The Use of Geotubes for the Disposal of Contaminated Dredged Material From Southern Dock of Buenos Aires City Port

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ABSTRACT: The south dock of Buenos Aires city port is at present the major crude oil exporting facility in the country and one of the most contaminated sites in the nation. To allow, operation of oil tankers at berths and, access along the south port channel, at least three feet of sediments have to be dredged and this depth must be regularly kept. This involves dredging 250,000 m³ of highly (solids) to medium contaminated sediments. This paper will discuss the implications that in site soils and sediments quality have in the election of the disposal technique and the dredging equipment to insure a safe disposal.

1 INTRODUCTION

The south dock of Buenos Aires city port contains the busiest oil exporting terminals in the country. Heavy metals concentrations present in the first meter depth of dock bottom sediments rise up to levels in the order of grams per kilogram. This scenario extends along a portion of about one and a half kilometers out of the berths and into the port access channel. The organic matter present within the sediment (solids) is also quite high and thus with significant potential to generate volatile organic compounds as well as methane and carbon dioxide. Regular oil spills have risen the hydrocarbon content within the dock water up to very high levels. Volatile organic compounds generation is verified by the regular presence of bubbles of gas coming out to the water surface. The size distribution of the material composing these sediments is more than 90 % finer than US sieve # 200.

250,000 m^3 of highly to medium contaminated *solids* (sediments) are in this condition. They lie along approximately 3 Km out of the berths area and into the access channel that leads to open sea. Depending on the dredging technique, this volume can increase. For a hydraulic dredger (most usual dredger type used in Argentina) the volume of suspended solids is usually of 25 % of the total (thus, 75 % is carrier water). Therefore, for the hydraulic dredge type the total volume of solids plus water to be handled is near a million cubic meters. Therefore dewatering techniques are essential (Gaffney et al. 1999) to allow consolidation and crucial for an efficient future use of the available space.

The smallest (tiniest) size fraction is the one carrying the highest concentration of pollutants. In fact, once hydraulically dredged it consists of a slurry of organic matter and clay size soil. The heavy metals appear chelated to the organic matter and adsorbed to the clay size particles. The organic matter into the harbor originates at untreated sanitary sewage system effluents. Heavy metals on the other side are part of untreated industrial liquid effluents also drained into the harbor (most through illegally installed drainage pipes). The contamination levels that these sediments present (table 1, 2 and figure 1) do not allow unconfined disposal under Dutch, American and Canadian classification methods.

2 CONTAINMENT

Therefore containment is crucial (particularly to avoid piping of fines). It can be achieved in several ways (with various degrees of efficiency) however, its design technology constitutes a difficult task. Disposal within sea or rivers´ bottom soils (under water) is only allowed for non highly contaminated sediments (Dutch Standards 1994 or USCOE 1987). The same goes for shore (under water or, under water table if within shore line) disposal. According to international standards upland confinement (in cells above water table level) should be undertaken for highly contaminated sediments. The use of geotubes (geotextiles tubes) has been gaining momentum in the last years, and its application in this case can be of great benefit. If used in combination with upland disposal projects, they can provide a very powerful tool to retain fine solids (Moo-Young et al. 1999) whilst allowing faster draining rates (Zhao et al. 1999) and better overall final strength.

Table 1 – Chemical (Organic) Sediment Characterization, all results in (mg/kg).

Sample #	WC %	% OM	pH	Tot. Hydr.	SO_4	Phenol
M1	56.6	13.0	8	2477	4263	33.6
M2	52.8	11.6	8	3199		19.7
M3	62.4	15.3	8	1800	3028	39.0
M4	40.1	6.3	8	900		25.4
M5	49.0	7.3	7.5	2186	969	45.1
M6	43.2	5.8	7.5	1047		25.2
M7	35.2	3.8	6.5	438	206	10.6
M8	49.9	4.5	7	712		13.4
M9	26.8	2.0	6.5	202		8.5
M10	31.0	3.1	6.5	181		10.7
M11	34.0	3.8	7	220		10.9
M12	34.4	3.6	7	312		11.3
M13	34.7	3.5	7.5	185		11.9
M14	35.6	3.6	7	256	99	14.0

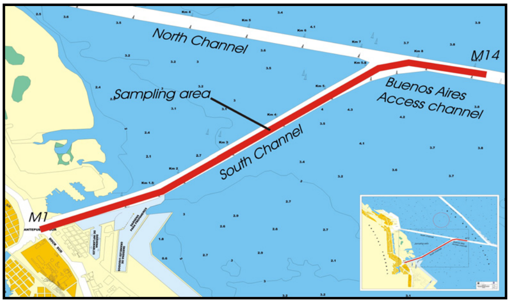
Table 2 – Chemical (Inorganic) Sediment Characterization at Buenos Aires South Dock, all results in (mg/kg) except for Fe (grs/kg)

Sample #	Fe	Pb	Cd	Cr	Zn	Cu
M1	47.15	553.0	5.0	1382	773.9	187.4
M2	62.54	593.6	5.2	1060	1.035.6	236.4
M3	59.85	279.3	4.0	1729	549.3	228.8
M4	41.75	133.5	0.8	83	141.9	52.6
M5	46.06	147.1	1.4	353	214.7	81.4
M6	58.96	88.0	0.9	106	73.0	41.4
M7	42.43	53.5	0.7	46	74.4	12.4
M8	55.89	30.0	0.2	30	35.1	19.3
M9	29.37	<6	0.2	20	62.8	6.2
M10	37.67	14.5	0.1	36	40.3	11.3
M11	40.11	12.9	0.2	19	26.6	12.2
M12	42.64	6.6	0.3	20	28.6	11.8
M13	32.15	7.6	0.2	15	24.7	11.1
M14	33.73	13.7	0.1	20	24.1	11.0

Each disposal technique has its advantages and drawbacks (US Army Corp of Engineers 1987), and some of them have been proposed to the provincial Port Authority and provincial Ministry for the Environment to cope with these polluted sediments.

Safe disposal is a necessity given the population density around the area and river recreational activities (shore and boat fishing, swimming, water sports, etc.). Additionally, water pumped from the river (at stations several kilometers upstream within La Plata river) is treated and distributed for human consumption.

Figure 1 – Sediment sampling area.



2.1 *Upland Containment*

2.1.1 *Sedimentation Behavior*

We will concentrate on this type of disposal technique due to the evident inability of sediments to be disposed otherwise. The United States Corp of Engineers gives an excellent background and disposal technology reference (USCOE 1987). According to this research institution, conceptual design for upland confinement for very fine solids with large volumes of carrier water, should be performed by using diked containment areas. The major objective (other than containment) is to attain the highest possible efficiency in retaining solids during dredging operations so that suspended solids (SS) requirements can be met. To comply with stringent SS regulations multiple dikes (subareas) and/or effluent detention basins (EDB) can be placed downstream of the inflow point. EDB´s may be used in conjunction with chemical flocculants (so called chemical clarification).

In general terms the average ponding depth and length of ponded surface are the most important parameters in the design of containment areas. The ponding depth is strictly related to the height of weirs serving at outflow points. The concentration of SS in the effluent will depend on the total depth at which fluid is withdrawn at the weir. In the containment area, larger particle flocs settle at faster rates, thus overtaking finer flocs in their descent. This contact increases the flocs sizes and enhances settling rates (USCOE 1987). If the withdrawal depth is shallow then non-settled particles will increase SS effluent concentration. Thus, the ponding depth is used as withdrawal zone and together with the ponded surface value are strictly related to the determination of minimum retention time (MRT) to meet a given effluent SS concentration requirement. The ponding depth presents a threshold value that while allowing enough time for sediments to settle is not excessive so as to keep the particles in suspension for a very long time. If this last happens then, re-suspension under for example wind effects, can take place increasing the effluents SS concentration again. Scenarios like this last can also take place if short-circuits develop between inflow and outflow points (diminishing residence time).

2.1.2 *Consolidation Behavior*

After dredged material is placed, within a containment area, it undergoes sedimentation and self – weight consolidation. Three types of consolidation may occur, primary consolidation, secondary and consolidation resulting from desiccation. Primary consolidation may take a very long time due to the highly compressible nature of very soft fine sediments (< Nº 200 sieve). Even more time will be needed for the secondary one. Evaporative drying is the basic principle behind formation of a desiccated crust under traditional disposal methods. The removal of water from the crust is a two stage process, the first one begins when all free water has been decanted or drained from the dredged material surface. The second stage drying will be an effective process until the material reaches a void ratio called the desiccation limit. Any additional evaporation will be limited to excess moisture from undrained rainfall and that water forced out of the material as a result of consolidation of material below the crust.

The complex nature of the consolidation and desiccation relationships for multiple lifts of compressible dredged material and the changing nature of the resulting loads turns compaction of fine sediments a very difficult task.

2.1.3 *Dredged Material Dewatering Operations*

Both surface trenching and underdrains may be used as a means of dewatering. However, surface trenching is reported to be more cost efficient (USCOE 1987). Up to fifteen years ago the best achievable dewatering objective was to "create a stable fast land at a known elevation and with predictable geotechnical properties". Nowadays the use of geotextiles and geotubes in particular, can greatly help avoiding stated complexities related to upland containment of fine sediments. Furthermore they can be of great benefit to quickly reuse the containment surface.

In fact geotubes coupled with traditional upland confinement can significantly diminish minimum residence time of sediments by reducing drainage path lengths. They also provide increased overall shear strength so that larger loads may be imposed on top of the containment surface once disposal has finished.

2.2 *Upland Containment Coupled with use of Geotextiles*

The use of geotextiles in the past (early nineties) was restricted to tensile reinforcement. At that time geotubes were not specifically produced, however, later research was conducted specifically devoted to evaluate geotubes performance. Both dewatering features and solids retention were studied on a real scale basis (Fowler et al. 1997). Data for filtration and compaction performance was obtained from experimental work conducted by filling a geotube. It was connected to a hose conducting sewage sludge from a digester up to a total height of 60 in. The geotube was 16 ft wide by 32 ft long and the hose was connected to a central point on top. Ninety percent consolidation occurred in 26 days dropping the initial 60 inches height to 15 in., i.e. *a reduction of 75 % in original volume*! The average loss for the geotube was about 15 gal/foot/day during first fifteen days of primary consolidation. Later research focused on the clogging potential of nonwoven and woven geotextiles (Aylidek et al. 2003) that also reported piping rates through them by evaluating remaining amount of solids both at laboratory and field scale studies. This research shows that the clogging rate after permeation on almost all candidate geotextile fabrics was very low (13 % at most). However, the gradient ratio increased (GR meaning the ratio of gradient on the soil to that at the interface of soil and geotextile) and consequently the flow across the geotextile should increase. This should allow a faster drainage and consolidation rate compared to the disposal of sludge without the use of geotubes, e.g. by the USCOE lay-out (USCOE 1987). Additionally geotubes allow to control the piping rate out of them. Aydilek et al. have also concluded that the clogging rate decreases with increasing geotextile permittivity and has been tied to the O_{50} constriction size in detriment of more commonly referenced O_{95} one. Moreover, the percentage of water content on dredged material seems to play a key role on the piping rate (as well as AOS, geotextile permittivity and distribution size) through them irrespective of its thicknesses. In fact 1600 % of initial WC seems to be the threshold value above which fine materials *are completely piped through*. Instead a 500 % WC value has been stated as a reasonable initial WC percentage for a good retention performance of double non-woven/woven geotextiles layers (Kutay et al. 2004). This finding is of utmost importance in the case of Buenos Aires city port at which mainly hydraulic dredgers are routinely used without specificcontrol on water content delivered at piping exit point. In 2006 Aydilek proposed a probabilistic methods called retain that allows to select a nonwoven geotextile by predicting its clogging potential based on several parameters among which the soil to be filtered grain size distribution and discussed the relative invalidity of traditional Ox/Dx ratios proposed by several authors.

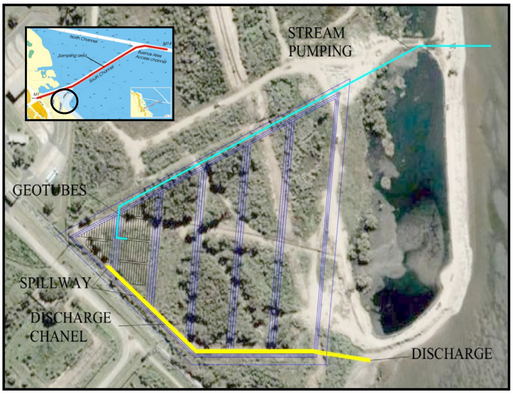
A very interesting approach to the problem of contaminated fines retention has been proposed by Kalinovich (Kalinovich et al. 2008) that has been tested at real scale for a permeable reactive barrier (PRB). Fines retention becomes very difficult under dynamic hydraulic conditions (also present at the

PRB case). In fact, at any problem where fines need to be retained geotextiles used as filters will tend to clog and consequently hydraulic gradient changes across the barrier. For the case of PRB lay-out, Kalinovich et al. have concluded that geotextile layers may be used to enhance final fines removal. They state that in the case of PRB´s they should be placed downstream of a mineral more permeable barrier. They argue that the mineral barrier is less prone to clogging due to its thickness, whereas if the geotextile is placed upstream promotes fabric clogging. This promotes stream overflowing it instead of permeating through it. This same concept is applicable to sediments removal from hydraulic dredge operations. In this case pumping the stream into geotubes overcomes the problem of overflowing the fabric or short circuiting outside its boundaries. Then a second stage removal, e.g. using the USCOE method can be set up at the exit dykes by placing a geotextile curtain on them to cope with non retained fines within the geotubes (first stage removal). This may avoid the use of settling cells and coagulants.

3 CONTAINMENT CONCEPTUAL MODEL

Figure 2 shows the conceptual model proposed for sediment retention and water drainage back to the port access channel. An arrangement of aligned geotubes fabrics that simultaneously dewater the dredge stream placed within a containment facility with exit dykes. Non woven geotextile fabrics placed on the upstream face of exit dykes. These dike structures may be repeated downstream to further polish the stream before draining it back. Monitoring of sediment concentrations should be performed regularly before water stream drainage back into the river.

Figure 2 – Conceptual model proposed for sediment retention.



4 ACKNOWLEDGEMENT

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