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IN THIS ISSUE

FEASIBILITY STUDIES FOR NAVIGATION PROJECTS EXECUTED BY NON-FEDERAL INTERESTS

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ABSTRACT

Non-federal interests, particularly port authorities, are coming under increasing pressure to shorten the project development cycle for major infrastructure improvements. Navigation projects have typically had the longest development times. Before 1986, non-Federal interests were not required to contribute to the development costs of such projects. Since 1986, they have been required to share in the cost. The need to shorten development times and the requirements to contribute a significant portion of the cost have pushed both non-Federal sponsors and the Corps of Engineers to pursue new, innovative ways of moving navigation projects forward.

This paper discusses an alternative that was created in 1986, but has not been widely used or understood. This alternative is referred to as a Section 203 Feasibility Study, a name taken from the section of the Water Resources Development Act of 1986 (WRDA 86), the same act which instituted cost-sharing with non-Federal sponsors.

INTRODUCTION

The maritime industry is demanding faster planning and construction timeframes to remain competitive. In response to these demands, Congress created a tool that ports can use to accelerate the planning process for navigation project development. The passage of PL 99-662, Water Resources Development Act of 1986 (WRDA 86), created a valuable tool for both non-Federal sponsors of navigation projects and the U.S. Army Corps of Engineers (Corps). Section 203 of WRDA 86 changed the project development landscape significantly by providing that a non-Federal interest (typically, a Port Authority) may on its own undertake a feasibility study of a proposed navigation project and submit the study report to the Secretary of the Army, represented by the Assistant Secretary of the Army (Civil Works) – ASA (CW). This approach allows a project to move forward quickly, even in an era of personnel cutbacks and budgetary constraints for the Corps.

Traditionally, U.S. Army Corps of Engineers (Corps) District Offices have performed all reconnaissance and feasibility studies for navigation projects. Prior to 1986, non-Federal interests were not required to contribute to the cost of these studies or the works that resulted from them. These projects were "government" projects and the non-Federal interest left the design, construction, maintenance, and funding up to the Corps. WRDA 86 required that non-Federal interests participate in the costs of the studies, construction, and maintenance of federal navigation projects. Now non-Federal interests pay 50% of feasibility study costs and

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approximately 35% of most navigation project construction costs. At the same time, competitive pressures to improve port infrastructure and expand capacity have increased exponentially. Non-Federal interests and project proponents now have reason to be concerned about the cost, timing, and duration of studies and construction projects.

This paper examines how the Section 203 Feasibility Study process works and the rationale for a non-Federal interest to pursue this approach.

ALTERNATIVE STUDY SCENARIOS

Although there are many scenarios under which a Feasibility Study can be executed, they fall into three groupings.

Traditional Approach

Under the "traditional approach", all of the project management and study development activities remain with the Corps of Engineers District Office. Under this approach, the Corps coordinates with the non-Federal interest, but the study is a Corps study. While the non-Federal interest must prove its ability to pay 50% of the total study costs prior to initiation of study activities, it actually pays its 50% in increments as the study progresses. This pattern has been the predominant pattern even after the passage of WRDA 86.

Section 203 Feasibility Study Approach

This scenario is the subject of this paper and will be explained in greater detail in subsequent sections. To summarize, the non-Federal interest takes responsibility for all study activities and funds the entire cost of the study. The non-Federal interest is eligible for a credit of 50% of the study cost during subsequent phases of the project if Congress approves and authorizes the project based on the study report. Under this scenario, any amount the non-Federal interest pays over and above the fifty percent required in the first scenario is an additional risk. However, by reducing the total project cost, the risk is significantly less than 50% of the project cost that would be incurred under the first scenario. It should also be noted that before a feasibility study is conducted, the Corps performs a reconnaissance study that determines if there is a Federal interest in the project and how the projected benefits are expected to compare to the projected costs. The reconnaissance study allows the non-Federal sponsor to assess the likelihood of a successful outcome for the feasibility study.

Project costs and the time to complete can be reduced because the non-Federal interest—with a dedicated Project Team--can react and adjust to changing project conditions more quickly and cost-effectively than the Federal government can—local control will allow for quicker execution. However, coordination with the Corps and involvement by Corps technical personnel are still critical determinants of a study's success.

Three port authorities have successfully executed Section 203 feasibility studies: Georgia Port Authority (Savannah), Los Angeles, and Oakland. A fourth project, Cedar Bayou, TX, initiated a Section 203 feasibility study but obtained Congressional authorization of the project before the study was completed, thereby making a formal Section 203 report unnecessary. The lessons learned in these efforts are incorporated into this paper.

In-kind Work Approach (for Portions of the Study)

Federal regulations allow for one-half of the non-Federal interest's share (25% of the total study costs) to be contributed "in-kind". In most situations, the tasks performed by a non-Federal interest can be accomplished at a lesser cost than if they were executed by the Federal government, thereby reducing the overall budget. In addition to a potential cost advantage, the non-Federal interest can provide expertise the Corps may not have and it can exercise significant control over or input into critical segments of the study effort. This scenario may be preferable when the non-Federal interest wishes to be more actively involved in the project, but may be uncomfortable with the political support it has or its ability to fund and staff a major study effort.

REGULATORY REQUIREMENTS FOR THE STUDY

While WRDA 86 imposed cost-sharing requirements on the non-Federal interest, it also allowed the non-Federal interest to conduct its own feasibility study in-house. These studies will be reviewed by the Corps to ensure compliance with Federal laws and regulations applicable to navigation project feasibility studies. The non-Federal interest pays for the study up front and, if the study is approved and the project is authorized by Congress and proceeds to construction, receives credit for 50% of allowable study costs during the construction phase of the project.

The requirements for the study report are specified in Corps regulation ER 1165-2-122 (Studies of Harbor or Inland Harbor Projects by Non-Federal Interests), the regulation which implements Section 203 of WRDA 86. Each of the report elements has very specific content and procedural requirements that must be met. The final report must be approved by the Assistant Secretary of the Army (Civil Works) before it can be forwarded to Congress. The following subsections summarize the requirements found in ER 1165-2-122.

Report Contents

At an absolute minimum, the report must contain the following:

Statement of the Problem(s). The report must describe the need for the project and the key assumptions underlying the predicted "without project" conditions.

Description of Alternatives. The study must develop all reasonable project alternatives which provide full or partial relief to the problems identified in the Statement of the Problem. Alternatives must provide information on: 1) the Federal portion of the project; 2) the non-Federal portion of the project (facilities to serve vessels and commerce needed to achieve the benefits of a navigation project, as well as lands, easements, rights-of-way, relocations and dredge material disposal areas (LERRD)); and 3) non-commercial navigational features. Features of a proposed project which are intended for uses other than commercial navigation may be cost-shared differently from general commercial navigation features.

Public Involvement and Coordination. Non-Federal studies will be evaluated in part on the degree to which the study process complied with the general policy of the Corps that openness and pubic involvement are key elements of the process.

Economic Analysis. The economic analysis should be consistent with the economic standards contained in the Water Resources Council's Economic and Environmental Principles and Guidelines (P&G) for Water and Related Land Resources Implementation Studies, March 10, 1983. Furthermore, the recommended alternative must be consistent with protecting the nation's environment. Typically, the plan with the greatest net economic benefit (benefits minus costs) consistent with protecting the nation's environment is the preferred plan. Corps regulation ER 1105-2-100 (Planning Guidance Notebook) clearly defines benefits and costs and how they are to be evaluated.

Environmental Analysis. Studies must comply with the requirements of the National Environmental Policy Act (NEPA) process and other Federal, State, and local laws and regulations as set forth in ER 200-2-2 (Procedures for Implementing NEPA) and ER 1105-2-100. Mitigation measures are to be formulated and evaluated incrementally. The non-Federal interest must document coordination and consultation with concerned Federal and State agencies on mitigation, ecological, cultural, and historical preservation matters.

Study Conclusions and Recommendations. The study must recommend a plan. If it is not the plan with the greatest net economic benefit, the basis for the deviation should be documented and justified.

Procedural Issues

Non-federal interests conducting a Section 203 Feasibility Study must develop all the documentation necessary to assess the existing environmental conditions, assess any potential impacts of the proposed project, and evaluate reasonable alternatives. The non-Federal interest must submit a draft Environmental Assessment (EA) or Environmental Impact Statement (EIS). Once the Assistant Secretary of the Army for Civil Works determines no additional information, studies, or public involvement are necessary, the Corps will circulate a draft EIS or EA to other agencies, organizations, and the public for review and comment. The final document will be filed with the Environmental Protection Agency (EPA) or a Finding of No Significant Impact (FONSI) will be made available to the public.

If, during the course of the study, the non-Federal interest comes up against issues or questions not clearly addressed in the Corps' regulations, it may request study guidance from the District or the ASA (CW) representative. Non-federal interests are also encouraged to meet periodically with District personnel to discuss the progress and status of the study effort.

The Corps is required by law to submit to Congress an analysis of the study report within 180 days of receipt of the report. Within 15 days of receipt of a Section 203 Study report, the Corps will transmit information regarding the project proposal, a draft EIS, and related documents to State and Federal agencies for comment, as well as to designated addressees for information. The notice will request that comments be submitted within 30 days. The draft EIS is filed with EPA.

The Corps will furnish a preliminary analysis of the study report to the non-Federal interest within 120 days of receipt of the report. At any time, the non-Federal interest may request deferral of further report processing and return of the report for revisions or other actions. If the non-Federal interest resubmits the report, it will be treated as a new report.

Funding

The non-Federal interest is responsible for funding all study costs except for Corps review, coordination, and processing of the report and NEPA documents. If the project is subsequently authorized and constructed, the non-Federal interest is eligible for credit of one-half of the actual costs, as long as such amount does not exceed the amount that would have been incurred had the Corps conducted the study.

RATIONALE FOR UNDERTAKING STUDY EFFORT

The funding scheme required by the regulations calls for the non-Federal interest to bear the risk of the project investment. The non-Federal interest will receive credit for 50% of the study costs IF the project is authorized by Congress upon recommendation of the Corps and then moves to construction. This implies that if the Corps refuses to provide a favorable recommendation, or if for political reasons Congress refuses to authorize the project, the non-Federal interest will have to pay 100% of the study costs. However, as mentioned earlier, prior to the feasibility study phase of a project, the Corps performs a reconnaissance study that determines if there is a Federal interest in the project and how the projected benefits are expected to compare to the projected costs. The reconnaissance study allows the non-Federal sponsor to assess the likelihood of a successful outcome for the feasibility study.

So why take the risk? To answer this question, the author reviewed documentation and interviewed project representatives from three major navigation projects which have adhered to the Section 203 Feasibility Study procedure: Los Angeles, Oakland, and Savannah. Legislation and regulations were also reviewed and analyzed. In addition to these three ports, the author has also held discussions with several others that are seriously considering the Section 203 process. Here are the main reasons for implementing a Section 203 study process:

Shorten the time frame - This is without a doubt the primary issue. Market opportunities are time-sensitive and can disappear forever after a certain window of opportunity closes. The non-Federal interest has the ability to dedicate resources full-time to the project and does not have many of the bureaucratic restrictions that are always going to be found in larger organizations such as the Corps of Engineers, especially in the area of the funding process. Furthermore, the Corps is being forced to cut back on the number of personnel available to conduct these important studies. The Corps' timetable can be uncertain due to priorities and funding issues in a given fiscal year. A non-Federal interest can make it a top priority throughout the life of the project.

This being said, it is important to note that Section 203 activities only deal with the concept of compressing the time frame for the study phase of a project—not the construction schedule. The construction schedule developed by the Corps of Engineers will determine the completion date for the project, regardless of the study approach used. The possibility exists for a non-Federal sponsor to construct the project using its own funds and then seek reimbursement, but this process—known as a Section 204 project—is complicated and is applicable only to a very narrow set of circumstances. The discussion of a Section 204 project is outside the scope of this paper.

Decrease overall study costs – Because the non-Federal interest can move quickly and can eliminate many overhead cost items that the Corps must contend with, study costs can be reduced by a considerable percentage (by some estimates, up to 35%).

Increase control – Many project sponsors would like to have more control over the study agenda, the schedule, and how the public involvement process is carried out, especially with regard to difficult environmental issues. Managing the study in-house allows a non-Federal interest to have this control. Furthermore, the non-Federal interest can work with interested parties in ways that the Corps cannot, which increases the opportunity to develop innovative solutions to very difficult problems (e.g., coalition building and technical interaction).

Other important reasons – Decrease uncertainty regarding funding flows and scheduling.

- Bring expertise to the project that the Corps may not have.
- Have more say in the project definition and project alternatives analysis.
- Innovative solutions can save millions in construction costs, whether for the project itself or for mitigation.

In a letter dated March 12, 1997, Major General Russell L. Fuhrman, former Director of Civil Works, U.S. Army, summarized the advantages of the Section 203 Study process. In a letter to the Georgia Ports Authority he stated, "We see several advantages to this approach including decreasing overall study costs, shortening the project development schedule and sponsor participation in the management of the study. These are goals we are striving toward in all our studies."

Role of the Corps

What role would the Corps play in such a process? *A very significant one.* Most importantly, the Corps must approve the final product and make a recommendation to Congress. Additionally, non-Federal interests have found it very useful to contract with the Corps for the Corps to provide assistance in certain areas of expertise the District office may have built up over the years. For example, the Savannah District Office provided engineering, cultural resources, and real estate input to the study. In Los Angeles, the non-Federal interest hired the Corps to do the economic analysis, provide environmental support, and prepare cost estimates. In Oakland, Corps personnel performed a significant portion of the economic benefit analysis, especially forecasts and cost estimating. In addition to technical expertise, District personnel can assist the non-Federal interest in being sure that procedural requirements are being met so as not to have to re-work any portion of the project. In short, this is a very important partnering situation in which the non-Federal interest manages the project, but still relies on the Corps for important segments of the work.

IMPORTANT PREREQUISITES FOR SUCCESSFUL SECTION 203 STUDIES

What should a non-Federal interest do if it finds this study process appealing? It is a fairly simple procedure:

- ***Make sure it has political consensus.*** Involve elected officials who have a say in what happens to the port, including U.S. Representatives and Senators. Make sure there is some sense of agreement that this is what the non-Federal interest should be doing.

- ***Make sure it has the funds available at the outset.*** Remember, one of the reasons to do the project in-house is to have assurance that funding will be available when needed.

- ***Put the study team together.*** Few port organizations can manage a study of this magnitude and move it along at a steady pace without outside assistance. It makes sense to bring together a consulting team that can push the project full-time and then disband when the study is completed.

- ***Advise the Corps of its intentions at the earliest possible date.*** The Corps is required to consult with the Chairman of the Senate and House Appropriations committees prior to entering into any agreements that potentially commit Congress to provide construction funds in the future. Furthermore, the Corps is limited to $10 million in credits and reimbursements for any given project in a fiscal year, and must not exceed $50 million in credits and reimbursements for all applicable projects in a fiscal year. Reimbursements for the Federal portion of Section 203 feasibility studies are included in these limits. The sponsor needs to notify the Corps of its intentions at the earliest possible date in order to assess the impacts these limits might have on its proposal.

- ***Work out the non-Federal interest/Corps relationship.*** It will be necessary for the non-Federal interest and the Corps to execute a Memorandum of Understanding specifying what each party is expected to do and the manner in which coordination of activities will take place.

SUMMARY

The Section 203 study mechanism is a valuable tool for non-Federal interests desiring to exert more control over the timing, cost, and/or focus of a navigation project feasibility study. It requires the dedication of significant resources over a period of years, but it can indeed result in significant benefits to the non-Federal interest. However, these projects are not without risk the non-Federal interest will be forced to pay 100% of the study cost if either the Corps or Congress does not approve of the report and the subject project. While this 100% amount will most likely be less than the total amount would otherwise have been, it will still be more than the traditional 50%. The non-Federal interest must gauge both the political support it enjoys and the cooperation it will obtain from the Corps in assessing the risk/rewards of a given study effort.

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DEEP OCEAN RELOCATION OF DREDGED MATERIAL: CONTAINMENT, TRANSPORTING, AND EMPLACEMENT

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ABSTRACT

This paper describes a system to dredge contaminated sediments, load containers, transport them to a deep ocean site, and ensure safe descent of the containers to the abyssal seafloor. Theoretical and modeling results describe the shape, orientation and trajectory of the sediment-filled geosynthetic fabric containers in falling 5000 m through the water column.

INTRODUCTION

This paper summarizes a portion of the results of a two-year study of the option of isolating contaminated dredged material on the abyssal seafloor. We focus on the technical aspects of containing, transporting, and placing the material. Our intent is to inform practitioners in the dredging industry about some of the novel technical concepts developed in this study, particularly the use of free-fall of geosynthetic fabric containers for material placement and isolation. Study results of physical, chemical, and biological impacts and cost projections of the dredged material placement in the abyssal environment are reported elsewhere (Young and Valent 1996, 1997; Valent and Young 1997, 1998) as well as a comprehensive review of sensors and techniques that could be used to detect and monitor possible contaminant leakage from such an abyssal site (Valent et al. 2001).

In the Strategic Environmental Research and Development Program Element of the 1993 Department of Defense (DoD) Appropriation Bill, the Congress directed the implementation of a "study of the advantages, disadvantages, and economic viability of storing industrial waste (defined as sewage sludge, fly ash from municipal incinerators, and contaminated dredged material) in the abyssal plains of the ocean floor." Please note, the DoD was asked to assess only the technical feasibility and environmental impact of deep ocean relocation and isolation. The

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DoD was neither asked to assess the acceptability of the deep ocean isolation concept with regard to U.S. Laws and international agreements, such as presented by the London Dumping Convention, nor was DoD asked to compare socio-economic impacts of the concept with those of other waste management options.

This work builds on a 1991 study by the Woods Hole Oceanographic Institution (WHOI) (Spencer 1991) and the Massachusetts Institute of Technology (MIT) (Chryssostomidis 1991) addressing the deep ocean option for disposal of various waste materials, including contaminated dredged material. That study concluded that it was potentially possible, without detriment to humans and their environment, to dispose of sewage sludge from municipal treatment plants, fly ash from municipal incinerators, and contaminated dredged material by emplacement of these materials on the abyssal seafloor. The WHOI-MIT workshop participants did allow that many technical and environmentally related questions required answering before proceeding with the abyssal seafloor waste management option.

THE ENGINEERING CONCEPT

Concept of Operation

The engineering concept is divided into four functional areas: dredging, transfer and loading, transportation, and placement (Fig. 1). Design of the dredging, transfer, and loading systems sought (1) to minimize water added to the dredged material during these processes, (2) to accommodate the majority of the dredging sites in the U.S., and (3) to reduce operational costs and environmental impacts. The bulk wet density of dredged material was specified as ranging from 1.4 to 1.7 Mg/m^3.

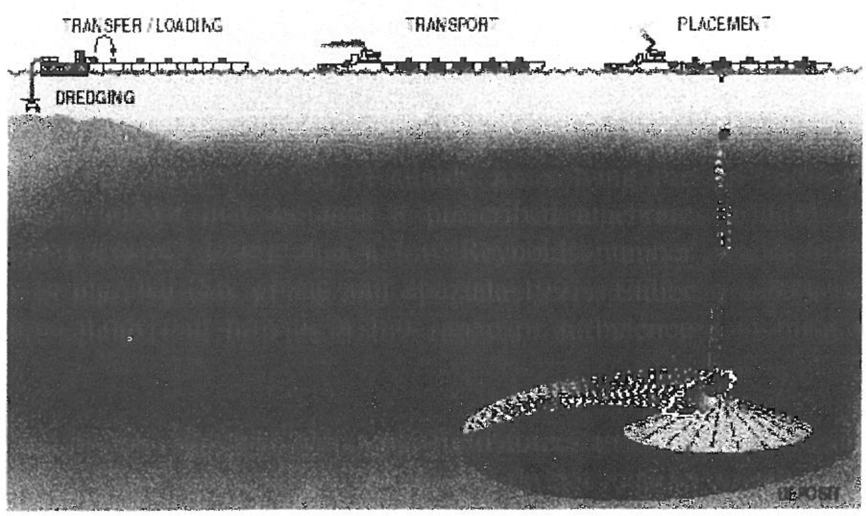

Figure 1. SimDor systems engineering concept

Dredging, Transfer, and Loading

A clamshell dredge system was selected among various clean dredge systems because of its capability to dredge with minimal water added to the material, to minimize leakage of dredged material and for greater flexibility in debris handling. The dredger system uses two 4-m^3 (5-yd^3) closed clamshell dredges, each capable of dredging 150 m^3/hr, working side-by-side on a dredging platform (Fig. 2). The dredging platform is a modified barge platform with a central storage hopper bin for short term sediment storage of up to 300 m^3 during dredged material transfer. At the base of the storage hopper in the dredging platform, two augers (one per hopper) transfer the material into the transfer hopper. The transfer hopper is the first hopper in the distribution series and serves in transferring the sediment from the dredging platform to the transporter vessel. The hoppers in the distribution series are over-sized to accommodate a buildup of material in the event of equipment malfunction. Dredged material is transferred by the auger system from the distribution hoppers into geosynthetic fabric containers (GFCs), one GFC in each of the cargo cells. The auger system has the maximum capability of transporting dredged material at a rate of 450 m^3/hr. The time required to fill the transporter, based on one dredge clamshell operating at 150 m^3/hr, is 81 hr.

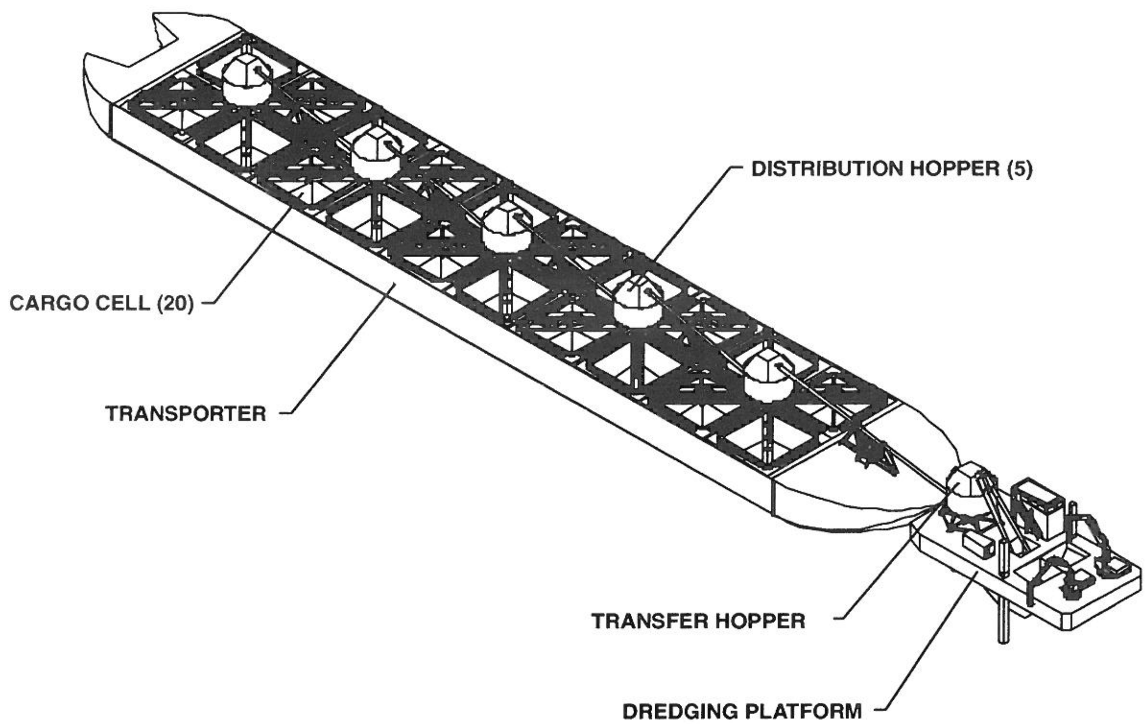

Figure 2. Schematic of dredging platform and transporter coupled for dredged material transfer and loading, oblique view.

Transport and Placement

The transporter concept selected is an integrated tug-barge (ITB) (Fig. 1) because its lower overall hydrodynamic drag offers higher average speeds, better control, efficient operation over a wide range of sea states, and better fuel economy when compared to other transport configurations. Transport of containerized dredged material from the Port of New York 850 naut. mi to a candidate disposal site at 10 kt average, release of material at the site, return, replenishment, and fueling would take 8 days. The barge contains a 10 x 2 array of cargo cells for transporting 19000 DWT (between 10,000-12,000 m^3 (13,000-16,000 yd^3)) of dredged material (Fig. 2). Each cargo cell has an inner compartment with bottom trap doors for releasing the containerized dredged material.

Structural Configuration of Transporter. The overall dimensions of the transporter barge are 241-m (790-ft) length, 32-m (106-ft) beam, and 5.5-m (18-ft) draft. The amount of freeboard added is based on the structural strength required for maintaining seakeeping while minimizing "*green water*" on deck, i.e., wave flooding of the deck and potential significant flooding below decks. The cargo cells make up 171 m (561 ft) of the midbody. The bow length is 18 m (60 ft) and the stern length is 21 m (67 ft) transitioning the parallel midbody to a ship configuration capable of traveling at a desired sustained speed of 12 knots. An integrated connection system, such as the Intercom (system, using a single degree of freedom connection, would allow free relative pitch motion. The connection is operable in sea states up to 5; threat of sea state 6 conditions would require disconnecting the tug and transporter and changing to a towed barge configuration.

Physics-Based Simulation of Transporter Design and Seakeeping. Seakeeping analysis was performed using the Ship Motion Program (SMP), a linear strip theory model developed by Dr. Nils Salvensen (1970). The transporter performance was evaluated for sea state 5 and sea state 8. In this preliminary analysis, the barge was evaluated independently of the tug, since the tug (being small in size compared to the barge) will have little influence on barge motions. The seakeeping calculation was performed for long-crested (undirectional) head seas. The analysis for sea state 8 predicted that the barge would be under green water given the design freeboard. The statistical results of the seakeeping simulations are presented in Table 1.

Table 1 — Seakeeping Simulation Results

PARAMETER	RESULTS	
Sea State	5	8
Significant Wave Height, m (ft)	3.11 (10.2)	15.6 (51)
Modal Period, sec	7	16
Significant Pitch, deg	0.25	5.9
Significant Heave, m (ft)	0.15 (0.48)	3.83 (12.6)

Two factors contribute to the large difference in transporter performance in these two sea states: (1) the energy in sea state 8 is much greater than in sea state 5, and (2) as wave heights increase, the energy is more concentrated at the low frequencies where this large, heavy vessel responds.

Compartment Design. Each cargo compartment is 12 m (40 ft) long by 12 m (40 ft) wide by 6 m (20 ft) deep, containing 500-620 m^3 (660-800 yd^3) of dredged material. The compartment bottom door design utilizes two doors configured similar to a typical split hull barge. The doors are held shut with a locking mechanism and a secondary hydraulic support system while in transit. The weight of the dredged material aids the opening of the doors.

The design requirements set for the release of the containerized dredged material aim at releasing the material quickly with minimal physical restrictions and stresses on the geosynthetic fabric container (GFC). The stresses on the container during release include: pressure of the dredged material against the compartment walls, frictional stresses between the container fabric and the compartment wall, hydrodynamic drag against the water, tension stresses owing to physical deformation of the container because of obstacles, and stresses due to the weight of the dredged material on the container and bottom doors. The stresses in the fabric were reduced: (1) by incorporating a freely flooded compartment; (2) fast, fully opening compartment doors; and (3) low friction, high density polyethylene (delrin) liners on compartment walls.

Dredged Material Container. Rupture of the container fabric and/or seams is believed to be the highest risk factor in the engineering concept. Since the fabric seams normally offer lower tearing strengths than virgin fabric, the container design/construction should minimize the number and length of seams. The recommended shape for the geosynthetic fabric containers (GFCs) is a spherical or ellipsoidal "pill-shape."

To avoid the possibility of container fabric floating to the sea surface if a container should rupture and tear at the seafloor, the specific gravity of the material should be greater than that of water. GFCs are currently made from polyester woven fabric with a specific gravity (S.G.) of approximately 1.3. Containers can be constructed using an outer permeable GFC with an inner impermeable polypropylene liner material (S.G. $\cong$ 0.91). Information on the use of GFCs to contain dredged material can be found in Fowler (1995) and Fowler et al. (1994, 1995). A summary of predicted polyester fabric performance in the abyssal ocean environment is reported by Valent and Young (1995, Sec. 1.4.2).

GFC DYNAMICS DURING RELEASE, FALL, AND IMPACT

Background

Sediment-filled GFCs have been placed from bottom-dump hopper barges in the Netherlands for coastal construction (Ockels 1991), in the U.S. for groin construction for channelizing river flow, and for containment of contaminated dredged materials (Fairweather 1995, Mesa 1995). To date, the GFCs have been dropped in water depth less than 30 m and are known to have experienced rupture or tearing problems during transport in hopper barges, release from barges, or impact on the bottom. The relocation of contaminated dredged material to the abyssal seafloor poses a problem of considerably different magnitude in that the filled GFCs will be free-falling through 5000 — 6000 m of water column over a time duration approaching 10 min and may impact on the seafloor at terminal velocities considerably higher than the 5 m/sec noted to date. Extrapolating from the behavior of rain drops falling in air (Green 1975, 1976), the GFCs during free-fall are predicted to assume the shape of an oblate spheroid flattened in the vertical direction. Further, dynamic forces acting on the GFCs will cause changes of shape and redistribution of stresses that could exceed limits of the GFC fabric. Vortex shedding during free-fall is expected to cause second-order shape changes of the GFC, particularly near the periphery. These shape changes, coupled with the vortex shedding, could result in significant tilt of the GFC from the vertical and accompanying lateral skating of the GFC as it free-falls. This lateral skating could result in considerable deviation of the GFC from its ideal free-fall path, resulting in a larger disposal mound than the 3000-m diameter size estimated in Valent and Young (1995).

Analyses of the GFC dynamics during release from the transporter, free-fall through the water column, and impact on the abyssal seafloor were conducted with finite difference codes. Closed-form solutions of the free-fall portion of the analyses were performed to better understand and validate the free-fall finite-difference model.

Release of GFCs from Cargo Compartment

The simulation code used in modeling of GFC release from the cargo compartments is a discrete element code used by Palmerton (1996) of the U.S. Army Waterways Experiment Station (WES) for simulations of containerized dredged material release from split hull barges. The Fortran code "nydrop.f" had been used for previous calculations by WES in support of demonstrations of the use of GFCs for shallow water applications. Code predictions of container fabric stresses and container fall rates have been validated by Dr. Palmerton against theory and field data from drops in shallow water for containers of fixed shape. The original Palmerton model was designed for use in a quiescent water column with an added capability for regions of constant current. It was assumed that motions of the GFC and contents would be governed by constant drag coefficients, and there was no provision to couple in externally supplied forces in dynamic calculations of the GFC motion. For releases in shallow water, where GFC lengths were on the same order as the water depth, these approximations were reasonable and could be bounded by experimentally derived error bars. For the calculations of bag descent and impact at abyssal depths, the external forces experienced by each discrete element (disks in the model) comprising the GFC wall would be different, and the resultant unsteady GFC shape changes and unsteady motions would be important factors in being able to determine the descent path of the GFC as well as the stresses experienced in the GFC wall. Therefore, modifications of the Palmerton code were necessary to provide the new unsteady forces at each timestep to each of the discrete elements comprising the GFC wall and contents. Iterations continued until a new GFC shape was achieved, and the new shape and position of the GFC were given as inputs to the gridding routines prior to the calculation of the new hydrodynamic forces.

The Palmerton model was modified to include several new capabilities: (1) vary the geometry and rate of opening of cargo compartment bottom doors, thus enabling input of data directly from detailed CAD simulations; (2) impart an initial vertical velocity to the GFC and its contents at release to account for the cargo compartment lowering/drop during the GFC release phase, and to incorporate the heave, pitch, and roll of the transporter derived from seakeeping calculations; (3) provide for coupling the code to a hydrodynamic code for self-consistent calculation of the effect of the external flow on the GFC and its contents, including boundary layer formation, unsteady wake effects, and vortex shedding; (4) provide for coupling the GFC position and shape back to the automatic gridding codes for external hydrodynamics calculations; (5) provide for subiterating the Palmerton model in conjunction with the hydrodynamics codes; and (6) add output of the forces acting on the GFC and its contents for post processing, particularly for visualization of stresses in the GFC wall induced during release, descent, and impact. As part of the model modification, the IBM-specific WES code was converted to run on a SGI machine to permit incorporation into the overall DOR simulation capability. For details of the full coupling between the codes, see Valent and Young (1997).

Free-Fall of GFC to Seafloor

The development of a predictive model describing the free-fall descent of a GFC enclosing 300 to 800 m^3 of dredged material through 5000 m water column, without benefit of model or prototype performance data of applicable scale, was undertaken along two paths. Author Green applied a closed form analytical approach combined with empirical data used to set some critical parameters, while Fritts led a team applying a Reynolds-Averaged Navier-Stokes (RANS) solver to the problem.

<u>Closed-Form Solution for Simplified Shape for Free-Falling GFC</u>. The conceptual model for a dredged material-filled GFC is a fluid-filled membrane which has a shape determined by the local balances of hydrodynamic, hydrostatic and membrane forces. The 'real' case should take account of local force balances at all points on the container and the variability of these balances due to deformation of container by fluctuations in the turbulent wake. The pressure at the bottom flow separation zone will tend to flatten the container, and the shape will be roughly ellipsoidal, if there is sufficient membrane stress to keep the interior fluid mass intact. Further, it is known that the hydrodynamic pressure must equal the ambient far-field value somewhere between the base of the container and its trailing edge. The most basic assumption in this model is that the shape is an oblate ellipsoid; this is an approximation of the equilibrium shape of the GFC.

The following analysis is based on the assumption that the fluid-filled, flexible container is constrained to the shape of an oblate ellipsoid that is deformed by the hydrostatic forces. Measurements of the pressure distributions around oblate ellipsoidal bodies at high Reynolds numbers and terminal fall speed show that the pressure is near the far-field ambient value in the vicinity of the equator. For the case of a fluid-filled membrane, this allows an additional assumption: the hydrostatic force and intrinsic pressure force are balanced by a membrane tension force evaluated at the equator. The flattening of the ellipsoid increases the surface area and decreases height so that the internal hydrostatic pressure is balanced by the wall tension. The degree of flattening of the ellipsoid can be shown to be a function of the Bond number, $B = \sigma^{(-1)}\left(1 - \frac{\rho_w}{\rho_c}\right)\rho_c\, g\, a_0^2$, or more properly for the case of GFCs, a function of the bulk wet density of the GFC contents, ρ_c, where σ is the wall tension parameter, ρ_w is the density of the water surrounding the GFC, g is the acceleration of gravity, and a_0^2 is the radius of a sphere with volume equal to the ellipsoid. The Bond number is the critical parameter in determining the shapes of the bags. If equivalent spherical radii are in the range 4–7 m and the container contents bulk wet density ranges 1.4–1.7 Mg/m^3, then the Bond numbers will be ~ 0.33–3.69. Over that range of B, the axis ratio of the ellipsoid decreases from ~5/6 to ~1/2. The lower values of B indicate a relatively "tight form," but the upper extreme values could be marginal for wake-induced shape instabilities.

When a bluff body such as a GFC moves through a fluid rapidly enough that purely viscous forces are not significant [large Reynolds Number R= *(Length Scale of Body)* x *(Velocity through the Fluid) / (Kinematic Viscosity)*], the wake becomes unstable and a stream of vortices are shed behind the body. The rate of vortex shedding is represented by the Strouhal Number (S). Considerable data exist about the shedding frequencies behind a variety of rigid body shapes, but there is no comprehensive analytical (or numerical) model that can accurately approximate the dynamics for arbitrary body forms. Therefore, this analysis uses the compilation of empirical results in Hoerner (1965).

The results of the combination of Hoerner's empirical model with the hydrostatically deformed ellipsoid and terminal fall speed models are self-consistent. The interpretation is simple: (1) the higher the Bond number – the flatter the ellipsoid; (2) the flatter the ellipsoid – the slower it falls; (3) vortex shedding frequencies from low-tension, smaller ellipsoids are higher than larger, stiffer ones. The shedding frequencies range from about 0.2 Hz for a small (4.8 m equivalent radius), lower density (1.4 Mg/m^3), stiff (800 N/m) tension bag to 0.32 Hz with the flaccid, smaller bag with higher density (1.7 Mg/m^3).

These models do not take into account the fact that the dynamics of the flow will distort the flexible GFC into non-symmetrical shapes and that these deformations may drastically affect the flight trajectory of the body. Fortunately, if the GFCs are flaccid, off-axis hydrodynamic lift will tend to redistribute the materials in the bag. Modal oscillations are expected to have lower frequencies than the shedding frequency, so resonances would be unlikely. If the bag is too flaccid (very high Bond number), it will not be able to maintain a predictable form, since the restoring force of wall tension will be ineffective. Twisted or isolated lobe shapes could result. In such cases, local stresses could tear the bag – particularly at the time of bottom impact.

This analysis has been based on empirical formulae, an axi-symmetric body shape and an approximation of wall, dynamic and hydrostatic balance at a single latitude of the ellipsoid. The differential geometry of the system, even in this simplified case, produced highly nonlinear expressions that had to be approximated. These models do not take into account the fact that the dynamics of the flow will distort the container into non-symmetrical shapes and that these deformations may drastically affect the flight trajectory of the body. Fortunately, in the real case, the GFCs will not be too flaccid; consequently, non-symmetric off-axis hydrodynamic lift will tend to be redistributed by shifting of the materials in the GFC, wall tension and hydrostatic forces.

Finite-Analytic Reynolds-Averaged Navier-Stokes Solution for Free-Falling GFC. A successful GFC drop simulation scheme must accurately account for (at least) three highly complex fluid flow phenomena: GFC wall stress prediction, GFC trajectory predictions, and impact plume prediction. All three problems require solution of the complete, unsteady, turbulent flow around the GFC. Wall stress predictions require a local distribution of forces. Trajectory prediction requires unsteady integrated forces and moments caused by both attached boundary layers and separated turbulent wakes. Plume prediction requires the ultimate level of knowledge of flow, including the complete flow field description around a GFC as it impacts on the seafloor.

The minimum level of Computational Fluid Dynamics (CFD) technology capable of providing all the necessary information for turbulent, vortical flows is the class of Reynolds-Averaged Navier-Stokes (RANS) solvers. This section of the paper describes the adaptation and application of one such solver, the Finite-Analytic Navier-Stokes (FANS) system to the GFC free-fall problem. FANS is a proprietary, well-validated, three-dimensional, unsteady, incompressible RANS code applicable to a wide range of high-Reynolds number steady and unsteady flows (Korpus 1995, Chen and Korpus 1993, Weems et al. 1994). (Note: While the RANS code is capable of three-dimensional analyses, funding constraints limited application to the GFC free-fall problem to two-dimensional geometries.) The FANS code supports body fitted, multi-block, overset (a.k.a. Chimera) grids, and can therefore resolve any flow domain with maximum grid quality. The code utilizes the finite-analytic technique for primitive velocity and turbulence quantities, and a SIMPLER/PISO non-staggered Poisson solver for pressure. FANS currently employs three state-of-the-art turbulence models: a modified $k\varepsilon$ turbulence model (k is the turbulent kinetic energy and ε is the rate of dissipation of turbulent kinetic energy) (Hanjalic and Launder 1990); a non-linear algebraic Reynolds stress model (Gatski and Speziale 1993); and a fully implicit seven-equation Reynolds stress model (Speziale et al. 1991): Two techniques are available for solving the turbulent dissipation rate equation: a two-layer model that assumes a prescribed algebraic distribution in the near-wall region (Chen and Korpus 1993); and a low Reynolds number extension technique that solves ε all the way to the wall (So, Zhang and Speziale 1991). Either technique can be used with each of the three models to provide a full range of turbulence capability.

Two aspects of the GFC free-fall modeling are unique: the need to couple fluid forces to GFC dynamics; and the need to couple fluid forces to GFC shape. While these aspects do not require complex capability development in the traditional sense, they do require the integration of capabilities which are complex in their own right. Coupling of GFC dynamics to the fluid forces, for instance, requires that the portion of grid which is fixed to the body be moved according to the equations of motion of the GFC. Thus, each time step requires solution of a solid-body dynamics equation for every degree of freedom of body motion.

FANS was applied to simulate the free-fall of GFCs, first computing the flow and resulting forces on the GFC, and then integrating to update the GFC velocity and position. After each update, the grid is regenerated, and the process repeated. Since experiments at the WES had indicated that bag shape is fairly constant and fairly elliptical, it was decided to use a 6 to 10 ellipse (ratio of minor axis to major axis dimensions) to represent the idealized GFC. A further advantage of this decision is that the University of Manchester (Lamont et al. 1995) steady-state ellipse data could be used as a "sanity" check. The simulation was performed using a GFC of 12.5 m beam and 7.5 m depth. Bulk wet density of contents was assumed uniform at 1.7 Mg/m^3. The initial attitude of the GFC was with long axis horizontal, and its initial horizontal, vertical, and roll velocities were specified as 0.3 m/sec, 0 m/sec, and 0 rad/sec, respectively. The test domain was limited to a section of ocean 300 m wide and 300 m deep in order to keep CPU times at reasonable levels. The computation was non-dimensionalized using a characteristic length of 12.5 m and characteristic velocity of 4.6 m/sec.

The grid contained about 80,000 points in four blocks, and 10,000 time steps were used to complete the 36 sec long drop time. Records of velocity and pressure were kept for every 40th time step for a total archive size of 209 megabytes. Video records were generated for pressure, vertical component of velocity, and vorticity. Two frames from the video record, one 10 sec into the drop and one 30 sec into the drop, are shown in Fig. 3. The unsteady wake expected from the von Kanman vortex street is visible, and the asymmetric forces resulting cause the body to pitch and translate horizontally. The 30 sec frame shows that the GFC leaves behind some significant "downward velocities in the wake" as the GFC cycles through its periodic horizontal motion. For the above initial conditions, FANS predicted GFC roll up to 40 degrees, horizontal translation of 30 m (over 300 m fall), and average fall velocity of 9 m/sec.

<u>Experimental Results for Physical Models of Free-Falling GFC</u>. While planning and conducting the analytical studies above, models were selected and assumptions made regarding the physics of GFC behavior during free-fall that were directing the outcome of the predictions. No data were known describing the dynamics of fluid-sediment-filled membrane-like containers in free-fall in a fluid. The studies above suggested that the GFCs in free-fall will oscillate and have erratic trajectories, but the distribution of impact points about a seafloor target was uncertain as was the significance of the downwash from added water mass and ejection of trapped water from beneath the impacting GFC. Project participants were uncertain of the validity of predictions and decided to conduct a low-budget, short-timeframe experiment to better understand the physics being modeled.

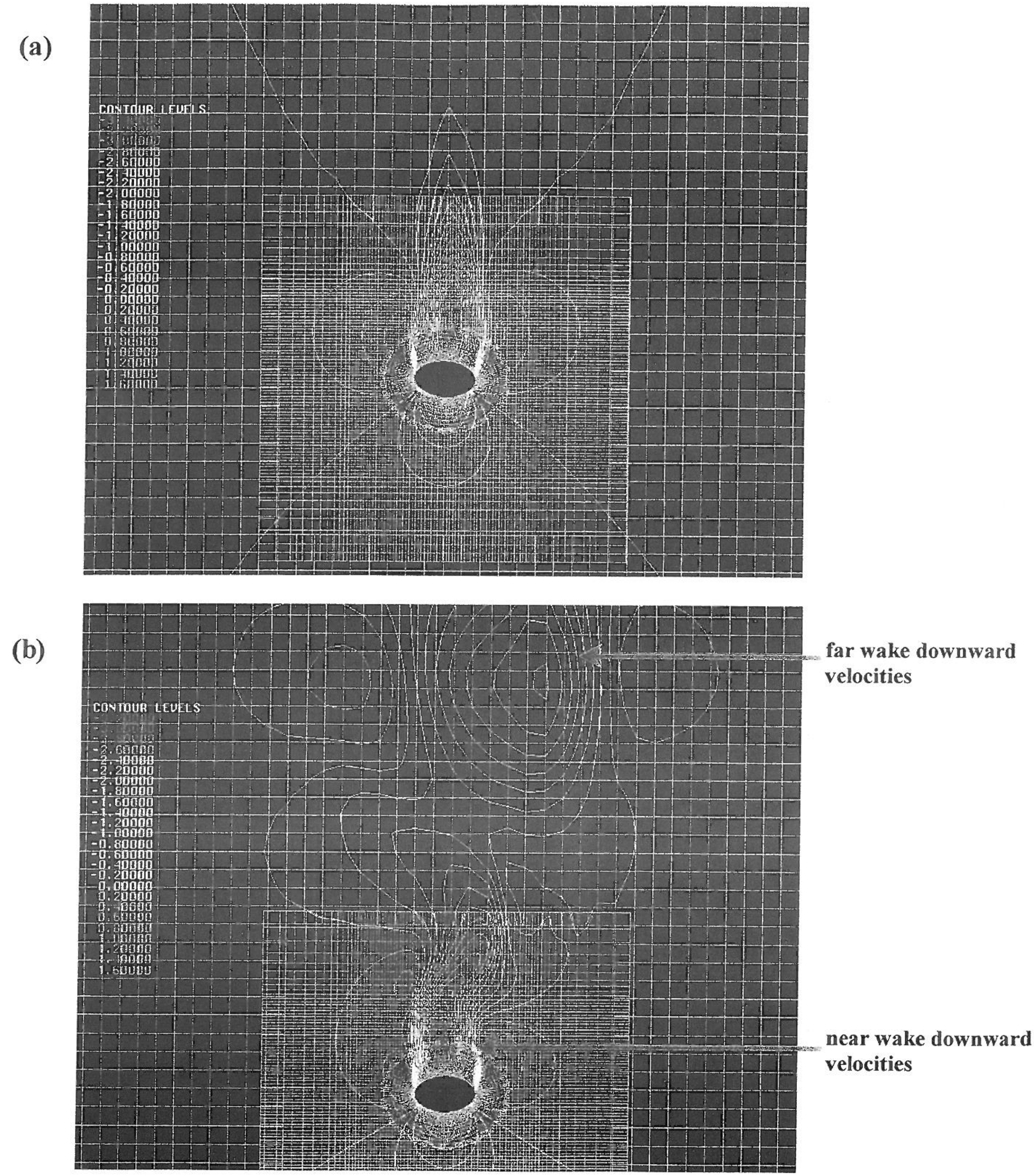

Figure 3. Contours of vertical velocity around GFC during free fall: (a) 10 sec into drop and (b) 30 sec into drop.

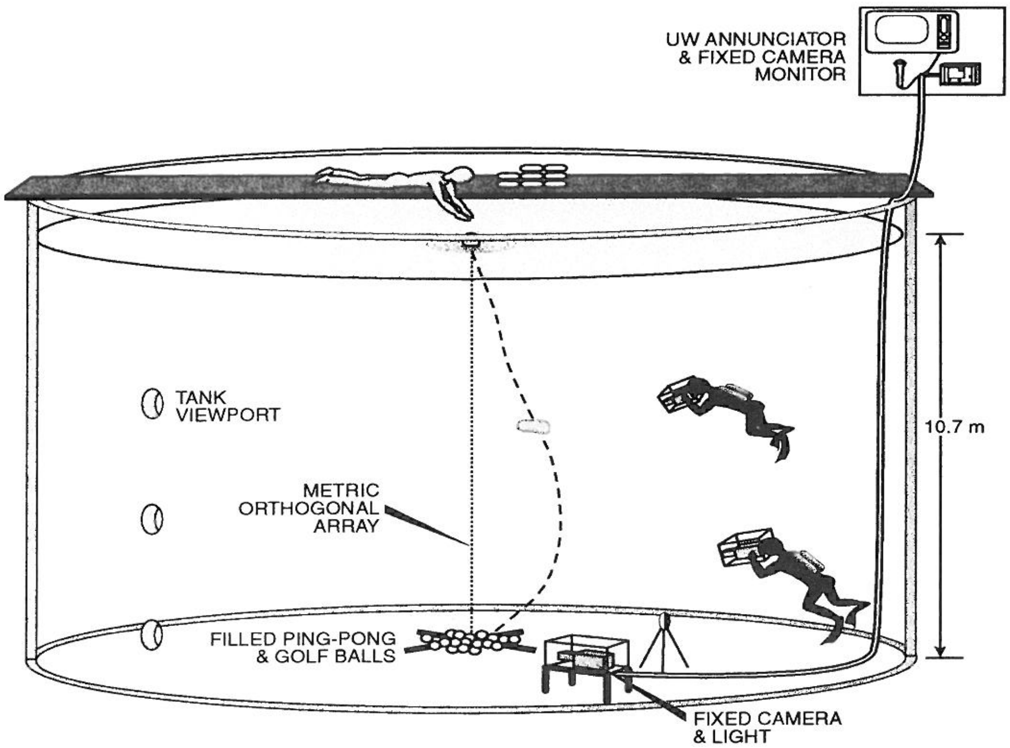

Figure 4. Bag drop experimental configuration.

To obtain answers to these questions, an experiment using model GFCs was conducted in a 10.7 m deep by 11.3 m diameter water-filled tank maintained by the National Marine Fisheries Service, NOAA, at Stennis Space Center. Large latex rubber balloons were employed as model GFCs filled to a nominal spherical diameter, a_0, of 0.12 m with a combination of near-spherical glass beads of 0.5-1.0 mm diameter. Three balloons were filled with combinations of water and glass beads to achieve contents of bulk wet density of 1.1, 1.4, and 1.7 Mg/m^3. Water-filled ping-pong balls and golf balls were arrayed about the center of the tank bottom to serve as indicators of water jets/plumes resulting from GFC impact on the bottom. Two video cameras, one on a stand at the bottom and viewing the center-bottom of the tank, the other diver-held to follow the balloon descents, were used to record time, displacements, and bottom impact locations (Fig. 4). The model GFCs were all released for free-fall from a hand-held position just beneath the water surface.

Data from the video provided for calculation of the ratio of vertical axis to horizontal axis dimensions of the balloons during free-fall of about 1.1 for the lightest loaded model (1.1 Mg/m^3), about 0.8 for the intermediate (1.4 Mg/m^3), and 0.65 for the heaviest loaded model (1.7 Mg/m^3), confirming the trend prediction reported earlier. The average vertical fall speed for the heaviest loaded model (10 test drops) was 1.58 m/sec ± 0.07 m/sec standard deviation and a standard error of ± 0.02 m/sec. This measured average vertical velocity of 1.58 m/sec for the model of nominal spherical diameter of a_o = 0.12 m translates to a predicted velocity of 9.67 m/sec for a full scale

GFC with beam of 12.5 m and depth 7.5 m. This velocity of 9.67 m/sec derived from our model experiments compares well with the 9 m/sec predicted by the finite-difference FANS code.

Contrary to analytical predictions, the free-falling model GFCs did not demonstrate significant oscillations in pitch. Rather, the heaviest loaded model, for which the greater number of drops were made (12 drops), fell about one balloon diameter during which time the balloon assumed its flattened ellipsoid shape, and then pitched about 30-45° and traversed a helicoidal/spiral path that came close to completing one full cycle in the 10.7 m fall. If there is dynamical similarity in the trajectory of the model GFCs and the prototype, then the prototype GFCs would complete 6-7 cycles of the spiral in their 5000 m fall.

The observed steep diving trajectory of the model GFC is of great significance in predicting the size required for a seafloor isolation site for the GFCs. Direct extrapolation from the 12 drops of the heaviest GFC model suggests that the average radius of the seafloor impact site, barring all other sources of deviation, would be 530 m, and the extreme radius would probably be about 1200 m. Given the possibility of non-symmetrical distribution of mass within the GFCs in the real world case, and given the limited data on which the earlier extrapolation is based, a conservative estimate of 2500 m radius for the impact zone is being used in a subsequent project researching the monitoring system to be used for the deep ocean relocation option.

One further data item observed during the model GFC drop tests was the failure to detect focused water jets with impact of the model GFCs on the tank bottom. In only one instance were the balls near the tank center moved concurrent with model GFC impact. The video data suggest that the model GFCs impacted the tank bottom in 20° leading-edge-down attitude and then rolled/flopped down to a horizontal position after leading-edge impact. The water jet noted appeared to be generated by the flop-down of the model, and appeared to be directed out from beneath the high side of the GFC as it flopped down.

PENETRATION/EMBEDMENT OF GFC AND CONTENTS IN SEAFLOOR

The surface seafloor sediments at likely abyssal sites for dredged material isolation will be hemipelagic or pelagic clays with a thin surficial layer, 5-15 cm thick, of bioturbated sediments with a steeply increasing undrained shear strength profile with depth. This surficial layer will be underlain by sediments with a profile of gradually decreasing water content and gradually increasing undrained shear strength (Rocker 1985). The impact on and penetration of the 300-800 m^3 of dredged material contained in the GFC will be resisted by the inertia of the seafloor sediment mass being displaced and by the undrained shear strength (dynamic undrained strength) along developed shear zones.

A predictive model for this impact/penetration phenomena is available (Rocker 1985, Chapter 8) but was not used and validated because effort was concentrated on the GFC release and free-fall phenomena model validation. The penetration prediction model was developed for rigid objects penetrating into a seafloor of unconsolidated sediments, either cohesive (clays, silts, muds) or cohesionless (sands). The application of the technique model to the description of penetration of a flexible (but incompressible), fluid-like dredged material filled bag would be considerably more involved than the method described in Rocker, to account for the deformation of the bag contents and associated redistribution of bag-seafloor contact pressures during pen-etration. The method in Rocker accounts for decelerating forces due to the density difference between the penetrator and the media being displaced, the inertial forces generated in accelerating sediment during penetration, and the resistance of the sediment to shearing.

CONCLUSIONS

The following conclusions were drawn from this study:

- The isolation of contaminated dredged materials on the abyssal seafloor, from the process of clean dredging through containerization, transport, and placement on the seafloor, is shown to be technically feasible through analytical modeling and preliminary component and system design.

- The Integrated Tug-Barge (ITB) concept is shown in sea-keeping analyses to perform well in sea states up through 5. In sea state 8 the ITB performance is shown to be not acceptable, requiring the tug-pushing-the-barge arrangement to be changed to a tug-towing-the-barge configuration.

- Geosynthetic fabric containers (GFCs) of length equal to width, properly filled, will traverse steeply-descending, irregular, generally helicoidal (or spiral) paths in free-falling through any significant water depth (greater than 2-4 GFC thicknesses).

- Although the particular path of any one GFC in free-fall is not predictable, the free-fall speed and the wall stresses, including dynamic stresses, in the GFC can be predicted to sufficient resolution for GFC design.

ACKNOWLEDGMENTS

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$$y = a + b + cx^2 \tag{1}$$

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