Dredging Operations Technical Support (DOTS) Program

Savannah District Request for Technical Assistance

Dredge Vertical Construction Accuracy

DOTS Response Number: 2006-011

26 March 2006

Background

Via e-mail communication of 15 February 2006, the U.S. Army Corps of Engineers, Savannah District (SAS) (Lyle Maciejewski SAS-OP-N), requested technical assistance from the U.S. Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL) (Douglas G. Clarke, CEERD-EE-W) through the DOTS program pertaining to the Savannah River Deepening Project. The request was subsequently forwarded to the ERDC Coastal and Hydraulics Laboratory (Tim Welp, CEERD-HN-CD) for analysis and response.

Savannah District (SAS) is developing a plan for deepening Savannah Harbor, Georgia. A shallow aquifer layer and pockets of soil enriched with cadmium lie in the channel to be deepened. Dredging will require tight vertical and horizontal control. SAS is familiar with the process of horizontal control, however, they have requested CEERD to conduct a DOTS request to gather more information about vertical dredging accuracies. Since the dredge type has not been selected, SAS requested CEERD to furnish information on what is the current state of vertical control of cutterhead and bucket (backhoe and clamshell) dredges. The sediments to be dredged are clay, so hopper dredges were not considered. Work conducted under this DOTS request consisted of a literature search and interviews with various dredging contractors, Corps employees, and instrumentation manufacturers.

The definition of vertical accuracy is very important in how the respective values are considered and applied. The different sources identified in this DOTS response have reported vertical accuracy in different ways (i.e., plus/minus ($\pm$) a value or in absolute numbers). Where available, the specific definitions from the various sources are presented in this report.

One of the more detailed accuracy definitions used by the International Association of Dredging Contractors (IADC) et al. (2001) to describe construction accuracy will be presented here to illustrate the various components that vertical accuracy is comprised of. In the document “Construction and Survey Accuracies for the Execution of Dredging and Stone Dumping Works” construction accuracy is defined as the extent to which the completed work corresponds to design requirements. Various factors influence the selection of dredging plant and its respective inherent accuracy(ies), for a specific project:

(1) Physical characteristics of material to be dredged.

(2) Quantities and physical layout of material to be dredged.

(3) Dredging depth.

(4) Location of both the dredging and placement sites and distance between them.

(5) Physical environment (i.e., waves, tides, currents) of and between the dredging and disposal placement areas.

(6) Contamination level of sediments.

(7) Method of placement.

(8) Production required.

(9) Type of dredges available

Construction accuracy achieved during a project will not only depend on the selected dredge type and its inherent excavation accuracy, but also on:

(1) Accuracies of the support hydrographic and positioning (two-dimensional reference) systems used.

(2) Level of quality control used to continuously monitor data quality

(3) Experience level of crew

The total construction accuracy is therefore dependant upon reference accuracies, steering (operator) accuracy, and excavation point accuracy (IADC 2001). The reference accuracy relates to errors in determining vessel position relative to fixed reference (coordinate) system. Steering accuracy concerns those errors introduced manually by the operator (leverman, etc.). Excavation point accuracy is related to the dredge type selected (e.g., shape and adjustability of suction mouth, cutterhead/suction mouth geometry, use of a level cut bucket as opposed to conventional bucket, etc.) and "linkage between reference positioning and depth measurement" (EPA 2005). IADC (2001) concluded from environmental dredging trials in the Ketelmeer Project that the inaccuracies become greater in the order of: reference inaccuracies, excavation mouth inaccuracies, then total construction inaccuracies.

Vertical and horizontal excavation control for a significant number of the larger cutterheads and mechanical bucket (backhoe) dredges in America is provided by a positioning system that indicates (to the operator) the dredge excavation point referenced to the dredging template.

While the amount of material disturbance by the dredges below desired depth (to achieve the design depth) will be a factor in determining contract specifications, this aspect was not specifically considered under this DOTS request. Documentation addressing this issue is discussed in greater detail in attachments 2 and 3 that consist of previous DOTS requests addressing this issue. Dredging accuracies are primarily determined by excavation results (depths) indicated by hydrographic survey (before dredge (BD) and after dredge (AD) surveys) relative to the dredging template (aka grade, neatline, etc.). The AD depths do not necessarily indicate the maximum depth that the cutterhead or bucket had to penetrate to achieve the final grade. The accuracy of these hydrographic surveys that are used to determine dredging accuracy and results should also be considered when evaluating overall dredging accuracy. The following information (broken down by dredge type) was collected from the various references cited.

Cutterhead Dredge

As a starting point, the Dredging and Dredged Material Disposal Engineer Manual (EM) 1110-2-5025 (1983) states that the vertical accuracy of a cutterhead dredge on a navigation dredging project is generally within ± 1 foot.

IHC's positioning system, the Dredged Profile Monitoring (DPM), gives the position of the "cutter" relative to the centerline of the design profile, and to the waterline and working depth set points. The stated accuracy for this system is 10 cm (0.3 ft). Personnel Communication with Ruud Ouwerkerk of Dredging Technology Corporation (a subsidiary of IHC), revealed that no U.S. dredges used in navigation projects were operating with the DPM. Because a system is possibly accurate to this tolerance, it does not necessarily mean that the dredge can achieve this accuracy limit given site specific conditions and operator efficiency considerations.

Various U.S. dredging companies have developed and use proprietary cutterhead positioning systems. Although no specific documented information on accuracies was identified for these proprietary positioning systems used on larger cutterhead dredge dredges in navigation dredging projects during the technical literature search, some information was available for cutterheads used for environmental dredging projects.

“Environmental dredging” is a term used in recent years to describe dredging that’s conducted primarily to remove contaminated sediment, as opposed to navigation dredging to maintain waterways for commercial traffic, national defense, and recreation. The objective of environmental dredging is to remove sediment contaminated above certain action levels while minimizing the spread of contaminants to the surrounding environment NRC (1997). Dredges used for environmental dredging are typically smaller than those used on the larger (yardage) navigation dredging projects. More emphasis is placed on controlling operational parameters (i.e., slower cycle times) and vertical accuracy in environmental dredging projects to minimize overdredging and sediment resuspension due to the significantly higher cost per cubic yard related to contaminant disposal or treatment aspects.

Ellicott’s new 8 inch (203 mm) “swinging ladder” cutterhead dredge with three (3) traveling spud carriages (uses no cables) is designed specifically for environmental dredging jobs. The manufacturer states that this swinging ladder dredge can dig to a depth of 22 ft and “has controls which tell the dredge operator exactly which layers the cutter is in. The cutter can dredge to tolerances of plus or minus one inch (25 mm) which is critical, especially for contaminated sediments. The operator controls keep re-suspension of the sediment back into the water column to an absolute minimum. All dredge functions are linked to global positioning systems.” (http://www.mudcat.com/environmental/new-dredging-tech-4.htm).

In guidance provided by EPA (2005) for sediment remediation of hazardous waste sites, Table 1 presents some of the currently available general information that is intended to help project managers initially assess, in the context of environmental dredging, dredge capabilities, and screen and select equipment types for evaluation at the feasibility study stage or for pilot field testing. The table is not intended as a guide for final equipment selection for remedy implementation because there are many site-specific, sediment-specific, and project-specific circumstances that will indicate which equipment is most appropriate for any given situation, and each equipment type can be applied in different ways to adapt to site and sediment conditions (EPA 2005).

The most pertinent parameter in Table 1 relative to this DOTS request, vertical operating accuracy, is defined (footnote 16) as the ability to position the dredgehead at a desired depth or elevation for the cut and maintain or repeat that vertical position during the dredging operation (accuracy and precision). This document, compiled with input from the USACE and caveated as general information only, lists the vertical excavation accuracy for 15 to 30 cm (6 to 12 inch inside diameter discharge pipeline diameter) cutterhead dredges as 10 cm (4 inches). Footnote 16 also states that “although positioning instrumentation is accurate to within a few cm, the design of the dredge and the linkages between the dredgehead and the positioning system will affect the accuracy attainable in positioning the dredgehead. A vertical accuracy of cut of approximately 15 cm

(0.5 ft) is considered attainable for most project conditions. Fixed arm equipment holds some advantage over wire-supported in maintaining vertical operating accuracy. The accuracies achievable for sediment characterization should be considered in setting performance standards for environmental dredging operating accuracy (both vertical and horizontal)."

Another EPA remediation guidance document (Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance 1994) provides operational characteristics on larger-sized dredges. Table 2 presents the operational characteristics of cutterhead dredges ranging in size from 6 to 30 inches (15 – 76 cm) in which the vertical dredging accuracy (assumed to be synonymous to construction accuracy) is 30 cm (1 ft) for all these sized dredges. It is not known if these accuracies are presented as those attainable in navigation or environmental dredging projects, or both.

The remaining pertinent document identified for this DOTS request was entitled "Construction and Survey Accuracies for the Execution of Dredging and Stone Dumping Works" (IADC 2001). The objective of this document is to present information on the construction accuracies of dredging and stone dumping works to minimize "certain tension between the requirements that arise from the design, the requirements with which the contractor, even with the application of maximum effort, can comply and economic considerations" (IADC 2001). Table 3 from this document presents "practical achievable vertical accuracies in meters of various dredging equipment for different bed types and working circumstances" source CROW 2001. An English version of this source (CROW (2001) was not available.

	EQUIPMENT TYPE[2]									
	Mechanical Dredges (2 to 8 cubic meter buckets)			Hydraulic/Pneumatic Dredges (15 to 30 cm pump sizes)						Dry Excavation
	Conventional Clamshell (Wire)[3]	Enclosed Bucket (Wire)[4]	Articulated Mechanical (Fixed Arm)[5]	Cutter-head[6]	Horizontal Auger[7]	Plain Suction[8]	Pneumatic[9]	Specialty[10]	Diver[11]	Various Mechanical Excavators[12]
OPERATIONAL CHARACTERISTICS[13]										
Operating Production Rate (m^3/hr)[14]	48 (2 m^3 bucket) 95 (4 m^3 bucket) 143 (6 m^3 bucket) 193 (8 m^3 bucket)			23 (15 cm pump) 41 (20 cm pump) 64 (25 cm pump) 93 (30 cm pump)			Site Specific	Equipment Specific	10	Site Specific
Percent Solids (by weight)[15]	Near In-Situ	Near In-Situ	Near In-Situ	5	5	5	15 or Higher	Equipment Specific	<5	In-Situ or Greater
Vertical Operating Accuracy (cm)[16]	15	15	10	10	10	10	15	10	--	5
Horizontal Operating Accuracy (cm)[17]	10	10	10	10	10	10	10	10	--	5
Maximum Dredging Depth (m)[18]	Stability Limitations	Stability Limitations	15	15	5	15	45	15	30	Stability Limitations
Minimum Dredging Depth (m)[19]	--	--	--	1	0.5	1	5	1	0.5	--

Table 1. Sample Environmental Dredging Operational Characteristics and Selection Factors (Source EPA 2005)

1	This table provides some of the currently available general information that can help project managers initially assess dredge capabilities, and screen and select equipment types for evaluation at the feasibility study stage or for pilot field testing. This table is NOT intended as a guide for final equipment selection for remedy implementation, and regions may find it useful to consider other sources of information for purposes of comparison. There are many site-specific, sediment-specific, and project-specific circumstances that will indicate which equipment is most appropriate for any given situation, and each equipment type can be applied in different ways to adapt to site and sediment conditions. In addition, because new equipment is being continuously developed, project managers should consult with experts who are familiar with the latest technologies.
2	Equipment types shown here are considered the most commonly used for environmental dredging in the U.S. Other dredge types are available. Equipment used for environmental dredging is usually smaller in size than that commonly used for navigation dredging. Information presented here is tailored for mechanical bucket sizes from 3 to 10 cubic yards (about 2 to 8 m^3), and hydraulic/pneumatic pump sizes from 6 to 12 inches (about 15 to 30 cm). Larger sizes are available for many equipment types.
3	Clamshell - conventional clamshell dredges, wire supported, conventional open clam bucket.
4	Enclosed Bucket - wire supported, near watertight or sealed bucket usually incorporating a level cut capability.
5	Articulated Mechanical - backhoe designs, clam-type enclosed buckets, hydraulic closing mechanisms, all supported by articulated fixed-arm.
6	Cutterhead - conventional hydraulic pipeline dredge, with conventional cutterhead.
7	Horizontal Auger - hydraulic pipeline dredge with horizontal auger dredgehead.
8	Plain Suction - hydraulic pipeline dredge using dredgehead design with no cutting action.
9	Pneumatic – air operated submersible pump, pipeline transport, either wire supported or fixed-arm supported.
10	Specialty Dredgeheads - other hydraulic pipeline dredges with specialty dredgeheads or pumping systems
11	Diver Assisted - hand-held hydraulic suction with pipeline transport.
12	Dry Excavation - conventional excavation equipment operating within dewatered containments such as sheet-pile enclosures or cofferdams.
13	OPERATIONAL CHARACTERISTICS - quantitative entries, reflecting capabilities and limitations of dredge types, and are solely a function of the equipment itself.
14	Production Rate - in-situ volume of sediment removed per unit time. Rates shown are for production cuts as opposed to "cleanup passes" and are for active periods of operation under average conditions. Rates for two bucket or pump sizes are shown for comparison. For mechanical dredges, the rates were calculated assuming 80% bucket fill with a bucket cycle time of 2 minutes. For hydraulic dredges, the rates were calculated assuming in-situ sediment 35% solids by weight, 5% solids by weight for slurry, and pump discharge velocity of 10 ft/sec. The rate shown for diver-assisted assumes a maximum pump size of 15 cm and roughly 50% efficiency of diver effort while working. Production rate for dry excavation is would be largely dictated by the time required to isolate and dewater the areas targeted for excavation. A variety of factors may influence the effective operating time per day, week, or season, and should be considered in calculating times required for removal.
15	Percent Solids by Weight - ratio of weight of dry solids to total weight of the dredged material as removed, expressed as a percentage. Percent solids for mechanical dredging is a function of the in-situ percent solids and the effective bucket fill (expressed as a percentage of the bucket capacity filled by in-situ sediment as opposed to free water), and near in-situ percent solids is possible for production cuts. A wide range of percent solids for hydraulic dredges is reported, but 5% solids can be expected for most environmental dredging projects.

Table 1. Footnotes for Sample Environmental Dredging Operational Characteristics and Selection Factors (Source EPA 2005)

16	Vertical Operating Accuracy - the ability to position the dredgehead at a desired depth or elevation for the cut and maintain or repeat that vertical position during the dredging operation. Although positioning instrumentation is accurate to within a few cm, the design of the dredge and the linkages between the dredgehead and the positioning system will affect the accuracy attainable in positioning the dredgehead. A vertical accuracy of cut of approximately 15 cm (one-half foot) is considered attainable for most project conditions. Fixed arm equipment holds some advantage over wire-supported in maintaining vertical operating accuracy. The accuracies achievable for sediment characterization should be considered in setting performance standards for environmental dredging operating accuracy (both vertical and horizontal).
17	Horizontal Operating Accuracy - the ability to position and operate the dredgehead at a desired location or within a desired surface area. Considerations are similar to those for vertical accuracy.
18	Maximum Dredging Depth - physical limitation to reach below a given depth. Wire-supported buckets or pumps can be deployed at substantial depths, so the maximum digging depth generally is limited by stability of the excavation. Reach of fixed arm supported buckets or hydraulic dredges is limited by the length of the arm or ladder. Conventional backhoe equipment is generally limited to about 15 m reach. Smaller hydraulic dredges are usually designed for a maximum dredging depth of about 15 m. Hydraulic dredges usually also have a limiting depth of removal of about 50 ft due to the limitation of atmospheric pressure, but this limitation can often be overcome by addition of a submerged pump on the ladder. The table entries should NOT be considered as hard and fast limits. Larger dredge sizes and designs are available for deeper depths.
19	Minimum Dredging Depth - constraints on draft limitations of some floating dredges or potential loss of pump prime for hydraulic dredges. Such limitations can be managed if the dredge "digs its way into the area." For smaller dredges, these limitations typically are at approximately the 1m water depth. Pneumatic dredges require a minimum water depth of about 5 m for efficient pump operation.

Table 1. Footnotes for Sample Environmental Dredging Operational Characteristics and Selection Factors Continued (Source EPA 2005)

Dredge Type	Percent Solids by Weight[a]	Range of Production Rates (m^3/hr)	Dredging Accuracy		Operational Dredging Depth		Debris Removal[b]
			Vertical (cm)	Horizontal (m)	Minimum (m)	Maximum (m)	
Clamshell	near *in situ*	23–460	60	0.3	0[c]	48[d]	+
Suction	10–15	19–3,800	30	~1	2	16–19[e]	–
Dustpan	10–20	19–3,800	15	~1	2-5	16–19[e]	–
Cutterhead							–
6–8 in. (15–20 cm)	10–20	25–105	30	~1	1.2	4[e]	–
10–12 in. (25–30 cm)	10–20	60–540	30	~1	1.4	8[e]	–
14–16 in. (36–41 cm)	10–20	160–875	30	~1	1.5	12[e]	–
20–24 in. (51–61 cm)	10–20	310–1,615	30	~1	1.6	15[e]	–
30 in. (76 cm)	10–20	575–2,500	30	~1	1.7	15[e]	–
Hopper	10–20	380–1,500	60	~3	3–9	21[e]	–
Horizontal auger	10–30	46–120	15	0.15	0.5	5	–
PNEUMA®	25–40	46–300	30	0.3	0[c]	48[d]	–
Oozer	25–40	340–500	30	~1	0[c]	48[d]	–
Clean-up	30–40	380–1,500	30	~1	1–5	4–21	–
Refresher	30–40	150–990	30	~1	1–5	4–21	–
Backhoe	near *in situ*	20–150	30	~1	0[c]	7–15	+
Matchbox	5–15	18–60	30	~1	1–5	4–21	–
Airlift	25–40	NA	30	0.3	6	V[f]	–

Note: NA - not available

Source: Adapted from Hand et al. (1978) and Philips and Malek (1984), as cited in Palermo and Pankow (1988). Additional data from Averett et al. (in prep.) and USEPA (1985b).

[a] Typical solids concentration under optimal conditions. Percent solids may be lower if operational difficulties (e.g., excess debris) are encountered.

[b] Ratings for debris removal: (+) can remove debris; (–) debris removal is limited.

[c] Zero if used alongside of waterway; otherwise, draft of vessel will determine the operational depth.

[d] Demonstrated operational depth; theoretically could be used much deeper.

[e] With submerged dredge pumps, operational dredging depths have been increased to 30 m or more.

[f] V - theoretically unlimited.

Table 2. Operational characteristics of various dredges (Source EPA 1994)

The accuracy on a “cutter suction dredger” (aka cutterhead dredge) in clay is listed as 0.4 m (1.3 ft). As qualified in the IADC (2001) table’s footnotes, “the given values have a 95% confidence value, so the probability they will be exceeded on one side is 2.5%. The tolerances are expressed in meters and are both positive and negative (for example : 0.10 = $\pm$ 0.10 meter). The values are indicative and depend upon, amongst others, the equipment aboard. The values above are the sum of the inaccuracies in construction and measurement, the inaccuracies of measurement can be an order of magnitude smaller than those during construction.“ This $\pm$1.3 ft value is qualified in a bulk effort level (for bulk products) where “a higher priority is assigned to a production level than to accuracy” (e.g. in a navigation dredging project). In the max (for maximum) effort “with a higher priority assigned to the accuracy and production is sacrificed in the interests of accuracy” (e.g in an environmental dredging project), the construction accuracy is increased to $\pm$0.3 m ($\pm$1 ft). The last footnote in Table 3 states that the “maximum (max) effort is a relative term. It is always possible, will yet more effort to reach a result that is even more better”.

In Table 3, both the bulk and max accuracies are supplemented for specific working circumstances i.e., working in unsheltered waters (add 0.1 m (0.3 ft) to accuracy), currents 0.5 - 1.0 m/s (1.0 - 2.0 knots) (add 0.1 m (0.3 ft) to accuracy), and water depths 10 - 30 m (30 - 100 ft) (add 0.05 m (.15 ft to accuracy). For the Savannah River Deepening project, where currents can exceed 2.0 knots and the water depth will exceed 30 ft, an additional 0.45 ft is added to the $\pm$1.3 ft accuracy value is qualified in a bulk effort, and $\pm$1.0 ft accuracy qualified in a max effort, totaling $\pm$1.75 ft and $\pm$1.45 ft respectively.

Bucket (Clamshell) Dredge

The Dredging and Dredged Material Disposal Engineer Manual (EM) 1110-2-5025 (1983) states that the vertical accuracy of this type of dredge on a navigation dredging project is generally within $\pm$1 foot.

bed	Dredging equipment: trailing suction dredger		cutter suction dredger		environmen-tal suction dredger		hydraulic crane (backhoe)		crane ship/ crane pontoon		bucket dredger		plough (supported)	
	bulk	max	bulk	max	bulk	max	bulk	max	bulk	max	bulk	max	bulk	max
sludge	0.4	0.3	0.4	0.25	0.2	0.1	0.4	0.2	0.45	0.3	0.3	0.2	0.3	0.2
sand	0.5	0.4	0.4	0.3	0.2	0.1	0.5	0.25	0.5	0.4	0.3	0.2	0.3	0.2
gravel	0.5	0.4	0.4	0.3	n/a	n/a	0.5	0.25	0.5	0.4	0.3	0.2	0.3	0.2
clay	0.6	0.5	0.4	0.3	n/a	n/a	0.5	0.35	0.6	0.5	0.3	0.2	0.3	0.2
rocks	n/a	n/a	0.5	0.4	n/a	n/a	0.6	0.4	n/a	n/a	n/a	n/a	n/a	n/a
supplements for specific working circumstances														
unsheltered water	0.1	0.1	0.1	0.1	n/a	n/a	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.2
current 0.5 - 1.0 m/s	0.1	0.1	0.1	0.1	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
water depth 10 - 20 m	0.1	0.1	0.05	0.05	0.05	0.05	0.1	0.1	0.1	0.1	0.05	0.05	0.05	0.05

Explanation and comments:

- The given values have a 95% confidence value, so the probability they will be exceeded on one side is 2.5%. The tolerances are expressed in metres and are both positive and negative (for example:0.10= +/-0.10 metre);
- The values above are indicative and depend upon, amongst others, the equipment aboard;
- The values above are the sum of the inaccuracies in construction and measurement, the inaccuracies of measurement can be an order of magnitude smaller than those during construction;
- "bulk" is for bulk products, where a higher priority is assigned to the production level than to accuracy;
- "max" is for maximum effort, with a higher priority assigned to accuracy and production is sacrified in the interests of accuracy;
- Maximum effort is a relative term. It is always possible with yet more effort to reach a result that is even better.

Table 3. "Practical achievable vertical accuracies in meters of various dredging equipment for different bed types and working circumstances" IADC (2001) (Source: IADC 2001)

Table 1 (EPA 2005) indicates that the vertical dredging accuracy of a clamshell dredge in an environmental dredging project is 15 cm (0.5 ft). Table 2 (EPA 1994) indicates that the vertical dredging accuracy of a clamshell dredge is 60 cm (2 ft). Table 3 (IADC 2001) lists the bulk construction accuracy of a "crane/pontoon" dredge in clay with currents and deeper water as ±2.6 ft (0.6 m (2 ft), plus 0.1 m (0.3 ft) for currents ranging from 0.5 - 1.0 m/s (1.0 - 2.0 knots), plus 0.1 m (0.3 ft) for water depths exceeding 30 ft. For the maximum effort project (max i.e., an environmental dredging project) the construction accuracy total (plus current and depth supplements) is ±1.8 ft.

A technical literature search by Scott et al. (2002) reports that the only one reference was found that verifies the tolerance of (environmental) clamshell dredging. This was a study conducted by ETV Canada using a Cable Arm environmental clamshell bucket. This bucket produces a level cut, as opposed to the "scalloped" cut of a conventional clamshell bucket. The report verified that dredging with an environmental clamshell bucket can "produce a sediment-surface profile with an average depth which has a maximum deviation of ± 20 cm (± 0.67 ft) from the specified depth for the project 95% of the time" Water Technology International Corporation (1998). Factors that may degrade the clamshell dredging tolerances include (Scott et al. 2002):

· "'the presence of debris, preventing full closure of the bucket;
· high tide range, causing the operator to chase the resulting high rate of water level change per unit time;
· high waves, wakes, and currents, causing the bucket to sway and bounce and the barge to heave, pitch, and roll;
· scalloped and uneven cut of the bucket cutting edge during closure;
· stretch and wear of bucket lines;
· inaccurate dredge positioning; and
· accuracy of cable markings and rounding of depth marks during dredging."

Bucket (Backhoe) Dredge

Table 1 (EPA 2005) indicates that the vertical dredging accuracy of an articulated mechanical (backhoe) dredge in an environmental dredging project is 10 cm (0.3 ft). Table 2 (EPA 1994) indicates that the vertical dredging accuracy of a backhoe dredge is 30 cm (1 ft). Table 3 (IADC 2001) lists the bulk construction accuracy of a hydraulic crane backhoe dredge in clay with currents and deeper water as ±2.2 ft (0.5 m (1.6 ft), plus 0.1 m (0.3 ft) for currents ranging from 0.5 - 1.0 m/s (1.0 - 2.0 knots), plus 0.1 m (0.3 ft) for water depths exceeding 30 ft. For the maximum effort project (max i.e., an environmental dredging project) the construction accuracy total (plus current and depth supplements) is ±1.75 ft.

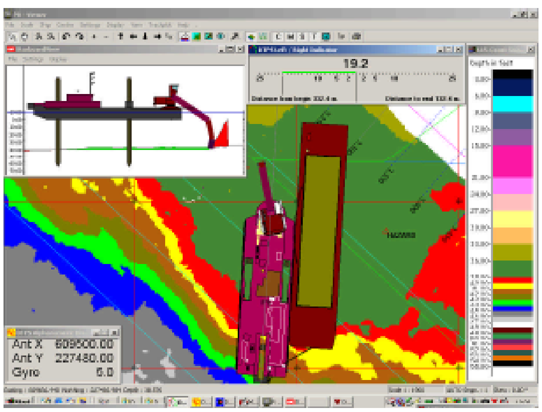
Similar to the DPM for cutterhead dredges, IHC has a positioning system for the backhoe dredge, called the Excavator Position Monitor (XPM). The following

Figure 1 describes the XPM onboard Great Lakes Dredge and Dock's dredge New York that an overall accuracy of < 10 cm (0.3 ft) is claimed (Mallee 2002).

Excavator "New York" work in progress

Recently, one of the largest excavators (LIEBHERR 996) on pontoon called " New York" owned by Great Lakes (U.S.A.) is equipped with a new Excavator Position Monitor (XPM) and the latest upgraded Dredge Track Presentation System.

IHC Systems has recently provided upgrades for the eXcavator Position Monitor (XPM) and Dredge Track Presentation System.
The DTPS system is extended with a conversion from standard metric values into feet's and fathoms. These overall systems, together with the owner supplied RTK positioning system, makes it possible to handle jobs with an overall accuracy of < 10 cm.



The DTPS system shows on-line the excavator in the Digital Terrain Model (DTM) with contours. The DTM or Bathymetric view with geographical co-ordinates can be rotated on-line by the operator and is also capable to store default views. The alphanumeric window shows all relevant data. The DTPS systems communicate bi-directional with the XPM. All XPM sensor data is converted to absolute position data and transferred back to the XPM.

The channel design with objects will be triangulated (max 300 triangles) and transferred on request to the XPM. The depth matrix of the working area will be continuously updated with bucket/clamshell dredge depth positions. The operator is able to see positions to be dredged, positions where dredging took be place or where digging is stopped. The DTPS system stores all time tagged data, such as RTK positions, gyro, bucket depth, angles, downtime and conversions. With the help of the replay function, the operator is able the make a scaled DTM and Bathymetric plots on a standard colour printer.

Figure 1. XPM onboard Great Lakes Dredge and Dock's dredge New York (Source Mallee 2002)

As per personnel communication with Ruud Ouwerkerk of Dredging Technology Corporation, the following U.S. backhoe dredges have an IHC XPM or IHC XPM Next Generation (NG):

XPM:
a. Great Lakes : NEW YORK (Liebherr 996)
b. Jay Cashman: A.J.FOURNIER (Liebherr 994)

XPM NG
c. Donjon Marine, Inc - J.R.BOISSEAU (Liebherr 995)
d. Jay Cashman: JAY CASHMAN (Liebherr 995)
e. J.E.McAmis, Inc - RENEE MEEGAN (Komatsu 3000)

In 1999, the EPA, USACE, and Foster Wheeler performed preliminary and detailed evaluations of current, available dredge technologies to meet the specific requirements of the full scale remediation project at the New Bedford Harbor Superfund Site. They decided to perform a Pre-Design Field Test (PDFT) of dredging systems that show potential for application on the New Bedford full scale cleanup, to acquire performance values for use in the final remediation design, and to select the final dredge system(s) to be used on the full scale cleanup (Lally and Ikalainen 2000). Dredging depths ranged from 1 to 5 ft deep.

"Bean Technical Excavation Corporation (Bean TEC) mechanical dredge Bonacavora with a 4.5 yd^3 horizontal grab bucket was trialed. This dredge used a Crane Monitoring System (CMS). The CMS, coupled with the RTK system provides bucket positioning in the x, y, and z planes.,,,,,, Over the course of the PDFT, the representative average production rate for the excavator was 80 cy/hr.,,,,,,,, Evaluation of dredging accuracy was carried out based on comparison of the post-dredge survey with the target depths. For dredge Cuts 5, 6, 7 and 8, where accuracy was a focus, 95% of the dredge area was within 6 in. of the target depth. In 90% of the dredge area the average vertical dredging accuracy was most nearly 4 in" Lally and Ikalainen (2000).

On Bean Dredging's website http://www.cfbean.com/beanenvi/defaultcont.htm it states that "using advanced positioning and control systems, Bean Environmental dredges can excavate material to vertical tolerances of 0.1 meters, or about 3 inches."

Summary

The various vertical dredging accuracies for cutterhead, clamshell, and backhoe dredges identified in this DOTS request are compiled in Table 4. As previously presented, the definition of vertical accuracy is very important in how the respective values are considered and applied. The different sources identified in this DOTS response have reported vertical accuracy in different ways (i.e., plus/minus ($\pm$) a value or in absolute numbers, incorporation of survey accuracies, etc.). Where possible, the specific accuracy definitions from these various sources were presented in this report.

While the amount of material disturbance below desired depth (to achieve that desired depth) will be a factor in determining contract specifications, it was not specifically considered under this DOTS request (two separate DOTS requests addressing this issue that were previously prepared for SAS and SPD are included in this response as appendices 1 and 2). One of the differences between navigation and environmental dredging is the relative shift in focus from production to increased accuracy to reduce the amount of un-necessary sediment being treated and/or disposed. A critical decision in these types of projects is to determine the allowed over depth that the contractor can dig to in order to achieve final grade, because, after a certain minimum distance, the closer that the grade and allowable over depth lines are together, the more the contractor has to expend time and energy to meet these contract specifications (and its respective impacts on production and cost). Reducing the over dredge allowance tends to slow production rates and increase the time and cost to complete the dredging project (Scott et al. 2002).

Some of the lowest dredging accuracies (or largest inaccuracies) are presented by IADC (2001). These values are construction accuracies that include both construction and surveying inaccuracies. The values provided by IADC (2001), USACE 1983, EPA (2005), EPA 1994, and the various individuals cited in this report are all presented with numerous caveats. These values should be viewed as general information as there are many site-specific, sediment-specific, and project-specific circumstances that will indicate which equipment is most appropriate for any given situation, and each equipment type can be applied in different ways to adapt to site and sediment conditions (EPA 2005).
The range in accuracy values in Table 4 is, in part, due to the difference of accuracy emphasis (and respective dredging costs) between navigation and environmental dredging. During environmental dredging, additional time must be allowed for other factors, such as greater precision of cut (EPA 1994). Some of the quoted accuracies were also obtained in relatively shallow (1 to 5 ft) quiet waters. IADC (2001) concluded from environmental dredging trials in the Ketelmeer Project that the inaccuracies become greater in the order of: reference inaccuracies, excavation mouth inaccuracies, then total construction inaccuracies.

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	USACE EM 1110-2-5025 1983	IADC 2001[1] Bulk[2] Depth and Current Corrected	IADC 2001[1] MAX[3] Depth and Current Corrected	EPA 1994	EPA 2005	IHC 2005	Mallee 2002	Scott et al. 2002
Cutterhead Vertical Accuracy (ft)	$\pm$ 1.0	$\pm$1.75	$\pm$1.45	1.0	0.5	0.3		
Clamshell Vertical Accuracy (ft)	$\pm$ 1.0	$\pm$2.6	$\pm$2.25	2.0	0.5			$\pm$0.67
Backhoe Vertical Accuracy (ft)		$\pm$2.2	$\pm$1.75	1.0	0.3		<0.3	

Table 4. Compilation of various vertical excavation accuracies

[1] Includes construction and survey inaccuracies
[2] Bulk is for bulk products where a higher priority is assigned to the production level than to accuracy
[3] Max is for maximum effort, where a higher priority is assigned to accuracy, and production is sacrificed in the interests of accuracy

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