

Evaluation of friction angle in sand and cohesion in Clay based on SPT-N values in Jordan, Palestine, and the USA

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Abstract

The Standard Penetration Test (SPT) is used to determine the soil strength for many purposes. This research aims to estimate the relationship between the friction angle of sand and the cohesion of clay in Jordan, Palestine and the USA, using SPT since the soil strength tests are expensive and the SPT is common test and widely use. After data collection, comprehensive laboratory tests were carried out. The regression analysis was used to draw relationship between studied parameters (friction angle vs SPT in sand and cohesion vs SPT in clay). The proposed equations were validated and compared with other equations obtained from similar regions. Furthermore, the proposed equations were used to calculate the friction angles and cohesion values. Moreover, the results from Palestine and USA equations show good correlations with errors not more than 10% and (13 to 30) kPa, for friction angle and cohesion, respectively. The Jordan national code equation overestimated the results compared with the proposed equation for Jordan. The Jordanian national code equations need to be changed to calculate friction angle and cohesion based on the proposed equations. Accordingly, the proposed equations are useful to estimate the friction angle and cohesion based on the SPT prior to the final design stage.

Keywords: Friction angle, cohesion, soil strength, SPT

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1 Introduction

The standard penetration test (SPT) is widely used in geotechnical investigation especially in Palestine and Jordan to determine the soil strength. The SPT test is low-cost and easy to carry out compared to other field tests such as Cone Penetration Testing (CPT) and Dynamic Cone Penetrometer (DCP) tests. The prediction of friction angle based on SPT was studied by many researchers (Association (1990); Brown and Hettiarachchi (2008); Chen (2004); Ching et al. (2016); Dalai and Patra (2021); Decourt (1989); Dunham (1954); Esmailzadeh et al. (2012); Ferdous (2007); Munenori Hatanaka and Uchida (1996); M Hatanaka et al. (1998); Hettiarachchi and Brown (2009); A. Hossain et al. (2022); M. M. Hossain et al. (2020); Kitazawa et al. (1959); Kulhawy and Mayne (1990); Kumar et al. (2016); Mahmoud (2013); MAKOTO and KHANG (2013); Mayne (2001); Meyerhof (1956); Mujtaba et al. (2018); Peck et al. (1974); Puri et al. (2018); Salari et al. (2015); Schnaid et al. (2009); Shioi and Fukui (1982); Terzaghi and Peck (1967); Terzaghi et al. (1996); Wolff (1989); Yusof and Zabidi (2018); Zekkos et al. (2004)). Figure 1 shows famous studies and the Jordanian national code of foundation and retaining wall equation (Jabaji and Saleh (1992)) for friction angle prediction based on SPT.

Terzaghi et al. (1996) used two relations between friction angle and SPT number based on grained sand based on the data from available literature (De Mello (1971); Schmertmann (1975); Stroud (1988)). Eq. 1 and Eq. 2 show the proposed relations for coarse and fine-grained sand, respectively.

$$\varphi = -0.0038N^2 + 0.5262N + 27.9 \quad (1)$$

$$\varphi = -0.0028N^2 + 0.4365N + 27.1. \quad (2)$$

Where N is SPT blow count and φ is friction angle.

Brown and Hettiarachchi (2008) used the energy balance method to find the friction angle based on SPT number. The proposed

correlation conducted from 36 SPT results at 24 different boreholes as shown in Equation 3.

$$\varphi = 0.3818 \tan^{-1} \frac{0.25NP_a}{\sigma'} \quad (3)$$

Where σ' is the effective overburden pressure and P_a is the atmospheric pressure. Furthermore, they found that their proposed equation gives better estimation and more conservative value compared with other studies (Munenori Hatanaka and Uchida (1996); Kulhawy and Mayne (1990); Wolff (1989)).

Mujtaba et al. (2018) evaluated relative density and friction angle based on the SPT number. The data were collected from 60 boreholes and soil samples classified poorly graded based on the Unified Soil Classification System. Finally, the proposed equation (Eq. 4) was verified and showed differences not more than 10%. Then, the results obtained from the proposed equation were compared with those from Munenori Hatanaka and Uchida's (1996) equation which showed overestimation and showed differences of less than 10% when compared with the results of Peck et al. (1974) and Japan Road Association (Association (1990)).

$$\varphi = 0.7 N + 18 \quad (4)$$

The cohesion based on SPT were studied recently in the available literatures in different locations (Ajayi and Balogun (1990); Alam et al. (2015); Bashar (2000); Bowles (1988); Brown and Hettiarachchi (2008); Decourt (1989); Edil et al. (2009); Fattah et al. (2006); Hara et al. (1974); Hettiarachchi and Brown (2009); İyisan and Ansal (1990); Kalantary et al. (2009); Kulhawy and Mayne (1990); Kumar et al. (2016); Mahmoud (2013); MAKOTO and KHANG (2013); McCarthy (1977); Mikasa (1971); Murthy (1993); Mutman and Karadeniz (2016); Nassaji and Kalantari (2011); NAVFAC (1986); Nixon (1982); Puri et al. (2018); Sanglerat (1972); Schmertmann (1975); Serajuddin and Chowdhury (1996); Shaha (2013); Singh et al. (2017); Sivrikaya (2009); Sivrikaya and Toğrol (2002), (2006);

Sowers (1979); Stroud (1974); Terzaghi and Peck (1967); Yanase (1969); Yusuf and Zabidi (2018)). Figure 2 shows the recent studies and the Jordanian National

code for site investigation correlation (Jabaji et al. (1990)) to predict the cohesion based on SPT.

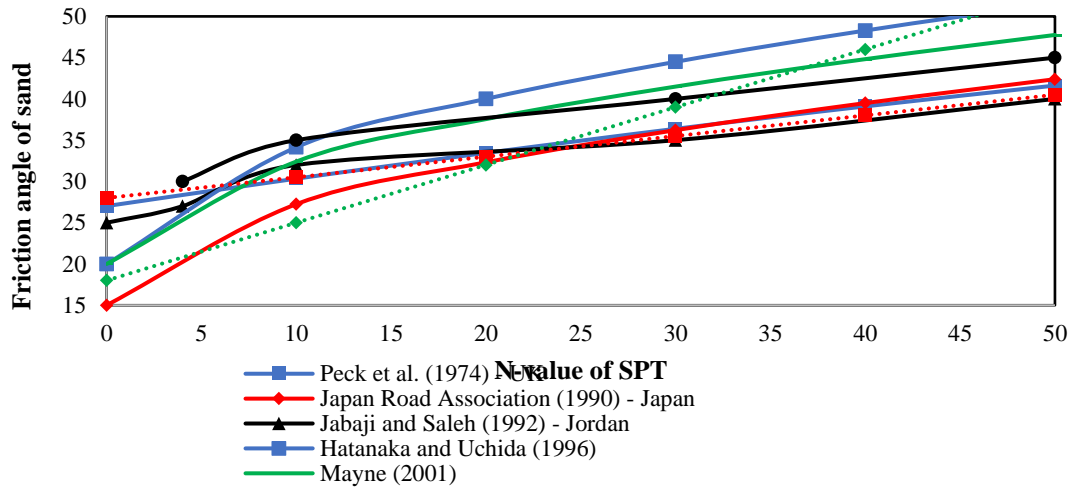


Figure 1. Prediction of friction angle based on SPT from some studies and Jordanian national code of foundation and retaining wall Jabaji and Saleh (1992).

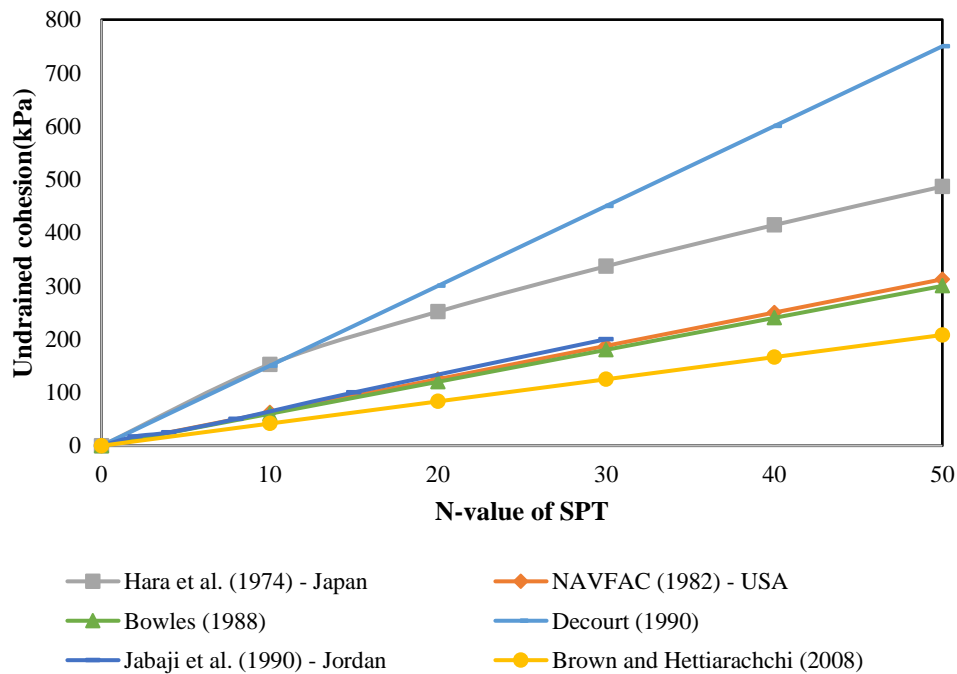


Figure 2. Prediction of friction angle from different studies and Jordanian National code (Jabaji et al. (1990)) based on SPT.

Hara et al. (1974) studied the relationship between unconfined compressive strength and SPT. They collected data from 25 sites

in Japan, and they proposed an equation (Eq. 5).

$$c = 0.297N^{0.72} \tag{5}$$

where c is cohesion in kg/cm^2 . Finally, they compared their results with those from previous studies (Mikasa Mikasa (1971) and Yanase Yanase (1969)) which were in accordance.

Sivrikaya and Toğrol (2006) 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 different types of soil and triaxial tests. The proposed equations are

$$c = 7.8N, \text{ for CH,} \quad (6)$$

$$c = 5.35N, \text{ for CL,} \quad (7)$$

$$c = 6.9N, \text{ for clay, and,} \quad (8)$$

$$c = 6.35N, \text{ for fine – grained soils} \quad (9)$$

Where c is in kPa. They compared their proposed equation with previous studies equations (Sivrikaya and Toğrol (2002); Sowers (1979); Stroud (1974)). For the CH type, Sivrikaya and Toğrol (2002) closed enough to their equations. For clay, their equation is underestimation for

Sanglerat (1972) and other studies, For fine-grained soil, the results are close to each other.

The aim of this study is to formulate of precise estimation of friction angle in sand and cohesion in clay based on the SPT test for Jordan, Palestine, and the USA

2 Methodology

The work was carried out as a soil lab; which was selected according to standard specifications and recommended from local authority. Then, data collection which includes friction angle, cohesion, and SPT.

Soil samples were collected from the three regions (USA, Jordan, and Palestine). The samples contained two types of soil which were sand, and clay. All of these samples were collected from soil laboratory reports and databases. Table 1 shows the number of samples collected from the regions (Jordan, Palestine, USA) for both soil types (sand, clay).

Table 1. The sample number collected from selected regions.

Soil type	Sample number		
	USA	Jordan	Palestine
Sand	71	35	1306
Clay	56	29	319

All the samples were classified according to the Unified Soil Classification System (USCS) as described in ASTM D-2487 and the Standard Penetration Test (SPT) was performed following ASTM D1586 standard and the friction angle in sand and cohesion in clay was performed following direct shear test (ASTM D3080) and unconfined compressive strength (ASTM D2166).

Then, the proposed equation was developed using regression analysis to find the formula between friction angle in sand and SPT and cohesion in clay and SPT and validated with other data that differ from the collected data to obtain the proposed

equations in each region separately. Finally, the proposed equations are checked and compared to other previous equations from available literatures and the national codes.

3. Result and analysis

3.1. Summary of Test Results

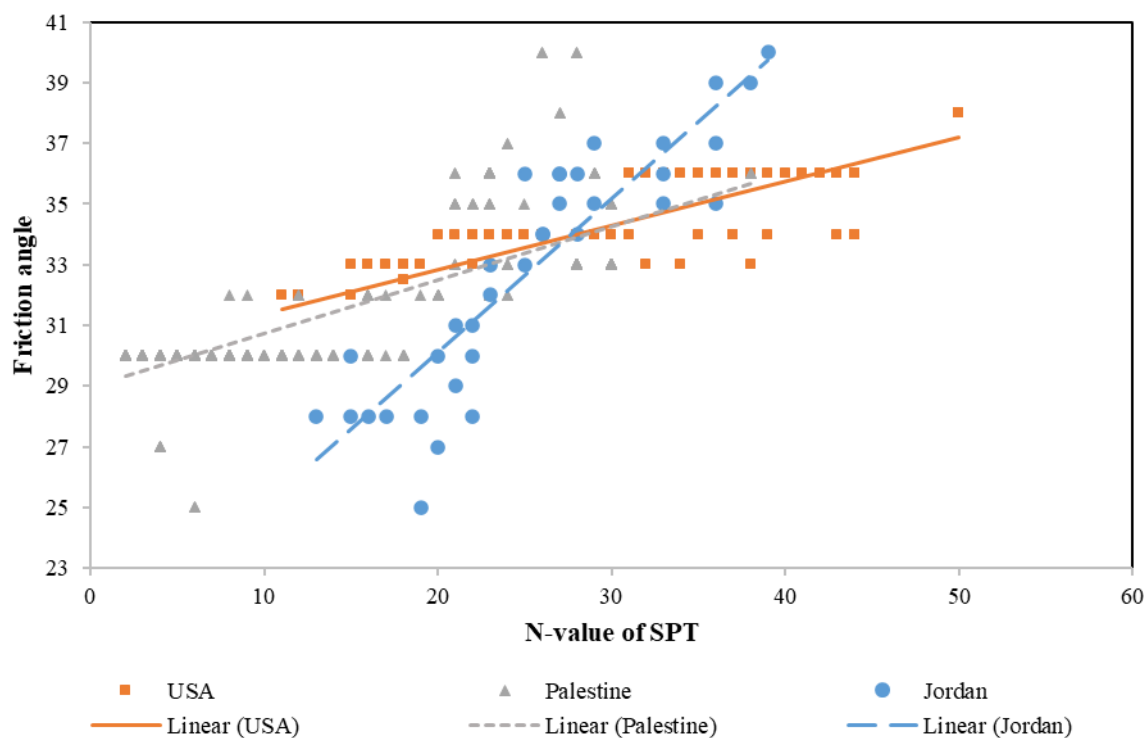
The properties of the sand and clay in the selected regions are shown in Table 2 and Table 3 respectively. Due to all the foundations in Palestine and Jordan being shallow (from 3 m to 6m), all the samples were taken from depths ranging from 1.0 to 6.0 meters.

Table 2. Properties of the sand in the selected regions.

Country	Friction angle	Dry unit weight (kN/m ³)	Bulk unit weight (kN/m ³)	No of blows
USA	20 - 38	16.1 - 17	17.2 - 21	10 - 50
Jordan	25 - 40	13.28 - 16.4	13.28 - 14.9	12 - 40
Palestine	20 - 38	15.7 - 21.46	16.2 - 22.49	3 - 38

Table 3. Properties of the clay in the selected regions.

Country	Cohesion (kPa)	Dry unit weight (kN/m ³)	Bulk unit weight (kN/m ³)	Liquid limit (%)	Plasticity index (%)	No of blows
USA	90 - 247	7.7 - 19.4	14.3 - 21.7	24 - 89	7 - 63	3 - 38
Jordan	73 - 126	15.1 - 18.5	17.2 - 21.2	37 - 56	9 - 30	15 - 45
Palestine	25 - 200	14.3 - 19	16.5 - 22.2	20 - 49	4 - 26	2 - 26



Error! Reference source not found. **Figure 3.** Shows the linear relationship between the friction angle and SPT values for sand – Jordan, Palestine, and USA, respectively.

3.2 Correlation between SPT-N versus friction angle for sand

Data used to correlate friction angle and SPT-N value for sand. Regression analysis was used to develop the correlation between the SPT and friction angle. The fi-

nal proposed equations for Jordan, Palestine, and USA are given and shown in Eqs. 10, 11, and Eq.12, respectively.

$$\varphi = 0.51N + 20 \quad (10)$$

$$\varphi = 0.18N + 29 \quad (11)$$

$$\varphi = 0.15N + 29.9 \quad (12)$$

As shown in Fig. 3, at SPT of 50, the friction angle is 37, 45, and 37 for USA, Jordan, and Palestine, respectively. Also, when SPT values ranged from 20 to 30, friction values in all regions were close to 0.5 to 1 degree error band.

3.3 Correlation between SPT-N versus cohesion for clay

Data was used to correlate the cohesion and SPT-N value for clay. Regression analysis was used to develop the correla-

tion between SPT and cohesion determined through an unconfined compressive strength test. The final proposed equations for Jordan, Palestine, and USA are given and shown in Eqs. 13, 14, and Eq.15, respectively.

$$c = 3.08N \tag{13}$$

$$c = 7.5N \tag{14}$$

$$c = 5.36N \tag{15}$$

Fig. 4 shows the linear relationship between cohesion and SPT values for clay – Jordan, Palestine and USA, respectively.

Table 4. The percentage of real values ranged from $\pm 10\%$ for sand and $\pm 20\%$ for clay.

Country	Soil type	Friction angle	Cohesion	$\pm N$ kPa for clay ¹
USA	Sand	90	-	
	Clay	-	60	30
Jordan	Sand	90	-	
	Clay	-	80	13
	Sand	100	-	
Palestine	Clay	-	70	25

1: N kPa is kPa values equal 20%

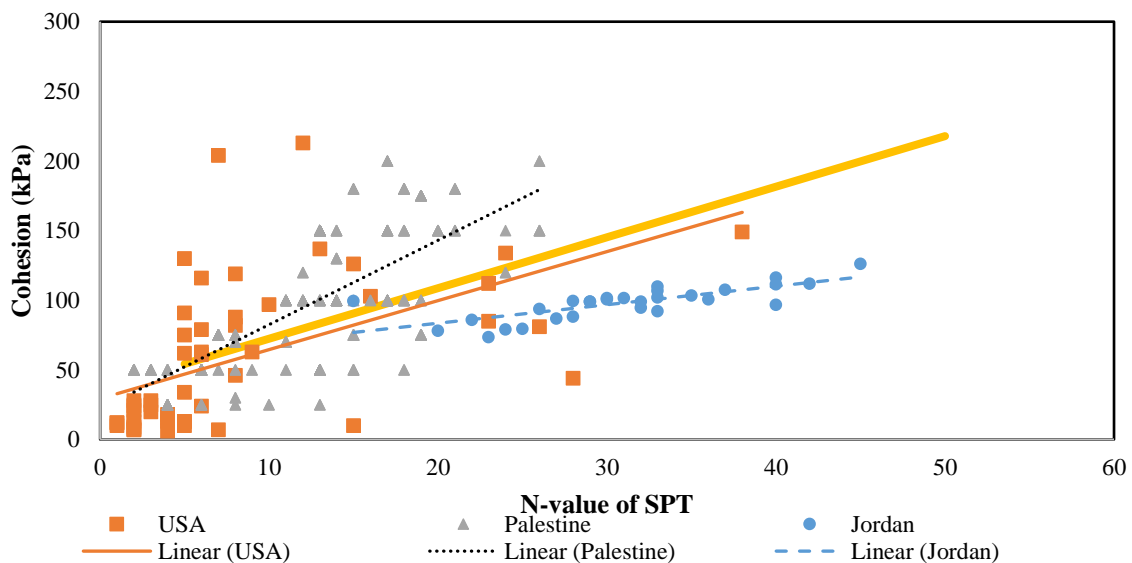


Figure 3. The SPT values - cohesion relationship for sand in USA, Jordan and Palestine.

As shown from the results, at SPT of 50, the cohesion values are 205, 123, and 320 for USA, Jordan, and Palestine, respectively, which show big differences between them. In contrast, when SPT values range from 5 to 10, the cohesion values in all regions are closed, with a 10 to 15 kPa error band.

4. Model validation

To validate the model, 10 samples were used for both soil types. Then the real data from the sample were compared with those from the proposed equations.

Table 4 shows the percentages of real values ranging from $\pm 10\%$ to $\pm 20\%$ for

estimated values for sand and clay, respectively.

The validation between real data and data from proposed equations in Jordan,

Palestine and USA are shown in Figure 5, Figure 6 and Figure 7, respectively.

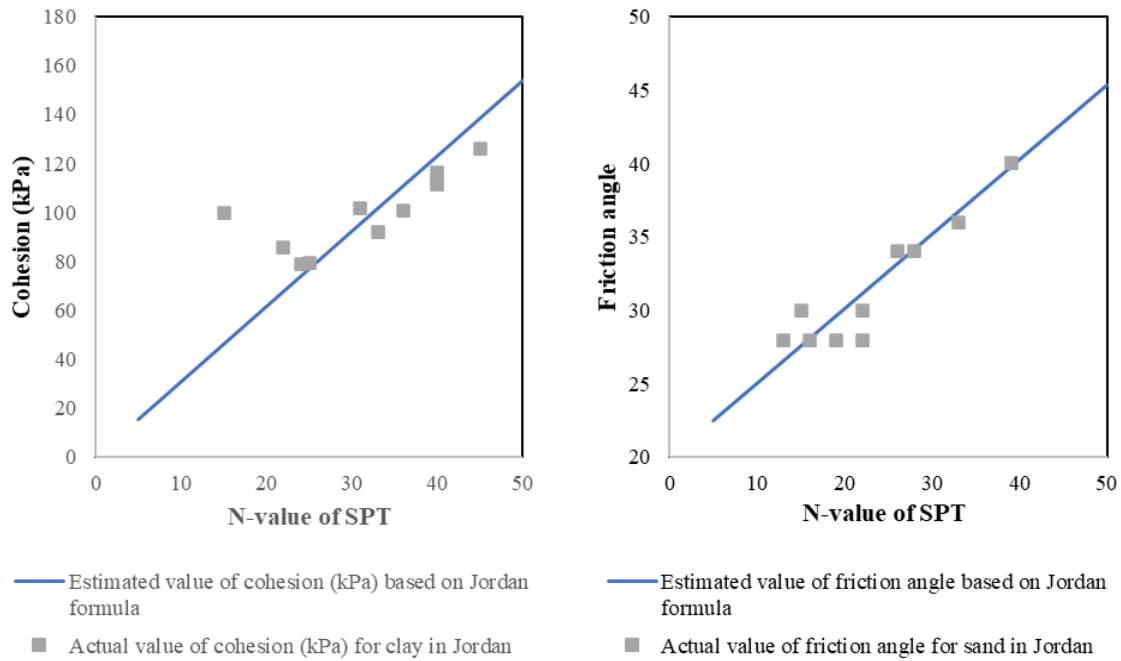


Figure 4. Comparison between real data and estimated data from proposed equation for Jordan for (a) friction angle (b) cohesion.

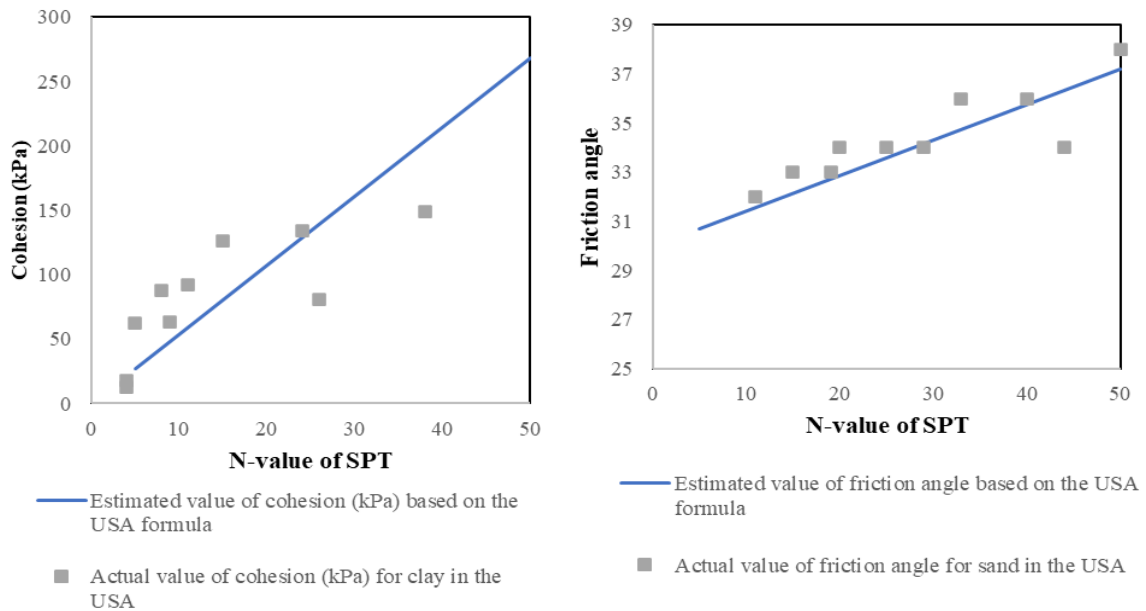


Figure 5. Comparison between real data and estimated data from proposed equation for Palestine for (a) friction angle (b) cohesion.

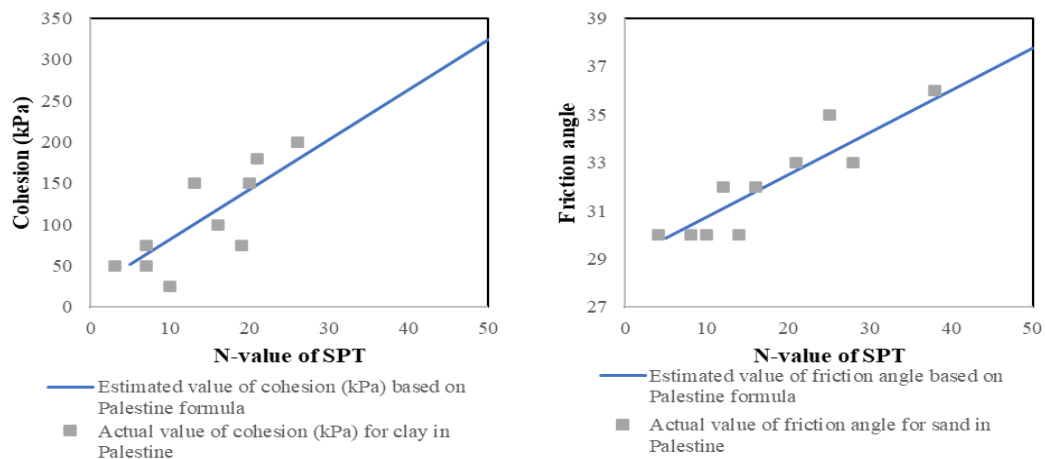


Figure 6. Comparison between real data and estimated data from proposed equation for the USA for (a) friction angle (b) cohesion.

5 Comparison between the obtained correlations to other famous and national code equations

Fig. 8 shows the comparison between the proposed equation of friction angle in sand for Jordan, Palestine and USA and famous equations used in previous regions. As shown in Fig. 8, in comparison between the friction angle based on SPT between the proposed equation for the USA and the famous equation in the USA that mention in Figure 1, the soils and foundations (Handbook (2012)) equation is closed to the proposed equation in the USA. Also, Jordanian national code (Jabaji and Saleh (1992)) equation shows a variation of 5 degrees compared with the proposed equation for Jordan. At the same time, Jordanian national code (Jabaji and Saleh (1992)) and Soils and Foundations (Handbook (2012)) equation are closed to the proposed equations for Palestine and the average. In the other side, the proposed equation for the USA is close to Dunham and other studies (Dunham (1954);

Ferdous (2007); Peck et al. (1974); Puri et al. (2018)). Also, the proposed equation for Jordan is close to the Japan Road Association equation (Association (1990)). While the proposed equation for Palestine is close to Dunham (1954) and Soils and Foundations (Handbook (2012)) equations.

In comparison between the cohesion based SPT between the proposed equation for the USA and famous equations in the USA that mention in Figure 2, Brown and Hettiarachchi (2008) equation is closed to the proposed equation for the USA more than NAVFAC (1986) equation. Also, Brown and Hettiarachchi (2008) equation is closed to the proposed equation for Jordan more than Jordanian national code (Jabaji et al. (1990)) equation. While Jordanian national code (Jabaji et al. (1990)) equation is closed to the proposed equation for Palestine. The proposed equation for the average is closed to Brown and Hettiarachchi (2008) equation.

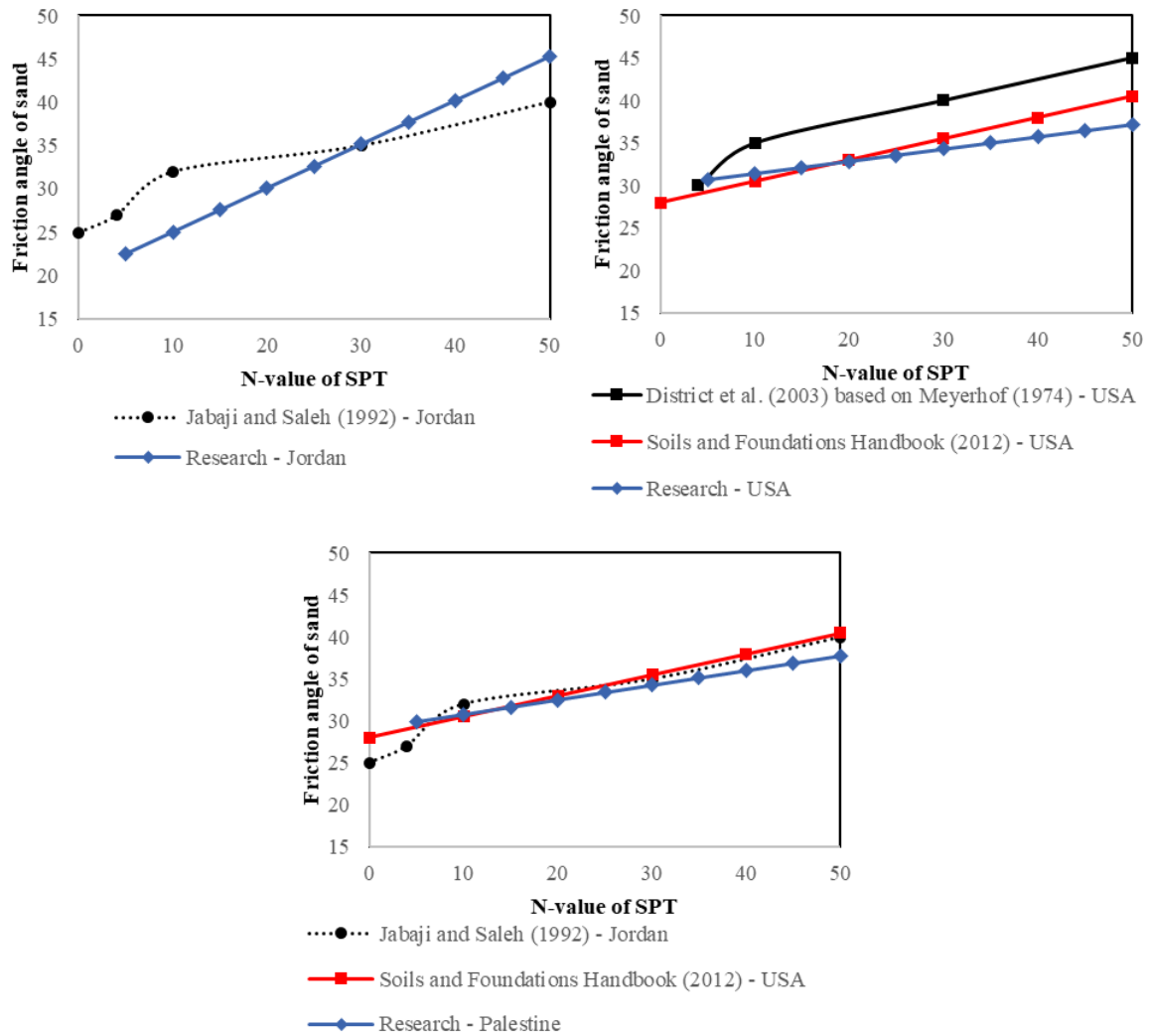


Figure 7. Comparison between correlations of friction angle in sand for Jordan, Palestine and USA and famous equations used in previous studies.

Figure 8 shows the comparison between the proposed equation of cohesion of clay for Jordan, Palestine, and USA and famous equations used in previous regions. As shown in Figure 8, the proposed equation for the USA is close to Brown and Hettiarachchi (2008) equation. Also, the proposed equation for Jordan is close to Kitazawa et al. (1959) equation. While the proposed equation for Palestine is close to Kumar et al. (2016) equation.

It is clear that there is no geographic contact between the country of proposed equations in the paper and other similar studies which should lead us to create the proposed equation of friction angle manually based on area and it is dangerous to depend on the previous equation for all the world unless it is proven via studies. Table 5 shows the proposed equation for Jordan, Palestine, and USA.

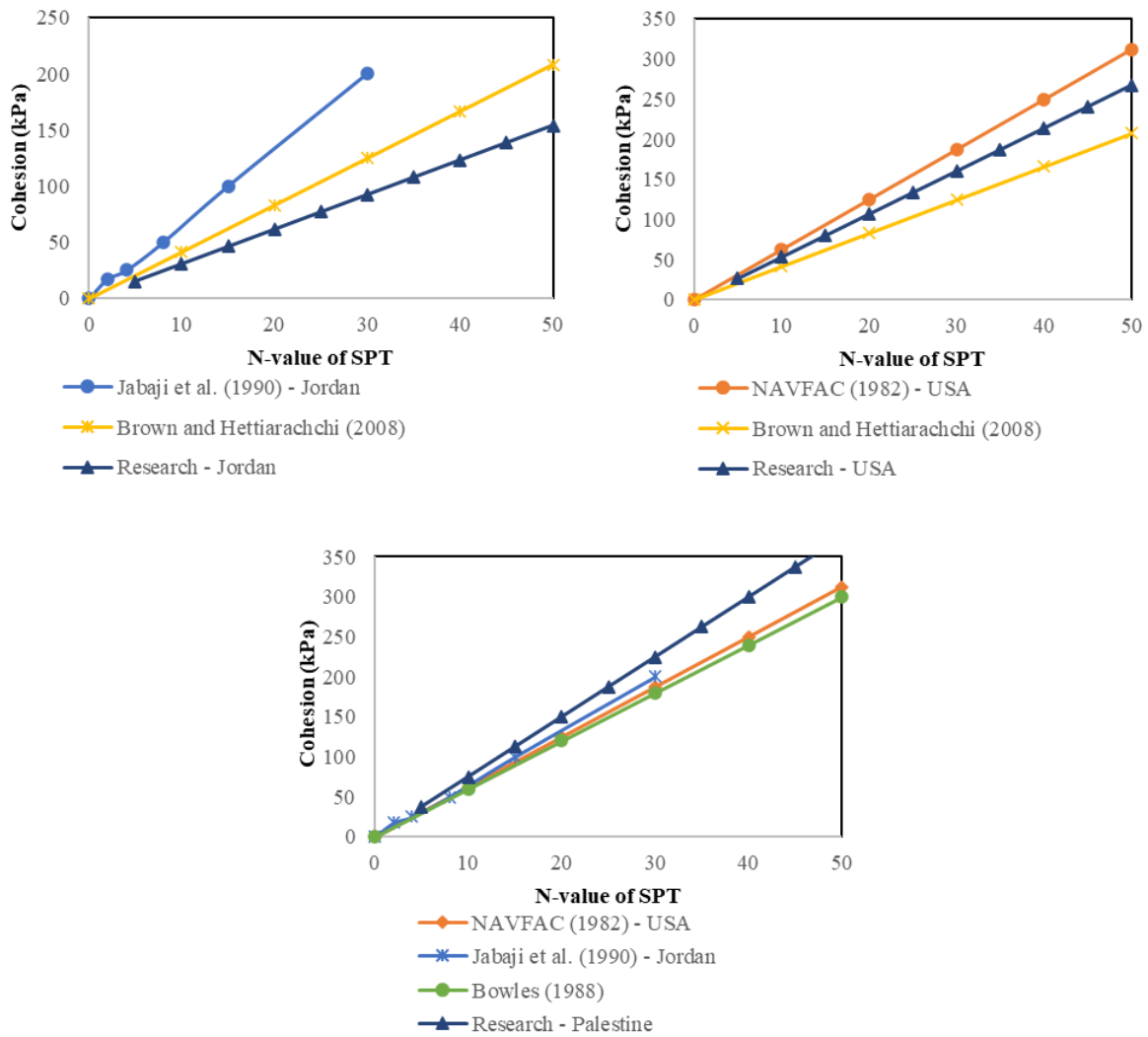


Figure 8. Comparison between the correlation of cohesion in clay for Jordan, Palestine, and USA and famous equations used in previous studies.

Table 5. The proposed equations for friction angle and cohesion based on SPT in different regions.

Country	Friction angle	Cohesion
USA	$0.15N + 29.9$	$3.08N$
Jordan	$0.51N + 20$	$5.36N$
Palestine	$0.18N + 29$	$7.5N$
Average	$0.28N + 26.3$	$4.67N$

6 Conclusions

Based on the data, results and discussions, the following conclusions could be drawn, The proposed equations for friction angle in sand based on SPT in the USA ($0.15N + 29.9$), Jordan ($0.51N + 20$) and Palestine ($0.18N + 29$) were proposed. The proposed equations showed

differences not more or less than 10% for all regions between the real and estimated data from the proposed equations. The equations for cohesion in clay based on SPT in the USA ($5.36N$), Jordan ($3.08N$) and Palestine ($7.5N$) were proposed. The validation model proved that the estimated values exist in accepted

range to real values.

The Jordanian national code equations need to be changed to calculate friction angle and cohesion based on the proposed equations. The proposed equations verified in this study could be used as an alternative to laboratory tests which is typically costly and time-consuming.

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