Geotechnical parameter study and solidification of Marine Sediment for Road Engineering

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Abstract. The Chinese coastal areas are the environment of multiple activities, and navigation occupies an important place. Dredging operations maintain access to port structures carried out regularly. These sediments' fate is problematic in Jiangsu province due to significant contamination of organic and mineral pollutants. A company called Nature Way aims to solve this problem. It is deeply committed to the treatment and use of sediment dredged from the seabed and uses proprietary solidification technology to transform all kinds of silt waste into new engineered materials that replace sand and sand. Gravel and traditional techniques and can be used as foundation materials for various projects in loose soil areas. In this work, we first studied the physic-chemical characterization of raw materials sediments supplied by Nature Way Corporation from Jiangsu province. Secondly, we have to mix the raw sediment and the solidifying agents and test the mechanical performance at 3%, 5% and 7% in a time interval of 7 days, 14 days, and 28 days. Finally, we have to measure the (CBR) “California Bearing Ratio” after 28 days, mix with the binder at 3%, 5%, 7%.

Keywords: Dredging, Sediments, Valorization, Stabilization, Solidifying agent.

1. Introduction:

Sedimentation is a natural phenomenon that, in the long term, leads to siltation harbor or rivers in China. The origin of the deposited material is natural (soil erosion, decomposition of matter plants, etc.), which is anthropogenic. In this case, these are agricultural, industrial or which may contain many inorganic toxins (heavy metals) and organic (hydrocarbon, PAH, PCB, etc.). China is experiencing phenomenal growth by hosting many polluting activities (metallurgical industry, tannery, etc.), particularly affected by these environmental problems. To ensure a sufficient draft for navigation and restore the environment's natural resources, it is essential to maintain watercourses by regularly dredging operations. We are four main sectors: landfilling, storage, recovery and treatment. When dredged sludge is heavily polluted, the first two solutions require taking certain precautions to prevent any contaminants' transfer into water or air. This generates a high cost, monopolizes land areas become rarer and rarer and raises many questions in a current policy of sustainable development. The valorization (spreading, use in Civil Engineering, etc.) confers sediment, but it can only be considered if their contamination complies with the current regulatory thresholds. To find a way out of these environmental problems, many treatment processes have emerged. They allow, by different technologies (biological treatment, physic-chemical, thermal, etc.), to eliminate or stabilize the pollutants in dredged products. To solve this problem, Nature Way Corporation has developed a new technologic methodology; sludge can become earthwork material with a certain strength and can be used as subgrades and foundation layers for roads or various engineering projects over soft-soil areas.
This paper aims to study the characterization of raw sediments according to the French standard and secondly study the mechanical performance of the raw sediment mixed with the solidifying agent furnished by Nature way Corporation.

1.1 Presentation of the marine sediments Solidification and Processing Methods

The technology of marine sediments solidification is a process of a series of physical and chemical reactions among the silt, water and material of marine mud solidification, adding marine sediments solidification into the silt. It can make silt become earthwork materials having some certain strength which used as a road foundation material. The project takes industrial waste materials as a material of marine sediments solidification, which can create an alkaline environment and causes a more fully hydration reaction to generate a variety of hydration products and more cementing materials. These cementing materials form a skeleton structure dominated by cementing and binding the small particles of silt to become a soil crumb structure. It makes the silt have a certain strength and stability and be suitable for soft ground construction projects as a new engineering material- Solidified Soil. Stirred equally solidified soil will be backfilled and compacted within 48 hours (in summer) or 72 hours (in winter). It can improve the strength and stability of solidified soil efficiently and be greatly enhanced than the strength in situ curing by controlling the best chemical reactions and physical compaction period. It can transform the waste silt of high-water content and low strength into efficient engineering soil. The treated silt has high strength and can be designed or adjusted solidified formulations and strength according to the project needs. It can achieve the project requirements by just once the treatment and has some advantages of large capacity and short processing time.

2. Materials and Methods

2.1 Binder

The solidifying agent used is a new type of cementitious material that can solidify clay, silt, sand, and enhance the strength of the soil, increase the bearing capacity, and increase the performance of impermeability. The solidifying agent used is KZ-F1, which was sent to us by Nature way.

2.2 Binder dosage

All marine sediments are stored in a large, airtight plastic bag. Before each stabilization mixture, a sufficient amount is taken with its water content. We determine the mass of the dry materials (table1) to know the amount of solidifying agent (KZ-F1) to add and the quantity of water necessary to have a good mixture.

| Table1. Real values of binder contents |
|---------------------------------------|
| Content mass wet                      |
| 3%                                   |
| 5%                                   |
| 7%                                   |
| Content mass dry                     |
| 4.65                                 |
| 7.75%                                |
| 10.83%                               |

2.3 Mixing procedure

Throughout the experimental procedure in binder stabilization treatments, it is important to unify the mixing and preservation phases. Liquid additions only concern reactive chemicals. The basic chemicals are mixed for 2 minutes and then poured into the sediment to be treated. Then, the other solid additions and the water are added.
2.4 Making specimens by picketing

We can draw inspiration from the realization of concrete specimens 16cm × 32cm, which advocates picking the material in the mould. Moreover, this process can be quicker to implement for the manufacture of a unitary test tube. After mixing the sediments and binders with the mixer, the paste obtained is put in the cardboard Mould, and then it is compacted manually using a rod in steel (figure1). This action is similar to concrete picking during picking specimens on-site or in a concrete plant. At the end of this operation, it is necessary to fill the entire mould and sharpen the two sections of the mould.

![Figure 1. Specimens with the sediments](image1)

2.5 Preservation of specimens

A conservation protocol has been defined, which is intended to be the most representative of applications in road sub-layers and pedestrian routes. For sediment stabilization treatments, test specimens are first stored in cardboard molds, then sealed tightly in plastic wrapping for 7 days, 14 days, and 28 days (figure2). These measures prevent any phenomenon of carbonation of lime with the ambient air; the specimens are molded directly after making. After demolding, the specimens are used for laboratory tests. Carbonation is a slow phenomenon that takes place in several steps. Carbon dioxide must penetrate and diffuse into the porous texture of the material to dissolve in the pores’ interstitial solution. For this reason, the content in water, the material plays a preponderant role. Indeed, carbonation is a reaction that takes place in an aqueous medium. The carbonation rate is physically controlled by the diffusion of carbon dioxide in the interstitial water. If the material is saturated with water, the CO2 diffusion will be extremely difficult.

![Figure 2. Specimen’s conditioning](image2)

2.6 Measurements and Tests

The characterization of raw sediments according to the Technical Guide for Road Earthworks - embankments and subgrades (French acronym GTR) (LCPC-SETRA, 1992). These include the determination of natural water content, Atterberg limits, particle size distribution, particle density, organic matter content, pH, absolute density, methylene blue values (VBS).
2.7 Physical Characterization of Raw Sediments
We will establish the physical characteristics of the raw sediments from Lianyungang; the main objective is to identify sediment parameters such as natural water content, particle size, organic matter content, granulometry, absolute density.

2.7.1 Natural Water Content
The measurement of the water content is an important parameter and one of the fundamental parameters. The water content defines the water status of the material and is designated \( w \) and expressed in% by the ratio of the dry mass and the wet mass of the material. The measurement of the water content must be evaluated by steaming at 105°C to constant mass, respecting a drying time of 24 hours according to standard NF P 94- 050. The value of the water content is then obtained by means of the following formula. The result is shown in Table 2.

| Test | W (%) | Average (%) |
|------|-------|-------------|
| 1    | 58.70 | 44.55       |
| 2    | 33.48 |
| 3    | 41.48 |

2.7.2 Particle size analysis
In this study, the particle size analysis curve of the sediments was established using two Techniques: Laser beam diffraction using a Malvern- Mastersizer 3000 type laser particle size LS230 [NF ISO 13320-1 standard] Laser particle size analysis is a technique based on the diffraction of a laser beam at the meets particles suspended in a fluid (figure3). In addition, particles are considered are spherical, opaque and non-porous. The diffraction angle of the light is inversely proportional to the size of the particles studied. The laser particle size analysis makes it possible to identify particles of sizes between 0.04μm and 2000μm.

Figure 3. Particle size distribution of the sediment
(0.01μm – 180μm)
2.7.3 Organic Matter Content

Organic matter content retains water and prevents puzzolanic reaction. The impact of organic matter on sediment characteristics depends on the nature and structure of the organic matter. The organic matter content is determined by calcination. First, a sample is placed in an oven at 550 °C, and each hour the weight variation of the sample is weighed. The curve of the mass is obtained as a function of time. According to the shape of the curves, it is decided that, for each test portion, the sample is kept for at least 4 hours in the oven whose temperature is 550 °C. After calcination, each crucible and its contents are weighed (table3).

| Parameters | Sample |
|------------|--------|
| 550 °C (%) | 2.78   |

2.7.4 Atterberg Limits

The limits of Atterberg are determined only for the fine elements of a soil (fraction passing through a 400μm sieve), because these are the only elements on which water acts in modifying the consistency of the soil.

Atterberg limit determination. Liquid limit, Plastic limit: Cone penetrometer method:

The principle of the Penetration cone method consists in measuring the depression of a standardized cone (angle at the top of 30 °, mass 80 g) for 5 seconds in a sediment sample. The liquidity limit is limited to 17 mm of the cone, according to the French standard [NF P 94 052 standard] and 20 mm according to the English standard [BSI 1990].

A linear relationship between the logarithmic cone penetration and the logarithmic water content is obtained by regression analysis on four data points for each soil tested. This linear relationship is extended to determine the plastic limit at 2 mm of cone penetration.

Liquid limit: (WL) = 33.26 Plastic limit: (WP) = 24.22 Plasticity index (PI):

This is the area between the states of liquidity and plasticity. This time is a difference of liquidity and plasticity, IP rating, is available in one-time-size: PI = 9.04%.

2.7.5 Absolute Density

The absolute density of a sample is determined according to standard NF P94-054. It corresponds to the ratio of the mass of the solid to the volume of the solid material, including the closed voids contained inside the grains.

To measure using a pycnometer knowing the mass and volume of the empty pycnometer. The most frequently used pycnometers are the liquid and gas pycnometer.

We measured the absolute density (density of the material solid) marine sediments using a water pycnometer. Knowing the mass and the volume of the empty pycnometer, this is to determine, from a dry sample whose mass is known, the volume of grains contained in the pycnometer. For this, we estimate by the difference in weighing the mass of water displaced by the material after saturation under vacuum in a desiccator. The measurement was carried out on 3 samples of 100 g each. The absolute density result of the sediments is 2.67 g/cm³.
2.8 Chemical Characterization

2.8.1 Methylene blue values (VBS)

This test makes it possible to evaluate the clay activity according to standard NF P 94 068. The greater quantity of methylene blue adsorbed means the clay activity will be important. Methylene blue value of soils is designated by (VBS) and expressed in (%). It expresses the quantity in grams of methylene blue adsorbed per 100g of soil. After doing this test, two cases are possible:

- The central droplet is surrounded by a colorless wet zone: the test is negative.
- The central droplet is surrounded by a wet area tinged with blue: the test is positive.

| Number of indoor soil samples | Number of field soil samples | Ions contents (mg/kg soil) |
|------------------------------|-----------------------------|---------------------------|
| 1                            | Dredged sludge              | Ca²⁺  | Mg²⁺ | Na⁺⁺K⁺ | Cl⁻ | SO₄²⁻ | HCO | CO₃⁻ | pH |
| 120.24                       | 24.3                        | 1903. | 2809 | 300.   | 167.2- | 75.0 | 8.87 |

Table 4. Ions contents of soluble of silt in Lianyungang

In our experiment the VBS is 0.08. It`s mean the sediments are insensitive to water. So, the sediment has a low absorption capacity

2.8.2 Conductivity

Electrical conductivity is a measure that approximates the concentration of soluble salts present in the sample. To carry out this test, it is necessary to take a quantity of 10g of sediment sample, put it in a polyethene bottle, add 50 ml of distilled water, close the bottle, and place it in a mechanical agitator with the horizontal movement for 30min. So, the conductivity is 15.47 ms/cm.

2.9 Mechanical Characterization of the Sediments

Material can be used for earthworks and foundation work if the load capacity can withstand heavy machinery's acceptable movement. These studies apply to soils sensitive to water and must meet high mechanical requirements. To carry out this mechanical study, the raw sediments were mixed with solidifying agents.
2.9.1 Unconfined compressive strength test

The Unconfined compressive strength tests were performed according to standard GB/T50123 (1999). The loading rate was 1.0 mm/min. The specimens have been made in the following dimensions: Diameter = 50 mm; Height = 100 mm (figure4). The purpose of the compression tests is multiple: it determines the age authorizing the placing on the market of construction machinery on the treated layer, checking the resistance of the diaper to immersion at a young age, and frost resistance. Both first points respectively constitute the criteria of trafficability and insensitivity to water (which is complementary to the CBR test.) To evaluate these 3 parameters on our specimens, we measured the compressive strengths samples after 7, 14, 28 days of normal ripening. The criterion of trafficability is considered satisfactory since the compressive strength simple is greater than 1 MPa. It is, therefore, necessary to estimate using the evolution curves the time it takes for this condition to be verified.

![Figure 4. Unconfined compressive test](image)

2.9.2 Indirect tensile strength test (Brazilian test)

The purpose of this test is to determine the mechanical tensile performance of the treated layer (indirect tensile strength) R_{it} at 7 days, 14 days, and 28 days of maturation. The Brazilian test is described in standard NF P98- 232-3; on cylindrical specimens in our case, we used moulds having the following dimensions: D = 50 mm; H = 100 mm. The test's principle consists of carrying out a diametric compression by applying a linear load on 2 opposed generators of the specimen (figure5). The Brazilian tensile strength (R_{it} in MPa) is determined from the applied force by the press at the time of breaking the sample (F_{r} in Newton), using the formula next.

3. Results and discussions

3.1 Natural moisture content

The average moisture content of the marine sediment was 44.55 %. A soil with natural moisture content higher than its liquid limit is considered very soft and may have deficient shear strength. The sediment's liquid limit is 33.26 %; it falls under this category of soft, weak material, requiring treatment before any beneficial reuse in engineering applications.
3.2 Atterberg limits

The liquid limit (WL) results correspond to a penetration of 17 mm, which gives us 33.26%. The average plastic limit (Wp) is 24.22%, and The plasticity index (PI = WL - Wp) is 9.04%. According to the Classification System’s plasticity chart, the soil is classified as silt-clay, the degree of plasticity is medium plastic, and this soil is cohesive.

3.3 Particle size analysis

The particle size analysis curve enables quantitative evaluation of the different fractions of grain compositions: Clay, silt and sand (clay < 2μm < silt < 63μm < sand). The particle size distribution curve of the sediment shows 10% of particles diameter measure 1.72μm, 50% of the particles measure 6.67μm, and 90% of particles measure 24.7μm. According to the laser particle size analysis result, 10% of this sediment are the clay, and 90% are silt. So the nature of this sediment is silt.

3.1 Absolute density

The average value of the 3 sediments samples is 2.67 g/cm³. The particle density of most mineral. Soils (sand, silt, clay) lies between 2.5 and 2.7 g/cm³. The range is fairly narrow because common soil minerals differ little in density. An average value of 2.65 g/cm³ is often assumed. In contrast, organic soils have lower particle densities since organic matter density is much less than that of mineral particles.

3.2 Unconfined Compressive Strength (UCS)

![Figure 7](image-url)

**Figure 7.** Evolution curve of the mechanical strengths in unconfined compressive of the binders according of the maturation time
According to the result (figure 7), it can be observed that depending on the dosage of solidified agent, evolutions and performances attacks are significantly different. It should also be noted that the dispersion of the compressive strength is relatively low at 3% for 7 days and 14 days' samples. The 7% binder is different from the others. Indeed, it is the one that allows obtaining the best mechanical performance at 7 days (1.6 MPa), at 14 days (2.35 MPa), at 28 days (2.70 MPa); besides, the shape of the curve allows considering even higher resistances with additional days. The criterion for determining the characteristics of mechanical compression is related to the performance of sediment solidified. It is considered like a subgrade when the compressive strength is greater than 1 MPa. This value is reached as early as 7 days for binders at 7%. But we think that beyond 28 days, the binder at 5% can reach 1 MPa and meet the criteria for use because we have 28 days (0.85 MPa). The catch’s initial development is fast, which is particularly interesting in the Sediment recovery scenario in road engineering as this minimizes the delay in implementing upper layers.

3.1 Indirect Tensile Strength

![Figure 8. Indirect tensile strength (MPa) according to the days](image)

The indirect tensile strength is an indicator of the resistance of the material solidified in traction (figure 8). The requirement set for reuse of the subgrade material is 0.25 MPa. The average values of the indirect tensile strength (Rit) measurements as a function of the number of days at different binder contents are shown. We also specified the values recommended by the Classification of French Sediments. The results obtained show the dosage at 7% for (7 days and 28 days) match with the French Sediment classification recommendations in terms of mechanical performance. However, the dosage at 5% for 28 days meets the conformity criterion; nevertheless, the dosage at 3% has a deficient performance.
3.1 Results California Bearing Ratio test

The CBR (California Bearing ratio) values increase exponentially with the addition of binders. We will notice, however, they are much higher at 7%. This is probably due to the very low water content. Finally, it should be noted that sediments treated with binder’s 5% and 7% offer acceptable bearing for used in road engineering (figure 9). Bearing capacity is high, the solidifying agent reinforces the sediment and solves the problems of the weakness of soft soil, and the low bearing capacity.

4. Conclusion

The sediments dredged in China are either discharged at sea or deposited in the ground. Discharge at sea is the most economical solution that is frequently adopted despite the presence of pollution. This paper aims to propose a new alternative, both ecological and economic, to manage Chinese marine sediments. A report on the sediment dredging problem and the innovative solutions of their management have been elaborated. The problem arises from the need to dredge large volumes of sediment.

This study deals with the valuation of marine sediments in building materials and, more specifically in road engineering. Physical characterization shows that sediments are not very plastic. It is also noted that the presence of organic matter in these sediments is low. The chemical characterization of these sediments made it possible to evaluate their recovery potential.

The last part of this work was devoted to studying the mechanical performances of the specimens with different contents of the solidifying agent (binder) of the sediments. These specimens were subjected to qualification tests that showed that the compressive strength is influenced by the binder content and the sediments’ low water content. Given the physical, chemical and mechanical properties of the samples produced with binders’ addition, it is noted that the rate of 5% at 28 days only and 7% from 7 days up to 28 days gives a better resistance. But the resistance is very low for an addition of 3% in binders and 5% between (7 days and 28 days). The values of compressive strength for a Valorization of (3%, 5%, and 7%) in binders at 28 days because they offer optimal values are respectively of the order of (0.255 MPa, 0.853 MPa, 2.708 MPa). The CBR (California Bearing Ratio) study shows that the sediment load of the binder-mixed Sediments increases proportionally with the addition of binders (3%, 5%, 7%) Respectively (3.67, 14.19, 45.16).
In parallel, we have observed that the performance of CBR (California Bearing Ratio) is higher when the water content is low. Therefore, according to our study's result, we recommend Nature Way to use the binder's dosage at 7% because all the test satisfied the test requirement for road engineering. But for the company to be profitable, we advise them to do more research for a dosage at 5%, which gave us interesting result.

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