CQA Methodologies for In-Situ S/S at Former Manufactured Gas Plants

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Introduction

In-situ solidification/stabilization (ISS) is gaining significant recognition as a cost-effective remedial technology at former manufactured gas plant (MGP) sites versus other approaches such as thermal desorption or excavation and landfilling. This technology provides an alternate controlled engineering option for dealing with difficult site conditions and coal tar related impacts. Distinct advantages of ISS include reduced above-ground handling of contaminated materials, reduced vapor phase emissions and odors, reduced long-term liability compared with excavation and off-site disposal and reduced energy costs (e.g., natural gas for thermal treatment) for implementation. Use of portland cement as a solidification/stabilization (S/S) reagent is continuing to gain confidence with the regulatory community as an effective means to reduce the toxicity and mobility of MGP residuals.

The Importance of CQA

Effective ISS performance requires a comprehensive construction quality assurance (CQA) program that addresses each phase of the project from bench-scale testing through full-scale field operations. It is important to monitor ISS performance in the field to ensure that project objectives are met and the ISS work is conducted in accordance with contract requirements. In the worst case, lack of an effective CQA program can lead to rapid and uncontrolled cost increases caused by the often extensive lag time between ISS sample collection and receipt of laboratory analytical data indicating satisfactory ISS performance. A CQA program allows the owner to rapidly assess construction performance and identify potential problems early in the process to allow for field adjustments or corrections and to minimize economic and future environmental risk.

Design Basis for a Sound CQA Program

Typically, successful ISS performance is dependent upon and measured by critical assessment of key parameters such as unconfined compressive strength, permeability and leachability of treated soils that are tested as work in the field proceeds.

Former MGP site—Milwaukee

Auger stem markings indicating depth of mixing

Consistent and satisfactory field and laboratory analytical results for treatment zone samples are necessary to meet treatment goals and establish a high level of confidence and acceptance with the public and regulatory agencies.

Monitoring and controlling the complex performance factors involved in this work requires a complete understanding of the technology and the realities of field implementation. A well designed CQA program accomplishes this, and helps ensure that the project achieves the proper environmental goals within schedule and budget constraints.

The first step in designing a CQA program is to clearly establish data collection objectives as part of bench-scale study to evaluate critical aspects of full-scale ISS construction. As with most bench-scale studies, an important goal is to reflect full-scale conditions as closely as possible because the results of the bench-scale testing often serve as the basis for contractor bidding and payment. The CQA program must be an integral part of the entire design process from pre-design data collection through full-scale construction. Every step of the process should be viewed in light of meeting full-scale performance requirements.

Pre-bench-scale data collection objectives require careful assessment of the variable subsurface soil conditions. Soil type, moisture content, and dry density data will serve as the basis for estimating the amount of reagent addition during full-scale ISS operations. It is therefore critical at the early bench-scale level to collect samples in a manner that accounts for heterogeneities and are representative of field mixing operations.

Typical performance and project cost issues that can arise due to an inadequate understanding of the ISS field conditions include the following:

- If dry densities are underestimated or overestimated then it is likely that reagent addition at full-scale may be respectively too low or too high. Reagent amounts that are too low may lead to ISS performance failure. Correspondingly, reagent amounts that are too high can lead to unnecessarily higher project costs. Dry density is a critical variable related directly to contractor payment since the amount of reagent added in the field is determined from design proportions in the bench-scale studies, which utilize somewhat basic measurements of dry density in field samples. Great care needs to be exercised in obtaining representative field samples for this purpose.
- Dry densities are directly related to moisture content and if the variation in moisture content is not adequately understood then they may correspondingly be underestimated or overestimated in the field.
- Variation in pre-treatment moisture content will also directly affect estimates for full-scale water to reagent ratios and may directly affect full-scale mixing requirements for reagent application.
- Variation in the percentage of clay and moisture content will directly affect the amount of "swell" or excess ISS material generated. This could have a negative impact on overall projected cost or site space logistics. Higher percentages of fines will typically result in higher volumes of swell.

CQA Considerations for Development of Reagent Mix Designs

Development of reagent mix designs for site specific ISS applications are of central importance. Thorough bench-scale testing is typically conducted using combinations of solidification/stabilization binding reagents such as portland cement, ground granulated blast furnace slag (GGBFS), fly ash, and commercial concrete additives to match the ISS with treatment performance criteria and site specific conditions. Selected reagents and proportions of an ISS mix design for MGP-impacted sites are primarily based upon the criteria of low permeability for treated soils as observed during historical test experience. Acceptable mix designs selected from the bench-scale studies are used in pilot scale testing at the site prior to full-scale implementation.

Cleaved "bucket cast" of treated soil. Note coal tar inclusions.

Two key CQA parameters that should be considered during mix design development are:

- Reagent Density-- The density of the reagent mixed with water at the batch plant is an important parameter as it relates directly to the quantity needed for treatment, based on the dry density of the soil, the estimated volume for treatment, and the specified mix design.
- Water to Reagent Ratios-- Typical water to reagent ratios are in the range of 1:1 and are directly related to reagent density. This parameter is important because some types of ISS injection applications require a minimum ratio to prevent problems such as reagent injector clogging of during application.

CQA field testing protocols can be evaluated in conjunction with a comprehensive geotechnical laboratory testing program during both bench-scale testing and full-scale field operations. Typical geotechnical and chemical analytical laboratory testing protocols include unconfined compressive strength, permeability, leachability, and durability. Field CQA protocols can be established on the basis of accepted ASTM procedures for moisture content, slump, liquid limit and viscosity.

The Transition from Bench to Pilot Scale Implementation

During the transition from bench to pilot scale testing, careful consideration of full-scale reagent mixing and injection requirements are critical to meeting remedial design objectives and controlling contract project costs. Accurate reagent densities are needed for establishing appropriate water to reagent ratios, reagent delivery rates and mixing effort in the treatment zone. In-situ mixing effectiveness is also dependent upon a range of factors such as the mixing technique (e.g., auger versus backhoe mixing) as well as operational parameters that include the number of auger passes through a column, rate of rotation and duration of mixing.

A Case Study

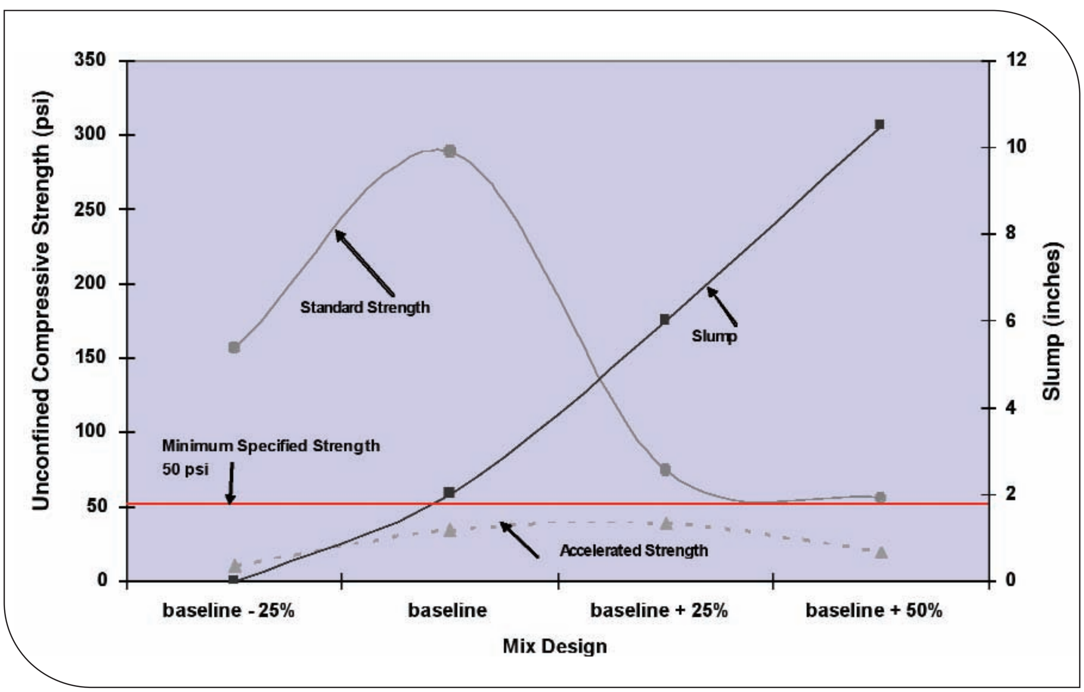
At a former MGP site located directly along the Menomonee River near downtown Milwaukee, Wisconsin, a timely laboratory and field CQA program was critical to the project success due to a number of factors. The project was close to active businesses, heavy commercial traffic and a remediation area located directly along the Menomonee River - a major flowage to Lake Michigan. Adding to these potential environmental receptors was the presence of a youth indoor skate park directly next to the ISS remediation area that required unimpeded public access throughout the remedial action. Subsurface conditions consisted of highly impacted estuarine silt and/or clay, river sediment and some organic matter. Presence of non-aqueous phase liquid (NAPL) was identified to depths of up to 25 feet (7.6 m) below grade.

A total of 25,000 cubic yards (19,000 m^3) of MGP impacted soil were identified for ISS. Approximately 5,000 cubic yards (4,000 m^3) of this material was located directly along 700 feet (200 m) of river bank behind an historic wood lap piling retaining wall which extended from approximately five (1.5 m) above to 15 feet (4.5 m) below the bottom of the river. The remainder of the material targeted for treatment was located inland and directly next to an embankment for a major City overpass.

Several custom engineered mix designs were developed to meet both treatment performance criteria and site specific challenges. Each of the mix designs was comprised of a mixture of portland cement and GGBFS. Treatment performance criteria included a target permeability of 1 x 10^{-7} cm/s and unconfined compressive strengths between 50 and 150 psi (0.34 MPa and 1 MPa). Specific mix designs were developed to address the following structural and logistical challenges:

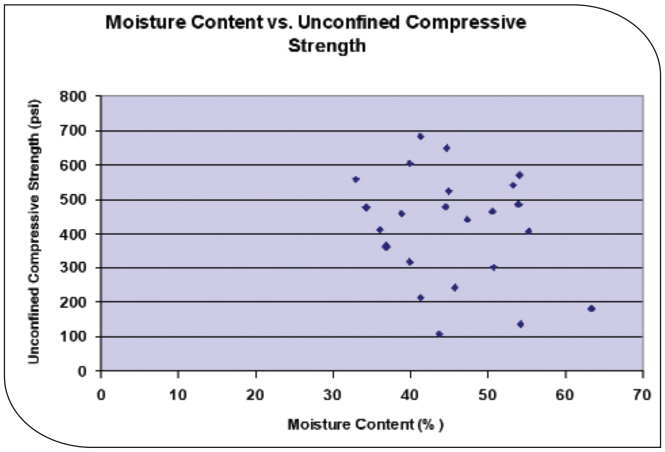
- Highly saturated conditions for ISS mixing directly along the river posed significant concerns for potential washout and/or dilution of fines. A mix design was developed using a higher percentage of portland cement and GGBFS combined with a commercial additive specifically developed for underwater concrete applications.
- The ISS treatment was adjacent to an embankment for a reinforced concrete bridge spanning the Menomonee River. To address concerns for potential slope or structural instability of the structure, a mix design with a higher percentages of portland cement providing higher unconfined compressive strength was used for ISS columns adjacent to the structure.
- For inland areas of the site where structural concerns were lower, a mix design was developed using lower percentages of portland cement and GGBFS to reduce overall project costs but still achieve long-term treatment objectives.

Bench-scale study results yielded a strong correlation between unconfined compressive strength, slump and moisture content as

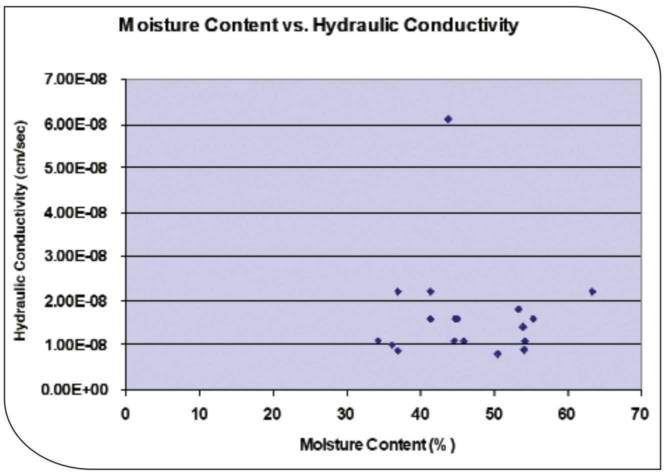


Notes:
1. Baseline represents moisture content of approximately 60 percent.
2. Standard strength data obtained from samples cured for 28 days.
3. Accelerated strength data obtained from samples cured for seven days then immersed in boiling water for 3.5 hours.

Baseline - 25% Moisture



Moisture Content vs. Unconfined Compressive Strength



Moisture Content vs. Hydraulic Conductivity

indicated graphically above. As shown, increased moisture content produced lower unconfined compressive strengths.

However, full-scale field testing did not reflect the same sensitivity to moisture content within the ranges encountered. Comparisons of slump versus moisture content generally indicated increasing slump with increasing moisture content. In contrast, both unconfined compressive strength and hydraulic conductivity appeared to be relatively insensitive to the range of moisture contents observed in the field as shown graphically.

As indicated, acceptable results were observed over a range of moisture contents (approximately 30 to 60 percent) and it should be noted that this range is much narrower then what was modeled during bench-scale testing. Regardless, the observed field results provided a high level of confidence during full-scale construction that follow-up geotechnical laboratory testing would meet treatment performance criteria. The field testing also provided a means for the contractor and engineer to rapidly assess unexpected field conditions and adjust reagent percentages and rates of application, as needed. For example, at one point, much higher percentages of clay were encountered which required a slight increase in reagent and a significant increase in water which lowered the grout density to improve mixibility but ensured sufficient reagent delivery across the entire ISS column.

Considerations for Future CQA Programs

The CQA program discussed above represents but one application under a unique set of site specific conditions. Continued evaluation of field CQA testing programs is needed to further asses the transition from bench-to full-scale ISS operations and the relationship between such factors as the quantity of reagent delivered, mixing effort, soil type and moisture content. Field CQA programs require evaluation on a site-by-site basis to allow for a tailored and effective means for timely assessment of ISS performance. A comprehensive field CQA program can include both visual (qualitative) and geotechnical field testing and should include contractor support and participation to promote teamwork and consensus on field ISS requirements.

Credits/Additional Information

Remediation Responsible Party:
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Environmental Engineering and Remediation Design:
Natural Resource Technology, Inc., Pewaukee, Wisconsin

Solidification/Stabilization Contractor:
Compass Environmental, Inc., Chicago, Illinois

Treatability Design and Testing:
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An organization of cement companies to improve and extend the uses of portland cement and concrete through market development, engineering, research, education, and public affairs work.