ERDC TR-13-6

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Water Quality and Contaminant Modeling Branch

Investigation of the Use of Geobags to Immobilize Submerged Munitions

A Report on the Concept, Development, and Testing

Barry W. Bunch, Carlos. E. Ruiz, Susan E. Bailey, W. Andy Martin, Raymond S. Chapman, and Pamela Sheehan

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Final report

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Abstract

Underwater munitions pose a risk to human health and safety as well as a potential threat to the environment. Current management options are limited to removal, in-place detonation, or leave-in-place. Furthermore, munitions subjected to ocean currents may be mobile, confounding monitoring, removal or detonation after initial detection. Capping technology used in the control of contaminated sediments has the potential to immobilize and isolate munitions from the overlying water column, thereby safeguarding human exposure and the environment.

This study designed, developed, and tested geobags for immobilizing submerged munitions. Geobags are constructed from synthetic geotextiles and filled with sand. The geobags used were typically 5 ft x 2.5 ft with filled weights varying between 500 and 1200 pounds. Tests were conducted in still and flowing waters to demonstrate whether geobags were a viable option for dealing with underwater munitions. Results indicate geobags, when properly placed, would immobilize a munition and completely surround it thereby isolating it from the overlying water column. This “cap” would prevent any spills or releases from the munition from entering the environment and also safeguarding human exposure. With an estimated design life exceeding 100 years, geobags provide an inexpensive, easy-to-implement method to address the issue of submerged munitions.

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Preface

This report provides results for a study undertaken to evaluate the feasibility and effectiveness of using geobags for immobilization and isolation of underwater munitions. This effort was funded by the Strategic Environmental Research and Development (SERDP) as SERDP MR-2102, Proof of Concept Study for Immobilization of Submerged Munitions using Geobags.

Dr. Barry W. Bunch of the Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Engineering Division (EPED), of the Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, Mississippi, was the lead investigator for this study. Co- investigators were Dr. Carlos E Ruiz, WQCMB; Susan Bailey, Environmental Engineering Branch (EEB) of EPED; Andy Martin, EEB; Dr. Ray Chapman, ERDC Coastal and Hydraulics Laboratory (CHL); and Pam Sheehan, Picatinney Arsenal. Dr. Bunch prepared this report, served as the principal investigator and study point of contact. A special thanks is extended to Richard Hudson (EEB), T.J. Beard (EEB), Slade Mitchell (EEB), and Glenn Myrick (CHL) for providing their assistance with this project. The authors also wish to thank Forest Cronia of Huesker Geocomposites for his advice, guidance, and assistance in this effort.

This work was conducted under the general supervision of Dr. Dorothy Tillman, Acting Chief, WQCMB and Warren Lorentz, Chief, EPED. Dr. Beth Fleming was Director of EL. COL Kevin J. Wilson was Commander and the Executive Director of ERDC was Dr. Jeffery P. Holland.

Summary

Objectives

This limited scope research effort evaluates viability of geotextile containers (geobags) for immobilizing submerged munitions. The goals of the study were to fabricate and place geobags on submerged munitions under laboratory conditions and evaluate geobag effectiveness in a dynamic environment with moving water. Of interest were the effectiveness of geobag coverage (encapsulation) of the munitions, geobag stability in flowing water, and assessment of whether geobags were able to immobilize munitions under flow conditions.

Technical Approach

This study was divided into two phases. Phase 1 involved actual geobag design, the development of techniques for handling geobags, and the testing of geobag performance in still water. Of primary interest was the geobags' ability to completely cover or encapsulate a submerged munition. Phase 2 consisted of the evaluation of geobag performance under flowing water conditions. These tests were conducted in a large flume with geobags placed on inert 155 mm munitions on hard smooth surfaces and packed gravel beds. Unrestrained inert 155 mm munitions were also placed in the vicinity of the geobags. The flume was turned on and behavior of geobags and unrestrained munitions observed. Tests were run using different water levels which resulted in geobags and un-restrained munitions experiencing a variety of flow conditions.

Geobags used in this study were made out of geosynthetic liner materials with sand used as filler. Geobags were rectangular and sized to accommodate the limitations of the tanks available for Phase 1 testing which translated into filled lengths of 5 ft and widths of 2.5 feet. Depending upon the degree of filling, geobag weight varied from 500 to 1200 pounds when dry. Wet bags weighed more due to pore water in the sand. Once filled, the open end of the geobag was securely closed to prevent any filler spillage. Geobags were fitted with lifting straps on sides to facilitate handling. Geobag sides, lifting straps, and the thread used to stitch the bag together were polyester, which resulted in an estimated design life of 114 years.

Results

Phase 1 results indicated that geobags could be placed on submerged munitions. Multiple munition orientations were evaluated and it was evident that geobags could be placed regardless of the orientation. Further, it was demonstrated that geobags, if large enough, could completely encapsulate a munition; i.e., the geobag is in contact with the sediment surface at all points around the munition. This results in the geobag acting as a “cap” in the event that there was any leakage or spills from the munition. For example, a partially filled geobag, 500 pounds total weight, was able to completely encapsulate a horizontal 155 mm munition on a hard surface, thereby providing a cap with a minimum of 6 inches of sand over and around the munition.

Phase 2 results indicated that munitions covered by geobags remained in-place under conditions which resulted in erosion of the packed gravel bed and movement of uncovered munitions. Complete encapsulation was maintained. Flow generated during these tests matched or exceeded those predicted by modeling for Ordnance Reef, Hawaii, which had been chosen as a reference location.

Benefits

This study developed and demonstrated a low-cost, easily implementable technology for immobilizing submerged munitions. This technology can be used short term to hold a munition in place until removal or detonation. It is suitable for long-term placement or encapsulation of munitions as an alternative to removal. The filler in the geobag acts a physical cap which isolates the munition and its components from the surrounding waters. With the design life estimated to exceed 100 years, geobags provide an inexpensive, reasonable, long-lasting alternative for addressing issues of mobile submerged munitions.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
lbs	0.454	kilograms
feet/sec	0.3048	meters/second

Acronyms and Units

CDF	Confined Disposal Facility
CHL	Coastal and Hydraulics Laboratory
CW	Chemical Weapons
CWA	Chemical Warfare Agents
EEB	Environmental Engineering Branch
EL	Environmental Laboratory
EPA	Environmental Protection Agency
ERDC	US Army Engineer Research and Development Center
ft	feet
FRF	Field Research Facility
HE	High Explosives
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocane
hr	hour
HWRC	Hazardous Waste Research Facility
ISC	In-Situ Capping
m	meter
mm	millimeter
MR	Munitions Response
MSDS	Material Safety Data Sheet
NW	Northwest
PPT	parts per thousand
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine
s	second
S	South
SERDP	Strategic Environmental Research and Development Program
SON	Statement of Need

SRL	Sediments Research Laboratory
TNT	2-4-6-trinitrotoluene
USACE	US Army Corps of Engineers
WQCMB	Water Quality Contaminant Modeling Branch
WSE	Water Surface Elevation
2D	Two Dimensional

1 Introduction

This study was conducted in response to the SERDP statement of need (SON) MMSON-11-02, which requested proposals for the following:

"cost-effective, safe, and environmentally preferable techniques are also needed for underwater items that cannot be moved due to explosive safety concerns and where blow-in-place operations underwater can significantly impact marine life."

The SON requirements rule out the traditional management options of removal, exploding, or just leaving the munitions alone. When encountered, these munitions may be of unknown origin and likely are of unknown condition and stability. Furthermore, the methods proposed for addressing this issue had to do so in a manner that did not degrade the environment.

Traditional Corps of Engineers options for dealing with contaminated sediments provided a foundation for approaching the problem described in the SON. In-Situ-Capping (ISC) is one method used for controlling contaminant releases from sediments. ISC would isolate and contain the "underwater items" in question without resulting in exposure to explosive conditions and limited short-term impact on marine life. While ISC would also be cost effective, it does possess a significant drawback. The spatial extent of even a small ISC would easily extend over significant areas beyond the vicinity of the munitions. Therefore, the ISC approach was modified to include all of the components of an ISC into a self-contained unit inside of a geotextile bag or geobag.

Study Objective

This limited scope research effort evaluates viability of geotextile containers (geobags) for encapsulation of underwater munitions in order to provide both chemical and physical stabilization in stationary and dynamic environments. Primary focus was the placement and stability of geobags and their ability to completely cover and encapsulate munitions. Effectiveness of actual adsorbent or reactive materials to suppress contaminant release was not evaluated, but is potentially viable for the described containment approach.

Background

Disposal of unwanted or unsafe munitions is a problem as old as the manufacture and use of munitions. Disposing of munitions at sea has been a common practice since the early 1700s; at that time, it was probably the easiest way to dispose of weapons-grade munitions and other trash that was not needed (ENS 2007). This process continued through the twentieth century when large quantities of unwanted munitions were disposed of in this way after World Wars I and II (Martin 2009). In 1972, the United States Department of Defense ceased disposing of conventional munitions and other waste materials at sea (Bull 2005). In addition to the munitions disposed of at sea, underwater munitions can also be found near former coastal battery installations, training ranges, and firing ranges.

Munitions Involved

Two main categories of munitions were disposed of in the oceans during the mid-twentieth century (World War I to the 1970s): 1) conventional munitions and 2) chemical and/or biological munitions. Conventional munitions include small arms ammunition (less than 0.50 caliber), grenades, mines, and torpedoes and other such munitions that are commonly used in the military arsenal. Conventional weapons contain high explosive (HE) compounds such as hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and 2-4-6-trinitrotoluene (TNT) that pose potential risk to the environment, shock hazard, or that can enter the food chain. Conventional munitions containing RDX, TNT, and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocane (HMX) can be toxic to marine life and, while not listed as human carcinogens, they have had toxic effects in some animal studies (Beddington and Kinloch 2005, MSDS-RDX 2006, MSDS-TNT 2006, MSDS-HMX 2006). Chemical Warfare Agents (CWA) [and Chemical Weapons-CW] as defined by Szarejko and Namienik (2009) are "munitions and devices, specifically designed to cause death or other harm through the toxic properties of the toxic chemicals which would be released as a result of the employment of such munitions and devices." Chemical munitions can have catastrophic environmental and health impacts if released even in small quantities (USACMA-APG 1988).

Munitions Disposal Locations

Records were not well kept in many instances, as the priority was to dispose of munitions and other surplus material. Records do indicate that conventional munitions were disposed of off the coasts of New Jersey, Delaware, California, Virginia, North Carolina, Maryland, Georgia, Washington, and Alaska (Bull 2005). Methods of disposal varied from tossing munitions overboard to sinking barges and ships loaded with munitions. Disposal sites off of Hawaii have received attention due to the shallowness of the sites and the potential access that people have to munitions located there.

Sediment Capping

Contaminated sediments are those which have higher than acceptable levels of contamination and that require removal or isolation from the benthic community (Palermo 1998). Traditional actions were to remove the contaminated material via dredging and place it in upland confined disposal facilities (CDF). This approach has limitations on available storage space and raises exposure concerns. An alternative is to remove the contaminated sediment and place it in a controlled manner at the disposal site and then cover or “cap” it with clean sediments, Figure 1 (Palermo 1998). The cap provides a physical barrier to contain the contaminated sediments and prevents biota access. A properly designed cap should be of adequate thickness to isolate the contaminated sediments from the food chain and also stable enough to remain in place. Armoring of the cap may be necessary to withstand erosive forces. Capping provides a method for managing sediments in-place, whereas removing or disturbing the sediment would spread contamination and increase risk to the environment.

Work is underway to enhance cap effectiveness by incorporating reactive materials tailored for the contaminant (e.g., granular or powdered activated carbon). These materials are designed to adsorb, react with, or transform any contaminants that are fluxing from the contaminated sediments. Making caps reactive enhances their ability to prevent contaminants from transiting the cap and entering the water column.

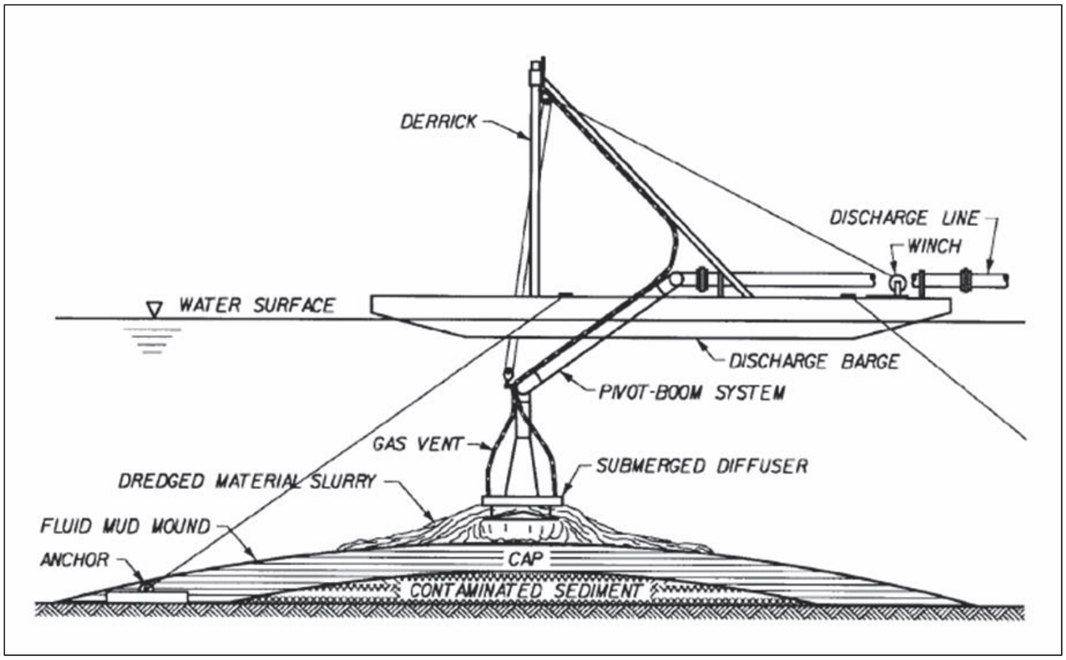

Figure 1. Cap placement technique for covering contaminated sediments.

2 Approach

This section discusses the approach undertaken in this study. Theory, rationale, and methods are discussed.

Encapsulation/Isolation

Encapsulation is a new approach for mitigating risks posed by the movement, leakage, and handling of submerged military munitions. Although reports of using concrete to encapsulate munitions exist (Albright 2008), published data on the design and performance of subsurface encapsulation is, at best, sparse. However, there are accepted engineering techniques for underwater encapsulation and containment that can be extrapolated for underwater munitions use. In simplest terms, the purpose of these encapsulation measures is to stabilize the sediments in their current locations. These methods include techniques for contaminated sediment capping and for countermeasures that prevent erosion or scouring of bridge abutments. Encapsulation prevents material from moving or degrading in high energy environments. In the case of contaminated sediments, as with munitions, the cap contains contaminant releases and reduces or prevents flux of contaminants into the surrounding environment. As a result, encapsulation isolates the contaminants from the biota of the natural environment.

This research effort combined two technologies in order to immobilize and contain underwater munitions: capping and geobags. Capping is a maturing capability widely used as a means of containing contaminants in sediments and mitigating their effects on the aquatic ecosystem. In-situ capping, where clean materials are placed over undisturbed sediments, has the advantage of not requiring removal and disturbance of contaminated sediments. Layers of cap material placed over sediments provide several functions, including physical isolation of contaminated sediments from benthic organisms, physical stabilization of the sediment, and reduction of contaminant flux to the water column. A variety of materials are used for ISC, including natural items such as sand, clay, clean sediment, and riprap. In addition, engineered products have also been used for encapsulation in submerged environments. The US Environmental Protection Agency (EPA) recognizes capping as an effective strategy for remediation of contaminated sediments and provides guidance for cap design and implementation (Palermo et al. 1998).

Geobags

Geobags are essentially geotextile cloth bags filled with local sediment or concrete, Figure 2. Geobags have been employed in different manners as means of placing and immobilizing sediments. Geobags can be large or small and options for filling them vary. In the case of Marina Del Rey, CA, sediments were placed in a hopper barge that contained a geotextile. When filled, the geotextile was wrapped around the sediments, closed, and sewn together. The bag was then dropped into an underwater confined disposal facility at the Port of Los Angeles (Palermo et. al 1998b). In other cases, the geobags have been used as filters when they are filled in place via pumping material into the bag and allowing it to dewater. In both cases, a geobag's role is to contain contaminated material on the inside and prevent its release and distribution into the environment.

Figure 2. Geobag attached to lifting frame.

Multitudes of materials with differing properties are available for geobag construction. Examples of these properties include blast resistance, chemical treatment, promotion of biological colonization, and retardance of biological attachment. The various options allow for site-specific conditions and requirements to be satisfied. Many reports describe the use of geo-synthetic containers to control erosion (Pilarczyk 2000, Heibaum 2004 and PIANC 1992). In fact, some studies have demonstrated that geobags are more effective at controlling erosion when compared to natural materials such as riprap or cable-tied block (Korkut et al. 2007).

The technology used in this study was essentially a "cap-in-a-bag" as it combines physical aspects of capping and containment within the confines of a geotextile bag. Advantages of this approach are numerous. First, the "footprint" of the activity is confined to that of the geobag. Traditional capping has a much larger footprint, potentially covering unintended areas even when targeted at small areas. Second, there is great flexibility on geobag construction materials and fillers. Materials used for geobag construction can be reactive or inert and have properties which promote or prevent colonization of living resources. A third advantage is that the geobag can be filled with a wide variety of material selected for their physical and chemical properties. These advantages ensure flexibility of the geobag concept to tailor a geobag-contained cap to the specific physical and chemical requirements of the situation, while providing full encapsulation of the desired munition.

Geobags can be simple or complex in construction. Simple ones consist of a geotextile bag filled with inert material such as sand. More complex configurations could use multiple geotextile panels in the geobag to separate different reactive fillers. The use of geotextiles between layers holds individual filler layers in place, preventing shifting and layer mixing. This reduces the need for thicker cap layers to prevent sifting between different size materials. Without geotextile between layers, cap design requires a gradation of different size granular materials to prevent vertical migration and intermixing of different layers which can increase the necessary cap thickness (Palermo et al. 1998). Given the range of geotextile and filler materials available, geobags can provide the necessary encapsulation and remediation technologies to reduce the risk of underwater munitions. Geobag construction can be adapted to meet the needs of the underwater environment and the remediation strategy, Figure 3.

The research undertaken in this study evaluated placement of geobags on/over underwater munitions in order to immobilize the ordnance and any contaminants currently present or originating in the future from the munition. Properly placed geobags provide security by preventing disturbance by swimmers, divers, fishermen, and boaters (anchors), as well as migration due to hydrodynamic forces.

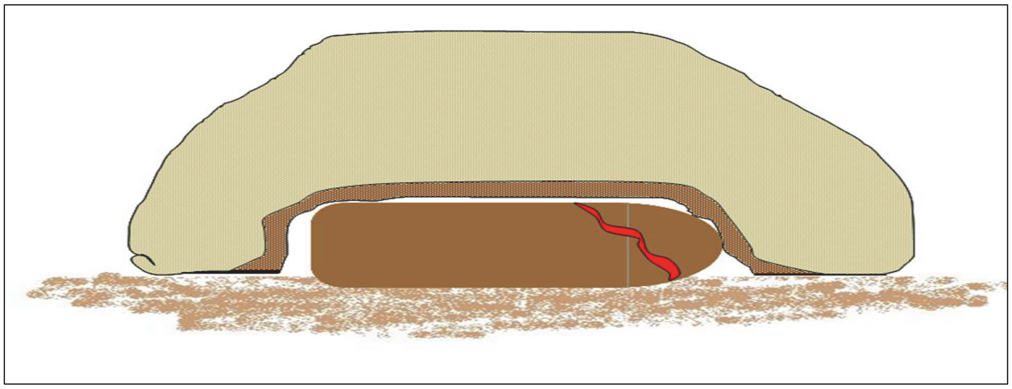

Figure 3. Cross-section of a geobag placed over underwater ordnance.

This work is unique in that the combination of capping and geobags enables the potential for site-specific contaminant isolation only at locations where it is required. Geobags provide complete isolation, containment, and – if desired – treatment while disturbing existing biota only in the immediate vicinity of a potential contaminant source; i.e., the underwater ordnance. Traditional capping methods without geobags can also provide isolation, containment, and treatment. However, the advantages of geobags are a reduction in cap thickness and footprint along with potentially improved erosion prevention and ease of deployment. To achieve the same degree of protection/erosion prevention, traditional capping requires a layer of sand (or other materials), then layers of gradually increasing particle size to prevent the sand from migrating to the top. Next, a layer of geotextile or riprap is needed to enhance erosion control. This not only requires a larger vertical thickness of material, but also a large, horizontal footprint to provide stability. Geobags, on the other hand, are self-contained, would not require the successive layers between materials, and could be anchored if necessary (rather than weighted with riprap). Containment of the materials susceptible to erosion inside the geobag means they will not erode away unless the geobag fails. The same cannot be said of traditional caps made of the same material that are of similar thickness.

As a limited scope study, this effort did not evaluate all relevant aspects of this technology. Specifically, the geobag's ability to capture and retain contaminants was not evaluated. The conceptual design of the geobag is flexible such that it could be implemented with any number of materials whose selection would likely be site/contaminant specific. Rather, the research here presents results and lessons learned about the geobag's ability to physically encapsulate underwater munitions and provide stability in underwater environments, including high-energy ones.

Experimental Methods

This research is based upon laboratory simulation of the geobag method of encapsulating and isolating underwater munitions. Laboratory simulation was selected to provide the best opportunity to evaluate this concept under controlled conditions. Experiments were conducted in two phases. Phase 1 tests consisted of placement of geobags on munitions in varying orientations under static conditions. Techniques and tools for geobag placement were developed during this phase. Phase 2 consisted of the testing of geobag mobility in comparison to that of munitions in dynamic conditions in a large flume.

Experimental Geobags

Geobags used in this effort were constructed by Huesker Geocomposites to the size requirements specified by ERDC. These geobags were designed to be placed in harsh environments and to withstand the rigors of lifting and placement. Two forms of geobags were manufactured. One type was manufactured of woven polyester and the other of unwoven polyester. All straps and threads were also of polyester. According to the manufacturer, the materials used in these geobags have an expected design life of 114 years when used in locations having a pH between 4-9 (McClinton 2012).

Materials used were selected for strength only. Other materials are available for geobag construction that would provide a reactive surface for substances released from the munitions. Still others are capable of promoting or retarding aquatic attachment and growth should that be an important consideration.

Phase 1: Static Placement

Results from this phase provide fundamental information on proper techniques for geobag placement for ordnance isolation/encapsulation. These experiments were conducted using existing equipment and prototype geobags. The geobag’s ability to isolate/stabilize a munition was evaluated. Full and partially filled geobags were used to investigate issues related to geobag configuration and their ability to provide complete isolation/stabilization. Munition displacement or lack of displacement was observed before and after geobag placement.

A large water-filled tank in the ERDC-EL's Sediment Research Laboratory (SRL) served as the primary test chamber for Phase 1 experiments, Figure 4. The tank contained estuarine sediment which served as a base. A geotextile was placed on top of this sediment, then washed, sieved sand was "rained" down to form a smooth sand bed with average thicknesses of 3 inches. The bed produced was firm. The sand bed was covered by three feet of water with a salinity of 13.5 parts per thousand (PPT).

Figure 4. Phase 1 Primary test chamber.

An inert, 155 mm M107 munition was placed in the tank on the sediment surface, Figure 5. Loading rings were left in place to facilitate handling. The 155 mm M107 was chosen for testing as it is thought that techniques and materials developed for its capping would translate well to the capping of smaller and larger pieces of ordnance. For instance, large pieces of ordnance such as 500-2000 pound bombs should be able to be capped in a similar manner with a larger geobag or multiple smaller geobags. The size and construction of geobags for larger munitions will require modifications to suit the weight and size of the geobag. In those cases, insight gained in working with munitions in this study will be invaluable and directly translated when addressing the issue of larger underwater ordnance.

Figure 5. Initial placement of 155mm M107.

Shown in Table 1 are the experiments conducted for Phase 1. All of these experiments were also repeated “in the dry” to gain additional insight on the coverage and encapsulation efficiency.

Table 1. Phase 1 Experimental Matrix.

#	Sediment Surface	Placement	Munition Orientation
1	Hardpan	Surface	Horizontal
2	Sandy	Surface	Horizontal
3	Sandy	Partially Buried	Horizontal
4	Sandy	Partially Buried	Protruding

Phase 2: High Energy Tests

Phase 2 involved placement of geobags in higher energy environments to evaluate stability under different dynamic flow conditions. A large flume at ERDC, the Olmsted 1:5 scale hydraulic flume, was used for this effort. The Olmsted flume dimensions are 25 ft wide, 130 ft long with water depths ranging to 10 ft, Figure 6. Information obtained included the effectiveness of the geobag at immobilizing munitions on different surfaces. Two types of sediment bottoms were investigated in this portion of the study. One is a hardpan case which facilitates munitions movement. The second is a porous, formable bed which should retard movement but may be easier for underflow to dislodge the geobag. Munitions used in this experiment were inert 155 mm M107 shells. Different munition positions were evaluated to determine the effect they have on geobag stability and effectiveness.

Figure 6. Olmsted 1:5 scale hydraulic flume, Phase 2 test bed.

The same experimental design described above was used to determine mobility characteristics of exposed munitions. The relative level of immobilization afforded by geobags in comparison to exposed munitions was evaluated. Table 2 contains the matrix of tests for Phase 2.

Criteria for evaluating geobag effectiveness in Phase 2 studies were based on several factors:

1. Does the geobag remain in place?
2. Is there evidence that appreciable flow is channeling underneath the geobag even though it remains in place?
3. Does the geobag roll, or partially displace so that portions of the muniton are exposed?
4. How is geobag performance under experimental conditions in comparison to that of the exposed munitions?

Table 2. Phase 2: Experimental matrix.

#	Sediment Type	Placement	Munition Orientation	Energy Level	Exposed/Geobag
1	Hardpan	Surface	Horizontal	Low	Exposed
2	Hardpan	Surface	Horizontal	Medium	Exposed
3	Hardpan	Surface	Horizontal	High	Exposed
4	Hardpan	Surface	Horizontal	Low	Geobag
5	Hardpan	Surface	Horizontal	Medium	Geobag
6	Hardpan	Surface	Horizontal	High	Geobag
7	Gravel	Surface	Horizontal	Low	Exposed
8	Gravel	Surface	Horizontal	Medium	Exposed
9	Gravel	Surface	Horizontal	High	Exposed
10	Gravel	Surface	Horizontal	Low	Geobag
11	Gravel	Surface	Horizontal	Medium	Geobag
12	Gravel	Surface	Horizontal	High	Geobag

Phase 2: Hydrodynamic Conditions

Since the focus of Phase 2 is the investigation of geobag stability and its effectiveness in flowing waters, a set of conditions were required to determine what flows to simulate. Initial plans were to produce velocity conditions that were similar to those occurring at sites with known underwater munitions. The site chosen for this was Ordnance Reef, Oahu, HI. This area has been monitored and continues to be monitored due to the proximity of the munitions to the surface.

To support determination of appropriate velocities for Phase 2 experiments, the Coastal and Hydraulics Laboratory (CHL) of ERDC performed numerical circulation simulations utilizing the two dimensional (2D) ADCIRC hydrodynamic model. ADCIRC provides the water surface elevation and depth-averaged current speed response to tidal and atmospheric forcing. An existing ADCIRC grid of the Hawaiian Islands (Figure 7) was applied to estimate current speeds over Ordnance Reef, which is located west of Waianae, Oahu (Figure 8 and Figure 9).

Figure 8 shows the island of Oahu and the relative narrow band of shallow depths at the coast. Figure 9 illustrated the grid resolution in the vicinity of Ordnance Reef.

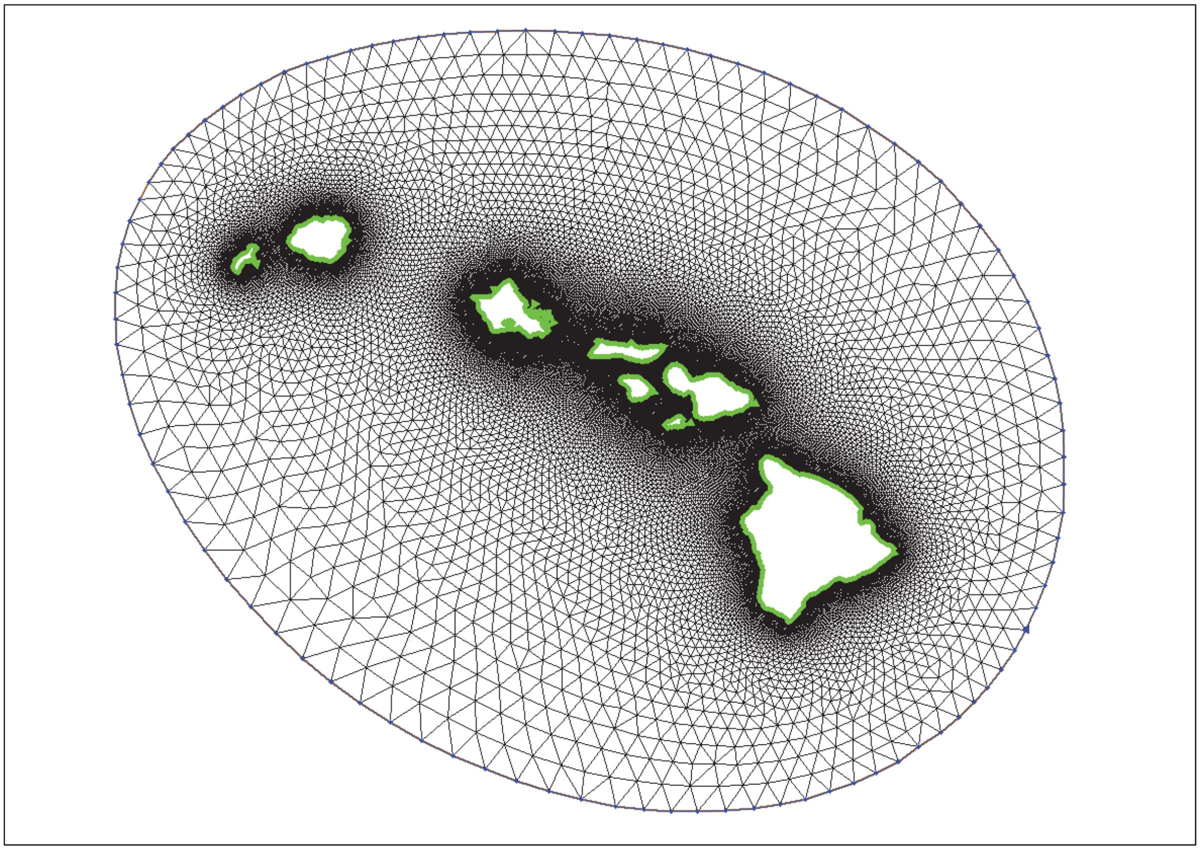

Figure 7. Hawaiian Island ADCIRC grid.

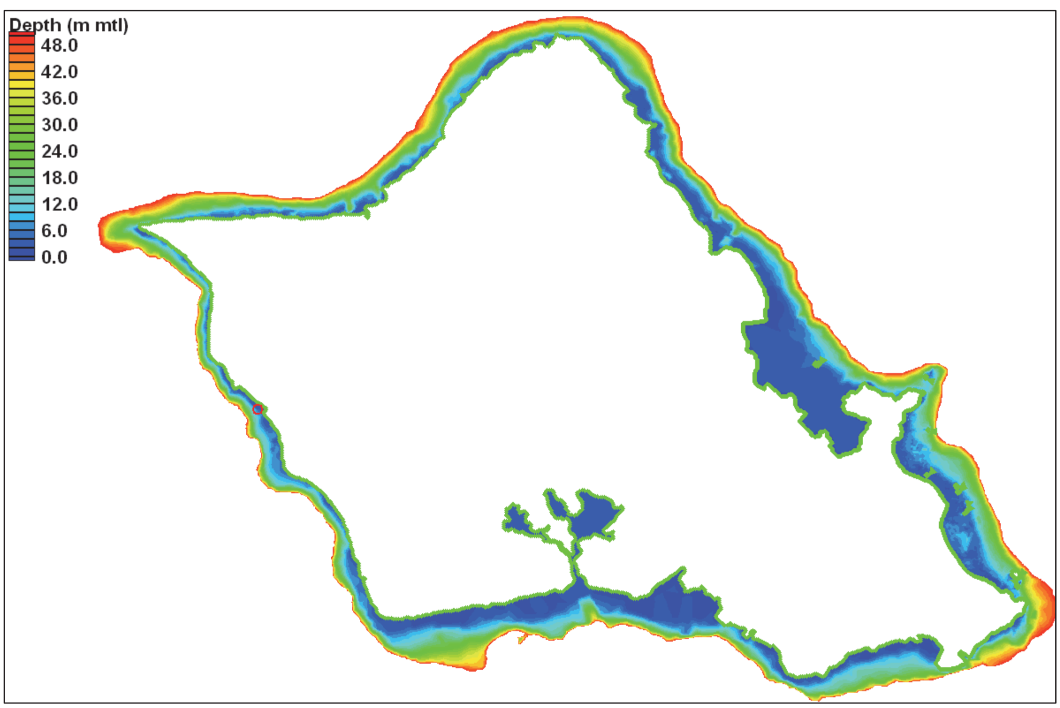

Figure 8. Ordnance Reef location, Oahu.

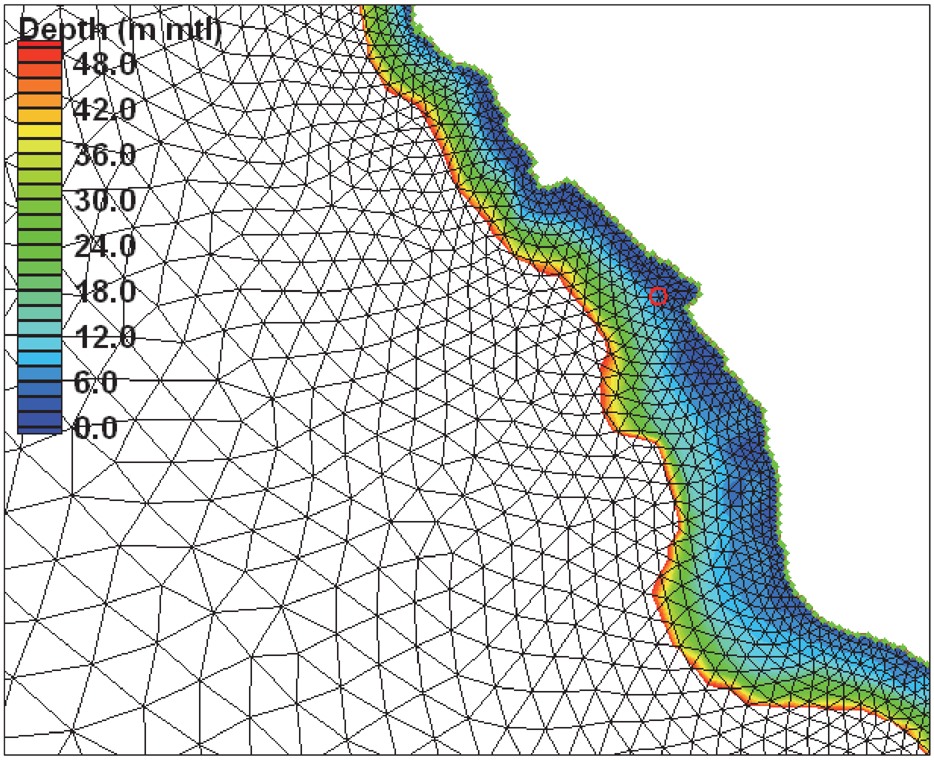

Figure 9. ADCIRC grid resolution and study location.

Model simulations performed consisted of a spring tide with and without idealized wind forcing. The characteristically small spring tide range (approximately 1 m) without wind forcing is shown in Figure 10.

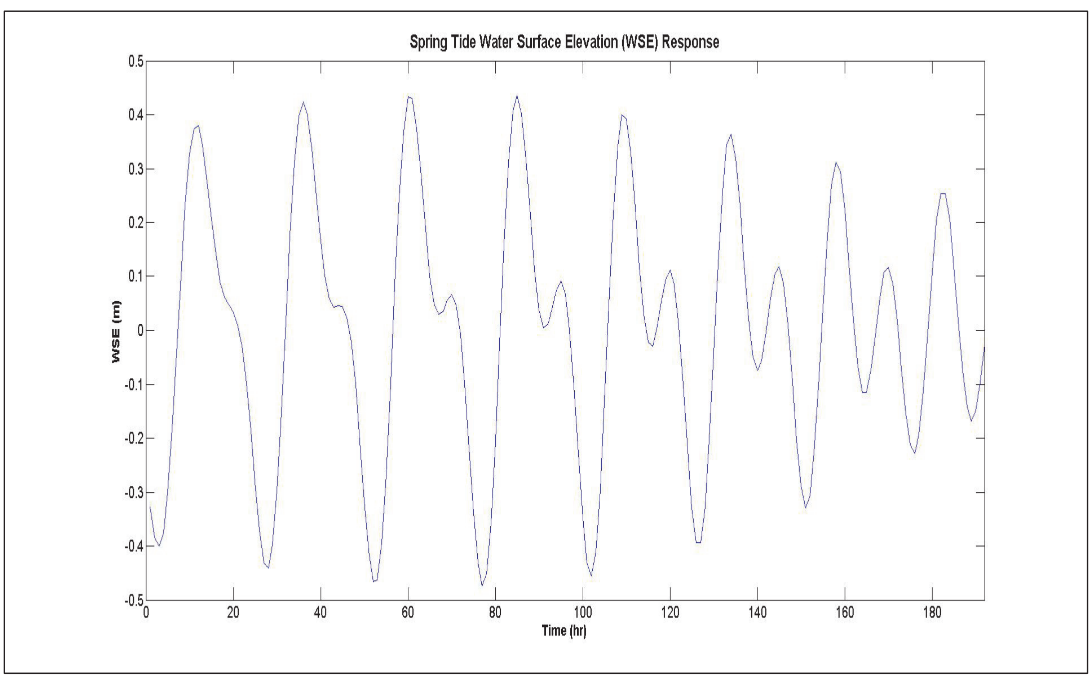

Figure 10. Predicted water surface elevation without wind forcing.

Next, a series of wind-forcing simulations were performed where steady 10 and 20 m/s wind speeds were applied from the South and Northwest. Figure 11 presents a comparison of tidal current speeds with and without wind forcing. The tide forced current speed without wind forcing (Black line) is shown to be small in comparison with the predicted current speed resulting from steady Northwest and South 10 m/s wind speed. Figure 12 presents the current speed comparison for South and Northwest 20 m/s steady wind forcing; a doubling of the wind speed results in a doubling of the current speed. The opposite phase response to wind direction forcing can be explained by examining the current direction without wind forcing (Figure 13), where the wind-forced current speed is either reinforced or opposed by the tidal current component.

Noting that the current speeds for both the 10 and 20 m/s steady wind forcing are significantly larger than the tidal current speed without wind forcing, it is seen that the wind-forced current directions are nearly constant (Figure 14). As a point of clarification, the wind directions are from the South and Northwest and the current direction are Cartesian (direction to), as indicated Figure 13 and Figure 14. Consequently, the predicted wind-forced currents are predominantly alongshore and modulated in strength by the tidal current component.

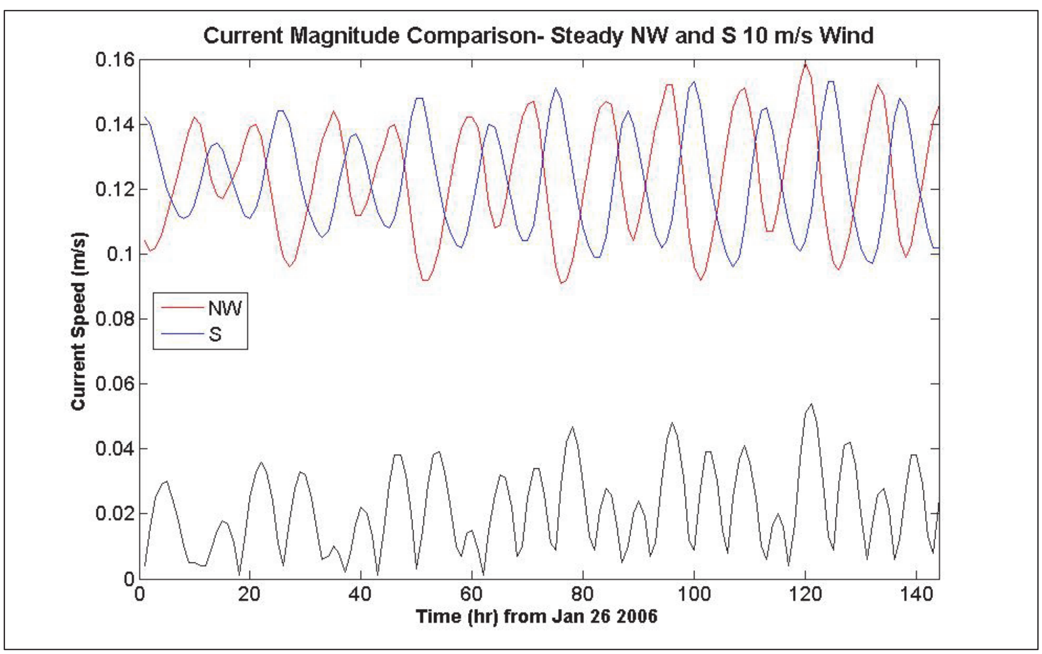

Figure 11. Comparison of tidal current speeds with and without wind forcing; the black line at the bottom represents the tide-forced current speed without wind forcing.

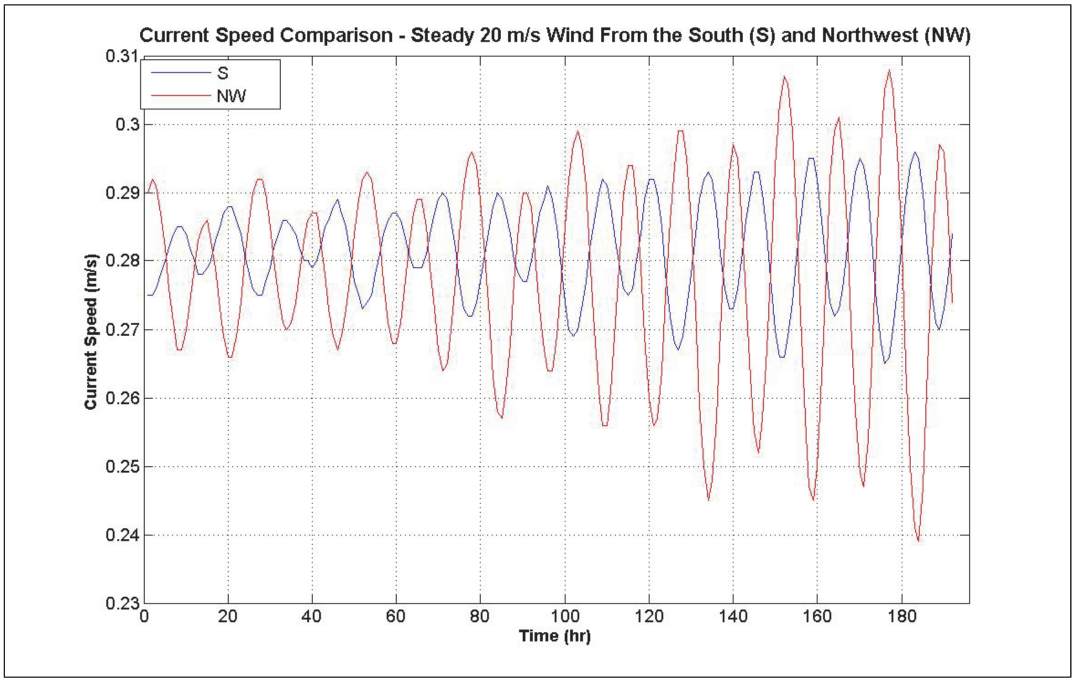

Figure 12. Comparison of tidal current speeds with 20 m/s wind forcing.

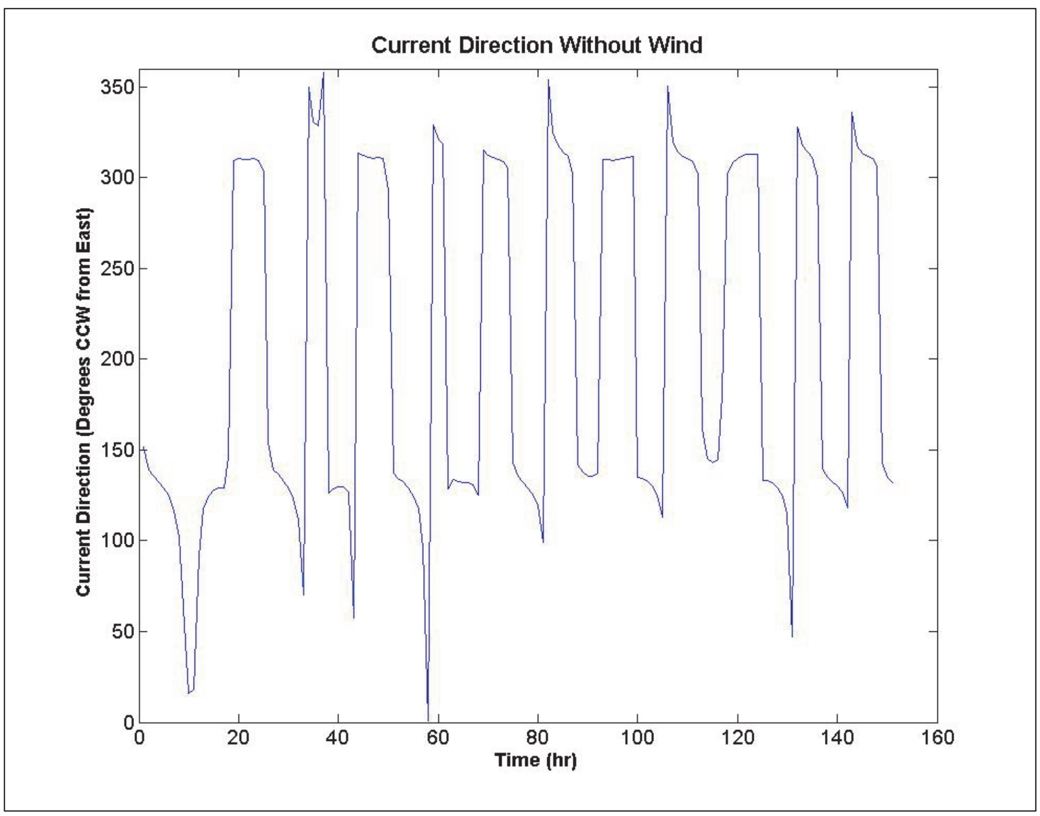

Figure 13. Tidal current direction without wind forcing.

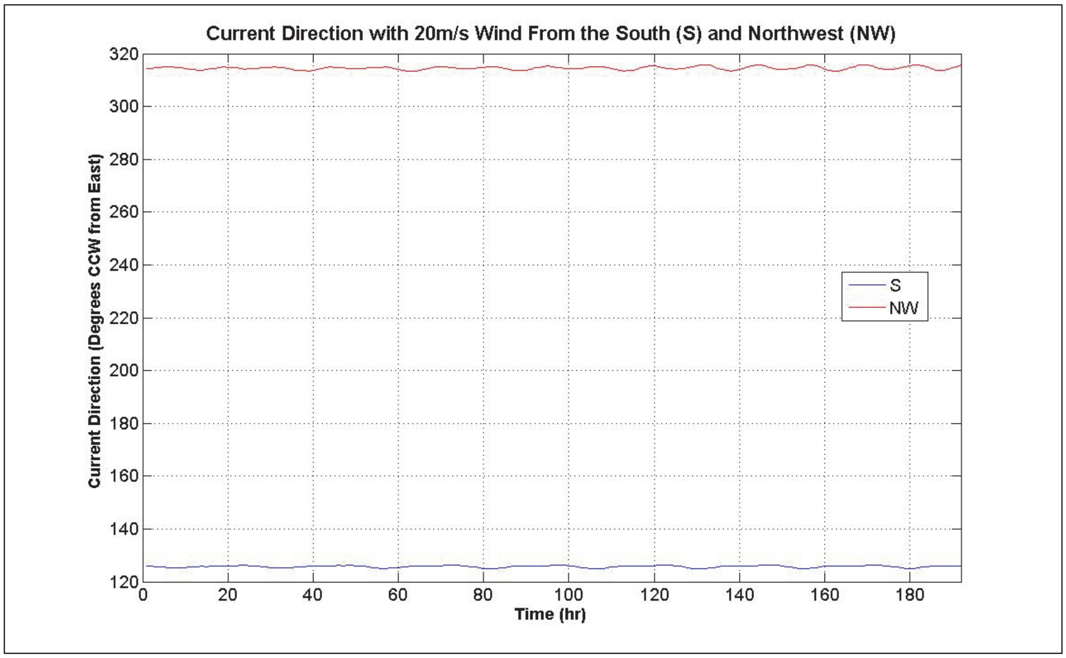

Figure 14. Tidal current direction with steady 20 m/s wind forcing.

The current speeds shown in Figure 14 represent a water depth of 4m. Figure 15 illustrates the variation in cross-shore current speed with depth where time series of currents speed with steady 20 m/s wind forcing are presented for depths of 2 m and 12 m. As expected with a depth-averaged representation of the alongshore current, the magnitude of the current speed decreases with increased depth.

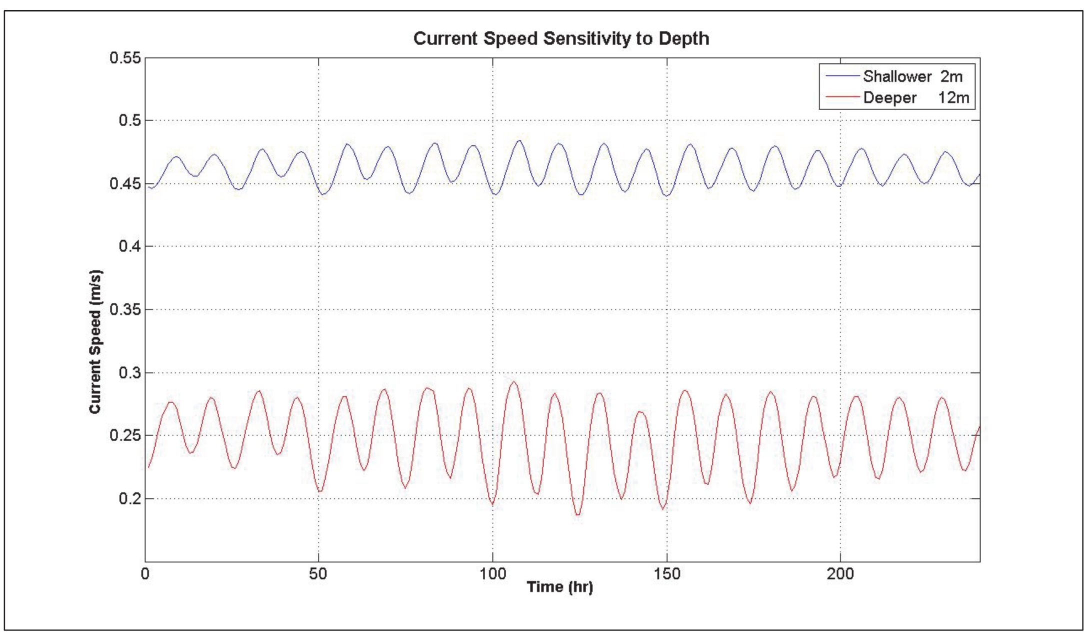

Figure 15. Cross-shore current variation with depth, steady 20 m/s wind forcing.

These modeling results do not account for any localized roughness or structures that can increase the velocity locally. Instead, they represent the expected velocities for the winds and tidal constituents simulated. Higher velocities are possible, especially in the vicinity of breaking waves. However, for the focus of this study, the velocities generated from the hydrodynamic modeling effort will serve as reasonable representative values for testing.

Based on the results of the hydrodynamic modeling, the highest velocities predicted were near 0.5 m/s in shallower waters. For deeper waters, the maximum velocity predicted was less than 0.3 m/s. On that basis, Phase 2 experiments were conducted with flows ranging up to 0.5 m/s. Efforts were made to generate conditions which would result in geobag distortion or movement.

3 Experimental Results

Phase 1: Static Tests

The effectiveness of placing geobags on munitions was evaluated under a matrix of conditions, shown earlier in Table 1. Two primary testing arenas were on dry, hard surfaces and underwater on sediments. Dry testing enabled evaluation of the effectiveness of bag encapsulation. Under these conditions, the weight of the bag is at its greatest (no buoyancy), and the hard smooth floor facilitated munition movement during placement. Testing in the water enabled evaluation of geobag placement effectiveness and identification of challenges arising from placement in water on specific targets.

Nominal size of geobags employed were 6 feet long and 3 feet wide when empty. Geobag size used in this study was dictated by the size of the testing tanks available. Geobags were constructed from a single piece of material folded over on itself. The sides and folded end of the geobag were stitched closed with heavy duty thread sewn through 2 inch strapping material. The open end of the bag had a flap that folded back over the upper third of the geobag. Six lifting straps were attached to the middle and the closed and open ends of the bag. Loops formed by the ends of these straps provided the means to attach to and lift the geobag, Figure 16.

Figure 16. Filled geobag.

Originally, the design of the geobag was such that the flap on the open end was to be secured using ratcheted straps placed around the bag after filling. This approach did allow for flexibility in filling geobags with differing amounts of sand. While this approach appeared to work satisfactorily if the geobag were placed and not moved, successive lifting and lowering of the geobag resulted in its contents shifting, which loosened the strap. Eventually the strap would loosen to the point that the flap was unsecured and geobag contents spilled. To counter this problem, an alternative approach to geobag closure was developed. Rows of aligned grommets were installed in the geobag bottom, top, and flap. When the geobag was filled to the desired level, the grommets were aligned and secured with bolts. This arrangement allowed for geobag movement without compromising the integrity of the contents.

Empty geobags weighed approximately 10 pounds. Filled geobag weight was dependent upon the amount of sand inside. Completely full geobags of the size used in this study required two barrels of sand and were estimated to weigh 1200 pounds dry. This “stuffed” geobag provided the equivalent of a cap of one foot of sand. However, the geobag “fullness” affected its overall shape and its contact area with the sediments. Fuller bags are more rigid and therefore do not readily sag or “flop” when unsupported. This flop is the characteristic that enables a geobag to surround and encapsulate the munition it is placed on. In addition, the flop ensures that the sand cap thickness on the munitions sides and ends are as significant as its top. The cross-section of the “stuffed” geobag, which had less flop, was more oval in nature than one filled with less sand. When larger amounts of sand are place in a bag, the bag’s cross section assumes a more rounded shape. Bags containing one barrel of sand had dry weights of 500 pounds. In these cases, the bags provided eight inches of sand cap when flat.

When bags were not completely filled with sand, the sand would shift as the bag was moved, resulting in unequal sand distribution in the bag. Sand would shift to one end of the bag or the middle. In these instances, the cap thickness over a munition may not be uniform and the encapsulation not complete. From the point of view of securing a munition in place, encapsulation may not be of concern. If the concern is to secure the munition and prevent exposure to any releases, then complete encapsulation is necessary.

To maintain a more uniform distribution of geobag contents, two panels were sewn on the inside of the geobag at 1/3 and 2/3 of the geobag’s width, effectively dividing it into three compartments. The panels prevented sand from shifting from the sides to the middle when the bag was lifted. Forming an attachment between the top and bottom of the geobag enabled a more uniform cap thickness without having to use larger bags.

Effective handling of filled geobags required a rigid lifting frame to prevent geobag deformation due to shifting of internal contents. It was necessary to keep geobags horizontal while they were being lifted and placed. Six short chains attached to the frame with hooks corresponding to locations of geobag lifting straps connect the frame to the geobag. When the frame was lifted, it would raise the geobag evenly and kept it level, resulting in minimal shifting of sand on the inside of the geobag. Once the geobag was in position and ready to be placed, the frame and the geobag were lowered until the bag was in contact with the ground. As this occurred, slack developed in the chains on the frame, enabling the hooks to slip out of the geobag straps, thereby releasing the frame from the geobag.

Dry Land Tests – Horizontal Munition

Dry land tests indicate that the geobags used were of adequate size to fully encapsulate a horizontal piece of ordnance under certain conditions. When the long axis of the munition is aligned with the geobag's long axis, then the geobag was of adequate length to span the munition's full length and contact the sediments on each end. At the same time, the geobag used was wide enough and flexible enough to make contact with sediments on both sides. This was the case for the 155 mm munition and for the smaller 75 mm surrogates. When properly in place, the geobag used provided over 8 in. of capping above and around the shell, Figure 17.

When the munition is oriented perpendicularly to the long axis of the geobag, coverage is still complete but the level of encapsulation is diminished. This is due to two issues. First, the length of the munition is comparable to the geobag width. This prevents the geobag from being able to fully flop over on both sides and encapsulate the munition. The other issue is that the middle lifting strap of the geobag runs the full width of the geobag and lies on top of the munition when the geobag is centered over the munition. This strap makes the geobag slightly stiffer and prevents its sagging. The effect of the strap is more evident on hard surface testing than it would be on a deformable bed.

Figure 17. Geobag with internal panels covering horizontal 155 mm M107.

Results for the two smaller munitions were similar to those of the 155 mm munition. The geobag was able to cover and encapsulate the munition when it was lying parallel to the long axis of the bag. When the geobag long axis is perpendicular to the munition long axis, it is covered and encapsulated but to a lesser degree.

Dry Land Tests – Inclined Munition

An inclined shell was evaluated by placing a 155 mm shell munition in a small jig that maintained an inclination of 30 degrees, Figure 18. In these tests, geobags used were adequate to cover the munition lengthwise but were inadequate for full encapsulation, Figure 19. Placing the munition at an incline effectively increased the height of the object being covered. Geobags used were adequate to touch the sediments and ground on both ends, but too narrow to make contact on the sides. Use of another bag with a larger width would provide adequate area to make contact completely, ensuring that a level of capping is maintained. This test was repeated with the geobag rotated ninety degrees.

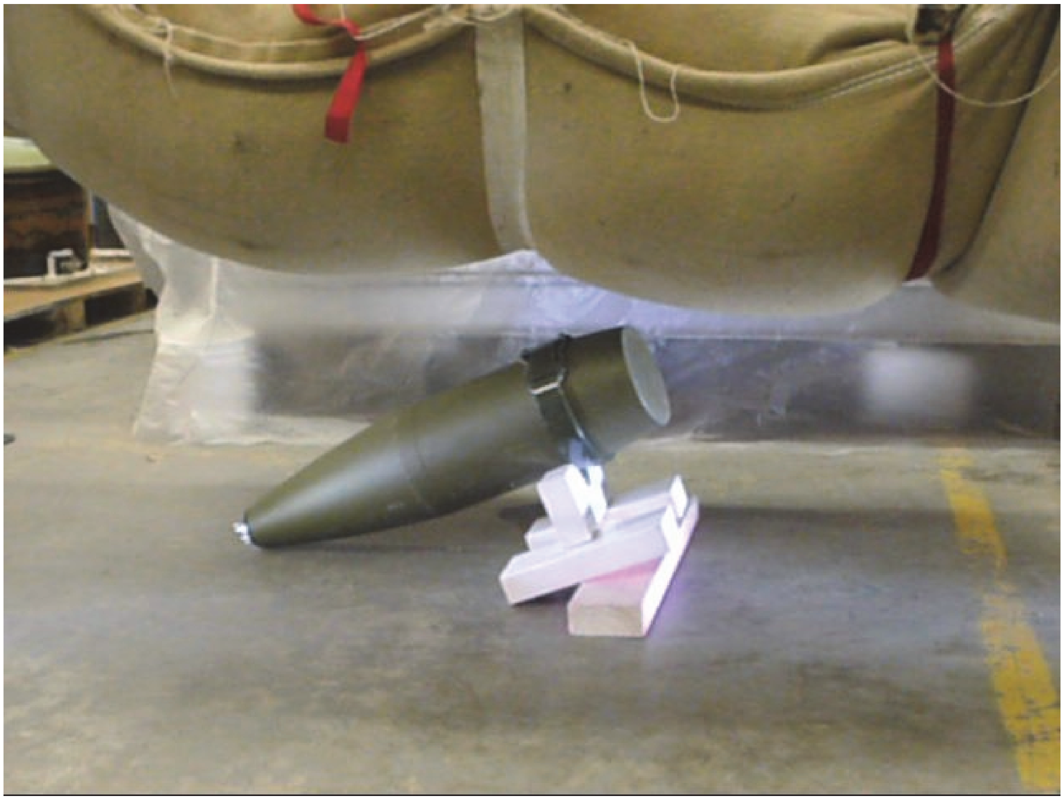

Figure 18. 155mm M107 in elevation jig.

Figure 19. Geobag covering inclined 155mm M107.

Dry Land Tests – Upright Munition

The test with the inclined munition was repeated using a fully upright 155 mm shell. This was a very harsh test in that the full height of the munition sitting on dry land must be covered. As in the instance of the inclined case, geobags used in this experiment were unable to provide full encapsulation. The geobag was too narrow to be able to touch on both sides, even though it was long enough to make contact on the ends, but the geobag could easily be redesigned to fully encapsulate an upright shell if needed.

This test was repeated using the 75 mm munition surrogates. The critical component in this test is not the diameter but instead its length, Figure 20. As with the 155 mm shell, the geobag was able to cover these shells but could not be said to fully encapsulate them. One consideration is that munitions in this orientation are the most unstable and easiest to dislodge.

Figure 20. Geobag on upright munition.

Wet Static Tests – Sandy Surface

Wet static tests were conducted in a 6ft x 6ft glass walled tank in the Sediment Research Laboratory at ERDC. The tank already contained estuarine sediment, which was used as the base. A geotextile fabric was placed on top of this sediment and then washed, sieved sand “rained” down to form a smooth sand bed. The bed produced was firm. The sand bed was covered by three feet of water with a salinity of 13.5 PPT.

Wet Static Tests – Horizontal Munition

The first test was to encapsulate a 155 mm munition in a horizontal position on the sediment surface. The munition was lowered horizontally and set carefully in place on the top of the sand bed without disturbing the adjacent bed, Figure 21. Once the munition was in place a geobag was hoisted and placed directly above the munition. The geobag was slowly lowered into the water until it was directly above the munition but not in contact, Figure 22. Next, the bag was lowered until it came in contact with the sand bed and the weight of the geobag was supported by the sand bed and munition. The support frame was disconnected and raised, leaving the geobag in the tank on the munition, Figure 23.

Visual examination of the geobag sides indicated that it appeared to be in full contact with the sand bed on all sides. Even the location of the middle lifting strap had full contact with the bottom. When the geobag was

Figure 21. 155mm M107 on sand bed.

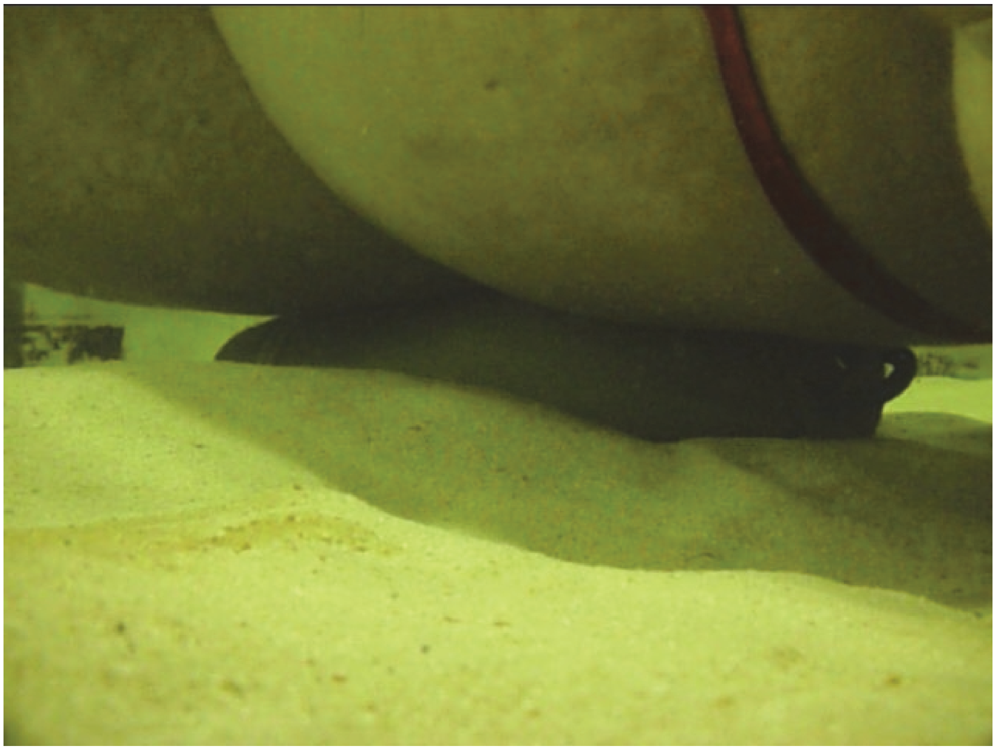

Figure 22. Geobag making contact with munition.

Figure 23. Geobag post placement.

removed, it was evident from the imprint in the sand that the bag had been in full contact with the sand in all directions around the munition. Also evident was that the geobag weight had depressed the shell slightly in the sand. The test was repeated with the ordnance already partially depressed and full coverage was observed.

Wet Static Tests – Inclined Munition

Wet static tests of an elevated shell were conducted using the same jig as used in the dry land tests. As the sand bottom was partially deformable, the nose of the munition sank into the sand, Figure 24. This lowered the overall height of the shell above the sediment surface. When the geobag was placed over the munition and jig combination it draped over the ends and made good contact with the sediments. However, the munition and jig combination was too tall for the bag to make contact with the sediments on the sides, Figure 25.

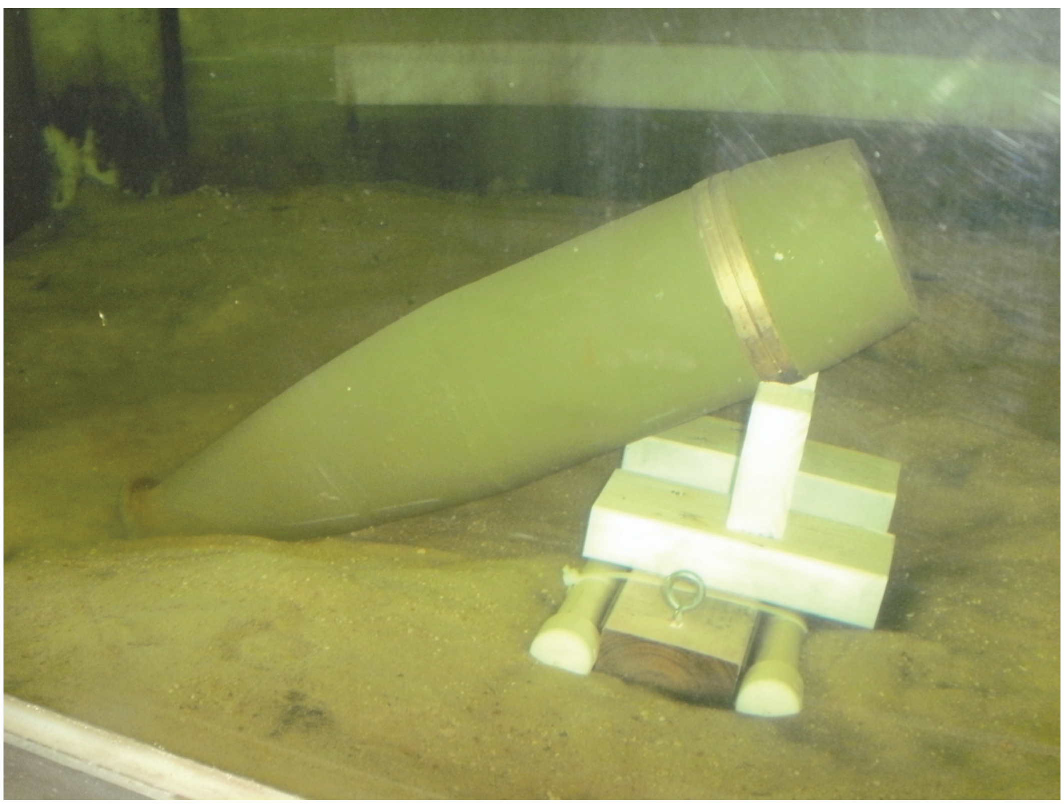

Figure 24. Underwater inclined 155 mm M107.

Figure 25. Geobag on inclined 155 mm M107.

Wet Static Tests – Upright Munition

Wet static tests of an upright muniton were similar to those of the static dry tests. The relative softness of the sandy bottom in comparison to that of the concrete slab made it easier for the munition to topple over under weight of geobag. Once this occurred, then placement was the same as placement on a horizontal munition.

Wet Static Tests – Clay Surface

Geobag placement tests for a munition on clay sediment were conducted in 7-ft diameter tanks in the Hazardous Waste Research Center (HWRC) Pilot Laboratory. The tank bottom was a smooth 10-inch bed of kaolinte overlain by 4 feet of water. The kaolinite sediment had been in place for over a year. Tank construction prevented viewing from the sides as was the case in the Sediment Research Laboratories 6 ft x 6 ft tank. Visibility from above the tank was good.

Wet Static Tests – Horizontal Munition

A 155 mm M107 munition was lowered in a horizontal orientation and placed on the top of the kaolinite bed without disturbing adjacent sediments. The bed was softer than expected and the munition initially sank into the sediments 1 inch. Following munition placement a geobag was hoisted and placed directly above the shell. The geobag was slowly lowered into the water until it was directly above the munition but not in contact. Next the bag was lowered until it came in contact with the sediment bed and munition. Some kaolinite was suspended but not enough to hinder viewing from above. The support frame was disconnected and removed leaving the sediment and munition to support the geobag's weight.

After placement, visual examination of the geobag indicated full contact with sediments along all sides. Kaolinite particles suspended by geobag placement remained in suspension several days until finally settling. Geobag removal indicated that the munition had been pushed deeper into the kaolinite sediment by the geobag weight. What had begun as a surface placement test had resulted in a partially buried case.

No additional munition orientations were evaluated using the kaolinite sediments due to sediment softness.

Phase 2: Dynamic Tests

Olmstead Flume

The Olmsted Flume at ERDC was used for this work. The flume currently has two surfaces: a consolidated 5 ft thick gravel bed in the upstream portion of the flume and a clean slab on the downstream portion. The gravel bed is in the flume for work not related to this project. The downstream end of the gravel bed is confined by a porous retaining wall. Flow can go through or over the porous wall, depending upon water surface height.

Gravel Bed

The gravel bed provides a good surface to evaluate geobag performance on porous surfaces. The porous nature of the gravel bed allows for assessment of the effect of upflow and scour on geobag effectiveness. The lower portion of the flume is open, smooth concrete which serves as a good surface for simulating conditions on hardpan sediments. This surface provided the best opportunity for geobag movement and dislodgement from encapsulated ordnance.

Hardpan Tests – Horizontal Munition

Three geobags were used in these tests. Each was placed on top of a 155 mm munition. A large geobag containing two barrels of sand filler was placed in line with flow direction. This is shown on the left side of Figure 26 with a red tie strap. Next, a geobag containing 500 lbs of sand filler was placed in the flume oriented to be in line with the flow direction. A third geobag containing 500 lbs of sand filler was placed perpendicular to the flow direction. Geobags were spaced adequately in the flume so that flow disturbances from one would not significantly alter another. The two geobags containing 500 pounds of sand filler were placed in what was felt to be the most energetic portion of the flow field where there would be the highest probability for movement. During the same tests, an unconstrained 155mm M107 munition was placed in the flume and allowed to move in response to flow conditions. Note that the munition was tethered to avoid damaging flume gates in the event it is completely dislodged.

Figure 26. Geobags and M107 munitions in flume.

Gate and pump settings during this test produced water depths exceeding 1 foot throughout the area containing the three geobags, Figure 27. The test was stopped when flow conditions through the gravel bed resulted in 1 inch size and larger gravel washing downstream onto the testing area. Velocities in the vicinity of the geobags prior to cessation of the test were observed to be 1.5 ft/s, or 0.5 m/s. Though no geobag moved, the uncovered munition did roll three times in response to the initial wave of water. It remained stationary once fully inundated.

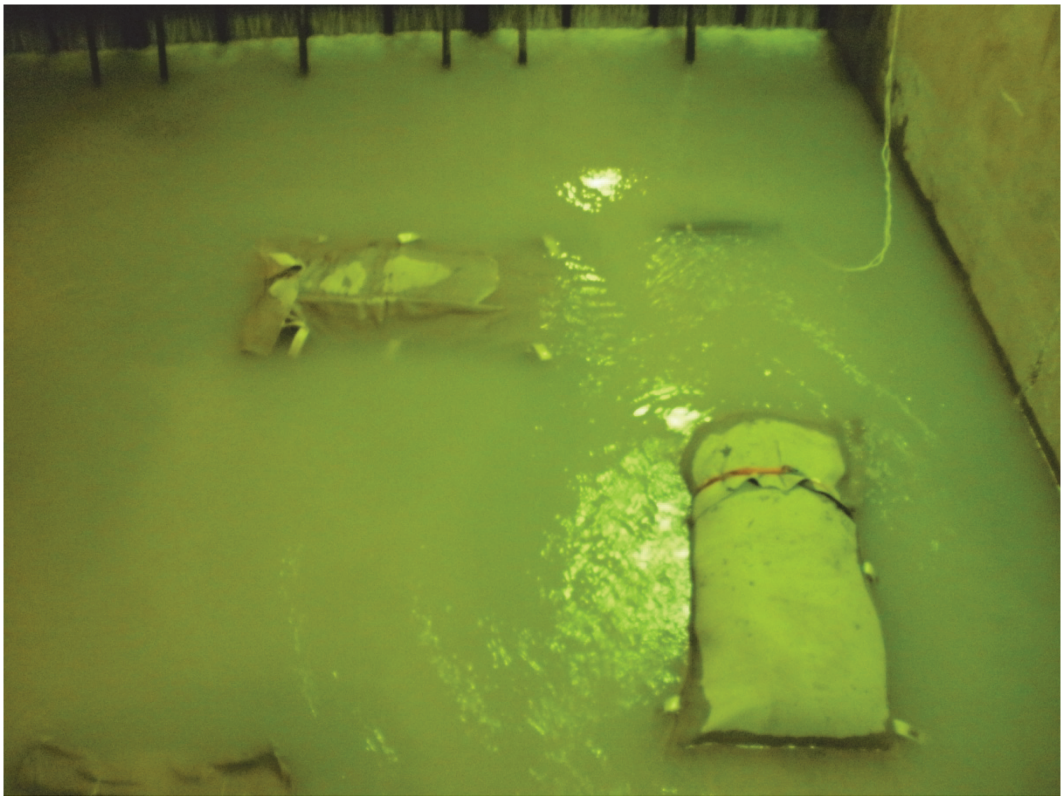

Figure 27. Phase 2 hardpan test under way.

Figure 28 shows the test site the next day. Sediments on the floor are deposits that washed from the gravel bed upstream, not the geobags. After the test, geobags were in original positions with no change in shape or orientation. No deformation was evident in the geobag shapes and no filler material was lost from any geobag. All flaps were secured and had not been dislodged by the flume test.

Additional Phase 2 tests were conducted in which the location and orientation of the geobags on the hardpan test bed were modified. Two bags were placed downstream of the gravel bed retaining wall. One was perpendicular to flow direction, the other parallel, Figure 29. A third geobag was placed perpendicular to flow direction near the downstream flume gate. The rationale behind placing the bags perpendicular to flow direction was to provide the greatest cross section, which should facilitate geobag

Figure 28. Geobags and free 155 mm M107 muniton after first flume test.

dislodgement, rolling, or other form of failure. A fourth geobag was placed on the packed gravel bed parallel to flow direction, Figure 30. All geobags were covering 155 mm munitions that were oriented with the long axis of the geobag. Three free munitions were placed in the hardpan test area and one on the gravel bed. All free munitions were attached to retention lines to prevent their reaching and damaging the flume gates in the event that the munitions were dislodged by the flow. All retention lines had adequate slack to allow munitions movement in response to flow forces.

Figure 29. Phase 2 hardpan area.

Figure 30. Geobag and exposed munition on flume gravel bed.

During these Phase two tests the flume was filled to a depth of eight feet over the hardpan test area and three feet over the gravel bed. This resulted in complete submergence for all geobags. Water levels were maintained at this level for one hour before turning off the pumps. The water in the flume was allowed to drain normally.

After the flume had completely drained, it was determined that none of the geobags on the hardpan test area were moved nor did any appear to have lost filler material. The closing flap of one geobag had been flipped up by the flow but the bag remained securely closed by the bolts connecting geobag top and bottom. Since the geobags were not moved, the 155 mm munitions that they covered were still in place. Upon closer inspection, it was determined that all geobags had not shifted and were in contact with the surface all around the munitions. At the same time, the flow conditions over portions of the hardpan test areas were adequate to mobilize one of the uncovered 155 mm munitions. This munition rolled in response to flow conditions until it was stopped by its retaining rope. Total distance traveled during the test was 10 feet. It would have gone further without the restraining rope.

Results for the geobag placed on the gravel bed indicated that it did not move. After the test, there was evidence that the disruption in flow patterns around the bag resulted in scour at the bag's upstream end, Figure 31. Scour depth was 6 inches and was observed at the upstream end of the geobag and along the sides. The scour did not extend under the bag and did not compromise the geobag's munition coverage. The free munition placed on the gravel bed did not move during this test, although there was evidence of scour.

Figure 31. Geobag on gravel bed after test showing scour on upstream (right) end.

4 Discussion

Discussion of the results obtained and observations made during this study are presented here. This study was of limited scope and a “proof-of-concept” effort to determine whether it would be reasonable to place geobags on top of underwater munitions.

Sizes and Coverage of Geobags

Geobags used for this work were sized to accommodate the limitations of the tanks used for Phase 1 Static testing. No accommodation was made for the bags to be able to fully encapsulate and cover the larger munition used (155 mm) in all possible orientations. As such, while the geobag did cover this large munition in all positions and orientations evaluated, it did not provide encapsulation in all instances. This failure was solely the result of the geobags being sized for the testing tanks. Had the bags been larger, then there would have been complete coverage and encapsulation.

Geobag Shape

Another consideration is that the Phase 1 geobags were all rectangular in nature. This shape is satisfactory for covering a single munition. Where clusters of munitions are a concern, different shape geobags may be desirable. An advantage of a round geobag is that it would extend equal distance in all areas provided it was centered over the munition.

Geobag Weight

It must be noted that larger geobags will require additional filler and will therefore have significantly higher handling weights. Depending upon the degree of filling, geobags used in this study weighed from 500 to 1200 lbs. A geobag filled with sand with nominal dimensions of 6 ft by 6 ft would weigh 2500 pounds or more depending upon cap thickness. Figure 32 to Figure 35 illustrate the weights for different sized rectangular geobags with varying thicknesses.

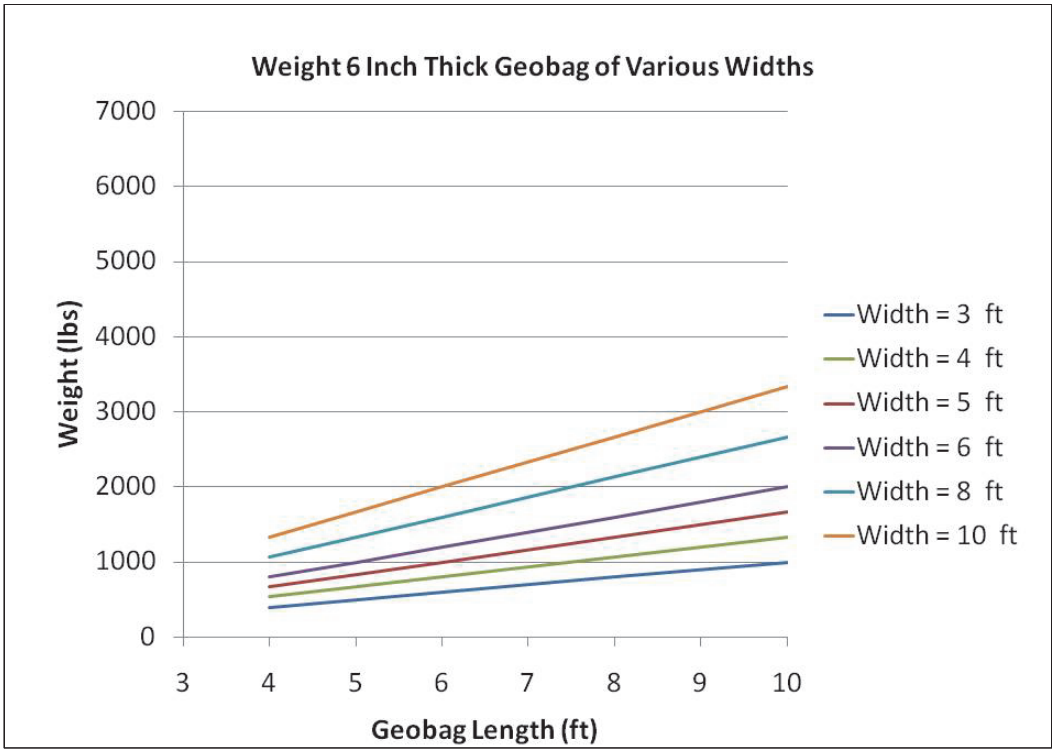

Figure 32. Weight of geobags with 6 inch thicknesses.

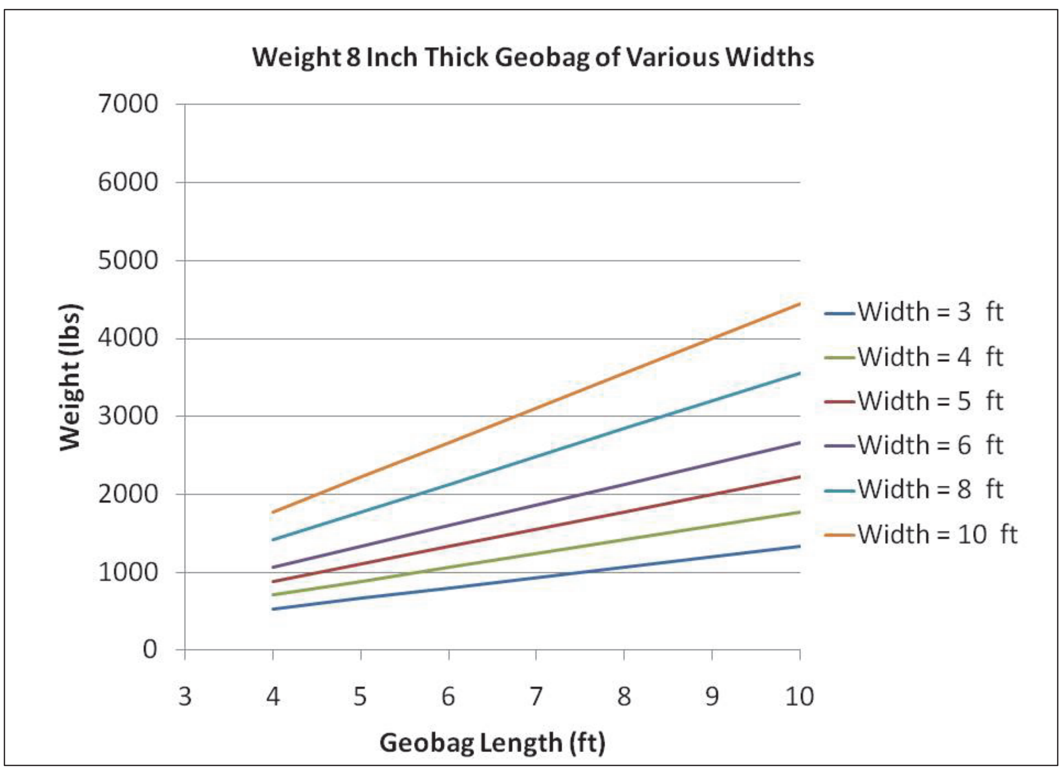

Figure 33. Weight of geobags with 8 inch thicknesses.

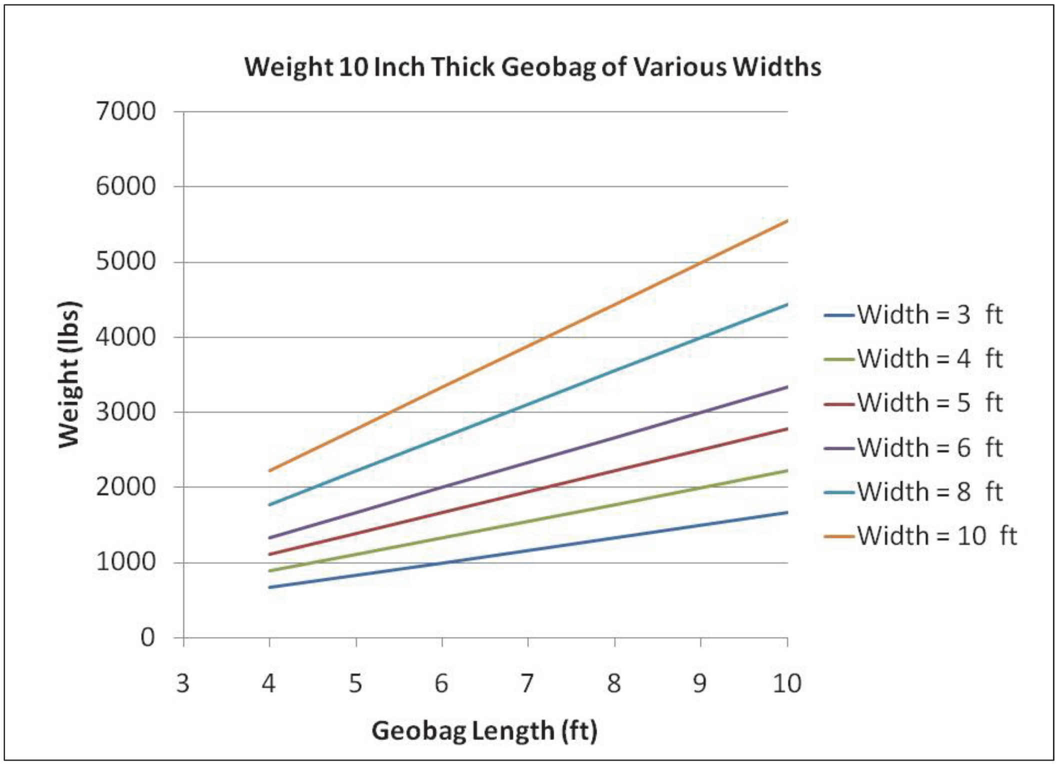

Figure 34. Weight of geobags with 10 inch thicknesses.

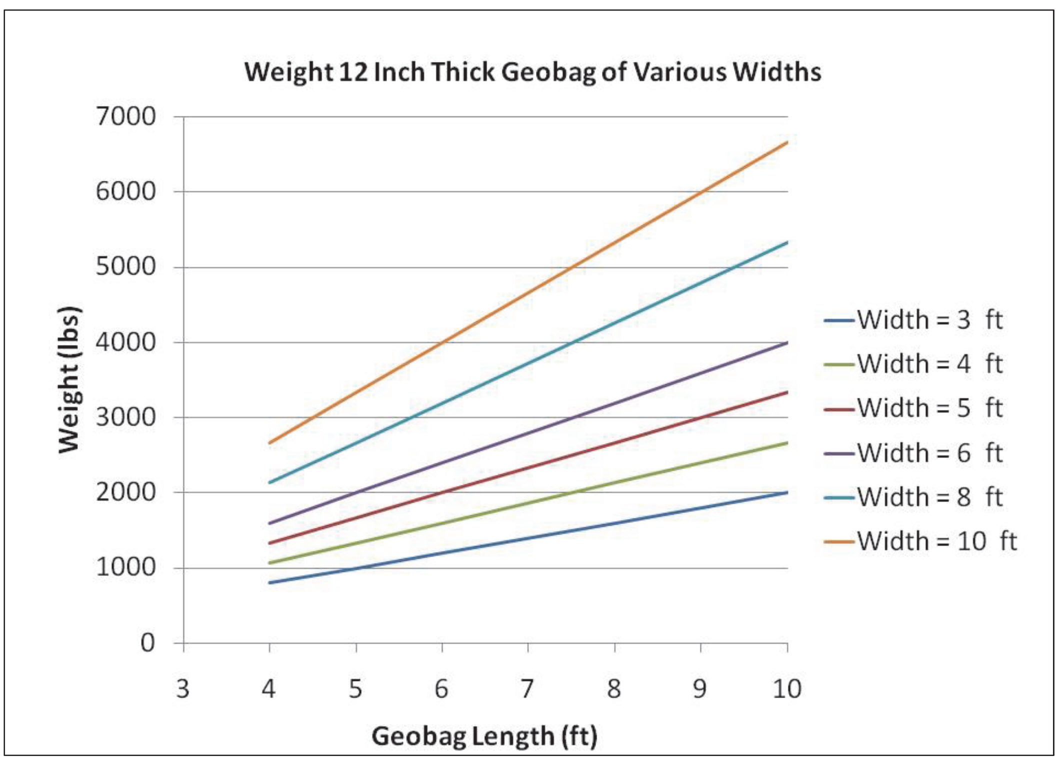

Figure 35. Weight of geobags with 12 in thicknesses.

Geobag weight is distributed over the area of contact. Properly placed geobag weight would be nearly uniformly distributed. Slight variations may occur due to the deflections in the geobag caused by the munition. Even in this case, properly constructed geobags would prevent significant redistribution or sloughing of geobag contents. Table 3 indicates the expected pressure generated by placement in salt water of a geobag filled with clean sand (Porosity = 40%).

Table 3. Geobag pressure.

Geobag Thickness (in)	Pressure (lb/ft^2)	Pressure (lb/in^2)
6	30.8	0.21
8	41.0	0.29
10	51.3	0.36
12	61.6	0.43

Geobag Modifications

Geobags as originally fabricated worked well during Phase 1 and initial Phase 2 testing. The materials and construction were sufficient to hold up to 1200 pounds of dry sand filler as it was hoisted and placed. Through the various phases of testing, two modifications to the geobag were identified. One is a modification to the method used to secure the flap. The other is addition of internal panels to maintain geobag shape.

Closing Flap

The simplest criteria were used for geobag design: it needed to be filled with a granular solid, placed horizontally, and fit the size requirements of the test tank environment. This resulted in a rectangular geobag with one end open to allow filling. A flap at the open end was used to close the bag. Initial plans were to hold the flap in place with ratcheted tie down straps. This concept worked well with stationary geobags filled to capacity. However, when a partially filled geobag was hoisted, shifting sand inside the geobag resulted in the tie down strap loosening. Tie down straps required continual adjustment to prevent slippage. At the same time, tightening the strap resulted in the sand in the bag being displaced, which caused the geobag to have distorted shapes with uneven sand thickness throughout the geobag.

As a replacement for the tie down strap, grommets were placed in the front and back of the opening of the bag and also the flap. Short bolts placed through these grommets enabled the open end of the bag to be secured without use of tie down straps. Securing the geobag without the strap also maintained the rectangular shape of the bag allowing it to provide a more uniform cap.

The Initial Phase 2 test indicated that geobag flaps should be completely secured. Though the bags in question were closed and secured, flowing water could flip the flap back and allow access to geobag filler. This is a concern if reactive components were used for filler. Also, exposing the filler enables it to be displaced over time, potentially lightening the geobag and easing displacement.

Interior Panels

The bags as constructed can hold two barrels of sand and weigh 1200 pounds. When filled to this degree, their shape is more tube-like than slab-like. The geobags were constructed from a single piece of material which was folded over and had the sides stitched together. Therefore, when the bag is filled, as the middle gets thicker, the bag cross section becomes rounder. This results in the sediment surface contact area of the bag decreasing and the bag having higher profiles. Alternatively, if the bags are only partially filled, they will maintain sediment contact areas near that of the empty bag. Their vertical projection is less, so that they present less cross sectional area to the overlying flow field. The problem with partially filling a geobag is that when the bag is lifted for movement or placement, the flexible nature of the geobag allows the interior sands to shift. Typically the sand shifted to the middle of the geobag resulting in uneven capping when the geobag was placed.

Longitudinal panels were sewn into the inside of the geobag to improve geobag shape stability. Two panels were attached on the interior resulting in the geobag having three compartments. The panels were three feet long and – when installed – 8 inches high. The panels served two roles. First, they prevented sand redistribution from the sides to the middle of the geobag when it was lifted. Second, by being attached in the top and the bottom surfaces of the geobag to each other, the panels stabilized the geobag shape ensuring that a more uniform cap was provided. A major advantage of the panels was that it enabled a partially filled bag (500 pounds dry weight) to maintain its shape and provide the same levels of capping and coverage as a bag without panels weighing 900 pounds.

Placement Experiences

Overall experiences from Phase 1 Static Tests indicated that geobag placement on munitions was a feasible task with a high degree of precision with the appropriate equipment. Movement and placement of bags in a laboratory setting was not difficult when using overhead cranes and electric hoists. Geobags filled with dry sand weights varied from 500 to 1200 pounds for the size bags used in this study. As discussed earlier, the rectangular bags used in the study did not always completely encapsulate the shell. Therefore, larger and heavier geobags may be required to encompass larger munitions or those with eccentric orientations. An alternative to larger geobags is to use multiple geobags stacked in a manner to completely cover the munitions.

A critical component was the rectangular frame from which the corners and sides of the geobag were suspended. This frame maintained the geobag's shape during placement. It also allowed precise movements to be made to ensure that the geobag was placed with the munition in the desired location. The flexible nature of the geobag lacks rigidity so the handling process distorts the geobag's contents when it is lifted by the straps alone.

Geobag Size Requirements

Geobags used in Phase 1 Static Tests were suitable to cover the munitions used in this work, provided they were in a horizontal position. The width or diameter of the munition controlled the effectiveness of the geobag coverage. The flexibility of the geobag was adequate to allow the areas not supported by the munition to sag or flop until it made contact with the sediments. This was not the case with elevated munitions. Widths of the geobags used in Phase 1 Static Tests were inadequate to cover the elevated munitions and reach the sediments.

In order to determine the size required for encapsulation, elevation of the munition above the surrounding area, munition dimensions, and filled geobag thickness are required, Figure 36. The dimensions necessary to overlap the munition are based on munition diameter, elevation above the ground, and geobag thickness, Equation 1. A summary of the minimum dimensions required are shown in Figure 37 to Figure 39. All units are in

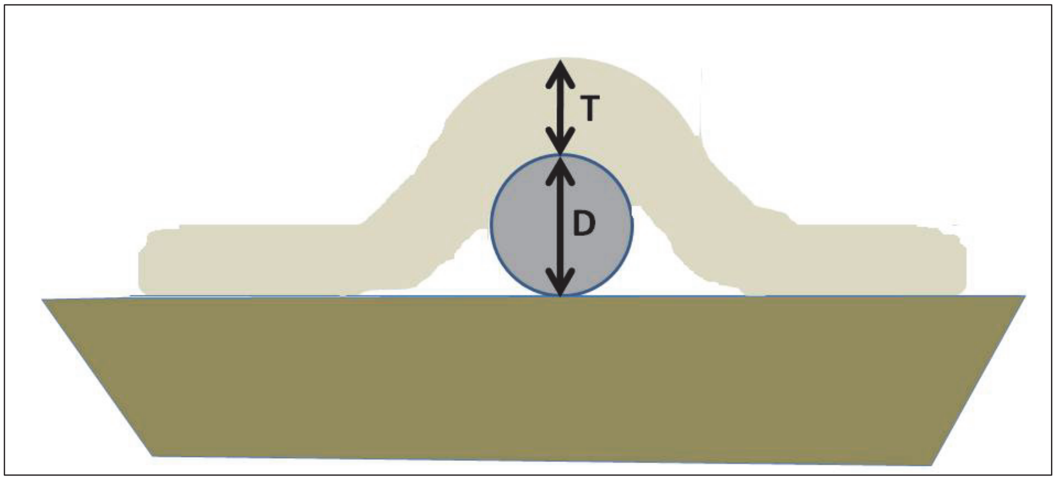

Figure 36. Geobag sizing information.

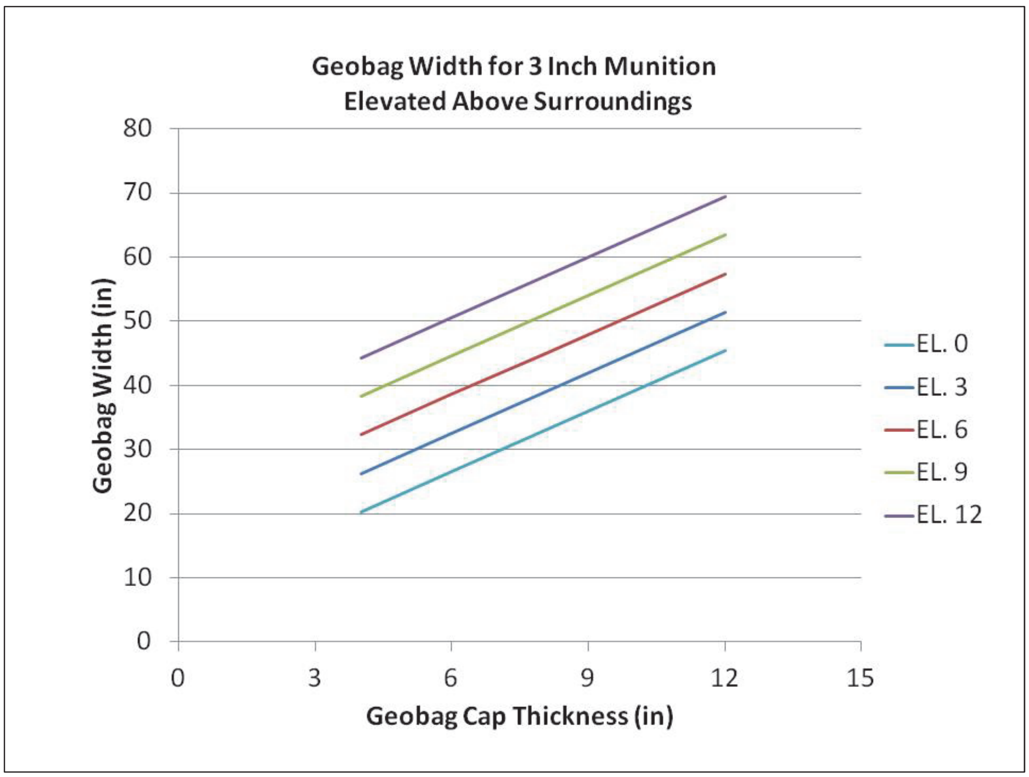

Figure 37. Geobag sizing guidance for 3 inch diameter or equivalent munitions.

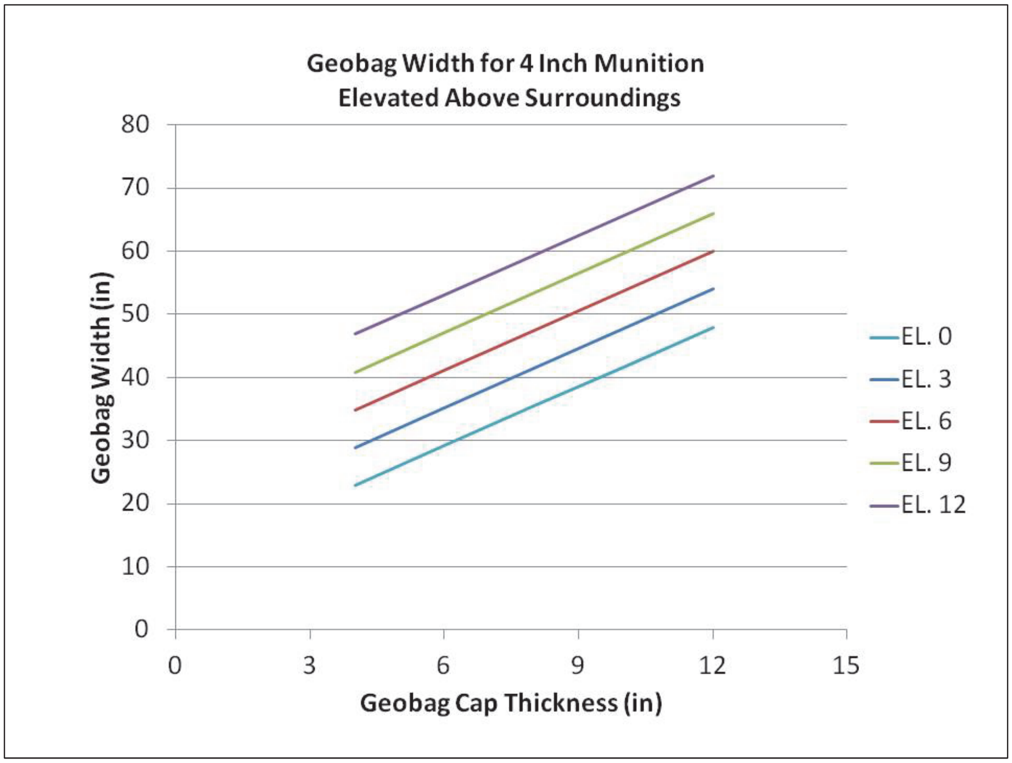

Figure 38. Geobag sizing guidance for 4 inch diameter or equivalent munitions.

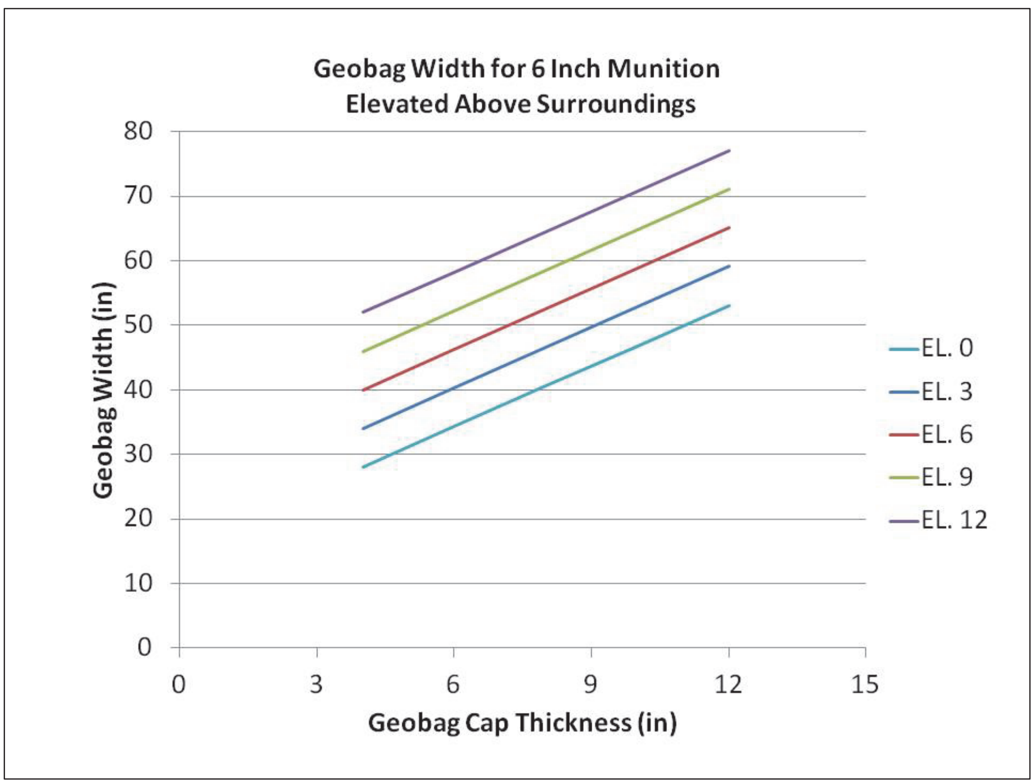

Figure 39. Geobag sizing guidance for 6 in diameter or equivalent munitions.

inches. It must be emphasized that these are the minimum. Geobag lengths should be adequate to extend past either end of the munition, no less than half the width specified in Figure 37 to Figure 39. This is necessary to completely cover the munition lengthwise and still reach the sediment. Another way to obtain the required geobag length is to ensure the geobags are larger than the widths obtained from Equation 1 and Figures 37 to 39, plus the full length of the munition.

Equation 1: Computation for minimum geobag width

$$Width = D \bullet \left(\frac{\pi}{2} + 1\right) + (T \bullet \pi) + 2 \bullet Elevation$$

where:

Width = minimum geobag width to encapsulate munition
D = Munition maximum diameter
T = Geobag thickness
Elevation = distance that bottom of munition is raised above sediment surface

5 Conclusions and Implications for Future Research

The objective of this study was an investigation of geobags for use in submerged munition immobilization. An initial geobag design was developed and its effectiveness evaluated using two criteria. Geobag coverage of the test munition (encapsulation) was the first criteria. Geobag stability in moving water was the second.

Conclusions

Immobilization

Geobags provide a feasible option for the immobilization of munitions in underwater environments. By completely covering a munition or a portion of it, geobags hold the munition in place and prevent its movement under conditions where it might otherwise move. Immobilization means that the munition's location is known, should further actions such as removal or detonation in place be desired at a later date. Immobilization also prevents a munition from relocating into areas where there is greater potential for human exposure.

Encapsulation

Properly sized and placed geobags are capable of completely covering and isolating munitions. This serves three purposes. First, completely covered munitions are not exposed for swimmers or divers to encounter nor are they exposed for fouling in fishing gear. Second, complete coverage of the munition aids in containing releases to the environment should any occur. Third, complete coverage of the munition decreases aquatic and marine life exposure to any releases from degraded or breeched munitions.

Geobag Stability

Geobags placed in flowing waters in a test environment were stable. No geobag movement, deformation, or filler spillage occurred during flow testing. Conditions encountered during testing were insufficient to dislodge geobags even though they were sufficient to move sediment, scour gravel, and move uncovered munitions.

Geobags used in this study withstood conditions similar to or exceeding those that would be experienced at Ordnance Reef, HI. It must be remembered that these modeling results are for predicted currents and do not necessarily represent conditions in a surf zone or where large waves are breaking. Geobags withstood conditions that were sufficient to move exposed munitions, dislodge sediment, and scour packed gravel in the Phase 2 flow tests. Conditions sufficient to dislodge a placed geobag would greatly exceed those required to move exposed munitions.

Geobag Handling and Placement

Geobags due to their size requirements and the amount of filler required are heavy. Handling outside of water requires assistance for lifting and placing. Placement in water requires access to cranes, hoists, or other lifting aids such as lifting bags to compensate for geobag weight. Smaller geobags require less sand filler than those used in this study but would still be too heavy to manage without mechanical lifting means.

Future Research Needs

This study has achieved its goal of demonstrating the feasibility of using geobags for immobilizing submerged munitions under controlled conditions. Through experiences and insight gained with this work, additional research tasks have been identified.

Demonstration of Geobag Performance in Natural Environment

This effort enables evaluation of the long term effectiveness of geobags and identification of issues that were not encountered or foreseen in the laboratory setting. The focus of this effort is the development and demonstration of equipment and techniques for effective geobag placement on top of munitions at depth. Once placed, geobag performance will be monitored with time to evaluate long-term immobilization and encapsulation. This task should be of the highest priority as it demonstrates the concept in “real world” conditions.

Geobag Configurations

Geobags in the current study were constructed according to testing site requirements. Other geobag sizes and shapes offer potential for different types of applications. Simple modifications implemented in the current study (internal panels, geobag closure processes) require refinement prior to widespread application. Alternative means of filling geobags are also of interest, such as pumping filler into an already placed partially filled geobag. This process would lighten geobags' weight during placement, thereby easing placement.

Development of Analytical Tool for Geobag Sizing

This effort will generate simple-to-use tools that enable one to correctly specify the size and characteristics of a geobag based on the munition to be covered. Criteria such as munition type and number, size, orientation, and location will be considered. Information on local flow fields will be used to assess hydrodynamic forces on geobags to refine design. Sediment characteristics will also be included in this tool so that scouring/erosion issues associated with geobag placement can be investigated. The final product will enable user development of application-specific geobag specifications that satisfy the needs of that project.

Use of Geobags for Localized Munition Spills and Containment

By immobilizing and encapsulating munitions, geobags limit distribution of contaminants originating from the munition. Selective use of materials for geobag construction and filling will enhance the geobags' ability to treat any spills that may occur. This facilitates hybrid geobag design development for different types of munitions or other contaminants that may be encountered.

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14. ABSTRACT

Underwater munitions pose a risk to human health and safety as well as a potential threat to the environment. Current management options are limited to removal, in-place detonation, or leave-in-place. Furthermore, munitions subjected to ocean currents may be mobile, confounding monitoring, removal or detonation after initial detection. Capping technology used in the control of contaminated sediments has the potential to immobilize and isolate munitions from the overlying water column thereby safeguarding human exposure and the environment.

This study designed, developed, and tested geobags for immobilizing submerged munitions. Geobags are constructed from synthetic geotextiles and filled with sand. Typical sizes of geobags used were 5 ft x 2.5 ft with filled weights varying between 500 and 1200 pounds. Tests were conducted in still and flowing waters to demonstrate whether geobags were a viable option for dealing with underwater munitions. Results indicate geobags, when properly placed, would immobilize a munition and completely surround it thereby isolating it from the overlying water column. This "cap" would prevent any spills or releases from the munition from entering the environment and also safeguarding human exposure. With an estimated design life exceeding 100 years, geobags provide an inexpensive, easy to implement method to address the issue of submerged munitions.

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