RECENT SOIL MIXING APPLICATIONS IN THE TRANSPORTATION INDUSTRY

By
Kenneth B. Andromalos, P.E.¹ and Eric W. Bahner, P.E.²

Abstract

In the mid 1950’s, Intrusion Prepakt of Cleveland Ohio first patented the soil mixing technique which was also known as the “Mixed In-Place Pile” technique. This technique was later refined by the Japanese in the 1970’s and then re-introduced to the United States in the 1980’s by Geo-Con, Inc. of Pittsburgh, PA. Since this time, soil mixing has become a tool for difficult soil conditions in the Transportation industry and has recently been accepted as a viable ground improvement technique by the Federal Highway Administration. To illustrate recent applications of soil mixing in a variety of conditions, several actual case histories are presented. On a project in Wisconsin in 1997, the multiple auger deep mixing method was successfully used for the first time in the U.S. to construct a permanent retaining/groundwater cutoff wall for a highway. The purpose of this wall was to prevent settlement of the adjacent structures due to a lowering of the groundwater table. This same method was utilized in 1999 on a highway project in Pennsylvania to limit lateral movement of adjacent historic structures and to prevent the loss of support due to unraveling soils. On another project completed this year, a hydraulic soil mixing technique known as jet grouting was utilized to stabilize foundation soils beneath a recently constructed and distressed Mechanically Stabilized Earth (MSE) bridge abutment. Finally, the soil mixing technique is currently being utilized as an areal treatment method to stabilize subsoils beneath large embankment highway fills.

¹ Group Manager, Brayman Construction Corp, Saxonburg, PA, Email: k_andromalos@braymanconstruction.com
² Senior Project Engineer, STS Consultants, Ltd., Milwaukee, WI, Email: bahner@stsltd.com
Introduction

Deep mixing method (DMM) has become a general term to describe a variety of soil mixing techniques to improve soils in-situ. The Federal Highway Administration has suggested these techniques can be classified based on 1) method of additive injection (i.e. wet or dry injection), 2) method by which additive is mixed (i.e. rotary/mechanical energy or by high pressure jet, and 3) the location of the mixing tool (i.e. near the end of the drilling rods or along a portion of the drilling rods).

The application of the DMM primarily uses a wet injection method where a typical cement based grout is used as a drilling fluid and as a binder to form a solidified column(s) of soil-cement. Figure 1 shows three common DMM techniques: Deep Soil Mixing (DSM), Shallow Soil Mixing (SSM) and jet grouting. The DSM method utilizes a series of overlapping augers and mechanical mixing shafts. The SSM method uses a single mechanical mixing auger located at the end of the drilling tool (Kelly bar). Jet grouting can be considered a type of soil mixing which utilizes high pressure, 28 to 42 MPa (4,000 to 6,000 psi) jets to hydraulically shear the soil and blend a cement grout to form a soil-cement column.

![Figure 1. Wet Deep Mixing Methods: DSM, SSM and Jet Grouting](image)

Applications

In the transportation industry, DMM has been used in the United States in the following applications:

- Excavation support with or without groundwater control;
- Underpinning using the jet grouting technique;
- Areal treatment for settlement control or liquefaction mitigation, and
- Subgrade struts for deep excavations.

The DMM has been used in a wide variety of applications for excavation support, particularly where there is a concern with groundwater control, vibration-induced subsidence, raveling or flowing ground, or contaminated soil and groundwater. Further, DMM walls constructed with wide flange or HP sections are very stiff and offer a cost-effective alternative to slurry walls and secant pile walls.

DMM has also been used in settlement control of soft soils supporting embankments, especially approaching bridges to control the differential settlement between bridge foundations and an embankment. It is also used to stabilize critical slopes and increase the overall factor of safety, and to form a composite gravity structure to support vertical excavations.

In settlement control applications for embankment or structure foundations in very soft soils, DMM is sometimes preferred over stone columns. Stone columns may not be technically feasible due to inadequate lateral support, or may be cost prohibitive due to the unavailability of appropriate aggregates. When compared to the use of wick drains and preloading, soil mixing permits an accelerated construction schedule and eliminates the cost of hauling in additional fill for the replacement of settling subsoils, and permits the construction of steeper embankment slopes, while maintaining the necessary slope stability safety factors. A recent transportation application includes the stabilization of the approach embankments for the new billion dollar Woodrow Wilson Bridge project near Washington, DC.

In certain applications, soil mixing is more economical or provides improved performance characteristics than some more traditional or other geosystem methods. These other systems include; augercast piles; stone columns; compaction grouting; wick drains/preloading; lightweight fills, and conventional retaining walls.

**Case Histories**

**Roadway Retaining Wall – Milwaukee, Wisconsin**

The Lake Parkway Freeway is an extension of Interstate 794 north of General Mitchell International Airport. Where this freeway passes through the city of St. Francis, the Wisconsin Department of Transportation (WDOT) initially proposed to construct an elevated freeway. However, public outcry in the city of St. Francis, especially over the potential division of the city by the bridge forced WDOT and their consultant to consider a depressed roadway section. WDOT decided on the design/build (D/B) approach to take advantage of contractor innovation, and minimize both schedule and cost.
A permanently tiedback deep mixing method (DMM) wall, was ultimately deemed the quickest and most cost-effective method. An example section of the DMM wall is shown in Figure 2.

![Typical Wall Plan](image)

**Figure 2. Roadway Retaining Wall Cross-Section**

The project consisted of approximately 912 m of depressed roadway. The alignment is positioned in a railway/utility corridor that runs through a residential area of St. Francis, and is approximately 1000 m west of Lake Michigan.

Groundwater was measured at depths of 0.6 to 3.7 m in deep in shallow wells along the alignment as part of the original geotechnical investigation. Shallower perched water was also anticipated in areas with sand and silt layers.

The design/build documents prepared by the WDOT identified the following criteria for the cutoff wall/retention system design:

- Minimum design life of 75 years.
- A maximum groundwater infiltration rate of 6200 liters/day per meter (500 gpd/lf).
- A maximum groundwater table drop of 152 mm at a distance of 15 m behind the cutoff walls.
- Maximum lateral wall movements not exceeding 25 mm.
- A minimum facing wall thickness of 610 mm at the base of the wall.
Driven sheeting was deemed an unacceptable scheme due to the potential for leakage through the interlocks, and between sheets driven out of interlock. To effectively create a cutoff around the perimeter of the depressed roadway section, a combination of DMM structural walls and non-structural cutoff walls were built. The termination depths of the cutoff walls were determined using the finite element program SEEP/W and hand calculations. A wall permeability of $1 \times 10^{-9}$ to $1 \times 10^{-7}$ m/s was assumed in the analyses. These analyses indicated that the design criteria identified above could be met by either keying the cutoff walls into the underlying very stiff clay till layer, or where the depth to the till layer was greater, penetrating intermediate layers of stiff clay, silt and clayey silt.

Jet grouting was used as the sole means of groundwater cutoff around underground utilities. The diameter of these utilities ranged from 300 to 3100 mm. The cutoffs were created by drilling vertical and angled holes to create soil-cement collars around the subject utilities that were of equivalent strength and permeability to the adjacent DMM wall.

The structural wall was constructed in two main steps. The first step consisted of drilling and in-situ mixing of the soils with cement-bentonite grout. This was followed by installation of steel soldier beams on 1.37-m centers within the freshly mixed (i.e.; prior to curing) columns.

Other work associated with the DMM retaining wall consisted of installation of tieback anchors, wales, and cast-in-place concrete facing. This was done upon DMM wall curing and mass soil excavation along the faces of the walls.

Post construction monitoring of the effectiveness DMM wall consisted of groundwater monitoring outside the wall. This was done through the use of piezometers. Deflection was also monitored through the installation of inclinometers at 3 wall locations, and survey-monitoring points installed along the walls.

Inclinometer readings were taken over a 6-month period during and after excavation. The measurements showed that the lateral movement measured by the inclinometers was well below the 25 mm maximum lateral movement limit. Survey data was generally consistent with the inclinometer data.

The Lake Parkway project provides an excellent example of the DMM earth retention technique. The approach resulted in the construction of a structurally sound, watertight, and aesthetically pleasing finished wall. DMM provided a notable cost savings over comparable diaphragm wall systems, and resulted in a shorter construction time schedule.

Cut and Cover Tunnel – Pennsylvania

The Pennsylvania Department of Transportation (PennDOT) planned to connect a new bridge crossing the Susquehanna River to State Route 54 and bypassing the Danville, Pennsylvania business district. The new route passed through the historic district, characterized by spectacular old mansions and a
narrow right of way. The new connector, and underpass, replaced an at-grade crossing.

The historic mansions are 0.9 to 1.2 m (3 to 4 ft) from the pre-construction location of the sidewalks. These 3-story mansions are constructed of brick, stone or stucco, notoriously brittle materials that crack from small movements. PennDOT’s designer, Gannett Fleming, Inc., recognized that the excavation for the underpass needed to limit ground movements to preserve the appearance of the adjacent historic mansions, and therefore, specified an excavation support system consisting of a concrete slurry wall, a secant pile wall or a deep soil mix (DSM) wall. These systems eliminate sloughing of cohesionless soils during excavation, which could result in lateral movements of the adjacent structures. Driving soldier piles or steel sheet piling was not permitted, due to the potential for vibration damage to the adjacent structures.

The project had approach sections at each end, and a rigid frame underpass at the deepest portions of the project. The excavation depth ranged from 0 to about 6.7 m (22 ft) in the approach sections to about 9.4 m (31 ft) at the deepest point in the rigid frame section. The designers needed to consider the proximity of the mansions located along the excavation. The support system needed to restrict horizontal and vertical movements resulting from the excavation.

The designers realized that controls implemented during construction had the most significant impact on the ensuing deformations. To minimize movement, the following measures were taken to control ground movements:

1. Designed the uppermost bracing level near the top of the excavation to limit ground movements resulting from the cantilever condition during the initial excavation.
2. Limited the maximum vertical distance between supports at any time during the excavation to 3.0 m (10 ft).
3. Prestressed the horizontal supports to 100 percent of the design load, except where struts were opposite basement walls.
4. Extended the excavation below a strut level to a maximum of 0.6 m (2 ft) before installing the strut.
5. Did not rely on unexcavated earth berms against the retaining wall for horizontal support, i.e., did not make the excavation along the centerline of the underpass before installing the struts.

The design of the earth retention system played only a part in controlling ground movements. Construction practice had an equal, or even greater significance. The construction practice used for the DSM wall is now described:

The DSM procedure blended the in-situ soils with a cement grout to form a continuous soil-cement interconnected wall on each side of the excavation. The walls were constructed so that the minimum effective wall width was 0.61 m (24 in). The length of each side of the permanent shoring was 186 m (610 lineal ft),
for a total of 372 m (1220 ft) of soil-mixed wall. In addition to the soil-mixed wall, steel beams (w18x40 soldier piles) were placed on 1.38 m (4.5 ft) centers into the soilcrete, prior to initial set, to provide sufficient stiffness and lateral reinforcement.

Two samples of cured soil-cement were collected per 15 lineal m (50 lineal ft) of wall. From each cored location, one sample was tested at 28 days for UCS and the remaining sample was stored until the underpass construction was completed. A total of 24 cored samples were collected at randomly selected wall locations. The average compressive strengths of these samples were 3.8 MPa (552 psi).

Contract documents required the contractor to establish a monitoring system to observe the behavior of the excavation support system. Data from the six inclinometers installed between the back of the DSM wall and the mansions were consistent and showed maximum horizontal movements ranging from about 5.6 to 6.9 mm (0.22 to 0.27 in).

The instrumentation data demonstrated that the excavation support system succeeded in limiting ground movements and protecting the adjacent mansions during construction. Ground movements were restricted to the minimum amount observed in previously documented case studies reported by others.

Figure 3. DSM retaining wall supporting adjacent historic structure.
Soon after construction of a Mechanically Stabilized Earth (MSE) bridge abutment, the abutment showed significant signs of settlement and distress. Based on concerns of failure of the horizontal reinforcement strips connected to the precast concrete facing panels, a rapid stabilization program was undertaken.

The results of an investigation program revealed unsuitable subsoils consisting of a mixture of cobbles, gravels, sands, silts and clays. Due to the amount and plasticity of the soil fines, conventional permeation grouting or compaction grouting solutions would not be technically feasible to stabilize the unsuitable subsoils. In addition, due to the concern of drilling through the horizontal MSE reinforcement strips which extended 30 feet behind the front faces of the MSE abutment walls, any such solution would require the ability to drill steep angle holes to access the subsoils requiring treatment.

Considering the above, combined with the desire of not having to shut-down the roadway to completely rebuild the abutment, a type of soil mixing known as jet grouting was selected as the desired stabilization technique.

The stabilization program involved the installation of over 326 jet grouting elements, constructed at angles from vertical to 5 degrees from horizontal (Figure 4). Based on the results of an initial test program, stabilized soil-cement column diameters were in the 0.9 m (3 ft) range and total drill depths were up to 18 m (60 ft), depending on the drill angle.

Figure 4. Installing jet grouting elements beneath an MSE abutment.
Summary and Conclusions

In certain circumstances, site constraints and ground conditions innovative earth retention and in-situ soil stabilization methods using DMM can prove technically superior and more cost effective than more common methods. As demonstrated in this paper, DMM is versatile enough to construct a variety of earth retention and soil stabilization schemes.

References


