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Development of q_c – V_s Correlation for Depok Silt-Clay

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Abstract

To initiate the development of cone penetration resistance q_c and shear wave velocity V_s correlations of soils from Indonesia, the results of mechanical cone penetration soundings and seismic downhole tests from Depok, West Java area are compiled and analyzed. The soils are predominantly silt-clay soils. The results of the tests are used to develop a q_c – V_s correlation. The results and the associated correlation are then compared to q_c – V_s correlations from other countries.

Keywords: *Shear wave velocity, cone penetration test, cone resistance.*

Abstrak

Dalam rangka pengembangan korelasi antara tahanan konus q_c dan kecepatan rambat gelombang geser V_s untuk tanah Indonesia, hasil dari uji sondir mekanik dan uji seismic downhole *dari daerah Depok, Jawa Barat dikumpulkan dan dianalisis. Tanah dari lokasi pengujian adalah tanah lanau-lempung. Hasil dari kedua jenis pengujian digunakan untuk mengembangkan korelasi antara q_c dan V_s. Korelasi tersebut kemudian dibandingkan dengan korelasi sejenis dari beberapa negara.*

Kata-kata Kunci: *Kecepatan rambat gelombang geser, uji sondir, tahanan konus.*

1. Introduction

The shear wave velocity of soils plays an important role in the design of geotechnical structures under dynamic loads. It is used mostly for determining the seismic site categories (e.g., BSN, 2002) and for an initial reference value for large strain problems related to seismic loading. In Indonesia, the shear wave velocity is typically measured using the seismic downhole test. However, the equipment is not widely available and, consequently, the test is generally too expensive to perform for most construction projects. On the other hand, mechanical cone penetration tests are the most common in-situ test because it is lightweight and easy to perform.

No direct cone penetration resistance q_c and shear wave velocity V_s correlations of soils from Indonesia are currently available. Furthermore, unlike correlations for standard penetration test results N-SPT and V_s, the available direct q_c – V_s correlations from other countries are limited (Andrus et al., 2003; Madiai and Simone, 2004; and Sun et al., 2008). Therefore, it is of interest to develop a q_c – V_s correlation of soils from Indonesia. To initiate this development, q_c and V_s data from the University of Indonesia complex in Depok, West Java are analyzed. In this paper, the database of the two parameters and the analysis conducted are described, followed by a discussion on the proposed correlation and on the comparison of q_c – V_s correlations.

2. Test Program

The test program considered in this study consisted of three locations (A, B, and C), with one mechanical cone penetration test (CPT) and one seismic downhole test (SDHT) conducted at each location. The locations were within the University of Indonesia complex in Depok, West Java. The distance between locations A and C was about 250 m, while the distance between locations B and C was about 180 m.

The mechanical CPTs were conducted in accordance with ASTM D3441 (2008). The cone with an apex angle of 60° is 10 cm^2 in cross-sectional area and has a 150 cm^2 friction sleeve. The cone penetration resistance q_c and the associated friction ratio R_f readings and calculations were taken and performed at 0.2 m interval. The Robertson (1990) procedure was modified to further interpret the CPT results; the normalized cone resistance Q and the normalized friction ratio F respectively are given by the following:

$$Q = (q_c - s_v) / s'_v \quad (1)$$

$$F = f_s / (q_c - s_v) \quad (2)$$

in which σ_v = total vertical stress and σ'_v = effective vertical stress, and f_s = sleeve friction.

The seismic downhole tests were conducted using OYO Borehole Pick Model 3315 and McSeis–SX 48 Model 1126C. The shear wave velocity was measured at 1.0 m interval.

3. Test Results

3.1 Location A

The cone penetration resistance q_c and the friction ratio R_f of the cone penetration test (CPT) for Location A are shown in **Figure 1**. The normalized cone resistance Q and the normalized friction ratio F are also shown in Figure 1. The shear wave velocity V_s from the seismic down-hole test (SDHT) in an adjacent deep boring is shown in **Figure 1** as well. Based on the results, three geomaterial layers can be identified: ① depth = 0 – 3.0 m, ② depth = 3.0 – 7.0 m, ③ depth = 7.0 – 18.0 m, and ④ depth = >18.0 m. In addition, the groundwater table in the deep boring was found at a depth of 6.2 m.

The Robertson (1990) procedure was used to further interpret the CPT results of the four layers. As shown in **Figure 2**, the first layer is predominantly in Zone 3 (clay to silty clay) with higher overconsolidation ratio (OCR), the second layer is predominantly in Zone 4 (clayey silt to silty clay), the third layer is predominantly in Zone 3 with lower OCR, and the fourth layer is predominantly in the Zone 4 and Zone 5 (silty sand to sandy silt) with relatively low OCR. It is noted that the particle size analysis (ASTM, 2002) of an undisturbed sample from depth of 5.5 – 6.0 m resulted in clay = 24%, silt = 75%, sand = 1%, while that of an undisturbed sample from depth of 14.0 – 14.5 m resulted in clay = 23%, silt = 76%, sand = 1%.

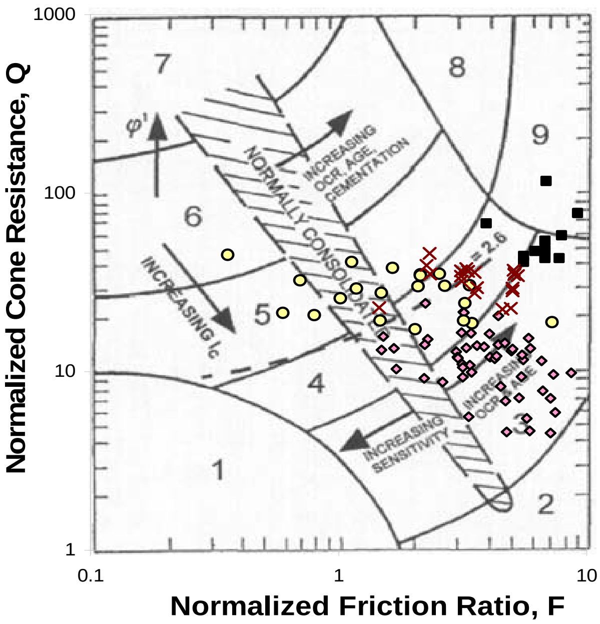


Figure 2. Q-F analysis for Location A
(■: 0-3.0 m, ×: 3.0-7.0m, ◊: 7.0-18.0m, ○: >18.0m)

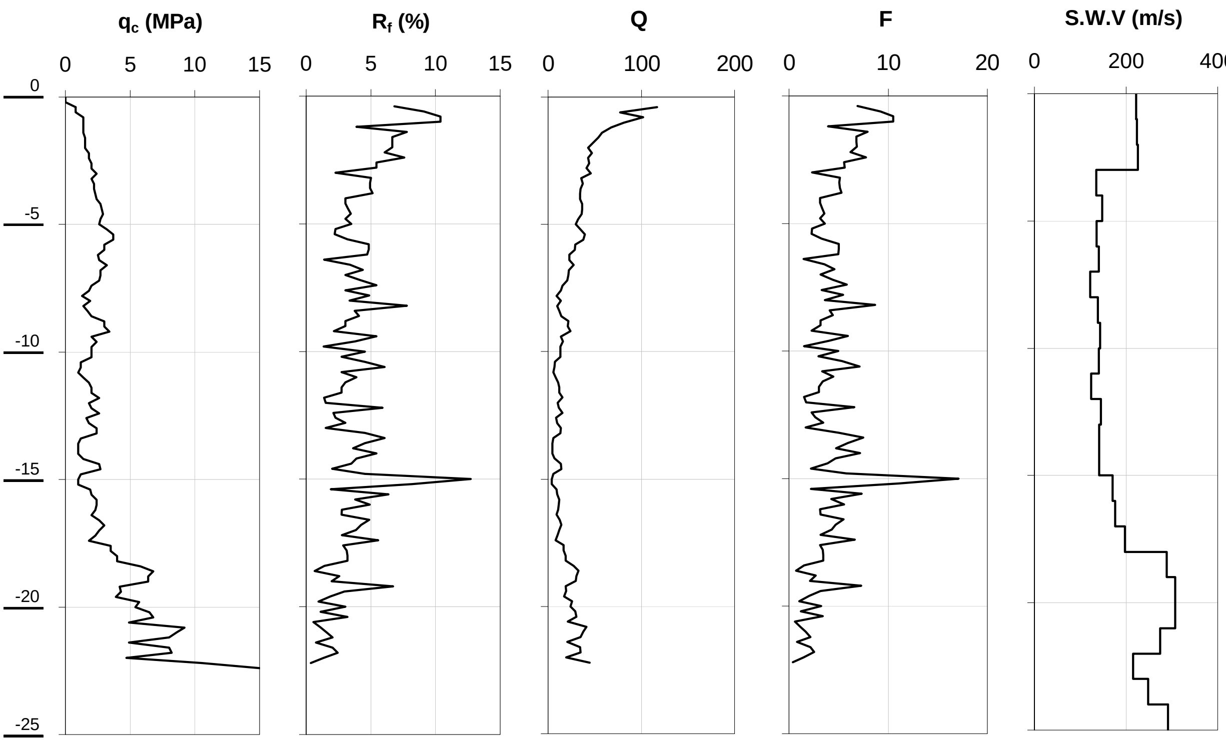


Figure 1. Mechanical CPT and SDHT results for Location A

3.2 Location B

The q_c and R_f profiles of the CPT for Location B are shown in **Figure 3**. The Q and F profiles are also shown in **Figure 3**. The V_s from the SDHT in the adjacent deep boring is shown in **Figure 3** as well. Based on the results, three geomaterial layers can be identified: ① depth = 0 – 3.0 m, ② depth = 3.0 – 7.5 m, ③ depth = 7.5 – 20.0 m, and ④ depth >20.0 m. In addition, the groundwater table was found at a depth of 9.1 m.

Based on the Robertson (1990) procedure shown as **Figure 4**, the first through the third layers are predominantly in Zone 3 (silty clay to clay) with decreasing OCR, and the fourth layer is predominantly in the Zone 4 (clayey silt to silty clay) and Zone 5 (silty sand to sandy silt) with relatively low OCR. It is noted that the particle size analysis (ASTM 2002) of an undisturbed sample from depth of 1.5 – 2.0 m resulted in clay = 23%, silt = 75%, sand = 2%, that of an undisturbed sample from depth of 8.5 – 9.0 m resulted in clay = 25%, silt = 74%, sand = 1%, and that of an undisturbed sample from depth of 17.0 – 17.5 m resulted in clay = 23%, silt = 76%, sand = 1%.

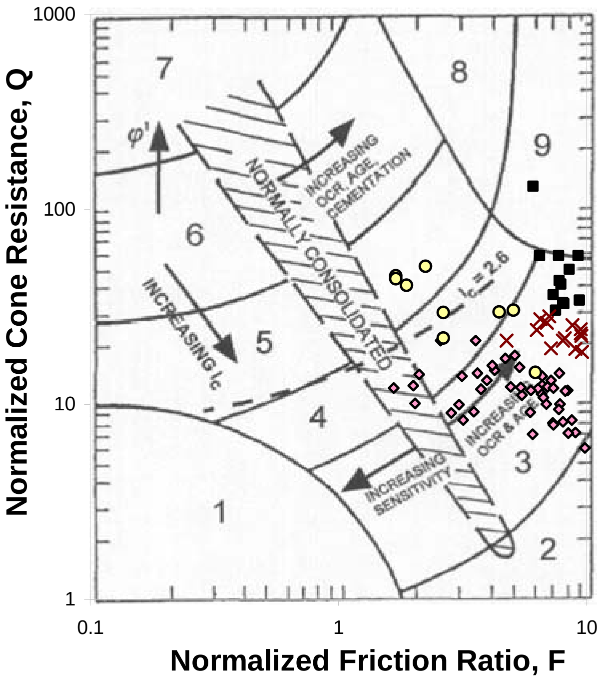


Figure 4. Q-F analysis for Location B
(■: 0-3 m, ×: 3.0-7.5m, ◊: 7.5-20.0m, ○: >20m)

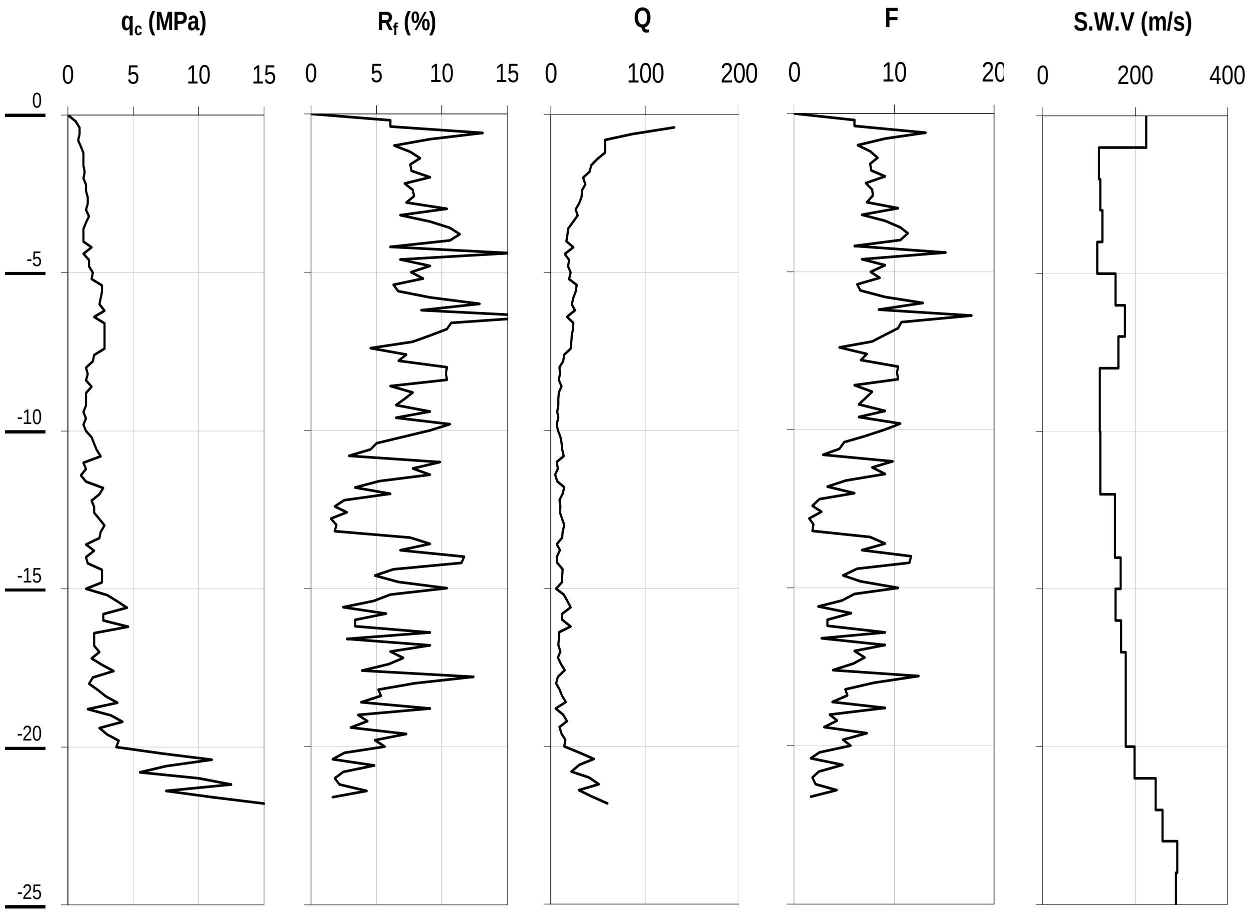


Figure 3. Mechanical CPT and SDHT results for Location B

3.3 Location C

The q_c and R_f profiles of the CPT for Location C are shown in **Figure 5**. The Q and F profiles are also shown in **Figure 5**. The V_s from the SDHT in the adjacent deep boring is shown in **Figure 5** as well. Based on the results, three geomaterial layers can be identified: ① depth = 0 – 3.0 m, ② depth = 3.0 – 19.0 m, and ③ depth >19.0 m. In addition, the groundwater table was found at a depth of 6.2 m.

Based on the Robertson (1990) procedure shown as **Figure 6**, the first and the second layers are predominantly in Zone 3 (silty clay to clay) with decreasing OCR, and the third layer varies between Zone 3 and Zone 5 (silty sand to sandy silt). It is noted that the particle size analysis (ASTM 2002) of an undisturbed sample from depth of 3.0 – 3.5 m resulted in clay = 23%, silt = 75%, sand = 2%, while that of an undisturbed sample from depth of 10.0 – 10.5 m resulted in clay = 23%, silt = 73%, sand = 4%.

4. Correlation Development and Discussion

A simple regression analysis was performed, taking the shear wave velocity V_s as the dependent parameter and the cone penetration resistance q_c as the independent parameter. As the q_c and V_s were determined at different intervals, five q_c values had to be averaged for the associated depth of V_s value. It is noted that the upper 3.0 m of V_s values at Location A, the upper 1.0 m of V_s values of Location B, and the upper 2.0 m of V_s values of Location C were not included in the analysis, as they appeared to be unusually high for relatively low q_c values.

Figure 7a compares q_c and V_s data for different materials based on the Robertson (1990) criteria. It can be observed that all data cluster in the same general range, and it can be concluded therefore that material types would not have a significant effect on the correlation.

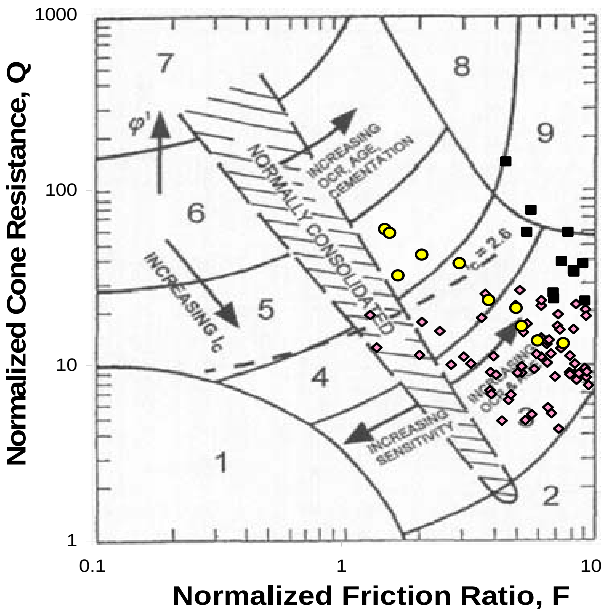


Figure 6. Q-F analysis for Location C
(■: 0-3 m, ◊: 3.0-19.0m, ○: >19m)

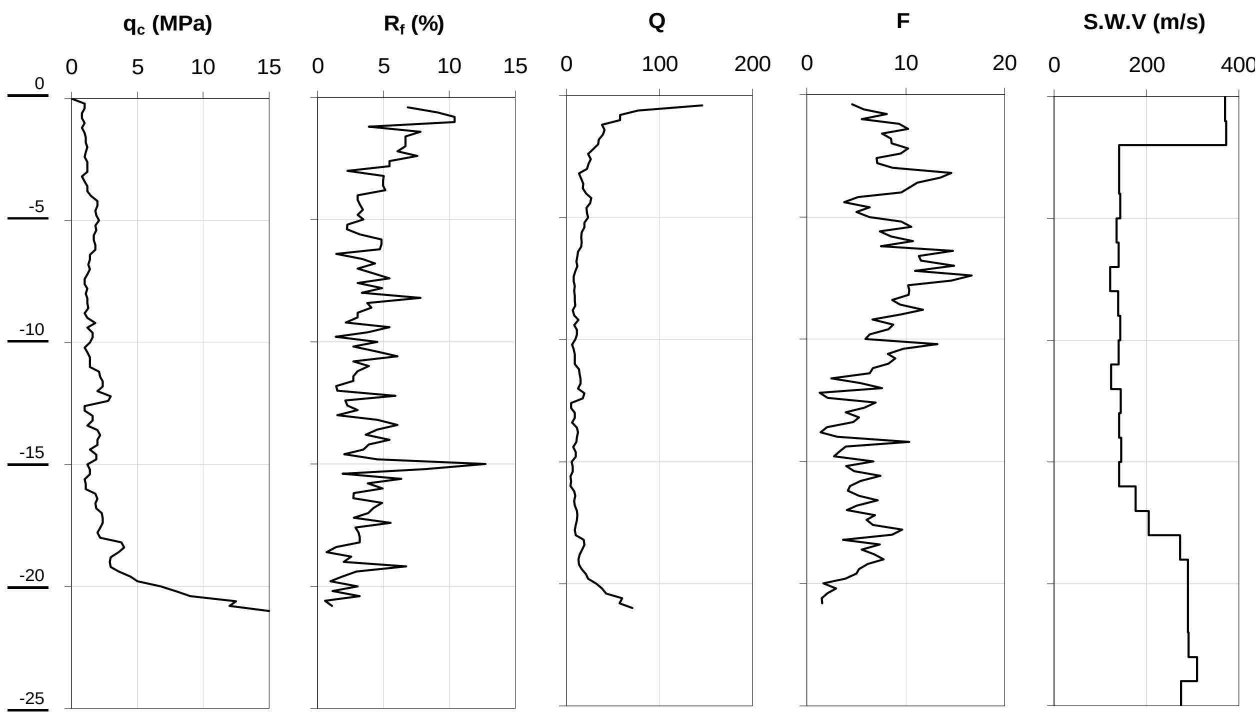
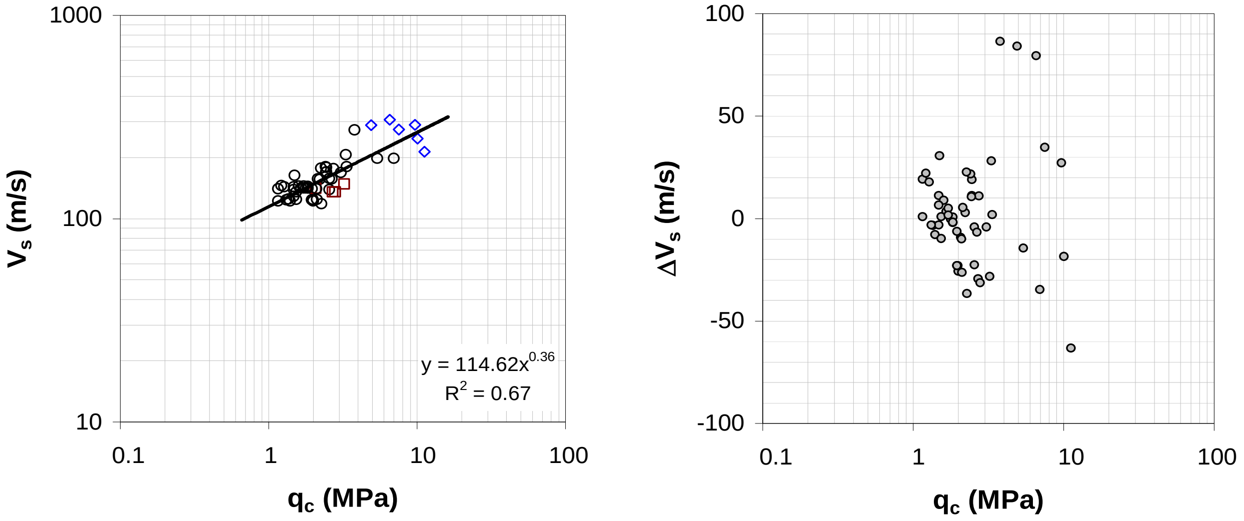


Figure 5. Mechanical CPT and SDHT results for Location C



a) Effect of material types and initial correlation **b) Distribution of V_s deviation**

Figure 7. Effect of material types (Materials: ○- Zone 3, □- Zone 4, ◇- Zone 5) and results of initial analysis

Figure 7a also shows the initial q_c – V_s correlation equation based on 56 data points. The distribution of the V_s deviation from this initial correlation equation is shown as **Figure 7b**, and the standard error is 27.39 m/s. There are four data points that deviate significantly (> 60 m/s), and these data points are considered as outliers in the further analysis.

Based on the select V_s and q_c data, the following correlation has been derived for the Depok silt-clay:

$$V_s = 115.70\ (q_c)^{0.34} \quad (3)$$

in which V_s in m/s and q_c in MPa, and the standard error is 18.16 m/s. Note that the number of data is 52 and the r^2 value is 0.69. The data and the regression line and equation are shown in **Figure 9**, while the distribution of the V_s deviation from the preposed correlation equation is shown as **Figure 10**.

The correlation above is compared with similar correlations from other countries. It is noted that direct q_c – V_s correlations for clayey materials are limited. Andrus et al. (2003) proposed the following correlation for clayey holocene soils from the USA (South Carolina and California), Canada, and Japan:

$$V_s = 6.21\ (q_c)^{0.444} \quad (4)$$

in which q_c in kPa (n = 31, r^2 = 0.83). Madiai and Simone (2004) proposed the following correlation for some clayey soils from Italy:

$$V_s = 211.2\ (q_c)^{0.231} \quad (5)$$

in which q_c in MPa (n = 46, r^2 = 0.871). Sun et al. (2008) proposed the following correlation for some clayey soils from South Korea:

$$V_s = 17.84\ (q_c)^{0.301} \quad (6)$$

in which q_c in kPa (r^2 = 0.741). In addition, Mayne and Rix (in Mayne, 2007) developed a clayey soil database for the q_t – V_s correlation. Although their database is a q_t database, but this database can be used to compare the above-groundwater-table data.

The comparison is shown as **Figure 11**. It can observed that the present q_c – V_s data and the associated correlation equation are slightly lower than the correlation proposed by Andrus et al. (2003) for q_c < 2 MPa and are slightly lower than the correlation proposed by Sun et al. (2008) for q_c > 2 MPa. However, the present data and correlation equation appear to be in the lower bound of the Mayne and Rix's database (in Mayne, 2007) and are significantly lower than the correlation proposed by Madiai and Simone (2004).

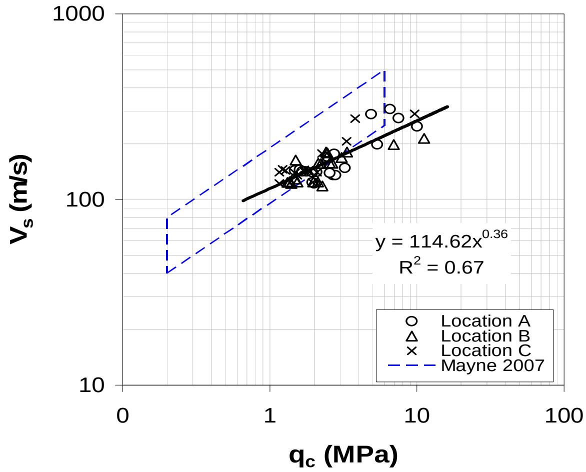


Figure 8. Correlation between Vs and qc for Depok silt-clay

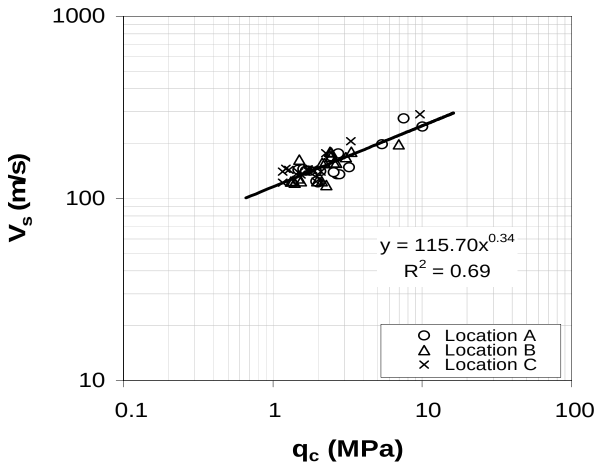


Figure 9. Correlation between Vs and qc for Depok silt-clay

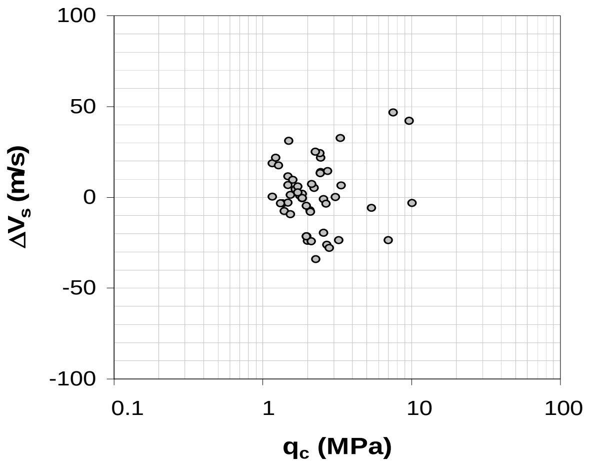


Figure 10. Deviation of V_s from proposed correlation equation

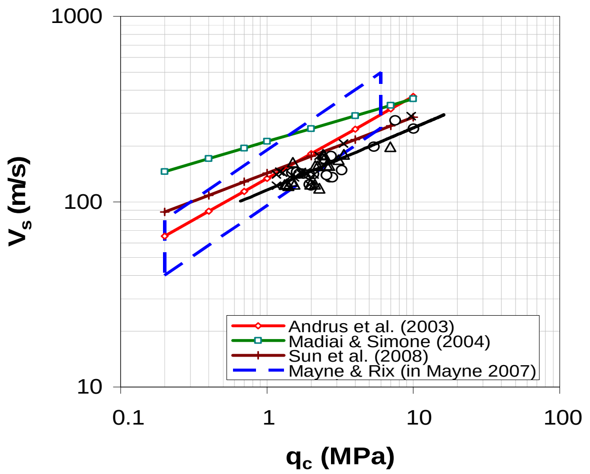


Figure 11. Comparison of present correlation to correlations from other countries

5. Conclusions

1. Cone penetration resistance q_c data obtained from mechanical CPTs and shear wave velocity V_s data obtained from seismic downhole tests from three locations within the University of Indonesia complex in Depok were evaluated.
2. The materials were predominantly silt-clay, determined using the Robertson's criteria and confirmed by particle size analysis results.
3. Based on the results, a site-specific trend that correlates measured q_c to V_s for Depok silt-clay materials was developed.
4. The proposed correlation between V_s and q_c can be used for rough estimates of V_s from q_c, particularly for preliminary studies and/or noncritical projects are under consideration.
5. From the comparison to similar correlations from other countries, the proposed correlation appears to be lower bound.

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