# A Case Study on Determination of Soil Improvement Realization Using CPT

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SYNOPSIS : This paper presents the site reconnaissance survey for the Borçelik Cold Rolling Mill Factory, a joint investment of about 200M US$ by Turkish, French and Italian steel producers in Turkey, related to the identification and geotechnical modeling of erratic subsoil conditions by means of CPT. Soft sensitive clays and loose saturated sands present major problems for the foundations of the factory and the technological units. The seismicity and subsoil conditions indicate a risk of soil liquefaction. Therefore stone columns are utilized to provide soil improvement against liquefaction. They also served the purpose of reducing settlements and increasing bearing capacity under high surcharge loads especially in storage areas. The spacing of stone columns is optimized by utilization of CPT prior to and after implementation of column construction. In addition, large scale zone loading testings by means of a rigid reinforced concrete plate with dimensions of 4m by 4m were performed prior to and after the application of stone columns to observe the settlement and load bearing capacity of the subsoil and to assess the degree of improvement with the installation of stone columns. In this paper critical evaluations of the stone column improvement are based on the interpretation of CPT's and large scale zone loading tests.

## 1. INTRODUCTION

Borçelik Cold Steel Rolling Mill is constructed by ASKON Construction Corp. The foundation design, design of soil improvement and consulting during foundation construction of factory buildings and technological units are carried out by ZETAŞ Earth Technology Corp. Seismic and geotechnical investigations of the site have shown that the zones with liquefaction potential and subsoil with settlement problem under large surcharge are present in the factory area (Ansal, 1990). The soil layers below the natural ground level down to 12.0 m depths are designed to be improved with stone columns using the results of comprehensive CPT testing. Total of ninety CPT tests covering about 2500 m length are performed for identification of soil conditions and for assessment of the results of the soil improvement. In certain areas where the bearing strata could be reached at reasonable depths stone columns up to bearing strata are constructed to eliminate the bearing capacity and settlement problems in storage areas with large surcharge loads. However, in some areas stone columns were terminated without reaching the bearing strata. The factory building and foundations of the technological units are founded on 50-60 cm diameter vibrex and 80-120 cm bored piles due to large structural and seismic loads and weak/compressible subsoil conditions. The general layout of the site and areas with stone column application is shown in Figure 1.

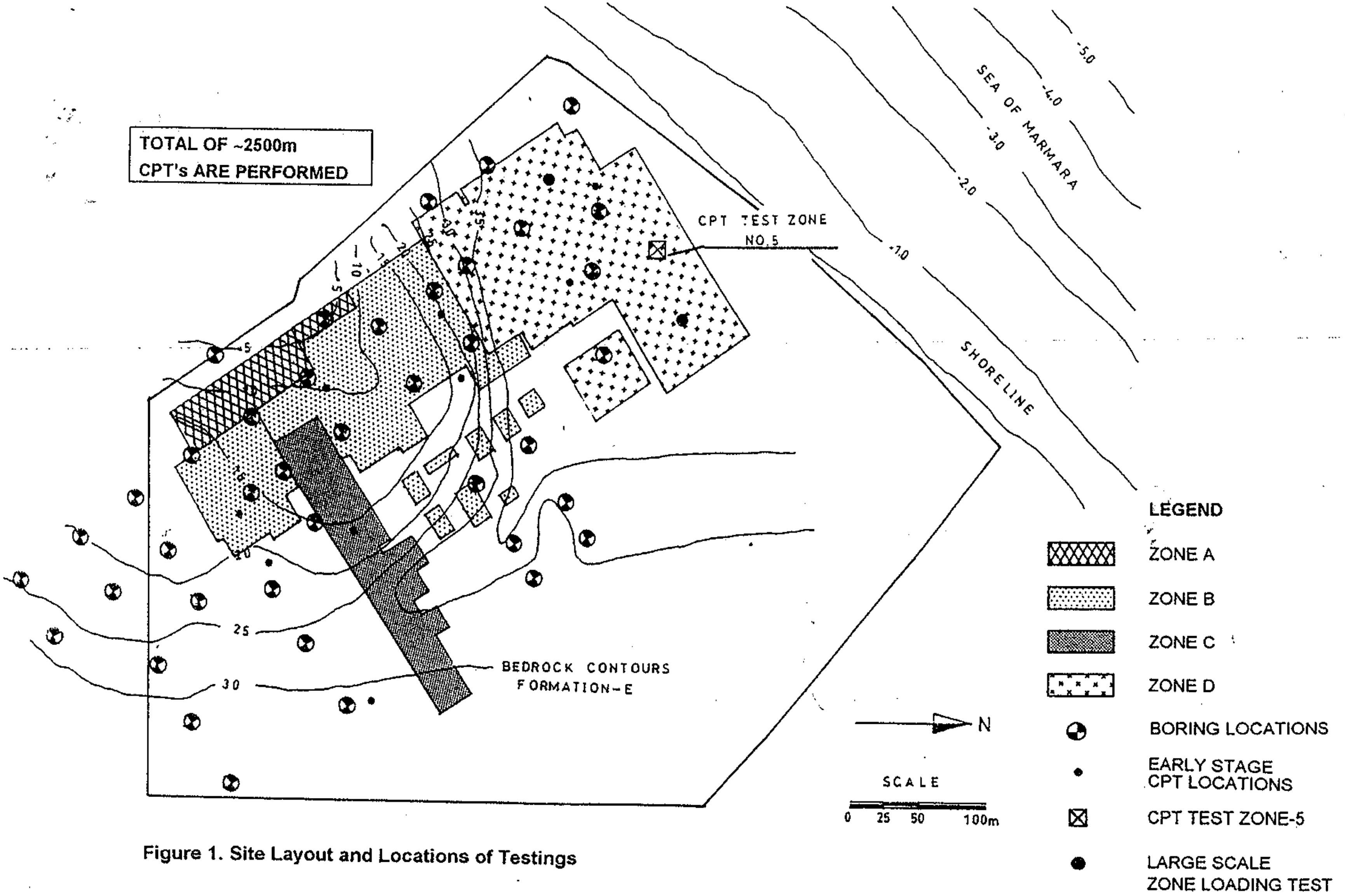

Figure 1. Site Layout and Locations of Testings

## 2. SUBSOIL CONDITIONS

The subsoil conditions at the site are determined by means of soil borings and CPT testing. Basically five different soil/rock units are identified for realization of geotechnical profile.

Formation A : Sandy silty overconsolidated clay is present to 4.0m depth, the thickness extends up to 6.0m-7.0m in the north sections

Formation B : Loose-medium dense sand, contains occasional gravel lenses, $D_r = 40\text{-}60\%$

Formation C : Normally consolidated clays, locally sensitive and having maximum thickness of 10.0m

Formation D : Overconsolidated clays, gravely in some regions, stiff to very stiff

Formation E : Bedrock, extensively weathered when exposed to surface

Four different zones are differentiated in foundation evaluations and design in the factory area taking the distribution of the soil layers introduced above into consideration. The location of the zones described above and the depth contours of the bedrock from sea level with other pertinent information are also shown in Figure 1.

Zone A : Formation E (bedrock) is very shallow or exposed at ground surface. Generally represents the southern portion of the west side of the factory.

Zone B : Formation E (bedrock) is in 10.0m or larger depth from ground surface, southern and middle portion of the site is within Zone B. In this zone formations A and B take place just above the formation E. Formations C and D are locally observed as intermediate layers.

Zone C : Overconsolidated formation D exits above formation E (bedrock). Formation C is thicker than other regions and generally represents the southwestern portion of the site.

Zone D : Soil stratification is like zone C but bedrock is deeper and in most of the region no bedrock is encountered. It represents the northern portion of the site.

## 3. SOIL IMPROVEMENT DESIGN

For the purpose of improving the subsoil conditions against liquefaction potential (Ansal, 1990) and to increase the bearing capacity at storage areas, stone columns are implemented. As a trial basis, in Zone C, 0.50m diameter stone columns with 2.0m spacing up to depth of formation D, in Zone D, 0.50m diameter stone columns with 1.5m spacing extending to 12.0m depths from ground level are implemented (ZETAŞ 1991a).

### 3.1. Assessment of soil improvement

Cone Penetration Testings and Zone Loading Tests have been performed to predict the degree of the soil improvement and to compare with final design requirements.

The area of stone column application is divided into zones each having 200 to 400 stone columns and six CPT's in total are conducted in each zone, two of them being before, and four of them after the stone column application with the configuration shown in Figure 2. CPT's are performed with 200kN capacity electrical piezocone and mechanical cone.

Four zone loading tests have been performed in two different zones in the plant area, two of them in zones without stone columns, and two of them in zones with stone columns. The explanations and examples for these tests are given below.

### 3.2. CPT tip resistance requirements for soil improvement

The in situ relative density estimated in the range of 40-60% is aimed to be improved to at least 75% with the application of stone columns in zones of saturated sands against the soil liquefaction.

The limiting CPT tip resistance curve with depth to satisfy this requirement is estimated by various procedures (Robertson and Campanella, 1988, ZETAŞ, 1991b) and represented in Figure 3.

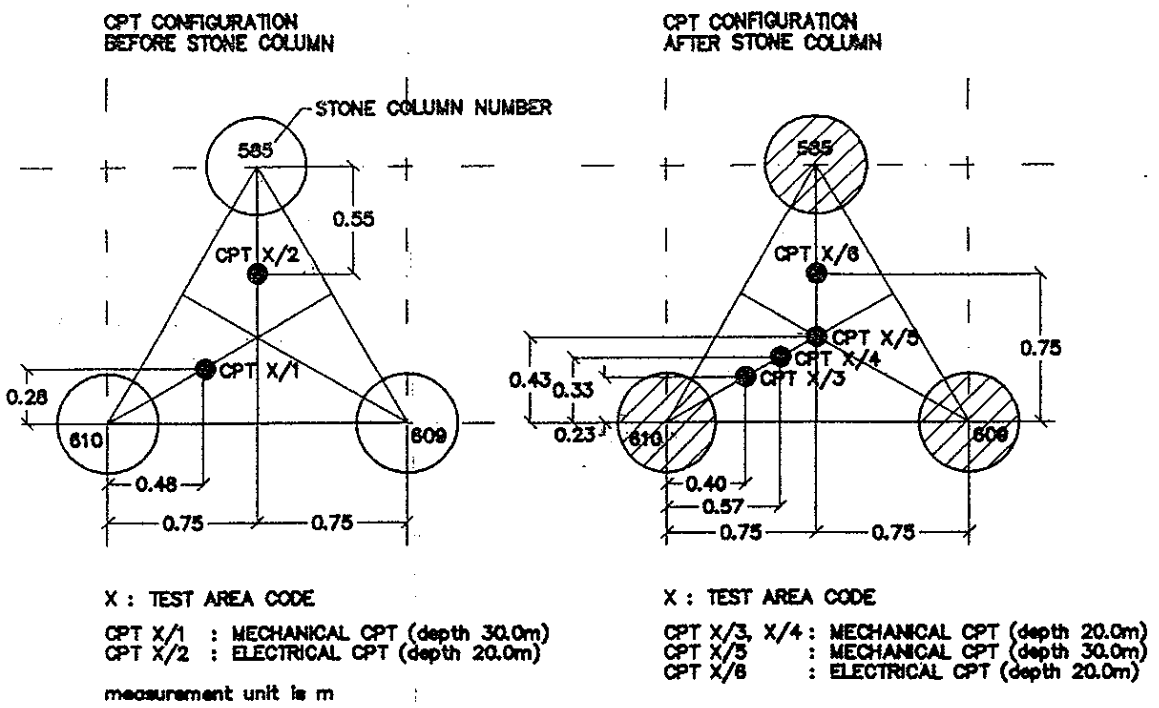

Figure 2. CPT Configuration for the Assesment of Soil Improvement

## 4. CPT TESTS AND EVALUATIONS IN A TEST ZONE

The location of the test zone 5 for the assessment of soil improvement is shown in Figure 1. Two CPT's before and four after the construction of stone columns are performed in this testing zone with the configuration seen in Figure 2 as described earlier for the purpose of assessment. The comparison of the penetration tests CPT5/1 (before improvement) and CPT5/5 (after improvement) are presented in Figure 3.

The typical tip resistance, skin resistance and friction ratio variations with depth for CPT5-5 are also presented in Figure 3. The evaluations related to these graphs are as follows (ZETAŞ, 1991b):

- Below the 2.0m thick working platform at 2.0m-3.0m and 5.0m-8.0m depths no important difference is observed at clayey layers with friction ratio FR > 3% for CPT tip resistance values before and after improvement. In other words application of stone columns does not improve soil strength in clay layers with FR > 3%. It has been observed in other regions that CPT tip resistance has decreased in sensitive clay layers with stone column application.
- CPT tip resistances measured after stone column application are in average 73% higher than the CPT tip resistance values before improvement in sand-silt layers with FR < 3%, present in 3.0m-5.0m and 8.0-15.0m depths.
- Trial spacings of stone columns were found to be effective to satisfy the design requirement of $D_r$ min 75% by means of measured CPT tip resistance curve after the improvement.
- It has been observed that there is an increase in CPT tip resistance in tests performed after a time interval compared to tests performed immediately after stone column application.

The first three observations are very common and are as expected. On the other hand observation four is thought to result from dissipation of pore water pressure in time. In order to determine this, piezocone is used in some tests in the measurement of pore water pressure. It has been observed that CPT tip resistance increases in time as measured pore pressure decreases to its hydrostatic value. As a result it has been determined that it would be most appropriate to measure the final soil improvement by CPT's performed after a time interval to allow for the dissipation of excess pore water generated with construction of stone columns.

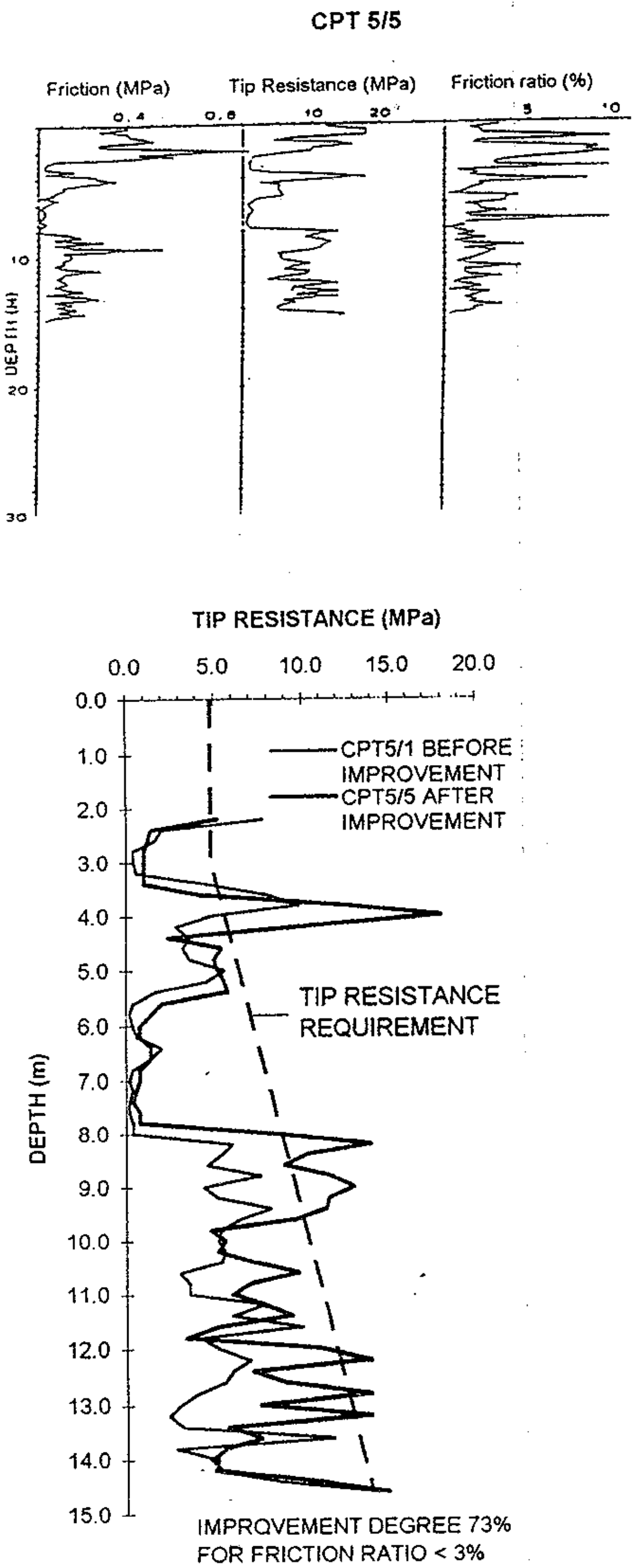

Figure 3. Comparison of CPT Tests in Zone 5

## 5. ZONE LOADING TESTS

Stock areas with 20, 50, 100 and 200 kN/m$^2$ surcharge loads are present within the Cold Steel Rolling Mill Factory area. Large dimension loading tests have been conducted especially in zones with high surcharge loads to investigate the soil bearing capacity and elastic/plastic settlements under such loads. Settlements have been measured in zone loading tests under loads up to 430 tons (~270 kN/m$^2$ base pressure) applied with steel rolls symmetrically placed on a reinforced concrete rigid plate with dimensions of 4.0m by 4.0m. Load settlement graphs are given in Figure 4, for two zone loading tests performed at one location before and after stone column application. The evaluations for the two performed zone loading tests are given below (ZETAŞ, 1992).

- Both zone loading tests show similar load-settlement behavior up to ~300 tons, 190 kN/m$^2$ base pressure. But after base pressure of 190 kN/m$^2$, settlements show a sudden increase in the zone without improvement while such an increase is not observed at the zone with stone column application.
- The increase in settlement after 190 kN/m$^2$ indicates plastic deformations at the subsoil in the zone without settlement columns and finally exhibit a general bearing capacity failure in the subsoil above this stress level.
- In the view of the above evaluations it has been determined that the storage areas up to 100 kN/m$^2$ surcharge is not to be improved for settlement and bearing capacity. Factor of safety for bearing capacity in the zone is in the order of 2.0 and it is satisfactory for support of steel rolls. However in zones with surcharge above 100 kN/m$^2$, such as surcharge of load 200 kN/m$^2$ if no soil improvement is implemented bearing capacity failure will likely to occur. Therefore stone columns are constructed at such zones with high surcharge as part of the soil improvement program.
- The results of zone loading tests have later been utilized in soil modeling and determination

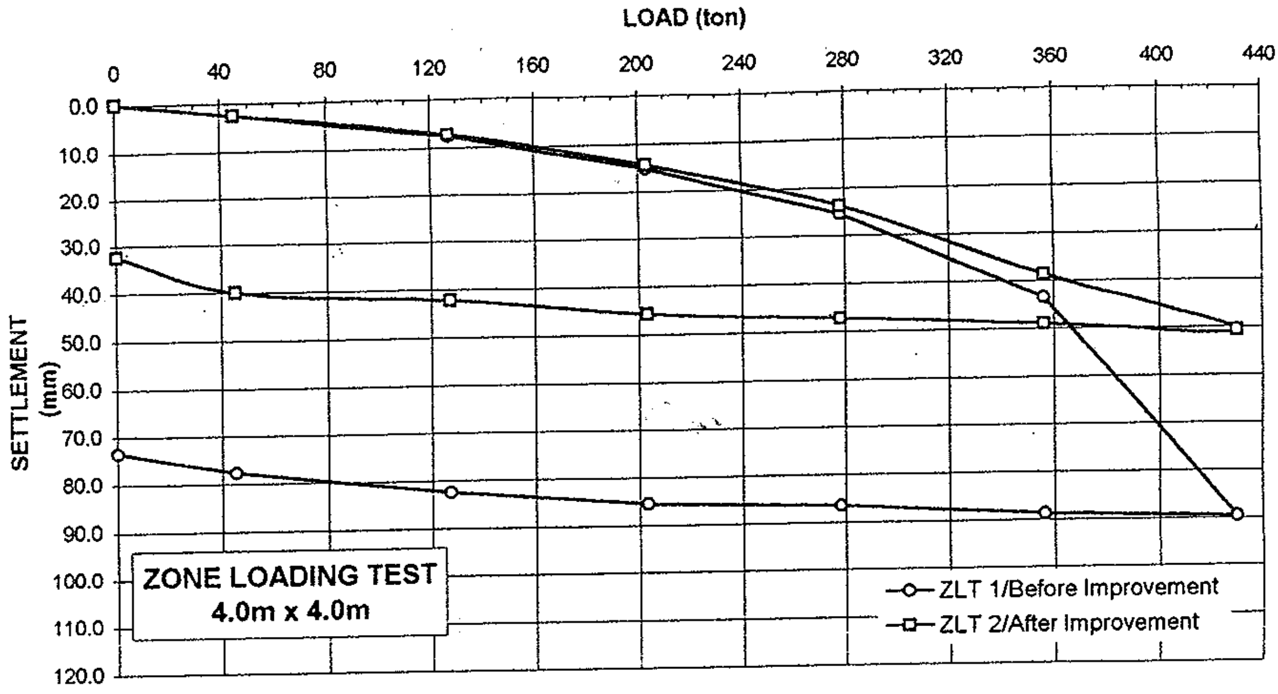

**Figure 4. Zone Loading Test for Assessment of Soil Improvement**

of allowable base pressure for shallow footings of office buildings located at similar subsoil conditions at the site.

## 6. SUMMARY AND CONCLUSIONS

Application of stone columns for soil improvement in Borçelik Gemlik Cold Steel Rolling Mill are outlined in this paper. The application of CPT testings, piezocone tests and large scale zone loading tests with 4.0m by 4.0m dimensions are realized for the assessment of soil improvement. It has been shown with examples that soils with large settlement and bearing capacity problems can also be treated with stone columns. In addition to improve their strength against soil liquefaction, the procedure for the measurement of soil improvement in different types of soils is explained and critical evaluations are made based on the comparison of CPT and Zone Loading Tests. In this case study CPT testing once more proved to be very beneficial with a site of most complex conditions having very poor and nonhomogeneous subsoil, high groundwater table, high seismicity and a factory building and technological units with high dead and surcharge loads and very strict settlement tolerances.

## 7. REFERENCES

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