DREDGED SEDIMENTS FROM PORT OF MOMBASA AS A MATERIAL IN VERTICAL CUT-OFF WALLS

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signature……………………………………….. Date……………..…………………

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This thesis has been submitted for examination with our approval as University Supervisors

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DEDICATION

To the soul of my mother and father, for being the best parents anyone could have in this world.

They taught me the importance of knowledge, the power of teamwork, and the spirit of giving. Best of all, they were wonderful role models for me, dedicated, selfless, and humble.

To my siblings, who always shows me the value of unity and compassion.

To my wife, son and daughter for their relentless encouragement, support, and patience during the time it took me to finish this thesis.

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LIST OF ABBREVIATIONS

Al	Aluminum
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
CH	Clay of High Plasticity
EFA	Environmental Protection Agency
K	Potassium
KPA	Kenya Port Authority
Mg	Magnesium
NY/NJ	New York and New Jersey
POM	Port of Mombasa
SiO_2	Silicon Dioxide
US	United States of America
USCS	Unified Soil Classified System
1B94DS5FA	1% Bentonite, 94% Dredged Sediments and 5% Fly Ash
1B91DS8FA	1% Bentonite, 91% Dredged Sediment and 8% Fly Ash

1B99DS	1% Bentonite Content and 99% Dredged Sediment by Weight
3B97DS	3% Bentonite Content and 97% Dredged Sediment by Weight

ABSTRACT

Dredged sediments are obtained from the process of dredging coastal areas and harbours in order to maintain navigable waterways. This study focuses on the potential of using dredged sediments as vertical cut-off wall backfill material including in and offshore waste disposal sites. Materials used as vertical cut-off wall material are expected to have low hydraulic permeability and good workable characteristics. Dredged sediment samples obtained from dredging works at the Port of Mombasa were used in this study. The sediment was plastic in nature and finer than the conventional slurry cutoff and offshore construction sites to exclude water in the construction sites. The tests were carried out to establish the effect of bentonite on the density and hydraulic conductivity of the dredged sediment mix. The effect of a combination of flyash and bentonite on hydraulic conductivity. The broad objective being was to find an appropriate mix of the sediment and bentonite that will be able to function as a vertical cut-off wall backfill material. The preliminary tests on the bentonite were carried out for screening purposes and to find an appropriate water content that will satisfy the desired viscosity range. Bentonite was then added to the dredged sediment in ratios of 1%, 2% and 3% of the total dredged sediment weight. The preliminary tests were repeated for each of these mixes to determine applicable trends and at what percentages of bentonite, the viscosity of the mixture was still in the workable range. The results showed that suitable moisture content of 463% and viscosity of 42s could be obtained that makes it usable in the mix design sediments. Increased bentonite content, to the percent tested (3%) lead to decrease in hydraulic conductivity and increased fly ash to 8%, lead to increase in hydraulic conductivity. The selected design mix (3BS97DS- 3% bentonite by weight and 97% dredged sediment) was found suitable as a backfill material for vertical cut-off wall. It was found that an optimum sediment mix was 3% bentonite by weight; the mud weight density of the dredged sediments was 10.58 kN/m^3 which was within the acceptable range of bentonite slurries of

10.06 - 12.58 kN/m3; increasing bentonite content to 3% resulted in a decrease in hydraulic conductivity; and increasing the fly ash content to 8% increased the hydraulic conductivity. It was found that the dredged sediment from Port of Mombasa channel could serve as an effective vertical cut-off material when modified with 3% bentonite. Therefore the sediments from the Port of Mombasa can be used beneficially for engineering purpose.

CHAPTER ONE

INTRODUCTION

1.1 Background

In these times, due to widening of scope and tightening of environmental regulations, there is a focus on using suitable recycled materials for beneficial purposes. This brings us to exploring the potential of dredged sediments as a vertical cut-off wall material. Materials, mainly soil bentonite mixtures, used in vertical cut-off wall construction are expected to have low hydraulic permeability and good workable characteristics (Abichou, 2012). Vertical barriers are used to limit the flow of groundwater and removal of contaminants from sites where necessary. Vertical barriers are often implemented in construction operations where trenching is necessary. Dredged sediments are obtained from the process of dredging coastal areas and harbors in order to maintain navigable waterways (Palmero & Wilson, 1997). After the sediment has been excavated, it is transported from the dredging site to the placement site or disposal area. Dredged sediments are generally defined as elastic silt with moderate organic content (typically 8%) with a low percentage of fine sand and clay. The Port of Mombasa dredged sediments was used for this study and are classified (according to the unified soil classification system (USCS)). From records, approximately 7 million cubic metres of sediment was dredged within a period of 11 months (February 2011 to Janaury 2012) from the main entrance channel of Mombasa (KPA Dredging Report 2012). Of this amount, approximately 200 thousand cubic metres was placed at a designated reclamation site (see Figure 3.1). The remaining 6.8 million cubic metres was dumped offshore (shown as dumping area 1 in Figure 3.1). Navigable channel are needed for trade through ports as this contributes greatly to the economy (Palmero & Wilson, 1997). Therefore, alternatives for disposal of dredged material should be looked at from a technical, economic, and environmental point of view. Until the 1970s, dredging was focused on efficiency of the dredging operation and production capacity, with an emphasis on economics (Palmero & Wilson, 1997). However, nowadays, with new environmental legislation (since the early1970s), the state of the practice has evolved to include a wide range of environmental considerations, and so the emphasis has shifted to a balance of economics and the environment which is refered to as Sustainable Technology. Additionally, sites often need to be remediated before further construction can proceed in current construction practices. Research and development of technologies that involve in-situ containment and treatment should therefore be promoted by industries and indeed the Kenyan Government. Through re-use of dredged material, the number of placement sites, disposal areas and associated environmental concerns could be reduced. In addition, because dredged sediment is a by-product of the dredging industry, the cost of the vertical barrier system can be reduced substantially than if other natural resources were used. The objective of this study is to find an appropriate mix of dredged sediments and bentonite that was able to function as a vertical cut-off wall backfill material. The preliminary tests on the bentonite were carried out for screening purposes and to find an appropriate water content that will satisfy the desired viscosity range. Bentonite was then added to the dredged sediments in ratios of 1%, 2% and 3% of the total sediment weight.

The preliminary tests were repeated for each of these mixes to determine applicable trends and at what percentages of bentonite, the viscosity of the mixture was still in the workable range. The 1% bentonite mix was additionally modified with the addition of 5% and 8% fly ash by weight. These mixtures were then subjected to API filter press tests (used as a rigid wall permeameter) to determine the effect of these mixes on the hydraulic conductivity. A literature review about the origin and properties of dredged sediments is given in Chapter 2. Chapter 3 includes the materials used in the testing program and the test methods. Chapter 4 displays the results found and discusses the general trend of the said results with respect to the objectives of this thesis. Chapter 5 summarises the findings versus the desired parameters. This chapter also recommends the appropiate design mix found and its beneficial use.

1.2 Statement of the Problem

Most of the dredged material is dumped at sea and only minor amounts of this dredged material are beneficially used. Due to the projected increased in world trade and shipping in East African there is need to beneficially use the dredged sediment for engineering purpose.

The dumping and dumping process of dredged sediments causes high water turbidity. This affects plant life, fish migrates impacting on fishermen and hence the economy. The light finer sediments suspended in water upto two years in some areas like Victor Islet (Erftemeijer et al. 2012).

Dredging can totally eradicate any seagrass and marine animals living on the sea floor in the dredged area. The impact may be caused by stirring up toxic chemicals such as heavy metals which is fatal for marine life. The extent of the impact depends on the size, characteristics and sensitivity of the dredged area and the dredging technique.

1.3 Justification of the Study

Due to the projected increase in world trade and shipping, it is likely that the need for dredging will remain high or even further increase in some areas due to the deeper draughts of ships, large container vessels, or the development of new port projects. This study will ensure that dredging and dumping projects will cost less because of the proposed usability of the dredged sediments, which in essence reduces the dumping distance. Secondly beneficial reuse of dredged sediments will drastically reduce the construction period mainly because the cycle time for dredging was reduced.

Thirdly the marine life environment will be maintained and the fishermen will continue with theirs activities uninterrupted. Fourthly this study will expand the scope of the existing knowledge regarding dredged sediments in the Port of Mombasa.

Lastly the result of this study is expected to minimize water pollution, which will include water turbidity, noise and water disturbance during the construction period (Grech, 2013).

1.4 Objectives

The main objectives of this study was to find an appropriate mix of dredged sediments from the Port of Mombasa and bentonite to function as a vertical cut-off wall backfill material

The specific objectives are:

i) To establish the effect of bentonite on the density of the dredged sediment mix

ii) To determine the effect of bentonite on the hydraulic conductivity of the dredged sediment mix

iii)To establish the effect of a combination of fly ash and bentonite on the hydraulic conductivity of the dredged sediment mix

1.5 Scope and Limitations

This study invloved geeting samples randomly from the field (Kilindini harbour channel) and conducted laboratory tests on the samples. The tests included tests for density, viscosity, moisture content, atterberg limits and hydraulic conductivity of the neat sediments from the field. The neat sediment was then modified by adding bentonite and flyash and the same tests described above were repeated for evaluated the effect.

The limitation of this study was the cost of the laboratory tests hence full scale testing was not conducted. Also the period of collecting the samples was limited between 2011 ans 2012 when the dredging works was being performed.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Dredging means to dig or gather with a dredge (Palmero & Wilson, 1997) – to deepen (a waterway) with a dredging machine. After the sediment has been excavated, it is transported from the dredging site to the placement site or disposal area. Dredging is often carried out using trailing suction hopper dredges, which has three cycles: loading, sailing and unloading or using more modern machinery. The transport operation, most often, is accomplished by the dredge plant or by using additional equipment such as barges, scows, pipeline, and booster pumps. The actual depth to which a channel may be dredged is referenced to an appropriate low water elevation. It may be greater than the authorized depth to accommodate needed vessel clearances, dredging " over depth" also allows for the accuracy of excavation, and provides room for accumulation of material before the next dredging cycle (Palmero & Wilson, 1997). The tendency of the shipping industry is to design and construct larger vessels for increased efficiency. This in turn, requires harbor channels to be periodically deepened, which increases the dredging requirement.

There are three general alternatives that may be considered for placement or disposal of dredged material: open water disposal, confined (diked / dredged fill containment areas located in an upland environment) disposal, and beneficial use applications. Beneficial reuses involve the placement or use of dredged material for some productive purpose. Generally, beneficial reuse involves either open water or confined placement in some form. Some beneficial reuses involve unconfined disposal, for example wetland creation or beach nourishment. Other disposal methods, such as mine reclamation and aquaculture are occasionally used or considered, but there are usually limitations imposed (Palmero & Wilson, 1997). Dredged material has also been used for landfill capping and lining.

Brick manufacture using dredged sediments is another innovation being explored (Bhat & Lovell, 2011). Selection of a disposal alternative is made based on considering the technical, economic, and environmental issues. Of the approximately 100 million cubic meters dredged annually in the United States (U.S.), approximately 15 million cubic meters are placed at about 108 Environmental Protection Agency (EPA) designated ocean disposal sites. The remaining 85 million cubic meters are placed in inland, coastal, or estuarine open water sites, confined disposal sites, or beneficial reuse sites (Palmero & Wilson, 1997).

2.2 The Mineralogy and Deposition of Dredged Fill

Dredged fill can be comprised of five soil types: sand; mixed type of soil between sand and clay, sandy silty clay or clayey silty sand; clay; mixed type of soil between clay and rock (Abichou, 2012). Dredged fill originates from coastal areas, where there is a need to maintain and improve navigable waterways and harbours and therefore dredging operations occur. A few such locations in the United States include the New York/New Jersey Harbor, the Baltimore Harbor in Maryland, the Mobile in Alabama, the Oakland Harbor in California; and in Africa, in Durban and areas of Egypt. The mineralogy varies somewhat depending on the coastal area from where the sediments are dredged (Vaghar et al, 1997). At the Fort point Channel in Boston, a typical subsurface profile includes: Miscellaneous Fill (20 Feet), Harbor Bottom Sediments/Organic Deposits (15 feet), Marine Clay (Boston Blue Clay, 80 feet), and Glacial Till (10 feet), overlying argillite bedrock (Fig. 2.1) (Vaghar et al, 1997). In this case there are two separate aquifers, one above and one below the Boston Blue Clay. The water in Fort Point Channel is tidal. At the Houston-Galveston Ship Channel, east of Houston, the soil that forms the upper limit of the Pleistocene Age Formation is a stiff to very stiff over consolidated clay material locally referred to as the ‘Beaumont Clay’. For the New York / New Jersey (NY/NJ) Harbour, the mineralogy of Newton Creek sediment was measured using x-ray diffraction, (Jones et al, 1997). These results are shown in Table 2.1. Regarding deposition, the main aspects to be concerned with on a reclamation area are the bulking, the bearing capacity and the trafficability. In the case of sand, on hydraulic (dredged) fills above the water level, the relative density is 60-70%, approximately 98% of the normal maximum Proctor density (Verhoeven et al, 1988). This information is important in calculating the difference in volume between the pit (when there is a good indication of density) and the fill. The trafficability of the fill is dictated by the permeability. Therefore the bearing capacity of wet sands can be misleading (too low) if the amount of fines is increasing or a section of the fill can have a lower bearing capacity than the other because of local separation of fines (Verhoeven et al. 1988). With clay fill, its behaviour is mainly judged from the percentage of lumps in relation to the percentage of slurry.

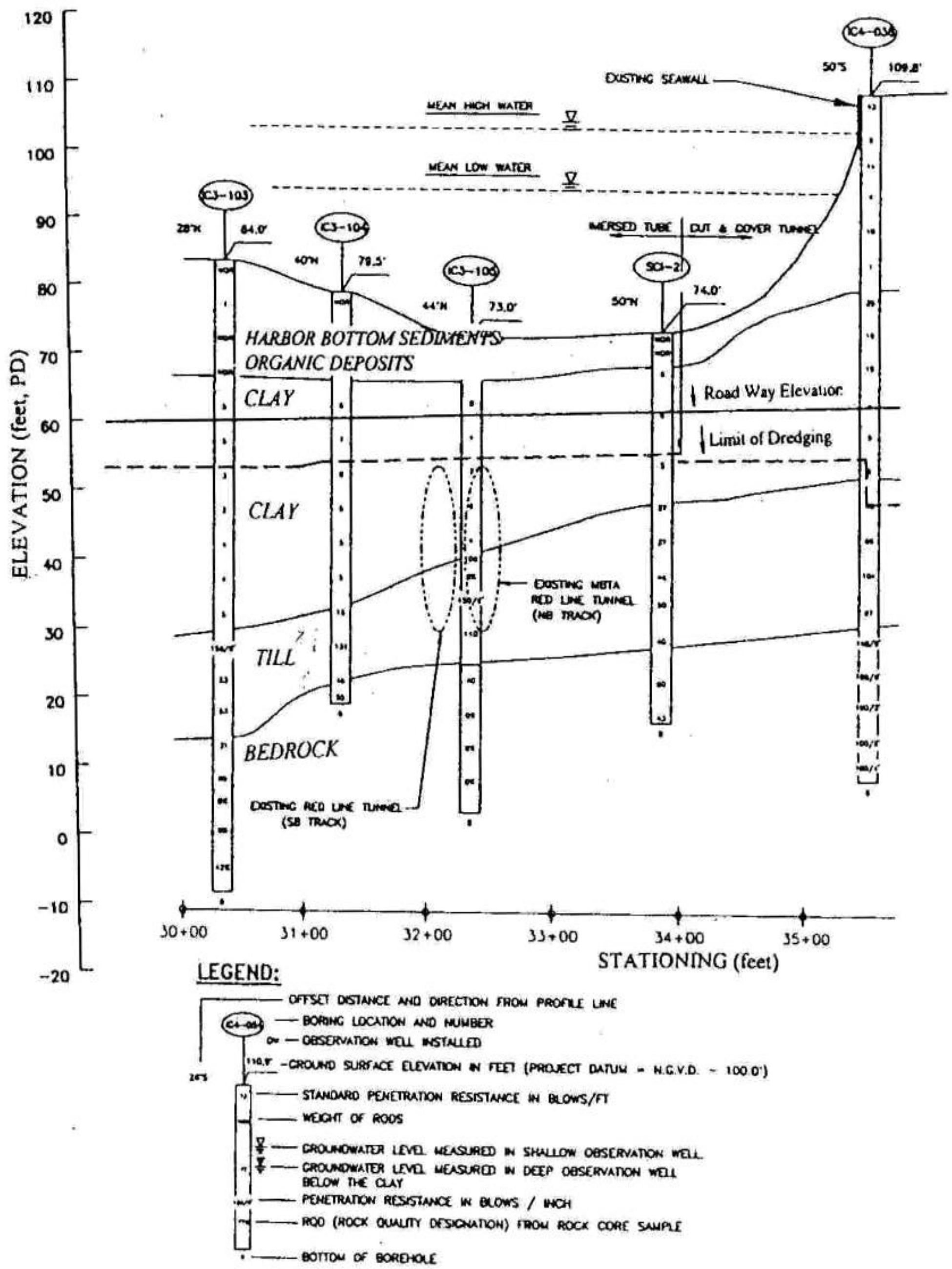

Figure 2.1: Fort Point Channel Subsurface Profile (Vaghar et al, 1997)

Table 2.1: Sediment Mineralogy of Newton Creek (Vaghar et al.1997)

Minerals Species	**Chemical Formula**	**Weight Percent**
Quartz	SiO_2	66 to 75
Muscovite (Mica)	K2O.2MgO.Al2O3.8SiO2.2H2O	11 to 15
Amorphous Phase	Organics	3 to 13
Kyanite	Al2O3.SiO2	6 to 7
Hydrated Aluminum Silicate	19Al2O3.173SiO2.9H20	5 to 6
Cronstedtitte	4FeO.2Fe2O3.3SiO2.2H2O	4 to 6

The bulking of the slurry can be determined from the consistency of the excavated soil and the Atterberg limits. It is assumed that a few days after the reclamation (at the start of consolidation under its own weight), the water content of the slurry is very high (2 to 3 times the liquid limit). The bulking can therefore be calculated from clay with natural water content to the slurry. The bearing capacity and trafficability of clay fills are usually negligible when considering deposition.

In the case of the rock material, the main aspect concerned with its deposition is the amount of fines. If measures are not taken, the water outside the reclamation area leading to a pollution problem can transport a large amount of fines. The bulking can be estimated; the bearing capacity and the trafficability are generally good.

For the mixed soil types, more information needs to be known. This information is needed to determine the soil parameters as similarly done for the clean soils. Because of the deposition of dredged fill, it is often hydraulically pumped along the banks of rivers or lakes or used to form small islands near dredging sites. In these areas the coarser solids settle from suspension and the excess water, with some suspended solids, then returns to the river/lake through an overflow weir (Krizek et al, 2011). Problems with this method of disposal are high water content, low shear strength, and high compressibility of the dredged sediments. Therefore a landfill made using these materials would perform ineffectively for long periods of time. Also, the drainage condition at the bottom of the sediment layer has an effect on the consolidation rate during the period of deposition.

2.3 Engineering Properties of Soil-Bentonite

This section presents engineering properties of soil-bentonite with a focus on deformation and strength properties. There is limited published information on deformation and strength properties. It can be difficult to characterize soil-bentonite in general because soil-bentonite mixtures can vary greatly. One reason for the variation is that soil-bentonite is typically made by mixing material excavated from the trench with bentonite-water slurry, and the excavated material can vary greatly from site to site or even across a particular site. The primary goal in designing a soil-bentonite mixture is to provide a cost-effective, low permeability material. In addition, a relatively low compressibility soil-bentonite mixture is desirable in order to prevent excessive settlement in the trench and reduce adjacent ground deformations. There are several recommendations on grain size distributions of the soil-bentonite in order to achieve these goals. D'Appolonia (1980) stated that a soil- bentonite would have low compressibility if there were enough granular particles to have grain to grain contact. For both low compressibility and low permeability, a well-graded material with gravel through clay-sized particles is recommended Evans et al. (2000). That study recommended a granular matrix with 20% to 40% plastic fines and a minimum of 1% bentonite. Evans et al. (2000) recommended a well-graded material similar to a glacial till with 10% to 20% fines and 2% to 4% bentonite. They also state that other gradations such as fine sands and clays have also been used successfully. For best placement consistency, the recommended slump is 4-6 inches (Evans et al., 2000) or 2-6 inches (D'Appolonia 1980). The slump is measured with a standard concrete slump cone apparatus.

2.4 Vertical Cut-Off Walls

Vertical cutoff walls are installed in the subsurface to control horizontal movement of groundwater and contaminants (Daniel, 1993). The use of vertical cutoff walls in the subsurface initially began with groundwater control and structural applications in Europe before 1950 (Xanthakos, 1994). Slurry trench cutoff walls have been used in environmental applications since the 1970s and have come into widespread usage since the 1980s as a component in the overall remedial system to control flow of groundwater (Daniel & David, 1993).

In defining the vertical cutoff wall objectives, it is important to decide whether the barrier is to act as a ground water barrier with low hydraulic conductivity or as a contaminant transport barrier. Depending on the objective of the vertical cutoff wall, different criteria are considered in the design. For instance, if the objective is to minimize the rate of contaminant transport off-site, it is necessary to consider contaminant transport through the wall, potential degradation of the wall, and the consequences of inadequate cutoff wall performance. Also, the environmental control system could include a vertical cutoff wall along with a low permeability cover, groundwater withdrawal system and treatment systems for the pumpage. Vertical cutoff walls often key into a stratum of naturally low hydraulic conductivity (Daniel and David, 1993). A key is not always necessary or cost effective when contaminated groundwater is being extracted or when the contaminants are concentrated near the ground surface or floating on the water table. In this study the focus was on vertical cutoff walls of low hydraulic conductivity. Typically, low permeability vertical cutoff walls are constructed by installing a vertical barrier into the subsurface. The vertical wall has a lower hydraulic conductivity than the surrounding formation. The vertical cutoff walls can be divided into groups based on construction methods. Different types of vertical cutoff walls can be constructed using the slurry trench method of excavation and are therefore called 'slurry trench cutoff walls' (Daniel and David, 1993). In the slurry trench method of construction, a vertical trench is excavated into the subsurface using slurry, typically of bentonite and water, for trench stability. The slurry is typically a bentonite-water mixture consisting of 5% bentonite and 95% water by weight. Bentonite, a montmorillonitic clay, swells in the presence of water, giving a viscous nature to the fluid and helps in the formation of a filter cake along the walls of the trench. For trench stability, the slurry level is kept at or near the top of the trench, typically within 1m. Trench widths vary between 0.6 and 1.5m, with 0.9m trench widths being typical. The completed excavation is then used to form the geometry of the cutoff wall (Daniel, 1993). The completed cutoff wall can consist of soil-bentonite (Tsai et al. 1998), cement-bentonite (Poindexter et al. 2010), plastic concrete (Evans et al., 2000), or structurally reinforced concrete (Kayyal et al. 1998). Once the trench is excavated to the desired depth, the bentonite–water slurry is replaced with a soil-bentonite backfill with a low hydraulic conductivity. The backfilled trench forms the completed vertical cutoff wall. The backfill optimally consists of a mixture of sand, silt, and clay, and bentonite-water slurry. The soil-bentonite is placed in the trench at a consistency of high slump concrete (100-150mm) (Daniel, 1993). In order to attain this consistency, the material needs to be ‘fluidized’ by adding bentonite-water slurry to the soil. Figure 2.2 shows a representation of the construction process.

The thickness of the wall is typically 0.6m to 1.5m, which corresponds to typical widths of a backhoe bucket (D’Appolonia 1980). Evans (1994) recommended that if walls are exposed to high hydraulic head conditions, such as beneath a dam, they should be analyzed for hydraulic fracture. If hydraulic fracture is a concern, a thicker wall is recommended ((Tsai et al. 1998). Although detailed design procedures are not available for analysis of hydraulic fracture of soil-bentonite cutoff walls, some rule-of-thumb approaches do exist, such as the U.S. Army Corps of Engineers' recommendation that soil- bentonite cutoff walls be at least 0.03m wide for every foot of head difference (Yamasaki et al. 1995).

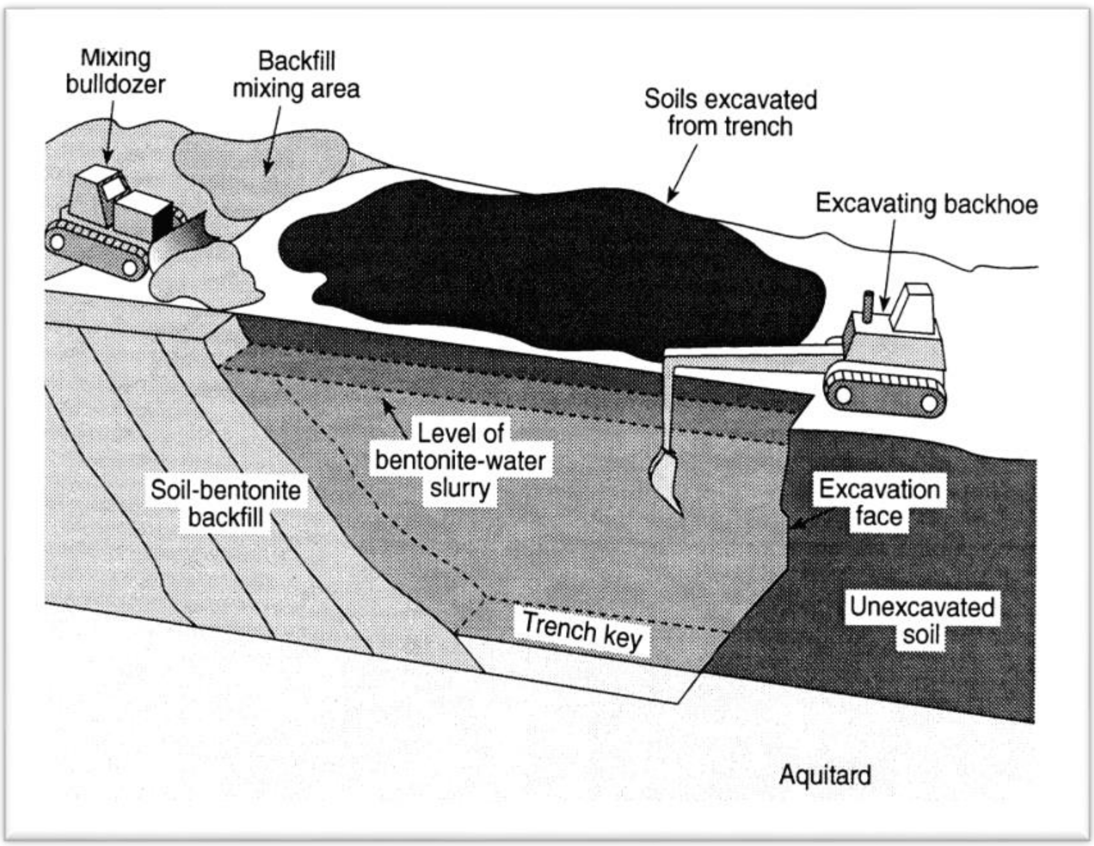

Figure 2.2: Soil-bentonite Cut-off Wall Construction Process (Evans, 1994)

In general terms, soil-bentonite slurry trench cutoff walls are among the least expensive techniques available in the U.S. for vertical barriers in the subsurface. This study is focusing on such soil-bentonite cutoff walls, with the possibility of substituting the soil with dredged sediments from the Port of Mombasa. After evaluating the hydrogeological and geotechnical aspects of the site, it is necessary to determine the appropriate properties for the soil-bentonite cutoff wall (Martinenghi, 1995). During the feasibility studies, it is important to determine the short-term and long-term performance of the cutoff wall. That is, it is necessary to determine its properties in terms of hydraulic conductivity, strength, and compressibility. One needs to determine if these properties are satisfactory to meet the objectives of the project in the short-term as well as the long-term.

The specific parameters of the Port of Mombasa dredged sediment-bentonite slurry were determined. These were compared with typical parameter values of soil-bentonite slurry. The correct proportions of each ingredient in the sediment-bentonite slurry were determined in order to achieve similar workability and purpose.

Sediment parameters were checked including grain-size distribution, density, viscosity, and flowability / filtrate loss. The main mix parameters were tested for include: density and viscosity of the sediment-bentonite slurry (slump) and hydraulic conductivity of the sediment-bentonite slurry (using a rigid wall permeameter API filter press test).

2.5 Recent Research Developments

It has been established that there are several engineered beneficial reuses for dredged material. These include landfill/brownfield liners and covers, certain transportation applications, levee construction, use as structural and non-structural fill, and recently use as an ingredient in the brick manufacturing process. The transportation applications that were investigated include use of the dredged sediments as roadway material and embankment material (Abichou et al., 2012). The embankment study seems to be the most thorough, complete study on the use of dredged materials to date. This study from New Jersey sediments were characterized and defined as an elastic silt with moderate organic content (8%) and they were found to have a low percentage (%) of fine sand and clay. The hydraulic conductivity was between $5x10^{-6}$ cm/s and $2x10^{-5}$ cm/s. (Kutay & Aydilek, 2003). It was found that it performed satisfactorily as an embankment material. This should not pose a problem though, as it has been proven that materials with lower hydraulic conductivities have performed effectively, namely soil-bentonite slurry trench cutoff walls ($1x10^{-7}$ to $1x10^{-8}$ cm/s) (Nash, 2012). The dredged sediments were mixed with Portland Cement PC (4% and 8%) and fly ash - (in the case that already had the 8% PC). The dredge sediments were dewatered to near optimum moisture content before compaction (specific % was not given). Dredged sediment beneficial use study; show that generally dewatering to 85 to 45% water content is normal (Nash, 2012). The Port of Mombasa dredged sediments compares with the New Jersey ones. From the KPA Dredging Report 2012, there is a difference in that the Port of Mombasa sediments are classified as a CH soil since they have more fines than the New Jersey ones. Therefore it seems appropriate that the Port of Mombasa sediments would perform satisfactorily under similar circumstances. In California, investigations have been done in terms of the beneficial reuse of dredged sediments for levee construction. Several demonstration projects have been initiated. Flowable fills are self-leveling liquid-like materials that cure to the consistency of a stiff clay (Abichou et al., 1998). Flowable fill is typically made up of sand or foundry sand (which contains bentonite), cement or flyash, and water. It is used for some applications similar to that which soil-bentonite is used for. These applications include use as backfill in utility trenches, building excavations and underground storage tanks. Design mixes are developed to satisfy local and state strength and flow requirements. Foundry sands, a by-product of casting and a mixture of fine sand and bentonite, (an ingredient in flowable fills), can potentially be used as a hydraulic barrier, e.g. in landfill liner and cover materials. A study done by Abichou et al. (1998) indicated that foundry sands (green sands) offer a superior barrier than conventional clays and possibly at a lower cost. In order to determine the suitability of soil-bentonite mixes for vertical backfill material applications, it is hypothesized that similar testing can be conducted. The testing (as it relates to dredged sediments) includes determination of index properties and hydraulic conductivity testing.

Paper mill sludge is another material being investigated for its use as a vertical barrier material. A study by Moo-Young et al. (2010) focused on the constructability, physical properties, and adsorption potential of paper mill sludge. With all this possibilities and literature this study will specifically focus on the beneficial use of Port of Mombasa dredged sediments in 2012 as a vertical cutoff wall backfill material.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The method of analysis used was quantitative. According to Horn and Salvendy (2006) numerous methods for gathering data have been developed such as interviews, feedback, databases, scenarios, protocol analysis and questionnaires. Hence, the selection of the method used depends on the type of information to be gathered (Horn & Salvendy, 2006). In this research study, databases were used as the only tool to collect data using random sampling.

3.2 Sampling

The dredged material used for this study was obtained from Kilindini Harbour located in the Port of Mombasa. The dredging operation involved more than 600 dredging positions. In this study the dredged material was obtained from six different points in the channel marked as (C4, C5, C6, C7, C8 and C9) in Figure 3.1. At each of the six points, thirty samples were collected resulting to 180 samples in total, which is equal to 30% of 600. According to Mugenda and Mugenda (2003), a sample of 30% is adequate for the generalization of the findings to the whole population if the sample size is more than 30 elements. The dredged sediments were divided into two equal samples A and B weighting 5kg each. Each sample was further divided into four groups so as to obtain the required parameters namely density, moisture content, viscosity and hydraulic conductivity.

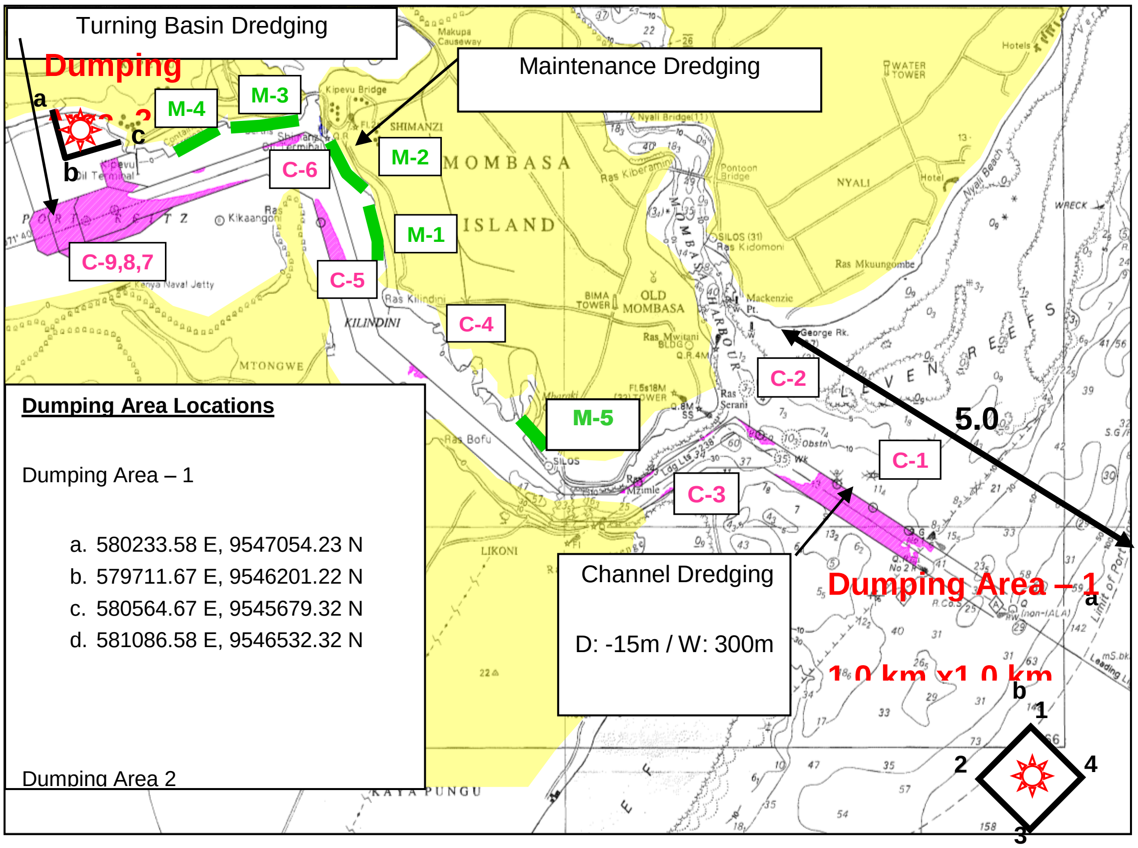

Figure 3.1: Locations for Dredging and Dumping Areas (KPA Dredging Report, 2012)

The bentonite used in this study, was obtained from Southern Engineering Company located in Likoni area within Mombasa County. The material obtained was a high quality, powdered sodium bentonite used in slurry wall construction, soil sealing and other hydraulic barriers. The product conforms to API specification of 13A. The fly ash used in the study was obtained from Southern Engineering Company located in Likoni Mombasa County. The testing laboratory was *Geoff Griffins and Associates*, which is located off Mombasa road next to Inland Container Depot (ICD) centre.

3.3 Determining Properties of the Dredged Sediment and the Mix

3.3.1 Density

Density was determined using the standard ASTM D792. The samples tested were treated as shown in the table 3.1.

Table 3.1: Summary of Samples Tested for Density

SAMPLE NOTATION	**SAMPLE DESCRIPTION**	**NUMBER OF SAMAPLES**
DS	Dredged Sediment (neat)	30
1B99DS	1% Bentonite, 99% DS	30
2B98DS	2% Bentonite, 98% DS	30
3B97DS	3% Bentonite, 97% DS	30

Source: Appendix 8, 14, 15 and 16.

For each sample type 30 tests were conducted and an average was taken.

3.3.2 Particle Size Distribution

The standard used for the particle size distribution, which is also known as grain size analysis, was ASTM D6913. The samples tested were treated as shown in the table 3.2.

Table 3.2: Summary of Samples Tested for Particle Size Distribution

SAMPLE NOTATION	SAMPLE DESCRIPTION	NUMBER OF SAMAPLES
DS	Dredged Sediment (neat)	11

Source: Appendix 10

For the sample DS 11 tests were conducted and an average was taken.

3.3.3 Atterberg Limits

The standard reference for measuring the atterberg limits was the ASTM D4318. The samples tested were treated as shown in the table 3.3.

Table 3.3: Summary of Samples Tested for Atterberg Limits

SAMPLE NOTATION	SAMPLE DESCRIPTION	NUMBER OF SAMAPLES
DS	Dredged Sediment (neat)	4

Source: Appendix 9

For the sample DS 4 tests were conducted and an average was taken.

3.3.4 Moisture Content

The standard reference for measuring the moisture content was the ASTM D2216. The samples tested were treated as shown in the table 3.4.

Table 3.4: Summary of Samples Tested for Moisture Content

SAMPLE NOTATION	SAMPLE DESCRIPTION	NUMBER OF SAMAPLES
DS	Dredged Sediment (neat)	15
1B99DS	1% Bentonite, 99% DS	15
2B98DS	2% Bentonite, 98% DS	15
3B97DS	3% Bentonite, 97% DS	15

Source: Appendix 11, 18, 19 and 20.

For each sample type 15 tests were conducted and an average was taken.

Calculate the moisture content of the soil as a percentage of the dry soil weight.

$$MC\% = \left(\frac{W2 - W3}{W3 - W1}\right) * 100 \qquad \textit{Equation } 3.1$$

Where:

W_1 = Weight of tin (g)

W_2 = Weight of moist soil + tin (g)

W_3 = Weight of dried soil + tin (g)

3.3.5 Viscosity

The standard reference for measuring viscosity was the ASTM D6910. Viscosity is the measure a fluid's resistance to flow in an unenclosed apparatus. The test used to determine the viscosity of the dredged sediments was the Marsh Funnel viscosity test. The test measured the total-time it took for a given volume of dredged sediments to pass through a calibrated orifice. The orifice at the bottom of the Marsh Funnel was stopped using a finger. The funnel was then filled with the dredged sediments by pouring it through the screen on the top of the funnel until it reaches the screen level. A 1-litre test cup was placed under the funnel.

The stopwatch was then started simultaneously while removing the finger from the funnel orifice to allow the fluid to flow into the test cup. The stopwatch was stopped when the fluid level reached the 1-litre line in the test cup. The fluid viscosity is described in terms of the amount of time, in seconds, that was necessary for 1 litre of the fluid to flow through the calibrated orifice. The samples tested were treated as shown in the table 3.5.

Table 3.5: Summary of Samples Tested for Viscosity

SAMPLE NOTATION	SAMPLE DESCRIPTION	NUMBER OF SAMAPLES
DS	Dredged Sediment (neat)	34
1B99DS	1% Bentonite, 99% DS	34
2B98DS	2% Bentonite, 98% DS	34
3B97DS	3% Bentonite, 97% DS	34

Source: Appendix 12, 20, 21 and 22. For each sample type 34 tests were conducted and an average was taken.

3.3.6 Hydraulic Conductivity

The standard reference for measuring the hydraulic conductivity was the ASTM D5084. The samples tested were treated as shown in the table 3.6.

Table 3.6: Summary of Samples Tested for Hydraulic Conductivity

SAMPLE NOTATION	SAMPLE DESCRIPTION	NUMBER OF SAMAPLES
DS	Dredged Sediment (neat)	30
1B99DS	1% Bentonite, 99% DS	30
2B98DS	2% Bentonite, 98% DS	30
3B97DS	3% Bentonite, 97% DS	30

Source: Appendix 13, 23, 24 and 25. For each sample type 30 tests were conducted and an average was taken.

The hydraulic conductivity, k in cm/s, was calculated by use of the following equation:

$$k = \left(\frac{q}{h}\right) * t \qquad \textit{Equation } 3.2$$

Where

q = ratio of the flow in mL/s and the area of the apparatus (cm^2)

h = pressure head converted (cm)

t = thickness of the filter cake formed (cm)

3.4 Test Plan

The intention of this testing plan is to find an appropriate mix of sediment and bentonite that was able to function as a vertical cut-off wall backfill material. The preliminary tests on the bentonite were carried out for screening purposes and to find an appropriate water content that will satisfy the desired viscosity range. Martinenghi (1995) recommend a well-graded material similar to a glacial till with 10% to 20% fines and 1% to 4% bentonite.

From the given literature bentonite was then added to the dredged sediment in ratios of 1%, 2% and 3% of the total dredged sediment weight. The preliminary tests were repeated for each of these mixes to determine applicable trends and at what percentages of bentonite, the viscosity of the mixture was still in the workable range. The 1%

bentonite mix was additionally modified with the addition of 5% and 8% fly ash by weight. These mixtures were then subjected to API filter press tests (used as a rigid wall permeameter) to determine the effect these mixes would have on the hydraulic conductivity. Table 3.1 shows a legend for the composition of the mix designs and Table 3.2 shows a summary of the tests performed.

Table 3.7: Legend and the Composition of the Design Mix

Sample ID	**Description**
DS	100% Dredged Sediment
1B99DS	99% Dredged Sediment +1% Bentonite
2B98DS	98% Dredged Sediment, 2% Bentonite
3B97DS	97% Dredged Sediment, 2% Bentonite
1B94DS5FA	94 % Dredged Sediment, 1% Bentonite, 5% Flyash
1B91DS8FA	91% Dredged Sediment, 1% Bentonite, 8% Flyash

Table 3.8: Summary of Tests Performed

Sample	Density	Moisture Content	Atterberg Limits	Viscosity	Hydraulic Conductivity
DS(Dredged Sediment)	X	X	X	X	X
1B99DS (1%Bentonite,99%DS)	X	X		X	X
2B98DS (2%Bentonite,98%DS)	X	X		X	X
3B97DS (3%Bentonite,97%DS)	X	X		X	X
1B94DS5FA (1%Be,94%DS,5%Fly)					X
1B91DS8FA (1%Be,91%DS,8%Fly)					X

Key

X – Test carried out to determine the engineering properties of the sample

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

4.1 Introduction

Preliminary testing on the dredged sediments (DS) was done to determine suitable physical parameters that could then be used in the mix design. The sediment was tested for density, moisture content, and viscosity and filtrate loss.

Similar tests were performed on the sediment mixes, made with 1%, 2% and 3% of bentonite by weight. These mixes are herein referred as the modified dredged sediment mix. These tests were carried out to determine the effect of bentonite on mud weight densities, moisture content, viscosity and hydraulic conductivity. Some of the mixtures prepared with 1% bentonite were modified with the addition of fly ash, to determine the effect of fly ash on hydraulic conductivity.

4.2 Results of Physical Properties of the Dredged Sediment at the Port of Mombasa

4.2.1 Density of the Dredged Sediment (DS) from Port of Mombasa

Density testing of the dredged sediments (DS) revealed an average density of 10.58 kN/m^3, (see appendix 8 for the data recorded) which compares to results from a study conducted on dredged New Jersey harbour bottom sediments which gave unit weight values in the range of 10.09-11.6 kN/m^3 (Vaghar et al., 1997). The heavier the mud density the better quality of the vertical cutoff wall. The mud weight density is of the Port of Mombasa harbour dredged sediments also falls within the documented average mud weight density from other parts of the world.

4.2.2 Atterberg Limits and Particle Size of the Modified Dredged Sediment

The Atterberg limits were measured in accordance with the standard ASTM D 4318. The liquid limit and plastic limit of the material were found to be 85 and 35, respectively (see Appendix 9). The material was classified as high plasticity clay (CH) according to the Unified Soil Classification System (USCS). Table 4.1 summarizes the index parameters of the dredged material.

Table 4.1: Engineering Parameters of the Dredged Material used in the Study

Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)	USCS Class.
85	35	50	CH

Source: **Appendix 9**

The soil gradation is very important because it’s an indicator of the hydraulic conductivity, which affects the quality of the vertical cutoff wall. From literature review for example clay is expected to have low hydraulic conductivity than silt.

4.2.3 Moisture Content of the Modified Dredged Sediment

The moisture content of the sediment ranged was found to have an average of 580 % (see Appendix 10). The mud moisture content of the dredged sediment falls within the range of the density of most dredged sediments, which is in the range of 380-630% (Vaghar et al., 1997).

4.2.4 Viscosity of the Modified Dredged Sediment

The average viscosity for the dredged sediment was found to be 32 s (see Appendix 12). For the dredged material to be in the lower allowable viscosity range of 32-40 (Verhoeven et al., 1988), the moisture content was on the upper end of its range. These results were found to fall within acceptable range.

4.2.5 Hydraulic Conductivity

The filtrate loss test resulted in a volume filtrate of 23.8 mL collected after 30 min, 50 ml after 1½ hours, and a total volume of filtrate of 375mL collected after an estimated time of 11hrs and 13mins. The gradient of the filtrate loss curve was averaged to be 8.6x10-3 mL/s (see Appendix 13). The filter cake thickness was 10 mm; it was smooth and black in color. The hydraulic conductivity of soil-bentonite used in vertical barrier construction is typically between 1x10-7 and 1x10-8 cm/s (Evans, 1994). The results showed that constants in Equation 3.2 were h=153.6cm^2 and t = 10cm. Using the same Equation 3.2 the average hydraulic conductivity of the dredged sediment (DS) was found to be 6.65x10^{-7} cm/s. (see Appendix 13).

Table 4.2: Summary Properties for the Dredged Sediment (DS)

PHYSICAL PROPERTIES OF DREDGED SEDIMENT (DS)		
SNo.	**ITEM**	**VALUE**
1	Density (kN/m3)	10.58
2	Liquid Limit (LL)	85
3	Plastic Limit (PL)	35
4	Plasticity Index	50
5	Soil Classification	CH (Clay of High Plasticity)
6	Moisture Content (%)	580
7	Viscosity (s)	33
8	Filtrate Loss (mL/s)	6.65 * 10-7
9	Hydraulic Conductivity (cm/s)	8.66 * 10-3

Source: Appendix 8,9,10,11 and 12.

The summary above shows the physical properties of the dredged sediment (DS) before any modification was done which included addition of bentonite and flyash in different proportions and detailed the sections below.

4.3 Effect of Bentonite Content on Density

The results of the mud weight (herein being referred to as modified sediment mix) densities revealed that with increasing bentonite content, the mud weight density increased. This is an expected trend as shown in Figure 4.1. When then dredged sediment is mixed with 3% of bentonite by weight the density is increase by about 2.64 % (see Appendix 16).

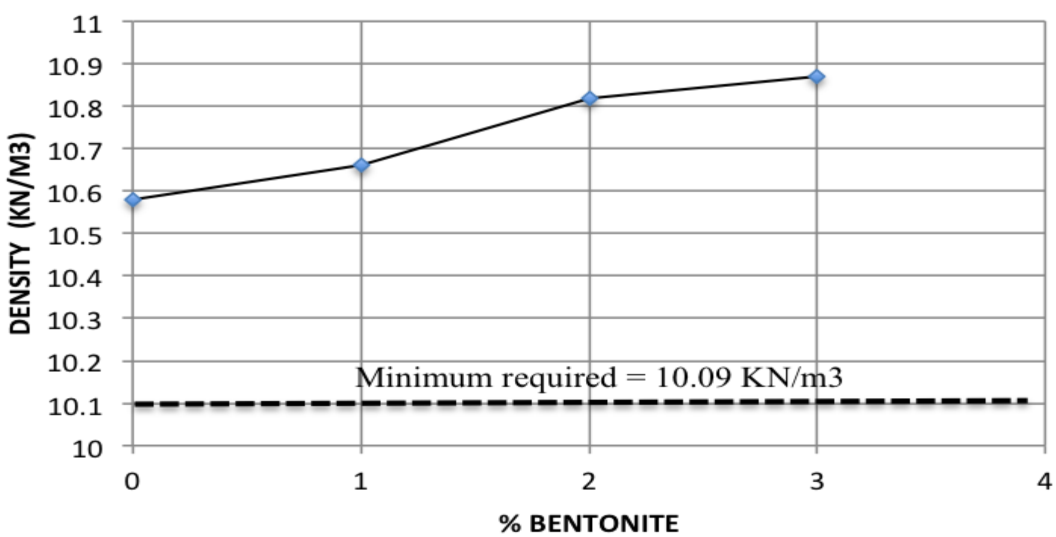

Figure 4.1: Effect of Bentonite on Sediment Mix Density

The data that generated the Fig. 4.1 above was drawn from Appendix 14 to 16. The net increase of the density is a desirable property since the heavier the mix the better vertical cutoff wall. The conventional slurry-bentonite mixes have average densities of 10.75 kN/m^3 (Vaghar et al., 1997). It will be easy to replace the conventional slurry-bentonite mix with this modified dredged sediment mix.

4.4 Effect of Bentonite Content on Sediment Mix Moisture Content

With increasing bentonite content there was decreasing moisture content (see Appendix 17, 18 and 19). Bentonite, montmorillonite clay, usually swells in the presence of water, therefore it is expected that the bentonite introduced would absorb some of the water in making the homogeneous mixture. Figure 4.2 shows the resulting trend.

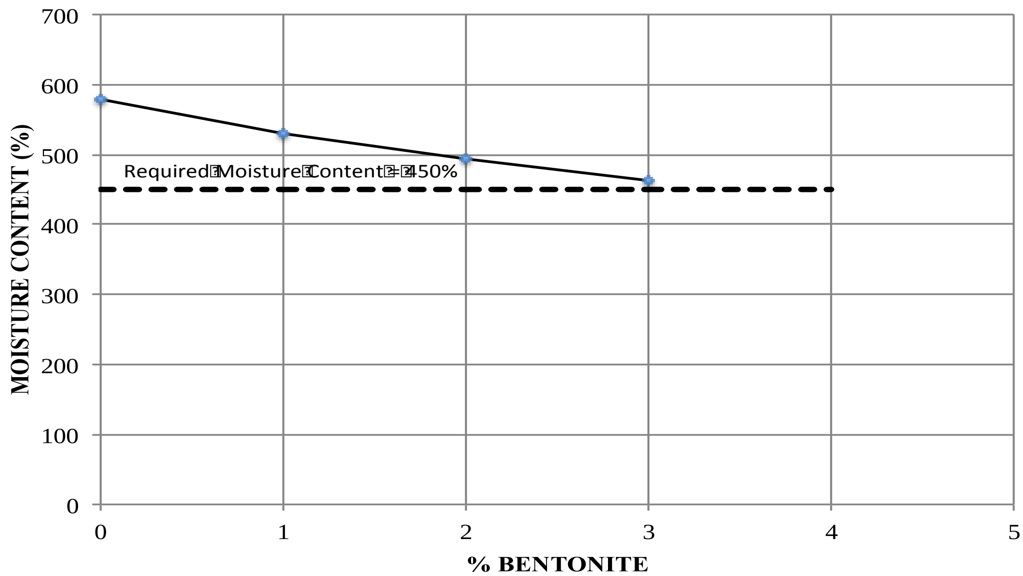

Figure 4.2: Effect of Bentonite Content on Moisture Content

4.5 Effect of Bentonite Content on Viscosity

The results showed that the viscosity increased as the bentonite content increased as shown in Fig. 4.3. Initial water content which gave a viscosity measure on the lower end of the suitable range (32-40 s) was used as stated by Verhoeven et al (1988). It was not difficult to adjust the water content, so that with the initial addition of bentonite so that higher or lower viscosity could be attained (see Appendix 20, 21 and 22).

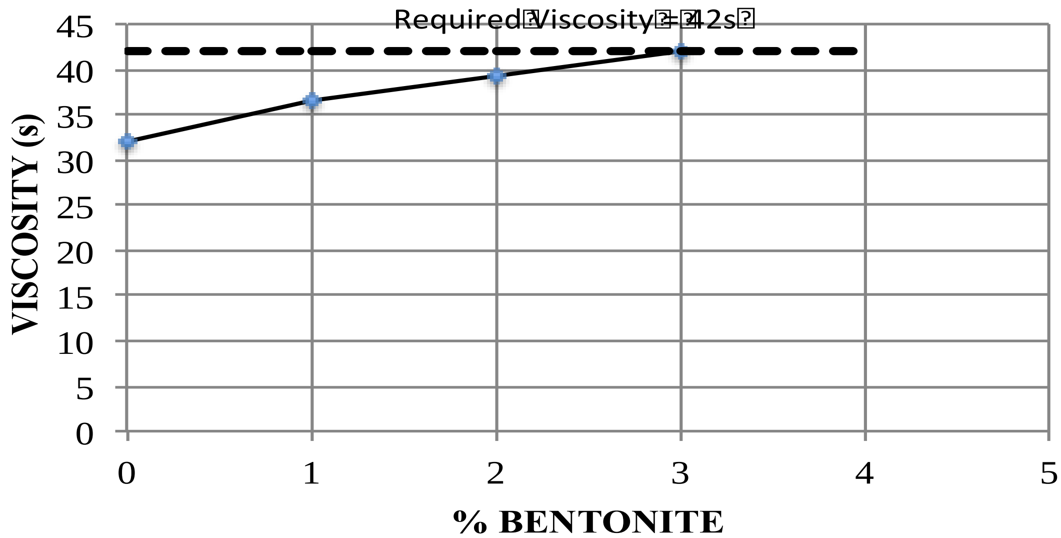

Figure 4.3: Marsh Funnel Viscosity versus Bentonite Content

Also, the sediment-bentonite mix was workable, even though there was some difficulty in attaining a homogeneous mixture in the laboratory due to the nature of the materials. As bentonite is a type of clay and denser than the dredged sediments, it is expected that the mixture, will become more viscous with increasing bentonite content.

4.6 Effect of Bentonite Content on Hydraulic Conductivity

The principal factor in the performance of vertical barrier systems is the hydraulic conductivity (Evans, 1994). Increasing bentonite content resulted in decreasing hydraulic conductivity. Comparable results have been found in studies by Evans (1994). It was found that increasing the bentonite content in a vertical barrier would decrease the hydraulic conductivity in soil-bentonite and in-situ mixed walls. For a particular mix used, the minimum hydraulic conductivity was found at a bentonite content of about 3%. A similar trend of decreasing hydraulic conductivity with increasing bentonite content was found in a study done by D'Appolonia (1980). The hydraulic conductivity of soil-bentonite used in vertical barrier construction is typically between 1x10-7 cm/s and 1x10-8 cm/s (Evans, 1994). Figures 4.3 show the effect of bentonite content on hydraulic conductivity at given applied pressure of 48.3kPa. From the Appendix 23, 24 and 25 was used to generate the relationship as shown in Fig. 4.4.

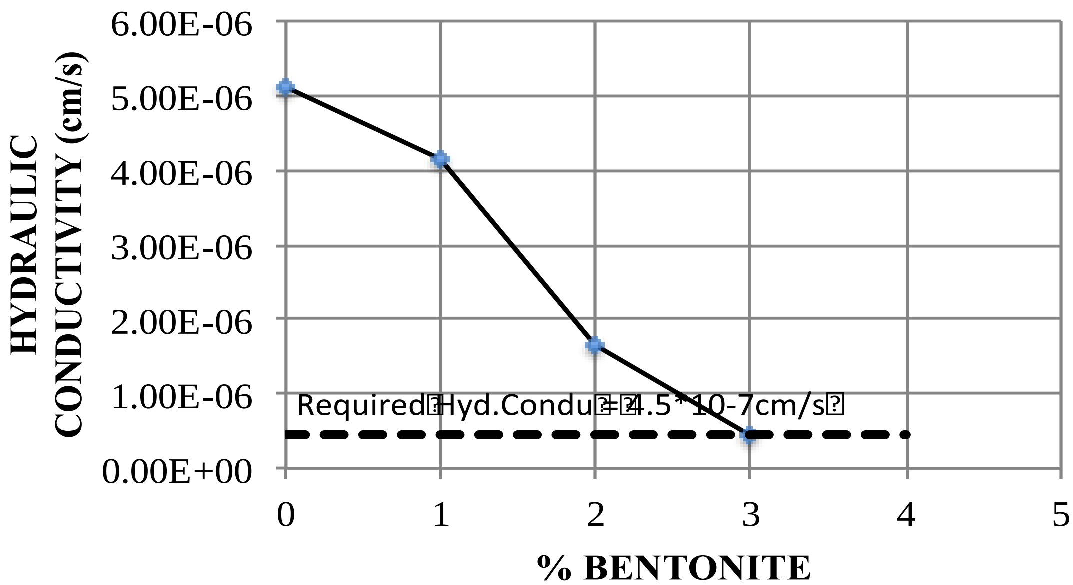

Figure 4.4: Effect of Bentonite Content on Hydraulic Conductivity

The hydraulic conductivity achieved was also generally lower for the sample mixes. This is expected as with increasing effective stress, the void ratio decreases and so would the hydraulic conductivity. A study by Evans (1994) showed similar results. For any given sample of vertical barrier material, the hydraulic conductivity decreases as the effective consolidation pressure increases.

4.7 Effect of Fly Ash and the Modified Sediment Mix on Hydraulic Conductivity

Increasing fly ash content, and the modified sediment mixture (1B99DS), the hydraulic conductivity of the mix was increased. This can be theoretically explained in that as the fly ash attaches itself to the fines present, the mixtures resemble a more granular structure, hence increasing the void ratio and hydraulic conductivity. Tables 4.4 and the corresponding Figures 4.5 show the effect of fly ash on hydraulic conductivity at the given pressure (see Appendices 25 and 26 for detailed information).

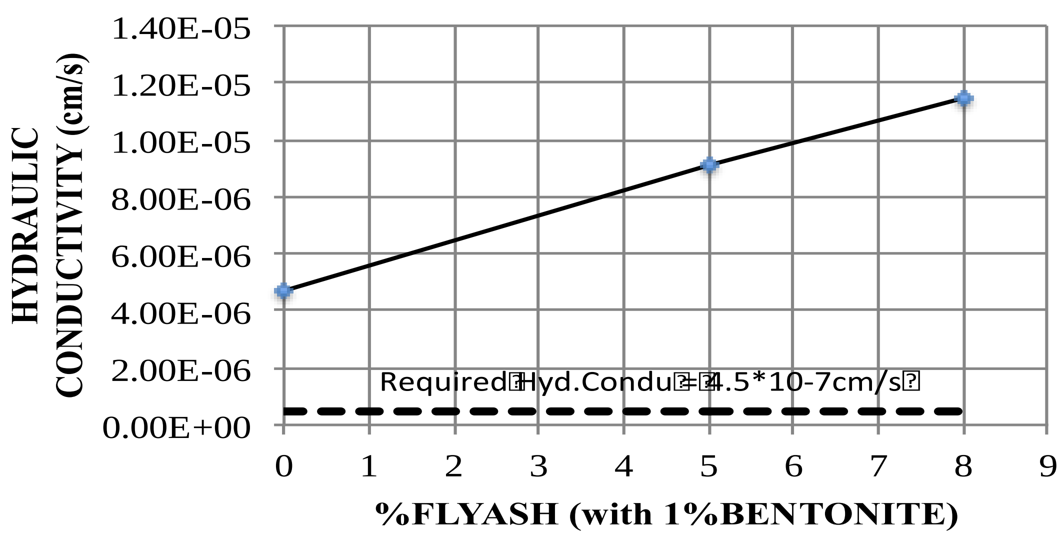

Figure 4.5: Effect of Fly Ash on Hydraulic Conductivity

Fig. 4.5 was used to conclude that increase of the fly ash content to the percent 8%, (with the neat dredged sediment and 1% bentonite by weight), increases the hydraulic conductivity of the sediment mix.

Table 4.3: Summary Properties for the Modified Sediment Mix

PHYSICAL PROPERTIES OF SEDIMENT MIX (DS MODIFIED WITH BENTONITE & FLYASH)

Sno	ITEM	VALUES (DS)	VALUES (1%Bentonite)	VALUES (2%Bentonite)	VALUES (3%Bentonite)	VALUES (1%B+5%Fly)	VALUES (1%B+8%Fly)	REMARKS (Standards)
1	Density (kN/m3)	10.58	10.67	10.82	10.86	N/A	N/A	10.8 kN/m3 is average (conventional bentonite-soil)
2	Liquid Limit (LL)	85	N/A	N/A	N/A	N/A	N/A	PI is not useful in cut-off walls as it is for pavement construction (directly affects the CBR).
3	Plasitcu Limit (PL)	35	N/A	N/A	N/A	N/A	N/A	
4	Plasticity Index	50	N/A	N/A	N/A	N/A	N/A	
5	Soil Classification	CH (Fat Clay)	N/A	N/A	N/A	N/A	N/A	Initial classification was sufficient.
6	Moisture Content (%)	580	531	493	463	N/A	N/A	500 % is average (conventional bentonite-soil)
7	Viscosity (s)	33	36.53	39.39	42.05	N/A	N/A	36 s is average (conventional bentonite-soil)
8	Filtrate Loss (mL/s)	8.66 * 10-3	6.77 * 10-3	4.9 * 10-3	3.06 * 10-3	9.11 * 10-3	11.46 * 10-3	
9	Hydraulic Conductivity (cm/s)	5.1 * 10-6	3.99 * 10-3	2.89 * 10-3	1.8 * 10-3	5.37 * 10-3	6.75 * 10-3	1.75 cm/s is average (conventional bentonite-soil)

KEY

1% Bentonite	1% of bentonte and 99% of dredged sediment by weight (1B99DS)
2% Bentonite	2% of bentonte and 98% of dredged sediment by weight (2B98DS)
3% Bentonite	3% of bentonte and 97% of dredged sediment by weight (3B97DS)
1% B+5%Fly	1% of bentonte, 5% Flyash and 94% of dredged sediment by weight (1B5FA94DS)
1% B+8%Fly	1% of bentonte, 8% Flyash and 91% of dredged sediment by weight (1B8FA91DS)
N/A	Not Applicable (was deemed not necessary or required)

Table 4.3 and Fig. 4.4 shows that the most appropriate sediment mix was the 3B97DS since it could be closed matched to the standard slurry-bentonite mix from the literature review. The best-matched physical properties mostly considered the values of hydraulic conductivity, viscosity and density.

The effect of adding flyash was inversely proportional hence found to be undesirable especially because of the increase in hydraulic conductivity.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

Detailed conclusions of this study can be summarized as follows:

1. The optimum sediment mix in this study was established at 3% of bentonite by weight (Sample ID: 3B97DS). This was the most appropriate mix to function as the backfill material for the vertical cut-off wall. This was mainly because increasing the bentonite content to the percent decreased the hydraulic conductivity of the sediment mix. This is a very desirable trend and beneficial to the backfill material required.
2. The mud weight density of the dredged sediments was 10.58 kN/m^3 and this value falls within the range of bentonite slurries 10.06 - 12.58 kN/m3. Increasing bentonite content leads to an increase in mud weight density by an average rate of 2.64%. This is helpful as the backfill material must be denser than the slurry in order to displace it in the conventional construction process.
3. Increasing bentonite content, to the percent tested (3%), resulted in a decrease in hydraulic conductivity. The optimum range to serve the purpose of use as a vertical cutoff wall (1x10-7 to 1x10-8 cm/s) was near realized (4.48x10-7 cm/s) at

3% bentonite by weight. This is a desirable characteristic and beneficial to the vertical cut-off wall material.

4. Increasing the fly ash content to the percent tested (8%), (with the base as dredged sediments and 1% bentonite by weight), increased the hydraulic conductivity. This trend was found to be undesirable hence introduction of fly ash is unsuitable for vertical cut off walls backfill material.

In a summary it can be said that the dredged sediment from Port of Mombasa channel can serve as an effective vertical cut-off wall material when modified with 3% bentonite. Hence it is possible to beneficially use dredged sediment from Port of Mombasa for engineering purpose.

5.2 Recommendations

The dredged sediments can be manipulated to moisture content, viscosity (32 - 40s) and density that satisfy the appropriate range of corresponding slurry values used in field practice today. The optimum mix design of the mixes tested was the mix of dredged sediments and 3% bentonite by weight which gave desirable properties and a hydraulic conductivity of 4.48×10^{-7} cm/s at an applied pressure of 48.3 kPa. Increased bentonite content decreases the hydraulic conductivity, which is the desired effect in the performance of a vertical cut-off wall. Increasing fly ash content had the opposite expected effect, that is, it increases the hydraulic conductivity.

As dredged sediments are the by-products of the dredging industry, cost savings will be realized through its use. The use of dredged sediments is also appealing from an environmental and social point of view, since the beneficial use applications reduce landfilling costs. Hence the function is retained and the costs are reduced.

The main requirements of a good vertical barrier system are its ability to limit the flow of groundwater and contain and remove or attenuate contaminants. In performing the literature review relative to this topic, very few detailed technical studies were found to specifically address the beneficial use of dredged sediments particularly in Africa. More studies need to be undertaken on this topic – (specifically their use as a vertical cut-off wall material) – in order to have a larger comparative base.

5.3 Areas for Further Research

Some of the proposed future research could include;

- More design mixes can be explored to determine possibly a more optimum design mix. In addition, the behavior of these walls in the field should be explored further to better understand the stresses they experience in the field and, hence, lead to better design work in terms of applied pressures.
- Investigation on the effect of bentonite and fly ash on adsorption. A great deal of dredging operations is carried out in harbors in industrial areas where the dredged sediments are already contaminated with certain heavy metals.

- More research on effect of bentonite and fly ash on hydraulic conductivity at different exerted pressures.
- Lastly more investigation can be established to find the value engineering aspect of dredged sediments on the social and economic point of view.

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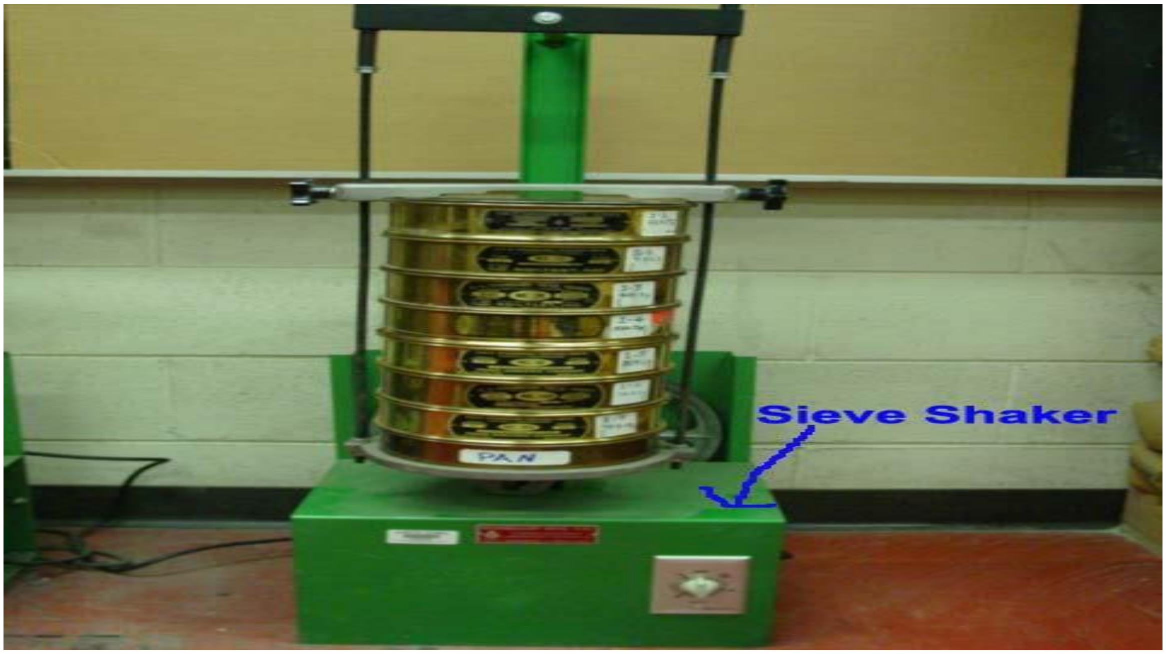
APPENDICES

Summary of Appendices Contained in this Section

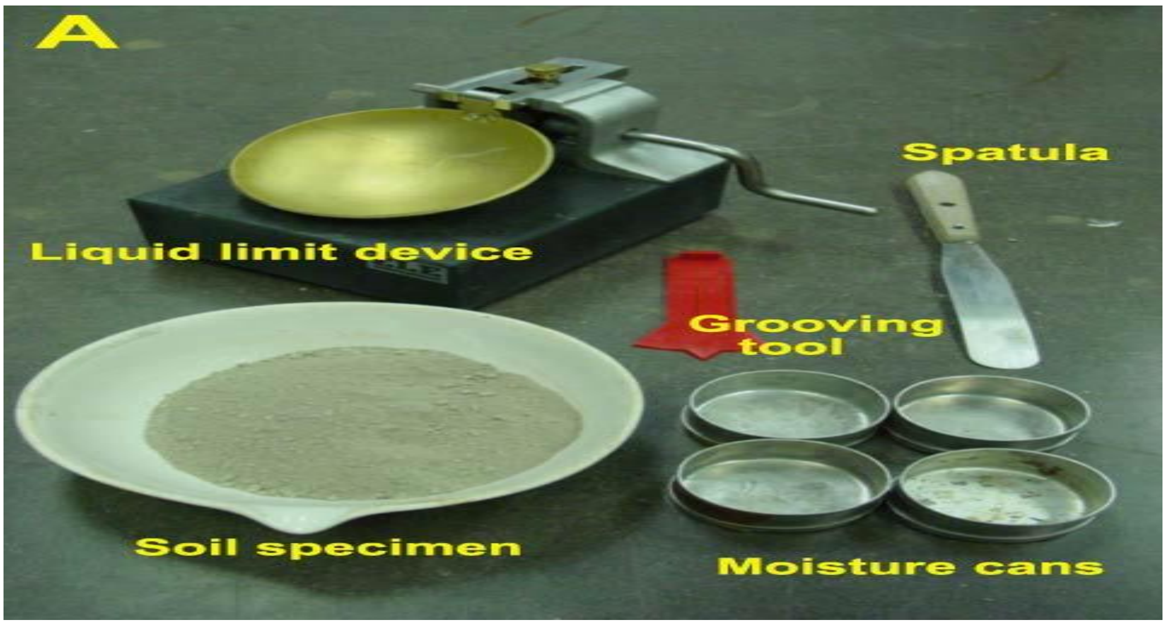
Appendix 1: Picture of Beaker with the Sediment on a Scale

Appendix 2: Laboratory Oven At 110 Degrees With Sediment Samples

Appendix 3: Grain Size Analysis Set-Up

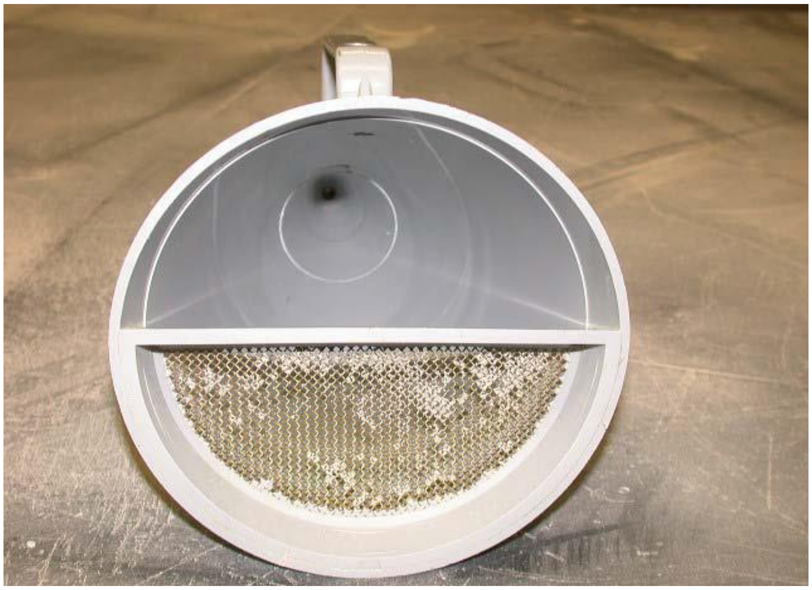


Appendix 4: Atterberg Limits Equipment Set-Up



Appendix 5: Side View Of The Marsh Funnel

Appendix 6: Top View Of The Marsh Funnel



Appendix 7: Filter Press Equipment

Appendix 8: Density of the DS (DS)

APPENDIX 8: Density of the Dredged Sediment (DS)

DREDGED SEDIMENT (DS) FROM POM

Sno	MASS (g) (M)	VOLUME (mL) (V)	Density (kN/m3)
1	5400	540	10.000
2	5500	520	10.577
3	5600	540	10.370
4	5600	520	10.769
5	5600	540	10.370
6	5600	550	10.182
7	5600	550	10.182
8	5480	520	10.538
9	5600	515	10.874
10	5600	515	10.874
11	5600	515	10.874
12	5600	515	10.874
13	5300	515	10.291
14	5600	545	10.275
15	5480	545	10.055
16	5600	500	11.200
17	5600	500	11.200
18	5600	520	10.769
19	5650	540	10.463
20	5549	520	10.671
21	5660	545	10.385
22	5480	530	10.340
23	5600	540	10.370
24	5650	520	10.865
25	5550	520	10.673
26	5650	520	10.865
27	5650	530	10.660
28	5500	530	10.377
29	5640	530	10.642
30	5600	505	11.089
TOTAL	**167,139.00**	**15,795.00**	
AVERAGE DENSITY (M/V)		**10.58176638**	

LABORATORY:	**Geoff Griffins and Associates, ICD Nairobi.**
Date:	**15th May 2012**

Appendix 9: Alterberg limits for modified DS (DS)

APPENDIX 9: Atterberg Limits for Dredged Sediment (DS)

DATA FOR ATTERBERG LIMITS TEST FOR THE DREDGED SEDIMENT (DS)								
TEST	**LIQUID LIMIT**				**PLASTIC LIMIT**			
Test No.	1	2	3	4	1	2	3	4
Number of Drops (N)	16.00	21.00	31.00	42.00				
Log (N)	1.20	1.32	1.49	1.62				
Tare Mass (g)	45.69	45.62	45.82	43.89	44.60	44.72	44.60	44.72
Tare + Wet Sample (g)	55.95	56.70	57.88	55.83	52.84	53.10	52.90	53.20
Tare + Dry Sample (g)	51.13	51.58	52.50	50.37	50.75	50.94	50.75	50.94
Wet Mass (g)	10.26	11.08	12.06	11.94	8.24	8.38	8.30	8.48
Dry Mass (g)	5.44	5.96	6.68	6.48	6.15	6.22	6.15	6.22
Water Content (WC)	88.69	85.89	80.54	84.26	33.98	34.73	34.96	36.33
Number of Tests					4	4	4	4
AVERAGE (LL) = (Slope WC)*Log 25+(Slope Log(N))) AVERAGE (PL) = Sum (WC)/4	85				35			
PLASTICITY INDEX (LL-PL)	**50**							

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DATE:	**15th May 2012**

Slope =	-13.31	Intercept =	103.61	N =	25

Appendix 10: Particle size for the DS (DS)

APPENDIX 10: Particle Size for the Dredged Sediment (DS)

DATA FOR PARTICLE SIZE ANALYSIS TEST FOR (DS)

Sieve Number (D)	Diameter (mm)	Weight Retained (g)	% Retained	% Passing
1	19	0	0	100
2	13.2	112.2	18.98	81.02
3	9.5	50.8	8.59	72.43
4	4.75	87.3	14.77	57.66
5	2.36	115.2	19.49	38.18
6	1.18	75.2	12.72	25.46
7	0.6	43.5	7.36	18.1
8	0.3	28.6	4.84	13.26
9	0.15	30.6	5.18	8.09
10	0.075	35.2	5.95	2.13
11	PAN	11.7	2.13	0
	TOTAL	**590.3**	**100.01**	**0.085**

Wt. of dry sample + container (g)	834.1
Wt. container (g)	242.4
Wt. of dry sample, (g)	591.7

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DATE:	**15th May 2012**

Appendix 11: Moisture content for modified DS (DS)

APPENDIX 11: Moisture Content for Dredged Sediment (DS)

DATA FOR MOISTURE CONTENT TEST FOR DREDGED SEDIMENT (DS)			
Sample Number	Sample Weight (SW) (g)	Oven-Dry Weight (OD) (g)	Oven-Dry Moisture Content (%MC)
1	2,550	370	589
2	2,580	360	617
3	2,570	380	576
4	2,550	350	629
5	2,530	380	566
6	2,550	390	554
7	2,550	350	629
8	2,540	370	586
9	2,550	380	571
10	2,950	450	556
11	2,550	390	554
12	2,550	380	571
13	2,550	370	589
14	2,550	380	571
15	2,580	390	562
TOTAL	38700	5690	
AVERAGE % MC= ((SW-TW)-((OD-TW))/((OD-TW))*100			**580**
Constant	Weight of the tin (TW) (g)	115	

LABORATORY:	**Geoff Griffins & Associates, ICD Nairobi**
DATE:	**15th May 2012**

Appendix 12: Viscosity for modified DS (DS)

APPENDIX 12: Viscosity for Dredged Sediment (DS)

DATA FOR VISCOSITY TEST (MARSH FUNNEL) FOR DS

Sample Number	Marsh Time (s)	Volume (mL)
1	35	1000.00
2	31	1000.00
3	34	1000.00
4	33	1000.00
5	32	1000.00
6	35	1000.00
7	31	1000.00
8	34	1000.00
9	33	1000.00
10	32	1000.00
11	35	1000.00
12	31	1000.00
13	34	1000.00
14	33	1000.00
15	32	1000.00
16	35	1000.00
17	31	1000.00
18	34	1000.00
19	33	1000.00
20	32	1000.00
21	35	1000.00
22	31	1000.00
23	34	1000.00
24	33	1000.00
25	32	1000.00
26	35	1000.00
27	31	1000.00
28	34	1000.00
29	33	1000.00
30	32	1000.00
31	33	1000.00
32	34	1000.00
33	35	1000.00
34	31	1000.00
AVERAGE VISCOSITY = (Sum t)/34) (s)		**33**
LABORATORY:		**Geoff Griffins & Associates,Nairobi**
DATE:		**15th May 2012**

Appendix 13: Hydraulic Conductivity for Dredged Sediment (DS)

APPENDIX 13: Hydraulic Conductivity for Dredged Sediment (DS)

DATA FOR HYDRAULIC CONDUCTIVITY (FILTER PRESS) FOR DS

Sample Number	Filtrate Time (T) (s)	Volume (V) (mL)	Filter Cake (t) (cm)	Filtrate Loss (V/T) (mL/s)	Hydraulic Conductivity k (cm/s)
1	1,800	23.80	10	13.22	0.000000859
2	5,400	55.00	10	10.19	0.000000662
3	40,380	357.90	10	8.86	0.000000576
4	1,800	23.00	10	12.78	0.000000830
5	5,400	40.00	10	7.41	0.000000481
6	40,380	360.00	10	8.92	0.000000579
7	1,800	22.00	10	12.22	0.000000794
8	5,400	45.00	10	8.33	0.000000542
9	40,380	361.00	10	8.94	0.000000581
10	1,800	23.80	10	13.22	0.000000859
11	5,400	51.00	10	9.44	0.000000614
12	40,380	350.00	10	8.67	0.000000563
13	1,800	23.00	10	12.78	0.000000830
14	5,400	50.00	10	9.26	0.000000602
15	40,380	350.00	10	8.67	0.000000563
16	1,800	26.00	10	14.44	0.000000939
17	5,400	51.00	10	9.44	0.000000614
18	40,380	345.00	10	8.54	0.000000555
19	1,800	23.00	10	12.78	0.000000830
20	5,400	45.00	10	8.33	0.000000542
21	40,380	340.00	10	8.42	0.000000547
22	1,800	22.00	10	12.22	0.000000794
23	5,400	49.00	10	9.07	0.000000590
24	40,380	350.00	10	8.67	0.000000563
25	1,800	23.80	10	13.22	0.000000859
26	5,400	49.00	10	9.07	0.000000590
27	40,380	350.00	10	8.67	0.000000563
28	1,800	25.00	10	13.89	0.000000903
29	5,400	49.00	10	9.07	0.000000590
30	40,380	340.00	10	8.42	0.000000547
AVERAGE FILTRATE LOSS (mL/s) * 10^-3			**8.66**		

Equation 3.2: k=(q/h)*t. Constants: h=153.86cm2; t=10cm {Average k= 6.65*10-7cm/s}

LABORATORY:	**Geoff Griffins & Associates, ICD Nairobi**
DATE:	**15th May 2012**

Appendix 14: Density of the modified DS (1B99DS)

APPENDIX 14: Density of the Modified Dredged Sediment (1B99DS)

SEDIMENT MIX WITH 1% BENTONITE BY WEIGHT (1B99DS)

Sno	MASS (g) (M)	VOLUME (mL) (V)	Density (kN/m3)
1	5500	500	11.000
2	5750	500	11.500
3	5600	520	10.769
4	5600	540	10.370
5	5600	520	10.769
6	5500	545	10.092
7	5750	530	10.849
8	5480	540	10.148
9	5600	515	10.874
10	5600	515	10.874
11	5500	515	10.680
12	5750	515	11.165
13	5300	515	10.291
14	5500	545	10.092
15	5750	545	10.550
16	5600	500	11.200
17	5600	500	11.200
18	5500	520	10.577
19	5750	540	10.648
20	5549	520	10.671
21	5660	545	10.385
22	5480	530	10.340
23	5600	540	10.370
24	5650	520	10.865
25	5550	520	10.673
26	5650	520	10.865
27	5650	530	10.660
28	5500	530	10.377
29	5500	530	10.377
30	5750	505	11.386
TOTAL	**67,769.00**	**5,710.00**	
AVERAGE DENSITY (M/V)		**10.67912158**	
% Increase from DS Density (10.58)			0.94
LABORATORY:	**Geoff Griffins and Associates, ICD Nairobi.**		
Date:	**15th May 2012**		

Appendix 15: Density of the modified DS (2B98DS)

APPENDIX 15: Density of the Modified Dredged Sediment (2B98DS)

SEDIMENT MIX WITH 2 % BENTONITE BY WEIGHT (2B98DS)			
Sno	**MASS (g) (M)**	**VOLUME (mL) (V)**	**Density (kN/m3)**
1	5750	530	10.849
2	5700	515	11.068
3	5750	515	11.165
4	5700	545	10.459
5	5600	545	10.275
6	5700	545	10.459
7	5750	530	10.849
8	5750	545	10.550
9	5700	530	10.755
10	5750	540	10.648
11	5750	520	11.058
12	5750	520	11.058
13	5750	520	11.058
14	5750	545	10.550
15	5670	545	10.404
16	5750	500	11.500
17	5700	500	11.400
18	5650	520	10.865
19	5670	540	10.500
20	5650	520	10.865
21	5750	545	10.550
22	5700	530	10.755
23	5750	540	10.648
24	5670	530	10.698
25	5750	540	10.648
26	5750	520	11.058
27	5650	520	10.865
28	5700	520	10.962
29	5750	530	10.849
30	5750	500	11.500
TOTAL	**[illegible]71,460.00**	**[illegible]5,845.00**	
AVERAGE DENSITY (M/V)		**10.8210792**	
% Increase from DS Density (10.58)			2.28
LABORATORY:	**Geoff Griffins and Associates, ICD Nairobi.**		
Date:	**15th May 2012**		

Appendix 16: Density of the modified DS (3B97DS)

APPENDIX 16: Density of the Modified Dredged Sediment (3B97DS)

SEDIMENT MIX WITH 3 % BENTONITE BY WEIGHT (3B97DS)

Sno	MASS (g) (M)	VOLUME (mL) (V)	Density (kN/m3)
1	5700	520	10.962
2	5730	520	11.019
3	5700	545	10.459
4	5700	545	10.459
5	5600	550	10.182
6	5700	500	11.400
7	5650	530	10.660
8	5730	545	10.514
9	5700	530	10.755
10	5750	540	10.648
11	5700	520	10.962
12	5730	500	11.460
13	5700	520	10.962
14	5750	520	11.058
15	5650	520	10.865
16	5730	545	10.514
17	5700	545	10.459
18	5650	500	11.300
19	5670	500	11.340
20	5750	520	11.058
21	5730	520	11.019
22	5700	520	10.962
23	5750	545	10.550
24	5670	545	10.404
25	5750	500	11.500
26	5750	500	11.500
27	5650	520	10.865
28	5700	520	10.962
29	5750	530	10.849
30	5750	550	10.455
TOTAL	[illegible]71,190.00	[illegible]5,765.00	
AVERAGE DENSITY (M/V)		**10.85886457**	
% Increase from DS Density (10.58)			2.64
LABORATORY:	**Geoff Griffins and Associates, ICD Nairobi.**		
Date:	**15th May 2012**		

Appendix 17: Moisture content for modified DS (1B99DS)

APPENDIX 17: Moisture Content Modified for Dredged Sediment (1B99DS)

DATA FOR MOISTURE CONTENT TEST FOR SEDIMENT MIX (1B99DS)

Sample Number	Sample Weight (SW) (g)	Oven-Dry Weight (OD) (g)	Oven-Dry Moisture Content (%MC)
1	2,460	390	531
2	2,650	410	546
3	2,460	400	515
4	2,550	410	522
5	2,600	420	519
6	2,650	420	531
7	2,550	400	538
8	2,550	410	522
9	2,650	420	531
10	2,650	420	531
11	2,460	400	515
12	2,550	400	538
13	2,650	420	531
14	2,600	400	550
15	2,700	420	543
TOTAL	38730	6140	
AVERAGE % MC= ((SW-TW)-((OD-TW))/((OD-TW))*100			**531**
Constant	Weight of the tin (TW) (g)	115	

LABORATORY:	**Geoff Griffins & Associates, ICD Nairobi**
DATE:	**15th May 2012**

Appendix 18: Moisture content for modified DS (2B98DS)

APPENDIX 18: Moisture Content Modified for Dredged Sediment (2B98DS)

DATA FOR MOISTURE CONTENT TEST FOR SEDIMENT MIX (2B98DS)			
Sample Number	Sample Weight (SW) (g)	Oven-Dry Weight (OD) (g)	Oven-Dry Moisture Content (%MC)
1	2,400	405	493
2	2,430	410	493
3	2,460	420	486
4	2,550	420	507
5	2,400	390	515
6	2,430	420	479
7	2,460	400	515
8	2,400	410	485
9	2,430	420	479
10	2,460	420	486
11	2,400	400	500
12	2,400	400	500
13	2,400	420	471
14	2,430	400	508
15	2,460	420	486
TOTAL	36510	6155	
AVERAGE % MC= ((SW-TW)-((OD-TW))/((OD-TW))*100			**493**
Constant	Weight of the tin (TW) (g)	115	

LABORATORY:	**Geoff Griffins & Associates, ICD Nairobi**
DATE:	**15th May 2012**

Appendix 19: Moisture content for modified DS (3B97DS)

APPENDIX 19: Moisture Content Modified for Dredged Sediment (3B97DS)

DATA FOR MOISTURE CONTENT TEST FOR SEDIMENT MIX (3B97DS)

Sample Number	Sample Weight (SW) (g)	Oven-Dry Weight (OD) (g)	Oven-Dry Moisture Content (%MC)
1	2,250	400	463
2	2,300	410	461
3	2,350	420	460
4	2,550	420	507
5	2,250	400	463
6	2,300	400	475
7	2,350	420	460
8	2,400	420	471
9	2,250	400	463
10	2,300	420	448
11	2,350	420	460
12	2,300	400	475
13	2,250	420	436
14	2,300	410	461
15	2,350	430	447
TOTAL	34850	6190	
AVERAGE % MC= ((SW-TW)-((OD-TW))/((OD-TW))*100			**463**
Constant	Weight of the tin (TW) (g)	115	

LABORATORY:	**Geoff Griffins & Associates, ICD Nairobi**
DATE:	**15th May 2012**

Appendix 20: Viscosity for modified DS (1B99DS)

APPENDIX 20: Viscosity for Modified Dredged Sediment (1B99DS)

DATA FOR VISCOSITY (MARSH FUNNEL) FOR (1B99DS)

Sample Number	Marsh Time (s)	Volume (mL)
1	37	1000.00
2	36	1000.00
3	36	1000.00
4	36	1000.00
5	37	1000.00
6	36	1000.00
7	36	1000.00
8	36	1000.00
9	36	1000.00
10	36	1000.00
11	36	1000.00
12	37	1000.00
13	37	1000.00
14	36	1000.00
15	37	1000.00
16	37	1000.00
17	37	1000.00
18	36	1000.00
19	37	1000.00
20	36	1000.00
21	37	1000.00
22	35	1000.00
23	37	1000.00
24	38	1000.00
25	36	1000.00
26	36	1000.00
27	36	1000.00
28	37	1000.00
29	37	1000.00
30	38	1000.00
31	38	1000.00
32	36	1000.00
33	36	1000.00
34	37	1000.00
AVERAGE VISCOSITY = (Sum t)/34) (s)		**36.53**
LABORATORY:		**Geoff Griffins &**
DATE:		**15th May 2012**

Appendix 21: Viscosity for modified DS (2B98DS8)

APPENDIX 21: Viscosity for Modified Dredged Sediment (2B98DS)

DATA FOR VISCOSITY (MARSH FUNNEL) FOR (2B98DS)

Sample Number	Marsh Time (s)	Volume (mL)
1	40	1000.00
2	39	1000.00
3	40	1000.00
4	38	1000.00
5	40	1000.00
6	40	1000.00
7	39	1000.00
8	40	1000.00
9	38	1000.00
10	40	1000.00
11	40	1000.00
12	39	1000.00
13	40	1000.00
14	38	1000.00
15	40	1000.00
16	40	1000.00
17	39	1000.00
18	40	1000.00
19	38	1000.00
20	40	1000.00
21	40	1000.00
22	39	1000.00
23	40	1000.00
24	38	1000.00
25	40	1000.00
26	40	1000.00
27	39	1000.00
28	40	1000.00
29	38	1000.00
30	40	1000.00
31	38	1000.00
32	39	1000.00
33	40	1000.00
34	40	1000.00
AVERAGE VISCOSITY = (Sum t)/34) (s)		**39.39**
LABORATORY:		**Geoff Griffins &**
DATE:		**15th May 2012**

Appendix 22: Viscosity for modified DS (3B97DS)

APPENDIX 22: Viscosity for Modified Dredged Sediment (3B97DS)

DATA FOR VISCOSITY (MARSH FUNNEL) FOR (3B97DS)

Sample Number	Marsh Time (s)	Volume (mL)
1	42	1000.00
2	42	1000.00
3	42	1000.00
4	43	1000.00
5	43	1000.00
6	43	1000.00
7	42	1000.00
8	42	1000.00
9	40	1000.00
10	43	1000.00
11	40	1000.00
12	42	1000.00
13	42	1000.00
14	43	1000.00
15	43	1000.00
16	43	1000.00
17	42	1000.00
18	42	1000.00
19	40	1000.00
20	43	1000.00
21	40	1000.00
22	42	1000.00
23	42	1000.00
24	43	1000.00
25	43	1000.00
26	42	1000.00
27	42	1000.00
28	42	1000.00
29	43	1000.00
30	40	1000.00
31	42	1000.00
32	42	1000.00
33	42	1000.00
34	43	1000.00
AVERAGE VISCOSITY = (Sum t)/34) (s)		**42.05**
LABORATORY:		**Geoff Griffins &**
DATE:		**15th May 2012**

Appendix 23: Hydraulic Conductivity modified DS (1B99DS)

APPENDIX 23: Hydraulic Conduc. Modified Dredged Sediment (1B99DS)

DATA FOR HYDRAULIC CONDUCTIVITY FOR 1B99DS

Sample Number	Filtrate Time (T) (s)	Volume (V) (mL)	Filter Cake (t) (mm)	Filtrate Loss (V/T) (mL/s)
1	1,800	20.60	10	11.44
2	5,400	45.50	10	8.43
3	40,380	270.00	10	6.69
4	1,800	21.00	10	11.67
5	5,400	46.50	10	8.61
6	40,380	270.00	10	6.69
7	1,800	20.60	10	11.44
8	5,400	45.50	10	8.43
9	40,380	270.00	10	6.69
10	1,800	21.00	10	11.67
11	5,400	46.50	10	8.61
12	40,380	290.00	10	7.18
13	1,800	23.00	10	12.78
14	5,400	50.00	10	9.26
15	40,380	290.00	10	7.18
16	1,800	26.00	10	14.44
17	5,400	51.00	10	9.44
18	40,380	280.00	10	6.93
19	1,800	23.00	10	12.78
20	5,400	45.00	10	8.33
21	40,380	340.00	10	8.42
22	1,800	22.00	10	12.22
23	5,400	49.00	10	9.07
24	40,380	280.00	10	6.93
25	1,800	20.60	10	11.44
26	5,400	45.50	10	8.43
27	40,380	270.00	10	6.69
28	1,800	21.00	10	11.67
29	5,400	46.50	10	8.61
30	40,380	275.00	10	6.81
AVERAGE FILTRATE LOSS (mL/s) * 10^-3				**6.77**

LABORATORY:	**Geoff Griffins & Associates, ICD Nairobi**
DATE:	**15th May 2012**

Appendix 24: Hydraulic Conductivity Modified DS (2B98DS)

APPENDIX 24: Hydraulic Conduc. Modified Dredged Sediment (2B98DS)

DATA FOR HYDRAULIC CONDUCTIVITY FOR 2B98DS

Sample Number	Filtrate Time (T) (s)	Volume (V) (mL)	Filter Cake (t) (mm)	Filtrate Loss (V/T) (mL/s)
1	1,800	17.50	10	9.72
2	5,400	38.50	10	7.13
3	40,380	205.00	10	5.08
4	1,800	18.00	10	10.00
5	5,400	39.00	10	7.22
6	40,380	210.00	10	5.20
7	1,800	22.00	10	12.22
8	5,400	40.00	10	7.41
9	40,380	215.00	10	5.32
10	1,800	23.80	10	13.22
11	5,400	51.00	10	9.44
12	40,380	210.00	10	5.20
13	1,800	17.50	10	9.72
14	5,400	38.50	10	7.13
15	40,380	205.00	10	5.08
16	1,800	18.00	10	10.00
17	5,400	39.00	10	7.22
18	40,380	210.00	10	5.20
19	1,800	23.00	10	12.78
20	5,400	43.00	10	7.96
21	40,380	215.00	10	5.32
22	1,800	22.00	10	12.22
23	5,400	45.00	10	8.33
24	40,380	218.00	10	5.40
25	1,800	17.50	10	9.72
26	5,400	38.50	10	7.13
27	40,380	205.00	10	5.08
28	1,800	18.00	10	10.00
29	5,400	39.00	10	7.22
30	40,380	210.00	10	5.20
AVERAGE FILTRATE LOSS (mL/s) * 10^-3			**4.90**	

LABORATORY:	**Geoff Griffins & Associates, ICD Nairobi**
DATE:	**15th May 2012**

Appendix 25: Hydraulic Conductivity Modified Dredged Sediment (3B97DS)

APPENDIX 25: Hydraulic Conduc. Modified Dredged Sediment (3B97DS)

DATA FOR HYDRAULIC CONDUCTIVITY FOR 3B97DS

Sample Number	Filtrate Time (T) (s)	Volume (V) (mL)	Filter Cake (t) (mm)	Filtrate Loss (V/T) (mL/s)
1	1,800	9.00	10	5.00
2	5,400	25.00	10	4.63
3	40,380	120.00	10	2.97
4	1,800	10.00	10	5.56
5	5,400	24.00	10	4.44
6	40,380	140.00	10	3.47
7	1,800	9.00	10	5.00
8	5,400	26.00	10	4.81
9	40,380	125.00	10	3.10
10	1,800	9.00	10	5.00
11	5,400	22.00	10	4.07
12	40,380	130.00	10	3.22
13	1,800	9.00	10	5.00
14	5,400	24.00	10	4.44
15	40,380	140.00	10	3.47
16	1,800	9.00	10	5.00
17	5,400	26.00	10	4.81
18	40,380	125.00	10	3.10
19	1,800	9.00	10	5.00
20	5,400	22.00	10	4.07
21	40,380	130.00	10	3.22
22	1,800	14.00	10	7.78
23	5,400	34.00	10	6.30
24	40,380	130.00	10	3.22
25	1,800	9.00	10	5.00
26	5,400	26.00	10	4.81
27	40,380	125.00	10	3.10
28	1,800	9.00	10	5.00
29	5,400	22.00	10	4.07
30	40,380	130.00	10	3.22
AVERAGE FILTRATE LOSS (mL/s) * 10^-3			**3.06**	

LABORATORY:	**Geoff Griffins & Associates, ICD Nairobi**
DATE:	**15th May 2012**

Appendix 26: Hydraulic Conductivity Modified DS (3B1B94DS5FA)

APPENDIX 26: Hydraulic Conduc. Modified DS (3B1B94DS5FA)

DATA FOR HYDRAULIC CONDUCTIVITY FOR 1B5FA94DS

Sample Number	Filtrate Time (T) (s)	Volume (V) (mL)	Filter Cake (t) (mm)	Filtrate Loss (V/T) (mL/s)
1	1,800	27.50	10	15.28
2	5,400	60.00	10	11.11
3	40,380	375.00	10	9.29
4	1,800	30.00	10	16.67
5	5,400	63.00	10	11.67
6	40,380	380.00	10	9.41
7	1,800	25.00	10	13.89
8	5,400	61.00	10	11.30
9	40,380	380.00	10	9.41
10	1,800	24.00	10	13.33
11	5,400	64.00	10	11.85
12	40,380	385.00	10	9.53
13	1,800	27.00	10	15.00
14	5,400	60.00	10	11.11
15	40,380	365.00	10	9.04
16	1,800	27.00	10	15.00
17	5,400	61.00	10	11.30
18	40,380	380.00	10	9.41
19	1,800	27.00	10	15.00
20	5,400	64.00	10	11.85
21	40,380	385.00	10	9.53
22	1,800	27.00	10	15.00
23	5,400	65.00	10	12.04
24	40,380	380.00	10	9.41
25	1,800	25.00	10	13.89
26	5,400	61.00	10	11.30
27	40,380	380.00	10	9.41
28	1,800	24.00	10	13.33
29	5,400	64.00	10	11.85
30	40,380	380.00	10	9.41
AVERAGE FILTRATE LOSS (mL/s) * 10^-3			**9.11**	
LABORATORY:		**Geoff Griffins & Associates, ICD Nairobi**		
DATE:		**15th May 2012**		

Appendix 27: Hydraulic Conductivity modified DS (3B1B91DS8FA

APPENDIX 27: Hydraulic Conduc. Modified DS (3B1B91DS8FA)

DATA FOR HYDRAULIC CONDUCTIVITY FOR 1B8FA91DS

Sample Number	Filtrate Time (T) (s)	Volume (V) (mL)	Filter Cake (t) (mm)	Filtrate Loss (V/T) (mL/s)
1	1,800	42.00	10	23.33
2	5,400	85.00	10	15.74
3	40,380	480.00	10	11.89
4	1,800	45.00	10	25.00
5	5,400	85.00	10	15.74
6	40,380	490.00	10	12.13
7	1,800	40.00	10	22.22
8	5,400	80.00	10	14.81
9	40,380	485.00	10	12.01
10	1,800	45.00	10	25.00
11	5,400	85.00	10	15.74
12	40,380	485.00	10	12.01
13	1,800	40.00	10	22.22
14	5,400	80.00	10	14.81
15	40,380	485.00	10	12.01
16	1,800	45.00	10	25.00
17	5,400	85.00	10	15.74
18	40,380	485.00	10	12.01
19	1,800	40.00	10	22.22
20	5,400	80.00	10	14.81
21	40,380	485.00	10	12.01
22	1,800	45.00	10	25.00
23	5,400	85.00	10	15.74
24	40,380	485.00	10	12.01
25	1,800	40.00	10	22.22
26	5,400	80.00	10	14.81
27	40,380	485.00	10	12.01
28	1,800	45.00	10	25.00
29	5,400	85.00	10	15.74
30	40,380	480.00	10	11.89
AVERAGE FILTRATE LOSS (mL/s) * 10^-3			**11.46**	

LABORATORY:	**Geoff Griffins & Associates, ICD Nairobi**
DATE:	**15th May 2012**