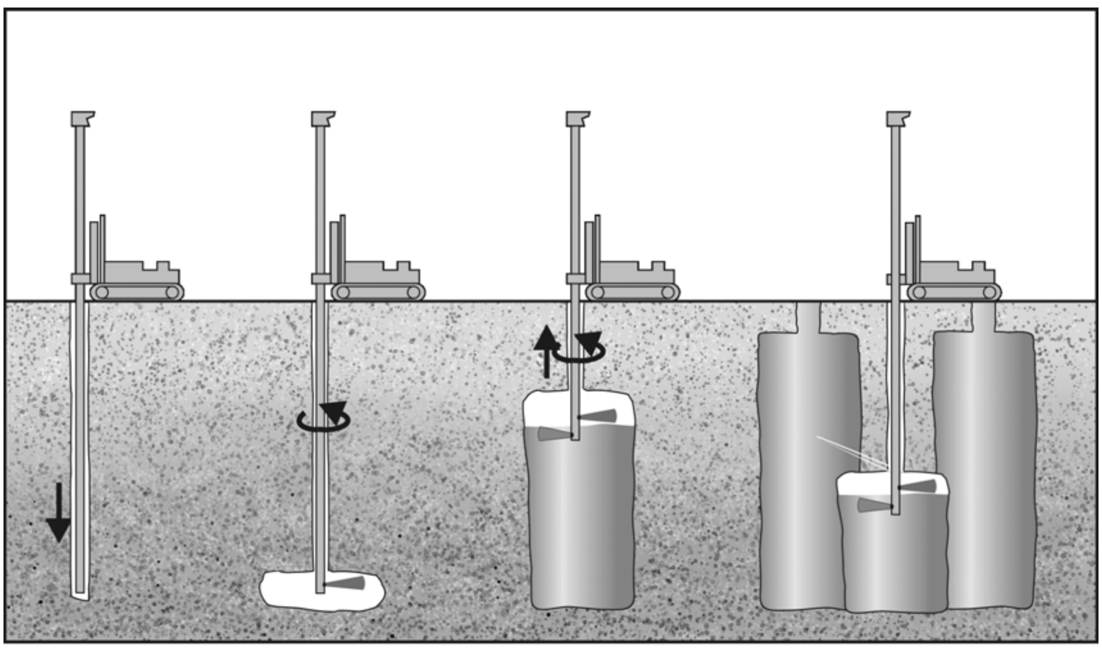

Figure 1. Jet grouting construction sequence, from Hayward Baker

Compared to any other grouting system, jet grouting is effective across the widest range of soil types, including silts and clays. Because it is a soil erosion-based system, geometry and quality can be predicted. The quality of the final jet grout product, often referred to as soilcrete (Burke and others 1992), is dependent on the soil types being jetted. Cohesionless soils typically erode more easily than cohesive soils as shown in Figure 3. Sands and gravels generally provide the highest strength, and clays provide the lowest (Figure 4). The result of higher strengths in granular materials is due to sands and gravels providing a better aggregate within the soilcrete matrix as opposed to cohesive materials, which provide soft inclusions within the soilcrete matrix.

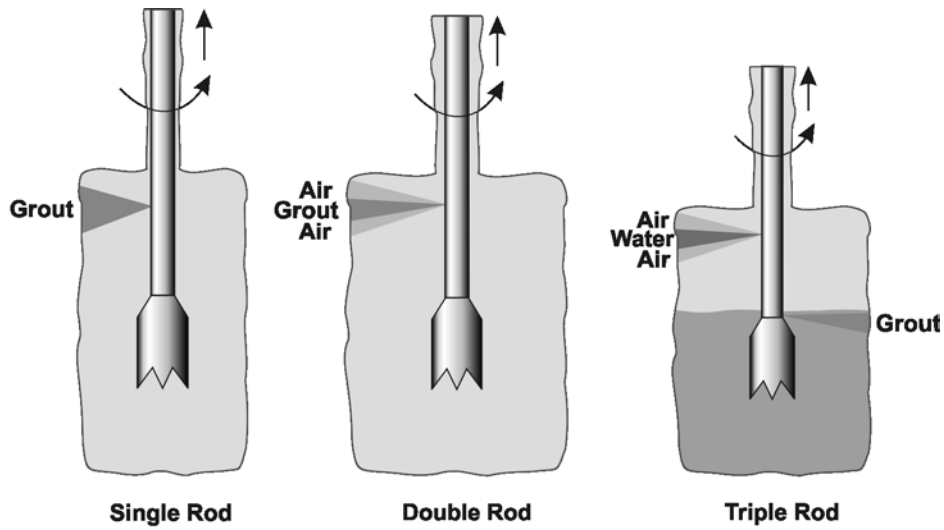

Figure 2. Jet grouting types, Single, Double and Triple fluid, from Hayward Baker

Figure 3. Erodibility scale for jet grouting systems, from Hayward Baker

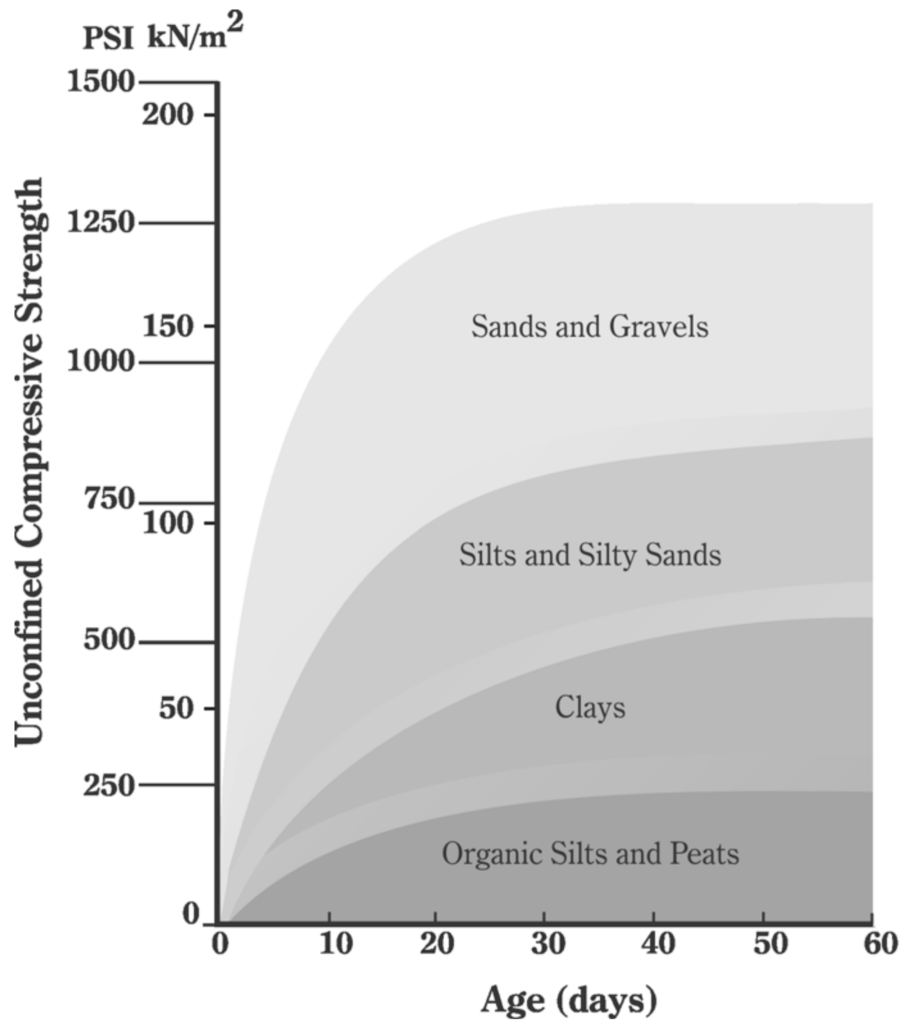

Figure 4. Typical strengths obtainable with jet grouting in various soil types, from Hayward Baker

To demonstrate the effective use of jet grouting as a scour countermeasure to repair or prevent the future impact of scour on structures, four projects are described in this paper. These projects are:

- **Old US-80 Highway Bridge at Gila River** in Maricopa County, Arizona, where jet grouting was used for scour repair and to arrest future scour of several affected bridge piers.
- **Highway 60 Bridge at Salt River** in Salt River Canyon, Arizona, where jet grouting was used to halt the further advancement of scour on an existing bridge footing.
- **CSX Railroad Bridge over the Conasauga River** in Conasauga, Tennessee, where jet grouting was used to halt the further advancement of scour on an existing bridge footing.

- **Bally's Park Place Hotel and Casino** in Atlantic City, New Jersey, where jet grouting was used to construct a barrier wall to minimize the future risk of coastal scour to the existing foundation.

Old US-80 Highway Bridge At Gila River

The Old US-80 Highway Bridge in Maricopa County, Arizona, over the Gila River is a nine span trestle type bridge constructed in the early 1900's. The bridge is situated approximately 91.44 meters (100 yds) downstream from Gillespie Dam, which controls downstream flows during heavy periods of upstream rains (Figure 5). The bridge's founding structure is composed of large concrete pedestal type piers founded upon caliche hardpan (Figure 6). During heavy desert monsoon rains in 1993, the dam failed, sending water in volumes of up to 4,248 cubic meters per second (150,000 cfs) downstream (Figure 7). The early 1900's bridge design did not allow for the structural endurance for such an event. As a result, the high velocity of water against the existing bridge created scour on the three eastern most piers. Pier numbers two, three and four suffered some minor cracking, which extended vertically down the center of the pedestal.

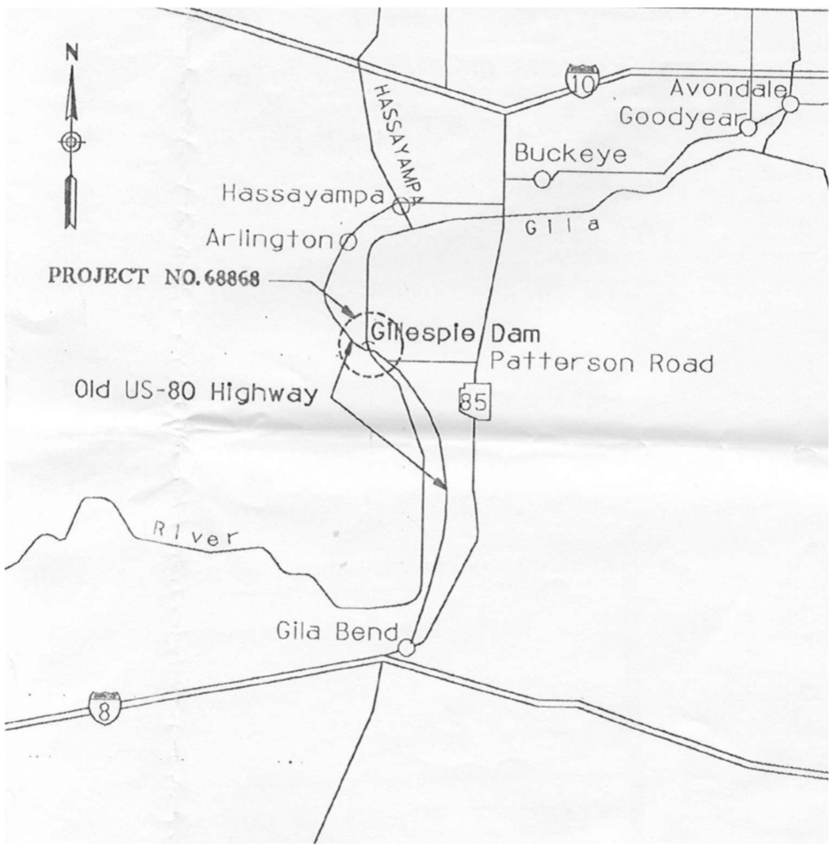

Figure 5. Site vicinity map from the Gillespie Dam project, from original contract documents

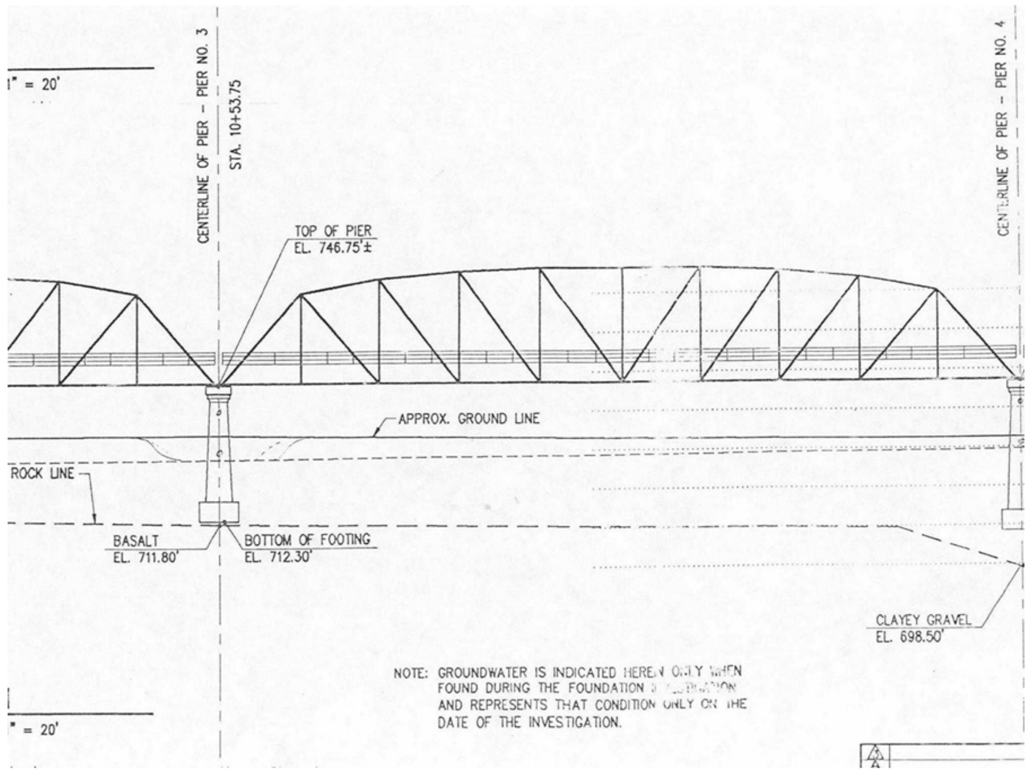

Figure 6. Elevation of typical span of the US-80 bridge over the Gila River, from construction documents

Figure 7. Failed portion of the Gillespie Dam just upstream from the US-80 Bridge

Once stream flows subsided, a geotechnical investigation of the foundation soils was performed near the affected piers of the bridge. All of the borings were performed from the existing streambed. The abutment and Pier number one was not damaged during the flood. Pier number two was constructed just below the rock line and Pier number three just above it. Pier number four was found to be constructed some six to ten feet above the existing rock line. The profile for the boring taken at Pier number four showed sands and gravels to a depth of 7.3 meters (24 ft) and then 1.8 meters (6 ft) of sandy clay overlying hard basalt (Figure 8).

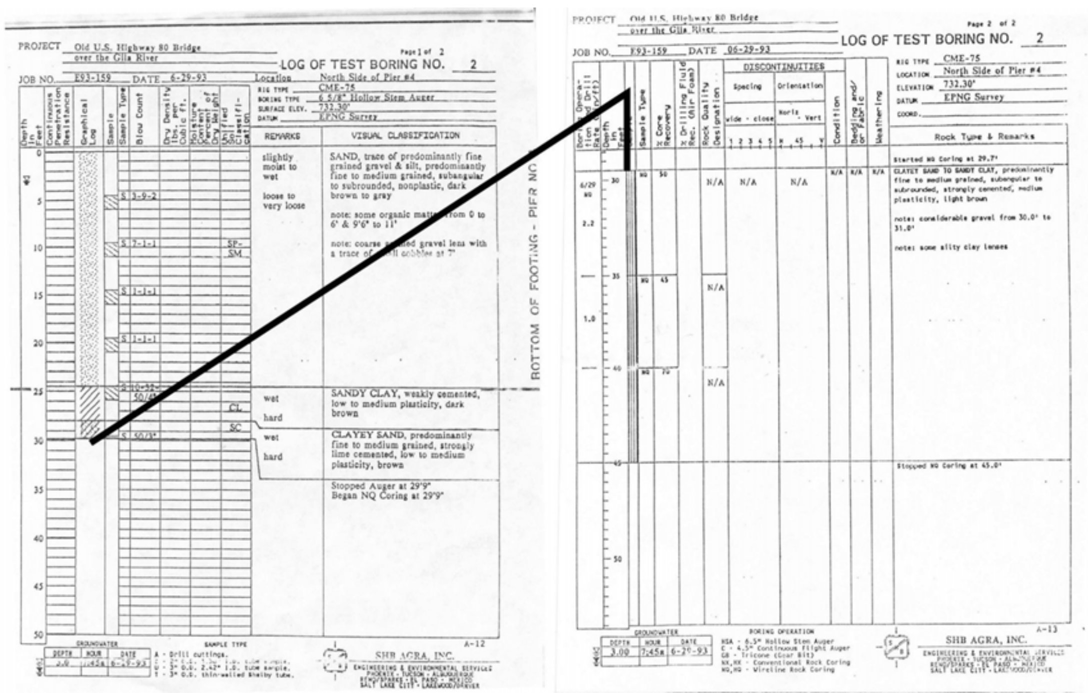

Figure 8. Log of test boring no. 2 taken at the site, from construction documents

During the review of repair options, jet grouting was determined to provide the most economical method to underpin and extend the life of the structure. Other underpinning options such as minipiles were found to be to time consuming to implement and not cost effective. Interconnected jet grout columns, 0.9 meters (3 ft) in diameter, were constructed along the upstream face of each of the three piers. The jet grout columns were installed from 0.9 meters (3 ft) above the foundation and socketed a minimum of 0.3 meters (1 ft) into the underlying basalt (Figure 9).

Prior to the start of production jet grouting, a section was tested to confirm that the minimum column diameter could be achieved in the foundation soils. The geometry of the jet grout columns was initially verified using feeler pipes, and was later visually inspected during excavation. In total some 81-jet grout columns were installed around each of the three piers using the triple system fluid of jet grouting. Soilcrete unconfined compressive strength from samples taken at the site ranged from 4.8 to 16.5 MPa (700 to 2,400 psi), depending upon the stratum being eroded during the sampling.

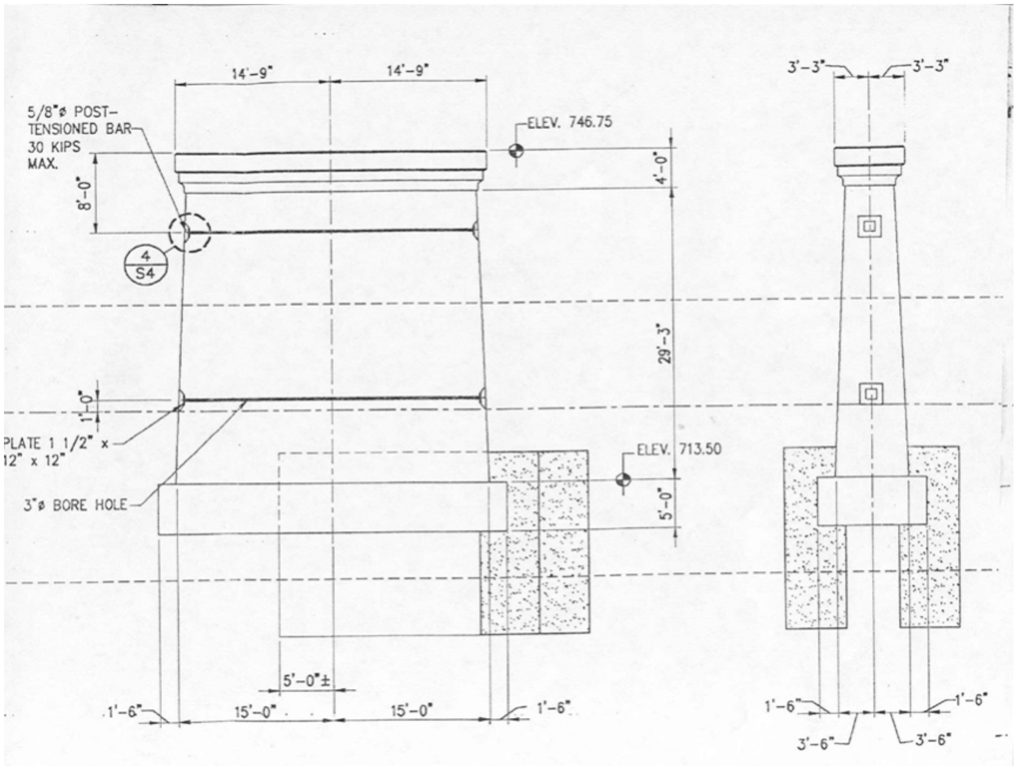

Figure 9. Jet grouting details for the repair of the scour damage, from US-80 construction documents

Highway 60 Bridge At Salt River

A new Highway 60 Bridge over the Salt River, located some 193 km (120 miles) east of Phoenix, Arizona, was constructed in 1993, some distance downstream from the original heavily traveled structure. During the construction period, excessive rains significantly increased the river flow to some 9.1 meters (30 ft) above normal, which was high enough to surround the new bridge abutment. Most of the canyon walls beneath the bridge are shear rock faces. Once the flow of the river subsided, an area immediately adjacent to the new abutment, which was thought to be rock face, was scoured out. This scour hole measured approximately 9.1 meters (30 ft) wide and 6.1 meters (20 ft) deep and threatened the newly constructed bridge abutment footing. The excessive volume and flow of water in the river also washed out the access road beneath the bridge.

The Arizona Department of Transportation (ADOT) quickly assessed the situation and determined that jet grouting of the soils beneath the water line, coupled with an above grade retaining wall constructed between the two sides of the scour hole, would provide a rapid solution to the scour problem. The existing soils at the site consisted of sands and gravel alluvium extending to a depth of some 3.1 to 6.1 meters (10 to 20 ft) below existing grade, with rock below this depth. The design called for three rows of interconnected jet grout columns to fill the scour hole below the normal river elevation (Figure 10).

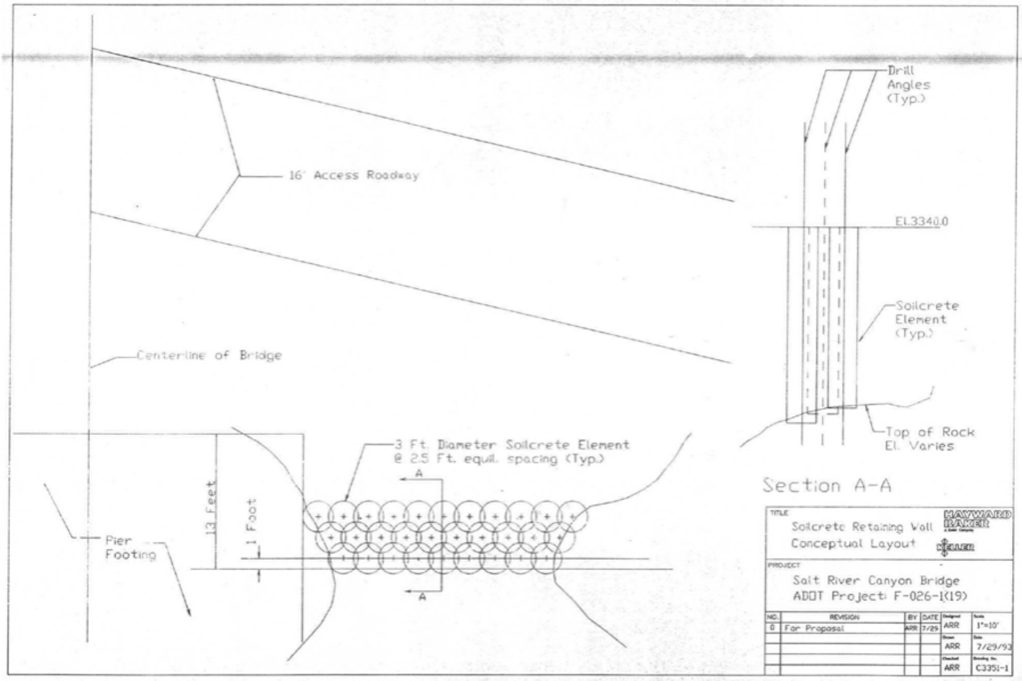

Figure 10. Layout of the jet grout columns surrounding the scour hole.

Figure 11. Completed repair of scour hole

Triple fluid system jet grouting was performed to construct 30, 0.9 meter (3 ft) diameter columns. Because of the tight working area and the loss of access roads, heavy cranes were used to place the jet grouting equipment near the problem area. Special precautions were taken to ensure that none of the jet grout backflow entered into the river. Following construction of the jet grout wall, a new retaining wall was constructed to complete the repair (Figure 11).

CSX Railroad Bridge Over The Conasauga River

The CSX Bridge is a single-track railroad bridge composed of a steel main truss span, supported on each side of the river by a concrete pier. The piers are rectangular in shape, with a semi-oval upstream face, and are orientated with its long axis extending East-West. The track, originally constructed in 1905, runs in a general North-South direction. Approximately 30 to 40 trains cross the bridge per day. It was discovered that during a four-year period, the South pier was rotating towards the South and slightly towards the Southeast. This movement was measured at approximately three to four inches and was probably caused by scour during periods of high flow. In 1990, CSX hired consultants to provide a soils report on the existing ground conditions.

The investigation showed the subsurface conditions beneath the pier consisted of a zone of boulders in a matrix of loose sands ranging in thickness from 1.1 to 7.5 meters (3.5 to 24.5 ft), founded upon hard to moderately hard limestone bedrock (Figure 12). This matrix of soil between the boulders allowed scour to occur beneath the pier and was most likely accelerated during the heavy rains and flooding that occurred in 1989.

To protect the bridge pier against further scour, triple fluid system jet grouting was performed. The use of jet grouting would ensure transfer of all structural loads to the underlying limestone bedrock. Core drilling of the jet grout column was used to confirm the column strength and diameter of 1.1 meter (3.5 ft) (Figure 13). The core pieces as well as samples retrieved during production were tested for unconfined compressive strength to ensure that the 3.5 MPa (500-psi) design strength was met. The compressive strength testing performed on all samples averaged over 4.8 MPa (700 psi). In all, some 30 vertical and battered columns were installed to underpin the existing railroad bridge pier (Figure 14).

Bally's Park Place Hotel And Casino In Atlantic City, New Jersey

Atlantic City ordinance requires that any foundation system constructed above elevation – 10 be protected against the potential effects of scour caused by coastal storm events. Consulting engineers for Bally's Park Place Hotel and Casino accepted a jet grout solution to provide an in situ barrier to resist scour of the foundation, especially because the proximity of the Casino to historic structures precluded the use of driven or jetted sheetpile barriers. . There is sufficient documentation in the industry (Droof and others, 1995) to support the underpinning of historical structures with jet grouting. This new scour protection wall was constructed in beach sands and extended 76.2 meters (250 ft) along the Boardwalk and had a 34.5 meter (100 ft) long perpendicular return at one end.

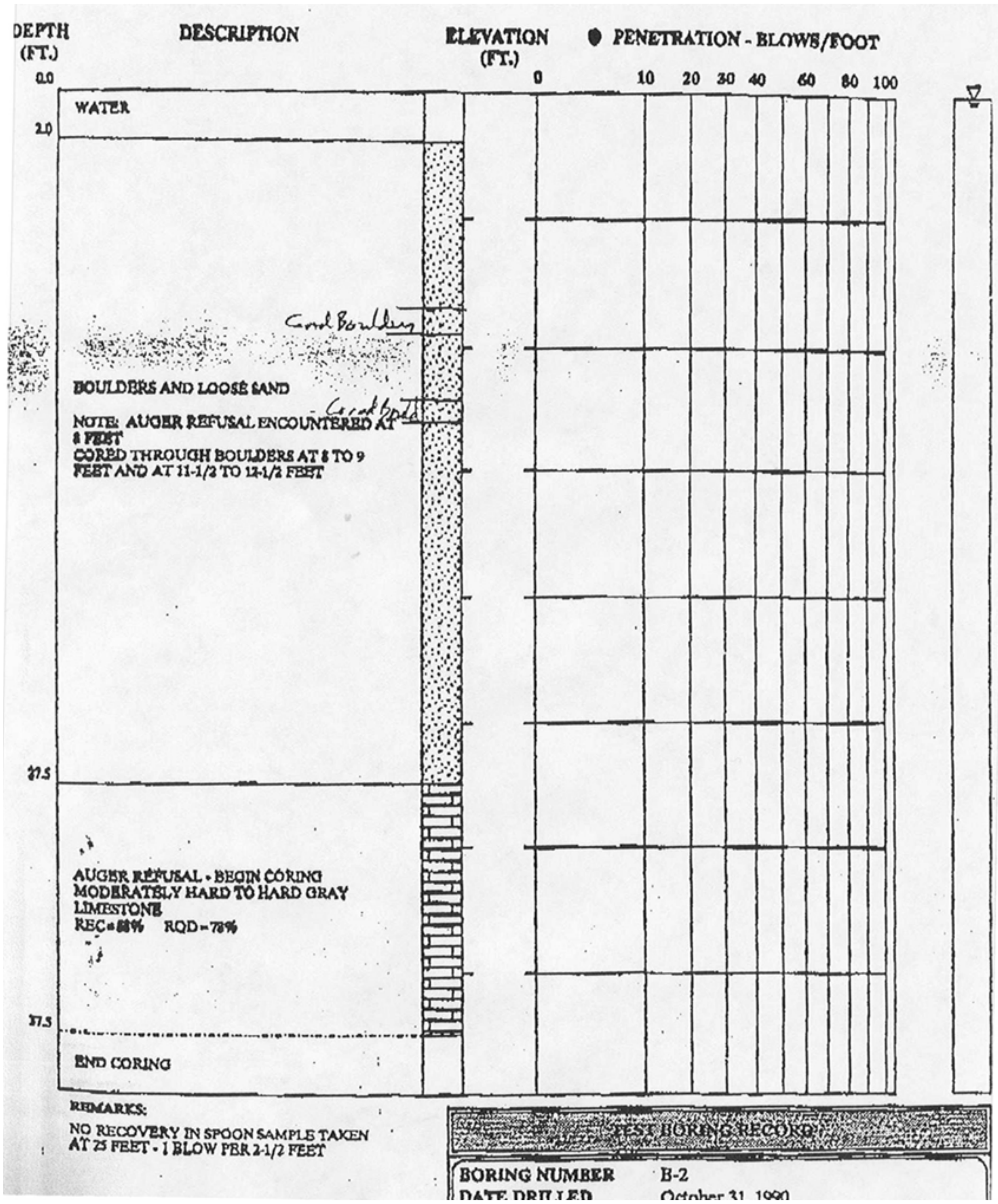

Figure 12. Boring taken from the site near the scoured Bridge Pier, from construction documents

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Soilcrete Coring Log

Job No. J0510	Hole #1	Surf. Elev. --	Sheet No. of
Project CSX Conasauga Pier		Soilcrete Age 5 to 7 days	Date 7/16/91
			Driller Mark Gunter
			Inspector Allen Furth

A	B	C	D	E	F	G	H	
Run No.	Depth & Time From	Depth & Time To	Run Length	Recvd Length	E ÷ D Recovery %	Total Length of pieces ≥ Diameter	G ÷ E SQD	Description and Remarks*
1	0 / 11:05	4'2" / 12:35	50"	50"	100%	10"	0.2	Large cobbles: 30 - 40% gravels No Soilcrete
2	4'2" / 12:55	8'2" / 1:24	48"	48"	100%	43"	0.89	Top 9" concrete: Soilcrete with trace gravels, trace inclusions
3	8'2" / 1:45	12'2" / 2:10	48"	48"	100%	23"	0.48	Soilcrete: Trace boulders and cobbles Limestone rock at 8 feet.
4	12'2" / 2:30	16'0" / 3:30	46"	36"	75%	21"	0.58	Soilcrete: 10 - 20% gravels Large cobbles at 12 feet.
5	16'0" / 4:10	19'0" / 4:41	36"	34"	94%	21"	0.62	16 inch piece of limestone/ bedrock @ bottom of core 70 - 80% large gravels and cobbles.
EOC								
		Totals:	19'0"	18'0"	94.7%			

* Indicate drilling fluid losses, down pressures, inclusions, cement odor, physical description and a degree of mixing.

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Figure 13. Core recovery results from a production jet grout column

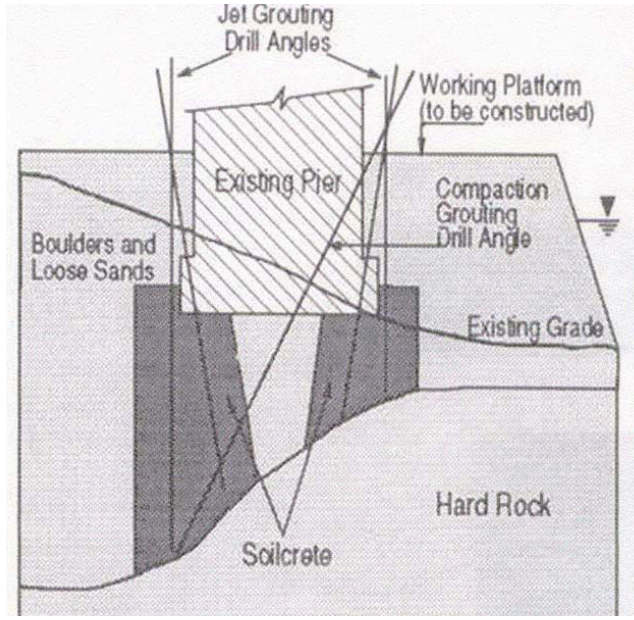

Figure 14. Cross section of jet grouting repair at the CSX Bridge

Jet grouting was performed using the double fluid system to construct five-foot diameter columns on 1.2 meter (4 ft) centers to the required depth of 4.6 meters (15 ft) below existing grade (Figure 15). The jet grout columns also supported loads from the structure where they coincided with each other. This would have been a difficult task using any other form of barrier wall. During the production work, jet grout wet samples taken exceeded the minimum required compressive strength of 5.5 MPa (800 psi). Jet grouting was also able to circumvent obstacles in the existing below grade soils. These obstacles, such as tie rods and dead man anchors, were once used to support an old bulkhead along the existing Boardwalk.

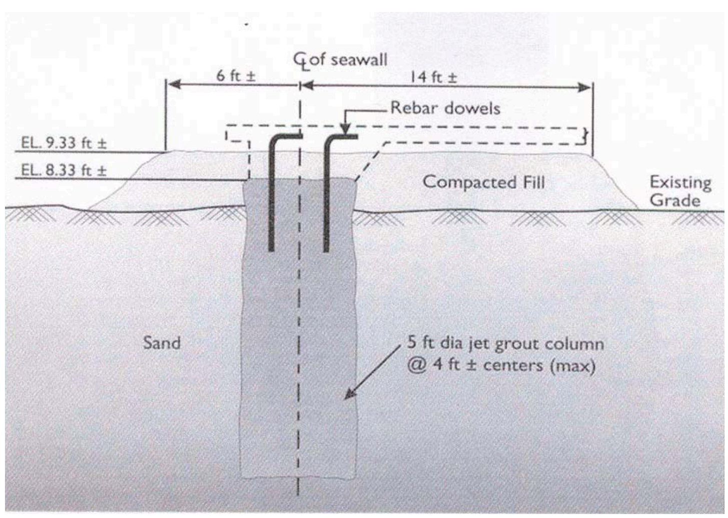

Figure 15. Cross section of jet grout scour barrier installed at Bally's Park Place Hotel and Casino

CONCLUSIONS

Jet grouting has gained a wide acceptance within the United States in the past decade and as a result, consulting engineers and other authorities have recommended it as a solution for a range of problems beyond conventional underpinning. The above case histories demonstrate how jet grouting can reduce the effects of scour, prevent scour or substantially extend the life of a structure subjected to the effects of scour. At the same time, jet grouting provides a solution that can be performed economically and quickly, insitu. These case histories also demonstrate how jet grouting can be done from above the effected structure without creating excavations or building structural connections to the existing structures. It is for these two reasons, that jet grouting provided the most economical approach in the repair of these structures. All of the repaired structures have been subjected to flooding, high stream flows and coastal storms since they have been repaired with jet grouting and have shown no signs of movement or additional scour.

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