Marine Pollution Bulletin 101 (2015) 61–68

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Merits of partial shielding in dumping sediment spoils

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ARTICLE INFO

Article history:
Received 23 July 2015
Received in revised form 6 November 2015
Accepted 6 November 2015
Available online 18 November 2015

Keywords:
Environmental dumping method
Split-hull barge
Hopper
Dredge spoils
Shielding
Environmental impacts

ABSTRACT

The commonly adopted method of dumping dredge spoil at sea using split-hull barges leads to considerable sediment loss to the water column and a subsequent dispersion of fine material that can pose a risk to sensitive "downstream" habitats such as coral reefs. Containing sediment loads using stitched closed geotextile bags is practiced for minimizing loss of contaminated sediment, but is expensive in terms of operational efficiency. Following promising observations from initial laboratory trials, the plunging of partially shielded sediment loads, released on open sea, was studied. The partial shielding was achieved with rigid, open containers as well as flexible, open bags. The loss of sediment from these modes of shielding was measured, and it was observed that even limited and unstitched shielding can be effective in debilitating the entrainment of water into the descending load. In particular, long-sleeved flexible bags practically self-eliminated the exposure of the load and thus losses.

1. Introduction

Dumping at sea of dredge spoils or other types of sediment loads is often carried out using split-hull or hopper barges. In split-hull barges the bottom splits open longitudinally on massive hydraulic hinges, and the load gravitates into the water below (Fig. 1). When the load is released the sediment forms a coherent plume plunging towards the seabed. The plume displaces the ambient water as it plunges, generating an upward (compensating) return flow field around it. The water separates on the lee-side of the plume, and is sucked into the core of the plume by the induced pressure differences. The dilution of the plume through the entrainment of water causes a rapid expansion of the plume, leading to a reduction in plume density and therefore its deceleration and greater retention time in the water column. This process increases the probability of fine sediment persistence, and as a consequence, a settling plume will be susceptible to emitting a large fraction of its fines to the ambient water. If exposed to ambient currents, these fines can potentially feed into far-reaching and persistent sediment plumes. Such regional plumes pose environmental challenges, particularly when in proximity to sensitive ecosystems (e.g. coral reefs, Erftemeijer et al., 2012).

The Water Framework Directive, the Marine Strategy Framework Directive and the Waste Framework Directive of the European Parliament all recognize human-induced changes to the concentration of suspended sediments in marine waters as a major pollutant, and the associated overflow of spoils and fines as a waste product. Consequently, there is a focus on developing environmentally friendly methods to effectively mitigate and control impacts of works involving the release of fines.

Mitigating impacts of turbid plumes in the open sea from dumping of dredged spoils is traditionally achieved by dumping at permitted sites. Dumping is normally only permitted at sites locationed sufficiently far "downstream" from sensitive receptors, and are typically found in deeper waters, where currents are benign, and subsequent re-suspension events have a small probability of causing environmental impacts. The existing dumping practice therefore relies on a relatively large ocean volume to contain the plumes and to keep it from sensitive areas.

Dumping of contaminated sediment and waste materials follows a different more restrictive practice to comply with the strict regulations on the dispersion of contaminated sediment into the marine environment. In this case, any interaction between the load and the ambient water is usually not tolerated (both during descent and when resting on the seabed), and at-source measures are necessary.

A common at-source measure is to seal the contaminated sediment or waste in containers or bags. Often strong geotextile bags consisting of several layers of woven polypropylene are used (see Bowles and Fleischer (1999)). These bags, when stitched closed, practically ensure the elimination of sediment spill (i.e., hinder the interaction between the sediments and the ambient waters), and are designed to remain

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http://dx.doi.org/10.1016/j.marpolbul.2015.11.023
0025-326X/

Fig. 1. Split-hull barge with Courtesy of International Marine Consultancy (IMCBrokers). Note the longitudinal hull splitting and the lowered gunwale (reduced freeboard).

sealed while deforming upon impact with the sea floor. Bowles and Fleischer (1999) report a volume loss from such sealed bags to be less than 0.003%. Moreover, the bags can withstand long-term salt-water exposure and wave-current weathering. The dimensions and applications of geotextile containers vary. For example, loading of 600 m^3 bags placed on the inside of hoppers, stitched closed and subsequently dumped, is practiced for the disposal of contaminated sediments (e.g., TENCATE Geocontainer brochures).

Adopting the above measure for contaminated sediment or waste as a common practice in dumping is, however, not feasible given the large volume of dredge spoils involved in even small dredging operations. This is partly because of the high requirements on the strength and impermeability of the textile, and partly because the sealing (stitching) is done manually.

The underlying motivation of this work is to outline a practical and environmentally friendly method for disposing of (uncontaminated) sediments (e.g., dredge spoils). It is believed that hopper-fitted bags mounted in split-hull barges have a potential for treating dredge spoils at the "source", and for reducing retention times and minimizing (if not eliminating) the releases of fines from dredge spoil disposal operations. The postulate is that container bags used even *unsealed*, will still offer significant shielding to the load. In general, the dumping of uncontaminated spoils in open (unsealed) bags will benefit from i) not having to be (manually) sealed, ii) not being subject to strict textile specifications on withstanding seabed impact and long-term strength and wear and iii) not being subject to demanding criteria for the emittance of fines from impact upon the seabed. These relaxed conditions can be converted to bags larger than those used for contaminated sediments and to bags made of e.g. degradable materials.

To investigate the efficiency of dumping using unsealed shielding of the load and to test the postulate above, two field experiments have been conducted. Both experiments were carried out in the near-shore waters off the southern coast of Cyprus, inside the bay of Ayia Napa, in March 2014 and July 2015, respectively. Various payloads in "household-sized" containers were released from a diving pontoon and hydrodynamical processes responsible for the losses of sediment were observed and the actual losses of sediment were recorded. A detailed description of the site, hydrographic conditions and the extent of the plumes associated with the loads released unshielded are presented in Jensen et al. (2015). In the following, the shielded experiments are described in further detail.

2. Initial experiments

Preliminary small-scale tests were conducted in the hydraulics laboratory at the Technical University of Denmark prior to the field experiments. Relatively small, open cylindrical plastic buckets and plastic bags half-filled with sediment were released in the water column of a relatively deep silo. The interaction between the shielded sediment load and the ambient water was observed, and the loss of sediment from the containers as a result of plunging through the water column, was measured.

2.1. Experimental settings

The height of the cylindrical bucket was 4.75 cm and its diameter 3.00 cm. When ironed out, the width and height of the bag were 5.00 cm and 4.75 cm, respectively; corresponding to an equivalent diameter (Eq. (1)) of approximately 3.00 cm. The silo was 97 cm deep offering a water silo-to-container height ratio of approximately 20. Both fine non-cohesive quartz sand with a mean grain diameter of 0.07 mm and a relative density of 2.65, and small plastic particles with a diameter of 2.0 mm and a relative density of 1.27, was used. The fine sand is identical to that reported in Sumer et al. (2011). Appendix A sets out formally the parameters governing the loss of sediment, and discusses briefly effects of model scaling.

Prior to its release, the measuring bucket was filled to the brim with sediment and water. The initial height of the packed sediment was set to the mid bucket mark, and the sediment then either transferred to the bag or kept in the bucket. The container was the lowered into the silo and released. Retrieval of the bucket from the bottom of the silo was done by pulling it back up by its small die-cut handles using a hook. The post-settled reading of the height was done from the bucket, which for the bags meant that the remaining sediment was transferred to the bucket. As only losses occurring during settling was of interest, the events where containers tipped over or somehow spilled upon contact with the bed were repeated. Based on the prereleased and post-settled packed sediment levels, the loss was estimated.

2.2. Key observations

Both types of containers (the rigid bucket and the flexible bag) showed good shielding ability and a pronounced reduction in retention time of the descending load compared to the retention time of a corresponding unshielded release. Shielding of the loads using the open bucket were found to partially prevent interactions with the ambient water; however, losses from the container never exceeded 5% of the initial sediment volume. The open bag, however, was found to fully eliminate losses in all test cases. The reason for the loss elimination is further discussed and explained in section "Shielding Ability of Flexible Containers".

3. Field experiments

As a continuation of the observations made in the laboratory of the shielding ability of containers (and to reduce artifacts of model scaling; see Appendix A), two field campaigns were conducted in open waters and on large water depths. The campaigns included underwater photographing and video recording of the settling loads (see also Jensen et al., 2015 for in-depth technical description), which can be viewed by using the link provided in the Reference section. The footage may be consulted as to support the experimental reports and references to observations presented in the following.

3.1. Experimental protocol

In total, 21 loads were prepared, dumped and filmed by divers during two campaigns. Table 1 provides a summary of these loads and container specs. The first 15 loads (i.e., Tests 1 to 15) were completed during the March 2014 campaign, whereas an additional 6 loads (i.e., Tests 16 to 21) where undertaken during the July 2015 campaign. The two campaigns were purposely timed to calm weather and thus