

A Case Study: Unreinforced Soil Mixing for Excavation Support and Bearing Capacity Improvement

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ABSTRACT

Soil mixing is widely used for environmental site remediation and ground improvement. The main objectives of soil mixing are to increase the strength and decrease the permeability of the soils. Conventionally, unreinforced soil mixing is an uncommon choice for an excavation support system, but a recent case study highlights the potential advantages of using a single technology to accomplish multiple site objectives.

The case study provides an overview of the site history, of the design methodology, and of the installation methods used in Lexington, VA. The work was performed in April and May of 2010. Wet “grab” soil-grout samples were collected immediately following installation. All of the soil-grout quality control samples achieved the project design minimum of 100 lbs/in² (~690 kPa) in less than 28 days of curing.

INTRODUCTION

Soil mixing (SM), also known as auger mixing, *in situ* soil mixing (ISSM), *in situ* stabilization (ISS), and shallow soil mixing (SSM), is widely used in environmental site remediation and ground improvement applications. Generally mixing augers with diameters of between four and eight feet are drilled into the ground while a liquid reagent blend is added to and blended with the native soils. Soil mixing has been previously discussed; Ryan and Walker (1992), Day and Ryan (1995), Bruce (2003) and Larsson (2005) as a start. The construction processes vary from auger mixing to rotary mixing, from single auger to multi auger, from *in situ* to *ex situ*, but the purpose of soil mixing is the efficient creation of composite mixtures with higher strength and lower permeability than the *in situ* soils. Frequently this objective is accomplished through the addition of Portland cement alone or in combination with bentonite, blast furnace slag, cement kiln dust, or flyash, among other additives. Unreinforced soil mixing has not been widely employed for excavation support in comparison to more conventional retaining wall construction methods in the United States, but a recent case study highlights the advantages of using a single technology to accomplish multiple site objectives.

For the project, single auger soil mixing was used for the installation of an 8-foot (~2.4 m) thick soil-grout gravity retaining wall for temporary excavation support, as well as 3-foot (~0.9 m) diameter soil-grout columns for bearing capacity improvement beneath permanent building foundations. The case study highlights

aspects of the subsurface investigations used to characterize the site followed by discussion of the design basis and construction methods, and finishes with conclusions about the project in Lexington, VA.

PROJECT BACKGROUND

The Phase I site history/subsurface investigation was conducted in 2008. The site is located in downtown Lexington, VA. The site was the location of various retail businesses from 1886 to 1930 at which point the site was converted to a gas station. At some unknown time between 1930 and 2010, the gas station was removed and replaced by an asphalt parking lot. Aerial photographs uncovered in the site history exploration indicated the presence of at least three underground storage tanks (USTs) located beneath the asphalt parking lot, presumably used for gasoline storage.

Generally, the site is underlain by limestone and calcareous shale bedrock and the soils encountered in the Phase I geotechnical study were consistent with residual soils created by the weathering of these bedrocks. Two borings were conducted during the Phase I investigation. Analytical test results indicated that the site soils contained small amounts of gasoline range organics (GRO) with levels in the soils ranging from >2 to 140 mg/kg. The conclusions of this report indicated that the contamination was not of a concerning level and would not pose a threat to human health in future site uses. (ECS 2008)

A Phase II geotechnical study was conducted in the fall of 2009. Six borings were advanced down to the weathered bedrock within the proposed footprint of the building. The conclusions of this report stated that the maximum allowable bearing capacity of the site soils was 1500 lbs/ft² (~72 kPa) and the maximum allowable bearing capacity of the site bedrock was 4000 lbs/ft² (~192 kPa). Partially due to the presence of petroleum or petroleum by-products in the site soils, *in situ* soil mixing was recommended as a means of transferring the building column and footing loads from the surface down to the bedrock. The *in situ* stabilization method is used to minimize disposal of and exposure to contaminated soils. (CEA 2009)

DESIGN JUSTIFICATION

The project specifications listed steel sheet piles for use in the basement excavation support system, but the construction team presented an alternate approach utilizing soil mixing for both excavation support and bearing capacity improvement. The construction team was tasked with supporting the use of soil mixing in both the excavation support and bearing capacity improvement applications.

Bearing capacity analysis was conducted on the soil-grout mixture to determine the ultimate bearing capacity of the improved subsurface (CEC 2010). The design specified a minimum unconfined compressive strength of the soil-grout mixture equal to 100 lbs/in² (~690 kPa), a value that could be achieved within a reasonable timeframe (< 28 days). Initial bearing capacity analyses were performed using traditional Terzaghi analysis methods, and the analyses were further verified using the Meyerhof method to incorporate shape- and depth-specific factors. The bearing capacity analysis indicated that, with a minimum factor of safety of 3, the 100 lbs/in²

(~690 kPa) soil-grout mixture would be sufficient to provide the 4000 lb/ft² (~192 kPa) bearing capacity required for the future building.

Following the bearing capacity analysis, the global and internal stability of the soil-grout retaining wall were analyzed. The soil-grout retaining wall was designed for use as a temporary gravity retaining wall. The generalized cross-section used for the excavation support stability calculations is shown in Figure 1.

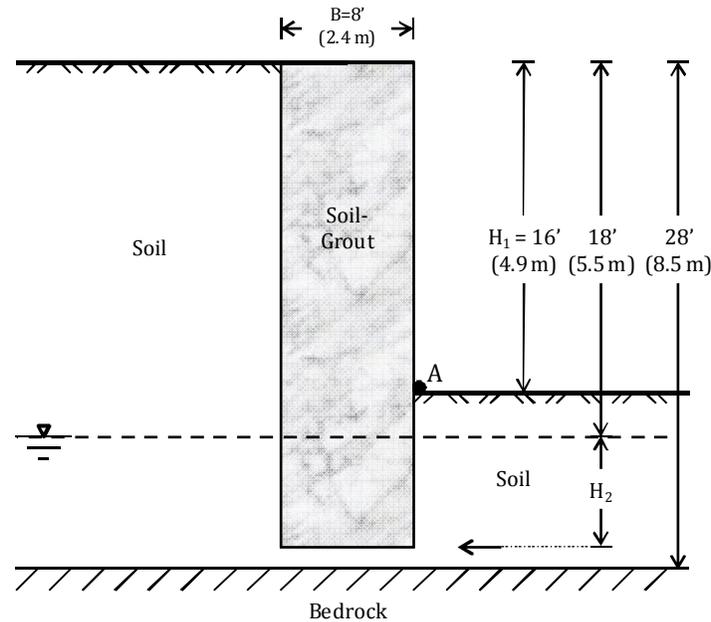


FIG 1. Generalized Cross-Section used in Excavation Support Stability Calculations (redrawn after CEC 2010)

The factor of safety for the temporary retaining wall was calculated for five failure modes; sliding, shear, overturning, bearing capacity, and global stability. The assumed soil and soil-grout mixture properties used in the calculations are shown on Table 1.

TABLE 1. Properties used in the Retaining Wall Failure Analysis (CEC 2010)

Soil Type	γ (lbs/ft ³)	γ (kN/m ³)	γ_{sat} (lbs/ft ³)	γ_{sat} (kN/m ³)	Φ (deg)	Cohesion (lbs/ft ²)	Cohesion (kPa)
<i>In Situ</i> Clay	115 ^a	18.1	125 ^b	19.6	28	200	9.58
Soil-Grout Mix	90 ^c	14.1	90 ^c	14.1	0	7,200	345

^a Estimated at 110 lbs/ft³. 115 lbs/ft³ used for conservatism

^b Assumed.

^c Based on past soil mixing in clays

Rankine earth pressure distributions were used to model the active and passive earth pressures on the soil-grout retaining wall. At the conclusion of the analyses, the 8-foot soil-grout retaining wall was determined to be sufficient for temporary excavation support at this site with a minimum factor of safety equal to 1.25. The minimum factor of safety resulted from the sliding failure analysis at the interface between the soil-grout block and the underlying soils. The low factor of safety at this

interface may be attributed to the reduced density of the soil-grout mixture and the limited interface friction between the soil-grout mixture and the saturated clay soils. Therefore, in order to maintain the minimum 1.25 factor of safety the soil-grout retaining wall would require a minimum embedment of 10 feet into the soils below the assumed water table. The embedment requirement necessitated the installation of the retaining wall to 28 feet (~8.5 m) below the ground surface or to the interface of the site bedrock, whichever was shallower.

CONSTRUCTION

The soil mixing was completed over a 3.5 week time span that ran from the end of April 2010 through the beginning of May 2010. An excavator mounted drill rig, 3-foot (~0.9 m) and 9-foot (~2.7 m) diameter soil mixing augers, a 28-foot (~8.5 m) hollow stem Kelly bar, and a custom batch plant were used to complete the project. The as-built column layout is shown in Figure 2.

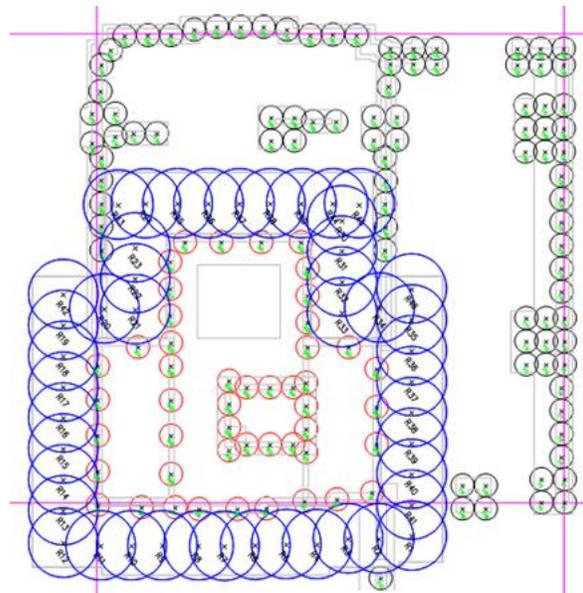


FIG 2. Soil Mixing Column Layout for Project in Lexington, VA

As part of the construction quality control, wet grab samples were taken from recently constructed soil-mixed columns. Samples were collected at a minimum frequency of one every 500 CY (418 CM) of mixing. The recently mixed soil-grout was placed in cylinders and allowed to cure in a moisture and temperature controlled environment. After the samples had cured, undisturbed, for a minimum of three days they were shipped to an offsite laboratory for unconfined compressive strength testing. The results of the unconfined compressive strength (UCS) tests are shown on Figure 3.

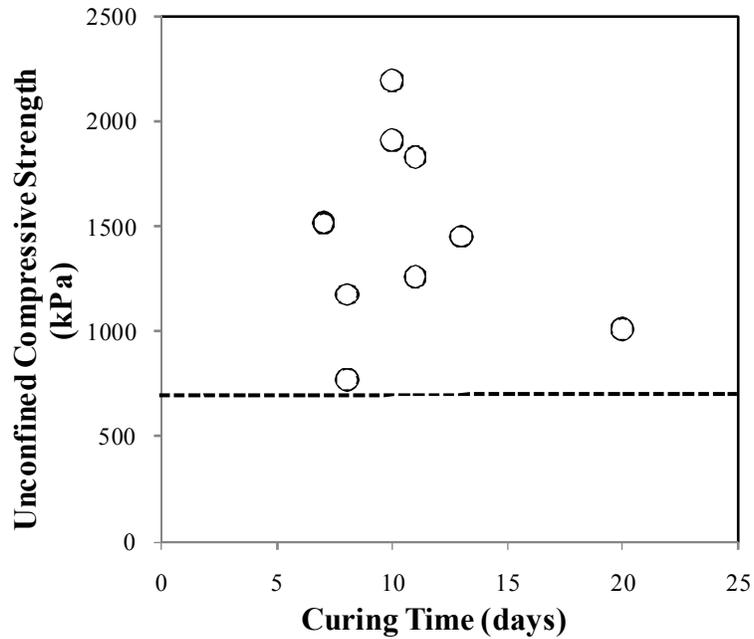


FIG 3. Unconfined Compressive Strength vs. Curing Time

All of the tests surpassed the 100 lbs/in² (~690 kPa) UCS design strength after curing periods ranging from 7 to 14 days, save one sample which required an additional 6 days. Once all samples had exceeded the design strength, the basement excavation and foundation construction commenced. Pictures taken in June 2010 of the excavated soilcrete retaining wall are shown in Figure 4.



FIG 4. Pictures of the Excavated Basement Exhibiting the Soilcrete Retaining Wall

COST COMPARISON

The project necessitated a means of bearing capacity improvement and excavation support. Site constraints limited the technologies, i.e. *in situ* treatment was suggested for the bearing capacity improvement due to petroleum impacted soils and there was limited working room for the excavation support system due to adjacent structures. *In situ* soil mixing was suggested as a cost effective solution to the bearing capacity improvement, but was not considered for the excavation support system until after project award. For comparison, a few select technologies are presented on Table 1 with budgetary price ranges for each.

TAB 1. Budgetary Cost Comparison Summary

	Mob (\$)	Bearing Capacity Improvement		Excavation Support	
		Unit Price (\$)	Units	Units Price (\$)	Units
In Situ Soil Mixing	\$30-\$50 k	\$50-\$80 / CY	875 CY	\$50-\$80 / CY	1675 CY
Jet Grouting	\$30-\$50 k	\$300 - \$500 / CY	875 CY	\$300 - \$500 / CY	1675 CY
Sheet Piling	\$10-\$20 k	NA	NA	\$25 - \$30 / VSF	5655 VSF
Aggregate Columns	\$10-\$20 k	\$5-\$10 / LF	6300 LF	NA	NA

Note: All units are estimated from the case study project. Mob is short for mobilization

Using the above budgetary cost ranges one may calculate an estimated total cost utilizing soil mixing alone, the cheapest alternate technologies, and the suggested technologies (those laid out in the bid documents). These calculated cost ranges are shown in Table 2.

TAB 2. Total Cost Comparison Summary

Technology	Low End Cost	High End Cost
Soil Mixing Alone	\$157,500	\$254,000
Cheapest Alternate Technologies ^a	\$193,000	\$273,000
Suggested Technologies ^b	\$225,125	\$309,650

^a Using aggregate columns for bearing capacity improvement and sheet piling for excavation support

^b Using soil mixing for bearing capacity improvement and sheet piling for excavation support

Utilizing a single technology allowed the owner to realize the cost savings associated with one vs. two mobilizations as well as the economies of scale due to the increased scope of work for the soil mixing contractor.

CONCLUSIONS

Soil mixing is widely used as a means for the *in situ* delivery of chemical reagents and stabilizing agents to contaminated or undesirable soils. The project in Lexington,

VA is a prime example of the cost saving benefits of using soil mixing for the simultaneous installation of ground improvement and excavation support elements. The design procedures employed for this project can be used as an example for other owners/engineers to follow when making the decision whether or not to implement unreinforced soil mixing for excavation support purposes. However, if the technology becomes more widely implemented in this application, further investigation will be warranted to refine and improve upon the design methods used on this project.

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