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Modeling Dredged Material Disposed in Open Water

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Abstract

Physical model disposal tests at a 1:50 scale have been conducted to provide guidance on numerical model developments and to provide data sets for numerical model verification. These tests have been conducted with a model split-hull barge and a multibin hopper vessel. Both stationary and moving disposals have been monitored. Results imply that the bulk behavior of the disposal material in both the descent and bottom surge phases can be approximately scaled to the prototype. Visual observations have resulted in modifications to an existing numerical model such that the disposal is represented by a series of downward convecting clouds from which material can be stripped.

Introduction

Under the Dredged Material Research Program (DMRP), numerical models to predict the short-term fate of dredged material disposed in open water were developed. These models were extensively modified by the US Army Engineer Waterways Experiment Station (WES) over a period of several years and utilized to assess the environmental impacts of disposal operations in the aquatic environment. The models proved useful for providing a qualitative assessment of disposals represented by idealized discharge conditions but required

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improvements to better simulate more realistic conditions and to yield quantitative predictions.

To improve the capability to numerically predict the initial fate (up to a few hours after disposal) of sediment discharged into open water, a large-scale test facility was constructed at WES under the Dredging Research Program (DRP). Data collected from the laboratory experiments have guided required numerical model refinements and/or developments through an increased understanding of the physical processes that occur during the convective descent and bottom collapse phases.

Physical Model Tests

A preliminary investigation by Soldate, Pagenkopf, and Morton (1988) suggested several factors to consider in choosing a model facility. The geometric scales of the model were fixed from a scaling laws investigation. This investigation determined that scaling of the prototype is possible for the bulk behavior of both the convective descent and bottom collapse phases provided that the model Reynolds number for each phase is high enough so that turbulent flow occurs. The Reynolds number requirements put a limit on the scales that can be used. To meet this criterion in typical disposal operations, the length scale factor should exceed 1:100.

The physical test facility was constructed in a sump at WES. Braced 1-ft-thick concrete walls fitted with two 10- by 13-ft windows were built to enclose on L-shaped viewing area. The floor and the walls opposite the viewing windows were painted white with a black 1-ft-spacing grid. The final design resulted in a 30- by 40-ft test area with water depths up to 6 ft being possible.

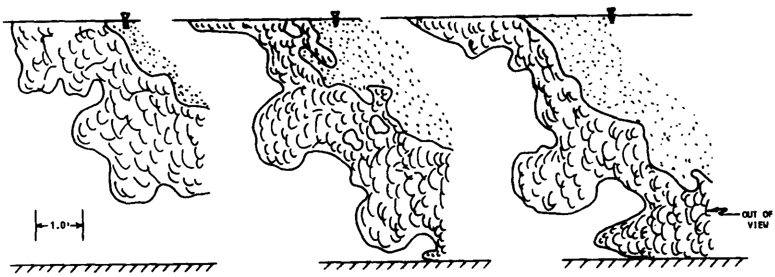
Two types of disposal vessels were used for testing: a split-hull scow and a hinged-door hopper. The split-hull barge was constructed at a 1:50 scale, with a disposal volume of 0.9 ft^3. At a scale of 1:50, this represents a disposal of approximately 4000 yd^3. The hinged-door multihopper disposal vessel was roughly based on the Wheeler, a Corps hopper dredge, and contained six hoppers. Each hopper has a maximum capacity of 0.28 ft^3.

Four materials were used as disposal material: sand, finely crushed coal, silt, and clay. The split-hull barge was tested with all four materials. However, the hopper was only tested with the silt. The silt and clay were mixed with water to form a slurry with a sample of the slurry being taken before each test to determine its bulk density.

Summary of Physical Model Results

Results from the physical model tests are presented by Johnson et al. (in preparation). Both stationary and moving disposal tests were conducted. The data collection consisted of videotaping, suspended sediment samples, and surveys of the bottom deposition for the coal and sand tests. From the video tapes, descent and bottom surge speeds were determined.

All of the disposal tests conducted released material in a dispersed form; thus the material was normally transported to the bottom as a dense jet. Figure 1 illustrates the basic behavior during descent of a moving disposal from the split-hull barge as viewed from the side of the barge. The disposal is in 6 ft of water.



a. 9.0 sec b. 13.0 sec c. 15.0 sec

Figure 1. Moving Disposal from the Split-Hull Barge (Side View) Showing Time Elapsed

As expected, the average descent speed of a disposal increases as the depth decreases since the greater depth allows for entrainment of the ambient fluid and thus a decrease of the descent velocity. The initial surge speed seems to be approximately the average descent speed. Normally one would expect the surge speed to decrease with distance from the impact point. However, this is not always the case. It was observed that quite often material left the disposal vessel as distinct globs (see Figure 1). In such cases the surge temporarily accelerated as relatively dense globs of material impacted the bottom and added additional energy to the expanding bottom surge.

Suspended sediment concentrations as high as 15-20 gm/ℓ were collected over the lower 6 in. of the sand and coal surges at distances 2-4 ft from the edge of the barge. For the fine-grained silt and clay disposals, maximum surge concentrations were generally only 2-3 gm/ℓ over the lower 6 in. of the surge. Because detailed field data on vertical profiles of suspended sediment concentrations in disposal surges do not exist, it is difficult to assess if the bottom surge concentrations in these tests are representative of the prototype.

Ninety-five percent or more of the material from a stationary disposal is deposited in approximately a circular pattern with a radius of 4-5 ft, corresponding to a prototype radius of 200-250 ft. These tests imply that the spread of the bottom surge and thus the area over which bottom deposition occurs increases with depth. There appears to be little difference between the spread of the sand and crushed coal disposal material, lending credence to the belief that scaling the bottom surge dynamics does not require an accurate scaling of the model sediment based upon the scaling laws developed by Soldate, Pagenkopf, and Morton (1988).

Numerical Model Developments

Numerical models for predicting the short-term fate of material from individual disposal operations have been developed, e.g., Koh and Chang (1973), Brandsma and Divoky (1976), and Johnson (1990).

A common deficiency of these numerical models is the inadequacy of their representation of the convective descent and collapse phases in real disposal operations. For example, the models developed by Koh and Chang and subsequently modified by Brandsma and Divoky and by Johnson treat the disposal from a split-hull barge as a single hemispherical cloud descending through the water column. Such an assumption prohibits the accurate simulation of water column concentrations of suspended sediments.

One of the most valuable uses of the physical model disposal facility has been in allowing the dynamic placement processes of descent and bottom surge to be visually observed. As a result of these observations it has been concluded that the existing numerical disposal models do not adequately represent actual disposal operations. There are no instantaneous disposals of material that are uniformly distributed within the disposal vessel. In addition, moving disposal vessels tend to create upper water column plumes as a result of a shearing effect that can leave extremely fine material trapped in the upper water column.

Within the framework of the existing numerical disposal model, modifications to allow for the observed behavior of prototype disposal operations are being made. These modifications are concerned with representing the disposal operation as a sequence of small clouds convecting downward as a result of their negative buoyancy. A stripping of fines from each of these clouds will result in the creation of small Gaussian clouds that are passively transported and diffused by the ambient environment. It is concluded that with such modifications not only upper water column suspended sediment concentrations but also bottom deposition can be more accurately modeled in real disposals of dredged material.

Summary and Conclusions

Although numerical models have been developed for predicting the short-term fate of dredged materials disposed in open water, a common deficiency of those models is the lack of adequate field and/or laboratory data sets to guide model modifications and verification. Under the Dredging Research Program Technical Area 1, entitled "Analysis of Dredged Material Placed in Open Water," both field and laboratory data on placement processes have been collected.

The laboratory disposal tests were made in a renovated sump containing a 40- by 30-ft test section with a maximum testing depth of 6 ft. Testing with both a 1:50-scale split-hull barge and a 1:50-scale multihopper disposal vessel for a range of material types were conducted. Both stationary and moving disposals were made. Data collection depended primarily upon videotaping, bottom profiling, and collecting discrete water samples. The videos provided useful qualitative information for guiding model modifications as well as quantitative information on descent and surge speeds. The discrete water samples provided a spatial distribution of suspended sediment concentrations.

Based upon these results, it has been concluded that real disposal operations can be represented as a sequence of small clouds convecting downward with fine material being stripped from the descending clouds. With such modifications, not only upper water column suspended sediment concentrations but also bottom deposition can be more accurately modeled.

Acknowledgements

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APPENDIX I. Conversion Factors from U.S. Customary to SI Units

To convert (1)	To (2)	Multiply by (3)
Cubic yard (yd^3)	Cubic meter (m^3)	0.76
Foot (ft)	Meter (m)	0.31
Cubic foot (ft^3)	Cubic meter (m^3)	0.028
Inch (in.)	Millimeter (mm)	25.4

APPENDIX II. REFERENCES

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