GEOTECHNICAL INVESTIGATIONS FOR DREDGING PROJECTS

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ABSTRACT

Dredging is the underwater excavation of soils and rock for channel and harbor deepening and for land reclamation. Often owners of dredging and reclamation projects will include information from geotechnical site investigations in plans and specifications to prospective contractors prior to bid. Dredging contractors interpret and use this geotechnical information to select dredging equipment and methodologies, to determine the location, characteristics, physical properties, and quantities of the materials to be excavated, to estimate production rates in the materials indicated by the borings, to estimate project costs, to assess dredging risks, and to bid, plan and ultimately perform the dredging and reclamation work. Soil location, area, classification, quantity, and physical properties are primary drivers of dredging equipment selection, production, costs, and ultimate project performance. Incomplete or inaccurate geotechnical information will likely produce an unsuccessful project for both the contractor and the owner. Complete and accurate geotechnical information can provide for both the owner and the contractor a successful project performed on time and to high quality. Site investigations must provide comprehensive and accurate geotechnical data representative of the materials throughout the project, such that the contractor can reliably estimate, price, plan and successfully perform the dredging project.

This paper describes the geotechnical information required by contractors for estimating, planning and performing dredging projects and the relationship of geotechnical properties to dredging production, costs, and performance. General guidelines and criteria are presented for performing geotechnical site investigations for dredging projects and providing information in plans and specifications.

INTRODUCTION

Dredging is the underwater excavation of soils for the deepening of channels and harbors and for land reclamation. Owners typically solicit dredging projects to dredging contractors for competitive bidding and often define the materials to be dredged in their solicitations by including the results of geotechnical site investigations in their plans and specifications. The geotechnical site investigations are either performed directly by the owner or contracted to a geotechnical engineering firm. In either case, the dredging contractor typically has no input to the design, methods, techniques, or deliverables of the site investigation.

Geotechnical site investigations for dredging projects typically involve the taking of soil borings or vibrocores to obtain samples for material classification and testing. Classification and testing can be done both insitu during the boring process and in the laboratory on samples obtained from the borings. Typical geotechnical information included in bid packages include logs from the borings indicating the soil stratigraphy and classification, the results of insitu testing of the material, and results from subsequent laboratory testing of soil samples from the borings.

Dredging contractors interpret and use this geotechnical information to select dredging equipment and methodologies, to quantify the location, quantities, and physical properties of the soils to be excavated, to estimate production rates in the materials indicated, to estimate project costs, to assess dredging risks, and to plan the performance of the project. The geotechnical information is a primary driver of the dredge production, cost estimate, bid pricing, and of ultimate project performance.

Inaccurate and/or incomplete geotechnical site information can result in incomplete or misrepresented scope, inappropriate application of equipment and methodologies, inaccurate production estimates, poor risk assessment, inaccurate cost estimates, and inappropriate pricing. Such situations can ultimately lead to unsuccessful projects not only for the contractor but also for the owner of the dredging project. Ultimately, poor geotechnical information can

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lead to budget overruns, late schedules, poor quality, disputes, claims, and even incomplete projects. As per the old adage, "garbage in, garbage out" is illustrated in Figure 1.

INNACCURATE & INCOMPLETE GEOTECHNICAL SITE INFORMATION →

- INCOMPLETE SCOPE
- INAPPROPRIATE EQUIPMENT & METHODS
- HIGH RISK LEVELS
- INACCURATE PRODUCTION ESTIMATES
- INACCURATE COST ESTIMATES & PRICING

→

- POOR PRODUCTION
- COST & BUDGET OVERRUNS
- LATE SCHEDULES
- POOR PERFORMANCE
- POOR QUALITY
- DISPUTES & CLAIMS
- INCOMPLETE PROJECTS

Figure 1 - Garbage in, garbage out

Accurate, complete and comprehensive geotechnical site information significantly lowers risk levels and leads to the application of appropriate equipment and methodologies, accurate production estimates, and appropriate pricing levels. For both the owner and the contractor, the result is a successful project completed on time, within budget, and to high quality standards creating a "win-win situation" as illustrated in Figure 2.

ACCURATE & COMPLETE GEOTECHNICAL SITE INFORMATION →

- COMPLETE SCOPE
- APPROPRIATE EQUIPMENT & METHODS
- LOWER RISK
- ACCURATE PRODUCTION ESTIMATES
- ACCURATE COST ESTIMATES & PRICING

→

- ANTICIPATED PRODUCTION
- ON COST BUDGET
- ON TIME WORK
- GOOD PERFORMANCE
- GOOD QUALITY
- SUCCESSFUL PROJECT FOR CONTRACTOR & OWNER

Figure 2 - A win-win situation

Thus, the geotechnical information provided is ultimately for both the owner's and contractor's benefit or risk. For better or for worse, "what goes around comes around" is illustrated in Figure 3. Bad geotechnical information will most likely result in a poor project for both Owner and Contractor. Good geotechnical information can lead to a successful project for both Owner and Contractor.

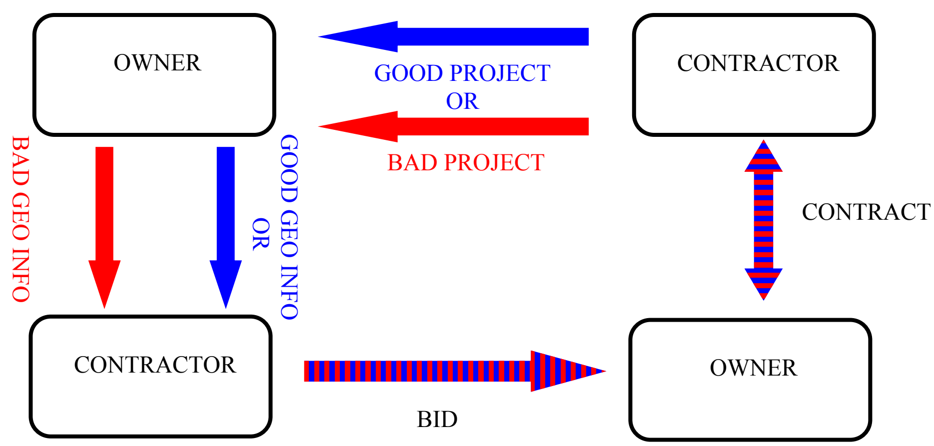


Figure 3 - What goes around…

This paper describes the geotechnical information required by contractors for estimating, planning and performing dredging and the relationship of geotechnical properties to dredging production, costs, and performance. General guidelines and criteria are presented for performing geotechnical site investigations for dredging projects and for providing geotechnical site information in plans and specifications.

GEOTECHNICAL INFORMATION FOR DREDGING PROJECTS

When estimating, planning and performing dredging projects, the dredging contractor must have information of sufficient quality and quantity to answer the following seemingly simple questions with a reasonable level of contracting certainty:

- where is the material to be dredged?
- how much material is to be dredged?
- what is the material to be dredged?

Where is it? How much of it is there? What is it? Although such questions may seem obvious and it may be reasonable that prospective bidders be provided sufficient and equal information to answer these questions prior to bidding, it can be the case that the geotechnical site information provided for dredging projects is inadequate or of too poor a quality to answer these questions within appropriate levels of certainty.

"Where and how much?" can be more technically described as the location, area, and quantities of the materials to be dredged. "What?" can be more technically described as the classification and physical properties of the materials to be dredged.

The location of each type of material to be dredged, in terms of both area and elevation, each material quantity, and the overall dredging quantity are primary factors affecting the type and class of dredging equipment required, the production of the dredging plant, and the duration of the dredging project. Similarly the classification and physical properties of the materials to be dredged are also primary factors in choosing the type and class of dredging equipment required and in determining the production of the dredging plant. Since the cost of dredging equipment is a function of its type and class, and the cost of a dredging project is a function of the dredge equipment cost and its productivity, then the material location, area, and quantity along with the classification and physical properties of the material to be dredged are all primary drivers of dredging costs and eventual project performance. The relationship of these primary drivers to project equipment, production, costs and performance is generally illustrated in Figure 4.

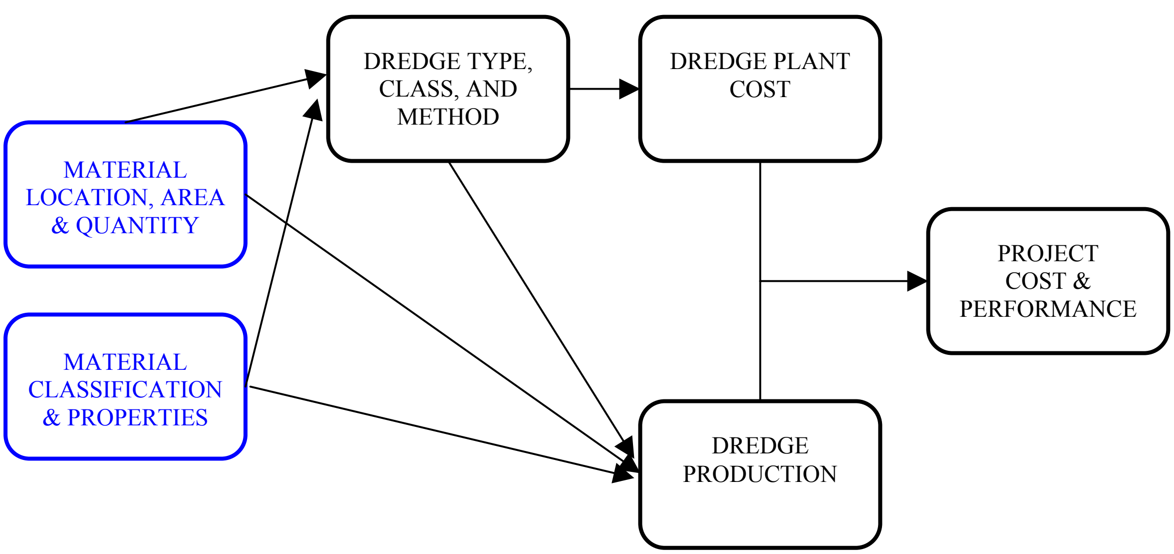


Figure 4 - Relationship of project factors

Location, Area, & Quantity

The location of the dredged material both in area and in elevation is of great importance in dredging projects. In order to choose appropriate plant and estimate quantities, production, and costs, the contractor needs sufficient and accurate information to determine for each material type in the dredging area:

- the depth,
- the absolute and relative quantities,
- the dredge area,
- the layer stratigraphy,
- the layer thickness (face), and
- the hard (or unsuitable) material surface.

Coordinates throughout the dredge area in x, y, and z are critical for determining the area and total volume of material to be dredged. Dredging projects often involve material profiles with soil layers of varying types - i.e. dense sand over rock or coral, silt overlying dense sands etc.. The contractor must be able to determine the total quantity of the materials to be dredged, the relative quantities of each material type, and the stratigraphy of the material layers in order to properly estimate dredge volumes and fill balances, choose the type and class of dredging plant for the project, and to estimate methodology and productivity of the dredge chosen.

Dredging projects are often bid on a unit rate basis without an individual unit rate or quantity for each material type to be dredged. This is sensible because the various material layers are often not re-measurable by practical methods in the field. Dredging production and costs vary widely by material types. Production in hard material is much lower than that in soft material and the dredging of hard material can be an order of magnitude more expensive than soft soil dredging. Thus, the relative quantities of each material type are important drivers of the overall production and unit cost. The contractor must be provided information concerning the location of the various materials to be dredged, both in area and in elevation, in order to determine the relative quantities of the materials to be dredged and the resultant cost for the overall dredging quantity.

The thickness and area of each material layer within the dredging template is the basis for the quantity take-off of each material type and for the total dredging quantity. Further, the thickness (or "face") of the overall layer, and of each material type, is an important factor contributing to dredging production. Generally, thick layers of material ("high face") are more productive and less expensive to dredge than thin layers ("low face"). In low face dredging, the dredge area to be covered may be the critical variable, rather than the material volume or physical properties.

Particularly when hard materials are to be dredged -- i.e. hard clay or rock -- the top of the hard material formation in relation to the required dredging depth, or "grade", is of major importance because it fixes the area, quantity, and thickness of hard material removal for quantity, production, and ultimate cost calculations.

All of the above location, area and quantity information can be determined from accurate and thorough bathymetric surveys (surface x,y,z), and borings or vibrocores (subsurface x,y,z) data.

Material Classification and Physical Properties

In order to choose appropriate plant and estimate production and costs, the contractor needs sufficient and accurate information to determine for each material type in the borrow area:

- soil classification
    - silts, sands, clays, or rock
    - descriptions per ASTM standards (loose, dense, fine, coarse, etc.)

- soil physical properties
  - grain size distribution (sands and silts)
  - insitu density (unit weight)
  - relative density (sands)
  - moisture content (silts and clays)
  - liquid limits and plasticity (clays)
  - strength (clay and rock)
  - quality (rock)

The classification of the soil to be dredged - i.e. silt, sand, clay, rock (fine, coarse, loose, dense, etc.) - plays a crucial role in determining the appropriate type and class of dredging equipment to be utilized. For example, non-cohesive materials such as silts and loose sands can often be efficiently dredged with trailing suction hopper dredges, clamshell dredges, or dustpan type dredges while cohesive or hard materials such as stiff clays and rock or very dense sands may require a cutter suction dredge for efficient excavation. Higher production requirements, stronger materials, and longer transportation requirements will require larger class dredges within each dredge type.

The geotechnical properties of the soil are also primary drivers of dredging equipment selection, methodology, production, project duration, and hence project cost. Soil classification and physical properties are most often determined from boring and vibrocore logs (classification), and insitu and laboratory tests (properties).

Dredge production can be described as being a combination of two types of production -- the digging production and the transport or hydraulic production.

Digging Production

Digging production is a function of, among others,

- the dredge's excavation characteristics (cutter power, swing speed, cutter dimensions, ladder weight, bucket forces, draghead weight, jetting power, trailing speed, etc.)
- material geometry and face,
- material insitu density (unit weight),
- material quality characteristics (for rock),
- the specific energy of the material to be dredged - which can be calculated from the physical properties of the material as obtained through proper geotechnical investigation.

For dredging silts and clays, specific energy is calculated primarily from the shear strength of the material. The shear strength can be measured directly with a torevane or penetrometer on site or in the lab, with a triaxial test in the lab (for clay), or can be correlated indirectly from the "N" value of the Standard Penetration Test.

For rock dredging, specific energy can be calculated from the compressive strength and the quality of the rock mass. The compressive strength is measured in the laboratory on sampled rock cores from the core run. The quality of the rock is a determination of the massiveness of the rock based upon insitu inspection of the coring, including the RQD (rock quality designation) and the facture index.

For sands, specific energy can be correlated to relative density and insitu penetration resistance such as the "N" value from the Standard Penetration Test (SPT) or the penetration resistance from the Cone Penetration Test (CPT).

Transport / Hydraulic Production

Mechanical transport of the material may be in a hopper dredge or hopper barge. For mechanical transport, the primary production driver from the material is the unit weight and bulking. For the purposes of this paper, we will focus on hydraulic transportation via pipeline.

Hydraulic production is a function of, among others,

- the flow, head and power characteristics of the dredge pumps,
- the length, diameter, elevation, and fittings of the pipeline system, and
- the hydraulic properties of the material to be dredged when slurrified with water.

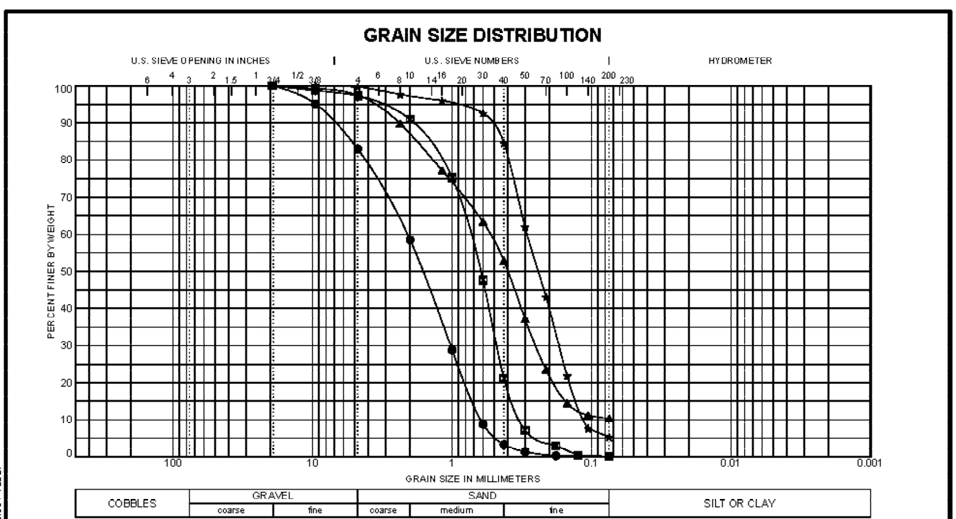
Of most importance from the material side of the equation is the grain size distribution of the particles along with the volumetric weight of the insitu soil. Each of these parameters can be determined from the physical properties of the soil as obtained through proper geotechnical investigation.

For silts, the hydraulic properties of the slurry can be calculated from the viscosity of the material and its "insitu" density (in place density) measured in the lab from samples obtained from borings (Shelby tubes).

For clays, the hydraulic properties of the slurry can be calculated from the Atterberg limits and insitu moisture content (to determine the extent of "clayballs" which will form) and from the material insitu density. Each of these parameters are measured in the laboratory from samples obtained from the borings (Shelby tubes) or from vibrocores.

For rock, the hydraulic properties of the slurry are estimated from the grain size distribution expected after cutting or blasting. Rock quality parameters are helpful in this estimation. Also required is the insitu density which can be measured directly from cored samples.

For sands, the hydraulic properties of the resultant dredged slurry are calculated from the sand grain size distribution, the % fines, and the sand in-place unit weight (insitu density). The grain size distribution is determined by standard sieve testing in the laboratory from samples obtained from borings or vibrocores. A typical sieve curve is shown in Figure 5 below. The insitu density must be estimated from the SPT "N" value or the cone penetration resistance. Also of much importance is the size and percent content of any shell within the sand matrix. The presence of shell in sand materials dramatically and adversely affects hydraulic transport production.



Specimen Identification	Classification	D100	D85	D50	D10	%Gravel	%Sand	%Fines	Remarks
● B-1 0.75 ft	POORLY GRADED SAND with GRAVEL SP	19.5	5.352	1.64	0.619	17.1	82.9	0.0	40% shell fragments
◘ B-1 3.75 ft	POORLY GRADED SAND SP	19.5	1.541	0.627	0.322	2.7	97.3	0.0	10 % shell fragments
▲ B-1 6.75 ft		19.5	1.816	0.399		2.5	87.2	10.3	20% shell fragments
★ B-1 9.75 ft		9.5	0.434	0.241	0.112	0.3	94.4	5.3	no shell fragments

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Project: Beach Reclamation Project
Location:
Number: 12345-DPR-002

Figure 5 - Sieve curves

GUIDELINES FOR GEOTECHNICAL SITE INVESTIGATIONS

Geotechnical site information is a primary driver of dredging project cost, performance, and success. Thus, the objective of a site investigation should be to provide comprehensive and accurate geotechnical data representative of the materials throughout the project, such that the contractor can reliably estimate, price, plan and successfully perform the dredging project.

In conjunction with a complete bathymetric survey, a comprehensive and effective geotechnical site investigation for dredging projects will include at the minimum multiple borings and/or vibrocores spaced evenly throughout the dredge area with an emphasis on establishing the material locations and physical properties important to the dredging process as described above.

Vibrocoring is a relatively efficient method for locating, classifying, and sampling granular materials and soft materials and for indicating refusal at hard material surfaces. Vibrocores do not, however, provide information regarding the insitu geotechnical properties of the granular materials to be dredged nor can they penetrate into rock, cohesive, or hard soils. Borings are required to provide the insitu physical information required such as insitu density, material strength, and rock quality.

A number of guidelines and criteria for geotechnical site investigation methodologies, insitu and laboratory tests, and presentation of such information in plans and specifications can be useful to help provide an adequate and accurate basis for estimating, planning, and performing dredging projects.

Many of the notes below are generally applicable to both boring and vibrocoring. The term "borings" is generally used to mean either borings or vibrocores.

General

1. Take borings and vibrocores within the dredge areas and in the materials to be dredged for the current project.

   Although this guideline might seem obvious, projects are often put on the street for bid with a majority of borings provided either outside the areas to be dredged or within materials which have been dredged away after the boring campaign.

   Marine traffic, current, and tides can make boring in a channel difficult, so borings are sometimes taken outside of the channel for convenience. In harbors, borings are often directed towards areas for civil works, such as dock and foundation work, instead of the dredge areas. Borings may have been taken in the same dredge area prior to dredging and reshoaling, or in adjacent dredging areas, and the owner elects to provide information from these borings instead of investing in further geotechnical investigation within the newly shoaled materials to be dredged for the current campaign or within the proper dredge area.

   Soil types and properties can be extremely variable in location and elevation. Geotechnical data from outside the dredge area is likely to be inaccurate and misleading, even if adjacent to the dredge area. Further, one cannot assume that materials which have shoaled into a once dredged channel or borrow area will have the same geotechnical properties for dredging considerations as that previously removed. Note that even a small change in sand gradation can result in a profound variance in hydraulic transport production.

   Information from outside the dredge area or from an area since dredged is of little or no value and will just as likely be misrepresentative of the soil to be dredged. *Representations of soil conditions must be from borings and vibrocores taken within the areas to be dredged and in materials to be dredged under the current campaign* .

2. Space borings and vibrocores evenly and completely throughout the dredge areas.

   Space and locate borings to provide information representative of the entire dredge area, not just concentrated areas. Do not emphasize non-representative locations. One guideline for dredging geotechnical site investigations is to space borings up to a maximum of 600 feet apart depending on the complexity and variability of the seabed and the dredging layers. (Verbeek, 1984) For rock dredging, rock cores spaced at about 300-400 foot centers are recommended. Use an alternating grid to provide for maximum coverage.

3. Take an adequate number of borings and vibrocores.

Material types and physical properties can be extremely variable within a project area and even within a given layer or formation. An adequate number of borings and subsequent insitu and laboratory tests are required to provide information and data that is representative of the materials to be dredged over the entire project area. An equation, modified from that of P.R.H. Verbeek (Verbeek, 1984), providing an indication of the number of borings needed for dredging projects is

$$N = 3 + (A^{0.5})/40,$$

where N = the number of borings (including vibrocores) to be taken and A = the dredging area in square meters.

For sand reclamation projects, a ratio of one boring for every three vibrocores is a good first rule of thumb. For cohesive material, hard material or rock, borings should be used exclusively as vibrocores will not penetrate to grade.

Risk due to incomplete geotechnical information in dredging is sometimes covered by contractors by adding mark-up contingencies for lower production, higher wear, longer dredging duration, more powerful plant, blasting, etc.. On nearly every dredging project (except possibly routine maintenance projects), such contingencies will be far more expensive than the cost of a comprehensive boring campaign. A complete boring campaign, with adequate coverage, will lower the risk levels in projects. Inadequate geotechnical information that leads to unsuccessful projects is far more expensive than the costs of a comprehensive boring campaign by orders of magnitude. A few more borings will certainly cost owners less than receiving bids with excessive risk coverage or than an unsuccessful project. A good example of boring coverage and spacing is shown in Figure 6 below, from the US Army Corps of Engineers Bal Harbor Florida beach nourishment project. (USACoE 2003)

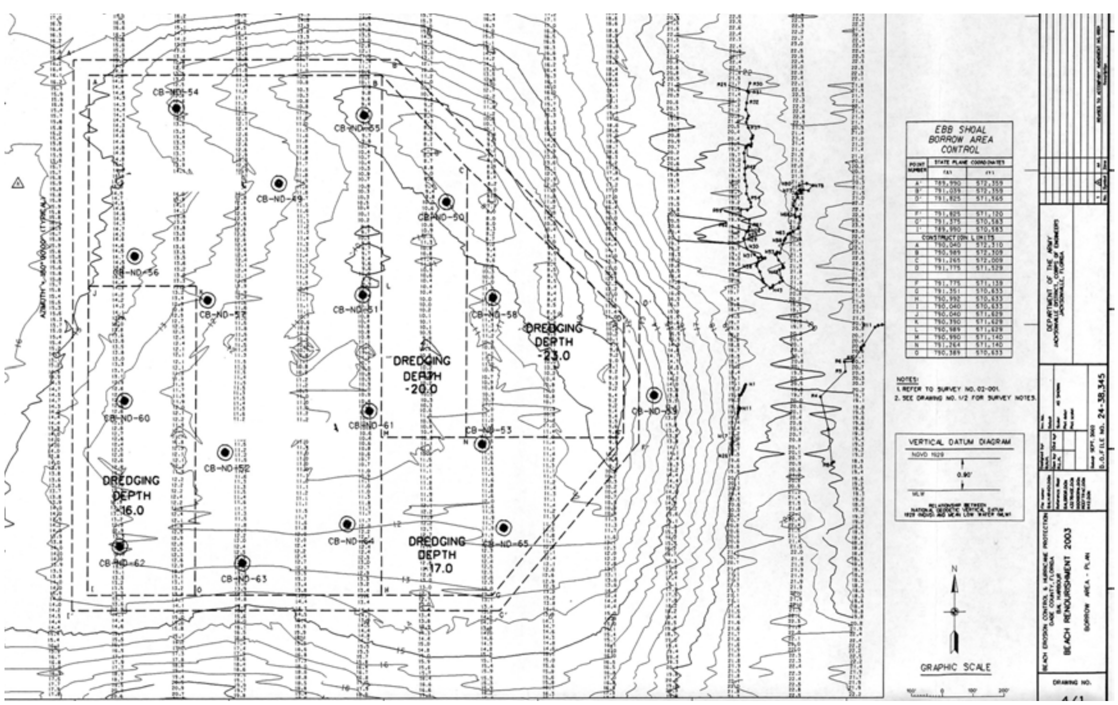

Figure 6 - Good boring coverage in borrow area

4. Penetrate to, and collect information from, well below the required dredging depth.

Penetrate to at least 5 feet below grade for non-rock projects and at least 8 feet below grade for locations with anticipated rock dredging. For dredges to clear the minimum dredging level over the dredge area, they must cut well below grade. Cutter dredges must over-cut due to spillage from the cutter. (See Figure 7.) In rock dredging, blasting centers must be drilled well below grade to achieve full fragmentation to and below required depth. Thus, geotechnical information is needed for the material down to and well below grade.

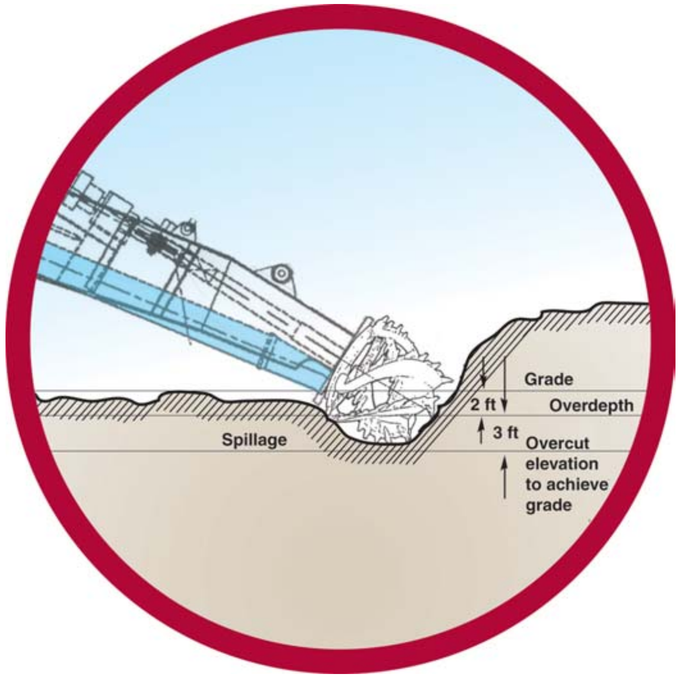

Figure 7 - Typical cutting below grade level

5. Perform all geotechnical investigations, boring campaigns, and geotechnical testing according to professional engineering standards.

For information from geotechnical site investigations to be of any use to owners, contractors, or designers, investigations and tests must be performed to uniform and professional standards. In the United States, ASTM Standards should be used. Refer to the *ASTM Annual Book of Standards* Section 4, Construction, Volumes 4.08 and 4.09. An excellent summary reference for dredging geotechnical investigation and classification is the "Classification of Soils and Rocks to be Dredged", a supplement to *Bulletin No. 47* published by the Permanent International Association of Navigation Congresses in 1984.

6. Store samples appropriately for testing.

Loss of insitu moisture can alter the geotechnical properties of soil and rock samples. Store smaller samples in airtight containers and wrap rock cores in plastic to avoid moisture loss.

7. Provide prospective bidders with complete geotechnical reports.

Geotechnical site investigations are often documented via narrative reports which are complementary to the borings and laboratory test results. Typically included in site investigation reports are narratives and data regarding all equipment used (marine, sampling, lab), positioning, datums, water depth measurements, boring logs, full laboratory test descriptions and results, field and lab notes, and the like. Provide these reports to prospective bidders for their evaluation.

8. Provide a color photo log of vibrocore runs and soil samples.

A picture is indeed worth a thousand words. Much qualitative information can be gleaned from clear color photo logs of the boring runs and samples. Photos should include identification of the boring, depth of each sample, and a length scale. For rock cores, total core recovery and rock quality designation should be labeled in the photo as well. All such data can be put on labels that are photographed along with the core. Photos should be taken at the boring site so that they show the state of the core with minimal disturbance from further handling. Presence of shell should be shown in photos of individual samples. An example from a vibrocore run is shown in Figure 8 and from a rock boring in Figure 9.

Figure 8 - Vibrocore photo log

Figure 9 - Rock core photo log

9. Save boring runs and samples for contractors' inspection.

A physical inspection of the boring run provides invaluable qualitative information for the contractor.

Location, Area, and Quantity

10. Take special regard of vertical control.

    Accurate vertical control is critical to the representation and determination of the top of hard or unsuitable material, of soil interfaces, and for determining the dredging areas and quantities. A dredging estimate is more sensitive to errors in vertical control than in horizontal control.

    Too often, tides are not correctly accounted for or inaccurate tide readings are applied to boring depths. Take advantage of DGPS and RTK vertical positioning technologies for cost effective and practical vertical control, which together eliminate the need for tide correction. If only conventional control is available, use a lead line with a flat plate for a sounding rope with tide corrections taken at short intervals from a near-by, calibrated, tide gauge.

    Take special care in measuring boring advance and corrections for offsets on the barge. Note the achieved vertical accuracy in the geotechnical summary report.

11. Borings and vibrocores can be efficiently supplemented with jet probes to thoroughly document the top of rock or hard material surface.

    Borings and vibrocores provide information concerning the hard material surface only at the point taken, and cannot be economically or quickly taken in the numbers required to completely reflect the top of rock or hard material surface throughout the dredge area. In many soils, water jet probes (high pressure water jetted through a pipe probe) are inexpensive, expedient, and can be used reliably and practically to document the top of the rock or hard material formation throughout the dredge or borrow area. Jet probes should be used in abundance as a supplement to borings to define the hard surface as shown in Figure 10 below. As with borings, vertical accuracy is critical and requires special attention and complete documentation.

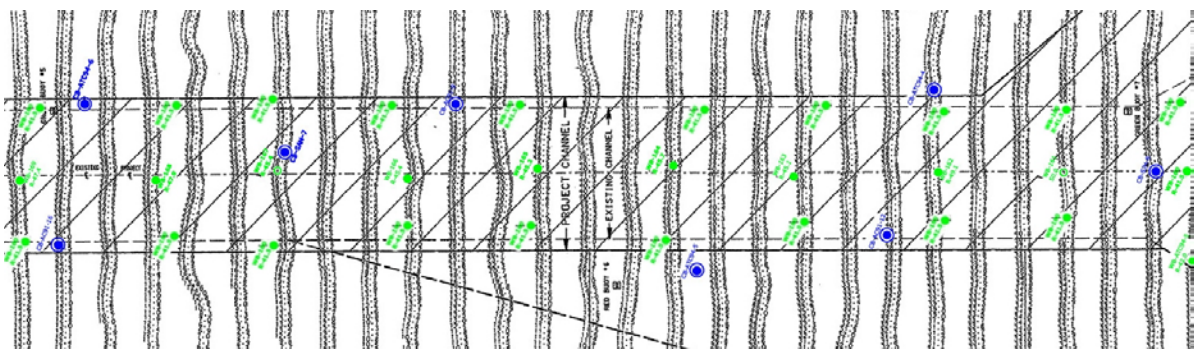

Figure 10 - Jet probes (in green) supplementing borings (blue)

12. Use geophysical investigation with caution and, at the minimum, correlate with geotechnical borings.

    Geophysical investigation methods such as seismic refraction and electric resistivity can be used to provide information concerning relative soil and rock location, elevation, and interface levels. Representation of soil location and interfaces from geophysical methods requires careful correlation and calibration with physical borings. In the author's experience, geophysical investigations have often provided misleading, inconclusive, and/or unreliable results.

Material Classification and Physical Properties

13. Perform required insitu and laboratory tests per ASTM standards and on sufficient samples in each boring.

Material testing required for dredging projects is presented in Table 1 below. For testing, try to obtain samples for every three feet of boring run.

Table 1 - Required Tests by Material Type

	Clay	Silt	Sand	Rock
Sample Type	Undisturbed,[1] vibrocore, & SPT	Undisturbed[1] vibrocore, & SPT	SPT & Vibrocore	Coring
Moisture Content	Yes	Yes	No	Yes
Atterberg Limits	Yes	Yes	n/a	n/a
Unit Weight[2]	Yes	Yes	Correlated from SPT	Yes
Grain-Size Analysis[3]	No	Yes	Yes	n/a
Shear Strength[4]	Yes	Yes	n/a	No
Compressive Strength[5]	Yes	If compact	n/a	Yes
Total Core Recovery[6]	If cored	If cored	If cored	Yes
Rock Quality Designation[6]	n/a	n/a	n/a	Yes
Fracture Index[6]	n/a	n.a	n/a	Yes

Notes:
[1]Undisturbed samples are required for unit weight and some shear strength tests.
[2]Unit weight must be in the sample's natural state to extent possible. Take care to seal the sample at site against moisture loss.
[3]Include % and size distribution of any shell on sieve log.
[4]Field tests for undrained shear strength are Pocket Penetrometer and Torvane (hand vane). Lab tests are miniature vane (motorized vane) and UU triaxial shear.
[5]Compressive strength measured by unconfined compressive strength test. Use L/D=2.5 if possible. Avoid L/D < 2.0.
[6]To be recorded at drilling time

14. Include boring and vibrocore logs with fully comprehensive classifications and descriptions of the materials in accordance with ASTM and include insitu and laboratory test results on the boring logs.

ASTM D-2487 and D-2488 provide standards for soil and rock classification and descriptions. Test results can be presented on the final logs. Graphical representations provide a good relative presentation of the boring run. Good examples are shown in Figures 11 and 12.

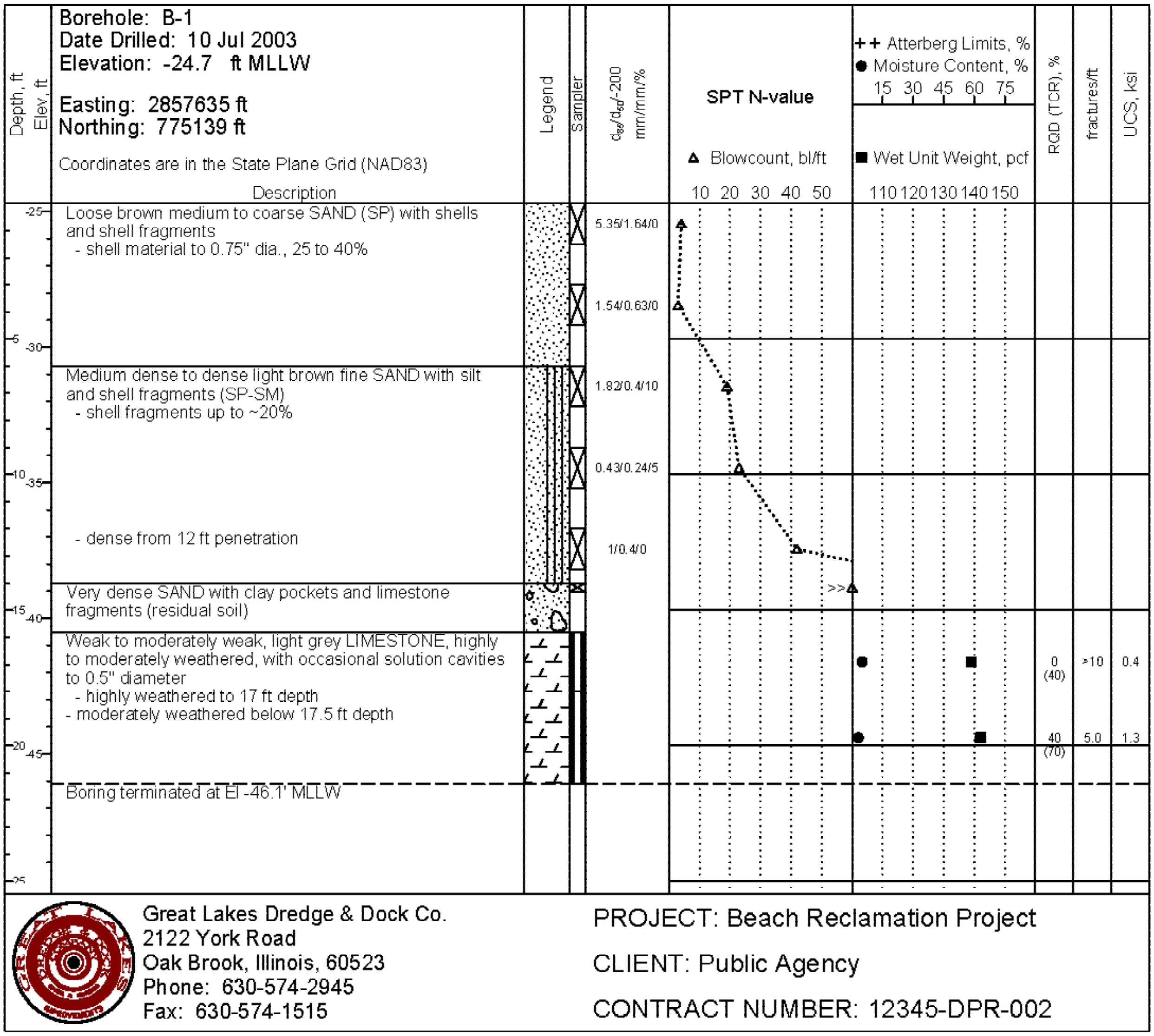

Figure 11 - An informative borrow area borehole log

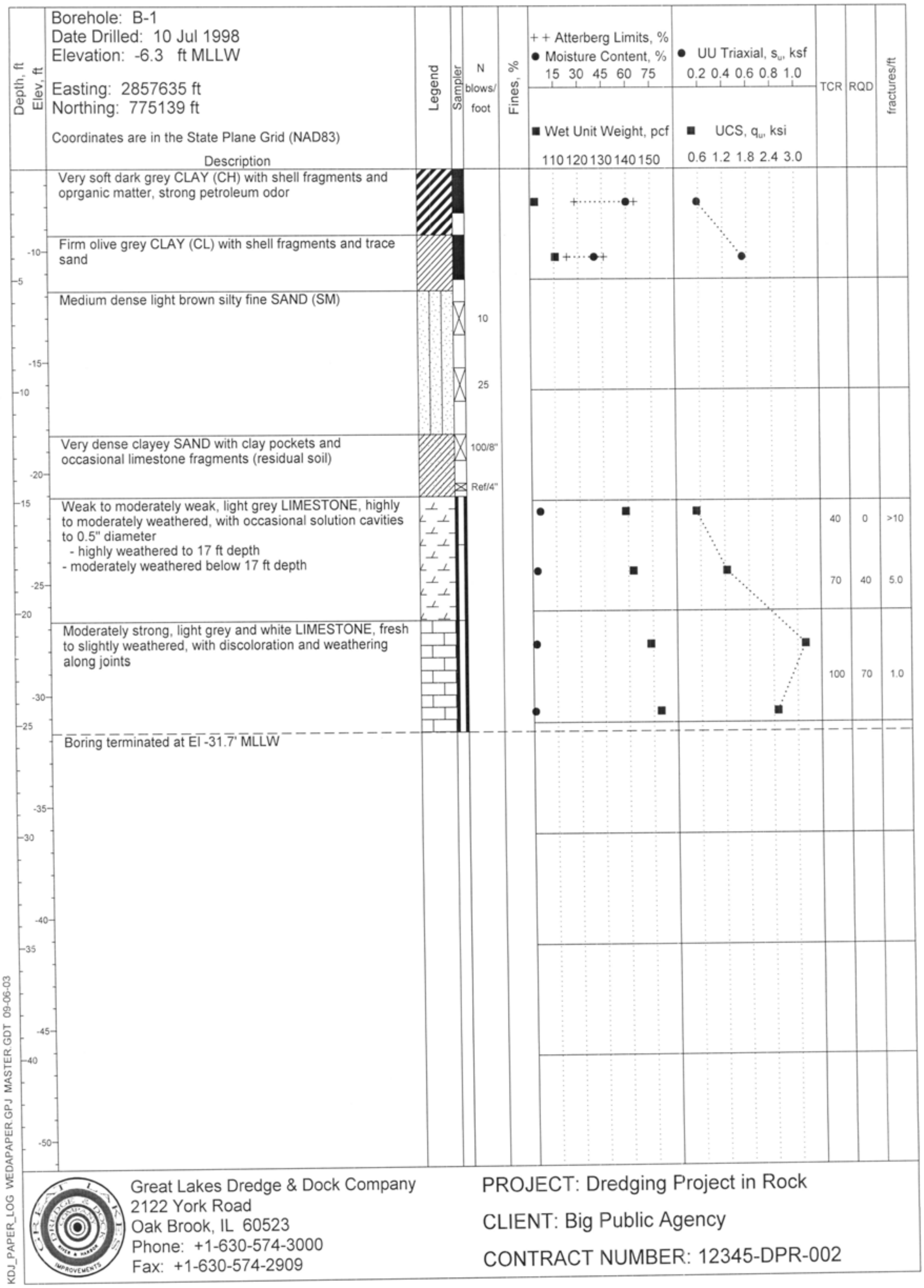

Figure 12 - An informative rock boring log

15. Investigate and document the shell content within sand materials.

The presence of shell in sand materials dramatically and adversely affects dredging hydraulic transport production. Of importance is the size and percentage shell within the sand. Best sampled with large diameter Shelby tubes. Report on the boring log (and sieve curve) both the size range and percentage of shell within the sample (as shown in Figures 5 and 11). Include a photo log of any sand and shell mixture recovered. An example of two sand samples is shown below in Figure 13. The sample on the left is described as Fine Sand with "some shell". The sample on the right is described as Fine to Coarse Sand with "shell hash". Again, a picture tells a thousand words.

Figure 13 - Sand samples described as Sand with "some shell" (left) and with "shell hash" (right)

16. Use the ASTM standard hammer and drop for Standard Penetration Tests (SPT).

The Standard Penetration Test is described in ASTM D1586-99. The test requires a 140-lb hammer to drop 30 inches in air for each blow. Do not use non-standard hammers such as the 300 lb. hammer with an 18 inch drop or non-standard samplers. There is no reliable correlation between non-standard hammers and drops with the Standard Penetration Test. The *Standard* Penetration Test is (obviously) a *standardized* test. It is dumbfounding that professional engineers would collect data with non-standard methods for a standardized test and then include such information in contract specifications. Non-standardized penetration data is of no value for geotechnical site investigations.

17. Do not continue SPT beyond refusal (50 blows / 6 inches). Core rock materials.

Blow counts higher than 50 blows per six inches is defined as refusal and cannot be correlated to soil strength or rock strength. Stronger materials -- i.e. rock -- must be cored. Classification and testing of rock cores must include the rock strength, core recovery, rock quality designation, rock fracture log, and unit weight -- all of which can be determined from proper rock coring and testing.

18. <u>When coring rock, measure and report on the boring log the rock core recovery, rock quality designation, and rock fracture log to provide information on the rock quality.</u>

Rock core recovery is the ratio of recovered core length to total core run and gives a subjective indication of the quality of the rock core.

A better indication of rock quality is the rock quality designation, or RQD. RQD is the sum length of pieces longer than 4 inches in the core run expressed as a percentage of the total core run length. (Deer, et al, 1969) RQD is 100% for strong, massive rocks and is near zero for closely jointed or for highly fragmented rock formations. (Franklin and Dusseault, 1989)

Valuable additional information can be gleaned from the rock fracture index. This index is a count of the number of natural fractures over an arbitrary length – often fractures per foot. (PIANC, 1984)

CONCLUSIONS

The location, area, classification, quantity, and physical properties of the material to be dredged are primary drivers of the type and class of dredging equipment required, of dredging production and costs, and of the ultimate success of dredging projects. Geotechnical site investigations must provide comprehensive and accurate geotechnical data representative of the materials throughout the project, such that the contractor can reliably estimate, price, plan and successfully perform the dredging project. A number of guidelines, procedures and geotechnical tests, both insitu and laboratory, are appropriate and are required to provide comprehensive and accurate information of the geotechnical properties of soils and rock for dredging projects.

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