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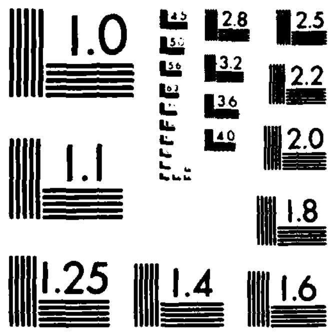
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FUTURE RESEARCH NEEDS FOR DREDGEABILITY OF ROCK

Rock Dredging Workshop, 1985

by

Hardy J. Smith

Geotechnical Laboratory

DEPARTMENT OF THE ARMY
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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

September 1986

Final Report

Approved For Public Release, Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

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Research needs relative to prediction of dredging difficulty in rock materials ~~are~~ identified and discussed. Proceedings of the 25-26 July 1985 Corps of Engineers workshop on rock dredging problems are summarized. ~~primary~~ purpose of the workshop was to ~~determine~~ the direction of future research for the Civil Works Investigation Study work unit on the dredgeability of rock. A plan of study is proposed for developing a dredgeability rating scheme for rock based on the given outline of rock dredging problem background, as identified prior to the workshop, and the topics discussed during the workshop. These topics included rock dredging case history reviews, existing predictive methods for dredge performance, exploration and design methods, and the relation of a solution for the problem at hand to the legal aspects of rock dredging claims.

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PREFACE

This study of future research needs in rock dredging was conducted by the US Army Engineer Waterways Experiment Station (WES). The Rock Dredging Workshop, held 25-26 July 1985 at Jacksonville, Florida, was organized by WES to determine field input to such needs. The ultimate success of this workshop was due to the ready cooperation of the participants and their respective districts and divisions. The work was sponsored by the Office, Chief of Engineers, US Army, under Civil Works Investigation Study (CWIS) 32344, Dredgeability of Rock. The Technical Monitor was Mr. P. F. Fisher.

This report was prepared by Mr. H. J. Smith, Engineering Geology and Rock Mechanics Division (EGRMD), Geotechnical Laboratory (GL), who also served as Principal Investigator. The report was edited by Ms. Odell F. Allen, Information Products Division, Information Technology Laboratory. The work was under the general supervision of Mr. J. S. Huie, Chief, Rock Mechanics Applications Group , GL, and Dr. D. C. Banks, Chief, EGRMD. Dr. W. F. Marcuson III was Chief, GL.

COL Allen F. Grum, USA, was Director of WES during the preparation of the report. COL Dwayne G. Lee, CE, was Commander and Director of WES during the publication of this report. Dr. Robert W. Whalin was Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

A G E N D A

ROCK DREDGING WORKSHOP
Jacksonville Beach, Florida
25-26 July 1985

Thursday, 25 July

7:45	Registration	
8:00	Welcome & Introduction: Background and Purpose	Hardy Smith Waterways Experiment Station, WESGR-M
8:25	Moderator: Scope, Organization of Discussions, and Introduction of Attendees	Jim Erwin South Atlantic Division, SADEN-F
8:30	Overview of Corps Experience with Rock Dredging	Tom Verna Water Resources Support Center, WRSC-D
9:00	Differing Site Conditions and Rock Dredging	John D. Brady Jacksonville District, SAV-OC
9:45	Break	
10:15	Dredging Mudstone for LA Harbor Deepening	Chuck Orvis Los Angeles District, SPLED-FG
11:00	Experience with Dredgeability of Coral Rock at Barbers Point Deep Draft Harbor	Harvey Minsky Pacific Ocean Division, PODED-G
12:15	Lunch	
1:30	General Questions, Discussion	
1:45	Dredging Problems with "Coquina"	Jack Keeton Savannah District, SASEN-GG
2:35	Subsurface Investigations and Design Considerations for Rock Dredging	Tom Thornton Jacksonville District, SAJEN-GG

3:15	Break	
3:30	Rock Dredging for Calion Lock & Dam	Danny Harrelson Vicksburg District, LMKED-FT
4:00	Government Estimates for Rock Dredging	Al Mohr Consultant CE, Retired
4:45	Differing Site Conditions Introduction	Al Hall South Atlantic Division, SAD-OC
5:00	Adjourn	

Friday, 26 July

8:30	Differing Site Conditions Mechanism of a Claim and Defense	Al Hall South Atlantic Division, SAD-OC
9:15	Rock Dredging, Brunswick Harbor	Jack Keeton Savannah District, SASEN-GG
10:15	Break	
10:30	Panel Discussion	Moderator: Jim Erwin South Atlantic Division, SADEN-F
11:15	Summary Comments and Discussion	Hardy Smith Waterways Experiment Station, WESGR-M
12:00	Adjourn	

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FUTURE RESEARCH NEEDS FOR DREDGEABILITY OF ROCK

Rock Dredging Workshop, 1985

PART I: BACKGROUND AND NEED FOR WORKSHOP

In recent years, the Corps of Engineers has experienced numerous differing site condition claims on rock dredging projects. Such claims have typically been large, often into millions of dollars and sometimes far exceeding the original bid cost. Several example claim situations are outlined in Part III. When the equipment and methods used by the contractor, frequently with advance approval of the Government, fail to remove rock at the expected rate, the contractor usually makes a claim against the Government. These claims are almost always differing site condition claims and are commonly based on the contention that the rock encountered is harder to dredge with available equipment than the contractor had inferred from bidding information. Such claims necessarily hinge upon either the description of the rock material or the predicted performance of particular dredging equipment in excavating such material, the two being interrelated. The basis for these claims as well as for their resolution is geotechnical. In some cases contractors have assumed that rock of a given description would be easily dredged with the same similar equipment which had been previously used on rock of the same type and general description, only to find that dredging performance was vastly different at a new site. When rock and equipment are not identical, such an assumption should be made only in the light of necessary additional information to determine the dredgeability of the rock. The term "dredgeability" as applied to rock is defined as the ability to excavate rock at economical rates underwater with respect to known or assumed equipment, methods, and in situ material characteristics. In particular, the dredging of rock by mechanical means (nonblasting) involves three considerations: (1) breaking up or cutting of the rock, (2) removal of cuttings from cutter or pick area as work progresses, and (3) removal of the comminuted material from the ocean floor or river bed. Any estimation of dredgeability for rock of particular characteristics must involve the first two of these considerations; and likewise, the design or performance assessment of rock dredging equipment must take these into account.

Although dredgeability is dependent upon equipment and in situ material characteristics, the significance of minor changes in equipment configuration or mechanical condition is not well known, nor is the relationship of the various rock mass parameters to dredgeability. In Invitations for Bids (IFB's) for dredging work, a common practice is to give results of boring logs at selected locations; unconfined compressive strength and/or geologic description are frequently given. Unconfined compressive strengths are not routinely obtained at all borings, and core samples are not usually preserved in as-taken saturated condition to allow for later testing; however, in some cases where unconfined compressive strengths were given, contractors have encountered unexpected problems. In addition to unconfined compressive strength, other rock and rock mass parameters may influence dredgeability such as abrasiveness, rock fabric, rock structure (fractures, joints, schistosity, laminations, and orientation), extent of weathering, and geophysical properties. Obvious to most of the dredging community involved in rock dredging is the fact that several engineering parameters influence dredgeability; unconfined compressive strength is often considered, and other concerns, particularly joint spacing and laminations, are sometimes recognized as having critical influence. However, no systematic methods are known to exist which estimate dredgeability of rock as a function of material properties. The need exists to determine which rock and rock mass parameters influence particular dredging operations and to determine the extent to which individual parameters govern dredgeability. Contributing to the resolution of this need, Permanent International Association of Navigation Congresses (PIANC) (1984) has produced a report on the "Classification of Soils and Rocks to be Dredged" in which recommended means of describing the engineering characteristics of the rock are given, and several of the rock mass parameters listed above are used. Although helpful, this classification is descriptive in nature rather than deterministic, and provides no means of rating the relative difficulty of dredging various rock materials. Guidance provided by ER 1110-2-1300, 26 June 1985 (Headquarters, Department of the Army 1985), does provide for determination of a "material factor" which relates directly to dredgeability; however, the entire range of material to be dredged is considered, from mud and silt to hard rock; and rock type materials are classified only by one of three descriptions: compacted shell, soft rock, and blasted rock.

Additional background applicable to the problem of rock dredgeability is provided in the WES Miscellaneous Paper GL-84-17 on "The Current State-of-the-Art of Rock Cutting and Dredging" (Hignett 1984). In addition to rock dredging, this state-of-the-art study addressed rock cutting in the "dry" environment (i.e., in tunneling, mining, open excavations) where a dramatic growth of technology has occurred in recent years. Possibilities exist for future technology transfer to rock dredging where development has been slow for both excavation equipment and for predictive systems.

PART II: PURPOSE AND SCOPE

The Rock Dredging Workshop, 1985, was held to provide a platform for the exchange of ideas, opinions, and information in support of the US Army sponsored R&D work unit on the dredgeability of rock which was initiated during FY 85. The stated purpose for the workshop as given in work unit documentation (Form 4417, Jan 85) was to provide background for formulating a detailed approach for future research on the dredgeability of rock. Since the major known difficulties with rock dredging in the Corps have been based upon contentions that rock was harder to dredge with mechanical equipment than contractors had inferred from bidding information, the scope of topics considered at the workshop was channeled toward mechanical dredgeability with respect to rock description and equipment used; however, blasting techniques were also of interest, particularly at that level of difficulty where either blasting or mechanical breakage techniques could possibly be used. While the workshop was directly concerned with these purposes, it also served to bring together personnel from several divisions and districts with rock dredging experience, so that the broad spectrum of problems related to rock dredging could be considered; thereby the place of rock dredgeability in the overall rock dredging morphology could be clarified. The major goals as specifically given at the workshop were to:

(a) Determine need for and direction of future research on rock dredgeability.

(b) Provide background information contributing to the identification and prioritization of field problems.

(c) Identify sources of information useful in developing predictive methods for estimating the dredgeability of a given rock mass.

In order to provide a means of focusing the attention of workshop participants on the ideas leading to development of a systematic means for estimating dredgeability, as opposed to the many other varied problems with rock dredging operations, Dr. Banks presented the conceptual diagram as shown in Figure 1. While no quantitative values are given, the difficulty of dredging increases from left to right throughout the diagram, ranging from loose soils to competent rock. The graph at the top presents the idea that production rates drop and costs increase as difficulty of dredging increases. Note that a set of such curves could exist for each particular dredge. Here, if ordinate values were determined and sufficient data existed to determine the shape of the curves, a systematic method for estimation of dredgeability would obviously be at hand. The middle part of the diagram shows the idea that each given dredge has an upper limit of capability as to economical use in harder materials. The lower part of the diagram indicates possibilities for classification of in situ material to be dredged. For soils, blowcounts or other widely accepted classifications may correlate with dredging difficulty; however for rocks, dredging difficulty for a given equipment configuration is a function of a complex of interrelated rock mass parameters as indicated here. A possible approach for developing a system to estimate the dredgeability of rock is to evaluate the influence of each rock mass parameter in order to determine an overall rock dredgeability rating as indicated. A predictive system for estimating production rates for tractor mounted single tooth rippers in dry rock was developed using a similar approach. The basis of this system is given in ETL 1110-2-282, 30 June 1983, (Headquarters, Department of the Army 1983).

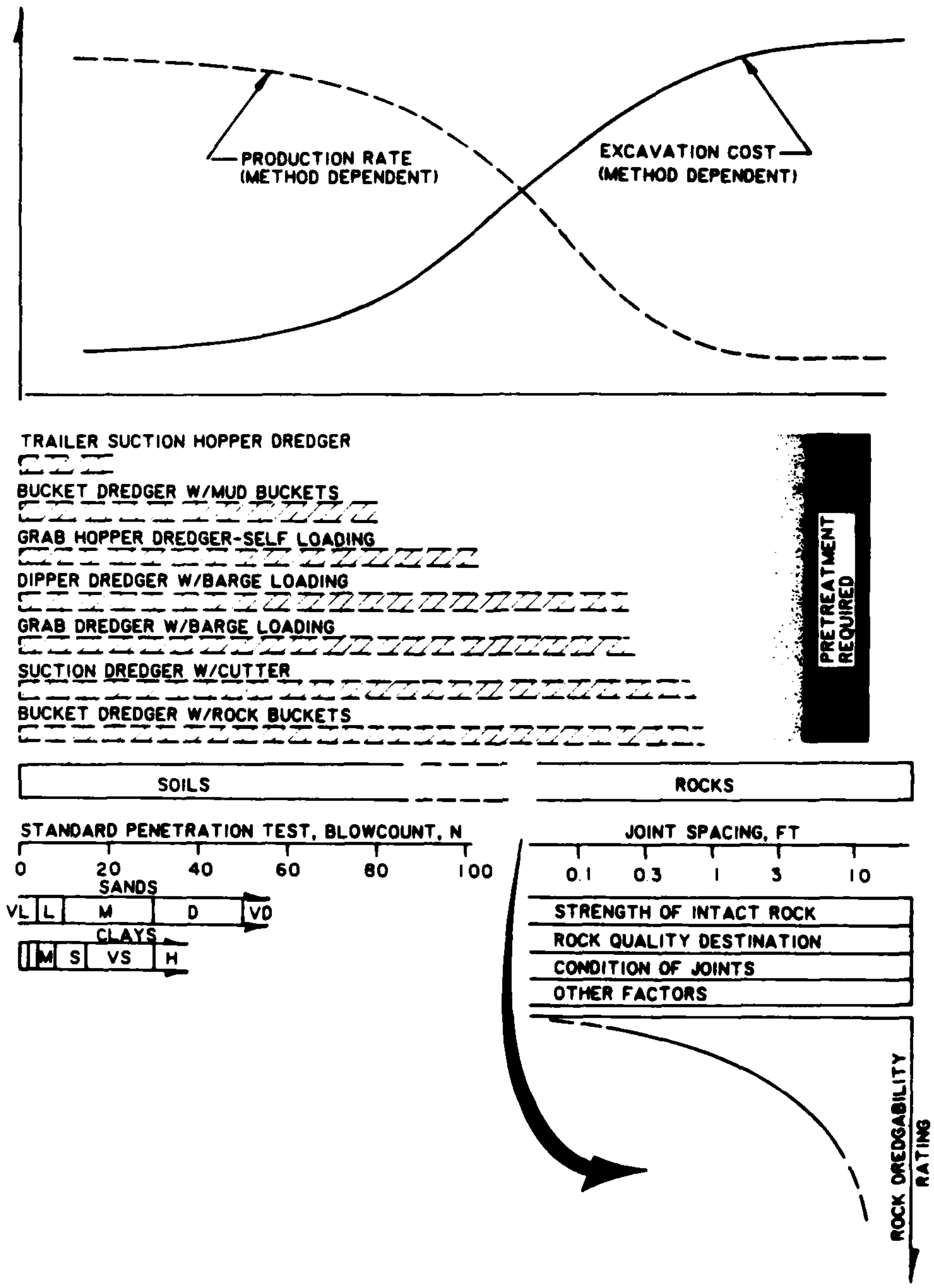

Figure 1. Influence of material properties on dredging capabilities

PART III: SUMMARY OF TOPICS DISCUSSED

Introduction of Topics and Format

A presentation/discussion format was adopted for the workshop with presentations used to air facts, ideas, and opinions relative to the listed agenda topics and, just as importantly, to stimulate discussion against the background of the presentations specifically directed toward problems with the dredgeability of rock. See Agenda, page 4, and the major workshop goals outlined in Part II.

Although the problems involving rock dredging claims are many-faceted and the discussions tended to be wide-ranging, Dr. Erwin, Moderator, kept the discussion focused appropriately resulting in a good balance between problems directly concerned with the process of physically dredging rock and related considerations which either influence the process or are influenced by it. These additional considerations included mobilization, environmental concerns, importance of equipment maintenance, equipment upgrading methods and costs, contractural/legal matters, and contractor/Government attitudes.

A wide range of topical areas were addressed with presentations generally falling into one or more of the following broad areas:

(1) Rock dredging case history reviews which served to help identify what goes wrong (or right) and why. These case history reviews also served to indicate (even though from a small sample) the general type and completeness of available data.

(2) Predictive methods for dredge performance.

(3) Exploration and design methods, which are necessarily interrelated with dredgeability assessments in both pre-IFB and postclaim situations.

(4) Legal aspects which, while providing no direct technical input for the problem at hand, provided needful background for discussion of the other topics since the extent of claims on rock dredging projects was the primary motivation for the rock dredging research work unit.

The topics presented are outlined below as they relate to the problem at hand; topics specifically on legal aspects are not included. Individual comments are also given in a similar abridged form with the person's last name given in parentheses.

Overview of Corps Experience

An overview of the Corps experience with rock dredging was presented by Mr. Verna of Water Resources Support Center.

- o Rock represents less than one percent of the 465 million cubic yards* which the Corps dredges annually. About 70 percent of all Corps dredging is accomplished by contract.

- o The two basic types of dredging equipment are hydraulic and mechanical. The hydraulic type relies on pump suction to remove material. Such dredges may be equipped with cutterheads or other attachments to aid in loosening difficult material. Conventional cutterhead dredges have been used on rock but have not been effective due to inadequate steel super-structure design and insufficient cutter horsepower. The Dutch firms of Volker-Stevin, Boskalis-Westminister, and HAM International have been instrumental in developing dredges to overcome such problems. Mechanical type dredges rely on the mechanical shearing action between the excavator and the material to be dredged. They consist of bucket (endless chain), grab (clamshell), dipper and backhoe (power shovel), and scraper (dragline) dredges. These vary greatly in size and capabilities. The bucket ladder and dipper dredges are the most efficient in excavation of dense or rock materials.

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

- The new work or improvement dredging share of the total dredging program has steadily declined for decades. The United States is now behind the world market place in developing new port deepening projects; the rectification of this problem in the coming years will likely produce a pronounced increase in rock dredging projects.

- Thirty to forty years ago, the Corps of Engineers were leaders in the field of rock removal as exemplified by the deepening of the Great Lakes ship channels and ports and the Panama Canal widening projects. Recent projects where rock was encountered such as Cape Fear, North Carolina and Port Everglades, Florida have resulted in high claims. These excessive claims indicate that we are not the experts we once were.

- A need clearly exists to better classify materials and to develop standards for classification. The adoption of the PIANC report (1984) on "Classification of Soils and Rocks to be Dredged" should be considered along with other alternatives such as the development of a national standard.

- The insufficient number of core samples that we take and the inadequate protection of these samples are the result of our limited experience in rock removal coupled with a desire for cost savings in project design. Consequently, these limitations misrepresent the facts and lead to large claims.

- The methods of engineering, design, and estimating, as well as the terminology, classification, and sampling procedures used in rock dredging should be considered for review.

- (Verna) Significant errors in tests of core samples have been known to occur due to core drying; the dried material is generally, although not always, the weaker.

- (Erwin) South Atlantic Division is moving toward specifying minimum level (size) equipment required.

- (Sanderson) Size (horsepower) does influence capabilities but is not so important as other considerations such as cutter design; even a small dredge is good if designed for rock.

Dredging Mudstone at Los Angeles (LA) Harbor

The dredging of mudstone for LA Harbor deepening was discussed by Mr. Orvis of Los Angeles District.

- Bedrock here consists primarily of the Repetto siltstone and the Milaga mudstone of the Monterey formation.

- Of the 14 million cubic yards to be excavated about 18 percent was to be bedrock.

- Of the 92 pre-IFB holes drilled about half were concentrated in the bedrock area, and most were 2-1/2 inches in diameter with penetration into the mudstone up to 12 feet, the average being 5.7 feet. Ranges for unconfined compressive strength and plasticity indexes were given. Penetration testing confirmed the mudstone, or clay-shale, is from stiff to very stiff, highly plastic, and contains scattered zones of hard nodules and gravel. It is unlayered at least to project depths and virtually massive.

- Two test demonstrations were conducted using small and large clamshells with several of the test locations selected by prospective bidders. Two large rocks (4 feet and 6 feet in largest dimension) were encountered. At other locations clay shale was encountered with a few small nodules. Results of both investigations were included as amendments to bidding documents.

- Dredge used was a 36 inch suction cutter type dredge; both sand and rock cutterheads were used. (Photographs of cutterhead showing shape of rock picks were shown and are available if needed for later case history evaluations.)

- To assess the potential for "hardrock" bodies larger than 6 feet, a new investigation of the bedrock area was conducted during the second and third year of excavation consisting of geophysical profiling and drilling. The geophysical surveying included simultaneous side-scan sonar of the harbor floor and profiling of the subfloor materials with a very high resolution, shallow penetration, pinger and a high-resolution medium penetration boomer. Beds needed to be 1 foot thick to be detected.

- The following is taken from statements of postclaim findings by the Contracting Officer:

  1. Investigations confirm that differing site conditions exist.
  2. Several areas of large boulders were encountered although the Corps geotechnical program was unable to confirm or deny the existence of them.
  3. The designation of differing site conditions and the necessity for a change were not addressed in contract specifications nor were they to be expected from the prebid demonstrations.
  4. The extensive geophysical and boring effort (in design phase) was generally considered to be "state-of-the-art." The inability of this program to accurately depict actual

conditions is apparently due to the relative isolated incidence of the differing site conditions.

- Final cost of the change order was $2.4 million; the original bid was at $61.3 million.

- (Mohr) The claim represented a small percentage of project costs and was in line with the Government's cost estimate for identified extra work. This is a good indication that complete descriptive information to the contractor is the best way to minimize claims.

- (Orvis) Contractor was given extensive information but showed little reaction or interest (pre-IFB). He commented "I don't think they really know what they are looking at." About $250,000 was spent on site investigation.

- (Orvis) Yes, cutterhead actually cut up the large boulders.

- (Orvis) Do not have production rate data with me; some may be available. Contract was completed in 1983; initial investigations were in 1977.

Dredging Coral at Barbers Point Harbor

The dredging of coral rock at Barbers Point Harbor was discussed by Mr. Minsky of Pacific Ocean Division.

- Specifications indicated that 50 percent of onshore and 40 percent of offshore rock would require drill-and-blast techniques. However, contractor systematically drilled and blasted the entire project. The job was bid with that intention.

- Pre-IFB conference was held which ran one week. A general comment was that more exploration funds were needed. Initially, dredge was specified by the Government based on environmental considerations; in the actual contract water clarity was specified, and the Government did not approve the equipment or the methods used by the contractor.

- Correlation between drill rates and material type was attempted, but equipment was too large and drilled too fast to establish a relationship.

- Test augering was done to determine difficulty of excavation (estimate auger production, determine possible alternative to drill and blast) using a 7 foot diameter auger, 10 to 15 feet on centers. Average excavation rate was 176 CY/hr.

- Project was completed 15 July 1985 with no claim based on difficulty of excavation, having excavated 10 million cubic yards of coral.

- Because contractor stated in advance his intention to systematically drill and blast the entire project, there were no marginally excavatable materials. There was little possibility for a claim based on difficulty of excavation, which could have been the case had mechanical excavation equipment been used.

- (Minsky) Production rates are available for the blasting operations.

- (Minsky) Problems with auger included a cracked auger which was removed by clamshell, and rapid wear on the carbide-faced teeth, which had to be changed often, requiring one full-time man.

Dredging Problems with "Coquina"

Conditions leading to a claim on the Cooper River Rediversion Project, South Carolina, were presented by Mr. Keeton of Savannah District.

- Material to be dredged consisted of limestones, shales, sandstones, claystones, sands and clays with the predominate rock type being limestone which was given to vary in thickness from 1 to 7 feet. Of 18 borings which encountered rock above grade, 9 describe the rock as a limestone "coquina" of varying degrees of hardness and cementation. No unconfined compressive strength data were given anywhere in the contract.

- Contract specifications indicated the following: all excavation would be done and paid on an unclassified basis with no consideration given to the nature of materials encountered; blasting may be necessary for portions of the excavation, and no separate payment will be made for such work; information and data furnished are for information only and the Government would not be responsible for any interpretation or conclusion drawn therefrom by the contractor. Also, bidders were to conduct their own investigations to decide for themselves the character of materials and the difficulty of performing the work.

- The contractor's claim alleged that a considerable quantity of rock required blasting for removal, showing that he had estimated 15,000 CY of rock prebid based on the Government's descriptions, and now estimates 200,000 CY of rock to be dredged with 45,000 CY requiring blasting. To a large extent contractor's claim hinged upon his being misled by the word "coquina" which was used on the boring logs. He claimed that inasmuch as "coquina" is inherently, and by definition, light, soft and crumbly, no difficulty would reasonably be anticipated in excavating even that portion described as relatively "hard" and "well-cemented."

- The claim of $2.3 million was negotiated to $900,000 lump sum, which included additional alleged problems such as substantially more soft organic surface material covering the site than was reasonably anticipated. The original bid cost was $10.7 million.

- The 18-inch hydraulic dredge, Fairfield, attained an average hourly production rate from June 1980 to October 1982 of 359 cubic yards for all materials. Figure 2 shows quantities and excavation rates for rock and nonrock materials.

- (Keeton) Available production rate information is typical of the type detail given in the above figure.

- (Smith and general consensus of group) While this appears to be a case of using a somewhat unusual geologic name to suit a predetermined purpose, even a "good" geologic description does not uniquely correlate to engineering properties. A standard way of describing material to be dredged needs to be developed. Refer to Verna's talk.

Subsurface Investigations and Design Considerations

Subsurface investigation and design considerations relative to Florida geology were discussed by Mr. Thornton of Jacksonville District.

- Florida coastal geology exhibits varying amounts of sands and silts overlaying limestone or sandstone which itself is normally interbedded with sandy layers or lenses; clay occurs but to a lesser extent. Rock varies rapidly in character both horizontally and vertically with large changes in hardness, density, vuggyness and bed thickness. Such irregularities have caused contractural problems and affects the exploration and design methods used.

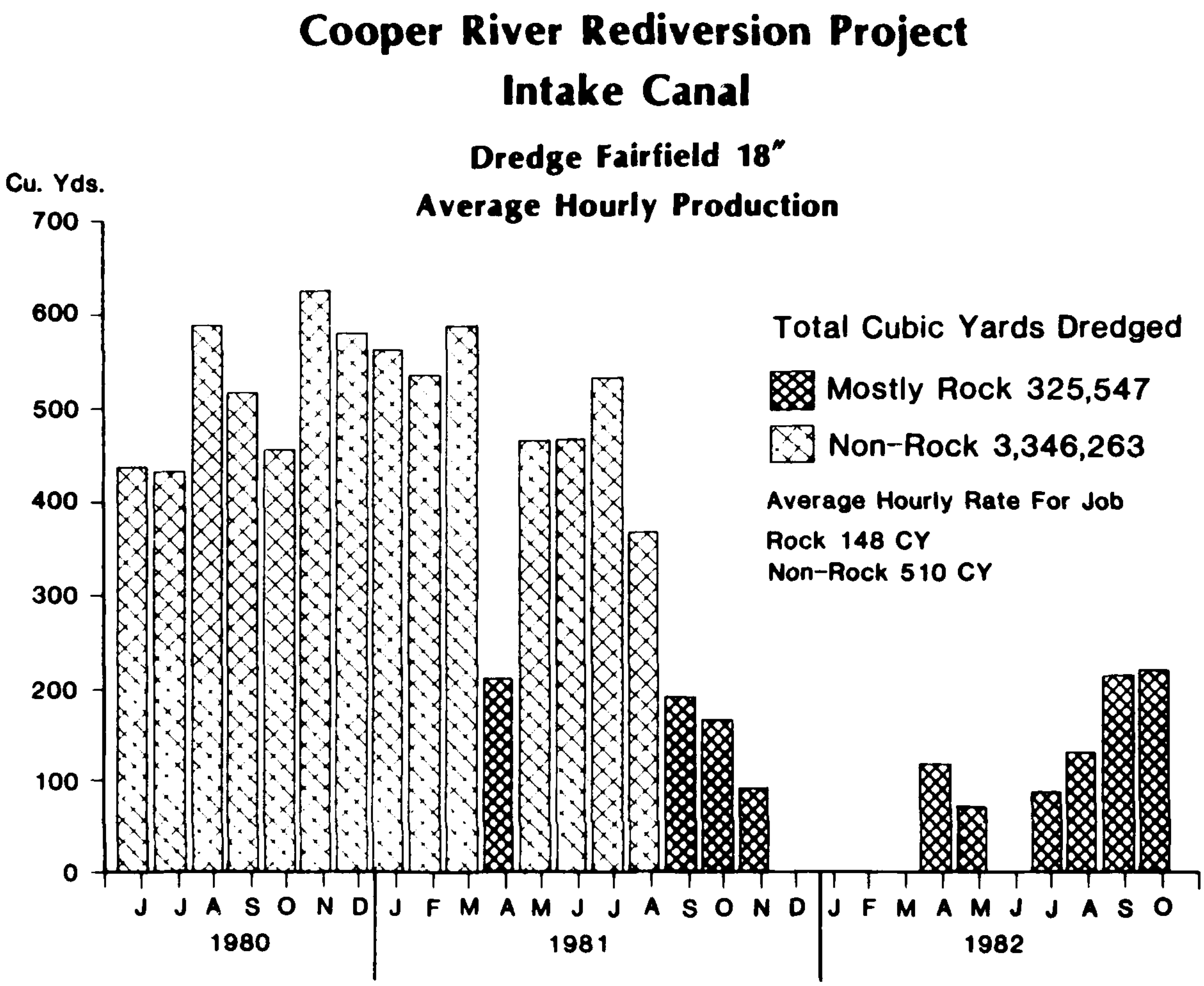

Figure 2. Quantities dredged and production rates in rock and nonrock materials

- Descriptions should relate to the intended work. Fossil descriptions and scientific names are of little or no value. Local or highly specialized names should be avoided. The use of the Corps' Geotechnical Manual for Surface and Subsurface Design, DM 1110-1-1 (US Army Corps of Engineers, South Atlantic Division, 1985), is recommended.

- Because of the type materials likely to be encountered, such as loose shelly sands, a larger spoon and hammer (compared to the standard driven split spoon) is often used. The larger spoon is 5 feet in length, 2 inches inside diameter, and is driven with a 300-pound hammer; the log is so noted. General practice has been to drive to 100 blows per foot and then switch to core barrel. There is an abundance of weak or vuggy rock in Florida that can be driven at 100 blows or less. Where blow count may be used as an indication of dredgeability, rock is driven and then bored to get core. A few unconfined compressive strength tests in the laboratory have lead to problems in claims usually because in situ conditions were not maintained or because tests were on small intact samples.

- For core the standard NX barrel is not used as it does not recover soft vuggy rock as well as the larger size; a 4 x 5-1/2 inch barrel is used. Use of the larger size also helps alleviate the difficulties often encountered in the degradation of core in transport or in storage. The contractor should always examine core while referring to the core log. The possibility of change from as-taken condition should be clearly emphasized in specifications.

- Seismic subbottom profiling has been useful for some purposes such as developing borrow areas needed for beach restoration but has been generally unsatisfactory in bays and waterways for dredging applications.

- Where blasting is necessary for economical excavation it should be specified and the limits of required blasting clearly delineated.

- Numerous rock dredging claims demonstrate that specifications need to be improved. Rock parameters applicable to dredging need to be determined and then we must tailor our exploration testing and data presentation accordingly.

Dredging at Calion Lock and Dam

Rock dredging for Calion Lock and Dam was described by Mr. Harrelson of Vicksburg District.

- The initial geologic investigation was not adequate. Prior to bidding only three borings were made which were about 1,500 feet from the excavation; they were representative of conditions but were not in the main channel.

- The structure was already completed and therefore blasting was precluded which led to the use of a hydraulic dredge.

- Rock material at the site is a very hard siltstone (quartz).

- After award of contract, 29 locations were sampled in the channel, and rock was encountered in 27 cases. Samples were taken with a backhoe equipped with ripper teeth which could break up the siltstone lenses and then recover fragments on the next bite. Mineralogy and hardness were noted.

- Contract was terminated to be readvertised with the material redescribed.

Dredging Cost Estimates Relative to Type Material

The estimation of costs for rock dredging projects was discussed by Mr. Mohr, CE retired, who reviewed his experience with Government dredging estimates over the past 15 years. He presented a wide spectrum of factors that influence dredging costs from type of contracting system used to the environmental considerations necessary in accomplishing final disposal of dredged material. Dredge production estimating has been and can be further improved by considering differences in dredged materials more accurately. Observations and statements of particular relevence to the problem at hand include:

- Dredging is far from being an exact science (or art): Measurement of dredged material volume (for general dredging operations) varies greatly, up to 50 percent or more. (Consensus of attendees, here.) Dredgeability cannot be directly or accurately measured; the overall system, involving many complex factors, must be considered.

- Claims are frequent in cohesive materials and, for contracts requiring rock dredging, claims based on difficulty of excavation may occur in as many as 90 percent of the cases.

- An overall system for estimating dredging costs is given in ER 1110-2-1300 (Headquarters, Department of the Army 1985), for which Mr. Mohr provided primary input. The material to be dredged has a pronounced effect on production. The recommended system includes a material factor which ranges from 3.0 for loose mud and silt to 0.2 for blasted rock. Production is estimated by taking the predicted production for loose sand and multiplying by the material factor. The material factors for various materials are lised in Table 1. A possible approach to rock dredgeability development is to expand the resolution given in this table for rock material factors; thereby rock dredgeability would be directly related to expected production rates in the loose materials encountered in maintenance dredging.

Table 1.

Material Factor Values for Materials To Be Dredged (ER 1110-2-1300)

Material Description	Average Inplace Density	Material Factor
Mud and silt	1200 gm/l	3.0
Mud and silt	1300 gm/l	2.5
Mud and silt	1400 gm/l	2.0
Loose sand	1700 gm/l	1.1
Loose sand	1900 gm/l	1.0
Compacted sand	2000 gm/l	0.9
Stiff clay	2000 gm/l	0.5-0.7
Compacted shell	2300 gm/l	0.4-0.6
Soft rock	2400 gm/l	0.3-0.5
Blasted rock	2000 gm/l	0.2-0.3

- As compared to hydraulic dredges, mechanical dredges handle material essentially as it is found in situ. As materials get harder, less of it is removed since the bucket shearing force is limited. In deep water the same shearing force applied to the dredged material stresses dredge components to a higher degree. Since mechanical dredges normally dump material in an adjacent barge, material transport may not be a constraint on the possible production rate.

- Hydraulic dredges require up to several hundred percent water added to the dredged material to transport it in a piping system. Cohesive materials, especially broken rock, require a great amount of dilution water and a high effluent velocity. Therefore, it is possible in dredging hard material where a long discharge line is required that the capacity of the dredge pump drive unit could control production instead of the efficiency of the rock cutterhead.

- The foregoing descriptions of dredge operation show that researching the effect of hard materials on overall dredge production cannot be confined to the characteristics of the material alone.

Rock Dredging at Brunswick Harbor

Rock dredging problems at Brunswick Harbor, Georgia were discussed by Mr. Keeton of Savannah District.

- Rock material to be dredged consisted of limestone, sandstone, calcareous claystones and siltstones (marl). Limestone consisted of varying amounts of sand, fossils, phosphate, and gravel. Layers of harder and softer materials were interbedded. Thickness of rock ranged from 0.2 to 3.3 feet. There were 34 boring logs, 2 unconfined compressive tests and 2 petrographic analyses given prior to bidding.

- The estimated 382,000 CY of material to be dredged was unclassified, i.e., payment price per CY was the same for all materials, although the available data on material characteristics and extent were included in bid documents as information only from which contractor would make his own interpretation.

- Dredging began November 1982 and was completed within one year. Resolution of a differing site condition claim of $4.7 million is pending; the original bid was at $1.8 million. The Government has denied the claim in total. (Decision was made March 1986 to settle the claim for $2.8 million.)

- One 18 inch suction cutter dredge and three dipper and backhoe type dredges were used in the work. A video tape showing all four dredges excavating rock materials was shown. The low volume production in harder material was evident.

- Contractor claimed a greater volume of rock than expected, using a textbook definition of "rock" which was not related to strength. An engineering definition of the term "rock" was not given in specifications. The video tape showed samples of this "rock" material being squeezed through a person's hand and other "rock" broken by the unaided hand.

- The two unconfined compressive strengths given in the contract documents were 725 and 1,055 psi. Postbid tests on core by both the contractor and the Government on over 100 samples yielded much higher values ranging up to 4,390 psi for saturated or 8,100 psi for dried samples. However, the median values for saturated samples vary by little more than 100 psi comparing prebid to postbid data. The reliance on two pieces of data as typical is not appropriate, given the variability of the geological materials.

- The contractor claims the Government did not correctly calculate the rock quality designation (RQD), thus understating the true values. In the method used by the contractor, soft zones were not accounted for in the core run, and core loss was likewise not included in the RQD determination. The question was raised: "Should the RQD be shown on boring logs for dredging projects?"

Panel Discussion

After the last topic was presented and before the summary comments by WES, Dr. Erwin convened a panel for discussion composed of Messrs. Hall, Keeton, Mohr, and Sanderson with discussion open to all attendees. Some of the following abridged comments are not associated with a participant's name because they reflect opinions expressed by more than one or a general consensus of attendees.

- (Sanderson) The solution to the dredgeability problem is very complex, involving much more than just determining material factors and how to name them.

- (Mohr) The use of the material factor in the range 0-0.4 is difficult; detail is lacking. In this range there are no direct data to back up now, but several rock jobs were visited and information obtained sufficient for the resolution given in the table of material factors.

- (Mohr) The material factor is solved for by taking the predicted table production (from the ER) and the actual production and then dividing.

- (Mohr) The cutter may not be the controlling element even in the hardrock if, for example, we have a long pipeline in a hydraulic dredge system.

- (Mohr) Specifications need to be uniform throughout the Corps - contractors do cross district lines.

- (Hall) Caution should be observed in correlating material and equipment characteristics; if you go that far, you have gone too far. (The assumed implication is that a scale of relative dredging difficulty with respect to material description could be established, but not correlated with specific items of equipment, since performance of such equipment varies with minor changes in dredge configuration, horsepower, or state of repair.)

- (Hall) In a claim situation the lump sum contract requires the contractor to assume cost increases without "unusual" condition. Once "unusual" conditions are claimed the Government must prove it wrong or accept it.

- (Keeton) Sometimes there is no relationship between rock strength and rock hardness, particularly when determined by scratch test.

- The need for standard material descriptions is recognized.

- The ability to predict dredgeability once the material is known (including engineering properties) should be developed. No systematic means exist to differentiate the dredgeability of various materials in the rock range.

- A critical need exists to obtain additional prebid exploration funding. When there is a large claim, which is common in rock dredging projects, an extensive exploration effort follows and usually at a much greater cost than an adequate prebid exploration program.

PART IV: SUMMARY AND CONCLUSIONS

Rock Dredgeability Rating: Its Relationship to the Dredging System

When a rock dredgeability rating is developed, (several years down the road) it will not:

- Include removal/transport/disposal considerations in that a purely rock mechanics solution will certainly not address these problems, although such considerations are important.

- Include environmental considerations.

- Be used, as was envisioned prior to the workshop, directly in the contract; but will provide background knowledge influencing the type of pre-IFB data gathered and Government estimates of costs and completion times.

The problem at hand is to develop method(s) for estimating the dredgeability of rock with respect to type equipment and methods used, having been given a geotechnical description of the rock mass. The problem of estimating dredgeability is two-pronged (perhaps three-pronged if the overall dredging system is to be considered). First, part of the present problem is to get a concise/complete description of the dredged material in place. Underlying this requirement is the need for adequate definitions of all terms used to describe the rock mass. Once one has a geotechnical description of the rock mass in hand, then equipment interactions with the material (i.e., dredgeability) can be estimated from knowledge of (1) equipment; (2) rock mass properties, descriptions; and (3) rock mechanics principles. In addition to the need for a description of material and a method to estimate dredgeability from such description, a "third prong" must be considered in determining overall dredging rates: removal, transport and disposal problems may dictate a modification of the dredgeability as estimated from a purely rock mechanics standpoint. Certainly these problems must be considered and coordinated as necessary in any application of a rock dredgeability rating. The diagram shown in Figure 3 outlines the above-discussed relationships.

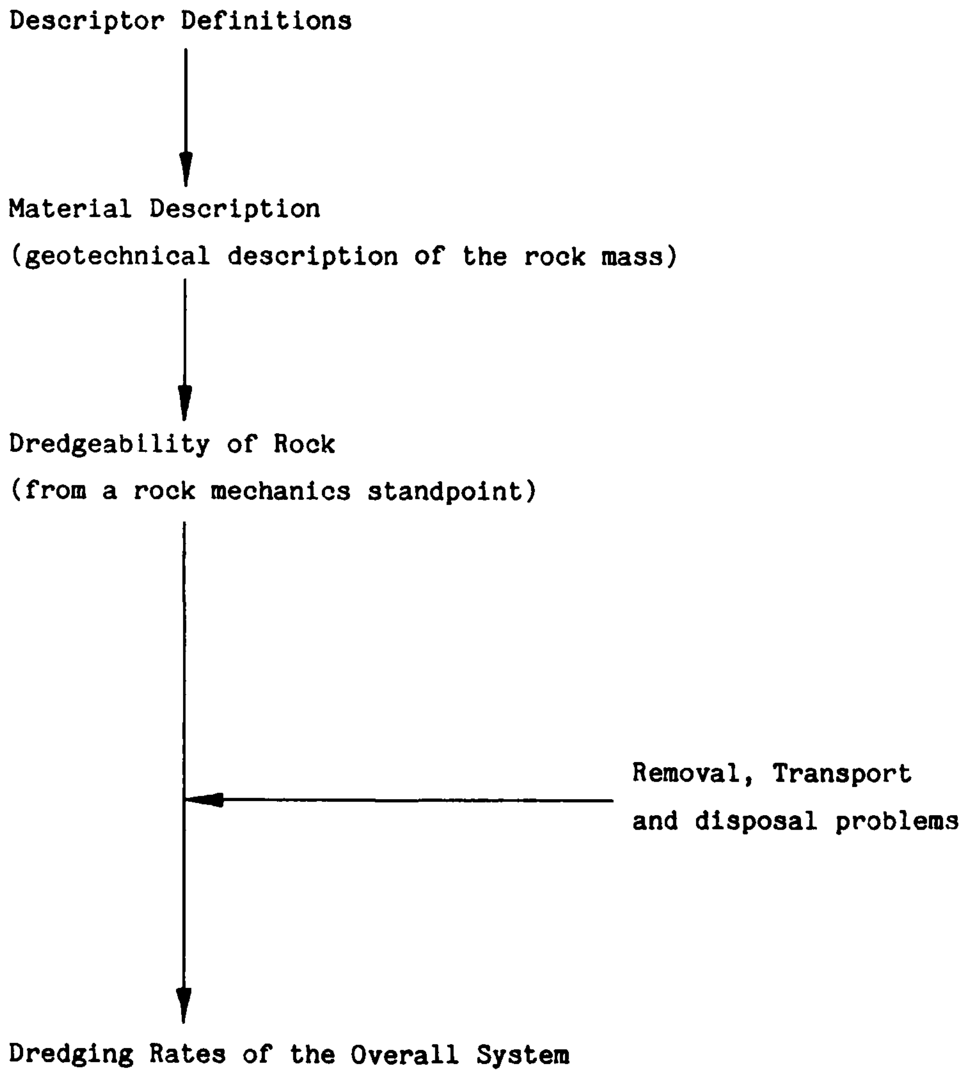

Figure 3. Dredgeability morphology

There is no need to address legal/contractual problems, many of which were discussed during the workshop, except to point out (as indicated during Mr. Hall's presentation and related discussion) that a dredgeability rating could possibly do more harm than good if included in contract documents. Results from the use of such a rating system would provide "extra" or judgement type information, and the Corps is not required to furnish results of a judgement type analysis, just the raw data. Opinions vary widely concerning the detail and depth of information which should be directly included in IFB's. Any rating system or method of analysis would, of course, be known by the contractor who could choose to use it to provide additional input for his engineering judgement of dredgeability. Even if not included in the contract, a dredgeability rating will be useful:

- Whenever we wish to specify or restrict equipment/methods, which has been a practice in the past (even though the pitfalls are and have been well known).

- To establish more accurate Government estimates for contracting or for "what-if" exercises.

- To determine the rock mass parameters which do likely influence dredgeability; and these should, of course, be included in the IFB, and should prove useful to both the contractor and the Government.

Case History Information

The workshop pointed to the need for more emphasis on supplemental information to the case histories. Although some case history information came to light and leads were found for additional information, it appears that case history information may be somewhat more limited than preworkshop hopes for empirical data. Although a "good" case history may exist and be generally well documented, to be useful for rock dredgeability it must include equipment description, production rates, and a geotechnical description of the rock mass. If some of this information is missing, assumptions would have to be made in order to use the case history information. Noteworthy here is that assumptions about the rock mass are what provided the basis for many of our claims which pointed in turn to the need for the research work unit on the dredgeability of rock.

Proposed Plan of Study

Based on preworkshop background, ideas expressed during the workshop, and the apparent level of availability of data from field experience, a proposed plan of study was formulated and is shown in detail in the work unit documentation, Form 4417, pages 38 and 39. Figure 4, which is similar to the plan of study as presented in the concluding remarks at the workshop, shows the proposed plan of study in flowchart format.

This plan of study is subject to change as the initial phases of the research are accomplished. For example, the final assessment of the potential for development of a dredgeability rating system can only be made after the rock mass parameters influencing dredgeability have been identified and the extent of available case history information is known. The work is also likely to be influenced by ongoing feedback from field personnel.

Survey CE for additional
information on case histories
(supplemental site inspection/
exploration if necessary)

WORKSHOP
Case history information
Methods of analysis
Background

STATE OF ART REPORT
---ROCK CUTTING & DREDGING

MP on typical rock
dredging case histories
Tabulate sources, knowledge
of rock mass
properties by case.

Propose rock mass parameters
which should have same or similar
influence on engineering properties
"wet" or "dry" and correlate results
with available case histories.

Draft ETL on rock
mass parameters influ-
encing dredgeability.

Develop a rock mass classification
system (dredgeability rating for rock)
such that a geotechnical description
of the rock mass may be used to estimate
dredgeability for specific type dredging
operations. (Relates to rock breakage -
removal and transport problem is
independent of rock mechanics problem
although the existence of these problems
must be recognized as they can have a
big influence - even ovrerriding.)

Prepare final report.
Technology transfer ac-
tivities as appropriate.
Publish TR.
Prepare information as
appropriate for revision
of CE guidance publica-
tions (EMs, ERs, guide
specifications) with re-
spect to rock materials.

<u>NOTE</u>

CE - Corps of Engineers
EM - Engineering Manual
ER - Engineering Regulation
ETL - Engineering Technical Letter
MP - Miscellaneous Paper
TR - Technical Report

Figure 4. Plan of study for dredgeability of rock

CIVIL WORKS RESEARCH & DEVELOPMENT WORK UNIT (ER 70-1-11)		RCS: DAEN-RD-3
1. DATE PREPARED 86 01 01	2. MISSION PROBLEM NUMBER(S) 12-047-3, 12-048-3	3. CURRENT NUMBER CODE 312 | 32344
4. PRINCIPAL LABORATORY USAE Waterways Experiment Station		
5. RESEARCH AREA Materials	6. RESEARCH PROGRAM Rock	
7. WORK UNIT TITLE Dredgeability of Rock		
8. R&D PERFORMING ELEMENT NAME: USAE Waterways Experiment Station ADDRESS: Engineering Geology & Rock Mech. Div. PO Box 631 Vicksburg, MS 39180-0631	9. INDIVIDUAL POINT OF CONTACT PRIMARY NAME: H. J. Smith TELEPHONE: 601-634-2431 (Comm) 542-2431 (FTS) ALTERNATE NAME: D. C. Banks TELEPHONE: 601-634-2630 (Comm) 542-2630 (FTS)	
10. KEYWORDS Rock Mass, Geotechnical Description, Dredging		

11. BRIEF TECHNICAL SUMMARY (OBJECTIVES AND APPROACH)

PROBLEM: In contracting dredging work common practice is to give the contractor results from boring logs at selected locations: unconfined compressive strength and/or geologic description are frequently given. In some cases contractors have assumed that rock of a given description is easily dredgeable with available equipment based on past experience with rock of similar description but with vastly different engineering properties. The CE is currently experiencing numerous large (into millions of dollars) differing site condition claims based on the contention that the rock is harder to dredge with mechanical equipment than the contractor had inferred from bidding information.

OBJECTIVE: To develop method(s) for estimating the dredgeability of rock with respect to type equipment and methods used, given a geotechnical description of the rock mass.

APPROACH: Using information obtained through the Rock Dredging Workshop (FY 85), a survey of CE District offices will be made to obtain dredge performance data and corresponding rock mass data. Thereby, available supplemental data on the case histories already known will be obtained, and additional case histories will be identified and documented. A determination will be mdae as to which rock mass parameters influence dredgeability, and relationships will be developed to estimate performance in particular dredging operations with respect to rock mass parameters such as unconfined compressive strength, abrasiveness, rock structure, geophysical properties, etc. Depending on available detail of case history data, peripheral site data may be required to make some case histories useful for the purpose at hand. Also depending on completeness of overall performance data, laboratory testing to determine underwater performance relative to "dry" performance of rock picks and cutters may be desired so that the more extensive development of excavation technology from the tunneling and mining industries may be utilized.

ACCOMPLISHMENTS PRIOR TO FY 85: None.

ACCOMPLISHMENTS FOR FY 85: Preliminary survey of rock dredging literature was made. A Rock Dredging Workshop was held involving participation of all Districts and Divisions with an interest in

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CIVIL WORKS RESEARCH & DEVELOPMENT WORK UNIT (Continuation) (ER 70-1-11)		RCS: DAEN-RD-3	
1. RESEARCH PROGRAM Rock	2. DATE PREFERRED 86 01 01	3. CURRENT NUMBER/CODE 312	32344
4. WORK UNIT TITLE Dredgeability of Rock			

rock dredgeability problems, for the purpose of determining the need for and direction of future research.

WORK PLANNED FOR FY 86: Emphasis will be placed on compiling and evaluating rock dredging case history information. Communication with or visits to Districts involved in rock dredging will be made to gather supplemental information. A MP on rock dredging case histories will be prepared for the purpose of documenting sources, performance data and rock mass properties which will be tabulated by source. Also results from the FY 85 workshop will be published.

WORK PLANNED FOR FY 87: The MP on rock dredging case histories will be published. Rock mass parameters which influence dredgeability will be determined based both on the case history study (FY 86) and available information on rock excavation in the "dry" environment (tunneling, mining, and open rock excavations). Rock mass parameters which are likely to have the same or similar influence on rock excavation behavior in both the "wet" and "dry" environments will be used to correlate dredging case history data with "dry" rock excavation principles to verify and/or expand knowledge of rock mass parameters which influence dredgeability. An ETL will be drafted on rock mass parameters influencing dredgeability. The potential for development of a systematic rating method for dredgeability will be assessed based on the background developed during FY86 and FY87, and the plan of study will be modified as appropriate.

WORK PLANNED FOR FY 88: A rock mass classification system (dredgeability rating for rock) will be developed such that a geotechnical description of the rock mass may be used to estimate dredgeability for specific types of mechanical dredging equipment. Such an estimation would be primarily made relative to rock breakage, although the removal and transport problem, which involves many non-rock mechanics considerations, must be recognized. While this problem may not be directly addressed, coordination will be made with field personnel involved in rock dredging to obtain input on possible limits which may exist on the use of rock dredgeability estimated from a rock mechanics standpoint based on the nature of the overall dredging system. Work will begin on preparation of final report on the dredgeability of rock.

WORK PLANNED FOR FY 89: A final report will be completed and published as a TR. Information needed for revision of CE guidance publications (EMs, ERs, guide specifications) with respect to rock materials will be prepared as appropriate.

TECHNOLOGY TRANSFER: "Non-mission Related Technology Transfer Potential - an application assessment of the potential for successful transfer of the technology or data resulting from this work unit to state and local governments and to private industry, in accordance with Public Law 96-480, has been performed. The assessment indicates that the product resulting from this work unit has low potential for non-mission technology transfer."

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REFERENCES

Headquarters, Department of the Army, 1985 (Jun). "Government Estimates and Hired Labor Estimates for Dredging," Engineering Regulation 1110-2-1300, Washington, DC.

__________________. 1983. "Rock Mass Classification Data Requirements for Rippability," ETL 1110-2-282, Washington, DC.

Hignett, H. J. 1984. "The Current State-of-the-Art of Rock Cutting and Dredging," Miscellaneous Paper GL-84-17, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Permanent International Association of Navigation Congresses (PIANC). 1984. "Classification of Soils and Rocks to be Dredged," Supplement to PIANC Bulletin No. 47, PIANC, Brussels, Belgium.

US Army Corps of Engineers, South Atlantic Division, Department of the Army. 1 March 1985. "Engineering and Design, Geotechnical Manual for Surface and Subsurface Investigations," DM 1110-1-1, Atlanta, Ga.

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