

EVALUATION OF FIELD METHODS FOR THE SOLIDIFICATION/ STABILIZATION OF CONTAMINATED SOILS AND SLUDGES

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ABSTRACT

The solidification/stabilization (S/S) technology has become a proven, cost-effective method for the treatment and/or immobilization of hazardous wastes and contaminated soils and sludges. The success of any S/S project is dependent on the individual success in the following three general areas: proper selection of reagent and proportions; the use of applicable field equipment and procedures; and, the implementation of proper quality assurance/quality control (QA/QC) and field sampling and testing procedures.

This paper evaluates several solidification/stabilization methodologies, discusses their advantages and limitations, and provides a general overview of the solidification/stabilization process including: initial bench-scale testing; full-scale implementation; and, field sampling and analysis.

INTRODUCTION

The S/S technology is considered an effective remedial action which limits the mobility or solubility of a waste, or detoxifies its hazardous constituents (stabilization), and/or improves its handling and physical characteristics (solidification). Through 1991, S/S was selected as the treatment technology for over 26% of the NPL sites, more than any other treatment technology. For the purpose of this paper, the term stabilization is used interchangeably with S/S.

Many methods currently exist for both in-situ (in place) and ex-situ (excavated) stabilization and subsequent sampling and analysis of the stabilized material. Each of the treatment methods have distinct advantages and limitations primarily related to the physical mechanism of the process site conditions, and the properties of the stabilized waste.

During the design of a S/S program, the Engineer should be aware of the field methods available for performing and evaluating all phases of a stabilization technology. Also, the selection of appropriate field equipment and procedures, in particular the appropriate mixing process, is critical to the overall success of a S/S project.

BENCH-SCALE/PILOT-SCALE TESTING

Bench-scale treatability studies are typically performed to develop information relative to the effectiveness, cost, and implementability of a S/S technology. Prior to initiating a bench-scale study, a work plan for completion of the treatability testing program should be developed. The work plan should consist of the methodologies to be employed, the various reagent:dosage applications to be employed, the physical/analytical testing program to be conducted, the requirements for program reporting, and list the possible health hazards associated with the treatability testing.

Since one of the most important processes in the S/S procedure is mixing of the unstabilized material and reagents, the work plan should be written such that the mechanical mixing method to be used for the treatability study should closely simulate the proposed field operations. Typical mixing procedures that would be used during this phase to simulate field operations would be: the use of a Hobart-type mixer or hand mixing simulating backhoe or other standard mechanical mixing operations; the use of a mortar mixer simulating batch mixing using a concrete transit truck; or, the use of a bench-scale pug mill.

The method in which the unstabilized waste and reagents are combined is another important process to consider during the bench-scale phase. The weight of reagents to be added for each mix design is usually based upon the moist weight of the untreated waste samples per the associated percent addition rate developed in the work plan. Reagents can either be added to the unstabilized material in a dry state, with water subsequently added as necessary, or in a slurried state. The method that is selected may be inherent to a specific treatment method (e.g., in-situ drilling or ex-situ slurry mixing) and can be optimized during the bench-scale phase. The actual quantity of water added depends on the properties of the unstabilized waste and/or specific site conditions.

When implementing a bench-scale treatability study, a tiered approach is often most advantageous to quickly evaluate specific reagent:dosage applications to achieve the predetermined project goals. A generic logic diagram for the tiered bench-scale treatability study is provided as Figure 1. Tier I generally involves mixing small quantities of the unstabilized soil/sludge with selected S/S reagent mixes. For each reagent formulation selected, generally, three reagent:dosage unstabilized soil/sludge ratios are evaluated. The first tier screening criteria are usually qualitative related to physical performance goals, or "percent reduction" related to analytical performance goals. Tier II of the study, in which all target goals are analyzed, further evaluates and refines successful Tier I mix designs using larger quantities of the unstabilized material. Subsequent iterative tiers can be performed to further evaluate, optimize, or duplicate a selected Tier II mix design which meet the treatability study goals.

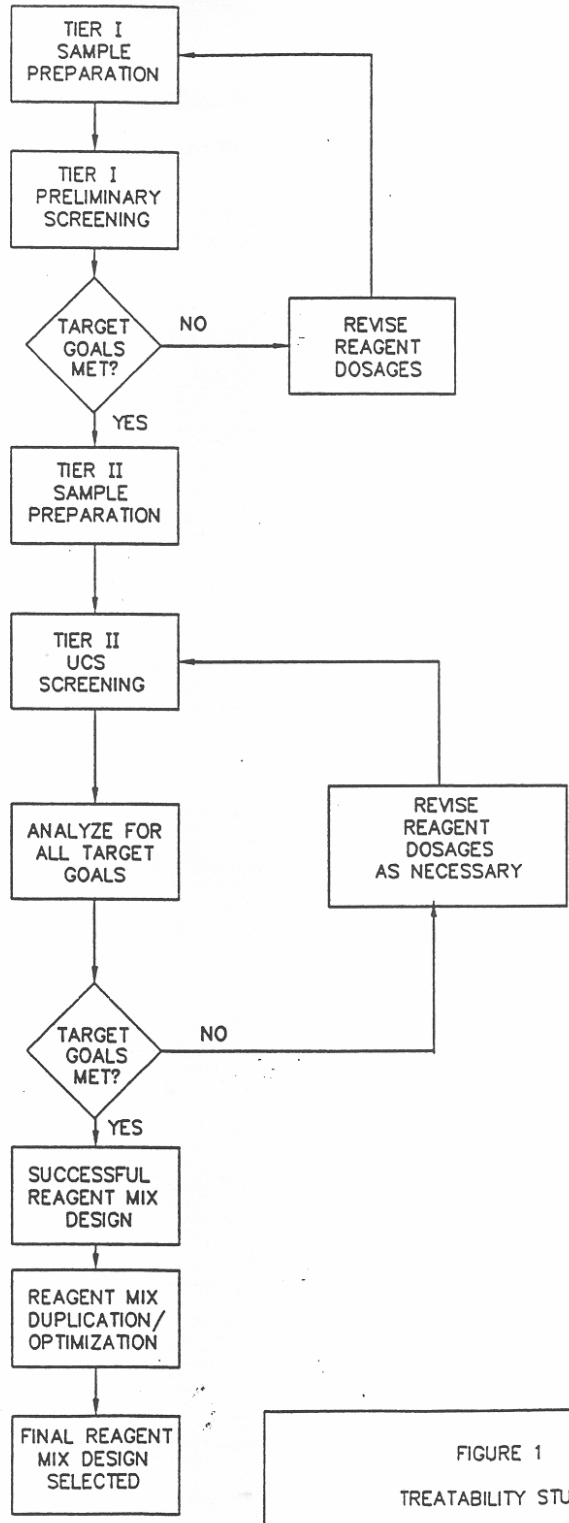


FIGURE 1
TREATABILITY STUDY

Prior to implementation of full-scale testing, a pilot-scale test is usually performed to confirm successful bench-scale results. The pilot-scale testing should be performed using the proposed full-scale equipment, or equipment that most closely simulates that proposed. As with the bench-scale testing, a work plan is typically required for pilot-scale testing. Additional information that should be included in the work plan is primarily related to QA/QC of the S/S process and sampling and analysis. Information can be obtained from the pilot testing that may lead to revisions or refinements in the proposed process that could significantly impact full-scale implementation.

PRODUCTION EQUIPMENT AND PROCEDURES

Most S/S projects are contracted under a performance-based specification. In the design of a S/S program, the Engineer should be aware of the appropriate equipment and procedures available, but should also provide sufficient flexibility in the contract documents to allow for contractor innovation and actual selection of the final equipment and procedures by the contractor. For instance, the contract documents may limit the general types of equipment which are acceptable (e.g., pugmill-type mixers), subject to approval by the Engineer. Some of the specialty S/S contractors have developed or modified a variety of mixing equipment to meet specific project requirements. These innovations often can provide a better product and lower project costs.

Factors to consider when choosing the appropriate mixing equipment and procedures include: type, depth and consistency of the waste; type and concentrations of the contaminants; regulatory considerations; presence, frequency and size of obstructions and debris; available work area; concern of fugitive emissions; and, final treatment criteria.

Mixing procedures can be performed on-site using in-situ or ex-situ techniques. In-situ stabilization involves the in-place mixing of reagents into the contaminated soil and/or sludges, without removing the waste from the existing disposal area. One regulatory consideration with using in-situ techniques is that Land Disposal Restrictions are not triggered, where applicable. Ex-situ stabilization involves the excavation or removal of the contaminated soil or sludges from the disposal area, where it is then processed and blended at or above ground level. The stabilized material is then subsequently placed back into the disposal area, a constructed landfill-type cell or hauled off-site.

The following sections briefly describe the general types of mixing equipment and procedures which can be utilized on S/S projects.

In-situ Mixing Techniques

The in-situ mixing of reagents into the waste material can be achieved utilizing the following general types of equipment and procedures:

- Backhoe/Excavator;
- Mixing Injector;
- Horizontal Rotary Mixer;
- Vertical Auger Mixing, and,
- Hydraulic Shearing (Jet Grouting).

In general the use of in-situ techniques typically requires less support area and significantly reduces worker exposure to hazardous contaminants during remediation activities.

The use of conventional backhoes and excavators are the most common types of equipment used for in-situ stabilization. Its applications are almost exclusively limited to the in-place stabilization of soft sludges to depths up to 15 to 20 feet. Reagents are typically pneumatically or mechanically applied in a dry form on top of the sludge, and then blended with the waste using the excavator bucket. This technique generally does not provide thorough mixing and should be limited in applications where the treatment criteria is primarily to provide increased strength characteristics. Advantages to this procedure include cost and the ability to handle and manage any debris or obstructions that may be encountered. Since this procedure typically uses dry reagents, fugitive dust is often a concern. Also, this procedure tends to be less efficient with reagent usage, and therefore should be limited to the use of lower cost reagents such as flyash and kiln dust.

Mixing injectors utilize a modified excavator to inject the reagents beneath the top of the waste and blend it with the waste using a stirring type motion of the excavator arm. This equipment is a contractor modified system where the excavator bucket is removed and replaced with a rack of several hollow mixing lances. The reagents can be injected through these mixing lances either in the dry form (pneumatically) or a wet slurry form (pumped). Just like the conventional excavator, this equipment has depth limitations in the 15 to 20 foot range. Utilizing dry reagents, this procedure is limited to the stabilization of soft sludges. Some soft soils of limited depths can also be stabilized using this technique, where the reagent is injected in a slurry form. Mixing ability is consistent with that of a conventional excavator, and fugitive dust is less of a problem when using dry reagents with this method.

Horizontal rotary mixers can generally be divided into two categories:

- Conventional type shallow mixers; and,
- Excavator-mounted systems.

Conventional type shallow mixers include equipment such as the Caterpillar© SS-250 Soil Stabilizer, the Brown Bear™ Hydrostatic Auger and other tilling/discing type equipment. This equipment is limited to in-place mixing depths of less than two feet. Because of its depth limitation, this equipment is often

used as an ex-situ process, using land farming techniques. In an ex-situ application, the waste material is brought onto a mixing platform or mixed in-situ. Typically a minimum of four to six passes are required to effectively blend the reagents into the waste. After blending, the blended layer is then removed and the next layer of waste is stabilized.

Excavator-mounted rotary mixers overcome the depth limitations of the conventional type shallow mixers. A majority of these types of mixers are limited to the stabilization of soft sludges, at depths of less than 20 to 30 feet. This equipment has the capabilities of injecting and mixing either dry or wet reagents into the waste. Figure 2 shows one such unit which has been developed by ITEX Environmental Services, Inc. ITEX has also developed another unit which utilizes a 325 HP hydraulic power pack, mounted on the back of the excavator, to power the mixing head. Because of its relatively high torque capabilities (30,000+ ft.-lbs.) for the size of its mixing head, this unit can also effectively stabilize soils at depths of 15 to 25 feet. As in any in-situ mixing technique, the presence of any large, or significant amounts of debris or obstructions which cannot be broken up by the mixing head, will create some operational problems, or make the use of in-situ technology undesirable. Using proper quality control procedures, this equipment has the capability to accurately proportion the required reagent to waste ratios.



FIGURE 2 – EXCAVATOR-MOUNTED ROTARY MIXER (Photo courtesy of ITEX Environmental Services, Inc.)

In the past five years, the use of vertical auger drilling equipment in environmental stabilization work has been refined and become more utilized. For shallow applications (less than 30 feet), a single auger caisson type drill rig can be utilized (Figure 3). Because of its high torque capabilities (150,000 to 300,000 ft-lbs.), this equipment can effectively turn mixing augers in the 6 to 12 foot diameter range. In-situ stabilization of the waste is achieved by drilling and injecting the reagents in an overlapping pattern across the site. An overlap of 20% between adjacent columns is often utilized. This equipment can effectively stabilize both sludges and soils, and is best suited for the injection of wet slurry or solution reagents. Fugitive dust and volatile emissions are typically not a concern and can be further controlled with the use of a shroud, if required. Large (greater than 4-6 feet) and nestled obstructions provide difficulties with this process. It is often worthwhile to have on-site, an excavator to support this operation, so that should unanticipated obstructions be encountered, they can be removed with the excavator and stabilization activities can continue.



FIGURE 3 – SINGLE AUGER CAISSON-TYPE DRILL RIG

In deeper applications (30 to 100 feet), specialty multiple auger systems can be utilized. There are presently only a handful of contractors in the United States which have this equipment. This equipment utilizes two to four overlapping augers with an average diameter of 36 to 48 inches each. Both the single and multiple auger systems have the capability to accurately proportion the proper reagent to waste ratios which is especially critical with the use of some of the expensive reagents and additives, and where there is more stringent treatment criteria.

The use of grouting technologies has some limited applications in stabilization applications, but in general is limited to chemical type fixation applications, where the waste or soil matrix is relatively, permeable. Jet grouting is one grouting technique which has the most potential in stabilization applications. This technique was initially developed as a soil improvement technique in Japan and Europe and utilizes a small drill rig to advance a 2 to 6 inch diameter drill rod to the bottom of the contaminated soil. Next, a reagent slurry or solution is injected through the drill rod and forced out through special jet ports located on the sides of the bottom section of the drill rod at pressures up to 4,000 to 6,000 psi. The reagent slurry exits the jet ports at a very high velocity and hydraulically shears the surrounding soil. During injection, the drill rod is then rotated and extracted at a controlled rate. This procedure results in the hydraulic mixing of the reagents with the contaminated soil to form a cylindrical column of treated soil.

Typical column diameters using the jet grouting technique are 2 to 5 feet. The individual columns are installed in an overlapping configuration, similar to that used with the vertical auger mixing equipment. One critical consideration with the technique is the need to assure that the proper column diameter is maintained to achieve treatment of the entire waste mass. A field pilot study is strongly recommended where individual columns are subsequently excavated and exposed to verify column diameter. In addition, the overlap pattern should be conservative enough to allow for waste variations. Jet grouting is generally limited to the stabilization of relatively non-cohesive contaminated soils that can be effectively hydraulically sheared. Advantages of this technique include its ability to work in low head room areas (i.e. inside buildings), and stabilize material beneath existing structures and around underground obstructions. Figure 4 shows a custom designed and fabricated double stem jet grouting system used to solidify a marine sediment located beneath an active loading pier and 50 feet of water. Due to its relatively high installation costs (\$300 to \$500/CY), this technique is often used to supplement other stabilization techniques in specific confined areas.

Ex-situ Mixing Techniques

Ex-situ mixing equipment and techniques for the stabilization of contaminated soils and sludges have been adapted from a variety of other related processes. These include: stationary chemical and waste treatment systems; aggregate

and general construction equipment; and, mixing equipment from the concrete industry. Many of these systems are used in combination to form a complete treatment system and modified by various vendors and contractors for specific use in the stabilization of contaminated soils and sludges. Because of this wide variety of available equipment, engineers should again provide enough flexibility in contract documents to allow for contractor innovation and the actual selection of equipment.

In general, ex-situ mixing techniques offer the following advantages and disadvantages over most of the in-situ mixing techniques:

Advantages:

- Ability to handle oversized material, debris and underground obstructions;
- Good overall mixing that can be easily verified;
- Accurate proportioning of reagents with waste; and,
- Ability to visually verify that all of the waste has been stabilized and take confirmatory samples of the bottom of the excavation.

Disadvantages:

- Increased worker exposure;
- Larger support area is typically required to stockpile material and set-up process equipment;
- Generally more labor intensive;
- Potential need to handle and treat contaminated groundwater during excavation and backfilling operations; and,
- Potential need for excavation support systems.

The types of equipment use to handle and stabilize sludges is generally quite different from that equipment used for contaminated soils. These treatment systems use both batch and continuous type processes.

Sludges, because of their fine-grain characteristics and high water contents are typically dredged or pumped to the mixing equipment, where the reagents (wet or dry) are added to the waste. Water is sometimes added to the sludge at the disposal area to pre-condition the sludge into a slurry consistency for transport to the mixing equipment and to aid in the mixing operations. Reagents are then added and blended with the sludge in mixing tanks or chambers, utilizing equipment derived from the chemical process and stationary waste treatment industries. Figure 5 shows the schematic of a unit specifically built for the on-site stabilization of sludges. This unit uses a homogenization chamber which is placed under negative air for the collection and removal of volatile organic compounds, which are subsequently treated using an air recovery and carbon filter system.

The ex-situ mixing of reagents into contaminated soils can be achieved utilizing the following general types of equipment and procedures:

- Mechanical Mixing with Excavators;
- Concrete-Type Batch Plants;
- Pugmills; and,
- Conventional Shallow Rotary Mixers (previously discussed).

Depending on the initial sizing of the contaminated soil and the presence of oversized material and debris, the soil may require some processing prior to being mixed with the reagents. This processing could include the following conventional aggregate, soil and debris processing equipment: shredders; screening plants; crushers; and, associated conveyor systems. The pre-processing of contaminated soil, if required, significantly increases the amount of work area required at the site.

The use of conventional excavators to mix reagents into a contaminated soil is one of the more basic methods that can be utilized. In this approach, the waste material is batched into a mixing cell or pad (e.g., bermed work area, roll-off box, etc.), the volume or weight of the waste is estimated or calculated, and then the appropriate amount of reagent is added (wet or dry). The reagents and waste are then blended using the excavator bucket. As with the use of excavators to mix reagents into waste in-place, this technique generally does not provide thorough mixing, but does offer the ability to handle and manage oversized material without any re-processing.

Concrete-type batch plants consist of the following two general types: central-mix and transit mix operations. A central mix plant consists of : reagent storage bin(s); weigh hoppers; conveyors with belt scales; and, a stationary mixing drum. The reagents, water and contaminated soil are proportioned and loaded into the stationary mixing drum where it is blended into a mortar consistency and then discharged into a ready-mix truck or the hopper of a concrete pump for transport to its final disposal location. Transit mix plants (Figure 6) include the same basic components as the central mix plant, with the exception that there is no stationary mixing drum. Instead, the components are loaded directly into a transit mix truck, where the actual mixing occurs. The advantages of the transit mix plant are lower mobilization costs and set-up time. Central mix plants, however, typically have higher output capabilities.

Pugmills and similar mixing equipment consist of generally mobile, trailer-mounted components that are well suited for the stabilization of contaminated soils. Associated equipment includes reagent storage bins (silos) and loading conveyors. Figure 7 shows a typical production pugmill system. Pugmills come in a variety of sizes, from small units for pilot studies to production units rated at over 500 tons per hour.

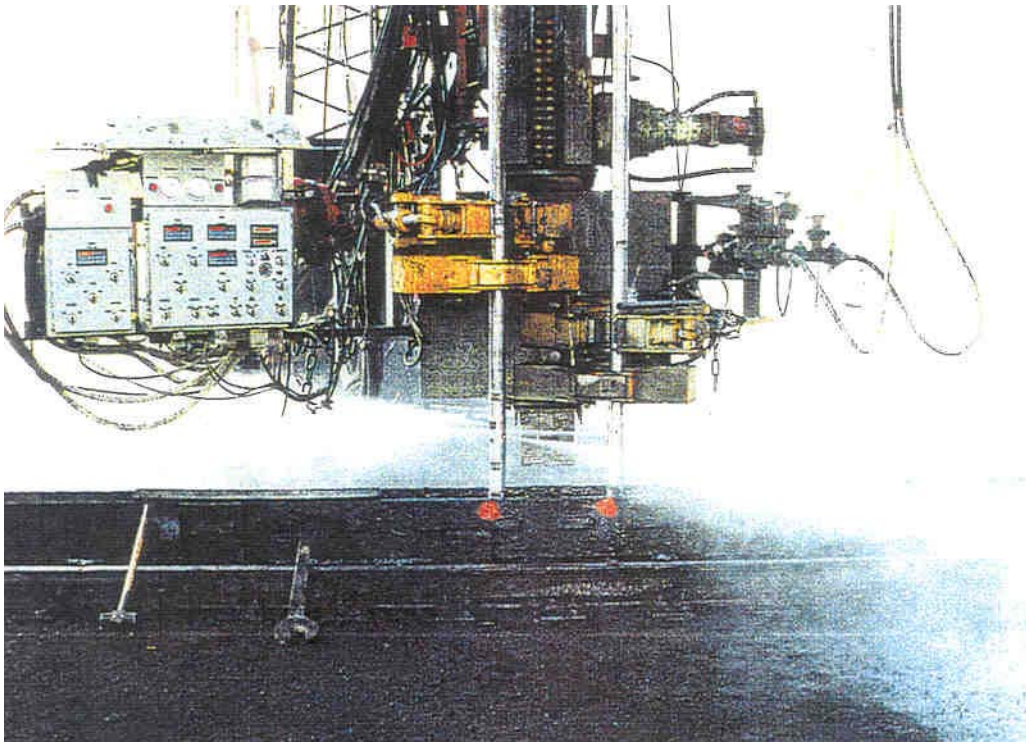
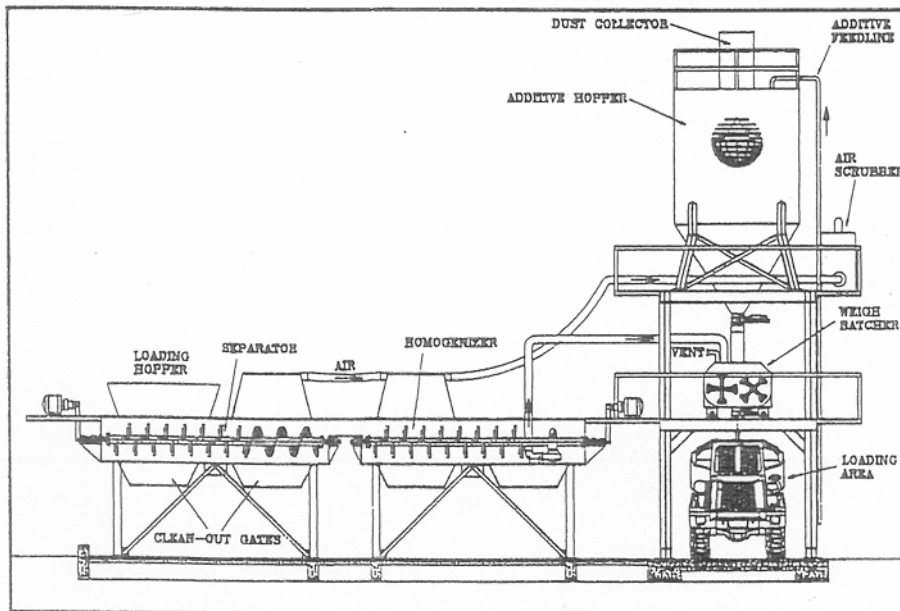


FIGURE 4 – DOUBLE STEM JET GROUTING SYSTEM



SCHEMATIC

FIGURE 5 – SCHEMATIC OF EX-SITU SLUDGE STABILIZATION SYSTEM
(Courtesy of ITEX Environmental Services, Inc.)

STABILIZED WASTE SAMPLING

To measure the effectiveness of a S/S technology, the preparation or collection of samples is necessary for subsequent analysis of the stabilized waste. Methods exist for obtaining these samples, both intrusive and non-intrusive.

Preparing molded samples of the stabilized waste during full-scale implementation is probably the quickest and most inexpensive method to obtain samples for subsequent testing. This method allows for the sample to be prepared immediately upon stabilization of the waste, prior to the material curing. For in-situ stabilization projects, the samples can be collected using a steel sampling device that can be attached to a hydraulic excavator or drill rig. The sampling device has a collection chamber(s) such that samples can be collected at specific depths. The device is lowered into the treated waste, the chambers opened then closed, removed from the treated waste, and the wet samples removed from the sampler. For ex-situ stabilization projects, the wet samples can be collected directly from the end of the treatment process. After collection of the wet samples, individual specimens can then be prepared in cylindrical plastic molds and allowed to cure for the specified time period prior to testing.

An intrusive method of obtaining cured samples of treated waste is with the use of thin wall (Shelby) tubes. The tubes are manufactured from seamless steel and are typically used to obtain 2- to 3-inch diameter undisturbed samples of soft to stiff silts and clay. The tubes, which are attached to drill rods, are hydraulically pushed into the cured material. The tube is then withdrawn from the borehole with the sample inside. The ends of the tube are then sealed and can be sent to a laboratory for subsequent testing.

Should the cured material exhibit excessive strength, the use of Shelby tubes may not be successful. Another sampling tool, typically used for hard cohesive soils and soft shale, known as a Denison sampler may be used. The Denison sampler contains an inner and outer core barrel, with the outer barrel containing cutting teeth. As drilling proceeds, the outer barrel rotates and hydraulic pressure is applied to the sampler. The stabilized waste sample is subsequently forced into the inner barrel which contains a spring device to contain the sample in the barrel. The barrel is then removed from the borehole and the sample retrieved.

The preparation of wet samples is typically the preferred method for sample collection since this method allows samples to be cured and tested with relatively no disturbance to the cured stabilized samples. This factor can be critical on some projects when disturbance of cured samples, due to sampling, could be detrimental to physical properties (e.g., unconfined compressive strength, permeability, etc.) of the stabilized waste.

FIELD ANALYSIS

There are many methods for analysis of a stabilization technology in the field. These methods include analysis of the treated material prior to and after curing. Analysis of the uncured stabilized material is more typically related to QA/QC of the stabilization process, while the analysis of the cured material is most always related to performance criteria of the project.

The incorporation of various field testing into the overall sampling and analysis plan help assure a more consistent final product which can consistently meet the established treatment criteria for the project.

Various field tests which can be performed include:

- Moisture Content of Unstabilized Waste;
- Density of Reagent Slurry;
- Density of Uncured Stabilized Material;
- Slump Test;
- Cement Content; and,
- Strength.

The moisture content of the raw waste can be readily determined in the field by weighing an initial sample of the raw waste, drying the waste using a microwave oven and then re-weighing the sample. These test results can be utilized to determine the quantity of water to be added during the mixing process, based upon the allowable limits determined in the bench-scale and pilot-scale studies.

The density of the reagent slurry can be readily determined in the field using an API mud balance. This information provides a quick analysis to assure that the correct water:solids ratio is being utilized and that the total water content and amount of reagent is properly blended with the waste.

The density of the uncured stabilized material can also be readily determined in the field using a small triple-beam scale. These values can be compared to pre-determined allowable limits.

Standard concrete slump cone tests provide good qualitative information that the uncured stabilized material is of the proper consistency. If the slump is too low (i.e., material is too thick), then proper mixing may become a problem, and if it is too high, then the material may have an excessive amount of water.



FIGURE 6 – TRANSIT MIX BATCH PLANT



FIGURE 7 – PRODUCTION PUGMILL SYSTEM

The cement content test is a test that can be performed in a field laboratory on material stabilized with Portland cement. The cement content of the treated waste can be determined by a titration method. Although this test is not a common field analysis method like the others, it can be used for a qualitative analysis. If it is anticipated that any of these tests will be used in the field during full-scale production work, they should be performed during the treatability study so proper correlation can be made from the bench-scale to full-scale production.

A qualitative method to analyze the strength of the cured material is the cone penetrometer test. The cone penetrometer is a device that is continuously pushed into the stabilized waste at a constant rate, usually after a specified time period, to measure the material's penetration resistance. The cone penetrometer is a relatively inexpensive test to perform and is practical for low strength (e.g., from 25 to 50 psi) stabilized materials. To determine the actual strength properties of the stabilized waste from the cone penetrometer testing, the field measurements obtained must often be correlated to values obtained in the laboratory, or the Engineer must correlate the results directly with performance of the test. The strength and consistency, as well as the experience of the operator and Engineer, are important factors affecting the success of this method.

The strength of the cured stabilized waste can also be determined in the field with either a pocket penetrometer, or by actually testing the unconfined compressive strength (UCS). The pocket penetrometer is a small device that can be used to determine the relative penetration resistance of a material. This method is a good qualitative method to estimate the strength of a material. Pocket penetrometer testing can be performed on samples until a desired strength is achieved, and the verified with UCS testing.

The UCS of cylindrical samples can easily be determined in a field laboratory with a mobile testing apparatus. The apparatus can apply a load to a sample at a constant rate. The total load at specimen failure is then recorded. The UCS is then calculated as the ratio of the applied load to the cross-sectional area of the sample, typically expressed in pounds per square inch. Correlation between strength and permeability or contaminant leachability can sometimes be demonstrated.

Cured stabilized waste can also be analyzed qualitatively with the excavation of the cured material with a hydraulic excavator. This method allows for visual examination of the test trench sidewalls and excavated material. This stabilized material can be inspected for uniformity of mixing and/or the homogeneity to determine the relative effectiveness of the treatment method.

CONCLUSIONS

Solidification/stabilization is proven cost-effective technology for the stabilization of contaminated soil and sludges. Understanding procedures, equipment, and

limitations of this, or any other treatment technology greatly increases the chance of a successful remediation project.

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