ANALYSIS OF BEARING CAPACITY AND SETTLEMENT OF JET GROUTING COLUMNS

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Abstract
In the paper interaction of jet grouting columns with the subsoil is presented ([2], [3], [11], [12]). The essence of interaction considered is the influence of soil properties on column's load bearing capacity and settlement ([3], [6]÷[8]). Bearing capacity and settlement tests for jet grouting columns were carried out in Bojszowy Nowe (Poland). In this paper analysis of the results of load and uplift tests for jet grouting columns and the results of the strength parameters for jet grouting material are presented.

Streszczenie
Polem dociekań i badań przedstawianych w artykule jest problematyka wzajemnego mechanicznego oddziaływania kolumn wykonywanych techniką iniekcji strumieniowej i podłoża gruntowego ([2], [3], [11], [12]). Istotą tej współpracy jest wpływ właściwości gruntu na nośność i osiadanie kolumn ([3], [6]÷[8]). Badania nośności i osiadania kolumn iniekcyjnych zostały wykonane na poligonie doświadczalnym w Bojszowach Nowych (Polska). W artykule przedstawiono analizę wyników otrzymanych z próbnych obciążeń na wciskanie i wyciąganie kolumn iniekcyjnych oraz podano parametry wytrzymałościowe tworzywa gruntowo-cementowego badanej kolumny iniekcyjnej.

Keywords: **Jet grouting technique; Jet grouting column; Trial load test; Trial uplift test; Strength parameters of jet grouting material.**

1.TEST STE CHARACTERISTIC

The test site for carrying out the load and uplift test for jet grouting columns was located in Bojszowy Nowe (Poland). It was formed of 9 anchoring jet grouting columns (K1÷K9) and 4 test jet grouting columns (P1÷P4). The arrangement of jet grouting columns is presented in Fig. 1.

All anchoring and test jet grouting columns were constructed in October 2006. Parameters of jet grouting are presented in Table 1, while the characteristics of the jet grouting columns' reinforcement in Table 2.

To obtain information on jet grouting columns' interaction with the surrounding subsoil, the following course of tests on the test site has been designed [3]:

a) performance of penetration tests (static and dilatometer sounding) in three stages, i.e. prior to the construction of jet grouting columns in the subsoil (stage I), after the construction of jet grouting columns in the subsoil (stage II), after a series of trial loading of jet grouting columns (stage III),

b) performance of uplift and load trial loading of jest grouting columns (in two stages),

c) sampling the material for strength tests of soil-cement jet grouting columns.

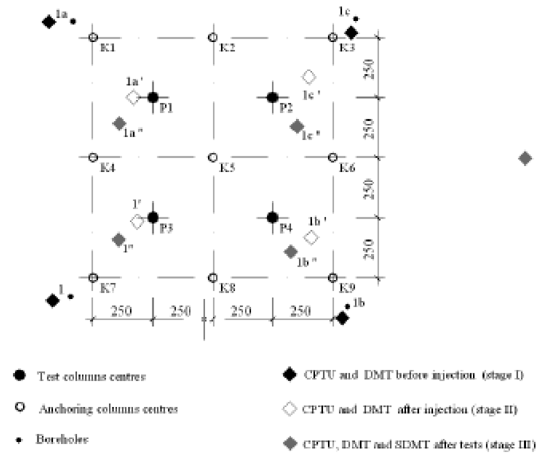

Figure 1.
View of the test site with the location of the CPTU, DMT and SDMT tests and localization of jet grouting columns at the test site in Bojszowy Nowe (Poland); K1÷K9 – anchoring jet grouting column; P1÷P4 – test jet grouting columns [3]

Table 1.
Specifications of jet grouting parameters (double jet grouting system) [3]

Type of cement	CEM II BS 32.5R
Producer	Górażdże (Poland)
Density of grout, kg/m^3	1500
Amount of used cement for creating jet grouting columns, kg	1620÷2160
Injection pressure, MPa	35
Diameter of drill bit, mm	130
Diameter of drillling rod, mm	110
Number of nozzles	2
Diameter of nozzle, mm	2,5
Average lift speed of drilling rod, s/m	60
Date of creating jet grouting columns	19 & 20.10.2006

The penetration tests were aimed at estimation of subsoil layers' parameters and at capturing the influence of jet grouting columns construction and trial loading performance on the soil massif properties.

Two stages of trial loading were designed to determine the uplifting and loading bearing capacity of jet grouting columns. Each of jet grouting columns was subjected to loading and/or uplifting. The characteristic of trial loading tests is presented in Table 3.

Four holes, 50 mm in diameter, were drilled to determine parameters of soil-cement material in a non-reinforced jet grouting column. The holes were wet performed using hammer-free method, by means of a Hilti boring machine using diamond crown drills 50 cm long, with extensions from 0.5 to 1.0 m. Samples of soil-cement material were taken from each hole during the core drilling, which were next transported to the laboratory to test its mechanical properties.

2. SUBSOIL CHARACTERISATION

The test site is situated in the municipality of Bojszowy, in the Silesian voivodship (Poland). Four exploratory boreholes, 8.0 to 14.0 m deep, were made on the site, soil samples were taken, which were macroscopically tested, and to determine the degree of non-cohesive soil compaction the sounding with a light SDPL penetrometer was carried out.

The subsoil parameters were determined based on penetration tests, i.e. static CPTU sounding and dilatometer DMT and SDMT tests in the test site in Bojszowy Nowe.

The subsoil penetration tests were carried out in three stages: before jet grouting columns construction in the subsoil (stage I), after columns construction in the subsoil (stage II) and after trial loading (stage III). The arrangement of tests at each stage is presented in Fig. 1.

A HYSON 20 Tf penetrometer of Dutch company A.P. van den Berg Machinefabriek from the Netherlands was used for penetration tests. HYSON 20 Tf penetrometer is classified into category I of penetrometers, acc. to the Instruction "International Test Procedure for Cone Penetration Test CPT, CPTU" of 2001 prepared by the Technical Committee TC-16 ISSMGE.

Electric piezo-cones, enabling continuous recording of three penetration characteristics, were used in the tests: cone resistance q_c, friction on the frictional sleeve f_s and excess pore pressure u_c at a depth. Results recorded in the original electronic form provided the basis to interpret diagrams of static sounding tests.

To determine geotechnical parameters of soil layers distinguished in the subsoil it is necessary to stan-

Table 2.
Specifications of jet grouting columns reinforcement parameters [3]

Number of jet grouting column	Tested jet grouting column		Anchored jet grouting column
	P1, P2, P4	P3	K1 ÷ K9
Assumption for diameter of jet grouting column, m	0.6	0.6	0.6
Length of jet grouting column, m	7.0	7.0	11.5
Type of reinforcement	HEB 240	none	HEB 160
Grade of steel	St3S	-	St3S
Characteristic parameters of reinforcement (H-section)	$A=106\ cm^2$ $m=83.2\ kg/m$ $I_x=11260\ cm^4$ $I_y=3920\ cm^4$ $W_x=938\ cm^3$ $W_y=327\ cm^3$	-	$A=54.3\ cm^2$ $m=42.6\ kg/m$ $I_x=2490\ cm^4$ $I_y=889\ cm^4$ $W_x=311\ cm^3$ $W_y=111\ cm^3$
Denotations: A – area of reinforcement, m – mass, I_x, I_y – moment of inertia for reinforcement, W_x, W_y – sectional modulus			

Table 3.
Characteristic of trial loading for jet grouting columns [3]

Number of jet grouting column	P1	P2	P3	P4
Stage I of tests: Type of test	Load test	Uplift test	Load test	Uplift test
Date of test	11.06.2007	4.06.2007	13.06.2007	5.06.2007
Stage II of tests: Type of test	Uplift test	Load test	Load test	Load test
Date of test	9.04.2008	29.04.2008	11.04.2008	17.04.2008

dardise the sounding parameters recorded to the form of coefficients and indicators used in the classification systems and interpretation procedures.

Soil types and states were determined based on penetration characteristics, supplemented with the curve of friction ratio R_f vs. depth. The classification system developed by the Department of Geotechnics of Agricultural Academy in Poznań in 1993 and the Robertson system were used in the penetration curves interpretation. 8-step Harder-Bloh procedure was used in the statistical analysis of penetration curves, acc. to which sounding parameters were subject to filtration and the penetration curves smoothed.

The course of five sounding characteristics vs. depth was analysed to determine boundaries of individual layers in the profile examined and to determine the type and state of soils making those layers: cone resistance qn, friction on the frictional sleeve f_s, pore water pressure u_c and previously defined friction ratio R_f and pore pressure parameter B_q.

To separate uniform soil layers in the subsoil the data was grouped in two stages. The data grouped in the first stage included the adjusted cone resistance qt and the coefficient of friction R_f. The Harder-Bloh procedure, modified by a sequential test, was used in the first stage, which allowed separating the layers acc. to statistic criteria and to localise them in the classification system of the Department of Geotechnics of Agricultural Academy in Poznań. In the second stage the grouping was carried out for data transformed from the penetration characteristics q_c and f_s to standardised parameters Q_t and R_f (the Heghazi-Mayne procedure).

Once the data was grouped, the groups position on the Robertson diagram was checked, what allowed checking the consistency of soils classification acc. to granulation with the system of the Department of Geotechnics of Agricultural Academy in Poznań [9] and assessing the correctness of soil state parameters changes and the oversonsolidation state variability. The grouping was carried out using the cluster theory methods, considering the task as uniaxial, along the path of subsoil penetration with the cone in the place of sounding.

Diagrams developed in the Department of Geotechnics of Agricultural Academy in Poznań and in Hebo company, Poznań, were used to determine the degree of non-cohesive soils compaction. The current theoretical solutions and comprehensive documentation material from sources quoted were considered in them.

Shear parameters of soil layers separated in the subsoil were expressed in effective stresses (Φ'). Those parameters were determined based on average values of sounding parameters (B_q and N_m), using the Senneset method.

The Lunne method was used to determine deformation parameters, expressed by means of oedometer primary modulus of compressibility M_o.

Those relationships include correction coefficients determined by the Department of Geotechnics of Agricultural Academy in Poznań and Hebo Poznań Ltd., which were obtained on the basis of extensive documentation material from CPTU and laboratory tests [9].

Dilatometer tests were performed using an original Marchetti equipment. The tests were carried out in accordance with the Instruction of TC-16 ISSMGE Committee "International Reference Test Procedure for DMT – Test" [10].

DMT tests were performed in immediate vicinity of static sounding places. The penetration was carried out to previously assumed depth, performing measurements of characteristic pressures in each profile, at every 20 cm increment of depth. Individual measurements were performed in accordance with the procedure recommended by the US Department of Transportation Instruction and guidelines for DMT tests prepared for TC 16 ISSMGE Committee.

CPTU tests characteristics (Fig. 2) and in particular the characteristics of cone resistance changes vs. depth and the excess pore pressure very well identify the occurrence of interbedding in the subsoil as well as zones of strengthening and weakening, which are caused by the construction of jet grouting columns in the subsoil.

The formation of zones of strengthening and weakening is reflected in strength and deformation parameters of individual soil layers.

The analysis carried out clearly shows that the zones of strengthening and weakening exist on large depths and the range of compaction degree variability in those zones is pretty wide – from 0.35 to 0.90. Similar situation exists for the variability range of effective angle of internal friction and of modulus of primary compressibility.

In a general assessment of strength and deformation parameters variability for individual soil layers of the subsoil based on penetration characteristics from CPTU, DMT and SDMT tests the following observations may be formulated:

- The occurrence of soil layers of diversified stiffness and strength has been found at each stage of tests. The spatial variability of those layers location is high. If characteristics from the SDMT tests are taken as the reference state, then it may be noticed that these zones only partially coincide with zones documented by characteristics of CPTU tests in individual test stages. Two factors decide about these differences, i.e. the differentiation of subsoil vertical and horizontal stiffness, which results from numerous soil layers interbedded in the subsoil, featuring various granulation and stiffness, and also effects related to the construction of jet grouting columns and their trial loading.
- The characteristic of excess pore pressure changes at its simultaneous hydrostatic distribution with the depth has shown that during individual stages the excess pore pressure was dispersing with time.

The subsoil tests in the test site in Bojszowy Nowe, carried out using CPTU, DMT and SDMT methods for two years, provided extensive material for detailed interpretation of soil strength and deformation parameters changes in the subsoil. Two aspects have been considered when assessing these changes: the effect of jet grouting columns construction and the trial loading. The passage of time of stage II and III tests should be also considered. The limitation to the three mentioned factors is possible, because characteristics from three test stages have shown that in the examined time range the tests were always performed in the subsoil, which structure and spatial arrangement had not changed.

The test results allowed carrying out detailed analysis, in which the aforementioned aspects have been considered:

- When comparing the characteristics of horizontal stress coefficient and secant dilatometer modulus changes with the depth (Fig. 4 and Fig. 5) with changes of secant oedometer moduli, obtained from the CPTU tests, it is possible to state that the variability of these parameters is high. This comparison allows assessing the anisotropy of individual subsoil layers. The comparative analysis was performed in the subsoil zones, which had shown the effect of strengthening and/or weakening. In each stage those zones may be identified based on the analysis of characteristics of cone resistance changes with the depth, i.e. based on static CPTU tests.

- When comparing the values of selected geotechnical parameters of the subsoil, determined based on penetration characteristics in time intervals, i.e. before the construction of jet grouting columns in the subsoil, after their construction and after a series of trial loading of the columns, it is possible to state that no significant difference in the values of effective angle of internal friction has been found in time intervals, while the most sensitive parameter is the oedometer modulus of primary compressibility, whose values determined after uplift and load trial loading were substantially decreased. At the same time it has been noticed that the construction of jet grouting columns and then the performance of trial loading of jet grouting columns results in an increase (after column's load trial loading) or in a decrease (after uplift trial loading) in cone resistances during the CPTU test.
- Some difficulties are encountered at the defining of jet grouting columns interaction with the subsoil, resulting from the fact that individual jet grouting columns were subjected to two stages of trial loading:

  – loading and uplifting (reinforced jet grouting column P1),

  – uplifting and loading (reinforced jet grouting columns P2 and P4),

  – loading twice (non-reinforced jet grouting column P3).

  The soil surrounded by tested jet grouting columns was changed after each series of their trial loading. The soil structure in the zone immediately adjacent to the column was disturbed (partly or totally damaged). It should be emphasised that with time the disturbed structure of the soil immediately adjacent to tested columns (uplifted or loaded) recovers.
- Results of examinations of coefficient of friction R_f changes vs. depth in the vicinity of jet grouting columns, subject to uplift trial loading and then to load trial loading (jet grouting column P2 and P4) show that values of coefficient R_f diminish. The R_f determined from tests in the vicinity of jet grouting column P1, first subject to load trial loading and then uplifted, has definitely higher values. The highest values of coefficient of friction occur in CPTU-1bis test, in the vicinity of non-reinforced jet grouting column P3, which was twice load trial loaded. Thereby in the vicinity of this column it is most noticed that the excess pore pressure has been dispersed.
- When comparing selected values of parameters determined based on DMT and SDMT tests it may be stated that the nature of penetration curves is comparable, while some discrepancies result from the fact that the distance between DMT and SDMT test points was around 12.5 m. The best fit of compared curves along the jet grouting column ($l=7.0$ m) occurs for material coefficient I_D and changes with depth of secant (oedometer) modulus of compressibility M.
- The analysis of modulus of primary compressibility values changes vs. vertical stresses, determined in the vicinity of jet grouting columns P1÷P4, shows that in stage II of tests (after jet grouting columns construction in the subsoil) the M_0 values decrease, while in stage III of tests (after trial loading of jet grouting columns) the M_0 values increase. That means that during columns uplift or load work the subsoil's stiffness increases.
- When comparing values of parameters determined based on dilatometer tests, performed in the vicinity of reinforced jet grouting column P2, it has been found that values of horizontal stresses coefficient K_D, of material coefficient I_D and of dilatometer modulus E_D decrease in the next test stages. The values of secant oedometer modulus, determined acc. to the Marchetti formula, also go down in the next test stages. When comparing values of M_0 (from the CPTU test) with values of M (acc. to the Marchetti formula from the DMT test), determined in the vicinity of reinforced jet grouting column P2, it has been found that the secant oedometer modulus M is around 2÷3 times higher than the modulus of primary compressibility M_0. This proves an increase in the subsoil stiffness after the construction of jet grouting columns as well as after columns load and uplift testing.
- Results of stage III tests inform of possible changes in parameters of the subsoil and jet grouting column contact layer after the application of external loads.

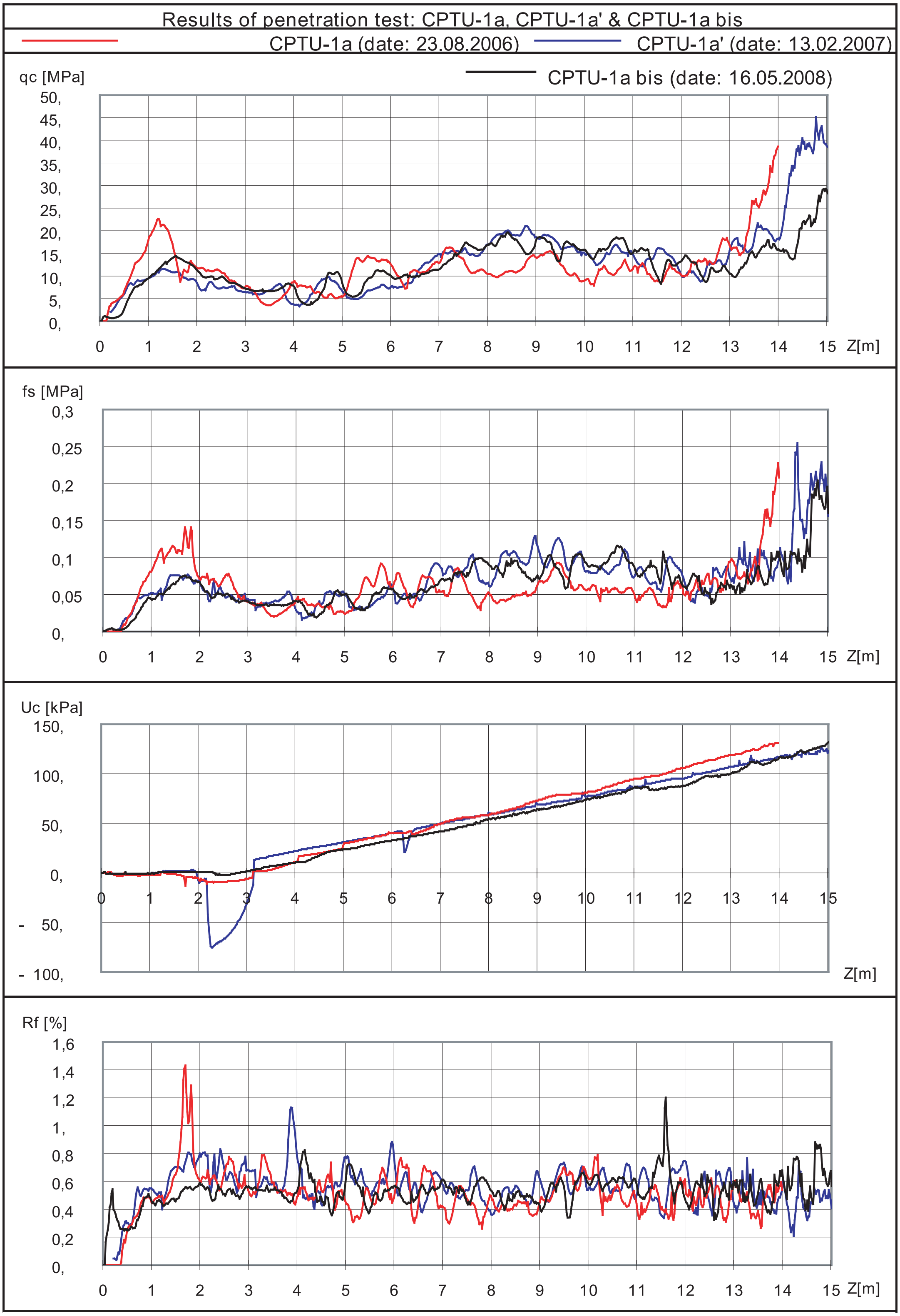

Figure 2.
Specification of the CPTU tests results at the CPTU-1a, CPTU-1a' and CPTU-1a bis tests at the neighbourhood of reinforced jet grouting column P1 [6] ÷ [8]

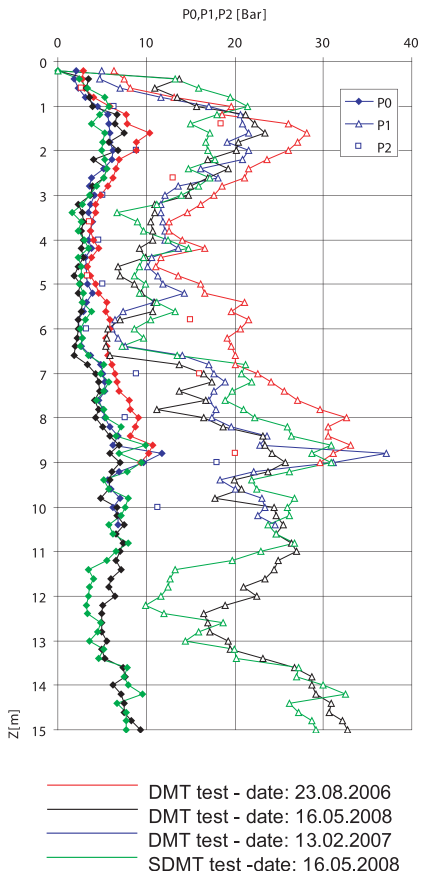

Figure 3.
Changes in pressures of p_0, p_1 and p_2 with the depth in the DMT and SDMT tests [6]÷[8]

3. AXIAL LOADING RESULTS

The trial loading of four jet grouting columns P1÷P4, constructed on the test site in Bojszowy Nowe, was designed ([1]÷[5]). The test jet grouting columns were arranged in a square grid of 5.0 x 5.0 m dimensions (cf. Fig. 1). The design anticipated uplift and load trial loading of reinforced and non-reinforced jet grouting columns. Tests were carried out in two stages:

- stage I comprised two uplift tests of reinforced jet grouting columns P2 and P4 and two load tests: of reinforced jet grouting column P1 and of non-reinforced column P3,
- stage II of tests – carried out 10 months after stage I – comprised three load tests of jet grouting columns P2, P3 and P4 and one uplift test of reinforced jet grouting column P1.

The tests performed aimed at obtaining an answer to the question, what part of the force is transferred to the subsoil by the jet grouting column shaft and what part by the base during test columns uplifting and loading.

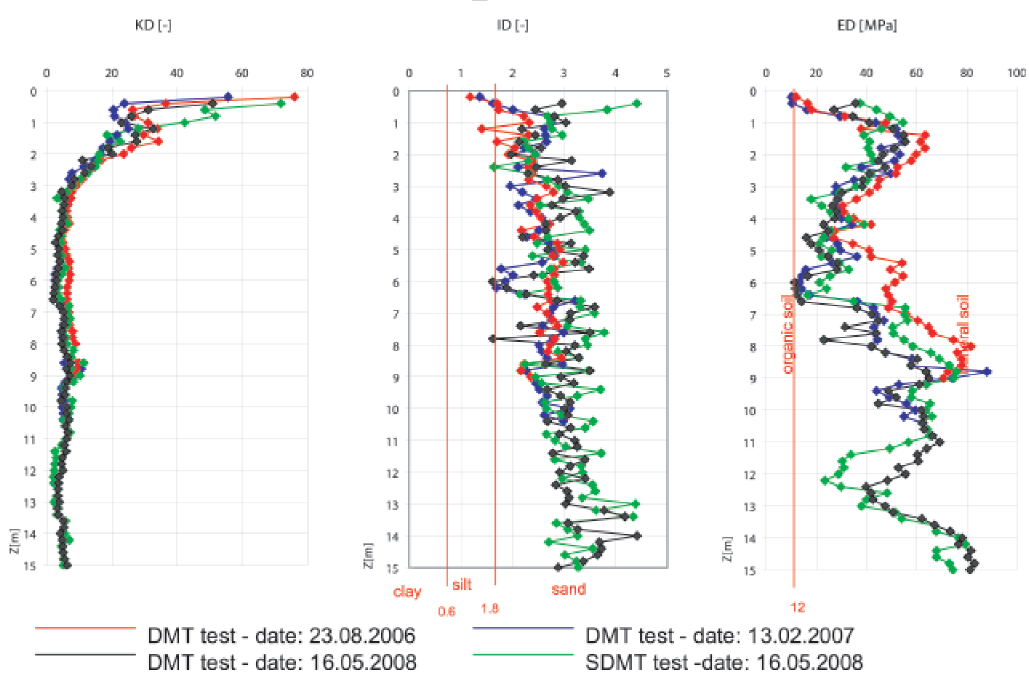

Figure 4.
Indexes characterising DMT and SDMT tests [6]÷[8]

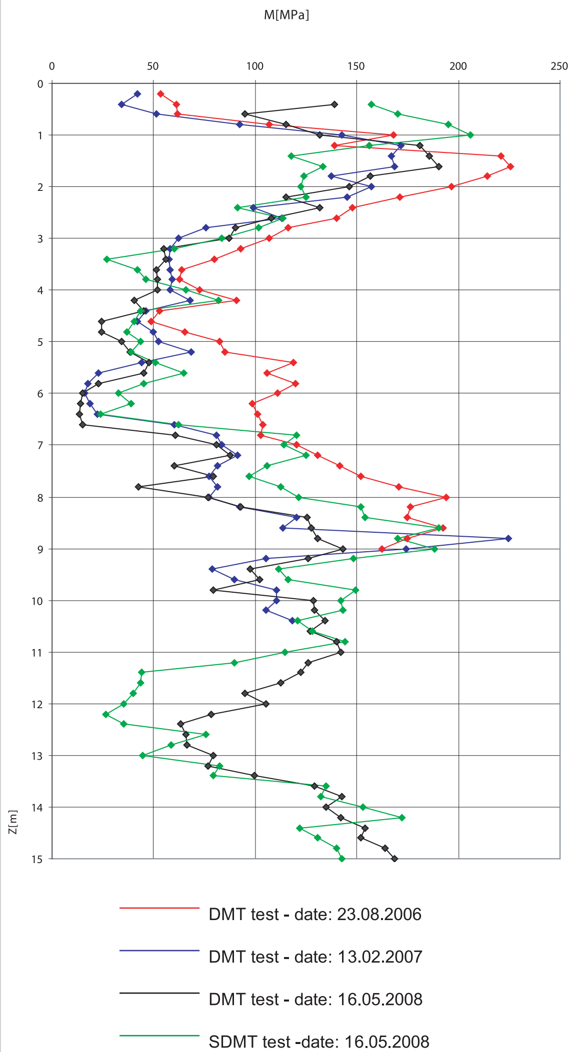

Figure 5.
Changes in compressibility modulus M with the depth on the basis of Marchetti theory for DMT and SDMT tests [6]÷[8]

The value of maximum jet grouting column loading, adopted for calculations of resistance frame structure elements, amounted to 4000 kN, while for trial pull out load – to 1200 kN.

Hydraulic actuators of lifting capacity up to 5000 kN together with accessories consisting of hydraulic hoses and a pump with manometers were used in the tests.

The "main beam – transverse beams" system was adapted to the anchoring columns and the loaded jet grouting column location so as to obtain equalised values of uplifting forces acting on individual anchoring columns [5]. Figure 6 presents the test stands for load and uplift tests of jet grouting columns.

4. ANALYSIS OF AXIAL TRIAL LOADS

4.1. Analysis of stage I tests

The following conclusions may be drawn based on the results of analysis of uplift and load trial loading:

1) the share of jet grouting column base in transferring the load is substantial and amounts to 48÷55% of total jet grouting column bearing capacity (compare Fig. 7),
2) the uplift bearing capacity of reinforced jet grouting columns tested (P2 and P4) amounts to $N^w = N_{shaft} \approx 1100 \div 1200$ kN= 1150 kN,
3) the load bearing capacity of reinforced jet grouting column P1 amounts to $N_t = 2500 \div 2600$ kN= 2550 kN; taking into account results for reinforced jet grouting columns P2 and P4 subject to uplifting tests and their bearing capacity $N_{shaft} = 1150$ kN, it may be concluded that the bearing capacity of reinforced jet grouting column base amounts to $N_{base} = N_t - N^w = 2550 - 1150 = 1400$ kN, hence $N_{base}/N_{shaft} = 1400/1150 = 1.22$,
4) from the comparison of load bearing capacity of jet grouting columns: non-reinforced P3 and reinforced P1 it results that there is no significant difference between a non-reinforced and reinforced column in the load range between 0 and 2000 kN.

a

b

Figure 6.
Test stand for jet grouting reinforced column a) load test; b) uplift test

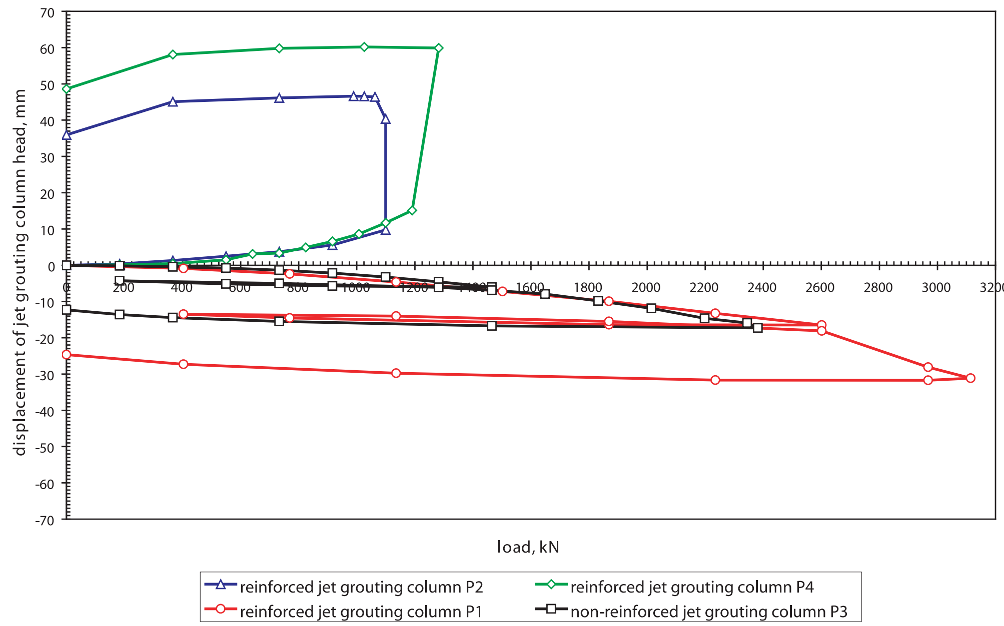

Figure 7.
Comparison of „load-displacement" relations for uplift tests of jet grouting columns P2 and P4 and load test of jet grouting column P1 and P3

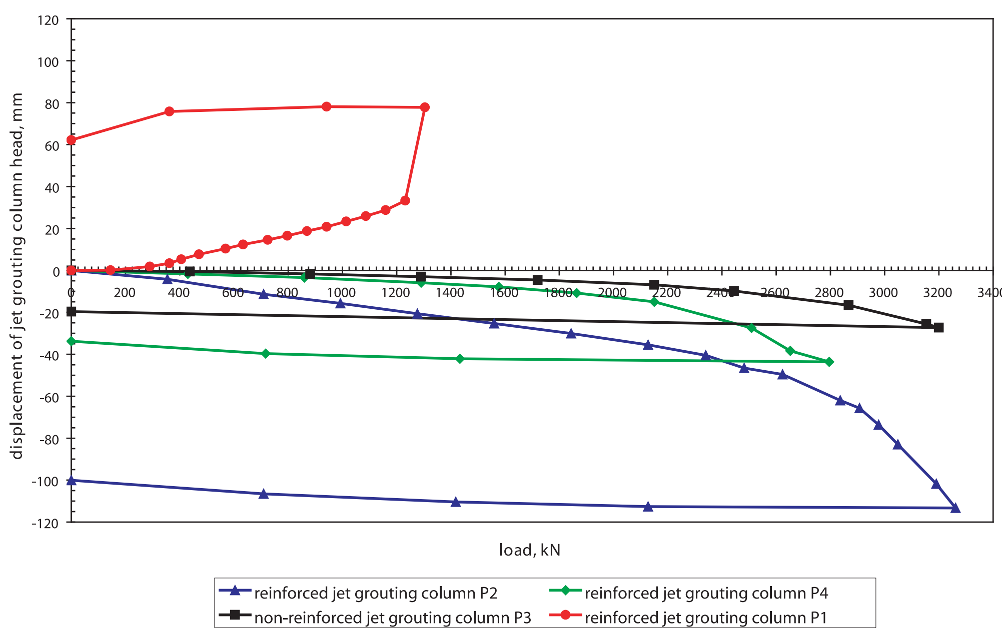

Figure 8.
Test results for reinforced and non-reinforced jet grouting columns at stage II of tests

4.2. Analysis of stage II tests

The following conclusions may be drawn analysing the results of jet grouting columns uplift and load trial loading:

1) the conclusion of test stage I has been confirmed, i.e. that the share of column base in load transferring to the subsoil is significant and amounts to 58÷61% of jet grouting column total bearing capacity (Fig. 8),
2) the uplift bearing capacity of reinforced jet grout-

ing column P1 amounts to $N^w=N_{shaft}\approx\approx1200\div1300$ kN$=1250$ kN,

3) the load bearing capacity of reinforced jet grouting columns P2 and P4 amounts to $N_t\approx3200$ kN; taking into account results for reinforced jet grouting column P1, uplift tested, in particular its bearing capacity $N_{shaft}=1250$ kN, the bearing capacity of jet grouting columns base $N_{base}=N_t-N^w=3200-1250=1950$ kN may be determined, hence $N_{base}/N_{shaft}=1950/1250==1.56$,
4) from the comparison of jet grouting columns load bearing capacity: non-reinforced P3 and reinforced P2 and P4 (Fig. 8) it results that $N_t(P3)=3000$ kN, $N_t(P2)=3200$ kN, $N_t(P4)=2800\div3000$ kN, so there is no significant difference in load bearing capacity of reinforced and non-reinforced column $N_t(P2)/N_t(P3)=3200/3000=1.07$; $N_t(P4)/N_t(P3)==3000/3000=1.00$.

4.3. Analysis of stage I and II tests

Taking into account results of uplift and load trial loading, performed in stage I and II, the following conclusions may be formulated:

1) the nature of "load – cap displacement" curves for reinforced jet grouting columns P2 and P4, tested for uplifting in stage I, is similar ($N^w=1100\div1200$ kN$\approx$ 1150 kN), but the course of similar relationship for column P1 loaded in stage I is slightly different, the bearing capacity N^w, however, achieves similar value of 1200 kN,
2) for reinforced jet grouting column P1, subject to load trial loading in stage I and to uplift trial loading in stage II $N_t=3200$ kN, for reinforced jet grouting columns P2 and P4, uplifted in stage I and loaded in stage II of the tests, $N_t=3000\div3200$ kN, i.e. it is slightly smaller than for the column, which is loaded in stage I,
3) when analysing results of tests for reinforced jet grouting column P1 subject first to load trial loading and then to uplifting, the following were obtained: $N_t=3200$ kN, $N^w=$Nshaft$=1200\div1300$ kN $\approx$ 1250 kN, hence $N_{base}=3200\text{-}1250=1950$ kN (compare Fig. 9),
4) when analysing results of tests for reinforced jet grouting column P2 subject first to uplift trial loading and then to load, the following were obtained: $N_t=3200$ kN, $N^w=N_{shaft}=1100$ kN, hence $N_{base}=3200\text{-}1100=2100$ kN (compare Fig. 10),
5) for non-reinforced jet grouting column P3, subject to load trial loading in stage I and II of tests (compare Fig. 11), the following results of tests were obtained: from stage I – $N_t^I(P3)=2300\div2400$ kN$\approx$2350 kN, from stage II – $N_t^{II}(P3)=3200$ kN, which means a significant increase in non-reinforced jet grouting column bearing capacity in

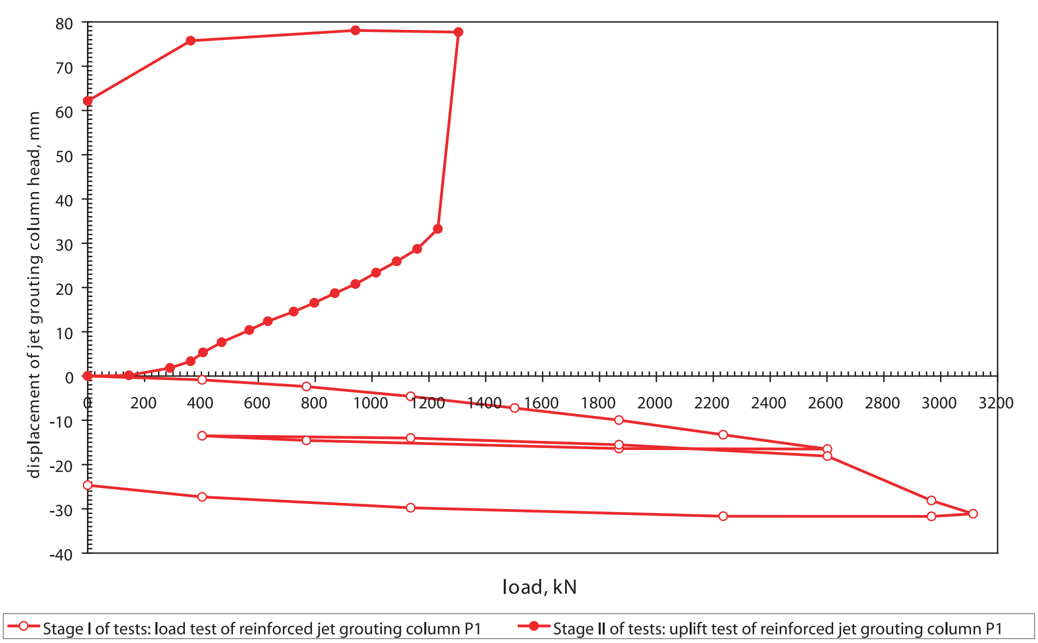

Figure 9.
Test results for jet grouting reinforced column P1 – stage I & II of tests

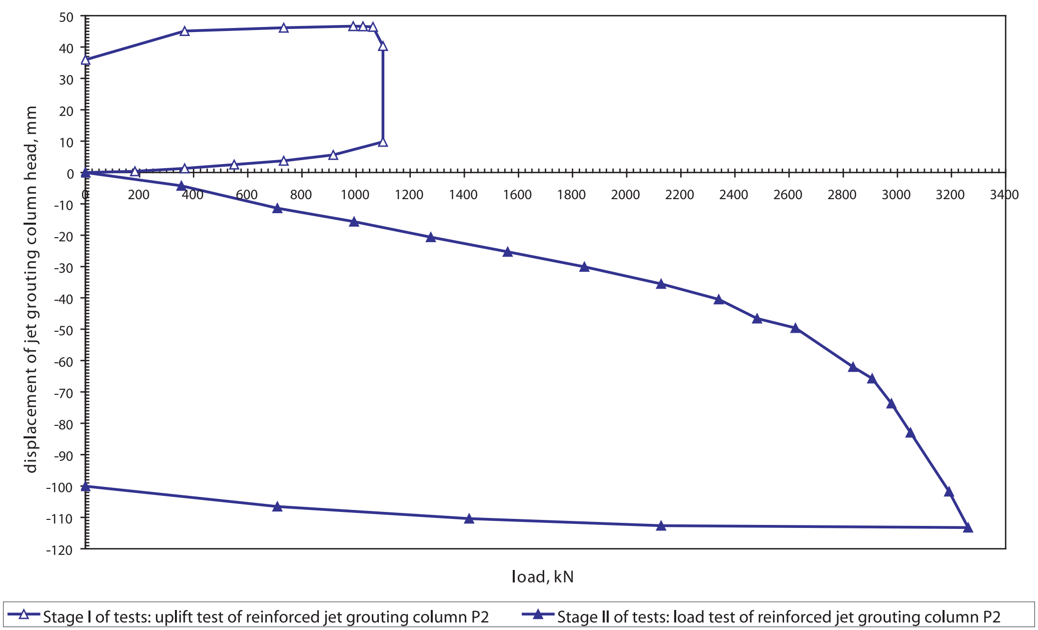

Figure 10.
Test results for jet grouting reinforced column P2 – stage I & II of tests

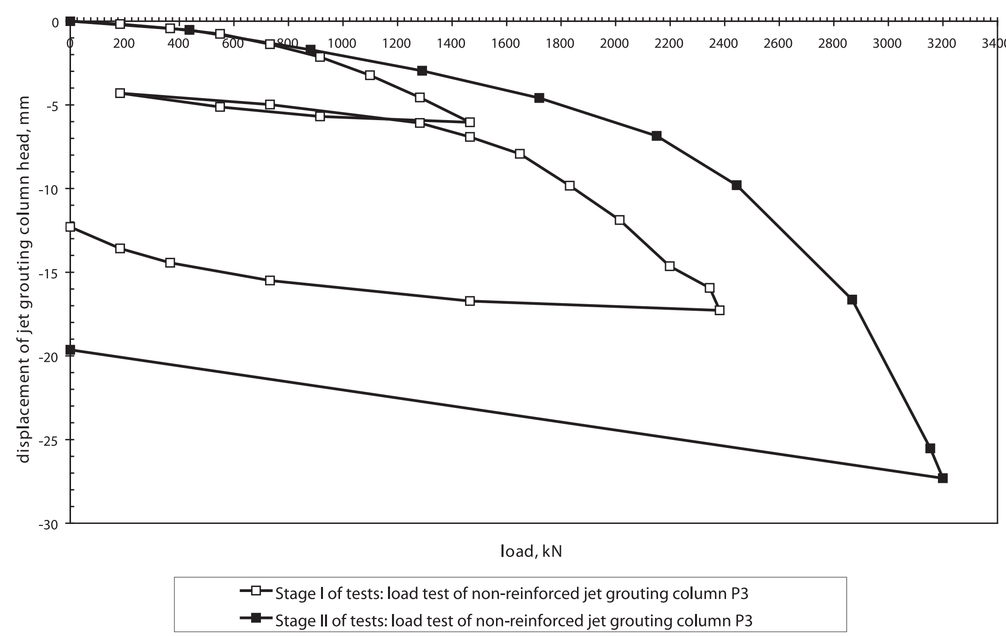

Figure 11.
Test results for jet grouting non-reinforced column P3 – stage I & II of tests

stage II of loading – $N_t^{II}(P3)/N_t^{I}(P3) = 3200/2350 = 1.36$,

6) when analysing results of tests for reinforced jet grouting column P4 subject first to uplift trial loading and then to load, the following were obtained: $N_t=2800$ kN, $N^w=N_{shaft}=1200$ kN, hence $N_{base}=2800\text{-}1200=1600$ kN (compare Fig. 12),

7) taking into consideration the fact that the reinforced jet grouting columns P2 and P4 tests were carried out in the same way, i.e. in stage I the reinforced jet grouting columns P2 and P4 were uplifted and in stage II loaded, the two tests could be

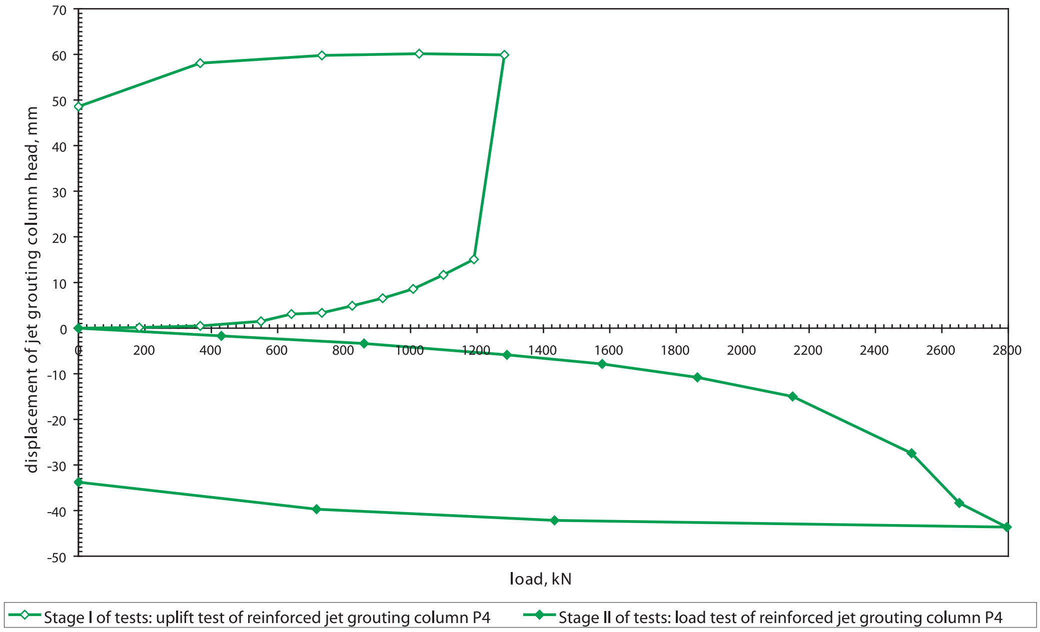

Figure 12.
Test results for jet grouting reinforced column P4 – stage I & II of tests

combined and average values of the bearing capacity determined: $N_t^{average}=(2800+3200)/2=3000$ kN, $N^{w\ average}=(1100+1200)/2=1150$ kN, hence $N_{base}^{average}=N_t^{average}-N^{w\ average}=3000-1150=1850$ kN,

8) from the comparison of test results of reinforced jet grouting columns P1 as well as P2 and P4 it results that $N_t(P1)=3200$ kN, $N^w(P1)=1250$ kN, $N_t(P2\ \&\ P4)=3000$ kN, $N^w(P2\ \&\ P4)=1150$ kN.

The comparative analysis shows that the operation of jet grouting columns first loaded and then uplifted is slightly better.

5. SOIL-CEMENT MATERIAL TESTING

The tests of mechanical behaviour of soil-cement material from the jet grouting columns in conditions of uniaxial compression were carried out in the laboratory on samples from the core material (Fig. 13), obtained from holes drilled in the column on the test site. Before starting tests on the jet grouting column material, electric resistance strain gauges were glued on the specimens to measure deformations. The average value of soil-cement material uniaxial compressive strength Rc amounted to 21.122 MPa.

The triaxial compression tests of soil-cement material samples were carried out in a triaxial KTK-60 high-pressure cell using a hydraulic SHM-MG 250/4 testing machine used for static and dynamic tests controlled by the force signal. The tests were carried out for the lateral pressure ranging from 0.4 to 2.0 MPa.

a

b

Figure 13.
a) View of shaft of jet grouting non-reinforced column P3 (l=7.0 m; head of jet grouting column D=1.6 m; below: D=0.8÷1.0 m; b) Samples of jet grouting material before uniaxial and triaxial tests

Based on "stress-strain" characteristics the values of modulus of elasticity E_i and the Poisson's ratio ν_i have been estimated. Average values of these parameters amount to E=9.888 GPa and ν=0.186.

The values of the angle of internal friction Φ, cohesion c and their standard errors are as follows: Φ=59.317°, s_Φ=4.395°, c=1.772 MPa, s_c=0.858 MPa.

6. CONCLUSIONS

The conclusions presented have been drawn only based on the analysis of trial loading results for four jet grouting columns in the test site in Bojszowy Nowe (Poland). The tests comprised the combination of three reinforced columns and one non-reinforced column. A multi-option load programme has been implemented, comprising performance of reinforced columns loading and uplifting in different order as well as two-stage loading of non-reinforced column. This allowed estimating the shares in transferring the base and shaft loads and also assessing the loading path influence on column's bearing capacity.

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