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Correlation of Cohesion Based on SPT-N Values and Finding Liquid Limit Based on Plasticity Index in United Kingdom: Case Study

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Abstract: This study is an attempt to evaluate the cohesion values based on number of blows of Standard Penetration Test (SPT) in the clay of the United Kingdom. To develop equation, twenty one samples were collected and The SPT-N values were between 6 and 54. Also, the cohesion values varied between 5 and 265 kPa. The correlation analysis was conducted for cohesion and number of blows in SPT (SPT-N). The proposed equation was validated using 5 independent values and the estimated values of cohesion based on SPT-N fall in the range of of actual values. Furthermore, real applications practice include bearing capacity and elastic settlement were used to validate the proposed equation using multiple way for calculation by previous equation and PLAXIS Model and they found that the proposed equation is applicable for using in geotechnical application.

INTRODUCTION

The soil strength is an important matter for all designer in geotechnical field. The soil strength is mainly based on cohesion (c), friction angle and modulus of elasticity. Also, the Standard Penetration Test (SPT) is widely used in evaluation of soil strength. Many researchers in the past have found relationship between SPT and cohesion in clay soil. These include Sowers[1], Hatanaka and Uchida[2], Terzaghi and Peck[3], Hara *et al*.[4], Stroud[5], Schmertmann[6], McCarthy[7], Nixon[8], Ajayi and Balogun[9], Kulhawy and Mayne[10], Murthy[11], Serajuddin and Chowdhury[12], Bowles[13], Sivrikaya and Togrol[14], Sivrikaya and Togrol[15], Fattah *et al*.[16], Brown and Hettiarachchi[17], Kalantary *et al*.[18], Hettiarachchi and Brown[19], Sivrikaya[20], Nassaji and Kalantari[21], Bashar[22], Mahmoud[23], Shaha[24], McCarthy[25], Alam *et al*.[26], Kumar *et al*.[27], Singh *et al*.[28], Yusof and Zabidi[29] and Puri *et al*.[30].

Hara *et al*.[4] evaluated the relationship between undrained shear strength and SPT. They collected data from 25 sites in Japan. The proposed equation is . They compared their equation with previous data from Mikasa[31] and Yanase[32] studies and the proposed equation gave closed values for actual data from these studies.

Stroud[5] collected 120 samples from 13 sites in London in the UK. He correlated between undrained shear strength and SPT. The proposed equation is.

Sivrikaya and Togrol[15] collected 1190 samples from private companies, universities and one public institution in different locations in Turkey. They correlated between unconfined compressive strength and SPT (field, correction) according to a different type of soil and different type of tests. The proposed equations are for CH for CL for clay and for fine-grained soils where c in all previous equations is in kPa. They compared their proposed equation with Sivrikaya and Togrol[14], Stroud[5] and Sowers[33] equations. For CH type, Sivrikaya and

Togrol[14] closed enough to their equation. Sivrikaya and Togrol[14] and Stroud[5] closed enough to their equations. For clay, their equation is underestimation for Nixon[8]. For fine-grained soil, Sivrikaya and Togrol[14] and Terzaghi and Peck[3] closed enough to their equations.

Edil *et al*.[34] collected huge data from Wisconsin in the USA. They compared their data (SPT versus cohesion) with previous equations and they found that Hara *et al*.[4] is the best fit for their data.

Singh *et al*.[28] collected 200 samples from Imphal in India. They correlated between SPT and unconfined compressive strength. The proposed equation is and they compared their equation with previous studies like Terzaghi and Peck[3], Hara *et al*.[4], Stroud[5], Sowers[33], Nixon[8], Sivrikaya and Togrol[14] and Hettiarachchi and Brown[19]. And they found that Terzaghi and Peck[3], Stroud[5] and Sivrikaya and Togrol[14] equations were the best fit with their data and their proposed equation.

MATERIALS AND METHODS

The methodology starts from data collection and data preparation. Then, the next step is model development and model validation in the end.

Data collection: Twenty-one samples of clay soil are collected from private sector company in the UK. The data contains SPT, cohesion, liquid limit and plastic limit results. The depth of samples is between 2 and 4 m depth. Furthermore, sieve analysis, dry density and moisture content are conducted for the samples. The SPT-N values were between 6 and 54. Also, the cohesion values varied between 5 and 265 kPa. While the liquid limit values vary between 21 and 92% and the plasticity index values vary between 5 and 70%.

Data preparation: The SPT-N values are corrected for field procedures and corrections are applied using the following equation:

$$N_{60} = \frac{N\eta H\eta B\eta S\eta R}{60} \quad (1)$$

Where:

N_{60} = The corrected standard penetration number for field condition
N = The measured value of standard penetration test in the field
η_H = Hammer efficiency (%)
η_B = Correction for borehole diameter
η_S = Sampler correction
η_R = Correction for rod length

Model development: The regression analysis is used to find the proposed equation for cohesion and SPT-N. liquid limit and plasticity index equation is found by regression analysis as well. The linear relationship is selected based on previous comprehensive studies.

Model development: To validate a model, two way of validation is used: the first way is comparison between the real values of independent five samples and the estimated values based on the research proposed equations and this way is used to validate both: the proposed equation of cohesion and SPT-N and the proposed equation of liquid limit and plasticity index. The second way of validation is two parts. The first part is comparison between the net allowable bearing capacity calculated using Terzaghi[35] equation based on real values and estimated values. In addition, the net allowable bearing capacity calculated using Terzaghi and Peck[36] equation.

The first part explained in next: Firstly, the net allowable bearing capacity is calculated based on Terzaghi[35] equation using real values. The Terzaghi[35] equation is:

$$q_u = 1.3c'N_c + qN_q + 0.4\,BN_\gamma \quad (2)$$

$$q = \gamma D_f \quad (3)$$

$$q_{all(net)} = \frac{qu-q}{FS} \quad (4)$$

Where:

qu = The ultimate bearing capacity (kN m^{-2})
B = Breadth of foundation was used (m) which equal 1 m
N_c, N_q and N_γ = Bearing capacity factors
D_f = Depth measured from the ground surface to under of foundation (m) which equal 1.5 m
c' = Cohesion (KN m^{-2})
$q_{all(net)}$ = The net allowable bearing capacity (KN m^{-2})
FS = A factor of safety which equal 3 as recommended by Das and Sivakugan[37]

Secondly, the net allowable bearing capacity is calculated based on Terzaghi[35] equation using the estimated values according to the same previous equation. Thirdly, the net allowable bearing capacity is calculated using Terzaghi and Peck[36] equation and it is:

$$q_{all(net)} = 15.13N \quad (5)$$

The second part is validation using calculation of the maximum elastic settlement and compared between calculation model based on PLAXIS 3D Model and

Janbu, etc. equation. The elastic Settlement (Se) is calculated for ensure of safety of the net allowable bearing capacity. And it is calculated based on PLAXIS Model and Janbu, etc., equation is:

$$S_e = A_1 A_2 \frac{q_o B}{E_s} \quad (6)$$

Where:

q_o = The net applied pressure on the foundation which equal the maximum of the net allowable bearing capacity of estimated values and actual values (kPa m^{-2})
μ_s = Poisson's ratio of soil which equal 0.35
Es = Average modulus of elasticity of the soil under the foundation which equal 20000 kN m^{-2}
L = Length of the foundation which equal 1 m
B = Width of the foundation which equal 1 m
H = Depth of the bottom of the foundation to a rigid layer which equal = ∞
A_1 = A function based on H/B and L/B
A_2 = A function based on

It is noted that the previous method of validation is used only for the proposed equation of cohesion and SPT-N.

RESULTS AND DISCUSSION

Model development: The correlation between SPT-N values and cohesion was developed to find the empirical formula. In addition, the plasticity index and liquid limit is correlated to find empirical formula. The proposed equations are in the following.

Correlation between SPT-N versus cohesion: Correlation Analyses is found relationship between SPT-N and cohesion and the proposed equation is:

$$c = 3.71N + 14.75 \quad (7)$$

Where:

c = Cohesion
N = Number of blows in the standard penetration test

Figure 1 shows the linear relationship between the cohesion based on SPT values of clay in the UK. The coefficient of determination is 0.66 and it indicate for directly proportional one to another.

The research proposed equation is compared to previous studies and the comparison shows that the proposed equation by Stroud, Brown and Hettiarachchi[27] and Schmertmann[6] are closed to the research proposed equation. Furthermore, the country of Stroud study and the research country are the same one which is the UK. Figure 2 shows comparison of cohesion based on SPT value between the research equation from side and the previous studies from other side.

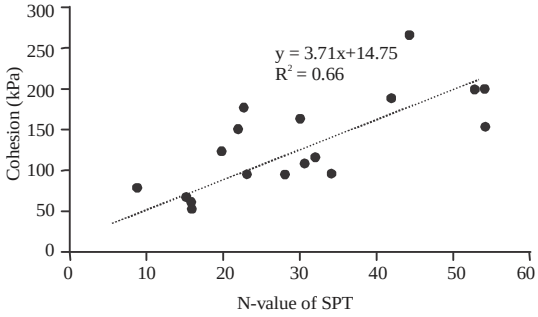

Fig. 1: The linear relationship between the cohesion based on SPT values of clay in the UK

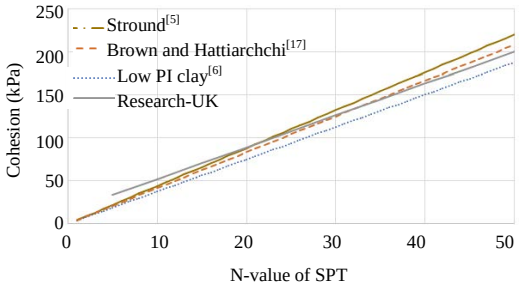

Fig. 2: Comparison of cohesion based on SPT value between the research equation and the previous studies

Correlation between SPT-N versus cohesion: Correlation Analyses between liquid limit and plasticity index is conducted and the proposed equation is:

$$PI = 0.95LL - 22.79 \quad (8)$$

Where:

PI = Plasticity Index
LL = Liquid Limit

Figure 3 shows the linear relationship between plasticity index and liquid limit in clay of the UK and the coefficient of determination is 0.86.

The research proposed equation is compared to previous studies and the comparison shows that the proposed equation by Naveena *et al.*[38] and Kuriakose, etc, are closed to the research proposed equation.

Table 1: The actual values and the estimated values of cohesion based on SPT-N

N-value of SPT	Actual value of cohesion (kPa) for clay in the UK	Estimated value of cohesion (kPa) based on research equation
16	64	74.11
32	117	133.47
42	190	170.57
53	200	211.38
54	200	215.09

Table 2: The actual and the estimated values of plasticity index based on liquid limit

Liquid limit (%)	Actual value of plasticity index (%) for clay in the UK	Estimated value of plasticity index (%) for clay based on research equation
25	12	0.95
37	14	12.35
49	25	23.75
55	33	29.45
70	45	43.7

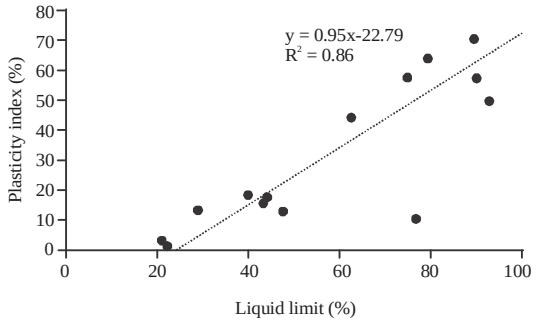

Fig. 3: The linear relationship between plasticity index and liquid limit in clay of the UK

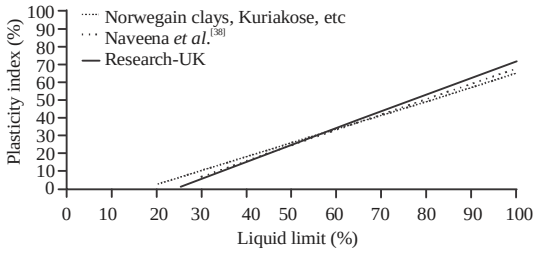

Fig. 4: Comparison of plasticity index and liquid limit between the research equation and the previous studies

Figure 4 shows comparison of plasticity index and liquid limit between the research equation and the previous studies.

Model validation: Table 1 shows the actual values and the estimated values of cohesion based on SPT-N. From Table 1, it is clear that the estimated values fall in the range of of the real values of cohesion based on SPT-N. Table 2 shows the actual and the estimated values of plasticity index based on liquid limit.

From Table 2, it is clear that 80% of the estimated values fall in the range of of the real values of cohesion based on SPT-N. Furthermore,

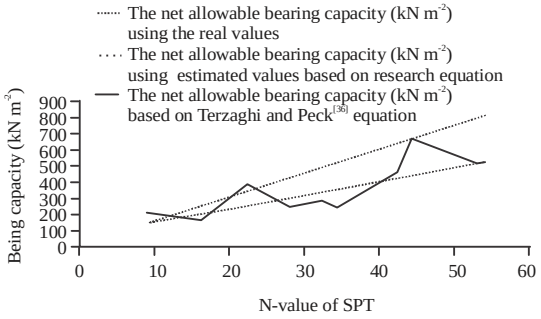

Fig. 5: The net allowable bearing capacity calculated based on real values and estimated values and the net allowable bearing capacity based on Terzaghi and Peck[36] formula

the 20% of the estimated values fall in the range of 20-30% of liquid limit values which could be ignored.

Figure 5 shows the net allowable bearing capacity calculated based on real values and estimated values and the net allowable bearing capacity based on Terzaghi and Peck[36] formula

It is clear from (Fig. 5) that the net allowable bearing capacity based on Terzaghi and Peck[36] formula is overestimated of other method and the net allowable bearing capacity using estimated values is closed to real values from other method. The maximum elastic settlement is calculated using PLAXIS 3D and the parameters of soil and load that used in soil settlement model for clay in PLAXIS 3D is shown in Table 3.

Figure 6 the PLAXIS model for the distribution of settlement of square foundation with B equal 1 m for sample of clay that has SPT value equal 32.

The maximum elastic settlement based on different calculation is still less than Meyerh of's theory which is 25 mm according to Fig. 7. Figure 7 shows the maximum elastic settlement calculated based on PLAXIS Model and Janbu, etc.

Table 3: The parameters of soil and load that used in soil settlement model for clay in PLAXIS 3D

Soil	Clay
Material mode	Mohr-Coulomb
Drainage type	Undrained B[1] Cohesion
	Minimum of the real values and estimated
Friction angle	0
Unsaturated bulk unit weight (Kn m^{-3})	17
Poisson's ratio	0.35
Young's modulus (kN m^{-2})	10000
Surface load	Maximum of the real values and estimated values of the net allowable bearing capacity Surface load
dimension (m)	1

Undrained B: Undrained or short-term material behaviour in which stiffness is defined in terms of effective properties and strength is defined as undrained shear strength. A large bulk stiffness for water is automatically applied to make the soil as a whole incompressible and (excess) pore pressures are calculated, even above the phreatic surface

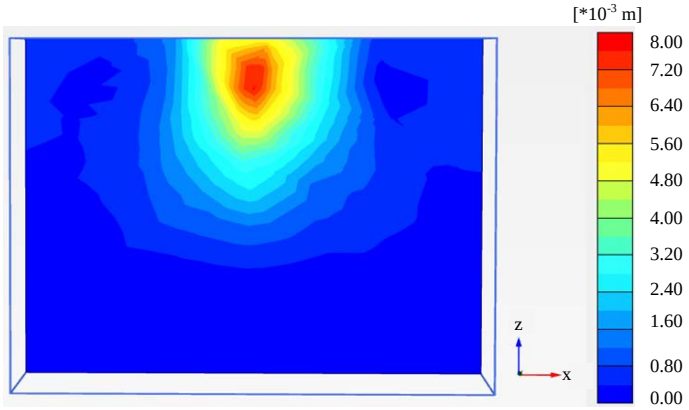

Fig. 6: The PLAXIS Model for the distribution of settlement of square foundation with B equal 1 m for sample of clay that has SPT value equal 32

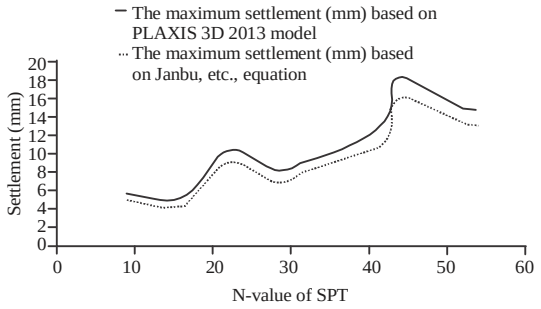

Fig. 7: The maximum elastic settlement calculated based on PLAXIS Model and Janbu, etc

CONCLUSION

On the basis of the above findings, the following conclusions can be drawn: twenty-one samples were used to correlate linear relationship between SPT-N and cohesion in clay of the UK. Furthermore, the proposed equation is c = 3.71 N+14.75. Also, the equation was validated using two way: the first way is comparison between the real values and estimated values and they found that the estimated values based on research equation fall in the range of of the real values of cohesion based on SPT-N. The second way is comparison between several ways of calculation of the net allowable bearing capacity and another comparison between two ways of calculation the maximum elastic settlement. In addition, they found that using research equation gives enough accuracy to calculate the net allowable bearing capacity and maximum settlement using manual method or model method.

Also, twenty-one samples were used to correlate linear relationship between plasticity index and liquid limit. And the proposed equation is PI = 0.95 LL-22.79. The equation was validated using the first way and it found that the estimated values based on research equation fall in the range of of the real values of plasticity index based on liquid limit.

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Simple summary: This study aims to find the cohesion of clay soil in the United Kingdom based on standard penetration test without carry out the test using the proposed equation. The proposed equation comes from correlation real data from the field and several method of model validations are used and the proposed equation is applicable to practice and use.

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