SCIENTIFIC MEASUREMENTS IN SERVICE TO DEEPENING AND DREDGING OF NEW YORK AND NEW JERSEY HARBOR

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ABSTRACT

The US Army Corps of Engineers and the Port Authority of New York and New Jersey are deepening 42 kilometers (26 miles) of navigation channels of New York harbor to -15.3m (-50ft) MLW. Three measurement problems are important for estimating and bidding: (a) characterizing rock, (b) quantifying black silt and separating from clean sediments, and (c) locating utilities and obstructions. To blast and remove unrippable rock costs much more than removing diggable materials. To remove and dispose black silt costs several times the cost of removing and disposing sands and silts. Utilities take years to remove and replace.

The plans and specifications are the primary information for managing the construction and engineering of the New York Harbor deepening project. We make geological and geophysical measurements that are incorporated into the plans and specifications. We map the geology, stratigraphic horizons, and the physical properties of the rocks and sediments throughout the dredging projects on a contract-by-contract basis. All data, maps, and cross-sections are compiled into a single reference frame.

Keywords: Material separation, orthosonograph, partially oil-saturated sediment, seismic imaging.

INTRODUCTION

The US Army Corps of Engineers and the Port Authority of New York and New Jersey are deepening 42 kilometers (26 miles) of navigation channels of New York and New Jersey harbor to -15.3m (-50ft) MLW. The project requires dredging 50 million cubic yards of rock and sediment. Beyond the halfway point, the project is on schedule and on the US$1.6 billion fully funded authorized cost.

Three (3) major challenges in this project have been: (1) how much of the 5.6 million cubic yards of rock are diggable with the dredging equipment available and how much will require pretreatment such as blasting, (2) locating and estimating the volume of industrial-age sediments, and (3) better definition of the location of existing utilities and checking for unidentified or unknown utilities and other obstructions. To help resolve these difficulties and stay on schedule and on budget, we made scientific measurements and published the data on a contract-by-contract basis. The plans and specifications are primary information for managing the construction and engineering of the harbor-deepening project. The scientific maps and cross-sections are incorporated into the plans and specifications. The value of the measurements to the project management has been demonstrable at multiple times the cost.

Geophysical techniques are developed for the project to map stratigraphic horizons and quantify the properties of the sediment and rock strata. We discuss in another paper (Murphy et al., 2011a) a series of techniques included calibration with standard penetration test borings and rock cores. Rock core properties, such as rock quality designation, are useful in determining diggability. Detailed core descriptions are invaluable. All data, maps, and cross-sections were compiled into a single reference frame. All images are georeferenced. All measurements are integrated in the interpretation. Orthosonography yields aerial-photograph-like maps of the seafloor. Reflection-seismic images were depth migrated and profile the approximate depth to rock. We interpret stratigraphic horizons and estimated physical properties in the seismic sections. The seismic properties are correlated with mechanical properties to estimate diggability. The results are calibrated with core borings. We presented the results as geological and geotechnical cross-sections with core borings.

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The cost of blasting and removing rock is many times the cost of removing clean sands. The diggability of bedrock without blasting or other pretreatment varies strongly with rock type. Shale has a high diggability (figure 1). Diggability decreases through pegmatite, metamorphosed sandstone, and diabase. We acquire many standard penetration test borings. The rock configuration and properties are measured. The quality of the descriptions is critical. We relate the intrinsic properties such as porosity to effective engineering properties such as rippability. Previous dredging of various rock types, the equipment used to accomplish that dredging, and test pits with various available equipment were invaluable in estimating diggability.

We (Murphy et al., 2011a) also discuss an example of mapping diggable rock in Arthur-Kill channel. This project involved locating ten test-pit areas using our geological and geophysical mapping tools, and combining the test-pit results with the geological and geophysical investigations.

Removal and placement of material unsuitable for ocean disposal (industrial material) is a significant part of most contracts. Industrial-age fine-grained black silt may be composed of 50% silt matrix, 25% water, and 25% solute by volume. The pore space of these sediments may include various components at levels that may affect marine organisms. Closed clamshell buckets are used to minimize the re-suspension of black silt. Dredging and placing black silt costs seven times the cost of removing clean sediment due to transportation and processing the material to stabilize it and place it upland. We have mapped the black silt material and verified the removal on an acceptance-area-by-acceptance-area basis.

ROCK MAPPING – GENERAL CONCEPTS

The areal extent of and depth to diggable rock must be characterized to determine the volume of rock that will require blasting before removal by dredging.

To produce maps of the distribution and depth to diggable hard rock, we use sidescan orthosonography, multibeam bathymetry, subbottom seismic profiling, calibration cores, and test digs. We calibrate the geophysical measurements using borings and laboratory measurements of ultrasonic velocities and rock strength. Undiggable hard rock is characterized by being intact and having low porosity, high ultrasonic and seismic velocity, high elastic modulus, high strength, high electrical resistivity, low fracture density, and high rock quality designation (RQD). We used a compressional-wave velocity of >2,300m/s (>7,540ft/s) to determine rock and >3,000m/s (>9,840 ft/s) to

Figure 1. Excavator New York digging rock in the Arthur Kill.
determine harder, more intact, less fractured rock. We used a rock quality designation (RQD) cut-off value of 50% to separate poor quality, fractured rock (RQD<50%) from good quality, intact rock (RQD>50%).

**Kill Van Kull Example**

Murphy et al. (2010) used a general diffraction-based seismic velocity estimation for the Kill Van Kull dredging project. This technique produces a local-base solution to the velocity estimation; this technique is calibrated with sediment cores. Figure 2 shows an example of this technique along the centerline of the Kill Van Kull channel. Figure 3 summarizes results from multibeam bathymetry, sidescan orthosonography, top of rock and top of fast rock (>3,000m/s) from boring and seismic data. Multibeam bathymetry image (top) shows elevation from -6.1m (-20ft) MLW (red) to -18.3m (-60ft) MLW (dark blue). The image shows striations from dredging to -13.7m (-45ft) MLW (light yellow). There are several feet of silt deposits on the southern channel toe and an area in the southwest that is below final grade of -16.6m (-54.5ft) MLW (light blue). Sidescan orthosonography (middle top) shows that the reflection coefficient of the silt is not that of black silt but more like gray silt. The top of rock (middle bottom). The top of fast rock (>3,000m/s). The slice map at -15.8m (-52ft) (bottom) shows the footprint of the top of rock and the top of more-intact rock. The rock constitutes roughly 32% of the total volume of material to be dredged. Much of the serpentinite and other metamorphic rock near the surface is highly fractured, less-intact rock. The more-intact rock constitutes less than 5% of the total volume of material to be dredged.

Figure 4 shows a collection of all the borings in Kill Van Kull projected along with the top of fast rock map as obtained from the seismic diffractions. Figure 4 bottom shows a collection of sediment cores obtained along the Kill Van Kull area.
Figure 3. (Top) Multibeam bathymetry showing striations from 45-ft dredging. (Top middle) Sidescan orthosonograph, insonified from the north. (Bottom middle) Top of rock, calibrated with boring control points showing intact rock, indicated by rock quality designation values RQD>50%. (Bottom) Slice map of rock at -15.8m (-52ft) below MLW; gray indicates top of rock above -15.8m (-52ft) and orange indicates fast rock above -15.8m (-52ft).
Arthur Kill Example

We used a new technique based on Fomel (2007) to use the diffraction nature of the seismic image to estimate velocities as a global inverse solution. Figure 5 (top) shows examples of depth-migrated seismic lines from the Arthur Kill channel. The seismic lines were correlated to core borings and multibeam bathymetry. The seismic velocities (Figure 5 – bottom) were mapped into the depth-migrated sections. The error in the velocity estimation with this new technique is approximately \(+/-100\) m/s (330 ft/s), which is more accurate than previous methods.

Figure 6 summarizes results from rock velocity mapping using seismic and boring data. The top figure is the top of rock map based on an integrated interpretation of borings and reflection seismology. Middle panel of Figure 6 shows surface map of the top of fast rock 2,900 m/s (9,510 ft/s). Bottom panel shows slice an map of top of fast rock for an elevation of -16.6 m (-54.5 ft) MLW. We use the definition of fast rock to include 2,900 m/s (9,510 ft/s) to place the test digs properly.

Note on Figure 6 the strike of the rock is N36\(^\circ\)E. The stratigraphic thickness (the thickness perpendicular to the strata) is almost 1,830 m (6,000 ft) along the 2,970 m (9,750 ft) of the channel. There are several regions that have sediment troughs through to -54.5 ft MLW. The area of rock defined by the compressional wave velocity of 2,900 m/s (9,510 ft/s) constitutes 36.7% of the total area. The area of rock defined by the compressional wave velocity of 3,000 m/s (9,840 ft/s) is 18.9% of the total area. That is, the area defined by 3,000 m/s is half the area...
defined by 2,900m/s. Almost all of the fast rock has a velocity near 3,000m/s. The fast rock layer follows the general strike of the rock.

Bottom panel of Figure 6, the slice map at -16.6m (-54.5ft) follows the rippability criteria of 2,900m/s (9,510ft/s) to delineate rippable from unrippable rock. We expected that all of the rock may be diggable because stratigraphic layering should allow all of the rock to be ripped. Even though we expected that all of the rock may be diggable, for the purposes of the test dig preparation and estimates, we considered all rock with a velocity greater than 2,900m/s to be unrippable.

Figure 5. Seismic velocity analysis, top corresponds to seismic image after processing, bottom is the estimated velocity model from diffraction seismic imaging.
Figure 6. Slice Maps AK. Top panel shows top of rock map. Middle panel shows top of fast rock map 2,900m/s (9,510ft/s). Bottom panel shows depth slice at an elevation of -16.6m (-54.5ft).
MATERIAL SEPARATION – GENERAL CONCEPTS

Before channel deepening can occur, the areal and thickness distribution of partially oil-saturated industrial sediment must be characterized to determine the volume that must be removed and sequestered in environmental disposal sites. The cost of black-silt removal and disposal is several times more than dredging clean sediments.

The composition of industrial black silt is approximately 50% silt particles, 25% bay water, and 25% hydrocarbon with trace amounts of heavy metals. Its acoustic properties are sensitive to temperature (Figure 7). The unique properties of black silt make it possible to map it and determine its thickness.

![Figure 7. (Left) Split core of black silt. Thickness in excess of 9”. (Right) Compressional wave velocity vs. oil/water saturation for black silt.](image)

**Mapping of Black Silt**

To produce maps of black-silt distribution and thickness, we use sidescan orthosonography, multibeam bathymetry, subbottom seismic profiling, calibration cores, and test digs.

We developed a processing method for side-scan data that results in a pair of complementary orthosonographs (Ward, et. al. 2004). Each pair of orthosonographs provides 100% seamless coverage of the same area of investigation but with illumination from opposite directions (i.e. illuminated from the east which emphasizes the western side of the river; illuminated from the west which emphasizes the eastern side of the river).

Figure 8 shows sidescan orthosonographs, which are maps of measured sonar reflection coefficients. Sidescan sonar frequencies are 440 kHz in the ultrasonic range and their penetration into the subsurface is on the order of centimeters. Bright colors indicate high sonar reflectivity, representative of Pleistocene till and varved silt and clay. Dark colors indicate low reflectivity, representative of varying thickness and smoothness of black silt. Thicker and smoother deposits of black silt yield lower sonar reflectivity. The figure shows the bottom has been scoured along the ship paths and turning areas. The black-silt footprint is dynamic and changes constantly with the currents and ship traffic. This interpretation from sonar imaging is consistent with core borings and subbottom profiling. The maximum thickness is 0.6m (2.0ft); the maximum sedimentation rate is 0.3m/yr (1.0 ft/yr).
Figure 8. Orthosonograph of Newark Bay showing the areal distribution of the black silt.
Figure 9 shows the bottom of the channel in Arthur Kill. Note the accumulation of black silt sediments accumulates at the channel toes and is not present at the channel centerline, which is the main path for ship traffic.

![Figure 9](image)

**Figure 9. Orthosonograph of Newark Bay showing the areal distribution of the black silt.**

Figure 10 shows an example of a subbottom profile seismic image. Some seismic sections have challenging imaging problems: 1) low-velocity attenuation layer due to large accumulations of black silt and 2) strong lateral velocity variations from low-velocity Holocene/Pleistocene sediment layers and high-velocity Jurassic/Triassic diabase and shale. To handle these challenges we use zero-offset wave-equation migration. The velocity model was built by combining prior geological knowledge of the area.

The black silt is identified as a low-velocity, transparent layer below the mudline (light blue in Figure 10). From the subbottom image it is possible to identify not only the lateral extension of the black silt (together with the orthosonograph) but also its thickness. The black silt (partially oil-saturated Recent sediments) tends to accumulate at channel toes and thins toward the channel centerline.

![Figure 10](image)

**Figure 10. Subbottom depth migrated seismic image showing black silt as a thin layer draping over the underlying Holocene and Pleistocene units.**
UTILITY LOCATIONS – GENERAL CONCEPTS

Utilities cross the channels throughout the NYNJ harbor. Oil and gas lines cross Newark Bay. Oil lines cross Arthur Kill. A sewer tunnel crosses Port Jersey channel. Water, oil, and gas lines cross the Anchorage.

Figure 11 shows nineteen (19) crossings found to cross Arthur Kill before the -42ft project. The area was designated as a pipeline crossing and 6 lines were expected. Nineteen was a surprise. Sidescan orthosonographs, sub-bottom seismic reflections, and magnetic field measurements were used to map the area. The pipelines were a combination of active lines, abandoned cleaned and capped lines, undocumented lines, and debris. The mapping was incorporated in the plans and specifications for the Arthur Kill deepening. Acceptance surveys confirmed removal, and no additional volume of debris was claimed at the end of the dredging.

Figure 11. Target locations for pipeline crossings on the Arthur Kill channel. There are 19 crossings, only 6 were anticipated. The locations and elevations were later confirmed by excavation and removal with no surprises. Identification of pipes using orthosonographs, magnetometer, and sub-bottom seismic.

Figure 12 shows an example of sub-bottom seismic reflection of the 107cm (42") water siphon between Brooklyn and Staten Island. After dredging to -15.5m (-51ft), the top of pipe would lie above the horizon for seven-foot protective overburden. The pipe had to be replaced.
CONCLUSIONS

The construction and engineering of the New York harbor-deepening project depends on the plans and specifications. The plans and specifications incorporated our geological and geophysical measurements. These measurements reduced uncertainty, improved project management and design, and reduced costs. Scientific maps and cross-sections are incorporated into the plans and specifications to manage dredging costs better. Dredged materials are not lumped together. Each material is quantified and treated separately. Dredge contracts can be targeted for expected dredge products. Risk and cost is reduced through more focused dredge programs.

REFERENCES


Fomel, S., Landa, E., and Taner, M. T. “Post-stack velocity analysis by separation and imaging of seismic diffractions,” *Geophysics* 72, U89 (2007), DOI:10.1190/1.2781533

CITATION