# Correlation of SPT to strength and modulus of elasticity of cohesive soils

## Corrélation entre le SPT, la résistance et le module d'élasticité des sols cohérents

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SYNOPSIS: The results of a large number of geotechnical projects (over 100) carried out by the authors have been computer coded and analyzed. From which about 60 projects corresponding to clayey and silty clay soils (CL and CL-ML) have been selected and used to study the correlation of standard penetration tests to the strength and elastic modulus of soils. It is found that for clayey and silty-clay soils encountered, both strength and elastic modulus correlate well with SPT number. Accordingly the standard penetration tests yield valuable results for predicting strength and elastic modulus and the pessimistic view of applicability of SPT to cohesive soils is not warranted. The correlation is better for cohesive soils with SPT number less than 25. Formulas relating strength and elastic modulus to SPT number are given and compared to those reported in the literature. Corresponding graphs are also shown.

## 1 INTRODUCTION

From over 100 soil investigation projects performed in different zones in Iran, about 60 projects were carried out in the areas of clayey or silty clay soils. The results of these projects have been computer coded and analyzed to study the correlation of Standard Penetration Tests to strength and elastic modulus of cohesive soils.

## 2 METHOD OF SOIL INVESTIGATION

In most of the projects the Standard Penetration Tests were carried out after machine drilling to the required depths. In each well the tests were performed in various depths. The cathead and rope method and one and half turn of rope was used. The standard safety hammer and split spoon sampler of North American type with 3 mm clearance were also used. The first 15 cm of penteration was disregarded and the number of blows for the next 30 cm penetration was recorded as $N_{30}$ for each test. The pipe corresponded to "$A_w$" drill rods according to the proposed European Reference Standards. The tests were carried out in depth intervals mostly 1 to 1.5 meters. In any depth water level in the drill hole was stabilized with ground water level if present. The weight of the hammer was 140 lb and the fall of it 2½ ft (ASTM 1954, 1958). In some of the projects hand dug wells were also used and the falling head Standard Penetration Tests were carried out with tripods. The mean depth of machine drilling was about 10 meters.

Apart from SPT, the tests carried out in various consulting and research projects the results of which have been used in this paper were as follows:

(1) Tests for classifying soils including sieve analysis, hydrometer analysis, and Atterberg's limits.

(2) Tests on natural condition of the soil such as natural water content determination, in-place density, dry density and specific gravity of the soils.

(3) Tests on strength of soils including:

(a) Field unconfined compression strength ($q_{uf}$) determination with pencil type recorder on samples taken by SPT spoon samplers at various depths.(From the graphs obtained, corresponding field elastic modulus $E_f$ for the samples were calculated ).

(b) At selected depths, laboratory unconfined compression tests on undisturbed samples taken by thin tubes allowing to determine laboratory unconfined strength $q_{ul}$ and corresponding elastic modulus $E_l$.

(c) Laboratory unconfined strength and corresponding elastic modulus on some remolded samples.

(4) Tests on consolidation characteristics when appropriate.

(5) Miscellaneous other tests when necessary.

The point about the tests performed in almost all projects is that they were carried out by the same field crew (6 per projects) and laboratory crew (4 per project).

## 3 METHOD OF DATA PROCESSING

The soil logs information were computer coded using Data Base (DBASE II) software. The structure selected contained 22 columns and 2307 rows showing all data. The sorted and selected data were analyzed by computer program which could analyze and plot the scatter diagrams for any pair of selected variables.

## 4 METHOD OF ANALYSIS

Due to abundance of projects on clayey and silty-clay soils and prevailing pessimistic view of applicability of SPT to cohesive soils, the projects selected for present paper were all on the soils classified as "CL" or "CL-ML" types. The parameters selected for analysis were liquid limit and plasticity index for classification, SPT number $N_{30}$, field and laboratory unconfined compression strengths ($q_{uf}$ and $q_{ul}$ repectively) and also corresponding values of modulus of elasticity ($E_f$ and $E_l$ repectively).

Diagrams showing the relation of SPT number to selected parameters were prepared for two ranges of SPT number, full range presenting all cases and low range showing cases with $N_{30}$ less than 25. Better correlations were shown in low range diagrams from which 5 diagrams were selected relating $N_{30}$ to $q_{uf}$, $q_{ul}$, $E_f$, $E_l$ and $q_{uf}$ to $E_f$. They are presented in Figures 1 to 5. On each figure a linear regression line relating variables, lines enclosing 90 per cent of data points and number of data points are shown.

## 5 DISCUSSION

From the analysis and graphs it was seen that:

(1) All test results correlate better for $N_{30} < 25$ than the full range.

(2) SPT has not shown good correlation with either depth or dry density in our investigations.

(3) The unconfined strength and modulus of elasticity are correlated to SPT number, correlation being better for field test (Figures 1 to 4).

(4) The field modulus of elasticity $E_f$ correlates well with field unconfined strength $q_{uf}$ (Figure 5) and the equation relating the two variables compares well with the results shown in Figures 1 & 3. The same is true for laboratory results.

(5) From Figures 1 to 4 it is seen that the field and laboratory (undisturbed) results are not significantly different in magnitude. This shows that probably thin tube sampling by impact is not as undisturbed as conceived, and if careful method of sampling by thin tube (like jacking or continuous sampling) is not used, the field and laboratory results of modulus of elasticity and unconfined strength are of the same reliability.

(6) Thus using the results shown on the figures, empirical formulae for design purposes of strength and modulus of elasticity can be recommended. Our recommendation for low range of SPT ($N_{30} < 25$) is as follows:

$$q_u(\text{KPa}) = 15 \times N_{30} \qquad (N_{30} < 25) \qquad (1)$$

$$E(\text{MPa}) = 0.17 \times N_{30} \qquad (N_{30} < 25) \qquad (2)$$

The strength formula [Eq. (1)] campares favorably with Terzaghi and Peck (1967) and Stroud (1974) values.

The results proposed by Stroud (1974) and Stroud and Butler (1975) for the coefficient relating $N_{30}$ to E are both higher than our recommended value of 0.17 MPa [Eq. (2)]. This is because we have chosen SPT numbers less than 25 while the values of modulus of elasticity for full range of SPT numbers show greater quantities.

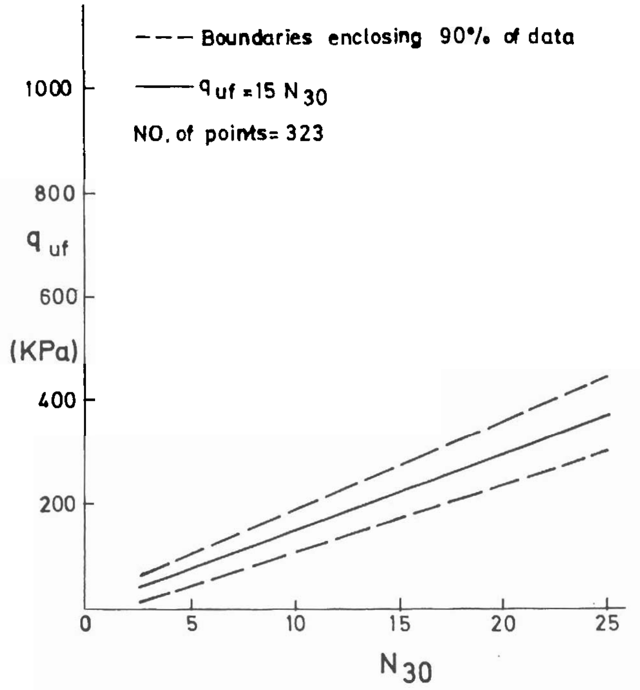


Figure 1. Field unconfined strength versus SPT number.

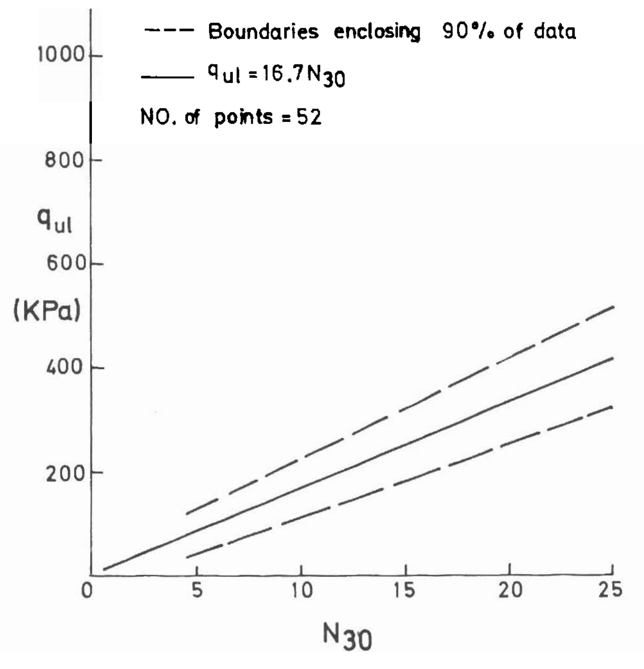


Figure 2. Laboratory unconfined strength versus SPT number.

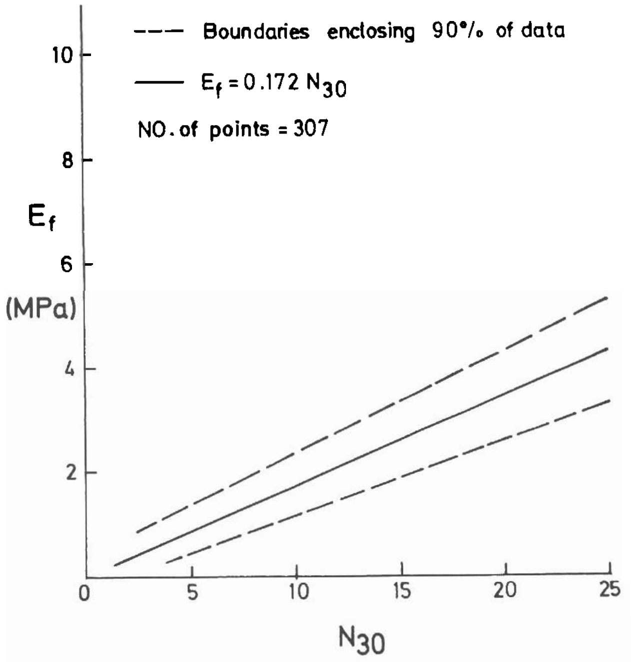


Figure 3. Field modulus of elasticity versus SPT number.

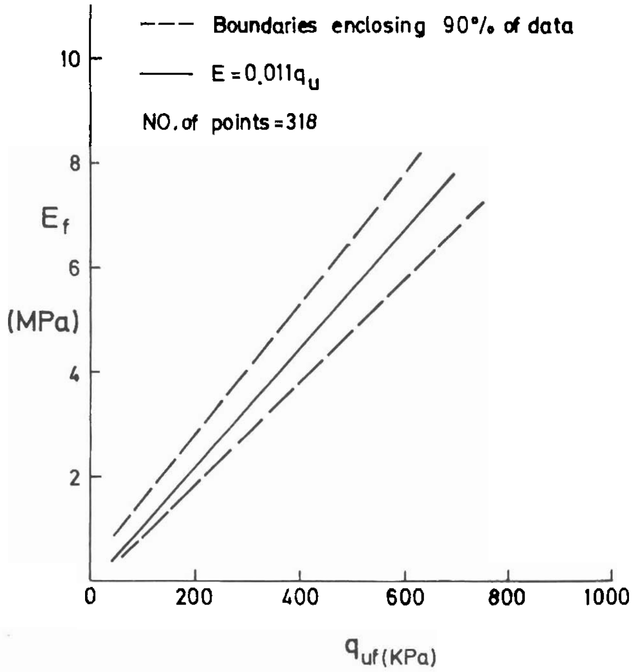


Figure 5. Field modulus of elasticity versus field unconfined strength.

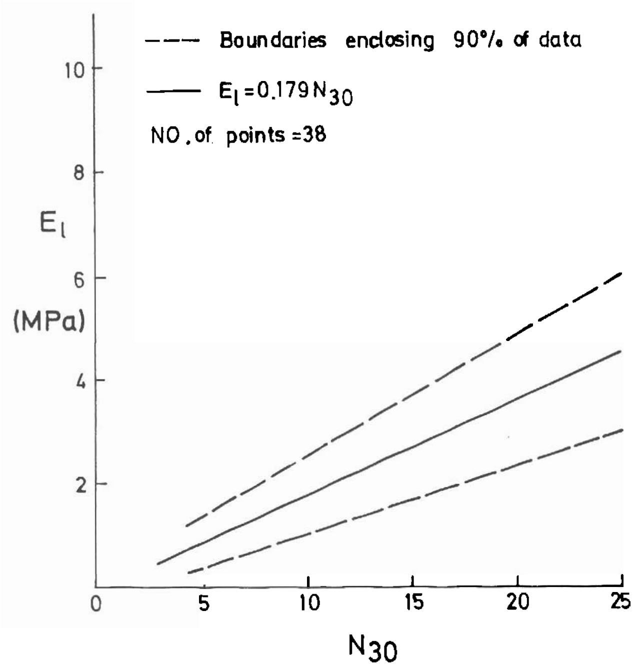


Figure 4. Laboratory modulus of elasticity versus SPT number.

6 CONCLUSIONS

Based on the analysis and the results presented above the following conclusions can be made:

(1) For "CL" and CL-ML" soils tested, the modulus of elasticity and unconfined strength of the soils correlate well with Standard Pentera-tion Test number, $N_{30}$, correlation being better for $N_{30} < 25$.

(2) By our results, the predicted unconfined strengths

$$q_u(\text{KPa}) = 15\ N_{30} \quad (N_{30} < 25)$$

are slightly higher, and the predicted values of modulus of elasticity

$$E(\text{MPa}) = (0.17)N_{30} \quad (N_{30} < 25)$$

are generally lower than values reported in the literature.

(3) For clayey and silty clay soils the Standard Penetration Tests yield valuable results for predicting modulus of elasticity and strength and the general pessimistic view of applicability of SPT to cohesive soils is not warranted.

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