



HAL
open science

Stabilisation of estuarine silt with lime and/or cement

Raoul Jauberthie, F. Rendell, Damien Rangeard, Laurent Molez

► **To cite this version:**

Raoul Jauberthie, F. Rendell, Damien Rangeard, Laurent Molez. Stabilisation of estuarine silt with lime and/or cement. *Applied Clay Science*, 2010, 50 (3), pp.395-400. 10.1016/j.clay.2010.09.004 . hal-01003706

HAL Id: hal-01003706

<https://hal.science/hal-01003706>

Submitted on 12 Apr 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Applied Clay Science 50 (2010) 395–400

<http://dx.doi.org/10.1016/j.clay.2010.09.004>

Stabilisation of estuarine silt with lime and/or cement

Raoul Jauberthie, Franck Rendell *, Damien Rangeard, Laurent Molez

Laboratoire Génie Civil et Génie Mécanique-EA 3913, Institut National des Sciences Appliquées, Université Européenne de Bretagne, 35043 Rennes Cedex, France

abstract

The tidal barrage situated at the mouth of the river Rance, near Saint Malo (France) has led to a considerable silting upstream of the barrage. The deposited material is fine estuarine silt which is frequently dredged to maintain navigable channels; the use of this material is only possible after stabilisation. This study evaluates the possible use of this material as a sub-base for lightly trafficked local roads; therefore the stabilisation has to achieve the required geotechnical characteristics. Physico-chemical characterisation of the silt was carried out using SEM with XRD. The estuarine deposit comprises clay, silt and sand; the characteristics of this material result from its mineral composition and its high organic content. Stabilisation tests were carried out with various mixtures of quicklime, Portland cement and a mixture of both. The results of the tests show an increase in the unconfined compressive strength and the CBR value with both lime and cement treatments. The characteristics of the deposit with lime–cement mixes were superior to those obtained with lime only and cement only treatments. Finally it is concluded that the estuarine silt has the potential to be stabilised to a standard suitable for use as a road sub-base; however further testing is required before proceeding to field trials.

1 Introduction

The Rance is a river on the north coast of Brittany; the geology of the catchment consists of granites, dolerites, diorites and briovenian schist. The river system consists of a fresh water river feeding into a saline estuary. A tidal barrage was constructed in the 1960s across the mouth of the Rance estuary near St Malo. An area of approximately 22 km² is impounded behind the barrage. The tidal range on the sea side of the barrage is of the order of 8 m whereas behind the barrage the range is reduced to approximately 2.5 m. Fifteen kilometres south of the barrage there is a second barrage at Châtelier, the site considered in this study, which is the upstream limit of the impounded tidal estuary. The tidal barrage at the mouth of the Rance estuary is responsible for the progressive silting of the impounded estuary. Dredging is regularly carried out to maintain navigable channels in the estuary, approximately 20 000 m³ of silt per year; the storage and disposal of dredged silt pose a considerable problem. This study considers the reuse of estuarine deposits from the area of Châteauneuf d'Ille et Vilaine, at the upstream end of the tidal estuary. Several applications have been considered for the reuse of similar materials, however they all require stabilisation prior to use (Keith and Murray, 1994; Harvey and Murray, 1997; Murray, 2000). The reuse of soils as a road sub-base is generally not possible without stabilisation as its characteristics fall below the minimum required (Kergoet, 2001). A number of parameters influence the soil properties: the time lapse after construction (Khatab et al., 2007); the temperature which controls the kinetics of stabilisation (Rao and Shivananda, 2005); the use of admixtures (Jha and Gill, 2006); mineral additions to the soil (Sivapullaiah et al., 2006). Some authors have demonstrated the possibility of stabilising organic mud from mangroves in the Niger delta (Konyeha and Ogbeide, 2007).

Studies and field trials on the use of low grade materials as road sub-base have been carried out in the UK. A detailed study of the stabilisation of clayey silt was carried out by Chaddock and Atkinson (1997); they demonstrated that a soil could be stabilised with a lime-cement mix to achieve a material with characteristics comparable to a Type 2 sub-base.

This work was followed up by field trials such as that carried out at Polgate by-pass UK by Waste & Resources Action Programme (WRAP) (WRAP, 2002).

Sétra, a technical department within the French Ministry of Transport and Infrastructure, recently published a technical guide concerning the treatment of soils with lime and/or hydraulic binders (SETRA, 2007). This guide covers the mix design, pavement design, implementation and quality control of stabilised road base.

The objective of the study is to evaluate the feasibility of using stabilised estuarine silt for a road base. This paper firstly considers the physico-chemical character of the dredged material and secondly, it studies stabilisation using lime and/or cement. The performance of the stabilised soil is evaluated by unconfined compressive strength (UCS) and Californian Bearing Ratio (CBR) value.

2 Materials

2.1 Untreated soil properties

Estuarine silt is a sediment that is deposited in tidal areas of coastal mudflats and is generally composed of a sand fraction, with calcareous shell debris and a fraction of silts and clays.

2.1.1 Mineralogical analysis

The mineralogical content of the silt was determined by X-ray diffraction (XRD). The XRD patterns were obtained using a Philips PW 3710 X-ray diffractometer with Bragg–Brentano geometry using Ni-filtered Cu K α radiation, operating with the voltage of 30 kV and emission current of 20 mA. The step-scan covered the angular range 2-60° (2 θ) in steps of 2 θ = 0.02°, 2 s by step. The analysed material was ground to a powder passing a 50 μ m sieve.

The recorded XRD pattern for the estuarine silt is shown in Fig. 1. The crystal phases are: quartz, calcite and the clay minerals illite and kaolinite. Examination of X-ray diffraction intensity, although qualitative, indicates that the proportion of clay minerals is very low with regard to other phases.

Further examination of the material was carried out using Scanning Electron Microscopy-Energy Dispersive Spectroscopy (SEM-EDS). This was carried out using a JEOL 6400 scanning electron microscope (accelerating voltage 9 kV and working distance 15 mm) coupled with an Oxford INCA microanalysis system. Observations with better definition and higher magnification were obtained with an electron microscope with field emission JEOL JSM 6301 FEG.

The observation shown in Fig. 2 and the micro analysis show the fine plates of clay with Si and Al atoms which correspond to the kaolin detected by XRD analysis; similar to the Si, Al and K corresponding to the illite (confirming a mineral with 1 nm diffraction).

The larger and rounded minerals are composed of Si (quartz). The organic fraction consists of spicules, coccoliths and diatoms; these particles are in some cases siliceous and others are calcareous.

2.1.2 Granulometric analysis

Granulometric analysis was carried out using a Laser Diffraction CILAS particle size analyser 1180 based on Mie and Fraunhofer scattering theories. A second analysis was carried out after a sample was attacked by hydrochloric acid to remove the calcareous material of organic origin. Fig. 3 and Table 1 show that the calcareous particles are of a larger particle size; after acid treatment the curve is moved towards the left.

Table 2 shows the geotechnical classification of the material. The liquid limit was determined by cone penetration NF P94-052-1 and by the Casagrande Cup method (XP CEN ISO/TS, 17892-12). The linear shrinkage was determined by ASTM D423-1966 and the methylene blue test carried out to the standard NF P 94-068. The values shown in Table 2 are the average of four tests, each being carried out on separate sediment samples.

The values of liquid and plastic limit obtained are characteristic of fine dredged sediments; the results are comparable with those obtained by other authors (Zentar et al., 2009; Boubaker et al., 2009).

2.1.3 Geotechnical characterisation

The Proctor Test is used to determine the optimal moisture content for compaction, that is to say the moisture content at which maximum dry density is achieved. The results from two Proctor Tests (carried out on different samples), dry density as a function of moisture content, are reported in Fig. 4. From these tests it was concluded that the optimum moisture content was of the order of 32% at which the dry density of about 1350 Mg m⁻³ was obtained.

The Californian Bearing Ratio (CBR) Test is carried out on untreated soil with moisture content close to the optimum i.e. 30%. Table 3 sets out the force at the prescribed penetrations; from these results it is noted that the CBR for the

untreated soil is 5.5.

2.1.4 Summary of the characterisation of the estuarine silt

- The estuarine silt has a 9.4 ratio silt/clay with 11.6% organic matter. From the granulometric analysis it can be seen that most of the organic matter removed by acid attack is between 50 μm and 100 μm . The clay fraction is inorganic which is confirmed by XRD.
- The methylene blue value of 2.7 and a Plastic Index of 25% classify the material as a silt of moderate plasticity (class A3 defined by NF P 11 300) the Casagrande classification for the clay is MH.
- The Plastic Index of 25%, the clay/silt ratio of 9.4 and linear shrinkage of 12.5% would, according to Burroughs (2008), be a soil favourable for stabilisation, i.e. 93% probability of achieving a UCS of 2 MPa.

2.2 Characterisation of lime and cement used for treatment

The lime used for stabilisation is industrial quicklime (PIGEON Saint Pierre Lacour 35). This product is currently used for the stabilisation of road sub-bases and capping layers in the Brittany region. The mineralogical composition was determined by XRD, see Fig. 5; this analysis shows that the quicklime contained a small quantity of calcium carbonate in the form of calcite and vaterite. A very small quantity of lime was not burnt.

The cement was a CEMI (without admixtures) (LAFARGE Saint Pierre Lacour). The mineralogical composition was determined by XRD and the XRD pattern is shown in Fig. 6. This cement contained principally alite C3S but it was strongly aluminous with significant quantities of C3A and C4AF.

3 Methods

3.1 Lime and/or cement stabilisation

3.1.1 Lime stabilisation

A sample of the estuarine silt was dried at a temperature of 100 °C and ground for 1 min with a planetary crusher. Quicklime was added to the ground sample to achieve a specified CaO/soil ratio defined by dry weight (1.5%, 3.0%, 4.0%, 5.0% and 7.0%). Water was then added to the mixture to achieve the optimal moisture content previously determined by the Proctor Test.

3.1.2 Cement stabilisation

The mixing and storage methods were the same as those used in the lime stabilisation tests. Cement was added to the ground sample to achieve a specified cement:soil ratio defined by dry weight (1.5, 3.0, 4.0, 5.0 and 7.0).

3.1.3 Lime–cement stabilisation

For these tests the ratio of cement:lime was fixed at unity by weight; the 28 day strength of samples stabilised with various cement+lime content of the soil (0.75% cement + 0.75% lime, 1.5% + 1.5%, 2.0% + 2.0%, and 3.5% + 3.5%).

3.2 Preparation and curing of UCS specimens

After mixing, the treated soil was statically compacted in a 40 mm diameter cylinder. This compaction was carried out on one layer of soil by two moveable pistons at the ends of the rigid mould.

The applied compaction force and moisture content were set to achieve the optimum dry density with the untreated material; these parameters were then used for all mixes.

Lime or cement treatments are known to increase the optimum moisture content and decrease the optimum dry density (Consoli et al. (2009)). It is to be noted that the compaction protocol adopted in this study resulted in dry densities lower than optimal for the various treatments.

After compaction the samples were extruded from the mould; the samples were 40 mm diameter and had an aspect ratio of 1.5. Samples were stored in air for 7 or 28 days (15 °C and 50% RH) prior to strength testing. These storage conditions were appropriate as they reflect conditions typically employed on local sites where quicklime carbonates are exposed to atmospheric carbon dioxide.

3.3 CBR tests

A CBR test was carried out on the estuarine silt stabilised with 4% quicklime and 4% cement (CEMI), with a water content of 30%, which is close to the optimal value. A sample was compacted in a CBR mould; to obtain a stable humidity the sample was sealed in a polythene bag for a period of eight days. This test protocol is commonly used for French highway studies (SETRA, 2007).

4 Results and discussion

4.1 Results of treatments

4.1.1 Lime stabilisation

The evolution of unconfined compressive strength (UCS) for the treated silt is shown in Fig. 7. As can be seen from this figure the UCS values at 7 days ranged from 0.8 MPa to 1.0 MPa for lime additions of between 3% and 7%.

Samples stored for 28 days showed a significant increase in strength; as can be seen in Fig. 7 the UCS increased by a factor of two for 7% lime content. This increase is evidence of the relatively slow lime reaction kinetics in the storage conditions (approximately 15 °C, 50% RH).

4.1.2 Cement stabilisation

The UCS for the samples stabilised with cement CEMI are shown in Fig. 8. These strengths are greater than those seen in the case of lime stabilisation; 7% cement addition achieving a UCS of 1.7 MPa at 7 days whereas 7% lime achieved 0.8 MPa. However the increase in strength from 7 to 28 days seen in the case of lime treatment is less evident in the case of cement treatment; for 7% cement the strength increased from 1.7 MPa to 2.3 MPa.

4.1.3 Stabilisation with cement–lime mix

The UCS at 28 days are shown in Fig. 9. Previous 28 day results are superimposed on this figure and it can be seen that the UCS of lime+ cement mixes were greater than those for lime and cement alone.

4.1.4 CBR results

At the end of the period the CBR value of the sample was 31%; the penetration force data are shown on Table 4. It can be seen that the CBR value of the estuarine silt stabilised with a cement lime mix achieved a CBR six times greater than that found for the non-stabilised soil.

4.2 Summary of the stabilisation treatments

The difference in the kinetics of the lime and cement reactions can be seen in Figs. 7 and 8. In the case of lime treatment the increase in strength with time was dependent on the concentration, whereas for the range of cement content tested, treatment showed an increase in strength which is independent of the cement concentration.

Fig. 9 shows the treatment with lime and cement led to the highest strengths; additionally a pre-treatment with lime would offer the possibility of controlling the moisture content prior to placement. Similarly quicklime added to a dry soil will modify the clay; the cement will bind the modified peds with a degree of long term strength gain due to the clay-lime reactions.

With the French geotechnical classification of soil strength the estuarine silt compacted at optimal moisture content is class P1 (CBR 3% to 6%), considered deformable and liable to rutting. After stabilisation with cement-lime at 5% the silt was class P4, slightly deformable and suitable for a 13t axle load. Referring to the UK specification for sub-base materials, it is seen that the estuarine silt stabilised with the cement-lime achieved a CBR value of 30% which is comparable with that required of a Type 2 unbound granular sub-base. The linear shrinkage of the material is of interest as many stabilised clay sub-bases tend to suffer early age shrinkage cracking. The reduction in linear shrinkage (LS) achieved by stabilisation is significant—LS of untreated silt being 12.5% which is reduced to the order of 3% for all the treatments studied.

5 Conclusion

1. Mineralogical, chemical and geological analyses of the estuarine silts, dredged from upstream of the tidal barrage, have been carried out. The mineral composition was principally quartz and calcareous materials emanating from biological species as well as clay minerals exist in the form of illite and kaolinite.
2. The un-stabilised soil had a Plastic Index of 25%, linear shrinkage of 12.5% and a CBR value of 5 at optimal compaction (30% m/c).
3. Stabilisation with a mixture of 3.5% cement plus 3.5% lime achieved the highest strengths, after 28 days the UCS being 3 MPa compared with 2 for 7% lime and 2.3 MPa with 7% cement. The CBR at 7 days was 31%, six times that of the un-stabilised material.
4. The stabilisation has achieved its objective in that the stabilised material fulfils the criteria required of a road sub-base—Class P4 and comparable with a Type 2 granular sub-base. It is concluded that it is possible to stabilise the estuarine silts from the Rance Estuary—this resource of reclaimed material would offer significant financial and ecological benefits.
5. Before adoption of this silt for an application as a road sub-base a second test programme is required:
 - (i) Improvement to the stabilisation process; analysis of the influence of complementary sulphate admixtures; optimisation of compaction energy; strength development of the stabilised soil under various levels of humidity.
 - (ii) A detailed characterisation of the final material; tests for swelling, frost resistance, module of deformation and tensile strength.

References

- ASTM D423-66, 1972. Method of Test for Liquid Limit of Soils. ASTM International, West Conshohocken, Pennsylvania.
- Boubaker, R., Boutouil, M., Pantet, A., 2009. Geotechnical properties of cement treated sediment: influence of the organic matter and cement contents. *International Journal of Geotechnical Engineering* 3 (2), 205-214.
- Burroughs, S., 2008. Soil property criteria for rammed earth stabilisation. *Journal of Materials in Civil Engineering ASCE* 20 (3), 264-273.
- Chaddock, B.C.J., Atkinson, V.M., 1997. Stabilised sub-bases in road foundations: structural assessment and benefits. Transport Research Laboratory UK TRL Report 248.
- Consoli, N.C., da Silva Lopez, L., Heineck, K.S., 2009. Key parameters for the strength control of lime stabilized soil. *Journal of Material in Civil Engineering ASCE* 21 (5), 210-216.
- Harvey, C.C., Murray, H.H., 1997. Industrial clays in the 21st century: a perspective of exploration, technology and utilization. *Applied Clay Science* 11, 285-310.
- Jha, J.N., Gill, K.S., 2006. Effect of rice husk ash on lime stabilization of soil. *Journal of the Institution of Engineers (India): Civil Engineering Division* 87, 33-39.
- Keith, K.S., Murray, H.H., 1994. Clay liners and barriers, In: Carr, D.D. (Ed.), *Industrial Minerals and Rocks*, Sixth Edition. Society Mining, Metallurgy and Exploration, Littleton, Colorado, pp. 435-452.
- Kergoet, M., 2001. Exemple d'étude de traitement pour déterminer l'emploi d'un sol en couche de forme (Study of possible soil treatments for use in road base). *Bulletin des Laboratoires des Ponts et Chaussées* 231, 19-24.
- Khattab, S.A.A., Al-Mukhtar, M., Fleureau, J.M., 2007. Long-term stability characteristics of a lime-treated plastic soil. *Journal of Materials in Civil Engineering ASCE* 19, 358-366.
- Konyeha, V.U., Ogbeide, F.N., 2007. Lime cement stabilised chicoco as a road pavement material. *Advanced Materials Research* 18-19, 3-11.
- Murray, H.H., 2000. Traditional and new applications of kaolin, smectite and palygorskite: a general overview. *Applied Clay Science* 17, 207-221.
- NF P94-052-1, 1995. Détermination des limites d'Atterberg. Partie 1: limite de liquidité—Méthode du cône de pénétration (Determination of Atterberg limits Part 1 liquid limit—penetration cone method).
- NF P94-068, 1998. Détermination de la valeur de bleu de méthylène d'un sol ou d'un matériau rocheux par l'essai à la tache (Determination of the methylene blue index for a soil or a rocky material by the stain method).
- Rao, M.S., Shivananda, P., 2005. Role of curing temperature in progress of lime-soil reactions. *Geotechnical and Geological Engineering* 23, 79-85.

- SETRA, 2007. (English Translation 2008) Technical Guide, treatment of soils with lime and/or hydraulic binders. Ref 0718, Ministry of Transport and Infrastructure, France.
- Sivapullaiah, P.V., Sridharan, A., Ramesh, H.N., 2006. Effect of sulphate on the shear strength of lime-treated kaolinitic soil. *Ground Improvement* 10, 23-30.
- WRAP (Waste & Resources Action Programme), 2002. Polegate Bypass Lime modified, cement stabilised weald clay for sub-base. http://www.wrap.org.uk/downloads/TheA27PolegateBypass_ABSOLUTE_FINAL_VERSION.f41b9266.1677.pdf2002.
- XP CEN ISO/TS 17892-12, 2005. Essais de laboratoire sur les sols. Partie 12: détermination des limites d'Atterberg. (Laboratory soil tests Part 12: determination of Atterberg limits).
- Zentar, R., Abriak, N.-E., Dubois, V., 2009. Effects of salts and organic matter on Atterberg limits of dredged marine sediments. *Applied Clay Science* 42, 391-397.

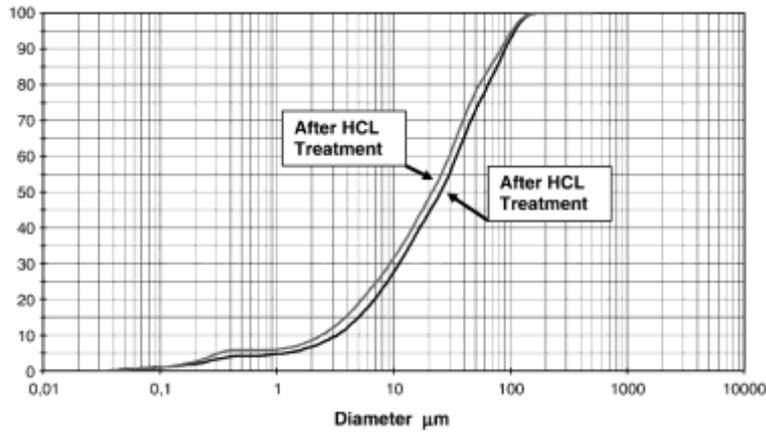


Fig. 3. Grain size distribution of the estuarine silt.

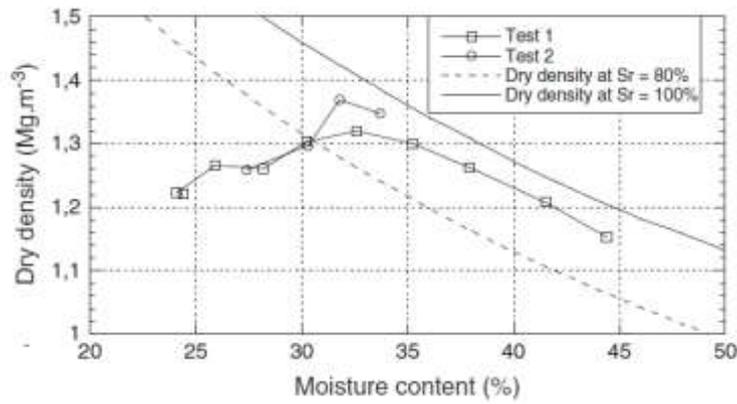


Fig. 4. Proctor test for the un-stabilised soil.

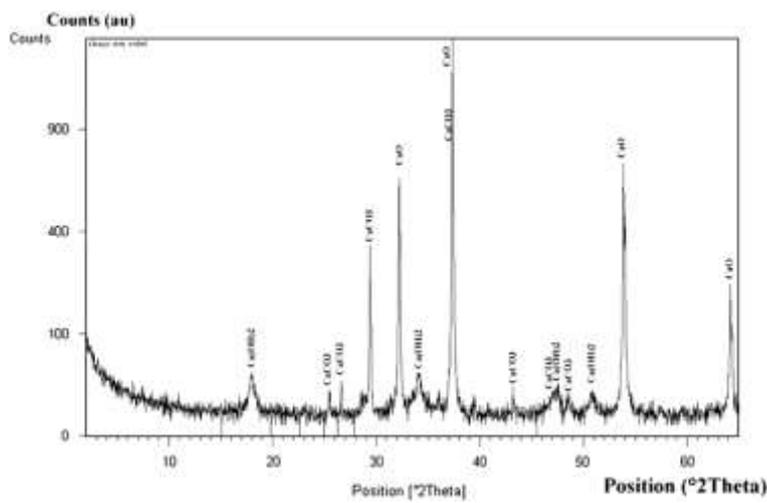


Fig. 5. XRD pattern of quicklime (Cu $\text{K}\alpha$ radiation).

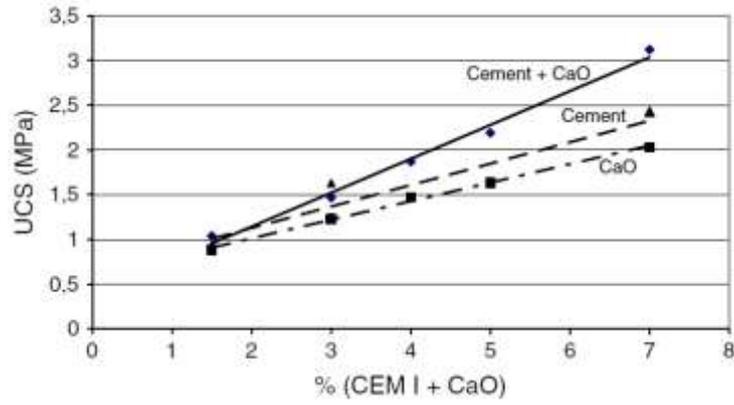


Fig. 9. UCS of estuarine silt at 28 days for all treatments.

Table 1
Grain size distribution of the estuarine mud.

Sample	%	Clay	Silt	Fine sand	Mean grain size
		0–2 μm	2–63 μm	63–200 μm	μm
Before HCl treatment	Partial	6.8	72.6	20.6	26
	Cumulative	6.8	79.4	100.0	
After HCl treatment	Partial	8.6	75.0	16.4	21
	Cumulative	8.6	83.6	100.0	

Table 2
Geotechnical properties of the estuarine silt (MB methylene blue test).

Sample - 902 Rance			
Plastic limit	40%	Linear shrinkage	12.5%
Liquid limit	65%	MB	2.7
Plasticity index	25%	Organic content	11.6%
clay/ silt ratio	9.4		

Table 3
CBR test on sample un-stabilised soil.

Penetration (mm)	Force (N)	Resistance (MPa)	ICBR
2.5	703	0.36	5.1
5	1140	0.58	5.5

Table 4
CBR test on sample treated with cement+ lime.

Penetration (mm)	Force (N)	Resistance (MPa)	ICBR
2.5	74280	2.167	30.95
5	6030	3.067	29.21