# A Laboratory Study on the Influence of Lime and Quarry Dust on the Marine Clay Subgrade for Flexible Pavements

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*Abstract*—**Many soft fine clay deposits are found on Indian coastal corridor, which usually suffer from high saturation, low density, less shear strength, sensitivity and deformation problems. They are normally consolidated and hence have been found to be most troublesome from engineering considerations. Improving the behavior of these deposits is a challenge to civil engineering in general and geotechnical engineering in particular.**

**Different stabilization techniques are in practice to achieve suitable performance, improve life time and to reduce maintenance costs of pavement sub grades on fine clays. Present study deals with the stabilization of marine clay treated with lime and quarry dust and also the affect of reinforcement technique for improving the load carrying capacity of the marine clay sub grade model flexible pavement.**

***Keywords: Marine clay; lime; quarry dust; OMC; FSC; load carrying capacity; deformations***



## I. INTRODUCTION

Sub-grade soil, an integral part of the road pavement structure should possess sufficient stability under adverse climate and loading conditions.

All over the world, marine clay sub grades proved inefficient and posed problems viz, cracking and break-up of pavements, railway and highway embankments, roadways, building, foundations, irrigation systems, water lines, canal and reservoir lining, thus making it highly expensive and tedious for construction.

In addition, the problems arising out of high compressibility and low shear strength of these weak marine deposits expose geotechnical engineers to considerable changes in the construction of various coastal and offshore structures. The performances of these soft fine grained deposits under different conditions of environment vary over wide limits. The quest for improving its engineering properties led to several innovative improvement techniques in the recent past by researchers worldwide.

Some of the earlier investigators (Clare and crunchy, 1957; Mateous, 1964; Thompson, 1964; Kennedy et al, 1987; Marc Choquette et. al, 1987; Sweeney et al, 1988; Kenneth Torrance, J , 1990; Tuncer 1991; Narasimha Rao.S et. al, 1994; Little 1995; Narasimha Rao.S et. al, 1996; Rajasekaran G, 1998; Rajasekaran.G 2002; Srinivasaraghavan, R et. al, 2003; Rao and Thyagaraj, 2003; Rajasekaran.G et. al, 2004; Al-Rawas et.al, 2005; Sabat and das, 2009; Koteswara Rao. D et al, 2010; Sabat, 2012) revealed that considerable improvements in the engineering properties of lime treated soils and these beneficial changes are explained through lime-soil reactions, namely ion exchange, flocculation (agglomeration), Pozzolanic reaction (cementation), carbonation. Many investigators recommended the lime stabilization technique for improving the soil characteristics, especially for sub-grades.

On the other hand, accumulation of various waste materials is now a serious concern to the environmentalists. Quarries and aggregate crushers are inevitable requisites for construction industry and quarry dust is a by-product of rubble crusher units. About 20–25% of the total production in each crusher unit is left out as the waste material-quarry dust (Ali and Koranne, 2011). The annual production of quarry dust is roughly around 200 million tonnes (Soosan et al.2005). The utilization of Quarry dust in soil stabilization was presented by Gupta et al. 2002;Gulsah 2004;Soosan et al 2005;Praveen Kumar et al, 2006; Sabat and das 2009 ; Ali and Koranne,2011; Charles M. et al. 2012;Sabat 2012. Geotechnical and mineralogical characterization of quarry dust and its interaction behaviour with soils can lead to viable solutions for soil stabilization besides its large-scale utilization and disposal.

## 1. OBJECTIVES

This investigation has been carried out with the following objects.

- To study the impact of lime and quarry dust on the properties of marine clay through laboratory experimentations.
- To evaluate the performance of lime and quarry dust on marine clay sub-grade model flexible pavement system.
- To investigate the suitability and adoptability of Geo-textile as reinforcement and separator in marine clay sub-grade model flexible pavement system.

## II. MATERIALS USED

### *A. Marine Clay*

The typical marine clay was collected at a depth of 0.30m to 1.00m from ground level at Kakinada Sea Ports Limited, Kakinada, A.P, India, and its geotechnical properties were presented in table-1.

TABLE 1 PROPERTIES OF MARINE CLAY

| Sl.No | Property | Value |
|---|---|---|
| 1 | Sand (%) | 10 |
| | Silt (%) | 29 |
| 3 | Clay (%) | 61 |
| 4 | Liquid limit (%) | 78.8 |
| 5 | Plastic limit (%) | 27.16 |
| 6 | Plasticity index (%) | 51.64 |
| 7 | Shrinkage limit (%) | 9.5 |
| 8 | IS classification | CH |
| 9 | Specific gravity | 2.44 |
| 10 | Optimum moisture content (%) | 33.79 |
| 11 | Maximum dry density (g/cc) | 1.364 |
| 12 | Soaked CBR (%) | 0.875 |
| 13 | Differential free swell (%) | 60 |
| 14 | Cohesion (t/m$^2$) at OMC | 11.25 |
| 15 | Angle of internal friction ($^0$) at OMC | 2.00 |

### *B. Lime Ca (OH)$_2$*

Commercial grade lime consisting of 58.67% of Cao and 7.4% Silica was used in the study. The quantity of lime was varied from 0% to 10% by dry weight of soil.

### *C. Quarry Dust*

The quarry dust used was collected from Padmavathi crusher unit situated at Yeleswaram, Andhra Pradesh, India and its physical properties were presented in table -2.

TABLE 2 . PHYSICAL PROPERTIES OF QUARRY DUST

| Sl.No | Property | Value |
|---|---|---|
| 1 | Gravel (%) | 14.6 |
| 2 | Sand (%) | 84.94 |
| 3 | Fines (%) | 0.45 |
| 4 | IS classification | SW |
| 5 | Specific gravity | 2.906 |
| 6 | Optimum moisture content(%) | 12.4 |
| 7 | Maximum dry density g/cc | 2.04 |
| 8 | Soaked CBR (%) | 9.26% |
| 9 | Cohesion (t/m$^2$) | 0.50 |
| 10 | Angle of internal friction ($^0$) | 22.00 |



### *D. Gravel*

Well graded gravel from Surampalem, East Godavari District, A.P, India, was used as sub-base course in all model flexible pavements and its geotechnical properties were as presented in table-3.

TABLE 3. PROPERTIES OF GRAVEL

| Sl. No | Property | Value |
|---|---|---|
| 1 | Specific Gravity | 2.67 |
| 2 | Grain Size Distribution | |
| | Gravel (%) | 60 |
| | Sand (%) | 30 |
| | Silt & Clay (%) | 10 |
| 3 | Compaction Properties | |
| | Maximum Dry Density kN/m$^3$ | 19.92 |
| | OMC (%) | 11.55 |
| 4 | Atterberg's Limits | |
| | Liquid limit (%) | 23 |
| | Plastic limit (%) | 17 |
| | Plasticity Index (%) | 6 |
| 5 | Soaked CBR (Compacted to MDD) % | 15 |

*E. Geo-textile*

Poly Propylene woven Geo-textile- GWF-40-220, manufactured by GARWARE –WALL ROPES LTD., Pune, India, was used as separator between the sub-grade & sub-base course interfaces in this investigation. The tensile strength of woven geo-textile is 60.00kN/m for warp and 45.00kN/m for weft.

*F. Aggregates*

40-20 mm road aggregate, confirming WBM- III standards was used for the preparation of the base course in the investigation of the model flexible pavements.

## III. LABORATORY EXPERIMENTATION

The behaviour of untreated and treated Marine clay with lime and quarry dust was investigated for following experimentation as per IS Codes of practice.

i. The grain size distribution
ii. Index properties –Liquid Limit, Plastic Limit, Shrinkage Limit
iii. Swell Tests- Differential Free swell
iv. Penetration tests- California bearing ratio tests.
v. Bearing tests- Cyclic plate load tests on model flexible pavements.

*A. Laboratory Cyclic Plate Load Tests on Untreated and Treated Marine Clay Sub-grade Model Flexible Pavements Construction Procedure*

These tests were carried out on flexible pavement systems in a circular steel tank of diameter 60cm. The loading was done through a circular metal plate of 10cm diameter laid on the model flexible pavement system. The steel tank was placed on the pedestal of the compression testing machine. Two dial gauges of least count 0.01mm were arranged for obtaining the deformations. A 5-Ton capacity hydraulic jack was placed on the loading as shown in the plate 1.

The steel tank was placed at centre of the loading frame. Marine clay which was used as a sub-grade is pulverized and the material passing through 4.75mm I.S sieve is used for this study. Each layer of 5 cm thick marine clay was compacted to 2 cm thickness at its OMC, to a total compacted thickness of 20cm as a sub-grade. On the prepared marine clay sub-grade, Gravel was used as a sub-base, of thickness 5cm is compacted in two layers. WBM-III was used as base course, to the total thickness of 5cm. The geo-textile was used as reinforcement and anchored to create the tensile force to offer maximum load carrying capacity and uniformly distributed over the treated sub-grade.


Plate 1 Author is conducting cyclic plate load tests on model flexible pavement or foundation soil bed

Cyclic plate load tests were carried out on untreated and treated marine clay sub-grade flexible pavements in separate model tanks (Plate 2) and the woven Geo-textile was used as reinforcement & separator between the treated sub grade and gravel sub base of model flexible pavement under pressures, viz 500,560,630,700 and 1000 $KN/m^2$ as per IRC Codes of practice. The tests were conducted until the failure of the marine clay sub-grade model flexible pavements at OMC and the results were presented in Table 7.

## IV. DISCUSSION ON TEST RESULTS

In the laboratory various tests were conducted by using different percentages of Lime and Quarry Dust (QD) with a view to determine the optimum percentages of lime and quarry dust.

*A. Compaction Properties*

The Compaction tests were conducted to get the optimum moisture content and maximum dry density of different proportions of marine clay with quarry dust and lime using modified proctor compaction apparatus. Table 4 & Fig. 1 present OMC & MDD values of treated and untreated marine clay.

CBR tests were conducted on various mixes of marine clay treated with lime and Quarry dust using OMC obtained from modified proctor compaction tests and the results are presented in the table 4 & Fig. 2.

It was observed that out of the different combinations tried in this investigation, 7.5% lime treatment as individually and with the combination of 25% Quarry Dust with marine clay has effectively improved the laboratory CBR value. However beyond the addition of 7.5 % lime, there is reduction in CBR values of treated Marine clay and the results are presented in table 5and Fig.3 & 4.

TABLE 4 OMC & MDD AND CBR VALUES OF MARINE CLAY TREATED WITH % VARIATION OF LIME

| Mix Proportion | OMC (%) | MDD (gm/cc) | Soaked CBR (%) |
|---|---|---|---|
| 100% MC | 33.792 | 1.364 | 0.896 |
| 96%MC +4%Lime | 22.795 | 1.260 | 3.287 |
| 95%MC +5%Lime | 23.083 | 1.290 | 3.735 |
| 94%MC +6%Lime | 24.274 | 1.307 | 4.482 |
| 93%MC +7%Lime | 24.800 | 1.320 | 4.930 |
| 92.5%MC+ 7.5%Lime | 25.830 | 1.330 | 5.378 |
| 92% MC +8%Lime | 26.836 | 1.320 | 5.079 |
| 91%MC +9%Lime | 27.209 | 1.305 | 4.930 |

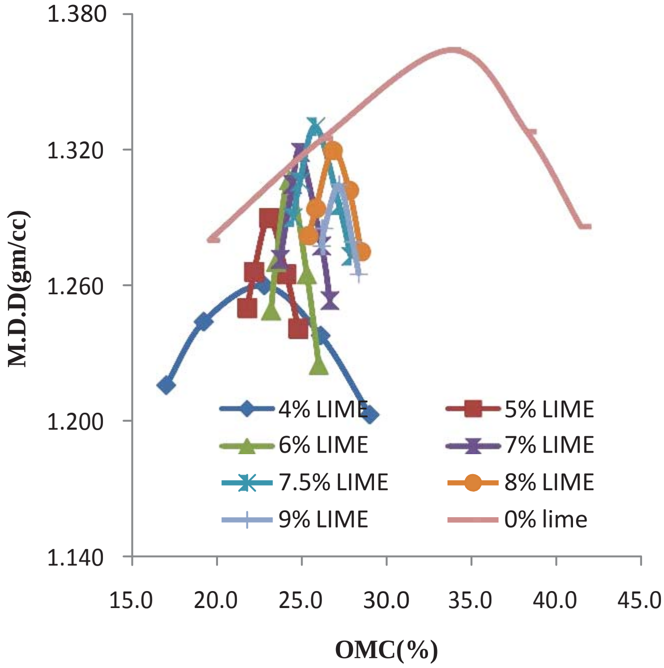


Fig 1 OMC & MDD Values of Marine Clay Treated with % Variation of Lime

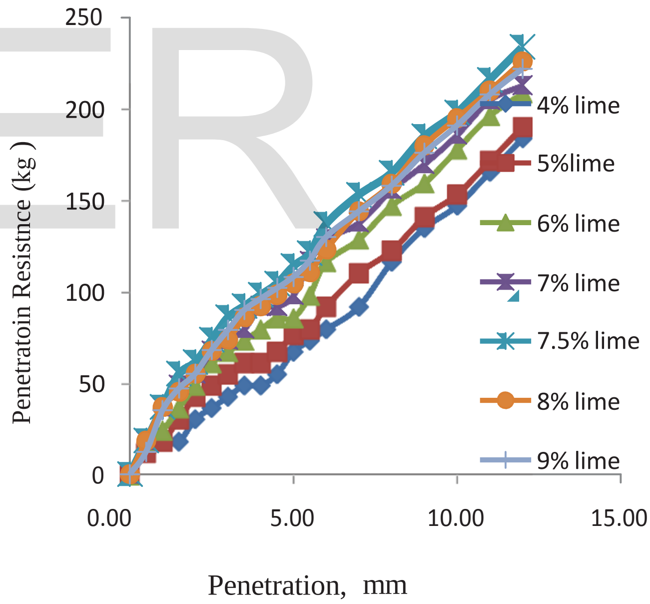


Fig 2 CBR Values of Marine Clay Treated with Different % of Lime

TABLE 5 OMC & MDD AND CBR VALUES OF 7.5% LIME TREATED MARINE CLAY WITH % VARIATION OF QUARRY DUST

| Mix Proportion | OMC (%) | MDD (gm/cc) | Soaked CBR (%) |
|---|---|---|---|
| 85%Lime treated MC+15%QD | 24.598 | 1.544 | 4.482 |
| 80%Lime treated MC +20%QD | 23.916 | 1.582 | 5.677 |
| **75%Lime treated MC +25%QD** | **23.275** | **1.623** | **6.573** |
| 70%Lime treated MC +30%QD | 20.650 | 1.641 | 7.171 |

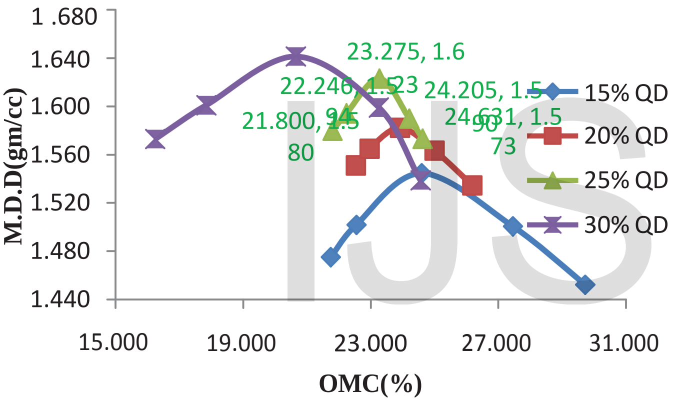


Fig 3 OMC and MDD values of Lime treatedMarine Clay with % variation of QD.rent % of Lime

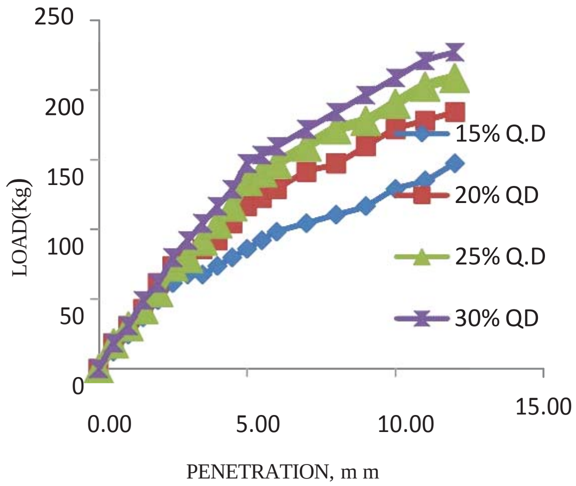


Fig 4 CBR Values of Lime treated Marine Clay with % Variation of QD

*B. Properties of Untreatedand Treated Marine clay*

Table 6 present the properties of treated and treated marine clay (7.5% lime, 7.5% lime+25% Quarry dust).

TABLE 6 PROPERTIES OF UNTREATED AND TREATED MARINE CLAY

| Sl. No | Property | Untreated Marine clay | 7.5% Lime treated Marine clay | 25% Quarry Dust + Lime treated Marine clay |
|---|---|---|---|---|
| 1. | Atterberg's limits<br>Liquid limit (%)<br>Plastic limit (%)<br>Plasticity index (%)<br>Shrinkage limit (%) | 78.8<br>27.16<br>51.64<br>9.50 | 65.20<br>30.50<br>34.70<br>12.00 | 49.50<br>32.65<br>16.85<br>15.50 |
| 2. | Compaction properties<br>Optimum Moisture Content, (%)<br>Maximum Dry Density (gm/cc) | 33.79<br>1.364 | 25.83<br>1.330 | 23.275<br>1.623 |
| 3 | Specific Gravity (G) | 2.44 | 2.503 | 2.669 |
| 4 | IS Classification | CH | CH | CI |
| 5. | C.B.R (%) | 0.895 | 5.378 | 6.574 |
| 6. | Shear Strength Parameters<br>Cohesion (t/m²)<br>Angle of internal friction ($^0$) | 11.25<br>2 | 8.5<br>7 | 5.55<br>11 |

The clay particles were replaced by means of coarser particles of quarry dust and thus the strength characteristics of marine clay have been improved. Further improvement was observed by adding of lime.

*C. Laboratory Cyclic Plate Load Test results on Untreated and Treated Marine Clay Sub-grade Model Flexible Pavements*

The Fig. 5 and table 7 show the laboratory cyclic plate load test result of untreated marine clay sub-grade model flexible pavement with gravel as sub base and WBM-III as base course.

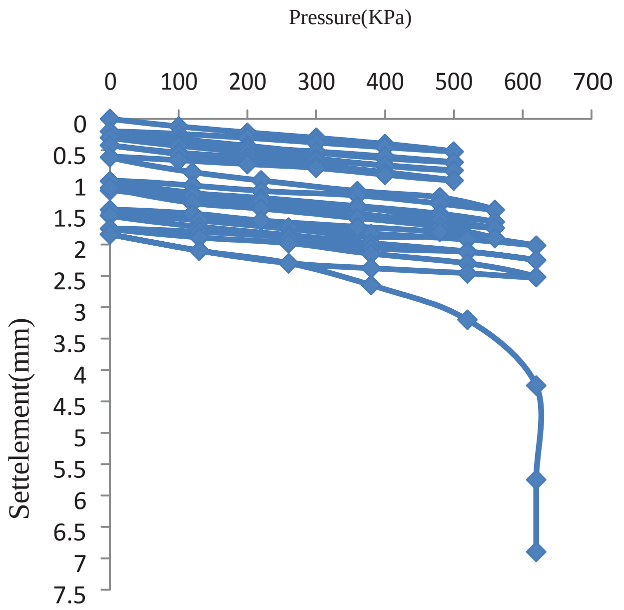


**Fig.5 Laboratory cyclic plate load test for untreatedmarine clay flexible pavement at OMC**

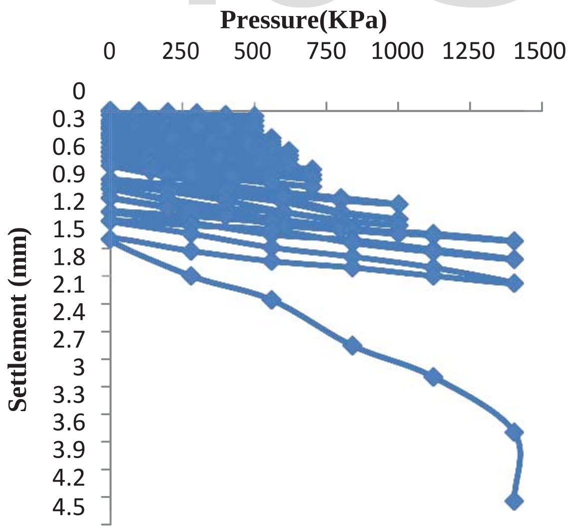


**Fig.6 Laboratory cyclic plate load test on treated marine clay model flexible pavement at OMC**

The Fig.6 and table.7 show the laboratory cyclic plate load test results of 7.5%Lime+25%QuarryDust treated marine clay sub-grade flexible pavement.

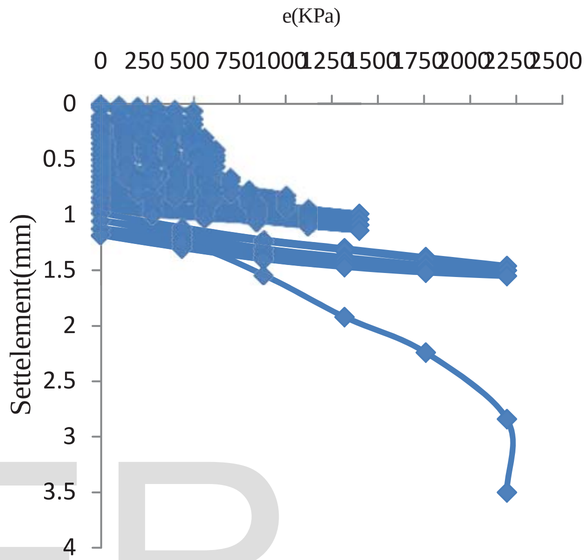


**Fig 7 Laboratory cyclic plate load test on Geo-textile treated marine clay model flexible pavement at OMC**

The Fig. 7 and table 7 show the laboratory cyclic plate load test results of treated marine clay flexible pavement with 7.5%$Ca(OH)_2$+25%QD & Geo-textile as reinforcement.

It was observed from the results that the combination of "7.5%Lime +25% Quarry dust" on marine clay with Geo-textile as reinforcement & separator has exhibited the highest results among the untreated and treated marine clay model flexible pavement and table 7 present laboratory cyclic plate load test results of treated and untreated marine clay sub-grade model flexible pavement at OMC.

TABLE 7 LABORATORY CYCLIC PLATE LOAD TEST RESULTS OF UNTREATED AND TREATED MARINE CLAY MODEL FLEXIBLE PAVEMENT AT OMC.

| Sl. No | Sub grade | Sub base | Base course | Ultimate cyclic Pressure (KN/m$^2$) | Settlements (mm) |
|---|---|---|---|---|---|
| | | | | **OMC** | **OMC** |
| 1 | Untreated marine clay | Gravel | WBM-III | **619.84** | **2.52** |
| 2 | Treated (7.5%Lime +25%QD) marine clay | Gravel | WBM-III | **1399.6** | **1.88** |
| 3 | Treated (7.5%Lime +25%QD) marine clay and Geo-textile provided as reinforcement & separator between sub-grade and sub base | Gravel | WBM-III | **2199.4** | **1.55** |

## CONCLUSIONS

The following conclusions are made based on the laboratory experiments carried out in this investigation.

1. It was observed that **7.5% lime** treatment as individually and with the combination of **25% Quarry Dust** with marine clay has effectively improved the laboratory CBR value.
2. It was observed that the liquid limit values are decreased by 17% and 37% on addition of 7.5% lime and 7.5% lime+25% Quarry dust respectively with respect to the untreated marine clay.
3. It was observed that the Plasticity index values are decreased by 33% and 67% on addition of 7.5% lime and 7.5% lime+25% Quarry dust respectively with respect to the untreated marine clay.
4. It was noticed from the laboratory investigations of the cyclic plate load test results that the load carrying capacity of the treated marine clay model flexible pavement has been increased by 254% at OMC when compared with untreated marine clay sub-grade model flexible pavement.
5. It was noticed from the laboratory results that, the total deformation at ultimate load carrying capacity of the treated marine clay model flexible pavement have been decreased by 40% at OMC when compared with the untreated marine clay sub-grade model flexible pavement.

**DISCUSSION:** As per IRC -37, 2001, the minimum required CBR value is 6% for a soil to be used as sub-grade in flexible pavements. The present study satisfies this requirement by the stabilization of marine clay with an optimum of 7.5% lime and 25% quarry dust.

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