VILNIUS UNIVERSITY

Gintaras Žaržojus

ANALYSIS OF THE RESULTS AND IT INFLUENCE FACTORS OF DYNAMIC PROBING TEST AND INTERRELATION WITH CONE PENETRATION TEST DATA IN LITHUANIAN SOILS

Summary of Doctoral Thesis

Physical Sciences, Geology (05 P)

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Doctoral thesis was prepared during 2006 – 2010 in Vilnius University

Research supervisor:

prof. dr. Kastytis Juozas Dundulis (Vilnius University, Physical Sciences, Geology – 05 P).

Consultant supervisor:

doc. dr. Saulius Gadeikis (Vilnius University, Physical Sciences, Geology – 05 P).

Doctoral thesis shall be defended in council of geological sciences in Vilnius University:

Chairman

habil. dr. Valentinas Baltrūnas (Nature Research Centre, Institute of Geology and Geography, Physical Sciences, Geology – 05 P)

Members:

doc. dr. Jonas Amšiejus (Vilnius Gediminas Technical University, Technological Sciences, Civil Engineering – 02 T)

prof. habil. dr. Jonas Mažeika (Nature Research Centre, Institute of Geology and Geography, Physical Sciences, Geology – 05 P)

habil. dr. Saulius Šliaupa (Nature Research Centre, Institute of Geology and Geography, Physical Sciences, Geology – 05 P)

dr. Albertas Bitinas (Klaipeda University, Physical Sciences, Geology – 05 P)

Opponents:

prof. dr. Arnoldas Norkus (Vilnius Gediminas Technical University, Technological Sciences, Civil Engineering – 02 T)

dr. Jonas Satkūnas (Lithuanian Geological Survey, Physical Sciences, Geology – 05 P)

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Address: M. K. Čiurlionio st. 21/27, LT–03101, Vilnius, Lithuania

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Gintaras Žaržojus

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Mokslinis vadovas:

prof. dr. Kastytis Juozas Dundulis (Vilniaus universitetas, fiziniai mokslai, geologija – 05 P).

Konsultantas:

doc. dr. Saulius Gadeikis (Vilniaus universitetas, fiziniai mokslai, geologija – 05 P).

Disertacija ginama Vilniaus universiteto Geologijos mokslo krypties taryboje:

Pirmininkas

habil. dr. Valentinas Baltrūnas (Gamtos tyrimų centro Geologijos ir geografijos institutas, fiziniai mokslai, geologija – 05 P)

Nariai:

doc. dr. Jonas Amšiejus (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija – 02 T)

prof. habil. dr. Jonas Mažeika (Gamtos tyrimų centro Geologijos ir geografijos institutas, fiziniai mokslai, geologija – 05 P)

habil. dr. Saulius Šliaupa (Gamtos tyrimų centro Geologijos ir geografijos institutas, fiziniai mokslai, geologija – 05 P)

dr. Albertas Bitinas (Klaipėdos universitetas, fiziniai mokslai, geologija – 05 P)

Oponentai:

prof. dr. Arnoldas Norkus (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija – 02 T)

dr. Jonas Satkūnas (Lietuvos Geologijos Tarnyba, fiziniai mokslai, geologija – 05 P)

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Adresas: M. K. Čiurlionio g. 21/27, LT–03101, Vilnius, Lietuva

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INTRODUCTION

Relevance of the thesis. With growing scopes of constructions and more complex buildings that foundations are located in deeper and deeper soil layers, required prompt and economical soil testing methods. The key information on soil characteristics while performing engineering geological researches is taken from various methods of penetration test. Among field researches, the most worldwidely used methods are the cone penetration test (CPT), and standard penetration test (SPT) is a little more rarely used. In Lithuania, performing engineering geological investigations, there are static (CPT) and dynamic (DPT) probes commonly used.

Due to their peculiarities, static cone and standard penetration tests are the most suitable for penetration of relatively weak soils without gravel and pebble admixture or their layers. In Lithuania, the most common basis of foundation is glacigenic and alluvial deposits of Pleistocene age that physical and mechanical properties of separate strata may differ significantly. These soils often contain quite large quantities of gravel and pebble admixtures, in some cases – their entire strata. Such usually complicated geological section encumbers work with CPT equipment and strata that need to be researched remain beyond penetration test. Dynamic penetration test is impossible to replace when deeper soil layers covered with strong soils must be tested. In case of complex constructions, their deepening often exceeds 15–20 m. Such depth is unreachable with CPT, therefore DPT is used instead, and then it is able to reach a target designed depth without any serious obstacles.

Dynamic penetration test is most often used to evaluate the physical condition of soils; however its results are not involved in foundation design directly. Following the current standard requirements, factors leading to energy loss and effecting DPT results are underevaluated. Interrelations of DPT and CPT parameters have not been studies sufficiently. Identification of these links and correlation would provide favourable conditions to design deep foundations according to DPT results directly.

Object of the thesis – soils occurring within the territory of Lithuania subject to basis of building foundations.

The aim of the thesis – reliability evaluation of dynamic penetration test data, processing of primary results and setting of correction coefficients, search and assessment of interrelation between data of dynamic and cone penetration tests.

Tasks of the thesis:

- to analyze methods of cone and dynamic penetration tests, application of received data for evaluation of soil properties and performance of geotechnical design, and to identify points of data interpretation;
- to evaluate reliability of dynamic penetration test parameters (N_x ir q_d), set the relation between values of the number of blows (N_x) of different type dynamic penetration tests and find interrelation coefficients;
- to identify factors effecting reliability of data of dynamic penetration test and assess the scope of such effect;
- to trace correlation of dynamic and cone penetration test parameters in soils within the territory of Lithuania and evaluate reliability of their relation.

Scientific novelty of the thesis:

- comprehensive evaluation of reliability of dynamic penetration test parameters and the ratio of the number of blows between different type probes have been performed;
- corrections of the number of blows due to the impact of lateral friction and overburden pressure on penetration data have been indicated, methods of blow efficiency evaluation of various dynamic systems have been applied to DPT data;
- correlation dependences between the number of blows (N_{20}) of dynamic penetration test parameter and cone penetration test parameter – cone resistance (q_c) have been estimated.

Defended propositions:

- dynamic point resistance (q_d) – the indirect, derivative parameter of dynamic penetration test is replaceable with the direct DPT measurement parameter – number of blows (N_x);
- during dynamic penetration test values of the number of blows (N_x) may be increased up to 80% due to the change of penetration test equipment mass, lateral friction and overburden pressure of soils;

- the number of blows (N_x) and cone resistance (q_c) are closely related and such relation depends of grain size distribution, mechanical properties and occurrence depth.

Scientific and practical value of the thesis. The thesis contributes in better understanding of energy transfer during the penetration test and allows confirmation of penetration test data. Through interpretation of the number of blows, significant errors resulting from impact of various factors may be avoided. The analysis of correlation between dynamic and cone penetrations tests allows simplified application of DPT data in geotechnical design.

Approval of the work results. The work results were discussed in the 4th scientific conference of the Faculty of Natural Sciences of Vilnius University "Science in the Faculty of Natural Sciences" (Vilnius, 2006); the 9th international conference "Modern building materials, structures and techniques" (Vilnius, 2007); the 11th geotechnical conference of the Baltic states "Geotechnics in maritime engineering" (Gdansk, 2008); the 2nd international symposium on cone penetration tests "CPT'10" (Huntington Beach, CA, 2010).

Publications. 9 scientific articles on the dissertation subject have been published, including 2 publications in editions entered in the list of Information Sciences Institute (ISI), 7 – in reviewed international, foreign and Lithuanian editions.

Scope and structure of the thesis. The thesis contains the introduction, 4 chapters, conclusions, the list of references and the list of the author's publications. The scope of the thesis – 147 pages. The text includes 104 figures and 37 tables. The list of references provides 95 bibliographies.

1. REVIEW OF GEOTECHNICAL PENETRATION TEST METHODS AND RESULT INTERPRETATION

In engineering geological investigations, there are various methods of soil penetration tests used that differ in both technique and parameters received during works. All probes used in geotechnics can be divided into two large groups, i.e. probes deepened under the influence of static and dynamic loadings. The key objective of interpretation data received during the penetration test is to assess values of parameters of geotechnical properties of soils of the investigation site (Fig 1.1). This is the only objective; however reliability of received data is rather different. Moreover, some probes are suitable for coarse (uncohesive) soils, the others – for fine (cohesive) soils. Calculating physical or mechanical properties of soils according to direct penetration data, reliability of the results also vary (Table 1.1). Thus, all these factors determine precise design of foundations and other underground or overground constructions.

Soil testing by means of cone penetration test takes the main part in engineering geological field investigations. Scientists are especially attentive to this particular research method as it enables indication of the greatest number of correlation dependences between CPT rates and geotechnical properties of soil; methods of building foundation designing are based on values of CPT parameters; there exists a number of evaluation methods of potential of liquefaction of soils and etc. (Lunne, Powell etc., 1997; Schnaid, 2009; Been, Quinonez etc., 2010; Robertson, 2006; Yu, 2006; Sagaseta, Houlsby, 1992 et al.).

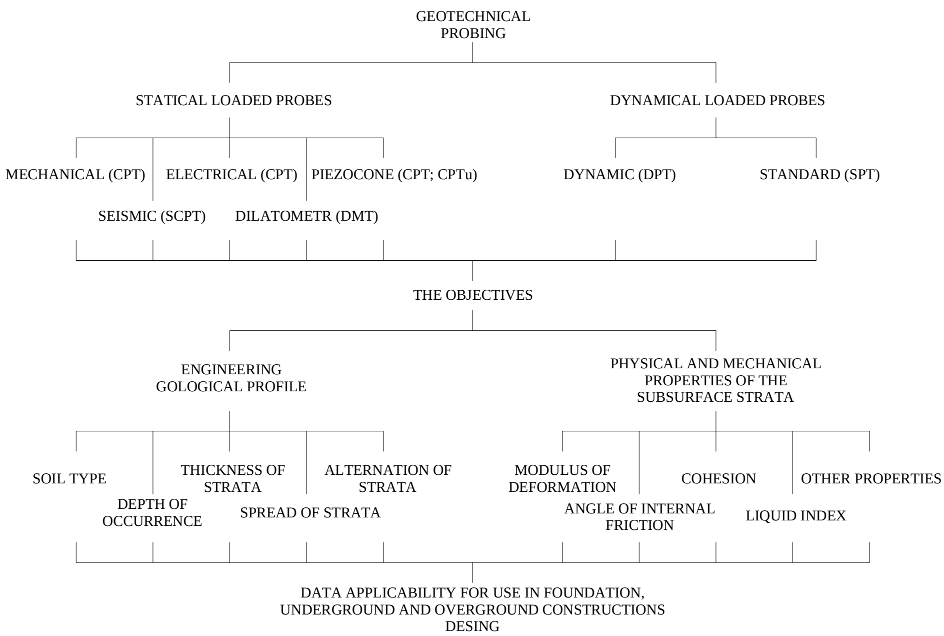

Fig. 1.1. Geotechnical penetration tests: types of probes, objectives and application

Table 1.1. The applicability and usefulness of in-situ tests (Lunne, Robertson and Powell, 1997)

Device	Soil parameters												Soil type				
	Soil type	Profile	u	φ	s_u	I_D	M_v	c_v	k	G_0	σ_h	OCR	Gr	Sa	Si	Cl	O
Dynamic (DPT)	C	B	-	C	C	C	-	-	-	C	-	C	B	A	B	B	B
Mechanical (CPT)	B	A/B	-	C	C	B	C	-	-	C	C	C	C	A	A	A	A
Electric (CPT)	B	A	-	C	B	A B	C	-	-	B	B C	B	C	A	A	A	A
Piezocone (CPTu)	A	A	A	B	B	A B	B	A B	B	B	B C	B	-	A	A	A	A
Seismic (SCPT)	A	A	A	B	A B	A B	B	A B	B	A	B	B	-	A	A	A	A
Dilatometer (DMT)	B	A	C	B	B	C	B	-	-	B	B	B	-	A	A	A	A
Standard (SPT)	A	B	-	C	C	B	-	-	-	C	-	C	B	A	A	A	A

Applicability: A – high; B – moderate; C – low; - – none.
Soil parameter definitions: u – static pore pressure (*in-situ*); φ – angle of internal friction; s_u – undrained shear strength; I_D – relative density index; M_v – constrained modulus; c_v – coefficient of consolidation; k – coefficient of permeability; G_0 – shear modulus at small strains; σ_h – horizontal stress; OCR – overconsolidationt ratio; Gr – gravel; Sa – sand; Si – silt; Cl – clay; O – peat.

While performing engineering geological field investigations with probes of other types (PMT, DMT, DPT, SPT), the usage of rate values in design of foundations or calculations of soil liquefaction is limited, therefore in such cases it is endeavored to relate them with CPT data and to use formula intended for the cone probe in further calculations.

Dynamic penetration test (DPT) has been rarely employed in performance of engineering soil investigations. Still this method is irreplaceable when deeper soil layers covered with strong soils need to be tested. Due to the lack of calculation techniques, receive data is hard to use in further works of geotechnical designing; therefore it is often attempted to relate DPT data with CPT parameters. These links may be direct or indirect, related to particular parameters of soil properties. For this purpose, the indirect link with intermediate relative density index (I_D) is the most commonly used (Mandolini, 1999; Gwizdala, 1997):

$$DPT \rightarrow I_D \rightarrow CPT . \qquad (1.1)$$

However such data linking (see formula (1.1)) results in big errors and distortion of final results. Especially with the absence of reliable equations of I_D determination when data is received by means of probe of DPSH type. All these factors encourage looking for more precise correlation dependences between direct DPT and CPT parameters.

2. EVALUATION OF RELIABILITY OF DYNAMIC PENETRATION TEST RESULTS

Indirect differences between the numbers of blows may be evaluated knowing the specific work per blow (E_n) of each type of probe at the moment of blow. The bigger specific work per blow (E_n) at the moment of blow, the smaller number of blows is required for the probe to penetrate into the targeted depth.

The performed data analysis shows that an average difference of the number of blows between DPL and DPSH–A is ~ 74%, i.e. N_{DPL} exceeded N_{DPSH-A} by 74%. A similar (only reverse) difference is observed between the specific works per blow (E_n) – 75%. The determined relative relation coefficient (β'_A) is 0.26. It should be taken into account that the relation coefficient of the number of blow (β'_A) is valid only in the case when the penetration stage is equal. In this dissertation, N_{20} as studied – this applied to all types of probes.

The analysis of DPL and DPSH–A type probes allows distinguishing different relative relation coefficients of the number of blows (β'_A) for soils of different genesis and lithological composition. It was observed that in fine soils the relative correlation coefficient increases together with the increasing quantity of coarse fraction. A similar situation is observed in coarse soils – the more coarse soil, the higher relative coefficient (β'_A) is. Relative coefficients of the number of blows (β'_A) of the most commonly met soil varieties are given in Table 2.1.

Table 2.1. Percentage and relative values of the relation coefficient of the number of blows (β'_A)

Soil type	β'_A, %	β'_A, unit
saclSi, saCl, clSi (till)	46.8	0.47
sasiCl, siCl (till)	34.8	0.35
saclSi, saCl, clSi	25.8	0.26
sasiCl, siCl	16.3	0.16
CGr, MGr, FGr, saGr	26.9	0.27
grCSa, grMSa, grFSa, CSa – with admixture of others fractions	19.1	0.19
MSa, FSa – with moderate admixture of others fractions	14.8	0.15
siSa, siFSa – up to dominate of fraction of silt	12.8	0.13

The relation coefficient of the number of blows (β'_A) may be determined knowing the coefficient depending on the composition of grain size distribution of soils. This coefficient (k) in fine soils varies from 1 to 4 and depends on the composition of grain size distribution of soil (see formula (2.1)). In coarse soils, such correlation coefficient is the size of prevailing fraction particles (d) (see formula (2.2)).

$$\beta'_A = 56 - 10 \cdot k\,; \tag{2.1}$$

$$\beta'_A = 2{,}2 \cdot d + 13{,}5\,; \tag{2.2}$$

where k – coefficient that depends on the composition of grain size distribution of the studied fine soil and varies from 1 to 4; d – fraction size that determines the soil type, mm.

Collected penetration data enabled to evaluate the difference of the number of blows penetrating glaciolacustrine fine soils with DPL and DPSH–B. The determined difference of the number of blows is ~ 86%, thus the relative relation coefficient (β'_B) is ~ 0.14.

Differences of the number of blows studying glaciolacustrine fine soils ere evaluated using DPSH–A and DPSH–B type probes as well. The percentage difference of the number of blows – approximately 10%., the relation coefficient (β'_{AB}) is ~ 0.9.

Data of dynamic penetration test can be also assessed using the indirect parameter – dynamic point resistance (q_d, MPa). To calculate this parameter, many various driving formulas can be used (Table 2.2).

Comparative calculations of dynamic point resistance were made analyzing the data of DPL and DPSH–A probes. Fine (cohesive) glacial soil (sandy clayey silt till) and coarse soil (fine sand) were selected for studies.

Having calculated values of dynamic point resistance (q_d, MPa) according to the data of DPSH–A probe received while penetration of sandy clayey silt till, it appeared that the difference between results estimated by various driving formulas is rather big: minimal q_d value is 4.9 MPa (calculated according to Hiley's formula), maximal q_d value is 30.3 MPa (calculated according to Haefeli's formula). Percentage difference between minimal and maximal q_d values is 84% (Fig. 2.1).

Table 2.2. Summary table of driving formulas used on calculations of dynamic point resistance (q_d)

Driving formula	Equation for q_d
Engineering News	$\frac{W \cdot H}{A^* \cdot (S + C)}$
Eytelwein (Dutch) or ISO 22476-2:2005	$\frac{W \cdot H}{A^* \cdot S} \cdot \frac{W}{W + W_P}$
Hiley	$\frac{e_f \cdot W \cdot H}{A^* \cdot \left(S + \frac{1}{2} \cdot (C_1 + C_2 + C_3) \right)} \cdot \frac{W + n^2 \cdot W_P}{W + W_P}$
Janbu	$\left(\frac{1}{k_u} \right) \cdot \left(\frac{W \cdot H}{A^* \cdot S} \right)$
Danish	$\frac{e_f \cdot W \cdot H}{S + \left(\frac{2 \cdot e_f \cdot W \cdot H \cdot L}{A^* \cdot E_P} \right)^{\frac{1}{2}}}$
N. M. Gersevanov	$\frac{n \cdot \omega}{2} + \sqrt{\left(\frac{n \cdot \omega}{2} \right)^2 + \frac{k}{h} \cdot \left(n \cdot \omega \cdot Q \cdot H \cdot \frac{Q + l^2 \cdot q}{Q + q} \right)}$
G. K. Bondarik (1961)	$\frac{P_1 \cdot H}{\left(1 + \frac{P_2}{P_1} \right) \cdot \pi \cdot r^2 \cdot s} + \frac{P_1 + P_2}{\pi \cdot r^2} - \frac{F}{\pi \cdot r^2}$
G. K. Bondarik (1964)	$\alpha \cdot A + \frac{q + Q - F}{\omega}$
A. J. Rubinshtein	$\alpha \cdot A - F_{ud} - P_{byt}$
R. Haefeli etc.	$A + \frac{q + Q}{\omega}$
E. Paprot	$\alpha \cdot A + \frac{q + Q}{\omega}$
GOST 19912-2001	$\frac{A \cdot K_1 \cdot K_2 \cdot n}{h}$

Recalculation of the direct data ($N_{DPSH\text{-}A}$) received from dynamic penetration test of fine sand with DPSH–A probe to the indirect parameter q_d shows that the difference between the minimal and maximal average is big: 4.5 MPa (according to Hiley's formula) and 20.9 MPa (according to Haefeli's formula), – it amounts 78% (Fig. 2.2).

Similar results have been worked out while analyzing the data of DPL probe in sandy clayey silt till. The minimal value q_d = 1.2 MPa (calculated according to Hiley's formula), maximal value q_d = 8.0 MPa (calculated according to Haefeli's formula). This difference between the minimum and maximum makes 85% (Fig 2.3).

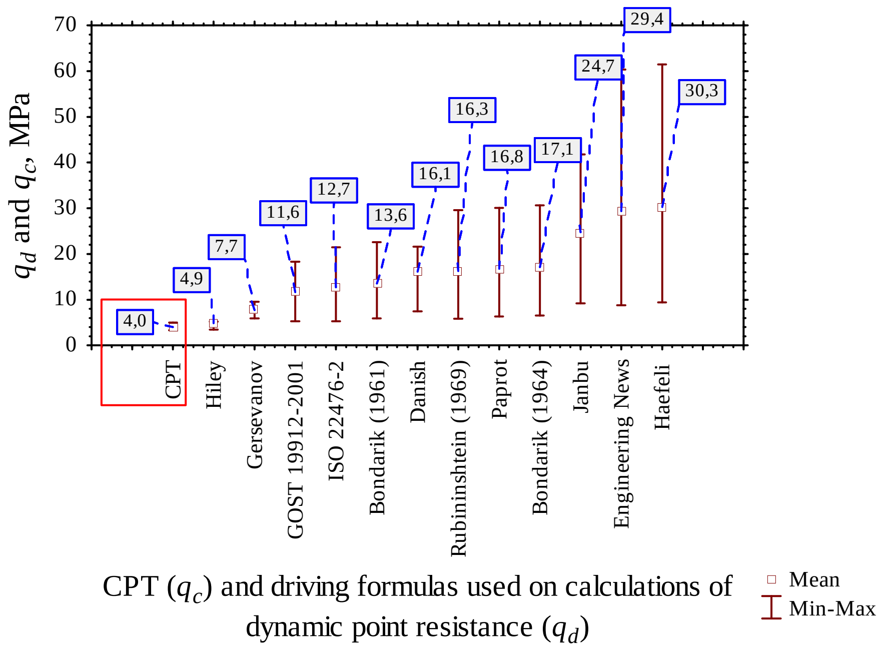

Fig. 2.1. Calculation results of dynamic point resistance (DPSH–A probe; sandy clayey silt till)

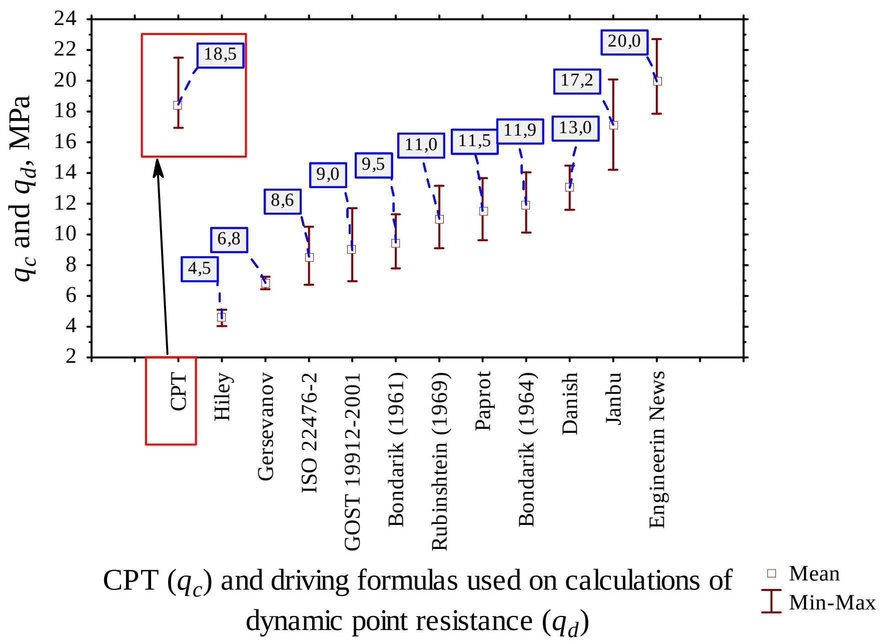

Fig. 2.2. Calculation results of dynamic point resistance (DPSH–A probe; fine sand)

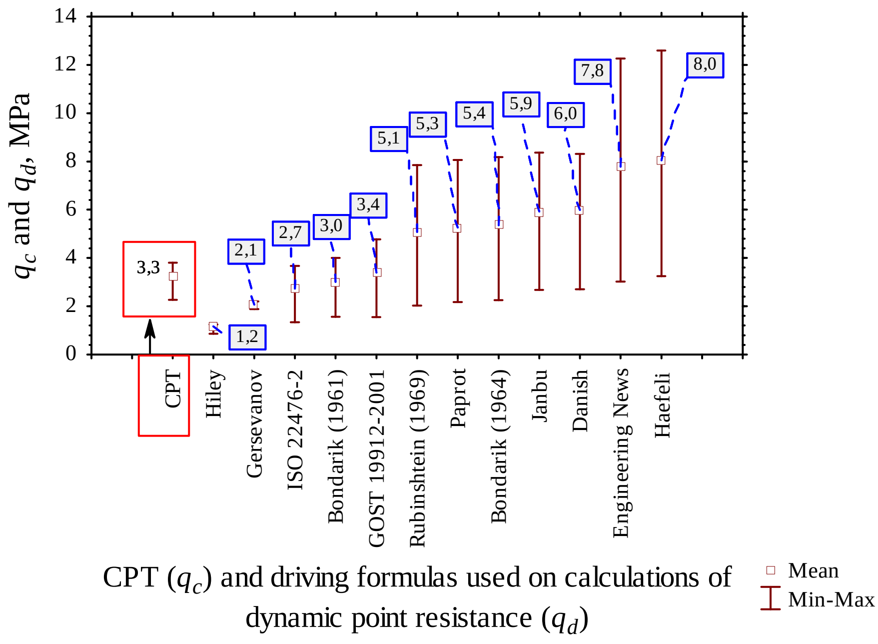

Fig 2.3. Calculation results of dynamic point resistance (DPL probe; sandy clayey silt till)

Recalculation of DPL probe data while penetrating fine sand to q_d values resulted in a large gap of arithmetic averages (q_d min. = 1.0 MPa, q_d max. = 4.3 MPa, – difference 77%). (see Fig. 2.4).

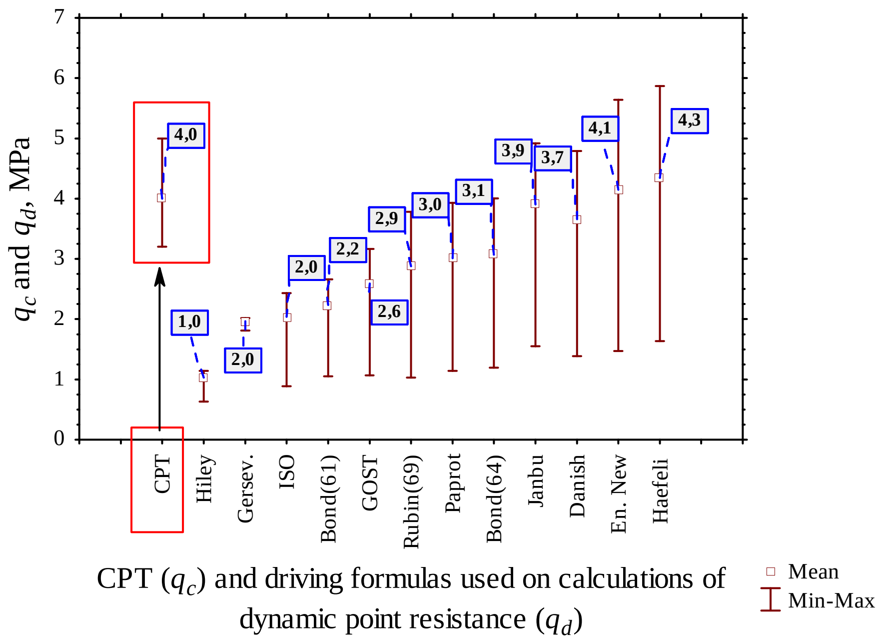

Fig. 2.4. Calculation results of dynamic point resistance (DPL probe; fine sand)

DPT probe data analysis reveals that while recalculating the number of blows to q_d values, various coefficients used in formulas are imprecise and do not reflect an actual soil resistance to the point penetration. The real value of dynamic point resistance is unknown, however it can be supposed that distribution of q_d values in the penetration depth in a particular ratio must repeat values of the cone probe data (q_c, MPa). These calculation results show that values of the dynamic point resistance are sensitive to the factors effecting the number of blows (blow efficiency, lateral friction of soils and geostatic pressure).

Penetrating similar soils with different probes, a different number of blows is worked out, and this is natural since probe dimensions differ. According to some scientists (Rubinshtein et al., 1984; Stefanoff et al., 1988), recalculation of the number of blows to the dynamic point resistance makes the data invariant, i.e. independent from the type of used equipment. Recalculations of the number of blows (penetrating in fine sand with DPL and DPSH–A probes) to q_d have not revealed any invariantability. Although calculating according to a number of formulas, the arithmetic average of the ratio (Δ) was close to 1.0, but there was a big data distribution in sample (see Fig 2.5). The arithmetic average cannot show invariantability. The values of analyzed data in sample must be close to the average, and the sample amplitude must approach zero ($A \rightarrow 0$).

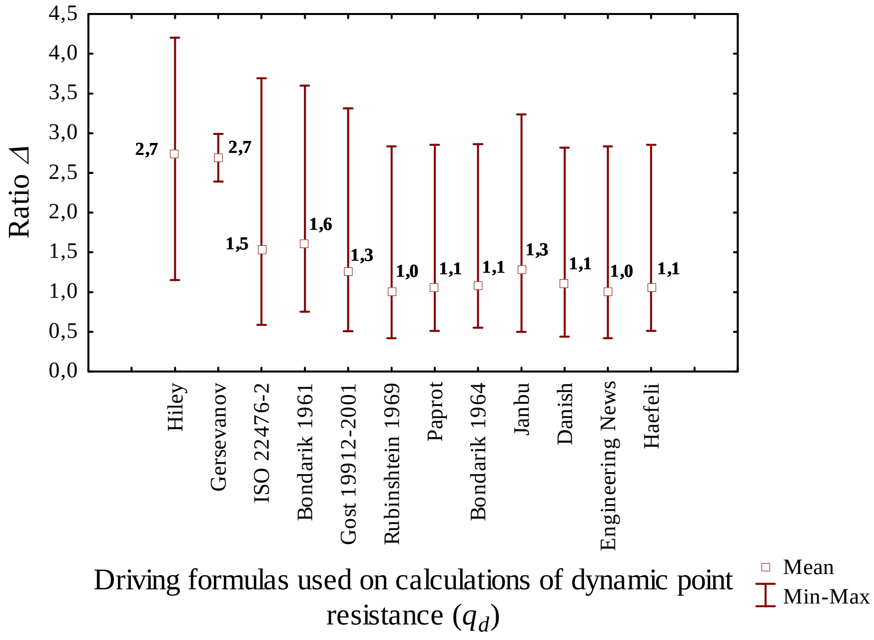

Fig. 2.5. Distribution of values of the ratio (Δ) calculating according to different driving formulas

The key weakness of all driving formulas is that the penetration energy value used in calculations is theoretic, and the real one in unknown. It is not possible to evaluate this by means of available formulas as a great number of factors are involved in energy transfer that distort values of initial delivered energy.

Having summarized the aforesaid research and calculation results, due to insufficient reliability of values of the dynamic point resistance (q_d) only the number of blows (N_x) may be used in further calculations considering the type of used equipment and evaluating the penetration depth.

3. ANALYSIS OF FACTORS EFFECTING THE NUMBER OF BLOWS

The number of blows (N_{20}) revealed during dynamic penetration test does not reflect actual strength properties of penetrated soil. Values of this parameter (N_{20}) depend not only on geotechnical properties of soils but also on the particularity of used equipment, i.e. the initial blow energy of the sledge-hammer (E_{smg}) and the energy amount in the point ($E_{k\bar{u}g}$). The blow efficiency or energy part distributed on the probe depending on the equipment type will differ (Fig. 3.1). In case of DPL probe, all the energy of the sledge-hammer will reach the probe only in the depth of 6 m, and in case of DPSH–A – only a part of the initial energy will reach the probe. This is true only if the lateral friction of rods to soil is eliminated.

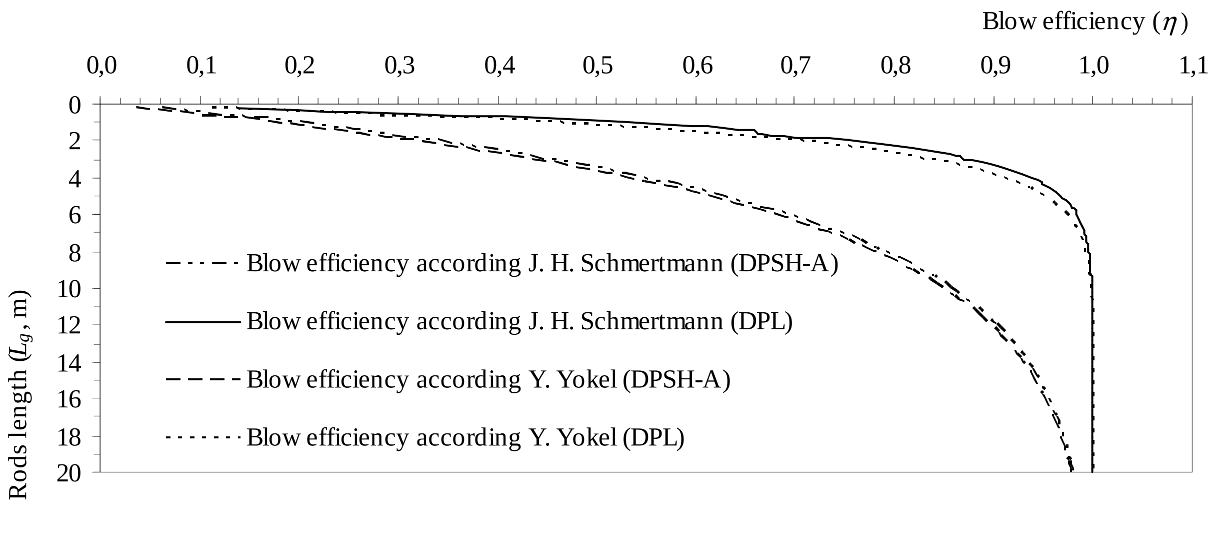

Fig 3.1. Blow efficiency depending on penetration type and selected calculation method

Researches show that despite the gap between soil and penetration rods caused by the difference of diameters of penetration rods (Ø 32 mm) and the cone (Ø 45 mm) (ratio 0.7), friction influences the number of blows in fine soils (N_{20}). This friction of lateral surface of penetration rods to soils consumes ~ 12.5% of energy that should be distributed to the cone point. In the investigated site, for this reason the number of blows increased by 4–5 blows approximately (Fig. 3.2). Penetrating in fine soils, such, though small, energy loss may distort results (N_{20}) significantly.

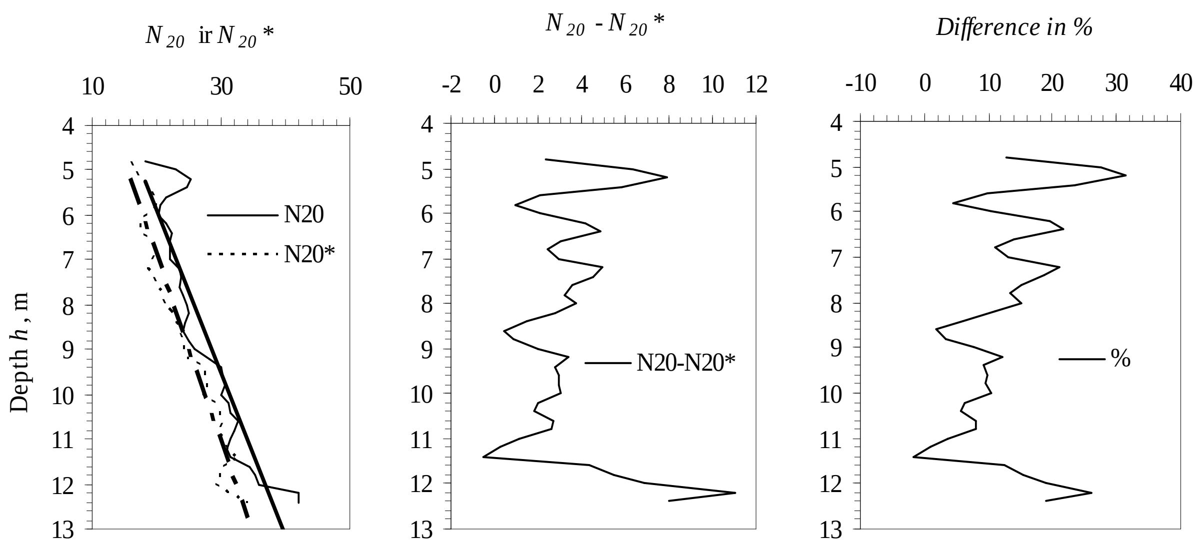

Fig. 3.2. Diagram of average values of points (No. 1, 2, 3, 4) of dynamic penetration test (DPSH–A)

The data of dynamic penetration test is greatly influenced by the lateral overburden pressure of soils. This influence is less observable in coarse soils. While analyzing the penetration data and calculating the ratio of cone resistance (according to CPT) and number of blows (according to DPSH-A) (q_c/N_{20}), the change of the ratio was observed when going deeper: the ratio in the depth range of 8–10 m was lower by 10% to 20% in comparison to the ratio in the depth of 1–2 m. The ratio reduction when going deeper is linear or close to linear. During the experiment, while penetrating in the stratum of coarse soil the number of blows N_{20} (penetrated from the ground surface) was around two times bigger than values of the number of blows N_{20}* (penetrated from the boring bottom), i.e. the percentage difference of the number of blows was ~ 50%. Such big ratio of the number of blows (N_{20}/N_{20}*) resulted from the till sandy silt layer with the thickness of 4 m above the coarse soil layer (Fig. 3.3). Considering the research and calculation results above it can be stated the results of dynamic penetration test in coarse soils increase when going deeper according to the linear equitation, and in the depth of 8 m to 10 m the percentage difference amounts 10–20%. When the geological section of penetrated thickening changeable and a stratum of fine soils cover coarse soils, the number of (N_{20}) may be up to 50% and more in comparison to the number of blows possible if penetration rods were not effected by the horizontal components of overburden stress.

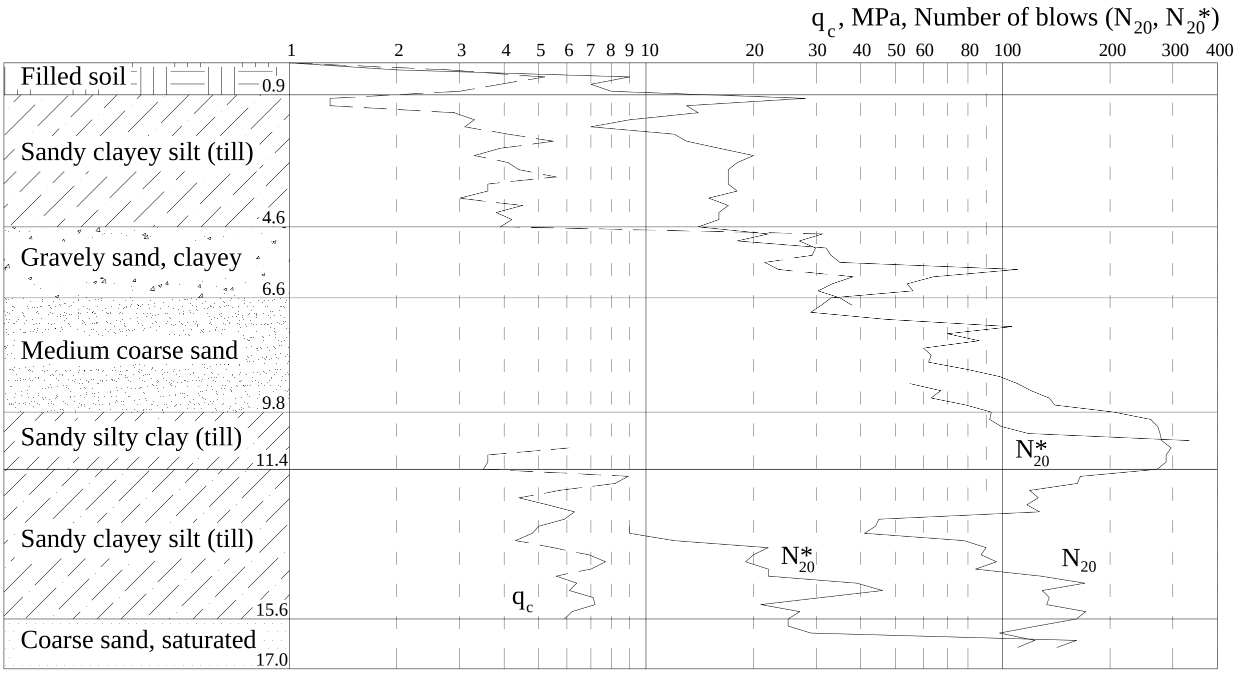

Fig 3.3. Geological profile in the investigated site, CPT and DPSH–A penetration data

Researches and analysis of various other probes show that the influence in fine (cohesive) soils is very high. The number of blows (N_{20}) increases approximately in the range of logarithmic curve, although geotechnical properties of penetrated soil in the geological section changes insignificantly. The logarithmic change results from ability of fine soils to maintain walls that appear between penetration rods and soil. The appeared cavity, according to the data analysis results, remains up to 4–5 m, further this cavity reduces do to the overburden stress, and soil starts pressing the rods. At the same time, the growing pressure increases friction and reduces energy transfer to the cone. According to the research results, penetrating in sandy clayey silt till in the depth from 13 to 16 m the ratio between the number of blows (N_{20}) and the number of blows (N_{20}*) is ~5, – it amounts around 80% of the initial energy loss (the number of blows N_{20} increases by 80%) (Fig. 3.3). Such big difference of the number of blows may crucial influence on the evaluation of properties of fine soil, therefore, calculating according to the formula (3.1), it is possible to assess approximately (correlation coefficient R = 0.86) what number of blows (N_{20}*) would be if the geostatic pressure or the real soil resistance to penetration of the driven probe was eliminated.

$$N_{20}^{*} = \frac{N_{20}}{0.5911 \cdot e^{0.1483 \cdot h}}, \tag{3.1}$$

4. INTERRELATIONS OF PARAMETERS OF DYNAMIC AND CONE PENETRATION TEST

In the process of dynamic penetration test, there are various side factors active. The most effective ones are the lateral friction and geostatic pressure and the change of energy transferred by the sledge-hammer. These three key factors are related to the depth of penetration (h). Relation of the number of blows (N_x) with the cone resistance (q_c) due to the said factors depends greatly to the penetration depth (h). Wile correlating N_x and q_c, it should be considered and then the correlation analysis becomes trinomial. Such correlation is pretty complex, thus its accuracy is often questioned. The use of the ratio of cone resistance and number of blows (α_x) (4.1)) in the correlation analysis facilitates it in the light of mathematics as only two parameters are correlated.

$$\alpha_x = \frac{q_c}{N_x}, \tag{4.1}$$

$$\alpha_x = \pm C_1 \cdot h^3 \pm C_2 \cdot h^2 \pm C_3 \cdot h \pm C_4; \tag{4.2}$$

$$\alpha_x = \pm C_2 \cdot h^2 \pm C_3 \cdot h \pm C_4; \tag{4.3}$$

$$\alpha_x = \pm C_3 \cdot h \pm C_4; \tag{4.4}$$

$$\alpha_x = a \cdot h^{\pm n};\quad (4.5)$$

$$\alpha_x = a \cdot e^{\pm b \cdot h};\quad (4.6)$$

$$\alpha_x = \pm d \cdot \ln(h) \pm c;\quad (4.7)$$

where C_1, C_2, C_3 and C_4 – trinomial (formula (4.2)), quadratic (formula (4.3)) and linear (formula (4.4)) equation constants; a and b – constants of equations (4.5) and (4.6); n – exponents of equations (4.5) and (4.6); d and c – constant of logarithmic equation (4.7); h – depth where the ratio value (α_x) is searched.

Correlation of light dynamic probing (DPL) and cone probe (CPT) parameters expressed through the ratio (α_{DPL}) shows a close and very close relation (R ~ 0.9). Inter-dependence of rates is clearly described in the trinomial (cubic) regression polynomial equation (4.2), which commonly works in the depth up to 4–6 m. In further depths, the ratio value is taken as a constant or its distribution is described as a power equation (4.5). Constant values of equations (4.2) and (4.3) depending on soil are given in Table 4.1.

Table 4.1. Constant values of equations (4.2) and (4.3) for different soils when penetrated with DPL

Soil type	Constants of polynomial equations (4.2) and (4.3)				Coefficient of correlation (R)	Remarks
	C_1	C_2	C_3	C_4		
GrSa; CSa; MSa; FSa	0.001	-0.0149	0.0568	0.0199	0.97	
Till sasiCl	0.0042	-0.0439	0.1319	-0.032	0.99	Applicable to 5.0 m of depth. Deeper use: $\alpha_{DPL} = 0.05$
Till saclSi	0.0024	-0.0306	0.1012	0.0333	0.96	Applicable to 6.0 m of depth. Deeper use: $\alpha_{DPL} = 0.5614 \cdot h^{-1.2626}$
saclSi saSi	-	-0.0024	-0.0063	0.1443	0.74	Applicable to 4.0 m of depth. Deeper use: $\alpha_{DPL} = 0.15 \cdot h^{-0.4}$
Si and clSi sasiCl, siCl	-	-	-	-	-	$\alpha_{DPL} = 0.06 \div 0.03\,(0.04)$

Data presented in table valid if the number of blows is recorded every 20 cm (N_{20}) penetration. If number of blows is recorded every 10 cm (N_{10}) penetration, then α_{DPL} values is necessary to multiply from 2.

The polynomial equations (4.2) and (4.3) (Fig. 4.1 and 4.2) of interdependence of parameters in the case of DPL correlation with CPT allow the statement that penetration data is effected by the efficiency of the blow of the sledge-hammer (η). Interdependence of the corrected ratio (α_{DPL}) and penetration depth (h) is described by both linear (coarse soil) and logarithmic and exponential (fine soil) equations.

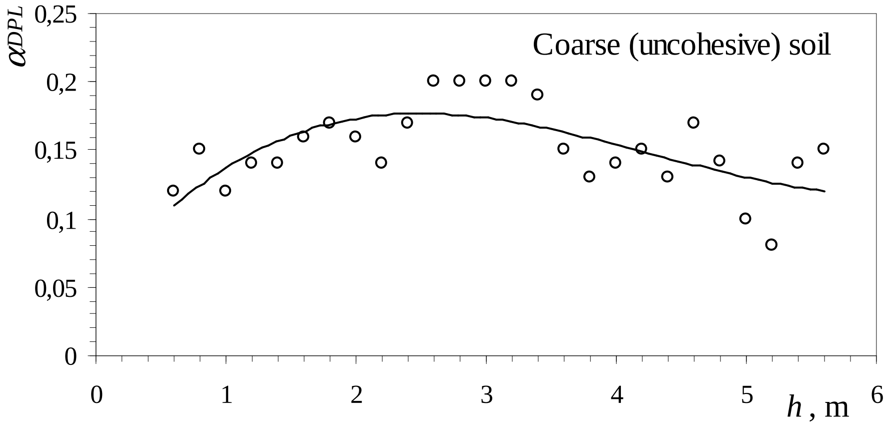

Fig. 4.1. Diagram of data distribution of average values of the ratio (α_{DPL}) in coarse soil (samples every 20 cm)

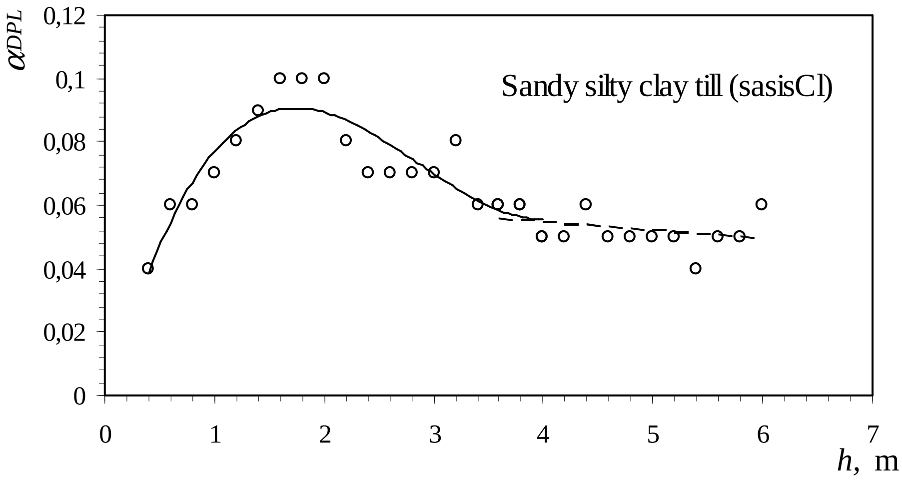

Fig. 4.2. Diagram of data distribution of average values of the ratio (α_{DPL}) and depth (h) in sandy silty clay till (samples every 20 cm)

Correlation of the parameters of super heavy dynamic probe (DPSH–A) and cone probe shows a close relation (R ~ 0.90) between the ratio ($\alpha_{DPSH\text{-}A}$) and penetration depth (h). Regression equations, which can be used to calculate ratio values, are very different and depend on grain size distribution and strength properties of soil. Ratio dependence on the depth in coarse soils is best described in cubic and quadratic equations (Fig. 4.3), and in fine soils – power, exponential and logarithmic equations (Fig. 4.4).

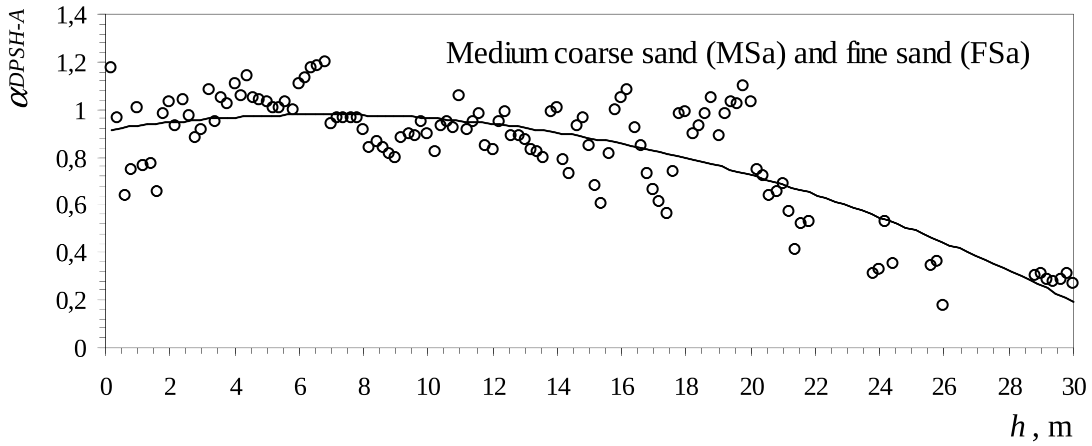

Fig. 4.3. Diagram of data distribution of the ratio (α_{DPSH-A}) with the polynomial approximating curve (samples for each 20 cm of penetration; penetrated in fine and medium coarse sand)

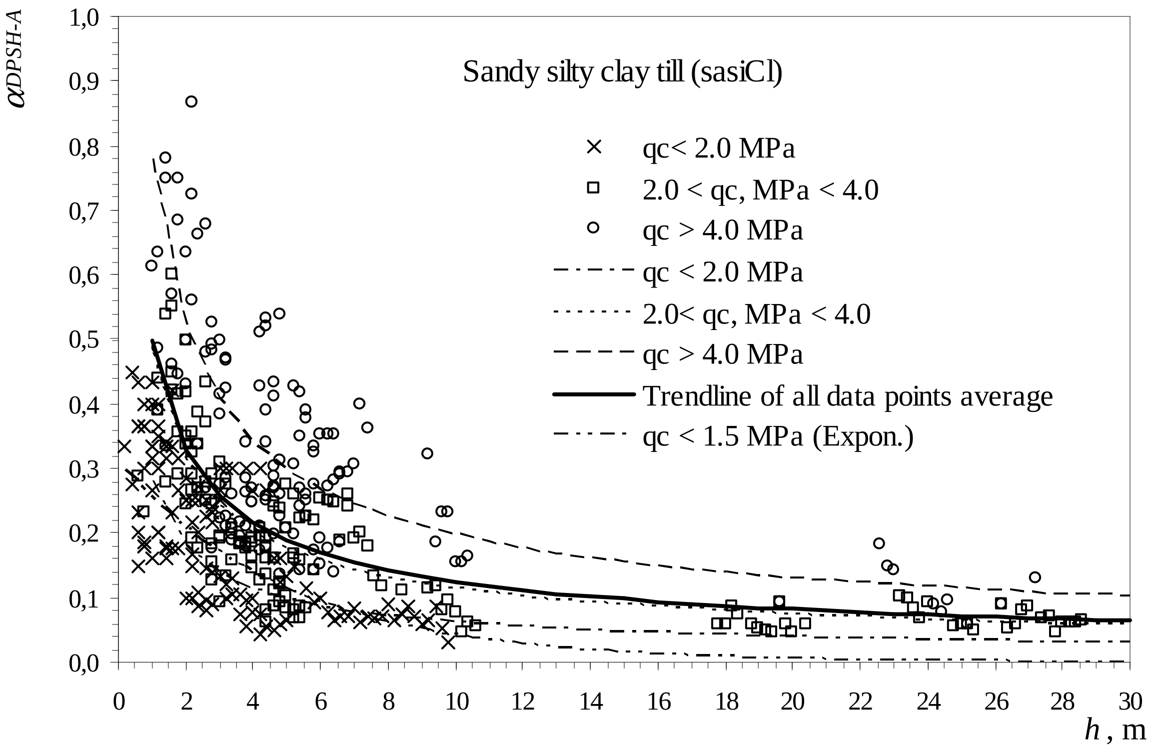

Fig. 4.4. Summarized diagram of data distribution of the ratio (α_{DPSH-A}) (sasiCl till)

Analyzing penetration data from coarse soils, the ratio α_{DPSH-A} is worked out from the quadratic equation (4.3), when coarse soil is gravelly and coarse sand, – in such case the ratio is determined according to the cubic equation (4.2) (working in the depth up to 12 m) and the linear equation (4.4) (working in the depth from 12 m). Constant values of these equations are provided in Table 4.2.

Table 4.2. Constant values of equations (4.2), (4.3) and (4.4), when penetrated with DPSH–A probe in coarse soils

Soil type	Constants of polynomial equations (4.2), (4.3) and (4.4)				Coefficient of correlation (R)	Remarks
	C_1	C_2	C_3	C_4		
siSa	-	-0.0005	-0.0184	1.0934	0.99	Applicable only for strata of coarse soil, with do not covered of fine (cohesion) soils
FSa Msa	-	-0.0015	0.00194	0.9352	0.93	Applicable only for strata of coarse soil, with do not covered of fine (cohesion) soils
CSa; GrSa	0.0014 -	-0.0332 -	0.20 -0.028	0.82 1.18	0.91	Applicable to 12 m of depth Applicable from 12 m
Coarse and fine soil	-	-	-0.015	0.663	0.81	Applicable only for strata of coarse soil, with is covered of fine (cohesion) soils

Data presented in table valid if the number of blows is recorded every 20 cm (N_{20}) penetration.

Table 4.3. Constant and exponential values of equations (4.5), (4.6) and (4.7), when penetrated with DPSH–A probe in fine soils

Soil type	Constant and exponential of equations (4.5), (4.6) and (4.7)					Coefficient of correlation (R)	Remarks
	a	b	c	d	n		
Till sasiCl	0.3238	-0.2045	-	-	-	0.92	$q_c \leq 1.5$ MPa
	0.277	-	-	-	-0.63	0.93	$1.5 < q_c$, MPa ≤ 2.0
	0.4216	-	-	-	-0.6	0.91	$2.0 < q_c$, MPa ≤ 4.0
	0.72	-	-	-	-0.6	0.94	$q_c > 4.0$ MPa
Till saclSi	0.4	-	-	-	-0.55	0.80	$q_c \leq 3.0$ MPa
	1.0	-	-	-	-0.8	0.80	$3.0 < q_c$, MPa ≤ 8.0
	2.3	-	-	-	-0.8	0.84	$q_c > 8.0$ MPa
Clay Cl	0.25 1380.0	-	-	-	-0.7 -3.6	0.60	$q_c < 3.0$ MPa to 11 m of depth from 11 m of depth
	0.36 811.0	-	-	-	-0.2 -3.32	0.77	$3.0 \leq q_c$, MPa ≤ 5.0 to 11 m of depth from 11 m of depth
	0.45 200.0	-	-	-	-0.2 -2.7	0.92	$q_c > 5.0$ MPa to 11 m of depth from 11 m of depth
Silt Si	2.0	-	-	-	-0.9	0.82	$q_c \leq 10.0$ MPa
	3.0	-	-	-	-0.9		$10.0 < q_c$, MPa ≤ 20.0
	4.0	-	-	-	-0.9		$q_c > 20.0$ MPa
sasiCl	-	-	0.34	-0.09	-	0.85	$q_c < 3.0$ MPa
	-	-	0.65	-0.18	-		$3.0 \leq q_c$, MPa < 5.0
	-	-	0.97	-0.27	-		$q_c \geq 5.0$ MPa

Data presented in table valid if the number of blows is recorded every 20 cm (N_{20}) penetration.

Dependence of the ratio (α_{DPSH-A}) and penetration depth (h) in cohesive soils is in many cases described in equations of power function (4.5) and the exponent (see formula (4.6)). However, when data is received while penetrating sandy silty clay, the ratio (α_{DPSH-A}) is determined according to the logarithmic equation (4.7).

Values of equations (4.5), (4.6) and (4.7) constants (a, b, c, d) and the exponent (n) depend on grain size distribution and strength of the penetrated cohesive soil (on q_c value). Summarized values of constants and exponents are given in Table 4.3.

While analyzing the data of dynamic penetration, it is relevant to know preliminary geotechnical properties of penetrated soils. Such information enables a more precise selection of formula constants of ratio calculation.

CONCLUSIONS

1. Dynamic penetration is an irreplaceable soil test *in-situ* method when strong or gravelly, pebbly soil strata need to be penetrated and big depths (up to 30 m) need to be reached. It is complicated to use this method in geotechnical design and this could be seen as its disadvantage; therefore data of dynamic and cone penetrations must be interrelated. Interrelations can differ, can be both direct and indirect, through parameters of other properties. The global practice does not offer reliable direct interrelations of DPT and CPT results. These interrelations are essential as provide significantly smaller errors.
2. Analyzing the data of dynamic penetration and employing experience of other countries in this field, it is necessary to take into account differences between probe types and their results. To use data completely and accurately, coefficients of interrelation of the number of blows need to be determined. During the work, it was indicated that the value of the coefficient of interrelation of the number of blows is approximately inverse to the value of specific work per blow. It was observed that in fine soils the relative relation coefficient increases together with the increasing quantity of coarse fraction. This value is the lowest when glaciolacustrine sandy silty clay and silty clay is penetrated (0.16), and the highest when sandy clayey silt till, sandy clay till and clayey silt till (0.47) is penetrated. A

similar situation is observed in coarse soils: when soil gets coarser, the relative coefficient (β'_A) increases. In silty sand β'_A = 0.13, in gravel β'_A = 0.27.

3. Having studied the results of dynamic point resistance calculations, it could be stated that distribution of values is great, and limits of change of statistic rates are also large. Such unevenness of received results is caused by use of different correction coefficients (or their absence), also by simplification of the blow process. Amount of energy transferred to the cone of the probe is probably the most important parameter required for accurate calculation of q_d. It is not possible to evaluate this with existing formulas as a great number of factors are active in energy transformation and they distort values of the initial energy. Provision of the data of dynamic penetration test by means of the indirect rate – dynamic point resistance (q_d) – is subject to change.
4. The results of dynamic penetration test are effected greatly by side factors: energy loss, friction of rods to soil and horizontal geostatic pressure. Energy volume per cone, besides equipment peculiarities, depends also on soil properties – the greater soil friction and overburden pressure (stress), the greater energy loss is. Research show that ~12.5% of energy is lost in fine soils due to the lateral surface friction of rods. When the pressure is higher, the friction is stronger and energy transfer to the cone is reduced. Following the research results, while penetrating in fine glacigenic soils in the depth from 13 to 16 m, energy loss may reach 80% (the number of blows N_{20} increases up to 80%).
5. Correlation of light dynamic probing (DPL) and cone probe (CPT) parameters expressed through the ratio (α_{DPL}) shows a very close relation (R ~ 0.9). Interdependence of parameters is clearly described in the trinomial (cubic) regression polynomial equation, which commonly works in the depth up to 4–6 m. In further depths, the ratio value is taken as a constant or its distribution is described as a power equation.
6. Correlation of the rates of super heavy dynamic probe (DPSH–A) and cone probe shows a close relation (R ~ 0.9) between the ratio ($\alpha_{DPSH\text{-}A}$) and penetration depth (h). Regression equations, which can be used to calculate ratio values, are very different and depend on grain size distribution and strength properties of soil. Ra-

tio dependence on the depth in coarse soils is best described in cubic and quadratic equations, and in fine soils – power, exponential and logarithmic equations.

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CURRICULUM VITAE

Name, Family name:	Gintaras Žaržojus
Date & place of birth:	5 October, 1978; Vilnius, Lithuania
Civil status:	Married
Present position, address:	Vilnius University, Faculty of Natural Sciences, Department of Hydrogeology and Engineering geology M.K. Čiurlionio st. 21/27, LT-03101, Vilnius, Lithuania

Education:

2000 – 2004	Vilnius University, Faculty of Natural Sciences, hydrogeology and engineering geology study of undergraduate (Bachelor) studies. In 2004 conferred geological Bachelor's degree (Diploma B No. 0312559) (Lithuania).
2004 – 2006	Vilnius University, Faculty of Natural Sciences, hydrogeology and engineering geology study of graduate (Master's) studies. In 2006 conferred geological Master degree (Diploma MA No. 0640668) (Lithuania).
2006 – 2010	PhD studies in Vilnius University (Lithuania). Subject of studies: Engineering geological field testing methods, interrelation between results of dynamic penetration test (DPT) and cone penetration test (CPT).

Occupation:

since 2002	JSC "GEOTESTUS" Work address: Ulonų st. 5, Vilnius, Lithuania. Capacity: engineering geologist. Specialization: engineering geological site investigation, geotechnical testing of foundations.

DINAMINIO ZONDAVIMO REZULTATŲ IR JUOS ĮTAKOJANČIŲ VEIKSNIŲ ANALIZĖ BEI SĄSAJOS SU STATINIU ZONDAVIMU LIETUVOS GRUNTUOSE

REZIUME

Augant statybos mastams ir statant vis sudėtingesnius statinius, kurių pamatų pagrindu būna vis gilesni grunto sluoksniai, reikalingi greiti ir ekonomiški grunto tyrimo metodai. Atliekant inžinerinius geologinius tyrimus pagrindinę informaciją apie gruntų savybes duoda įvairūs zondavimo metodai. Pasaulyje iš šių metodų plačiausiai atliekant lauko tyrimus taikomas statinis zondavimas (CPT), standartinis zondavimas (SPT) ir dinaminis zondavimas (DPT). Lietuvoje tradiciškai vykdant inžinerinius geologinius tyrimus naudojami statiniai (CPT) ir dinaminiai (DPT) zondai.

Statinis zondavimas dėl savo specifikos labiausiai tinka zonduoti palyginti silpnus gruntus be žvirgždo ir gargždo priemaišų ar jų sluoksnių. Lietuvoje pamatų pagrindu dažniausiai būna glacigeniniai ir aliuviniai pleistoceno amžiaus gruntai, kurių atskirų sluoksnių fizikinės ir mechaninės savybės gali labai skirtis. Toks dažnai sudėtingas geologinis pjūvis apsunkina darbus CPT įranga, todėl reikalingi ištirti sluoksniai lieka nezonduoti. Dinaminis zondavimas (DPT) leidžia zonduoti tvirtus gruntus iki 30 m gylio.

Dinaminis zondavimas dažniausiai naudojamas gruntų fizikinei būklei įvertinti, tačiau jo duomenys tiesiogiai pamatų projektavime nenaudojami. Pagal šiuo metu esančius norminius reikalavimus nepakankamai įvertinti DPT metu rezultatams įtakos turintys energijos nuostolius sukeliantys veiksniai. Praktiškai neištirtos DPT ir CPT rodiklių tarpusavio sąsajos. Šių sąsajų ir koreliacinio ryšio nustatymas sudarytų palankias sąlygas tiesiogiai pagal DPT rezultatus projektuoti giliuosius pamatus.

Šio darbo tikslas - dinaminio zondavimo duomenų patikimumo įvertinimas, gautų pradinių rezultatų apdorojimas ir pataisos koeficientų nustatymas, sąsajų tarp dinaminio ir statinio zondų rodiklių paieška bei įvertinimas.

Darbo uždaviniai: išanalizuoti statinio ir dinaminio zondavimo metodikas, gaunamų duomenų panaudojimą gruntų savybių įvertinimui ir vykdant geotechninį projektavimą, nustatyti duomenų interpretacijos problemines vietas; įvertinti dinaminio zondavimo rodiklių (N_x ir q_d) patikimumą, nustatyti ryšį tarp skirtingo tipo dinaminių zondų

smūgių skaičiaus (N_x) verčių ir rasti sąsajų koeficientus; nustatyti dinaminio zondavimo duomenų patikimumui įtakos turinčius veiksnius, įvertinti jų įtakos mastą; rasti koreliacinius ryšius Lietuvos gruntuose tarp dinaminio ir statinio zondavimo rodiklių, įvertinant jų sąsajos glaudumą.

Atlikus dinaminio zondavimo rezultatų ir juos įtakojančių veiksnių analizę bei sąsajų su statiniu zondavimu nustatymą gautos šios išvados:

1. Dinaminis zondavimas yra nepakeičiamas gruntų tyrimo *in-situ* metodas, kai reikia zonduoti per tvirtus ar žvirgždingus, gargždingus grunto sluoksnius ir pasiekti didelius (iki 30 m) gylius. Šio metodo trūkumas – esamas metodikas sudėtinga panaudoti geotechniniame projektavime. Todėl dinaminio ir statinio zondavimo duomenis būtina susieti tarpusavyje. Sąsajos gali būti įvairios – tiek tiesioginės, tiek netiesioginės, per kitus savybių rodiklius. Pasaulinėje praktikoje nėra pasiūlyta patikimų DPT ir CPT rodiklių tiesioginių tarpusavio sąsajų. Šios sąsajos yra esminės, nes duoda gerokai mažesnes paklaidas.
2. Analizuojant dinaminio zondavimo duomenis ir naudojant įvairių šalių patirtį šioje srityje, būtina įvertinti skirtumus tarp skirtingų zondų tipų ir jų rezultatų. Kad duomenys būtų visiškai ir tiksliai panaudoti, reikia nustatyti smūgių skaičiaus sąsajos koeficientus. Darbo metu buvo nustatyta, kad smūgių skaičiaus sąsajos koeficiento dydis yra apytiksliai atvirkščias savitojo zondavimo darbo dydžiui. Nustatyta, kad smulkiuose gruntuose, didėjant rupiosios frakcijos kiekiui, santykinis sąsajos koeficientas didėja. Mažiausias jis būna, kai zonduojamas limnoglacialinis smėlingas dulkingas molis ir dulkingas molis (0,16), didžiausias – kai zonduojamas moreninis smėlingas molingas dulkis, smėlingas molis ir molingas dulkis (0,47). Rupiuose gruntuose stebima panaši situacija: gruntui rupėjant, santykinis koeficientas (β'_A) didėja. Dulkingame smėlyje β'_A = 0,13, žvyre β'_A = 0,27.
3. Išnagrinėjus dinaminės kūgio smigos skaičiavimo rezultatus galima teigti, kad gautų verčių išsibarstymas yra didžiulis, statistinių rodiklių kitimo ribos taip pat yra didelės. Tokį gautų rezultatų nevienodumą lemia skirtingų korekcijos koeficientų panaudojimas (arba jų visiško nebuvimas), taip pat smūgio proceso supaprastinimas. Energijos kiekis, perduotas į zondo kūgį, yra bene svarbiausias rodiklis, reikalingas tiksliam q_d apskaičiuoti. Turimomis formulėmis to įvertinti negalima, nes energijos perdavime veikia labai daug veiksnių, kurie iškraipo pradinės

suteiktos energijos dydžius. Dinaminio zondavimo duomenų pateikimas netiesioginiu rodikliu – dinamine kūgio smiga (q_d) – yra keistinas.

4. Dinaminio zondavimo rezultatus smarkiai veikia šalutiniai veiksniai: energijos nuostolis, štangų trintis į gruntą ir horizontalus geostatinis slėgis. Energijos kiekis, tenkantis kūgiui, be įrangos specifikos, priklauso ir nuo grunto savybių, – kuo didesnė grunto trintis ir horizontalus geostatinis slėgis, tuo energijos nuostoliai didėja. Tyrimais nustatyta, kad dėl štangų šoninio paviršiaus trinties smulkiuose gruntuose netenkama ~ 12,5% energijos. Didėjantis slėgis kartu didina trintį ir mažina energijos perdavimą į kūgį. Pagal tyrimo rezultatus, nuo 13 iki 16 m gylio zonduojant smulkiuose glacialiniuose gruntuose, energijos nuostoliai gali būti iki 80% (smūgių skaičius N_{20} padidėja iki 80%).
5. Lengvojo dinaminio zondo (DPL) ir statinio zondo (CPT) rodiklių, išreikštų santykiu (α_{DPL}), tarpusavio koreliacija parodė labai glaudų (R ~ 0,9) ryšį. Rodiklių tarpusavio priklausomybę geriausiai aprašo trinarė (kubinė) regresinė polinominė lygtis, kuri paprastai galioja iki 4–6 m gylio. Giliau santykio vertė priimama konstanta arba jos pasiskirstymas aprašomas laipsnine lygtimi.
6. Ypač sunkaus dinaminio zondo (DPSH–A) ir statinio zondo (CPT) rodiklių tarpusavio koreliacija parodė, kad ryšys tarp santykio ($\alpha_{DPSH\text{-}A}$) ir zondavimo gylio (h) yra glaudus (R ~ 0,9). Regresinės lygtys, pagal kurias galima apskaičiuoti santykio vertes, yra labai įvairios ir priklauso nuo grunto granuliometrinės sudėties bei stipruminių savybių. Santykio priklausomybę nuo gylio rupiuose gruntuose geriausiai aprašo kubinės ir kvadratinės lygtys, smulkiuose gruntuose – laipsninės, eksponentinės ir logaritminės lygtys.