Soilteknik-RU0781

Evaluation of Erosion Potential of Estuarine Sediments in NY/NJ Harbor

(Impact of In-Situ Stabilization of the Remediation of Soft Sediments – A Preamble to Erosion Testing and Evaluation)

Final Report
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16. Abstract

The primary objective of the project are to perform a review of existing in-situ techniques of sediment erosion potential evaluation in contaminated "superfund" sites in the United States and those from Europe and Japan and the applicability of soft soils in-situ stabilization and solidification techniques in marine environments. The project will also determine design parameters for field application of in-situ solidification of marine sediments. (Issues such as binder compatibility and chemical stabilization potential will be considered in the selection of these binders). Finally, the project will provide a review and evaluation of experimental design program for the ex-situ testing phase of sediments amended with the selected binders.

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1.0 INTRODUCTION

Soilteknik Inc was engaged to provide consultation and expert advice on the design of experiments to be conducted by the CAIT team on the “Evaluation of Erosion Potential of Estuarine Sediments in NY/NJ Harbor using an Advanced Ex-Situ Erosion Testing Method” project. The main focus of the consulting assignment was to evaluate the potential of in-situ stabilization on the remediation of contaminated sediments. Such an understanding is required for the experimental design and selection of appropriate binder agents for future testing and evaluation in the Ex-Situ system.

1.1 PROJECT OBJECTIVES

The project objectives are as follows:

a. Review of existing in-situ techniques of sediment erosion potential evaluation in contaminated “superfund” sites in the U.S. and those from Europe and Japan.

b. Review the applicability of soft soils in-situ stabilization and solidification techniques in marine environments.

c. Determination of design parameters for field application of in-situ methods for stabilization of contaminated sediments.

d. Recommendation on the appropriate types of reagents to be considered for in-situ solidification of marine sediments. Issues such as binder compatibility, durability and chemical stabilization potential will be considered in the selection of these binders.

e. Review and evaluation of experimental design program for the ex-situ testing phase of sediments amended with the selected binders.

This study is to assist with the Center for Advanced Infrastructure and Transportation (CAIT) of Rutgers University’s plan to propose a laboratory and analytical study to evaluate the applicability of using Cement Deep Soil Mixing (CDSM) technology as both an interim, and final, remedial measure of contaminated sediments in estuarine environments. The Study is intended to evaluate the benefits and/or risks of mixing Portland cement slurry into contaminated river sediments for immobilization of organic/non-organic contaminates within the sediment matrix. The potential effects of cement hydration on the volatilization and/or solubility of sediment bound or entrained contaminants will be evaluated.

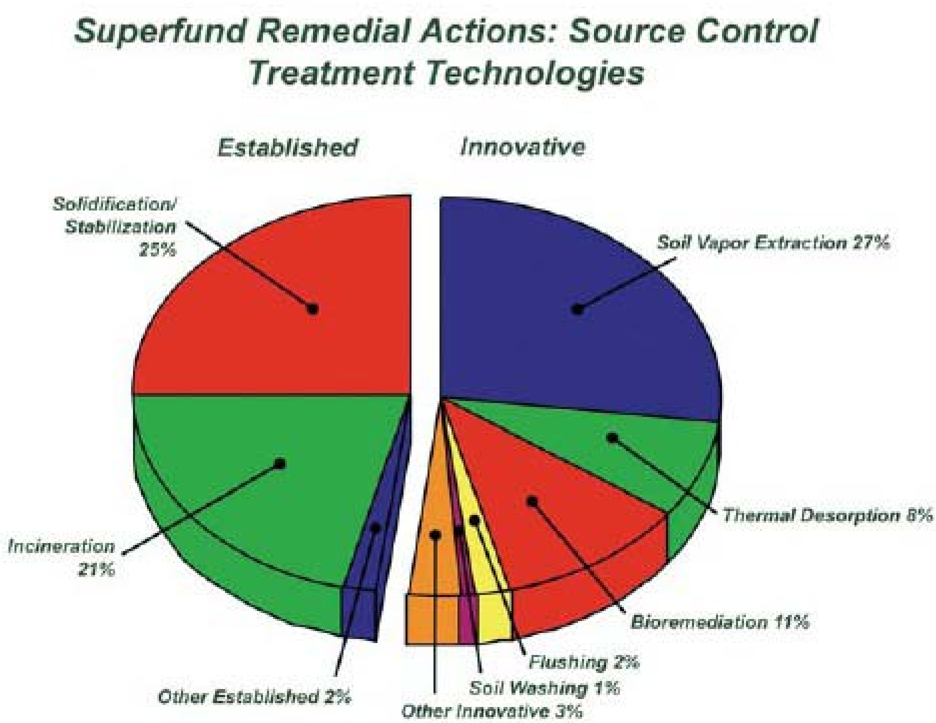
Physical and engineering properties of interest such as short and long term shear strength, permeability, erodibility, and durability of cemented sediments will also be studied to evaluate long term post construction performance of cemented sediments.

2.0 BACKGROUND

2.1 SOLIDIFICATION AND STABILIZATION

Solidification/Stabilization (SS) is one of the most widely used techniques for remediation of contaminated sites particularly those contaminated with substances classified as hazardous waste. The treatment immobilizes the contaminant in the media by mixing it with a binding reagent which prevents its migration to the receptors. The USEPA has identified SS as Best Demonstrated Available Technology (BDAT) for 57 RCRA-listed hazardous wastes. [USEPA 1993]. SS is the most frequently selected treatment for controlling the sources of environmental contamination at superfund program remediation sites. (Figure 1) [USEPA 2001]

Figure 1- Distribution (in percent) of methods of treatment of contaminated soil within the superfund project [from Wilk, 2003]



2.2 IN-SITU TECHNIQUES

In-situ mixing is usually divided into two categories of Deep Soil Mixing (DSM) for depths greater than 40ft and Shallow Soil Mixing (SSM) for depths less than 40 ft. DSM Equipment consists of a multiple auger mixing tool and SSM equipment has a single auger. For DSM the typical equipment used consists of a set of two to four tools, top driven by either hydraulically or electrically powered motors. The mixing tools consist of thick-walled rods, usually 10-12 inch diameter, with 2-3 inch diameter center holes, for slurry conveyance. Attached along each rod are mixing paddles which are designed to overlap with the paddles on the adjacent, counter rotating rod to create a pugmill-like mixing environment for the soils and injected slurry. At the bottom of each rod is a cutting head, also with a hollow center, that is designed to lift the soil to the mixing paddle area where it is blended with the previously injected slurry. As the rods and paddles penetrate the soil, they continuously rotate and mix the slurry and soil together. When the bottom of the stroke is reached, further slurry is injected while the shafts maintain that depth and mix for a short period to ensure blending of the bottom of the column. The rods are then slowly pulled from the ground with continued rotation and slurry injection at a reduced rate [Nicholson et. al, 1997].

During CDSM, cement slurry is hydraulically injected and mixed with *in-situ* sediments using hollow-stem rotating shafts equipped with cutting tools and mixing paddles. CDSM produces a soil-cement matrix which can be extended to form wall grids, or blocks for various purposes including stabilization, containment or removal of contaminated sediment beds. The use of CDSM for the solidification of the silty sediments typical of NY/NJ Harbor has been previously evaluated in a field pilot study and found to be technically feasible (Maher et al, 2005).

In general, contaminated sediments in estuarine environments are continuously disturbed by hydrodynamic forces of the River flow and tides. This may result in migration of contaminated sediments beyond their existing location adversely impacting aquatic ecosystems. The *in-situ* physical and chemical fixation of contaminants to sediment particles or the *in-situ* solidification of sediments attained by CDSM is intended to minimize the mobility dispersion of contaminants and to mitigate the risks of sediment dispersion (refer to EPA studies). Furthermore, previous studies suggest that significant reduction in the concentration of contaminants leaching following cement mixing of sediments should be expected. Questions remain however regarding the short term and long term impacts of this treatment on the fate and transport of sediment-bound and entrained contaminants, especially at high concentrations.

The advantage of CDSM as a remedial tool for highly contaminated sediments is two-fold. If cemented sediments are to be dredged, CDSM enhances workability of mixed material thus mitigating the risks associated with dispersion during dredging, transportation, treatment and disposal. Alternatively, if sediments are left in place and capped, the risk of migration of, or exposure to, contaminants will be minimized. There is also no potential limit for the time between treatment and removal, allowing for a unique staged remedial solution while treatment and disposal options for removed sediments are explored or developed.

3.0 SCOPE OF WORK

Prior to using CDSM in the solidification and stabilization of highly contaminated soft silt sediments under field conditions and to develop guidelines for full scale implementation, a number of fundamental questions need to be addressed in the laboratory. Laboratory testing will provide information regarding:

Potential effects of cement hydration on the volatilization and/or solubility of contaminants, The optimum cement content to achieve maximum improvements in the immobilization sediment contaminants and short and long term physical and engineering properties of cemented sediments, Health and safety measures to be adopted during field implementation, Potential for adverse environmental impacts (air or water quality) and mitigation measures.

If the results of this study demonstrates that CDSM is technically feasible in enhancing the environmental and geotechnical properties of cemented sediments, specifications for a Field Pilot Study could be developed.

As part of the laboratory scope of testing, sediment/cement mixtures with various percentages of Portland cement content will be evaluated to ensure that dispersion of the sediments are minimized during dredging, and that the treated sediments may be excavated using conventional dredging equipment. The potential effects of cement hydration on the volatilization and/or dissolution of contaminants will also be evaluated.

Comprehensive analytical testing on the mobility of contaminants in raw and cemented sediments is proposed. The optimum cement content will be determined based on the results of the sediment-water column exchange testing as well as physical and engineering properties to ensure: 1) Maximum reduction in the concentration of contaminants in pore water is achieved, 2) The short and long term performance of the cemented sediments with respect to shear strength, erodibility, and strength gain is optimized, and 3) The proposed percentage of cement is economically feasible and optimized for full scale implementation of CDSM and future dredging using conventional dredging equipment is possible. In developing the scope of work for the laboratory phase of the Pilot Study, the following tasks were identified:

Task 1- Literature Review
Task 2- Source Characterization
Task 3- Preparation of Work Plan
Task 4- Experimental Design
Task 5- Analytical Testing
Task 6- Environmental Modeling
Task 7- Geotechnical Testing and Modeling
Task 8- Analysis of Results and Reporting

TASK 1 - LITERATURE REVIEW

A comprehensive literature review of the existing studies on the effect of cement addition on the fixation and mobilization of contaminants in sediments will be conducted. In particular, the effects of high pH and temperature increase in the transformation and mobilization of the different contaminants will be reviewed. The effects on hydrolysis rates, changes in speciation, ion-exchange, precipitation and dissolution due to acid-base reactions will be evaluated. The effects of increased temperature on the physicochemical parameters that affect volatilization and solubility of the different contaminants present in the sediments of the Passaic River will be assessed.

Similarly, the existing studies on modeling of the thermal behavior of cement-sediment or cement-soil mixtures will be reviewed. It should be noted that to the best of our knowledge a coupled thermal-physicochemical model for contaminant migration during CDSM has not been developed.

The literature review will also include review of existing studies on the engineering properties of sediment-cement mixes. The engineering properties of interest include long and short term shear strength, compressibility, permeability and durability.

Task 2 – SOURCE CHARACTERIZATION

The proposed study will use the Lower Passaic River estuarine system as the source for contaminated sediments to be studied. The restoration of Lower Passaic River in New Jersey was initiated in October 2003. The restoration project involved studying possible scenarios for the cleanup and restoration of the Passaic River. The study was headed up by a landmark regional partnership, made up of both state and federal agencies, including the U.S. Army Corps of Engineers New York District, the U.S. Environmental Protection Agency (EPA), the New Jersey Department of Transportation (NJDOT), and the New Jersey Department of Environmental Protection (NJDEP).

The Lower Passaic River Restoration Project focused on a study area that stretches 17 miles from the Dundee Dam south to the point where the Passaic River enters Newark Bay. This area of the Passaic River, referred to as the Lower Passaic River, is highly industrialized and commercialized.
As a result, the water quality in the area has long been degraded, the sediments contaminated, and many of the wetland areas have been completely destroyed or significantly reduced. Moreover, many properties along the River's shore have been left abandoned or underutilized.

In addition to studying the Lower Passaic River itself, the Project took a comprehensive look at its tributaries. For all of the study areas, the Project team determined the sources and extent of contamination, assessed the condition of plant and animal habitats, and calculated the risks to human health and the ecosystem. Following the project team's evaluation, a comprehensive cleanup and restoration plan will be proposed to address the water quality, sediment contamination, and the loss of habitat. This restoration plan will be developed in consultation with stakeholders and the public.

As part of the restoration project, the EPA, under Superfund authority, plans to test the river sediment for contaminants, determine the sources of contamination, and assess the risk that these contaminants might pose to human health and the river's ecosystem. Prior to testing river sediments, the EPA will first review and evaluate previous studies. These studies indicate that, as a result of commercial and industrial activities along the River, there are a number of contaminants in the river sediment, including dioxin, DDT, PCBs, pesticides, mercury and heavy metals. The contamination is widespread, but is also concentrated in numerous "hot spots," especially along the lower portions of the River. Because this part of the estuary is highly dynamic, there is some concern regarding the potential release of these contaminated sediments during storm events, or during dredging activities. If the sediments are disturbed during storm events or dredging operations, sediments and sediment-bound contaminants can be dispersed into the River. The potential for sediment release is exacerbated by (i) a high liquid content and, (ii) fine grained matrices, then techniques designed to alter these characteristics could potentially limit contaminant dispersion.

A detailed review of the existing sediment characterization studies for the areas of concern in the Passaic River will be conducted. In particular the existing physicochemical characterizations of the sediments will be critically evaluated. Based on the reported spatial variability of the characteristics of the sediments, and the existing contaminants and concentrations reported, a detailed protocol for additional field sampling and laboratory testing of the sediments will be developed, if needed. Sediment samples will be collected for additional analytical laboratory testing (if needed) and to perform the experimental test proposed as Task 4 and geotechnical testing proposed as Task 6.

TASK 3 - WORK PLAN

A detailed experimental work plan will be developed to perform the laboratory and analytical evaluation of the effect of CDSM on the migration of contaminants in the Passaic River sediments. It is anticipated that a laboratory study supported by a mathematical model of the process will be used to characterize the hydration of cement during mixing of contaminated sediments, and study its effects if any on the volatilization and solubility of contaminants. A detailed work plan for experimental testing and analysis will be prepared to include protocols for conducting the laboratory analytical and geotechnical testing, sampling procedures, and analytical studies.

TASK 4 - EXPERIMENTAL DESIGN

The laboratory study will be performed in accordance with the work plan to be developed as part of Task 3. Without completion of Task 3, the laboratory equipment, instrumentation, and required monitoring and sampling cannot be detailed.

It is important to recognize the impact of different scales, laboratory verses field, on the thermal phenomena that occur during cement hydration. The laboratory scale will have a much higher area to volume ratio and consequently, it could dissipate the heat of reaction faster than the field. Therefore, the design of the laboratory scale will need to simulate the actual boundary conditions in order to reproduce the temperature increase and dissipation during the curing process. This is a critical part of the experimental design, and as such, it will be carefully addressed in the work plan.

The experimental design will address the issues of reproducibility of the results and will use standard protocols wherever these are available. Special attention will be given to aspects of sediment sample preservation, spatial variability, and compatibility of the materials with the existing contaminants during all phases of the project.

TASK 5 – MATHEMATICAL MODEL- ANALYTICAL TESTING

A mathematical model of the effects of the thermal effects generated during CDSM on the migration of contaminants from the Passaic River will be developed and implemented. It is expected that the model will consist of three main modules that will interact: a thermal module, a physicochemical module and a contaminant transport module.

The thermal module will include the enthalpy of reaction during the cement hydration and curing and thermal transport phenomena in the sediments. This module will predict the extent of the temperature increase and decrease in time during the cement reaction with the sediments. This module will be calibrated with the data gathered during the experimental phase of the project. It is anticipated that the module will consider the spatial gradients that will be generated due to the boundary conditions in the sediment water inter-phase.

The physicochemical module will use the temperature profiles in time generated by the thermal module, and will used them to obtain the changes in the physical-chemical characteristics of the contaminants that control its mobility in the sediments. In particular the increase in solubility and volatility of the different compounds will be evaluated as part of the model. The model will also consider the spatial gradients generated by the temperature profiles in the sediment.

The transport module will simulate the movement of the contaminants in time as a result of the increase temperature generated by the cement addition to the sediments. The increase transport as a result of the temperature increase will be evaluated. The model will be calibrated using contaminant profiles obtained during the laboratory tests.

In order to produce initial estimate of the time and resources required to conduct the laboratory evaluation of sediment-water column containment exchange during the hydration process of the cement stabilized sediments, a preliminary protocol has been developed. The laboratory tests will be conducted to reproduce the thermal conditions expected during the field application of the cement-stabilization technology. In particular the temperature conditions during the test will be controlled. The set point of the temperature will be selected based on the different heat of reaction due to the different proportions of cement added to the sediment for stabilization.

Samples of the sediments obtained directly from the field according to the procedures developed in Task 2 will be processed to remove big-sized objects that will interfere with the scale of the laboratory test. Sediments will not be exposed to air during transport and manipulation to avoid any losses of chemical constituents due to preparation. The samples will be stored in a refrigerated room until processing. Processing will take place within 24 hours of sample extraction from the field. A representative sample will be obtained and divided into six (6) identical aliquots. Three (3) of the aliquots will be mixed with different proportions of cement in order to establish the effect of the cement to sediment ratio in the final stabilization of the contaminants. A fourth aliquot will not be amended with cement and will serve as a control. The other two (2) samples will be used to conduct characterizations tests on the sediment according to the table presented below:

Monitoring Frequency (Measurement/sample)						
	Location					
Variable	Sediment Samples		Sediment Chambers		Sediment - Water Isotherms	Type of Analysis
	mixture	pore-water	mixture	pore-water		
Number of Samples	4	4	4	4	12	
Temperature	1	1	30	30	12	on-off site
pH	1	1	6	6	12	on-off site
Particle Size Distribution	1	1	1			off-site
DOC	1	1	2	2	2	off-site
TOC	1	1	2	2	2	off-site
Density	1	1	1			off-site
Porosity	1	1	1			off-site
% Moisture	1	1	1			off-site
Oil and grease	1	1	2		2	off-site
PAHs	1	1	6	6	2	off-site
PCBs	1	1	6	6	2	off-site
PCB congeners	1	1	6	6	2	off-site
Methylmercury	1	1	6	6	2	off-site
Dioxins	1	1	6	6	2	off-site
Metals	1	1	6	6	2	off-site
Cadmium	1	1	6	6	2	off-site
Selenium	1	1	6	6	2	off-site
Lead	1	1	6	6	2	off-site
Mercury	1	1	6	6	2	off-site
VOCs	1	1	6	6	3	off-site

TASK 6 – ENVIRONMENTAL MODELING

The mathematical model will be applied to simulate the scaled up condition of the field in the Passaic River and will provide with an evaluation of the effects of the increased temperature on the fate of contaminants from the sediments to the water column as a result of the cement hydration during CDSM process. The results will be summarized and presented as part of a final report.

TASK 7 – GEOTECHNICAL TESTING AND MODELING

The geotechnical testing will be designed to address short and long term behavior and durability of cemented sediments mixed with various percentages of Portland cement. The testing will be conducted on field collected sediment samples. Samples will be mixed with Portland cement slurry using four different dosages of cement to evaluate the engineering proprieties of river sediments with high organic matter contents and organic/non-organic contaminants.
In particular, strength gain over time will be thoroughly studied for various mixes to ensure:

a) Sufficient strength is gained such that cemented sediments will not erode while they are subjected to hydrodynamic forces and
b) Strength gain is not excessive to make future dredging possible using conventional dredging equipment.

Permeability and compressibility tests will be performed to determine:

a) The reduction in contaminant mobility associated with reduction of the permeability of cemented sediments and
b) Deformations within the cemented and underlying sediments due to existing loading are acceptable.

Other physical properties such as grain size, unit weight and plasticity will be determined as part of the geotechnical testing. Finally, durability of cemented sediments due to freeze-thaw and wet-dry cycles will be studied to better determine the long term performance of cemented sediments. A summary of the geotechnical tests and frequencies to be conducted on four sediment-cement mixtures is provided in the Table below:

Type of Test	Testing Frequency		Test Method	Total
	Raw Sediment	Sediment-Cement Mix		
Particle Size Distribution	4	16	ASTM D-422	20
Unit Weight	4	16	----	20
Tri-axial Shear At one, six and 12 month Intervals	N/A	96	ASTM D-2850	96
Permeability (one and 12 month intervals)	2	32	ASTM D-5084	34
Consolidation	2	N/A	ASTM D-2435	2
Freeze-Thaw Cycles	N/A	16	ASTM D-560	16
Wet-Dry Cycles	N/A	16	ASTM D-559	16

TASK 8 - ANALYSIS OF RESULTS AND REPORTING

Upon completion of laboratory testing, a report will be prepared to include the following:

Summary of the laboratory testing protocols, laboratory analytical and geotechnical test results, QA/QC procedure for the tests performed on raw and cement- sediment mix samples, Description of the sediment mixing and testing chamber and the procedure followed to generate the required data to be used as input for the analytical models, Mathematical model of the fate and transport of contaminants in the CDSM stabilized sediments due to increased temperature during cement hydration, Evaluation of the expected long-term behavior of the sediment-water column contaminant exchange after CDSM stabilization, Evaluation of the expected behavior of contaminants during both small and large scale CDSM applications, Recommendations on the optimum cement content for applications, Recommendations on the health and safety measures during applications, Recommendations regarding monitoring and testing required during and post CDSM applications.

References

Nicholson, P.J., B.H. Jasperse, and M.J. Fisher, 1997, "Economic Alternatives for Containment Barriers," International Containment Technology Conference, St. Petersburg, Florida, February 9-12.

Maher, A., Douglas, W. S., Jafari, F., and Yang, D., “In-Situ Solidification of River Sediments using Cement deep Soil Mixing (CDSM), Proceedings of Geo-Congress 2006, ASCE, Atlanta, Georgia.

U.S.EPA. Innovative Treatment Technologies: Annual Status Report, 10th Edition, EPA-542-R-01-004, February 2001.

U.S.EPA. Technology Resource Document--Solidification/Stabilization and its Application to Waste Materials, EPA/530/R-93/012. June 1993.