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The use of marine sediments as a pavement base material

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ABSTRACT

The management of marine sediments after dredging has become increasingly complex. In the context of sustainable development, traditional solutions such as immersion will be increasingly regulated. More than ever, with the shortage of aggregates from quarries, dredged material could constitute a new source of materials.

In this study of the potential of using dredged marine sediments in road construction, the first objective is to determine the physical and mechanical characteristics of fine sediments dredged from a harbour in the north of France. The impacts of these materials on the environment are also explored. In the second stage, the characteristics of the fine sediment are enhanced for use as a road material. At this stage, the treatment used is compatible with industrial constraints. To decrease the water content of the fine sediments, natural decantation is employed; in addition, dredged sand is added to enhance the granular distribution and to reinforce the granular skeleton. Finally, the characteristics of the mix are enhanced by incorporating binders (cement and/or lime). The mechanical characteristics measured on the mixes are compatible with their use as a base course material. Moreover, the obtained results demonstrate the effectiveness of lime in the mixes. In terms of environmental impacts, on the basis of leaching tests and according to available thresholds developed for the use of municipal solid waste incineration (MSWI) bottom ash in road construction, the designed dredged mixes satisfy the prescribed thresholds.

1. Introduction

Dredging operations are necessary to maintain navigation in waterways and access to harbours. Each year, several 100 millions of tons of materials are dredged around the world (Boutin, 1999). These materials, ranging from rocks to clays, can contain a variable amount of organic matter and different types and levels of contaminants.

Management of dredged sediments is a worldwide problem. After dredging, traditional solutions such as dumping the sediments at sea are constrained by national and international regulations. Alternative solutions, such as terrestrial disposal, are costly and require large areas (LIFE, 2002; Grégoire, 2004). The development of beneficial use strategies for dredged sediments is therefore necessary.

According to European directive number 75/442/CE (JOCE, 1975), dredged sediments are classified as waste under section 17 05 05* (polluted sediments) and section 17 05 06 (other sediments). Due to shortages of natural resources and the sustainable development approach adopted by several countries, the beneficial use of dredged sediments has gained broad acceptance in different domains such as civil engineering, agriculture, and manufacturing (Centre Saint Laurent, 1993; Boutouil, 1998; LIFE, 2002; Ulbricht, 2002; Colin, 2003). The beneficial use in the civil engineering domain, which consumes over 400 million tons of such materials each year in France (Michel, 1997; UNPG, 2005), is interesting from several points of view. With environmental constraints concerning the opening of new quarries, combined with the continuous increase in demand for aggregates, dredged sediments can be viewed as a new source of materials. In the road construction field, the characteristics of dredged materials could be similar to those of currently used materials, from grain size distribution (fine to coarse aggregates) to the variability of required mechanical performances for the road layers.

Previous research on the use of raw fine sediments in road construction has shown that treatment by hydraulic binders could satisfy the needed mechanical characteristics. However, the proportion of hydraulic binders needed to meet prescribed specifications is important. For sediments from Le Havre Harbour (France), about 15% of a hydraulic binder was necessary (Boutouil, 1998). The need for a large amount of hydraulic binder makes the use of raw dredged sediments unlikely from an economic point of view. Moreover, the presence of organic matters can constitute a problem with regards to cement hydration (Kujala et al., 1996). According to Clare and Sherwood (1954), different types of organic matter can interact

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differently with cement. A decrease in strength can be found, but this is not systematic. The presence of acid compounds, such as fulvic acids, can slow the rise of pH, preventing the pozzolanic reactions. In addition, during the hydration phase of cement, organo-mineral complex, which is often found in organic soils, breaks up with increasing pH, releasing organic matter. This organic matter can fix the released calcium ions, which cannot participate in the formation of hydrates. The addition of lime to supply the organic matter with calcium ions and to allow for normal cement hydration may be an interesting solution.

In this context, this study is aimed at developing a road construction material based on fine dredged sediments in combination with sand and binders. To evaluate the influence of binders on the mechanical behaviour of the designed materials, mixes are treated with cement and with a combination of cement and lime, and compared. Moreover, the environmental impacts of the raw fine sediments and the designed mixes are investigated by performing leaching tests.

2. Materials and methods

After description of the site from where the sediments are dredged, the basic characteristics of the studied materials are discussed and a developed methodology is implemented to identify mixes for use in the road construction field.

2.1. Site description

The marine sediments used in this study were dredged from Dunkirk Harbour (Fig. 1). This harbour, situated in the north of France, is well known for its intensive industrial activities (e.g. petroleum, gas, and steel). Dredging operations to maintain waterways generate over 3.5 M m^3 of dredged sediments each year (IFREMER and MATE, 1999). The dredged fine sediments presented in this study are from the West Harbour (Lambert coordinates: $X = 588200$, $Y = 370600$). These sediments are denoted D1 material. Previous studies have shown, according to French legislation (JO, 2000), that the level of pollution in the sampling zone is low, and that the dredged material is mainly composed of silt (Grégoire, 2004; Mac Farlane, 2004). The sediments are dredged from the sea-bed at about 23 m in depth. Samples of the dredged materials were stored in hermetic containers of 0.054 m^3 in volume.

2.2. Characterization of dredged sediments

2.2.1. Environmental impact of fine raw sediments

In order to characterize the environmental impacts of the dredged sediments (D1 material), leaching tests were performed on three samples from the same batch according to European test standard EN 12457-2 (AFNOR, 2002). In the leaching tests, a liquid-to-solid ratio of ten was adopted. In the leachates, metallic elements and ions as fluorides, chlorides and sulphates were analyzed, whereas BTX, hydrocarbons, and PAH were analyzed on the solid matrix.

The average values from the three tests are shown in Table 1. According to the prescribed limits establishing the criteria and procedures for the acceptance of waste at landfills (JOCE, 2003), the disposal of the material on a terrestrial site would require treatment due to the high levels of chlorides. For the reuse of dredged sediments in road construction, at present, no specific threshold has been developed. However, according to French order No. 94-IV-1 of May 1994 regarding the beneficial use MSWI bottom ash (FME, 1994), the dredged sediments could be allowed for use in road construction.

Table 1
Analysis of physico-chemical elements in leachate after leaching test

Tests	After leaching test
Soluble fraction (mg/kg)	«17,780»
pH	[8]
As (mg/kg)	[<0.5]
Cd (mg/kg)	[<0.1]
Cr (mg/kg)	[<0.1]
Cr(VI) (mg/kg)	[<0.1]
Cu (mg/kg)	[<0.5]
Hg (mg/kg)	[<0.01]
Ni (mg/kg)	[<0.4]
Pb (mg/kg)	[<1]
Zn (mg/kg)	[<0.5]
Cyanide (mg/kg)	[<0.1]
Fluorides (mg/kg)	[7.8]
Chlorides (mg/kg)	▹32,700◃
Sulphates (mg/kg)	«3100»
Ammonium (mg/kg)	[200]
Phenol index (mg/kg)	[<0.1]
TOC (mg/kg)	[250]
Tests	On solid matrix
COT (mg/kg)	[26,000]
Benzen–Toluene (mg/kg)	[<5]
Ethylbenzen–Xylen (mg/kg)	[<10]
PCB (seven elements) (mg/kg)	[<0.01]
Hydrocarbon (mg/kg)	[13]
HAP (mg/kg)	[0.806]

References	Pollution level					
European directive 2003/33/CE (JOCE, 2003)	Low	Class III Inert waste	Class II Non-dangerous waste	Class I Dangerous waste	Treatment to store	High
		[ ]	« »	§§	▹◃	

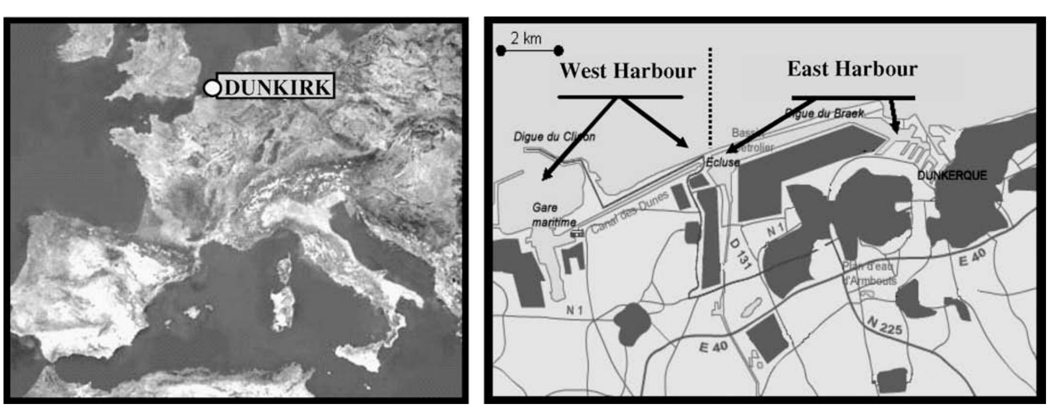

Fig. 1. Location of Dunkirk (left) and Dunkirk Harbour (right).