An in-Situ Study of DCP and Hand Penetrometer (HP) Tests on Swedish Postglacial Sand

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ABSTRACT

The dynamic cone penetrometer test (DCP) is useful for evaluating the relative quality of soils in situ. By dropping a dead weight from a certain vertical distance, the penetration depth per blow of a cone is measured. A similar test that evaluates resistance to penetration is the hand penetrometer (herein referred to as the HP). This approach involves pushing a cone into the soil and determining the force needed to penetrate an incremental depth into soil. By conducting four in situ soundings on natural deposits of postglacial sand and clay, the correlation of the penetration resistance between these instruments is studied. The investigation reveals agreement between the methods as it indicates that for relatively dense soils, for which the DCP index is ≤ 37 mm/blow, the DCP index is related to cone resistance with an acceptable degree of confidence. Furthermore, for the practicing engineer, the DCP and HP tests are correlated herein to the effective friction angle of soils, which combined may provide tool for an initial determining of bearing capacity in situ.

KEYWORDS: In situ; testing; penetrometer; DCP; bearing capacity; soil.

INTRODUCTION

Regarding soil quality and constructability, knowledge about the structural properties of soils, whether natural deposits or man-made soil structures, is important for the practising engineer. In engineering, a soil’s bearing capacity, i.e., its ability to support loads, which is related to shear strength, is perhaps the most important property. Empirical methods to evaluate in situ soil strength are typically those that measure resistance to penetration by an object of sorts. In this study, two instruments are compared: the DCP (i.e., dynamic cone penetrometer) and the hand penetrometer (HP). The DCP test is a widely used approach to assess soil quality, and it has been converted into several geotechnical properties that are useful for evaluating in situ strength (Hamid, 2015; MnRoad, 1996; Webster *et al*., 1992). Unlike the DCP, which determines resistance to the penetration of a cone by dropping a weight from a certain height and then recording the penetration depth per blow, the HP test yields a manometer reading that indicates the maximum resistance to penetration by pushing the cone by force an incremental depth into soil (Eijkelkamp, 2013). These two test approaches are fast and simple in situ measurements that allows for an initial indication of soil-bearing capacity.

Herein, four in situ tests were conducted on natural deposits of Swedish postglacial sand. This paper explores the correlation of the results from the DCP and HP instruments and discusses the methods from a geotechnical perspective. The soil is a narrowly graded sand with relatively low permeability sitting on top of a sandy silty clay, a characterization derived from auger samples, forensic photos, particle size distributions, as well as in situ infiltrometer testing and laboratory permeability test.

METHODOLOGY

The DCP-test

The DCP, dynamic cone penetrometer, is an instrument that determines the resistance to the penetration of a cone by dropping an 8kg hammer from a vertical distance of 575mm (figure 1), which generates a driving energy of 45J (Mohammadi *et al*., 2008). In engineering practice, the DCP is used, for example, to evaluate the in situ stiffness characteristics of compacted embankments and to locate weak soil layers (Hamid, 2015). The penetration depth per blow of a 60˚ cone with a diameter of 20mm is recorded, which determines the DCP index (in mm/blow). Less than 25mm penetration after 10 blows indicates refusal (Webster *et al*., 1992). The default measuring depth is approximately 900mm, but deeper probing can be achieved by using extension rods. However, caution should be taken to avoid side friction on the rod that may affect the measurements. Thus, augering to create clearance may be necessary; for example, in highly plastic clays, a sounding depth greater than 300mm, without creating clearance, may result in exaggerated dense measurements due to clay sticking to the rod (Webster *et al*., 1992). Furthermore, the DCP is not a suitable instrument for soils with a maximum particle size exceeding 50mm (Hamid, 2015).

The HP-test

The hand penetrometer measures the penetration resistance by a 60˚ cone that is manually pushed an incremental length into soil at a constant rate of 2 cm/sec (figure 1) (Eijkelkamp, 2013). A manometer records the maximum resistance to penetration over this length. The default measuring depth is approximately 1 m, but extension rods can be used. Depending on the size of the cone, i.e., the cone surface, the cone resistance is achieved from the manometer reading, and the maximum measuring range is 10MPa if the smallest cone is used (i.e., 1 cm^2 surface area, 11 mm diameter). The maximum sounding depth is 500mm when using the smallest cone if clearance is not created.

The test-site

The test site is located in the coastal region of the south part of the Swedish province of Norrland (the north of Sweden), situated 250km north of Stockholm (figure 2A). By removing a 300mm layer of organic top soil, the postglacial sand deposit was uncovered over an area of 800 by 1100mm (figure 2B). Augering revealed postglacial clay underneath the sand (figure 4). The penetrometer soundings are located in the corners of a 300 by 300mm square, and the auger drill point is located in its center (figure 2B).

Postglacial soils are those formed after the latest glaciation through the transportation of older glacial soils by water (SGU, 2017). Large parts of Sweden were under water after the melting of the in-land ice, which, in combination with land up-lift and deposition from streams, formed uniform fractions of soil at the bottom of the ocean. Due to up-lift, the previous off-shore deposits became on-shore postglacial deposits.

RESULTS

The hydraulic conductivity of the surface layer of postglacial sand was determined in situ to approximately 10^{-6} m/s based on the infiltration curve obtained from the double-ring infiltrometer (figure 4A) and was confirmed by laboratory permeability tests (figure 4B). This suggests a low-permeability soil, e.g., silty sand (Larsson, 2008). Auger corings drilled at the centre of the sounding points area revealed a 300 to 400mm thick deposit layer of sand that gradually transitioned to sandy, silty clay. Figure 4 shows the top layer of postglacial sand and the first marked layer of clay encountered at depth 550mm.

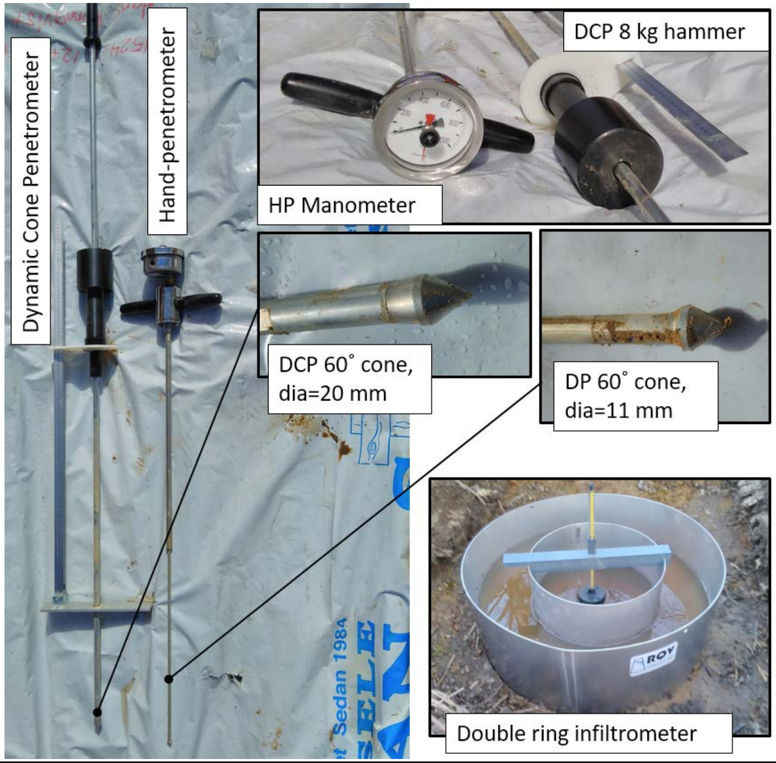
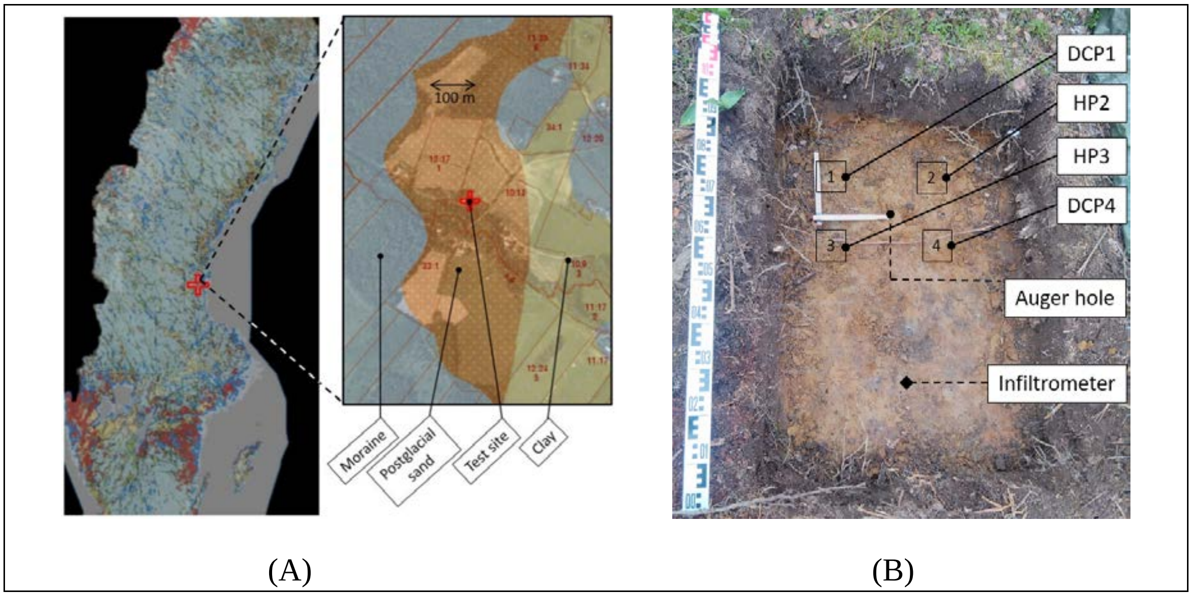
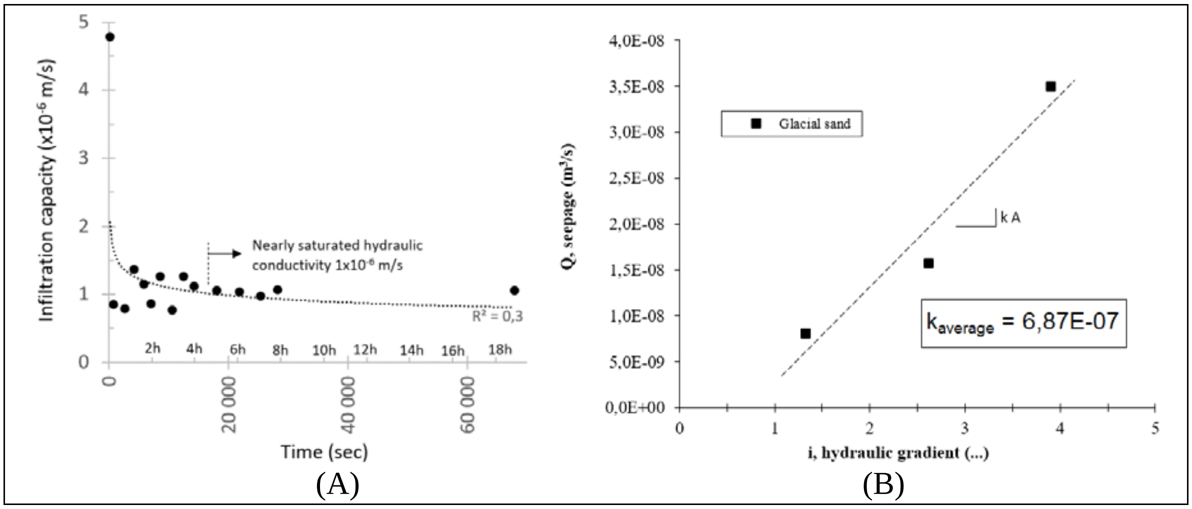


Figure 1: The DCP and HP instruments and double-ring infiltrometer.



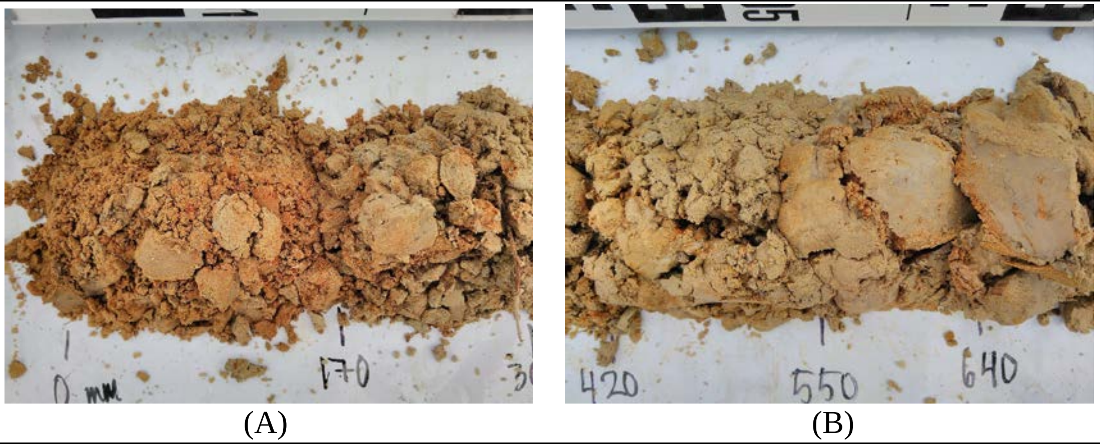
(A) (B)

Figure 2: A) location of the test site in Sweden and soil map (after SGU, 2017), and B) surface of postglacial sand with sounding points, auger hole and infiltrometer area.



(A) (B)

Figure 3: Hydraulic conductivity from the A) infiltration curve from the in situ infiltrometer and B) laboratory permeability tests.



(A) (B)

Figure 4: Forensic close-up photos of (A) the surface soil of sand (depth 0-170 mm) and (B) underlying sandy, silty clay (depth > 550 mm).

Particle size distributions by depth are shown in figure 5. By punching sample rings into the soils, the bulk unit weight of undisturbed samples was determined, on average, to be Υ = 18.7 kN/m^3 for the top 300mm of soil (average water content, ω = 30 %) and Υ = 18,1 kN/m^3 (ω = 32 %)for the soil underneath to a depth of 500mm. Their respective dry unit weight is thus on average 14.4 kN/m^3 and 13.7 kN/m^3, respectively. Undisturbed samples deeper than 500mm were unachievable due to the influence of the groundwater table. The smallest available HP cone was used during the probing, i.e., 1cm^2 surface area, which allows up to 10MPa of pressure. At the time of testing (i.e., springtime in May), the soil temperature at the 100mm depth was 2.7˚C and the ground water temperature was 4.0˚C. The ground water table was encountered at a 340mm depth (as measured in the centrally located auger hole).

Typically, the soil strength increases with depth, but weak layers may exist for various reasons. The penetration profile is shown in figure 7; a low DCP index (mm/blow) indicates higher resistance to penetration, similar to high HP cone resistance values (MPa). The relative stiffness estimates from Mohammadi et al., (2008) and Larsson (2008) showed good agreement; e.g., “Loose soil” achieved a DCP index of 25 to 45 mm/blow, which corresponds to a “Low stiffness” of 2.5 to 5 MPa. The penetration profiles from DCP and HP measurements showed relatively good agreement (figure 5). A dense layer was encountered at a depth of 500mm, where the silty sand transitions to clayey soil (figure 6B), which is confirmed in good agreement, yielding a DCP of 10 to 20 mm/blow and HP of 7 to 9 MPa cone resistance (figure 5).

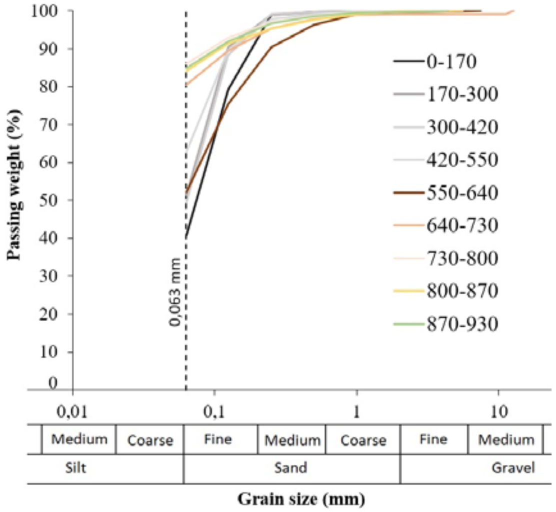


Figure 5: Particle size distributions by depth.

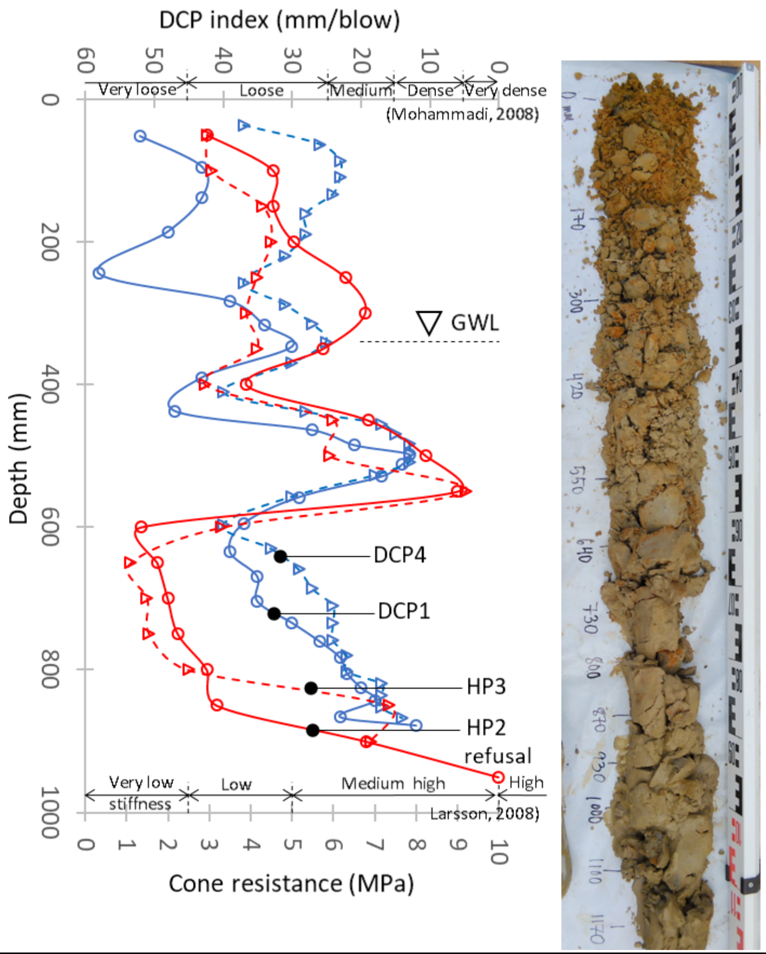
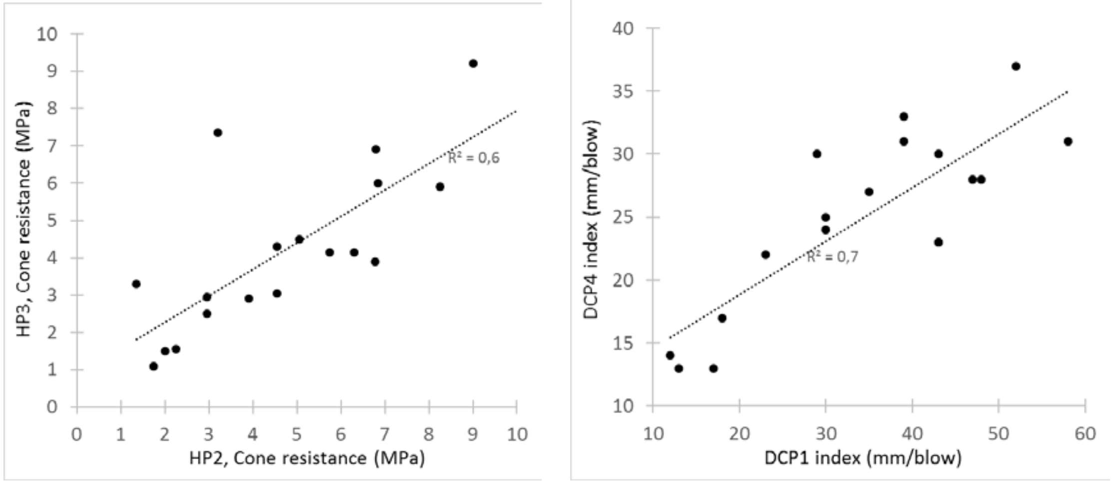
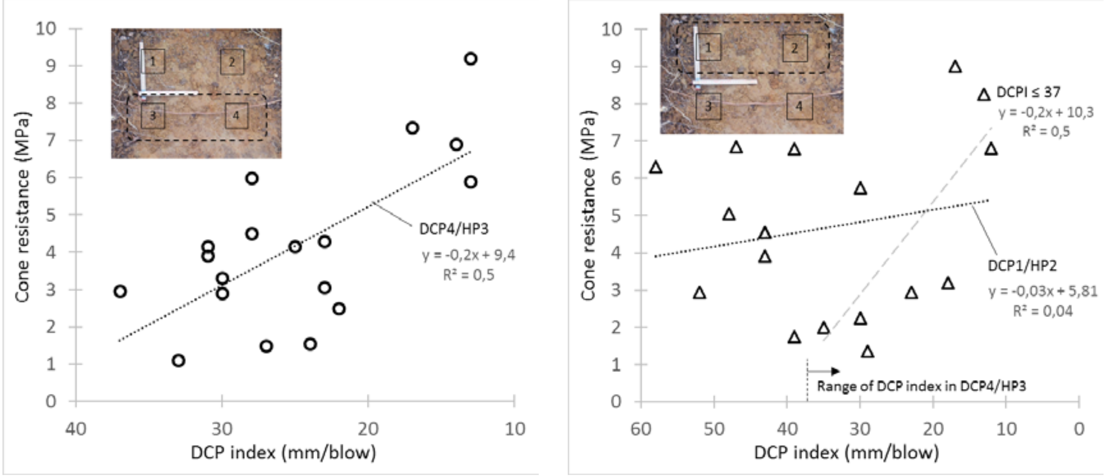


Figure 6: DCP index (mm/blow), cone resistance (MPa) and forensic corings by depth.



(A) (B)

Figure 7: Correlations between (A) HP points no 2 and 3, and (B) DCP points no 1 and 4.



(A) (B)

Figure 8: Correlations between DCP and HP for (A) stiffer soil in points no 3 and 4, and (B) softer soil in points no 1 and 2.

At greater depths at about 600 to 700mm, the dense layer transitions to loose soil with low to very low stiffness. However, when closing in on the instruments' reach capacities (approximately 850-900mm), higher levels of cone resistance were gradually achieved until the HP refusal at a depth of 950mm (10MPa).

DISCUSSION

The DCP measurements in sounding points no 2 / 3 and HP measurements in points no 1 / 4 (figure 3) revealed moderate to strong intercorrelations (figure 8A, 8B). By extracting the densest

DCP index (i.e., lowest values) within the same 50mm increments as those for the HP measurements, moderate to relatively strong correlations with goodness-of-fit R^2 of 0.5 are achieved between DCP/HP in points no 3 / 4 (figure 9A), suggesting the following linear relationship

- $HP = 9.4 – 0.2(DCP)$ (*Eq. 1*, $R^2=0.5$ @ $DCP < 37$)

Eq. (1) is based on a DCP index of < 37 mm/blow, which indicates a relatively dense soil. If the softer sounding point of DCP1 is considered, for which the DCP index is > 50 mm/blow, the correlation becomes weak (figure 9B, points no 1 and 2). Nevertheless, by excluding those loose DCP index measurements of DCP1 (i.e., removing DCP index > 37), the correlation becomes equal to that of *Eq. (1)* (figure 9B). This suggests that HP is related to DCP in terms of relatively dense soils, and less so for softer soils.

In sandy soils, Mohammadi et al., (2008) correlated the DCP index (mm/blow) with the effective friction angle (φ’, ˚) by

- $\varphi' = 52.16/(DCP)^{0.13}$ (*Eq. 2*)

Thus, *Eq. (1)* suggests that the medium to loose soil above the ground water level (i.e., 23 < DCP < 37 mm/blow) (figure 6), corresponds to an HP cone resistance of 2 to 5MPa. *Eq. (2)* indicates that this layer of soil (i.e., in DCP4, figure 6A) corresponds to an effective friction angle of 32-34˚, which is a reasonable upper estimate for sandy soils (Larsson, 2008).

By elaborating on *Eq. (1)* and *Eq. (2)* it suggests that the effective friction angle (φ’) is related to the HP penetration resistance by

- $\varphi' = 52.16/(47 – 5\,HP)^{0.13}$ (*Eq. 3*).

Eq. (2) and *Eq. (3)*, see figure 9, shows again the relatively close relationship for DCP ≤ 37 mm/blow and HP >~ 2 MPa between DCP and HP, here plotted against φ’ > 32˚. However, at φ’ < 32˚, the correlation becomes gradually less (also Figure 8B, DCP > 37).

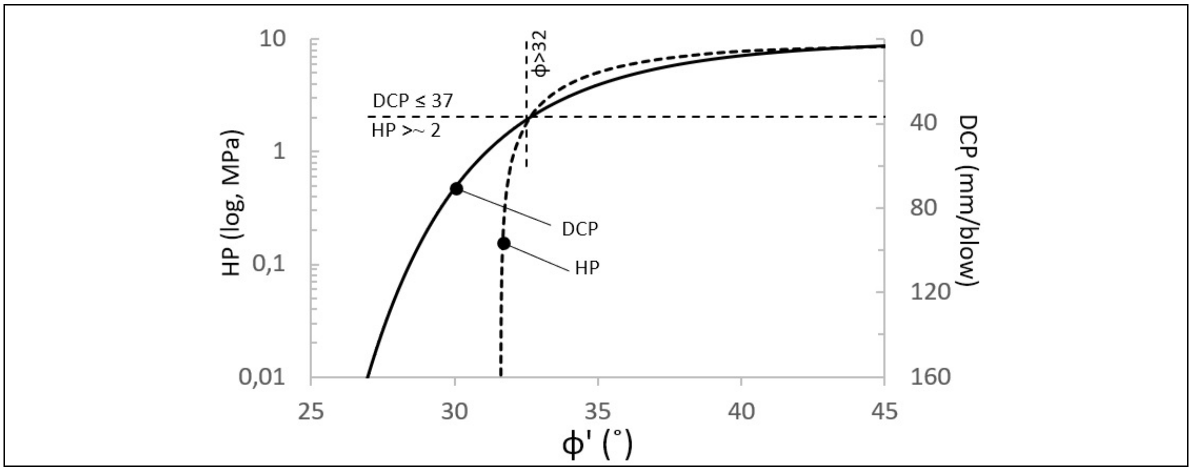


Figure 9: The plots of the DCP and HP (log scale) in relation to effective friction angle.

CONCLUSIONS

In the present study, the widely used dynamic cone penetrometer (DCP) was correlated with hand penetrometer (HP) measurements. The tested soil was a natural deposit of Swedish postglacial sand sitting on top of a sandy, silty clay. Relatively good agreement between the methods was obtained, indicating that for relatively dense soils with a DCP index ≤ 37 mm/blow, the DCP index (mm/blow) correlates to the HP cone resistance (MPa) by the linear relationship of $HP = 9.4 – 0.2(DCP)$ with a correlation coefficient of $R^2 = 0.5$. Furthermore, for the practicing engineer, DCP and HP measurements are correlated herein to the effective friction angle of soils, which combined may provide a tool for an initial determining of bearing capacity in situ.

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NOTATION

DCP index	Dynamic cone penetrometer, mm/blow.
HP	Hand penetrometer, MPa.
R^2	Coefficient of determination, “goodness-of-fit”, Correlation coefficient.
GWL	Ground water level.
Φ’, φ’	Effective friction angle, (°).
ρ	Density, kg/m^3, = m/V.
ϒ	Unit weight, kN/m^3, = ρ * g.
ω	Water content, %, = $m_w/m_{s.}$
m	Mass, kg.

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Editor’s note.
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