Pneumatic Flow Tube Mixing for Processing and Beneficial Use of Fine-Grained Dredged Material

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This paper discusses the feasibility of using a novel sediment solidification/stabilization technique, the Pneumatic Flow Tube Mixing (PFTM), which has been successfully used in Japan for the last decade in large scale reclamation projects utilizing stabilized soft sediments. The study was conducted by the Center for Advanced Infrastructure and Transportation (CAIT) at Rutgers University and its research partners to evaluate PFTM for stabilization and solidification of soft sediments dredged from the New York/ New Jersey Harbor. The study included a comprehensive laboratory investigation aimed at determining the ideal mix for PTFM stabilization, and a pilot scale demonstration of the PTFM technique in the field. Material stabilized during the demonstration was analyzed via unconfined compression tests, needle tests, laboratory vane shear tests, and flow tests in the laboratory and the cone penetration test in the field. Curing times for the samples were 3, 7, 14 and 28 days. The three cement content mixes were 4%, 8%, and 12% by weight (wet weight). Furthermore, samples of raw and stabilized dredged material were evaluated for total constituent concentrations (SVOCs, Metals, Pesticides, and PCBs) via the SPLP procedure. The results of the field testing program demonstrated that PFTM is an effective and efficient technique for solidification/stabilization of soft contaminated sediments from NY/NJ harbor with unconfined compressive strength values from laboratory and field samples averaging about 75 kPa (8% cement content), with a uniform field mixture quality. Furthermore, the chemical analysis of the stabilized sediments indicated no detectable mass of SVOCs, PCBs, or Pesticides.

Keywords: dredged soil, pneumatic flow mixing method, unconfined compressive strength, applicability, field test

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Introduction

The Rutgers University Center for Advanced Infrastructure and Technology recently completed a study to evaluate sediment amendment using the Pneumatic Flow Tube Mixing Apparatus (PFTM) in NY/NJ Harbor. PFTM is a rapid construction technique for stabilizing, transporting, and placing reclaimed dredged materials, soft soils and mud, which allows for their beneficial use as structural and non-structural fills. It can be used on land or off shore (within rivers and canals) and is especially well suited for the reclamation and processing of contaminated dredged materials from large scale navigational and remedial dredging projects. Prior to the development of this method, stabilization of dredged sediment and soils required special mixing plant vessels or cumbersome on-land processing plants. With the PFTM System, onsite pneumatic conveying capabilities, requiring ordinary equipment and facilities, can be used to simplify the mixing process within a small footprint and process enclosed in a tube to minimize odors. It has also been shown to eliminate the expensive and environmentally problematic disposal of dredged materials while simultaneously providing an economical and effective beneficial use application for structural fill purposes. Developed in the early 2000's in Japan, the method has been used extensively in projects of all sizes and scopes including offshore reclamation for the construction of the Tokyo Haneda International Airport Runway, Osaka International Airport, Nagoya International Airport, and within numerous harbors in Japan (Kitazume and Satoh 2003, 2005, Mizukami and Matsunaga 2015).

Method Description

The PFTM stabilization process is entirely enclosed from the time when it is loaded until the stabilized material is discharged from the system. The system receives dredge materials similar to other stabilization systems; a scow containing dredge material is brought to the process location. The scow is unloaded via excavator and loaded into a grizzly.

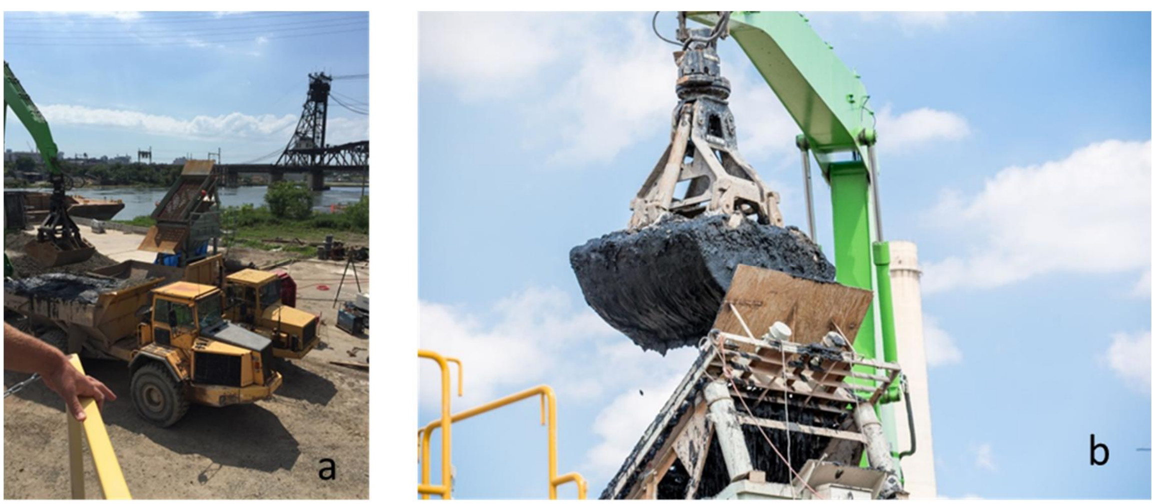

Figure 1. (a) Vibrating with being loaded from a truck (b) Screen and vibrator configuration.

Once the dredged material is screened it is fed into a hopper where it enters the PFTM process flow. It is pumped as slurry from this hopper to the mixing tool. During transport the slurry density is measured, this measurement is fed to the automated cement pumping system to ensure that the proper dosage of cement is added. A process flow diagram is presented as Figure 2.

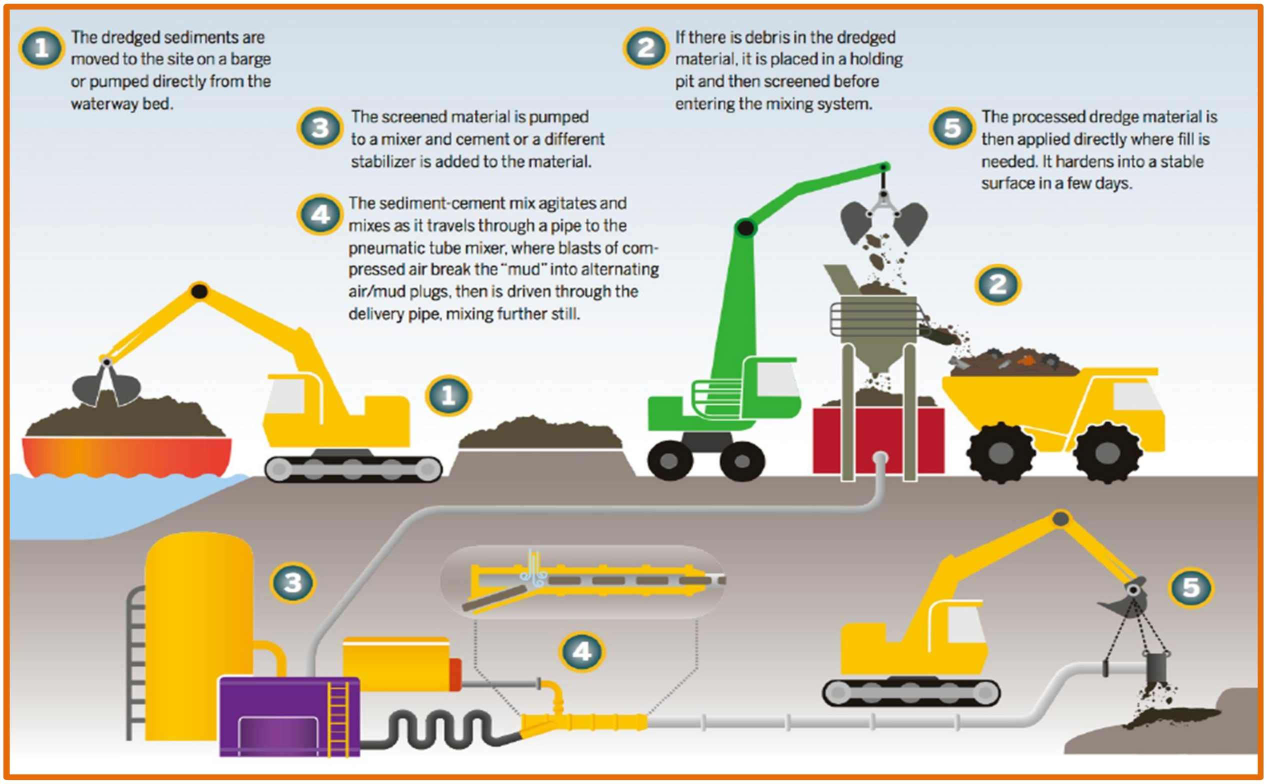

Figure 2. Process Flow Diagram for the PFTM System

The PFTM system mixes sediments with designated binders in a pipe via compressed air, during transportation from a source to the final placement site (Ministry of Transport, The Fifth District Port Construction Bureaus 1999; Kitazume and Satoh 2003; Coastal Development Institute of Technology 2008). The mixture of soft sediment and binder (cement) forms many separated mud-plugs in the pipe, and these are thoroughly mixed during transport via turbulent flow (short distance) generated within the plug. The soft sediment stabilized with binder has rapid increase in strength, and the strength of stabilized sediment can be easily controlled by changing the amount of binder and water content of the soil through a real-time computer monitoring system. The sediment mixture deposited and cured at the site can gain relatively high strength rapidly so that no additional sediment/soil improvement is required. Transport of soft sediment in a pipe without any amount of air requires high pressure to compensate for friction generated along the inner surface of the pipe. When pulses of compressed air are injected into the pipe together with soft sediment and the binder, the mixture is separated into small plugs. The plugs are then pushed to an outlet. The formation of plugs reduces the friction along the pipe's inner surface and can considerably reduce the air pressure required for transport.

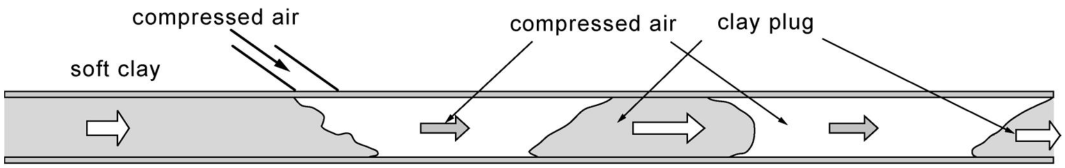

Figure 3. Conceptual Diagram of Mud-Plugs

The air pressure required for transporting sediment depends upon many factors such as sediment properties, injected air volume, pipe diameter and length. In the current practice, an inlet air pressure of 400 to 500 kPa is used (Coastal Development Institute of Technology 2008). The plugs are transported at speeds exceeding 10 m/sec in the pipe resulting in turbulent flow within the plugs due to the friction along the inner pipe surface which mixes the sediment and binder. PFTM has been used for a variety of sediment types with varied effectiveness. The results are summarized in Table 1.

Table 1. Soil properties suitable for pneumatic flow tube mixing method (Coastal Development Institute of Technology, "Technical Manual of Pneumatic Flow Mixing Method", revised version, 187p, 2008.)

Soil type		Water content	Applicability	Evaluation	
				binder content	Pumping ratio
Cohesive soil	Sand content 30-50%	High	good	middle	Somewhat low
		Low	good	middle	Low
	Sand content < 30%	higher than 200% (higher than 2.8 wl)	not good	-	-
		110 to 200% (1.5 to 2.8 wl)	good	rich	fair
		90 to 110% (1.3 to 1.5 wl)	good	middle	fair
		70 to 90% (1.0 to 1.3 wl)	good	middle	Somewhat low
		50 to 70% (0.7 to 1.0 wl)	good	middle	Low
		lower than 50% (lower than 0.7 wl)	not good	-	-

Plugs of stabilized material are transported to the discharge point. This discharge can be located at a staging area or potentially at the point of use, such as for filling behind bulkheads.

Figure 4. (a) PTFM mixing pipe (b) discharge of stabilized material from pipe

NY/NJ Harbor Demonstration Project

The evaluation of the PFTM method for use in the New York / New Jersey Harbor was conducted at a sediment management site in Kearny, New Jersey operated by Clean Earth Inc., of Hatboro, Pennsylvania, from July through September of 2015. The PFTM system was brought from Japan and erected at the site. The first preliminary test occurred on 7/24/2015, and the first week of production was 8/4/2015 through 8/7/2015. The total amount of material processed during the deployment was limited to 3929 m^3. The field production was completed on 9/4/2015. This project successfully demonstrated that the PFTM process could be used for impacted sediments dredged from the Arthur Kill waterway - NY/NJ Harbor and the resulting amended material possessed the required strength and chemical characteristics for upland placement and beneficial reuse.

Chemical analyses completed for these samples include SVOCs, Metals, Pesticides, and PCBs. Each of the three raw materials were analyzed for total constituent concentrations (mass of contaminant/mass of sample) and for leachate concentration via the SPLP procedure. Comparison of the total constituent concentrations to the NJ Residential Direct Contact Soil Remediation Standards indicates that the material is relatively clean with few violations. Violations included Benzo(a)anthracene, which ranged in concentration from 0.171 to 1.79 mg/kg (standard = 0.6 mg/kg), Benzo(a) pyrene which ranged in concentration from Not Detected to 1.24 mg/kg (standard = 0.2 mg/kg), and Benzo(b) fluoranthene which ranged in concentration from 0.182 to 1.85 mg/kg (standard = 0.6 mg/kg). In addition, all of the materials had elevated arsenic concentrations (average value of 40 mg/kg with a range ±5 mg/kg) above the 19 mg/kg standard.

Analysis of the contaminants in the leachate derived from the SPLP procedure indicates that there is no detectable mass of the target SVOCs or any of the other SVOCs compounds. The concentrations of Arsenic in the leachate from the raw sediment for the 8% mix were 14.8 and 15.9 µg/L and 3.97, 3.47 and 3.97 µg/L in the stabilized material. Similarly, the concentrations of Arsenic in the leachate from the raw sediment for the 12% mix were 14.8 and 17.6 µg/L and 2.16, 3.29 and 3.29 µg/L in the stabilized material. These results indicate that approximately 75% of the leachable arsenic is bound by the 8% Portland cement mix and approximately 80% is bound by the 12% Portland cement mix. These concentrations are greater than the Leachate Criteria for the NJ Site Specific Impact to Ground Water Soil Remediation Standards of 3 µg/L, however for the calculation of the site specific standard, dilution must be considered (NJDEP 2013). Thus with even a small amount of dilution, the site specific standard will be greater than the measured leachate concentrations indicating that that they will have no offsite impacts.

The index properties of each of the amended sediment mixes were determined prior to all chemical and physical measurements. A summary of the index properties of the amended sediments is presented in Table 2.

Table 2. Index Properties Summary

Sample	Water Content% (ASTM D2216)	LL% (ASTM D4318)	PL% (ASTM D4318)	USCS (ASTM D2487)	Organic Content (ASTM D2974)	GS (ASTM D854)
Shallow 4%	117.35	85	37	OH	8.7	2.27
Shallow 8%	80.78	72	32	OH	7.7	2.39
Shallow 12%	124.68	56	42	OH	6.2	2.53
Deep 4%	153.72	91	40	OH	8.2	2.42
Deep 8%	128.41	63	39	OH	6.9	1.94
Deep 12%	116.86	74	38	OH	6.6	2.02

The grain size distribution is presented in Figure 5.

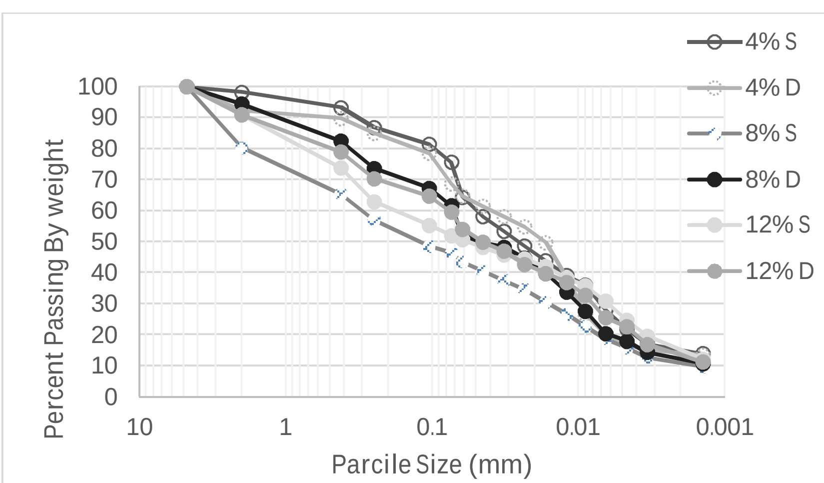

Figure 5. Grain Size Distribution

In-situ evaluation of stabilized materials were conducted using Cone Penetrometer Tests (CPT, ASTM D5778). CPT evaluation were conducted for each of the test pits to determine the vertical profile of in-situ material strength.

Figure 6. Cone Penetration Test

The results (Figure 7a.) show that the material strength is fairly uniform throughout the depth profile for each of the stabilized mixes with the 12% being the strongest. Linear regression was used to determine the relationship between tip resistance and measured UC strength for samples collected throughout the depth profile at all the test pits.

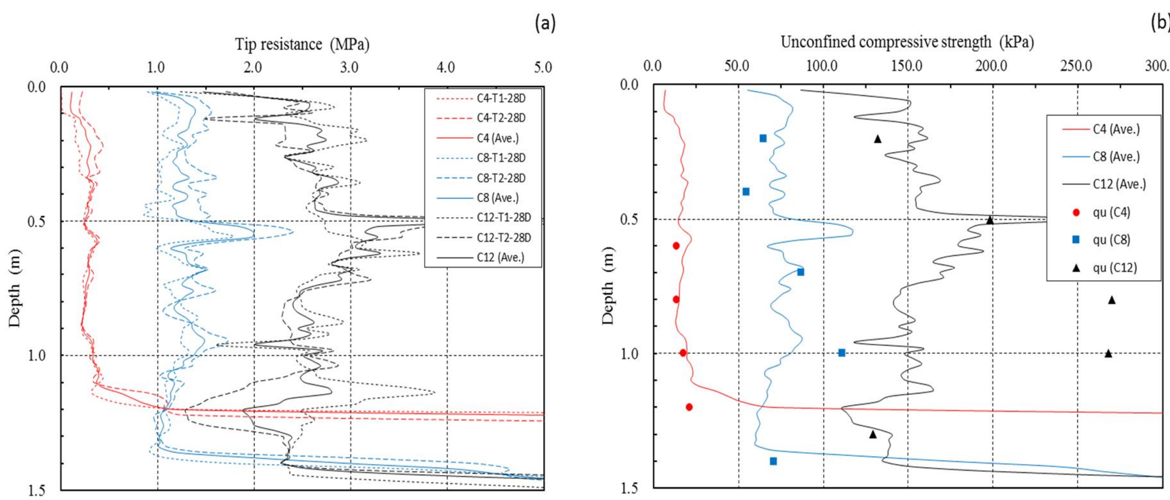

Figure 7. (a) CPT measured tip resistance throughout the stabilized dredged material profile (b) Estimated UC strength throughout the stabilized dredged material profile.

The PFTM's relatively small footprint and ability to push sediment up to 1 km inland in the processing make it an ideal mobile system for on-site S/S of impacted sediments. One potential configuration is a barge mounted system shown in Figure 8. This type of configuration would allow the treatment barge to be brought to the project site, process the sediment and transport it upland to a placement site or staging area. The benefits of this system over conventional methods is the elimination of multiple handling steps and no requirement for bulkheads or other infrastructure required for loading/unloading of scows.

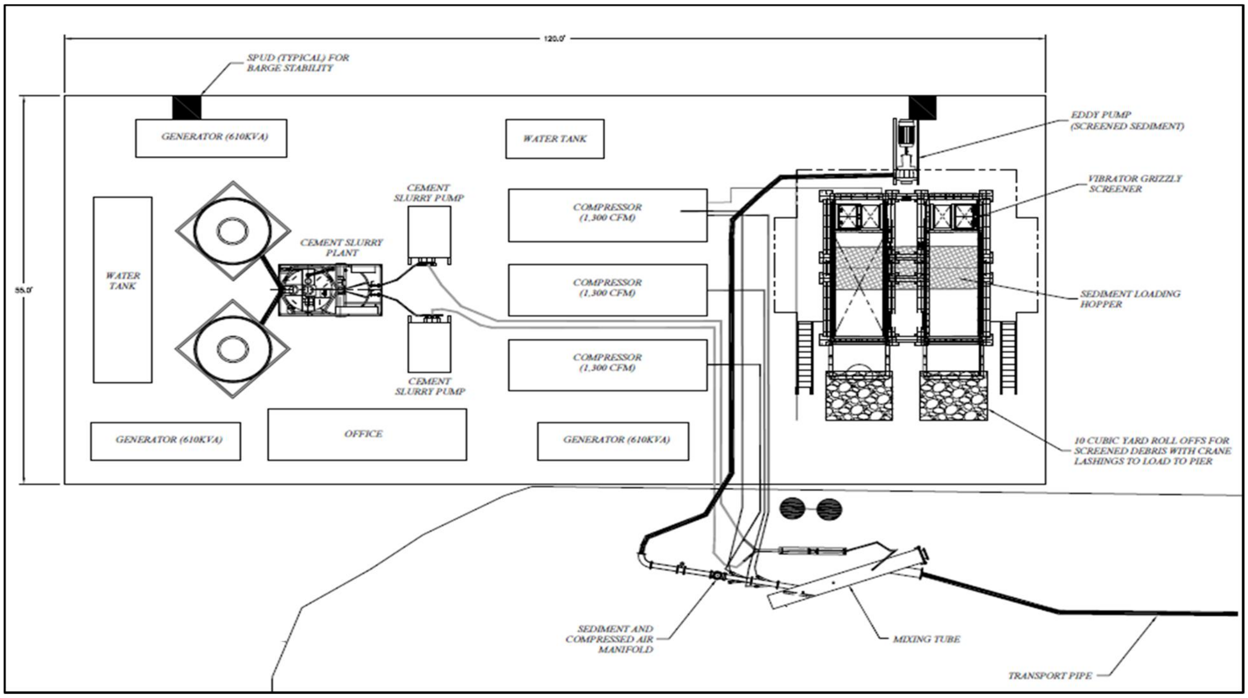

Figure 8. Barge Mounted PFTM Configuration

Conclusions

The results of this experimental program demonstrate the utility of PFTM as a rapid and efficient method for stabilization and placement of soft sediments dredged from the NY/NJ Harbor. The material stabilized using PFTM had uniform geotechnical properties and acceptable chemical properties resulting in a high potential for beneficial use. PFTM is a viable technology that can be used for the stabilization of dredged sediments. The system has attributes that may be beneficial compared with tradition processing strategies. These include the small footprint of the system, the excellent mixing provided by the method, the ability to transport material 1000 meters upland as part of the treatment process, and the enclosed/automated nature of the system which will reduce handling/exposure which may be more beneficial with more contaminated sediments.

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