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GEE 2017 Session Schedule

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SOLIDIFICATION/ STABILIZATION OF METAL CONTAMINATED MARINE DREDGED SEDIMENTS

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Department of Civil Engineering, State University of Medan, North Sumatera, Indonesia

Abstract: In order to maintain the harbor activities, large amount of sediments are dredged every year, thus the reuse of polluted marine dredged sediments is urgently needed to realize. The main objective of this study is to enhance the physical, mechanical and chemical characteristics of the mix by incorporating binders (hydraulic binders and Silica Fume). The preliminary study performed on fine polluted marine dredged sediments revealed the identification of the mechanical characteristics measured on the mixes is compatible with their use as a base course material. The result shows that the treatment by hydraulic binders and silica fume could satisfy the needed mechanical characteristics. However the proportion of hydraulics binders and silica fume needed to meet prescribed specification is important so the reuse of the marine dredged sediments of Port of Port-en-Bessin, France in road construction as an alternative material could be achieved. After the experimental study in laboratory results show as expected then the construction of the experimental road in real size has allowed to evaluate the compatibility of this designed material with the current practice with standard materials. To evaluate the environmental impacts of the used material, leaching tests are performed. The leaching tests were performed to verify the predicted release of pollutants based on total dissolution. And for the final part, the test results show that the polluted marine dredged sediments could be safely used (in term of environmental impact) as a new material for the platform road.

Keywords: Polluted marine dredged sediments, Silica Fume, physical and mechanical characteristics, environmental impact.

1. Introduction

Efficient and environmentally reutilization of dredged waste material in France, calls for a multi disciplinary effort. That is why, the scientific, technological and economic information required to make an optimal choice among dredged waste because material disposal sites is now urgently needed in France. Available or attainable, there are many constraints on policy implementation needed to be design. The reutilization of waste materials such as dredged sediment in road construction is one of the main applications. Information about the physical, chemical and biological processes that need to be considered in particular dredged waste material situation are linked together by means of predictive techniques. Various alternative existing treatment methods to reuse dredged sediments have been investigated in European country The ideal percentage of hydraulic binders needed to meet prescribed specifications is very important. The previous research using dredged sediments from Cherbourg (France), about 9 % of a hydraulic binder was necessary (Silitonga, 2010). For sediments from Le Havre Harbour (France) about 15% of a hydraulic binder was necessary (Boutouill 1998) . Silitonga E., (Silitonga et al. 2009) needed 11% hydraulic binders to stabilized dredged sediment from Port en Bessin Basse Normandie (France).

The reutilization of dredged sediment provide economic benefits by reducing disposal costs and mitigating possible negative environmental effects, originating in either the fly ash (Mehta 1985) or the solid waste, through proper engineering control, which is why in this study the researcher tried to replace Silica Fume as alternative binders. It has been known that the addition of Silica Fume improves the geotechnical properties, due to the pozzolanic reaction and its role as a micro-filler. To achieve effectiveness of Silica Fume on soil stabilization work, some researchers added a small amount of hydraulic binders such as lime and cement.

The need for a large amount of hydraulics binders make the use of raw dredged sediments unlikely from an economic point of view. Trying to make a more productive use of Silica Fume would have considerable environmental benefits, reducing air and water pollution.

2. Materials and Methods

2.1 Materials

This harbour is a commune in the Calvados department in the Normandy region, which is situated, in the northwestern France, this harbour is well known for its medium industrial activities. The dredged sediments were taken from four different locations (PEB A-1, PEB B-1, PEB C-1, PEB D-1). The sediments are dredged from the sea-bed at about 20 m in depth. Samples of the dredged materials were stored in experimental area located around 10 km from the harbor.

2.2 Characterization of Dredged Sediments and Binders.

2.2.1. Particle size Distribution

From **Figure 1**, we confirm that the particle distribution of dredged sediment taken from four different locations (PEB A-1, PEB B-1, PEB C-1, PEB D-1) is almost similar, this result show the homogeneity of the dredged sediment of Port en Bessin. The result show that, dredged sediment studied in these experiments contain an important quantity of silt fraction size sediments (2 - 63 µm). This study was performed using the marine dredged sediments from Port of Cherbourg, France. Two types of Silica Fume (SF) were used in this part of the main research: named SF1 and SF2.

As shown in **Table 1**, all binders utilized have different particle size distribution from the point of view of diameter particle most representative; SF2 (93 µm) has particles almost 2 times bigger than SF1 (207 µm), regardless of the small different of percentage (see Table 1). Two type of Silica Fumed studied in these experiments contain an important quantity of silt fraction size sediments. The previous experiment by Silitonga [8] showed that the compressive strength tends to reduce as the mean particle size increase for all curing ages. This maybe caused by coarse particles of binder reduces the ability of packing effect of binder and negatively affected on its pozzolanic activity.

Table 1. Particle size distribution utilized.

	Cement	SF1	SF2
D10(µm)	0.6	4.8	19
D50(µm)	32.6	36.5	127
D90(µm)	730	93	207
Clay Friction (<2 µm) (%)	15.2	7	2.5
Silky Friction (2 - 63 µm) (%)	53.3	67	17.3
Sand Friction (> 63 µm) (%)	31.5	29.7	72.1

From a study of the strength contribution potential of seven bituminous fly ashes from the U.S. (Binichi et al. 2007), reported that the particles larger than 45 µm show little or no reactivity under normal hydration conditions and the pozzolanic activity was directly proportional to the amount of particles under 10 µm. From this theory we can observe that FS2 has coarse particles (> 50 µm) more important than FS1 but in the same time FS1 has more important quantity of fine particles (<10 µm) than FS2. From this particle size point of view,

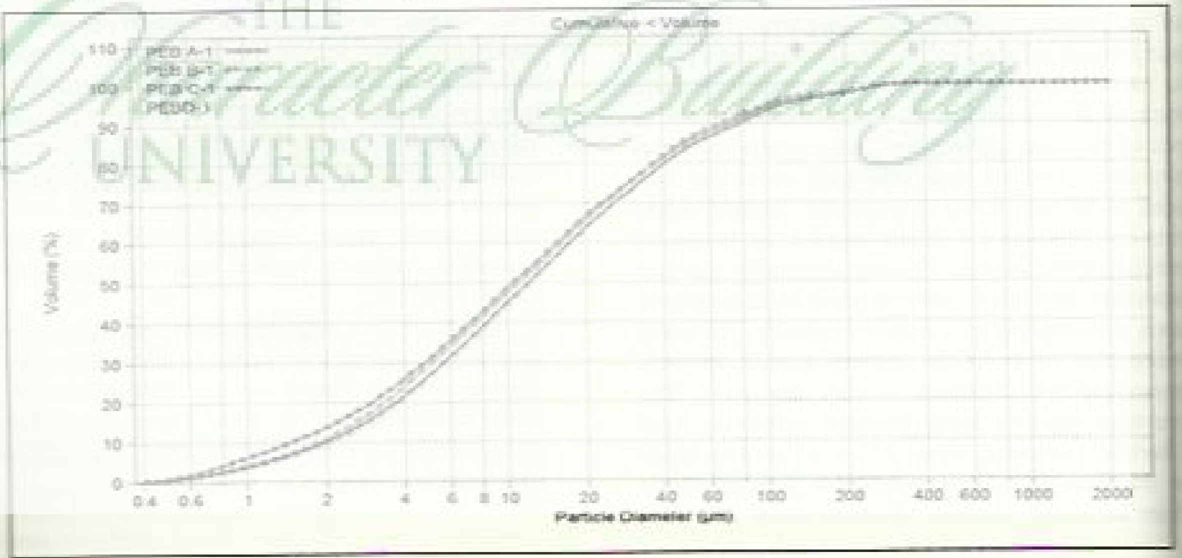

Figure 1 Particle size distribution of Dredged sediment

we could expect that FS1 will be more reactive than FS2. It is well known that particles size distribution is one of important factor beside packing effect and smoothness of surface texture, to control the water demand and workability of the mixture. A previous work (Jatupirakul et al. 1999) showed that calcium content, the size distribution and the shape of the particle of pozzolanic binder were the most important parameter governing the strength development rate. Silitonga (Silitonga et al 2010) claimed that the coarse pozzolanic binder gained very low compressive strength when its addition was used more than 30% of cement replacements. The previous experiment study by Benici et al (Benichi et al 2007)] showed that the specimen with a better fineness and a narrower particle size distribution had the highest compressive strength, sulfate resistance than the others specimens. According to Joshi and Lohtia (Joshi et al. 1997), the influence of the finer particle size of pozzolanic binder produces more reactive pozzolanic reaction because smaller particle size of Binder with a higher surface area and glassy phase content also improved the pozzolanic reaction.

2.2.2. Chemical properties

As shown in **Table 2** shows the differences in chemical analysis between SF1 and SF2 that can influence the mechanical properties of the sediment stabilized. It can be seen that SF1 is characterised by a higher content of SiO2. On the other hand SF2 has higher total amount of free CaO, SO3 content. According to this result, we can expect that SF1 will be more reactive than FS2 as a pozzolanic binder. Silitonga on his researcher noticed that Silica Fume possesses higher content of SiO2, Fe2O3 or Al2O3 produces higher resistance on Unconfined Compressive Strength Test.

Table 2. Chemical analysis of Silica Fume

Colour	SF1	SF 2
SiO2	90 - 92	85-90
Fe2O3	1,5 - 2	1,5 - 2
Al2O3	1	1
CaO	0,5 - 1	0,5 - 1
MgO	1 - 1,5	1 - 1,5
Na2O	0,5 - 1	1 - 1,5
K2O	1 - 1,3	1 - 1,3
C	0,5 - 1	1-1,5
free Si (%)	< 0,2	< 0,4
Free CaO (%)	< 1	< 2
SO3 (%)	< 1	< 2
Cl (%)	< 0,2	< 0,5
Surface écifique (m2/g)	18 - 25	15 - 30
Masse volumique g/m3)	500 - 700	500 - 700

3. Results and Discussion

3.1. Preparation of specimens

The dredged sediment, oven-dried for 5 days at 60°C was pulverized to 2mm sieve size, it was initially mixed with determined quantities of Silica Fume, lime and cement as a binder, in a dry state and subsequently mixed with water by a mechanical mixer with a speed of 150 rd/min for a period of approximately 8 minutes. After mixing the samples were prepared with the static compaction method, at the optimum moisture content and maximum density determined by *Proctor* test. Cylindrical specimens (ø = 40mm, h = 80mm) were used for unconfined compressive strength testing. The compressive strength is determined using a 10 kN capacity automatic compression machine according to NF EN 196-1 (NF, 1995) on a simple speed cross-head moving machine at a speed of 1 mm/s. The samples were pushed out from the mold directly after completion of the compaction and were stored in the curing room until testing at 7, 14, 28, 60, 90, 180 and 360 days

3.1 Results

3.1.1. Mix Design

In order to determine the effect of pozzolanic binders on the mixtures performances, several compositions were realized.

Name	SF1 (%)	SF2 (%)	Lime (%)	Cement (%)
SF-1A	2	-	2	2
SF-!B	4	-	2	2
SF-1C	6	-	2	2
SF-2A	-	6	2	2
CEM	-	-	-	7

Table 3 . Different compositions of binders

To study the influence of the Silica Fume on the strength gained, samples SF1-A, SF1-B and SF1-C were set with different Silica Fume content. The goal of manufacturing SF2-A, was to compare the influence of using 2 types different Silica Fume in the mixture. The amount of 5% of cement was the common amount that normally used in the road construction field, due to this reason, the sample CEM 1 was realized. Sample CEM1 was realized to identify the behaviour of the stabilization process with content of cement only. The different formulas in this experiment are given in **Table 3**

3.1.2. Unconfined Compressive Strength (UCS)

The UCS values after 60 days of curing period, the strength value of the specimens with 4% and 6% of Silica Fume (SF1-C, SF1-B and SF2-A) obtained the highest UCS Value than specimens with less of Silica Fume Content (SF1-A and SF1-B), but at more than 100 days only Sample with 6% Silica Fume content that show a increase until up to 360 days. The strength development for samples with 6% of Silica Fume content (SF-1-C and SF2-A), continues up to 100 days curing period, on the other hand for sample with less than 6% Silica Fume (SF1-A and SF1-B) show the strength variation from 60 days to 360 days curing period, this increase strength shows that the development of strength in high percentage of Silica Fume treated sediment still continues, but its value depends on the characteristic of the sediment treated, because we can assume that the weak strength variation can be attributed to the quantity of the silica and alumina present in the dredged sediments. This clearly indicates after 60 days curing period, the role of Silica Fume start becomes more important to provide silica and alumina in stabilization matrix to enhance the strength of the specimen, as long as the pH of the specimen keep stable at 12 (or more). On the other hand samples with different type Silica Fume (SF1-C and SF2-A) show that there isn't any important different between UCS values. At this case we consider that, the chemical properties of Silica Fume used in this study, aren't high enough to make any different.

The UCS values after 60 days of curing period, the strength value of the specimens with 4% and 6% of Silica Fume (SF1-C, SF1-B and SF2-A) obtained the highest UCS Value than specimens with less of Silica Fume Content (SF1-A and SF1-B), but at more than 100 days only Sample with 6% Silica Fume content that show a increase until up to 360 days. The strength development for samples with 6% of Silica Fume content (SF-1-C and SF2-A), continues up to 100 days curing period, on the other hand for sample with less than 6% Silica Fume (SF1-A and SF1-B) show the strength variation from 60 days to 360 days curing period, this increase strength shows that the development of strength in high percentage of Silica Fume treated sediment still continues, but its value depends on the characteristic of the sediment treated, because we can assume that the weak strength variation can be attributed to the quantity of the silica and alumina present in the dredged sediments. This clearly indicates after 60 days curing period, the role of Silica Fume start becomes more important to provide silica and alumina in sta-

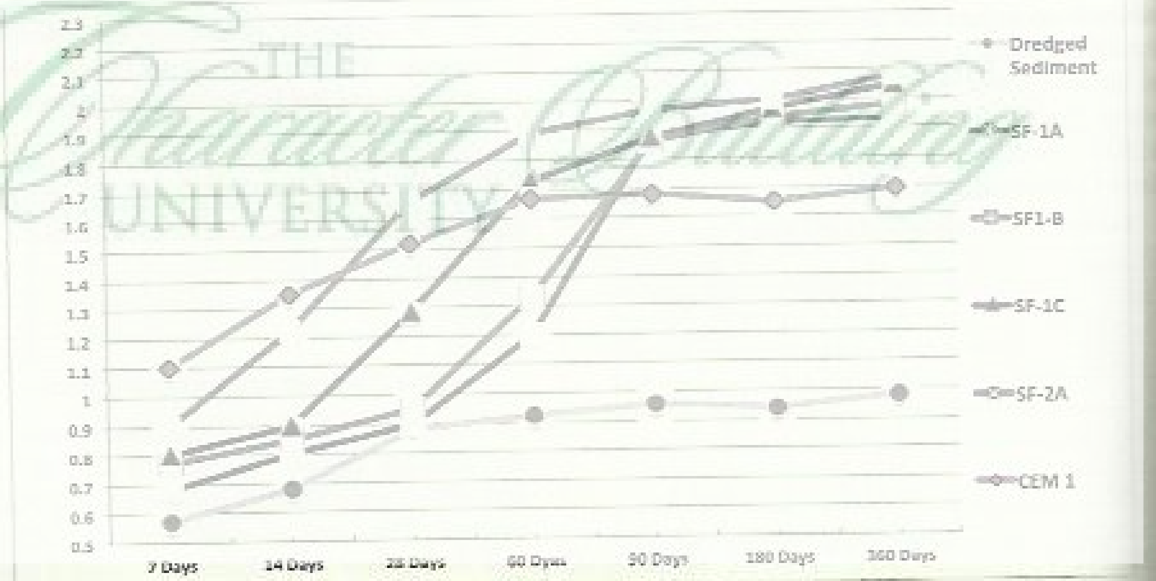

Figure 2 : Unconfined Compressive Strength

bilization matrix to enhance the strength of the specimen, as long as the pH of the specimen keep stable at 12 (or more).

3.1.3. Leaching Test

The dredged sediment was planning to land application. However, as the land applied dredged sediment is subjected to drying and oxidation, transformations in the chemical forms of heavy metals may affect their mobility and bioavailability, and phytotoxicity may be occurred by the dredged sediment land application. Therefore, it is necessary to assess the environmental risk of the dredged sediment before its land application. This Leaching Test was realized according to French standard *NF X 31-210* (1998), refers to the solution containing the solubilized elements during the test, which are performed on the analytical characterization. This leaching test is a simulation to identify the mixture reaction to aggressive chemical environment.

Table 4. Reference Values fro dredged sediments

Inert Waste	Non-Hazardous Waste	Hazardous Waste
0,4	10	40
0,04	1	5
2	50	100
0,01	0,2	2
0,5	10	50
4	50	200
0,01	0,2	2
0,5	2	25

The leaching test is divided in three step according to the chemical environment applied in the test :a) The static leaching, we identify the leached elements in solution after presenting sample to the aqueous solution, b) semi dynamic leaching, where test applied with a regular renewal of the leaching solution, c) The dynamic leaching test in which the leaching solution is continuously renew.

The decision of the *European Council No. 2003/33 / EC* has established reference values for the acceptance criteria for dredged sediment. This reference divided in 3 classes; inert waste, non-hazardous and hazardous waste.

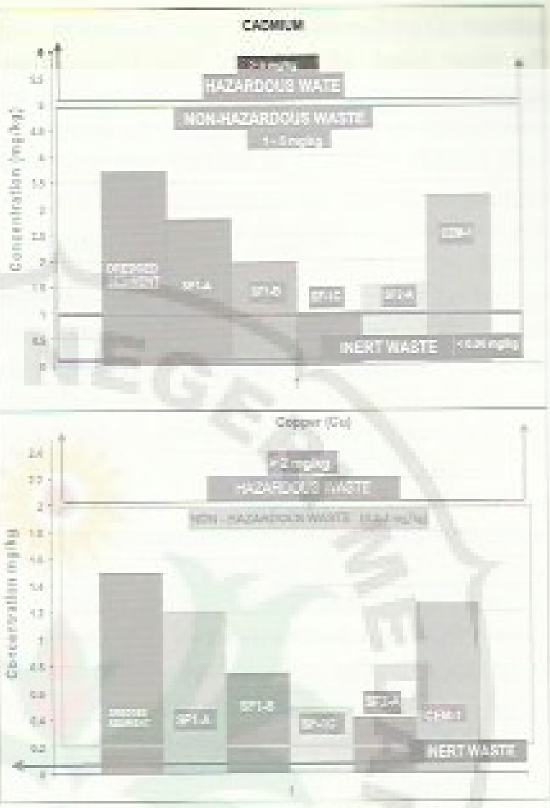

Figure 5. Leaching result fro Cadmium and Copper

These reference values relate to the elements contained in the leachate and not in the raw material. The reference values were shown in **Table 4**. In order to classify the dredged sediment of Port en Bessin, this reference values used to identify/ classify the amount of pollutants in sediment of Port of Bessin.

In order to classify the dredged sediment of ort en Bessin, this reference values used identify the amount of pollutants in sediment from the Port en Bessin. According to the European Council Reference, the dredged sediments from Port en Bessin content a medium - high amount of pollutants, in this paper only the result of Leaching Test for Cadmium (Cd) and Copper (Cu) were presented. **Figure 5** shows that dredged sediment contains 3.69 mg/kg of Cadmium and 1.52 mg/kg of Copper, these amount according to European reference value categorize in Non Hazardous waste. Sample content only Cement (CEM1) due to its hydration reaction show a small amount of reduction on content of Cadmium (from 3,69 to 3.2 mg/kg) and Copper (from 1.58 to 1.25 mg/kg), this result show that cement as a binder is not effective/powerful enough to reduce the amount of pollutants in dredged sediment. On the other hand, all samples with Silica Fume show a remarkable reduction on amount of pollutants, as shown in **Figure 5**, especially with sample with 6 % of Silica Fume type 1, is capable to reduce the concentration of Cadmium to 1.01 mg/kg and categorized as Inert Waste, at this point, dredged sediment is confirmed as a harmful for environment material and ready to use. In this test the different type of Silica Fume (SF1 and SF2) shows a remarkable different performance on reducing the Pollutants content, as shown at **Figure 5** SF1-C and SF2-A content a different amount of Pollutant, in Cadmium SF-1 show a higher performance by reducing the amount of Cd to lower level (Inert Waste) but in Copper, SF-2 content lower amount of pollutants. This result show a different performance of Adding Silica Fume as a binder proved that with a certain amount of Silica Fume could reduce the amount of pollutants in dredged sediments

4. Conclusions

The main goal of this experiment is to identify the effect of Silica Fume on the strength behavior, its capacity to reduce the pollutants. The improvement in mechanical properties such as unconfined compressive strength values were investigated. Sediment-cement mixture, sediment-lime mixture and sediment-Silica Fume-lime-cement-sand mixture were prepared and compacted at the optimum water content. Unconfined compressive strength tests were then performed on these mixtures in normal conditions and in extreme condition. The UCS value gained by specimen treated Silica was continuously increase up to 100 days, for the specimens treated by cement, the increase of UCS value strength almost stop after 60 days. The research has shown that, from the comparison of different various specimens, the sediment stabilized with Silica Fume-lime-cement with8 % have the most potential values than the others to offer an alternative for stabilization of dredged sediments. The different type Silica Fume (SF1-C and SF2-A) show that there is not any remarkable different between UCS values, thus the chemical properties of Silica Fume used in this study, are not high enough to make any different in UCS value.

From the leaching Test, the present of Silica Fume in mixture proved effective to reduce the amount of pollutant in dredged sediment, especially Silica Fume type 1 with 6% of SF1, is capable to reduce the amount of Cadmium, from Non Hazardous waste to Inert Waste, thus the dredged sediment is confirmed to be harmful to the environment and could be reused as a new material.

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