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Chemical Stabilization of Deltaic Lateritic Soil Using Cement and Superplasticizer

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Abstract

In this study, two chemical stabilization techniques were used to stabilize deltaic lateritic soils obtained from Ujevwu in Delta State, Nigeria. The two chemical stabilization techniques involved the use of only cement and a combination of cement and superplasticizer. Compaction and California Bearing Ratio (CBR) tests were conducted on the soil samples before and after stabilization. From the results obtained, it was observed that the natural soil only satisfied the requirements for use as a subgrade material, based on the specifications for road pavement materials prescribed by the Nigerian Federal Ministry of Works and Housing (FMWH) Highway Design Manual. Stabilization by addition of only cement to the natural soils gave CBR values of 30% and 80% with cement contents of 6.2% and 10% respectively. However, when superplasticizer contents of 1.2% and 1.8% were added alongside the cement, CBR values of 30% and 80% were achieved with cement contents of 4% and 6% respectively. Based on the results, it was seen that combining cement with superplasticizers as stabilizing materials, can lead to significant reduction in the amount of cement required for soil stabilization.

1. Introduction

According to [1], most Nigerian roads are failing due to the use of soils having poor or insufficient engineering strength. Hence, it has become a major concern for highway engineers to source for good and adequate soils as materials for road construction. It was stated by [2], that the residual soils in a particular location may not possess the required engineering properties to carry the wheel loads that are expected to act on it. Therefore, soils from other locations that have good engineering properties may have to be imported to replace the residual soils in the location, or the inherent properties of the residual soils can be improved to make them more suitable for use. The latter approach is known as soil stabilization, and is described as any treatment applied to a soil to enhance its strength properties and reduce its susceptibility to water. Generally, a soil is regarded as stable, if after been treated, it becomes capable of resisting the stresses that will be imposed on it by traffic load under all weather conditions without experiencing excessive deformations [3]. The two main techniques often used in stabilizing soils are mechanical and chemical. Mechanical stabilization employs physical processes to enhance the properties of the soil, either by modifying the physical configuration of the soil by mixing it with other soils or by inserting barriers in the soil to attain the desired effect [4]. On the other hand, chemical stabilization involves the use of admixtures to modify or change the chemical properties of the soil to achieve the desired properties [5, 6]. The two most common admixtures or chemicals used in this method are cement and lime. Of these two, cement stabilization is the most widely used. However, due to the environmental concerns regarding the production of cement, which contributes significantly to greenhouse gases emission, efforts are being put in place to reduce the use of cement and its associated products. This has led to the use of alternative materials that can either reduce the amount of cement required for soil stabilization or altogether completely replace it [7 – 10].

The Niger Delta region is a riverine environment that is superficially underlain by various soil types, all covering the deltaic coastal plain sand [2]. These superficial soils comprise the fine sands of the coastal ridge; the very soft and highly compressible marine mud of the extensive mangrove swamp; the highly montmorillonitic active silty clay soil of the freshwater zone, which swells and shrinks in the raining and dry seasons respectively and the deltaic lateritic soils of the dry flatlands and plains [11]. Amongst these soils, only the deltaic lateritic soils have been seen to be adequate for use as subgrade materials in their untreated forms or with minor treatment [2]. As a result of this, materials are usually transported over long distances for roadworks in this area thus increasing the cost of road construction in the area. In Nigeria, according to the specifications of the Federal Ministry of Works and Housing Design Manual [12], a material that will be suitable for subgrade, subbase and base must have a minimum California Bearing Ratio (CBR) of 5%, 30% and 80% respectively. Given the poor engineering properties of these deltaic lateritic soils, it would be interesting to see if upon stabilization, these deltaic lateritic soils will be deemed adequate for use as pavement construction materials. In a recent study by the authors [13], three different types of soil stabilization techniques (mechanical, chemical and a mixture of both mechanical and chemical stabilization technique) were employed in stabilizing these soils. In the study, it was discovered that the mixed method of stabilization, which involved the use of cement and sand, gave the best engineering properties. In this study, a new approach is being introduced, which will involve the use of cement and a superplasticizer for the stabilization of these deltaic lateritic soils. Superplasticizers have been known to improve certain properties of concrete, when incorporated into concrete mixes. Hence, it will be interesting to see how they would impact on the engineering properties of soil, when they are used alongside cement as stabilization materials.

2. Methodology

2.1 Study Area

The study area is located in Warri, Delta State within the rain forest climatic zone of Nigeria. The water table in the area is located very close to the ground surface and ranges between 0 to 4m [14]. The samples used in the study were collected from the Borrow Pit at Ujevwu (shown in Figure 1).

Figure 1: Map showing sampling locations [13]

2.2 Soil Sampling
The natural soil samples were recovered from a trial pit dug to a depth of 1m to 2.5m at the sampling location. The recovered samples were immediately placed in cellophane bags to avoid moisture loss during transportation to the laboratory for testing and analysis.

2.3 Materials
Cement
The cement utilized for the study was Portland cement, which was purchased from local vendors. The chemical properties of the cement, which conformed to the specifications given in BS 12, are presented in Table 1.

Table 1: Chemical properties of the cement used in the study

Property	%
Lime (CaO)	60.87
Alumina (Al_2O_3)	5.36
Soluble silica (SiO_2)	20.55
Iron oxide (Fe_2O_3)	4.00
Chloride (Cl_2)	< 0.1
Magnesia (MgO)	0.74
Sulfuric Anhydride (SO_3)	1.83
Insoluble residue	2.93
Al_2O_3/Fe_2O_3	1.34

Superplasticizer
The superplasticizer used in the study was Master Rheobuild 561M – a water reducing superplasticizer. It was purchased from local vendors. The chemical properties of the superplasticizer are shown in Table 2.

Table 2: Properties of superplasticizer used in the study

Property	%
Ammonium Hydroxide (NH_4OH)	5
Sodium Hydroxide (NaOH)	20
Ferric Hydroxide ($Fe(OH)_3$)	2
Carbon (C)	1
Magnesium Hydroxide ($Mg(OH)_2$)	22
Potassium Hydroxide (KOH)	25
Calcium Hydroxide ($Ca(OH)_2$)	15
Others	10

2.4 Chemical Stabilization by Cement
Chemical stabilization was carried out by addition of cement to the natural soil samples at proportions of 2%, 4%, 6%, 8% and 10% by weight of the natural soil sample.

2.5 Chemical Stabilization by Cement and Superplasticizer
Chemical stabilization was also carried out by a combined addition of cement and superplasticizer to the natural soil. The superplasticizer was added alongside cement in controlled proportions of 0% to 10% by weight of the soil. Table 3 gives a summary of the mixing programme adopted for the different methods of stabilization utilized in the study.

Table 3: Mix programme for the different methods of stabilization

Stabilization method	Mix ID	Cement (%)	Superplasticizer (%)
None	Control (C0)	0	0
Cement	C2	2	0
	C4	4	0
	C6	6	0
	C8	8	0
	C10	10	0
Cement + Superplasticizer	C2+S1	2	1
	C2+S2	2	2
	C2+S4	2	4
	C2+S6	2	6
	C2+S8	2	8
	C4+S1	4	1
	C4+S2	4	2
	C4+S4	4	4
	C4+S6	4	6
	C4+S8	4	8
	C6+S1	6	1
	C6+S2	6	2
	C6+S4	6	4
	C6+S6	6	6
	C6+S8	6	8

2.6 Laboratory Tests

Laboratory tests for index properties (moisture content, specific gravity tests, particle size distribution, consistency limits test, compaction test) and strength (CBR) properties were carried out on the natural and stabilized soil samples. The tests were carried out in accordance with the procedures outlined in BS 1377:1990 (parts 1 to 7).

3. Results and Discussion

3.1 Properties of the Natural Deltaic Lateritic Soil

The results of the laboratory tests conducted on the natural deltaic lateritic samples are presented in Table 4. The results showed that the percentage of the natural soil sample passing through the No. 200 sieve (75 microns), which was taken as the percentage of fines, was 48.7%. This implies that the natural soil contains a large amount of fines (silt and clay). The consistency limit parameters of the soil, which comprises of the liquid limit, plastic limit and plasticity index, were obtained as 34.0%, 18.7% and 15.3% respectively. According to the Casagrande's plasticity chart, the natural soil can be classified as CL (clay with low plasticity), while according to the American Association of State Highway and Transportation Officials (AASHTO) soil classification guide, the soil can also be classified as an A-6 soil. The optimum moisture content (OMC) and the maximum dry density (MDD) obtained from compaction tests were 13.4% and 1.86g/cm^3 respectively, while the soaked CBR of the soil was obtained as 5%. According to the specifications given in the Nigerian Federal Ministry of Works and Housing (FMWH) Highway Design Manual [12] for pavement materials, the natural soil samples seem to be only suitable for use as subgrade materials.

Table 4: Properties of the natural deltaic lateritic soil as obtained via laboratory tests

Property	Value
Percentage fines (%)	48.7
Liquid limit (%)	34.0
Plastic limit (%)	18.7
Plasticity index (%)	15.3
OMC (%)	13.4
MDD (g/cm^3)	1.86
CBR (%)	5.0

3.2 Results of Cement Stabilization

Figure 2 and 3 shows the impact of the addition of cement on the OMC and MDD of the natural deltaic lateritic soil. From Figure 2, it can be seen that the OMC decreased as the cement content increased from 0 to 4%, and further increased as the cement content was increased to 6%. The addition of cement beyond 6% did not have any significant impact on the OMC. In the case of the MDD, which is shown in Figure 3, it was observed that as the cement content increased from 0 to 4%, the MDD increased. This was followed by a sharp decrease in the MDD as the cement content was increased from 4 to 10%. These findings agree with those of [15, 16] and is due to the hydration reaction that occurs between the cement particles and the water in the soil, which will lead to the cementation/agglomeration of the soil particles [17].

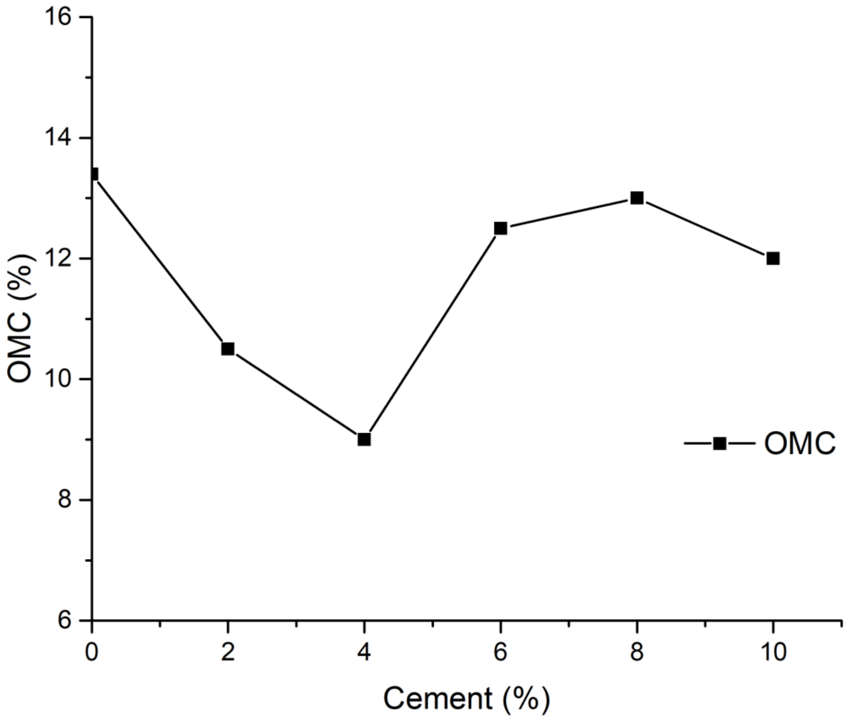

Figure 2: Effect of cement addition on the OMC of the natural soil

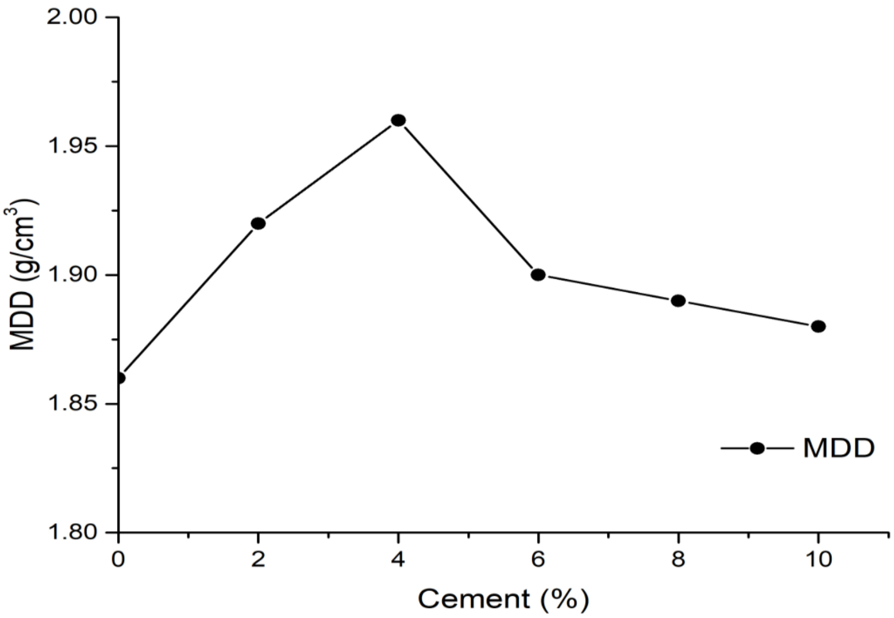

Figure 3: Effect of cement addition on the MDD of the natural soil

The effect of cement addition on the CBR of the natural soil is shown in Figure 4. A steady increase in the CBR was observed as the cement content was increased from 0 to 10%. This is in agreement with previous studies by [18 – 21], and can also be ascribed to the hydration reaction occurring between the cement particles and the water present in the soil matrix. This reaction will result in the formation of hydrated phases such as calcium-silicate-hydrate (C-S-H) and portlandite (CaOH) that has the ability to bind and cement the soil particles together, thus increasing the strength of the soil. As a way of determining the suitable cement content for stabilizing the natural soil, two horizontal lines were drawn at 30% CBR and 80% CBR, in the plot in Figure 4. These lines represent the minimum CBR recommended by the Nigerian FMWH Highway Design Manual for materials that are suitable for use as subbase and base materials. The data in Figure 4 was then fitted with a non-linear exponential curve, to give two cement contents – 6.2% and 10% for CBR of 30% and 80% respectively.

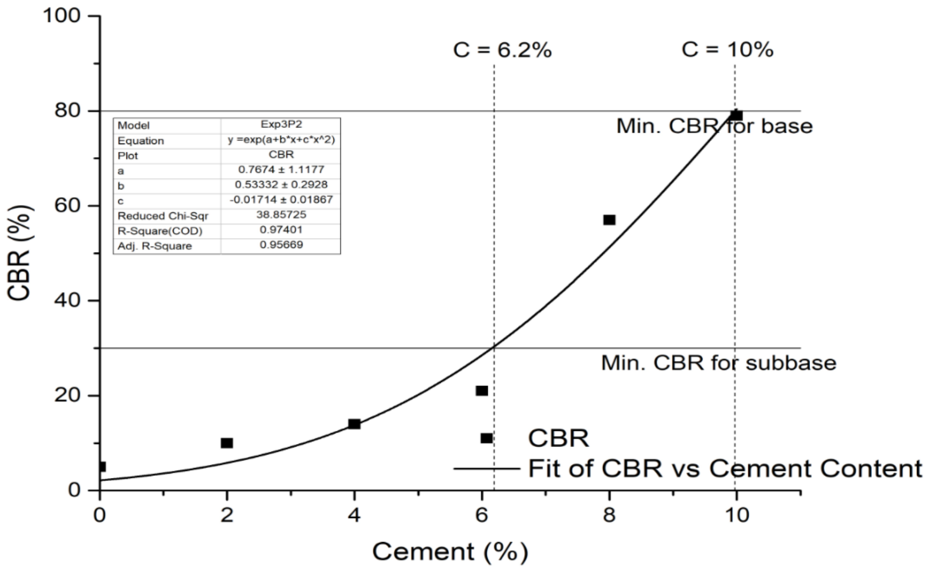

Figure 4: Impact of cement addition on the CBR of the natural soil

3.3 Results of soil stabilization using cement and superplasticiser

Figure 5 and 6 shows the results of the OMC and MDD respectively, as obtained from compaction tests conducted on the natural soil stabilized with cement and superplasticiser. From Figure 5, for the soil samples stabilized with 2% cement content, the OMC was seen to increase as the superplasticiser content increased, reaching a maximum of about 14% at a superplasticiser content of 4%. Further increase in the superplasticiser content beyond 4%, resulted in a decrease in the OMC. Similar trend was also observed for the soil samples stabilized with a cement content of 4%; while for the 6% cement stabilized soil samples, no clear trends or relationships were observed between the OMC and the superplasticiser content.

For the case of the MDD results, which is shown in Figure 6, it was observed that as the dosage of the superplasticiser increased from 0 to 2%, the MDD of the cement stabilized soils increased. However, as the dosage of the superplasticiser was increased beyond 2%, a sharp decrease was observed in the MDD of the cement stabilized soil samples. Similar findings were also reported by [22] in their study on rapid chemical stabilization of soft clay soils.

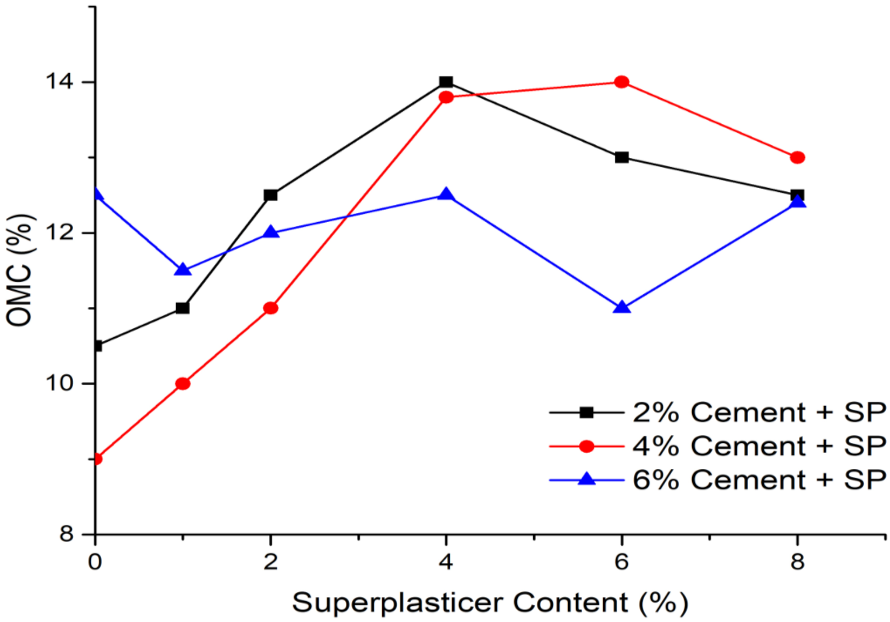

Figure 5: Effect of cement and superplasticiser addition on the OMC of the natural soil

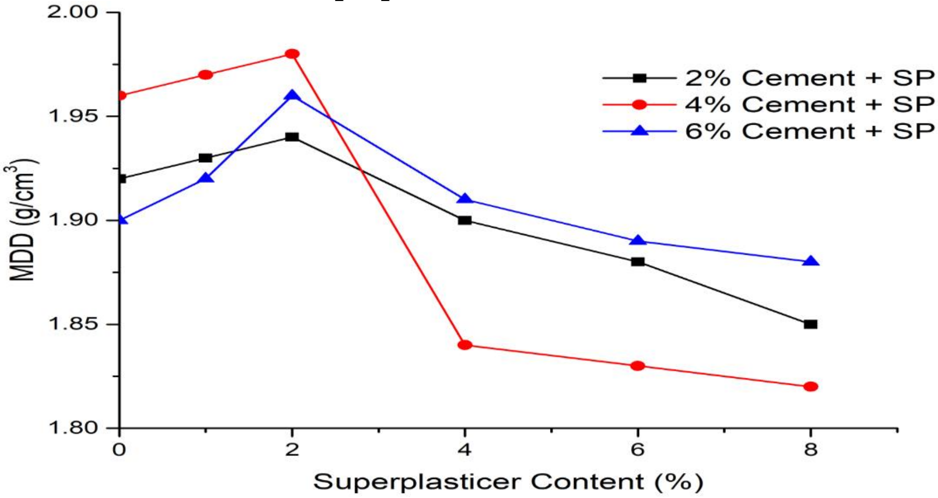

Figure 6: Effect of cement and superplasticiser addition on the MDD of the natural soil

The results obtained from CBR tests conducted on the soil samples stabilized by the combination of cement and superplasticiser is shown in Figure 7. Just as was observed in the MDD results, the CBR of the cement stabilized samples increased as the dosage of the superplasticiser was increased from 0 to 2%, and decreased on further increase of the superplasticiser dosage from 2 to 6%. As was done in the case of the natural soil samples stabilized with cement, horizontal lines were also drawn at 30% CBR and 80% CBR to the plot in Figure 7. From the figure, it can be seen that stabilizing the soil with cement and superplasticiser contents of 4% and 1.2% respectively, can produce soils with CBR of 30%; while on the other hand, stabilizing with 6% cement and 1.8% superplasticiser will result in CBR of 80%. Comparing these values to those shown in Figure 4, where 6.2% and 10% of cement was needed to obtain CBR values of 30% and 80% respectively, it can be seen that the mixture of cement and superplasticiser as a stabilizing agent can result in a significant decrease in the quantity of cement needed for soil stabilization. This is important as a result of the high cost of cement as a construction material, and also the environmental concerns associated with the production of cement.

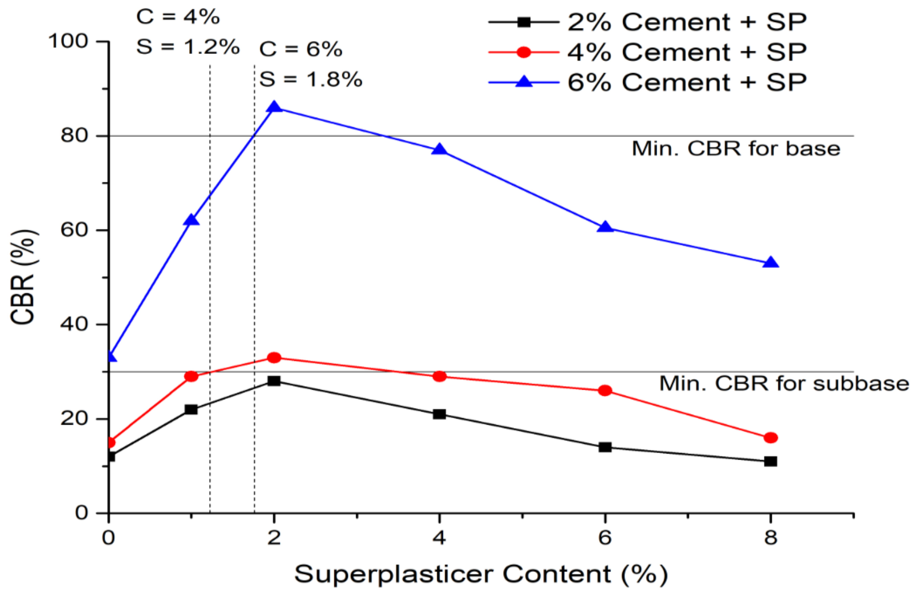

Figure 7: Effect of cement and superplasticiser addition on the CBR of the natural soil

4.0 Conclusion

This study investigated the effect of using two different chemical stabilization techniques to improve the properties of deltaic lateritic soils obtained from Ujevwu located in Delta South within the Niger Delta area of Nigeria. The first technique involved the addition of cement to the natural soil at various percentages, while the second technique involved the addition of cement and superplasticiser to the natural soil, also at various percentages. Compaction and CBR tests were conducted on the soil samples before and after stabilization, to determine the effect of the two stabilization methods on the strength properties of the natural soil. From the results obtained, it was seen that the method involving the use of cement and superplasticiser improved the strength properties of the soil more than the method involving the use of only cement. In particular, it was observed that the amount of cement required to achieve CBR values of 30% and 80% was significantly reduced when superplasticisers were added alongside the cement. This shows that one way to reduce the amount of cement used in soil stabilization might be to incorporate superplasticisers alongside the cement. An approach such as this will not only result in cement savings, but also and more importantly in the reduction of the carbon footprint associated with the use of cement.

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