Prediction of Angle of Internal Friction Based on SPT N Values

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Abstract. The present study focused to estimate the angle of internal friction (ϕ) of cohesionless soil and cohesive (c-ϕ) soil considering field standard penetration test (SPT) data. Based on the SPT data an empirical correlation has been established between standard penetration number N and internal friction angle to predict the friction angle of soils. All the field standard penetration test data are collected from six different places of East India. Regression analyses were performed using the SPT data collected from 40 different boreholes containing 330 data points. The SPT-N values obtained from different sites are observed to vary between 4 and 70. The in-situ bulk density of undisturbed samples recovered through pitcher sampler is in the range of 17.90 kN/m^3-18.90 kN/m^3. In situ water content and fines content observed plays an important role in case of c-ϕ soil, hence plasticity index (PI) and fines content (p) are also included in model equation in case of c-ϕ soil. The predicted results obtained from developed model equation appears to be in good agreement with existing equations in various literature. By using regression analysis, the empirical equations are developed. The most important thing is to find out the friction angle of c-ϕ soil which is useful for the fields. The estimated equations are verified by validating the correlations with experimental values obtained from field which in turn can be used for geotechnical engineering design problems. Thus, the study provides a simplified and faster analysis of angle of internal friction for different types of soils.

Keywords: Friction angle, Standard penetration test, c-ϕ soil, Empirical correlation.

1 Introduction

Standard penetration test (SPT) is widely used in-situ test for measuring the geotechnical properties of soil, bearing capacity of soil and shear strength of soil. For the construction site, standard penetration test is required to get the undisturbed soil sample. The penetration resistance depends on grain size of soil. After determining the SPT blow count (N), the various parameters can be measured by correlating the blow counts.

Correlation is necessary for saving the equipment cost and time for all the tests to be done. In some literatures, there are existing correlations with SPT N value after using the corrections in SPT N value [1, 19]. Correlation is done with the relative density for the cohesionless soils [3 to 12]. Similarly, there is relation between the angle of friction of soil and SPT N value for cohesionless soil [12 to 17]. By using the SPT N value, shear strength and unconfined compressive strength of cohesive soil [6 to 18] can be evaluated from the regression analysis. Regression analysis is curve fitting process in which the values of parameters that cause function to be best fit the observed data. There is correlation between the angle of friction and SPT N of soil for cohesionless soils. But there is no correlation for the cohesive frictional soil. The present study focused on empirical equations for the cohesionless soil and cohesive frictional soil by using the regression analysis. The empirical equations are validated by the equations given by the existing literatures. The variation of the predicted values and measured values of parameters falls within ±10%.

2 Methodology

2.1 Linear regression analysis

In the present study, linear regression analysis is used as predictive model to an observed data set for predicting, forecasting and error reduction. In this study, linear regression model is used for correlation between angle of internal friction and SPT (N) value by involving the parameters plasticity index and percentage finer. To correlate the unconfined compressive strength, SPT (N) value and plasticity index, linear equation is derived. Linear regression model gives simple equation with greater accuracy. It can be used in field condition because the results are validated with experimental value of the response variable. Some results are validated with previously existing equations given by researchers.

2.2 Non-Linear regression analysis

In order to predict the simple equation non-linear variation, NLREG is used in the present study. For cohesionless soils, NLREG is used as power function and polynomial function to estimate the equation between angle of friction and SPT (N) for different type of soils i.e. sandy and silty sand soils. In this analysis, coefficient of variation is above 0.80. It is acceptable if co-efficient of variation is greater than 0.8. Polynomial function is also known as multiple linear function. For c-ϕ soil, NLREG is used as power variation, multiple linear function and polynomial function. For c-ϕ soil, unconfined compressive strength is estimated for unconsolidated undrained condition where confining pressure is zero and angle of friction is also zero. Shear strength of c-ϕ soil is estimated by Mohr Coulomb theory which depends on cohesion and angle of friction of soil. Shear strength of clay is correlated with SPT N value by NLREG analysis which gives higher accuracy with simple correlations.

3 Results and Analysis

3.1 Cohesionless soil

Sandy soil. Here the correlation is established between angle of friction of soil and SPT (N) value for poorly graded sand where fines content is varying from 0 to 15% of low plastic. SPT is widely used method for measuring the geotechnical properties. The number of borehole used for collecting SPT (N) value is sixty and depth of each borehole is 30m to 100m. The effective grain size of sand is ranges from 0.075mm to 0.42mm. Ground water table is at depth of 6.5m to 8.6m of borehole. SPT (N) value ranges from 4 to 100. NLREG analysis is carried out to find simple relation between angle of friction and SPT (N) value with a co-efficient of variation 0.802. The predicted values are compared with experimental values to estimate the variation which comes within ±10%. Then the predicted equation is validated with the equation given by Peck et al. It shows good similarity with the equation given by wolff(1989).

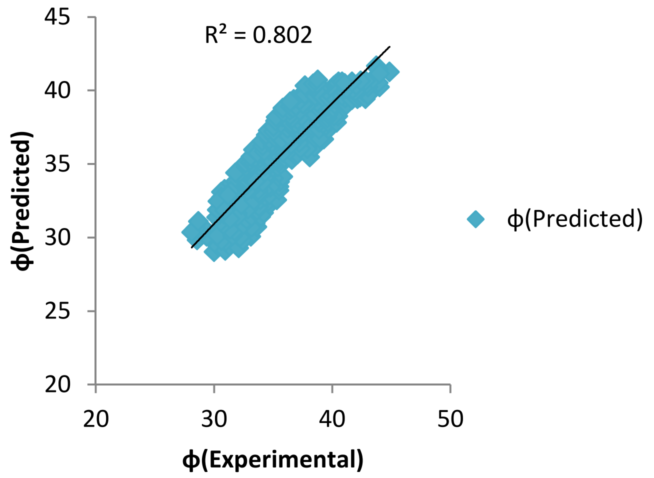

Fig.1. Variation between Predicted and experimental angle of friction

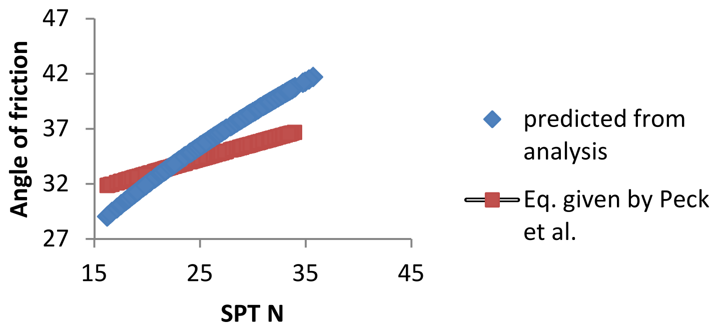

Fig.2. Comparison between predicted angle of friction and given by Wolff (1989)

From the NLREG analysis, the predicted equation is

$$\emptyset = 8.103 \times N^{0.458}$$

In the current study, the corrections are not made for field SPT N value. It is directly used for prediction the equations. So it gives difference. It is for cohesionless soils.

3.2 C-ϕ soil

A geotechnical investigation is carried out on ash pond of NTPC at Kahalgaon. Bihar. Laboratory tests are carried out at ash silo, ESP unit area and chimney area. SPT is conducted with split spoon sampler to determine the properties of soil. Tests are done at sites are unconfined compressive strength, direct shear test, triaxial shear test for all conditions, consolidation test, standard proctor compaction test and chemical test. Total 22 number of boreholes are sunk in different zones by using shell and auger boring. Undisturbed soil samples are collected from the borehole and disturbed soil samples are collected from the split spoon sampler. The soil varies from medium stiff to very stiff silty clay with traces of kanker in ash silo zone. Dense to very dense yellowish grey silty sand soil is observed in ESP unit area in which SPT N ranges 51 to 56.

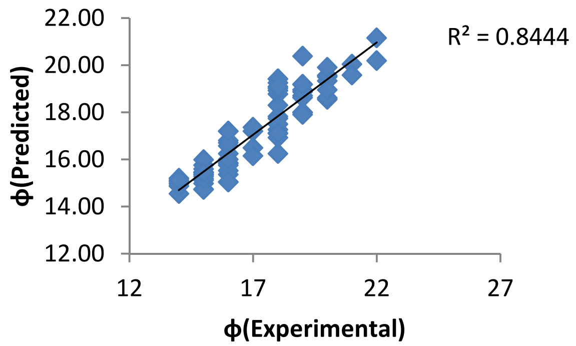

Fig.3. Variation between Predicted and experimental angle of friction of silty-clay for consolidated undrained case

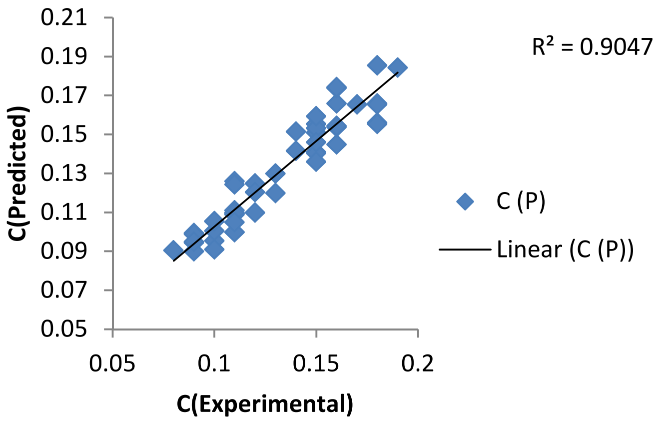

Fig.4. Variation between Predicted and experimental cohesion for over consolidated undrained case

The predicted equation for shear strength parameters

$$c = 0.00054 \times I_p + 0.005 \times N + 0.09$$

$$\emptyset = 0.24 \times N + 0.0061 \times I_p - 0.313 \times p + 43.42$$

The above predicted equations are valid for consolidated soil not for all soils.

4 Conclusions

The present study focuses on the correlation of angle of friction, cohesion, shear strength and unconfined compressive strength with SPT (N) value for various types of soil.

1. For cohesionless soil, the present study has been considered sandy deposits. For sand deposit with fines content 0 to 10%, the SPT data from sixty boreholes of depth 30m to 100m are taken to analyze the correlation of angle of internal friction by regression analysis using NLREG. The SPT (N) value ranges from 4 to 100. The predicted results of angle of internal friction from the correlation shows good matching with the equation given by Wolff (1989). The predicted equation can be used in fields as it gives 88% of efficiency. The predicted equation can be used in the soil where fines content varies 0 to 10%.

2. The present study focuses on shear strength parameters of cohesive frictional soil. More than 100 soil samples are used to perform analysis on silty clay soil with 10 to 15% sand and traces of kanker. This equation is applicable to mostly silty clay soil. Plasticity index and percentage finer is introduced to the predicted equation to improve the accuracy.

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