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VARIOUS TYPES OF COLUMNS USED NOWADAYS IN GEOTECHNICAL ENGINEERING

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Abstract

It is said that the structure is as strong as its foundations are. Even 3000 years ago people knew that it is necessary to improve the ground when they build the temples or other important structures. Nowadays ground improvement methods gain in popularity. Very often the localization which is used for an investigation has poor soil conditions (high ground water level or high thickness of soft soils layer) or the settlements limitations are very high. These are the main situations where the improvement method needs to be considered.

The designer has various types of techniques to choose. In the paper three main types of foundation columns have been compared:

– Deep Soil Mixing columns,
– Jet grouting columns,
– Vibro Stone columns.

To make the comparison more clear and uniform, the same assumptions were made in case of localization, geotechnical conditions, loading and foundation levels. Additionally, FEM analysis with the use of Z-Soil software was made to check the simplified calculations.

Streszczenie

Metody wzmacniania podłoża gruntowego znane są od ponad 3000 lat. Początkowo stosowane je dla zabezpieczenia ważnych obiektów strategicznych lub religijnych w celu zapewnienia ich świetności na wieki. Obecnie powody te nieco się zmieniły. Ze względu na coraz większy rozwój gospodarczy i brak dogodnej lokalizacji w dużych ośrodkach miejskich, konieczne stało się wykorzystanie terenów „drugiej kategorii", tj. z trudnymi warunkami geotechnicznymi (z wysokim poziomem wód gruntowych czy dużą miąższością gruntów nasypowych i organicznych).

W celu zapewniania rygorystycznych wartości dopuszczalnych osiadań nowoprojektowanych budowli, wiele z tych lokalizacji wymaga wzmocnienia. Jak dobrze wiemy, współczesny projektant ma wiele możliwości do wyboru, a jednym z nich jest wykorzystanie kolumn formowanych w gruncie.

W artykule przedstawiono wyniki obliczeń trzech najczęściej stosowanych typów kolumn, czyli:

– kolumn formowanych za pomocą wgłębnego mieszania gruntu – kolumny DSM,
– kolumn formowanych w technologii iniekcji strumieniowej – kolumny iniekcyjne,
– kolumn formowanych w technologii wibrowymiany – kolumny żwirowe.

Keywords: **Ground improvement techniques; Deep Soil Mixing column; Jet grouting column; Vibro Stone column.**

1. INTRODUCTION

For the localization of the investigation a small Masuria's town was chosen which is called Giżycko. Till today there exists the same old pare of Teutonic Castle, which is going to be rebuild (Fig. 1).

The first idea of fortification in Giżycko was invented by pagan tribe – the Yotvingians. After the Teutonic occupation which took place in 1290, a small wooden watch tower was build in a local area. Half a century later it was replaced by a greater structure – "the Castel" – which was still a wooden construction. The initiator of this investigation was the Master of the Teutonic Order – Dietrich von Altenburg. In 1365 the invasion of prince Kiejstut took place and the structure was completely burned. Again, in 1377-1399 the Teutonic rebuilt "the Castel" but this time they used masonry and stone elements to make the structure stronger. In that time "the real Castle" was the seat for the inferior in range officer, called the bailiff.

The increase in the politic meaning took place at the beginning of XV century, when the public prosecutor moved there. What is interesting, the armament had never been impressive – ten years after the Great War (with Poland) there were only five cannons for stone shot, two for lead shot and only ten crossbows.

After the Thirteen Years' War, in 1455 the fortress, without effort, was conquered by Prussian compound with accompany of the local inhabitant. The object came back to Teutonic in 1466, and once again was rebuilt and served till 1520.

After secularization of the Teutonic state in 1525, the office of mayor of Prussian Princes moved to the Castle and changed the architectural style from middle-aged to renaissance. During this works two renaissance tops were built. Next construction changes appeared in the second decade of XVII century – two wings and ground floor edifice were outbuilt. In 1749 the wings were burned and soon after this they were removed.

In 1945 the Castle was renovated and in the early 70s transformed into a motel. After that, the situation became worse. Because of a necessity of renovations, to save money, the owner needed to close the Castel for visitors.

Nowadays, only the main house with two renaissance tops still exists. The windows openings were bricked up by the last owner. For the last few years because of very bad technical conditions the Castle has been closed. In 2006 the first floor broke down and one year later the main wall collapsed.

Figure 1.
Castle in Giżycko – photo from 2007 [2]

Figure 2.
Visualization of the "new Castle" [3]

Recently a lot of changes have been made. The object was sold to a private owner, who wants to rebuild the Castel, make there a modern hotel with a restaurant, a spa area, a swimming pool and bowling (Fig. 2). A lot of works need to be made before the idea comes true. The first step of the investment is to improve the ground for a new part of the structure [1].

One of many things to do was improving of the ground conditions. According to [4] the following soil layers were found:

upper layer – made ground, the mixture of middle and fine grained sand with elements of masonry units,

I layer – The layer is composed of aggradate mud, peat and gyttja. Lots of organic parts occur in soft

Table 1.
Cross-section legend with soil parameters [4]

CROSS SECTION LEGEND WITH SOIL PARAMETERS										
Castel in Giżycko										
GEOTECHNICAL EXPLANATION										
LAYERS			symbol acc. PN-EN ISO 14688-1	SOIL STATE I_D	I_L	NATURAL MOISTURE w_n [%]	DENSITY ρ[t·m^{-3}]	COHE-SION c_u [kPa]	FRICTION ANGLE ϕ_u [°]	EODOMETRIC MODULUS M_o [kPa]
		made ground		-	-					
	I	mud, peat and gyttja	Or	-	-	495÷620	1.1	10	10	200
	IIa	middle and fine grained sand	MSa, FSa	0.45	-	15	1.78	0	31.5	74000
	IIb	all in aggregate/ gravel	Gr	0.45	-	12	1.89	0	36.2	144000
	III	organic aggradate mud	Or	-	-	55÷96	1.6	10	10	1500
	IV	fine grained sand	FSa	0.50	-	23	1.9	0	30.5	63000

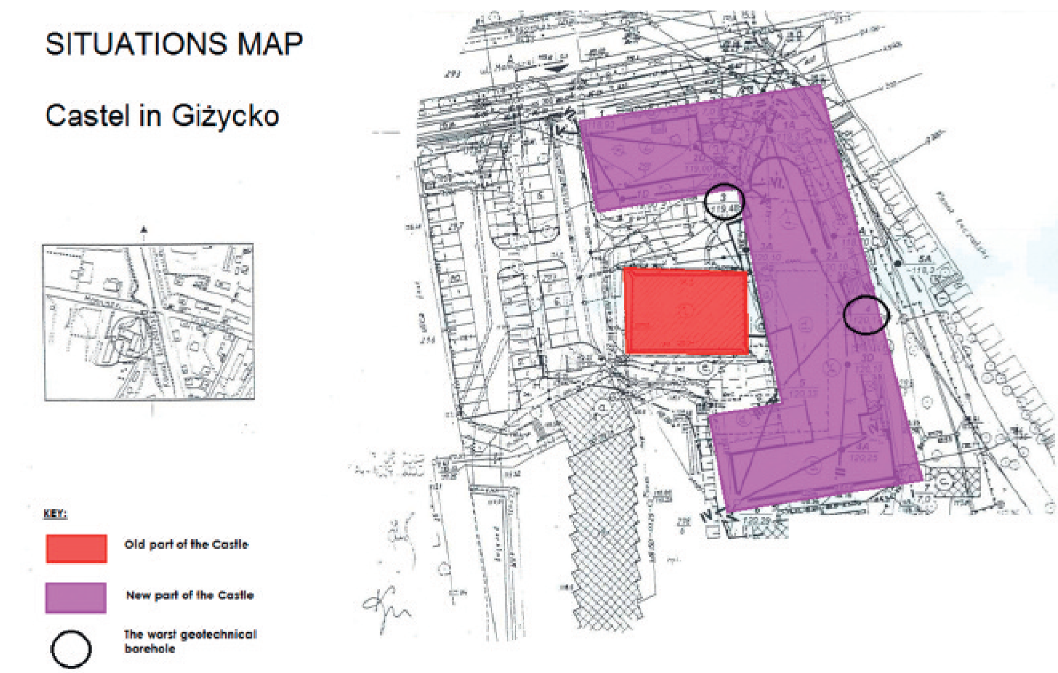

Figure 3.
Localization of the boreholes [4]

plastic state,

IIa layer – Middle and fine grained sand. The density index I_D=0.45. Semi solid state of the soil,

IIb layer – All in aggregate. The density index I_D=0.45. Semi solid state of the soil,

III layer – Organic aggradate mud. Plastic consistence of the soil,

IV layer – Fine grained sand. The density index I_D=0.50. Semi solid state of the soil.

Tests result and geotechnical parameters of soils are shown in Table 1.

The foundation level was taken from the Designer of the "new Castle" structure and it is equal from -4.78 m (116.30 m.a.s.l.) – in main part of the structure, to -5.68 m (115,40 m.a.s.l.) – in staircase location. Details are shown in Fig. 4.

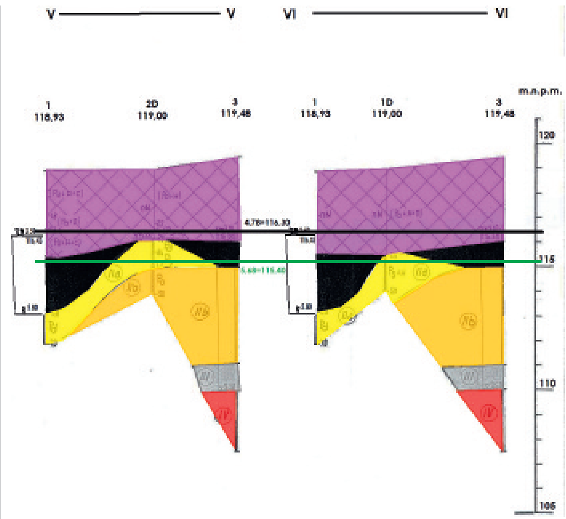

Figure 4.
Cross sections [4]

2. SIMPLIFIED CALCULATIONS METHOD

Loading on the continuous footing was between 95÷370 kN/m. On the spot footing maximum loading was equal to 2000 kN. The width of continuous footing was equal to B_f = 1.0 m.

Detailed loading arrangement is shown in Fig. 5.

2.1. Deep soil mixing columns

According to previous information the first idea was to make DSM columns. To do this, the single mixing tool and wet technology was used. Also CEM III/A 32.5 R was recommended as the main binder (200-250 kg/m^3 of column).

The design value of the Ultimate Compressive Strength after 56 days should reach $R_{b(56)G}$ = 3.00 MPa and after 28 days 70% of $R_{b(56)G}$=2.10 MPa.

Safety factor of the non-homogenous ground was obtained 2.5.

Additionally, because of possibility of some small horizontal forces occurrence and because of huge depth of soft soils steel section IPE 140 (St3S) was applied.

According to calculations to satisfy all the previous assumption the following columns should be made:

– 21 DSM columns of diameter 0.8 m and length 5.0 m, reinforced with steel section IPE 140, length 5.0 m.

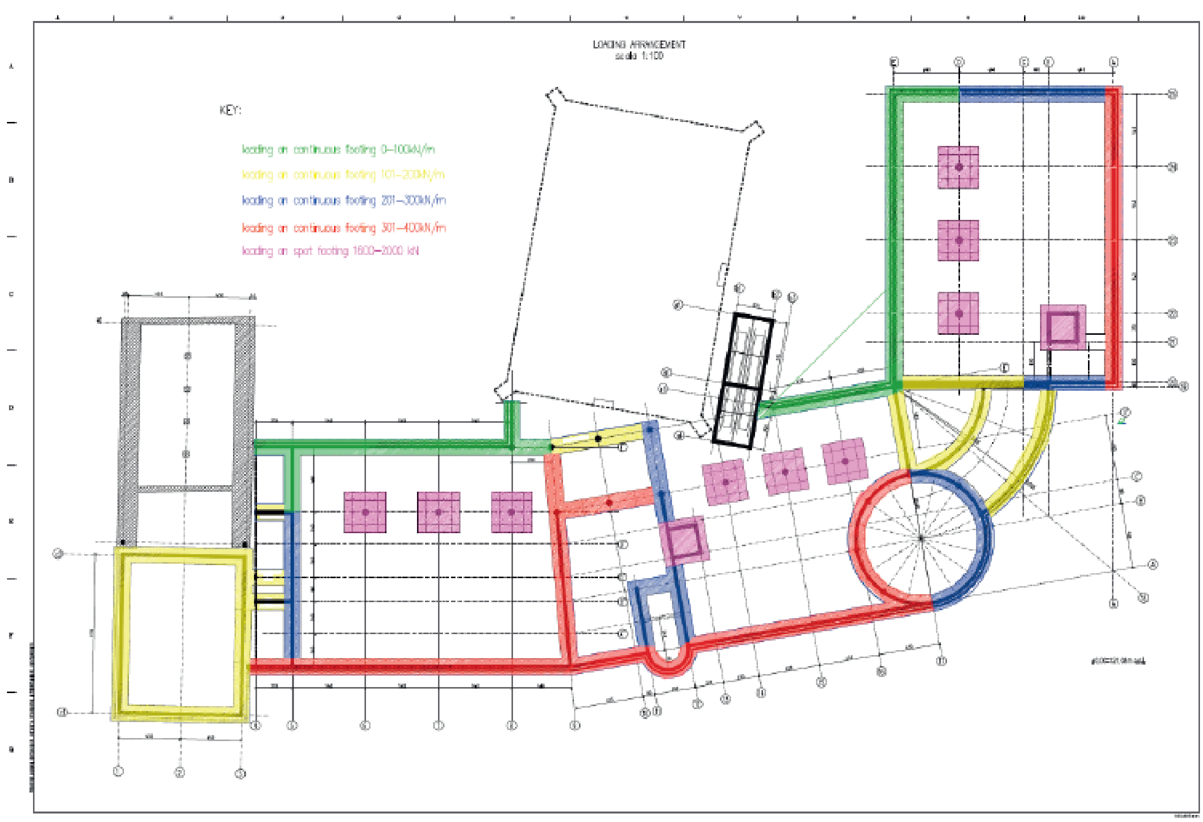

Figure 5.
Design loads arrangement

– 38 DSM columns of diameter 0.8 m and length 6.0 m, reinforced with steel section IPE 140, length 6.0 m.
– 9 DSM columns of diameter 0.8 m and length 7.0 m, reinforced with steel section IPE 140, length 7.0 m.
– 240 DSM columns of diameter 0.8 m and length 8.0 m, reinforced with steel section IPE 140, length 7.0 m.

2.2. Jet grouting columns

Next proposition was to design jet grouting columns. The calculations were made based on [5].

External bearing capacity of the column

For a jet grouting column calculation according to *Żmudziński & Motak* (1995) [5] algorithm was used. It was assumed that total loads are taken over by the column shaft and the base (10%).

For the calculation the following parameters were taken into account:

– $\phi_{cal} = 0.8$ m design diameter of the column,
– $S_d = \frac{2\pi\Phi_{cal}}{2} = 2{,}51m$ design circuitry of the diameter,
– $t_i^{(n)}$ characteristic values of the frictional resistance $t^{(n)}$ of jet grouting column's shaft area,
– to form the column CEM II 32.5 R or CEM I 32.5 R was recommended.

Internal bearing capacity of the column

Internal bearing capacity of a jet grouting column was calculated with the formula presented in Polish Standard [6] for the concrete compressed elements.

– for the local ground conditions, it was assumed that the column will be made of soil-cement mixture with design compressive resistance f_{cd}= 3.5 MPa,
– for single column the substitute cross section was assumed b=h, with the area equal to the area of circular shape,
– the external capacity of the column shaft was calculated with the use of formula:

$$N_{rd} = \phi f_{cd} bh$$

where: $\phi = 0.9$ according to Table 10 in Polish Standard [6].

Based on calculations the internal bearing capacity of the jet grouting columns, with diameter 0.8 m, in all assumed cases was greater or equal to the external bearing capacity. This is why additional safety margin needs to be taken into consideration by means of steel section IPE 140 (St3S) which should be placed inside the column. Its length, from 5.0 to 7.0 m, was matched in comparison to the local ground conditions. To guarantee the design properties they should be finished in the fine grained sand layer.

According to calculations to satisfy all the previous assumptions the following columns should be done:

– 9 jet grouting columns of diameter 0.8 m and length 5.0 m, reinforced with steel section IPE 140, length 5.0 m,
– 30 jet grouting columns of diameter 0.8 m and length 6.0 m, reinforced with steel section IPE 140, length 6.0 m,
– 9 jet grouting columns of diameter 0.8 m and length 7.0 m, reinforced with steel section IPE 140, length 7.0 m,
– 170 jet grouting columns of diameter 0.8 m and length 8.0 m, reinforced with steel section IPE 140, length 7.0 m.

2.3. Vibro stone columns

The last idea was to design Vibro Stone Columns. Calculations were base on the paper [7] and Hughes & Withers theory which can be found in [8].

Assumption:

Design load (on foundation level): $N_d = 370$ kN/m

Foundation width: $B_f = 1.0$ m

Material parameters of the column (all in aggregate):

– Internal friction angle: $\phi_c = 49$ deg
– Young modulus: E= 67 MPa
– Poisson's ratio: $v_c = 0.2$
– Density index: $I_D = 0.5$

Results for the 3rd borehole:

Column diameter: $D_c = 1.0$ m

Column length: $L_c = 6.5$ m

Spacing of the columns: $a_c = 4.0$ m

$$p_k' = 741 \text{ kPa} \le \gamma_f \cdot p'_{kf} = 890 \text{ kPa}$$

Results for the 4th borehole:

Column diameter: $D_c = 1.0$ m

Column length: $L_c = 8.0$ m

Spacing of the columns: $a_c = 2.7$ m

$$p_k' = 1030 \text{ kPa} \le \gamma_f \cdot p'_{kf} = 1065 \text{ kPa}$$

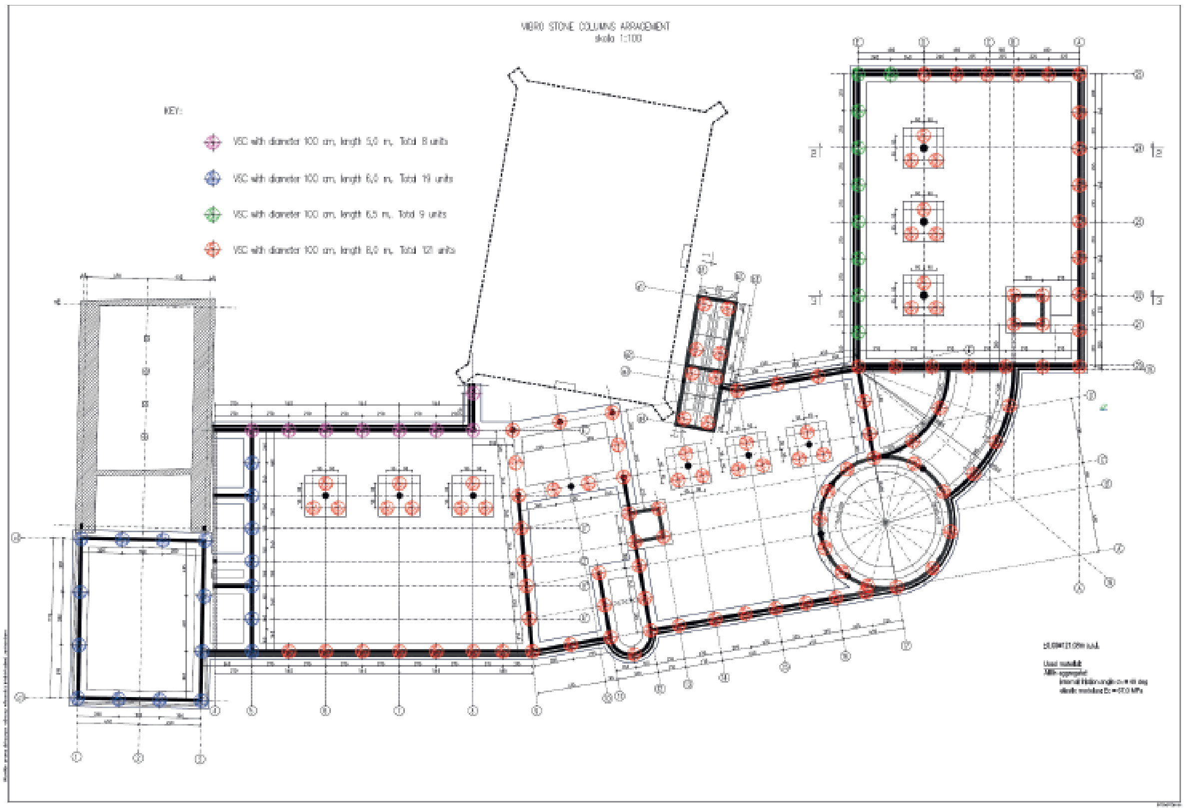

Figure 6.
Vibro Stone Columns arrangement [1]

Table 2.
Soils parameters

	Soil type	unit weight [kN/m^3]	Poisson ratio ν	βsk	E_o [kPa]	E[kPa]	M_o [kPa]
	Concrete (foundation)	25.00	0.30	-	-	29000000	-
	Made ground	15.50	0.23	0.55	15000	8250	~40000
I	Or aggradate mud, peat and gyttja	10.79	0.30	0.50	200	100	200
IIa	MSa, FSa Middle and fine grained sand	17.56	0.25	0.70	47000	32900	74000
IIb	Gr All- in aggregate	18.54	0.20	0.70	75000	52500	144000
III	Or Organic aggradate mud	14,70	0.30	0.50	1000	500	1500
IV	FSa Fine grained sand	18.64	0.30	0.65	32000	20800	63000
VSC	All- in aggregate	19.00	0.20	0.80	84000	67200	-
JG	soil + binder	20.00	0.20	-	-	350000	-
DSM	soil + binder	18.50	0.20	-	-	210000	-

According to calculations to fulfill all the previous assumptions the following columns should be made:
– 8 VSC with diameter 1.0 m and length 5.0 m,
– 19 VSC with diameter 1.0 m and length 6.0 m,
– 9 VSC with diameter 1.0 m and length 6.5 m,
– 121 VSC with diameter 1.0 m and length 8.0 m.

Fig. 6 shows the Vibro Stone Columns arrangement.

3. FINITE ELEMENT METHOD

To control previous calculations, the FEM analysis was carried out. Table 2 presents the values of soils parameters used in Z-Soil software analysis [1].

Some of these parameters were taken from Table 1 (internal friction angle, cohesion and soil weight – characteristic values) and the values of the Young modulus were taken from tables 7.10 and 7.11 from [9] and [10]. Because some data was missing in the made ground parameters, to finish calculations some assumptions needed to be made.

ASSUMPTIONS:

– Analysis and Driver definition:
  • Initial state
  • Time dependent
– Material formulation: elastic
– Loading: N = 360 kN/m
– Loading function: 0-0
  1-1

During design phase the settlement differences are the most dangerous for the structural elements. Unfortunately, because of the software limitation for the FEM analysis only small part of the soil conditions was taken into account. Fig. 7 and 8 show the main problem – without improvement the structure is susceptible to irregular settlements

To avoid this problem some techniques of soil improvement need to be used. It does not only make the future settlement more uniform but also limits it to the allowed value.

In the analysis where no ground improvement technique was used the following results were obtained:
– max. displacement in Y direction: - 6.73 cm
– max. displacement in X direction: - 1.01 cm

As a comparison in the analysis where Vibro Stone Columns were used the following results were obtained:
– max. displacement in Y direction: - 0.64 cm
– max. displacement in X direction: - 0.12 cm

It is necessary to add that in both other methods (DSM and jet grouting columns) the values of settlements were similar.

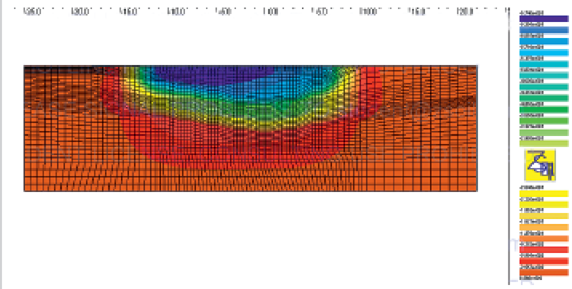

Figure 7.
Displacement Y – without ground improvement (Z-Soil software) [1]

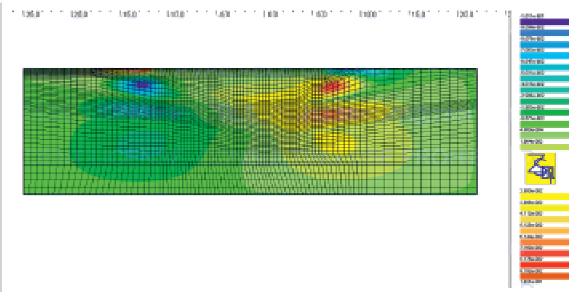

Figure 8.
Displacement X – without ground improvement (Z-Soil software) [1]

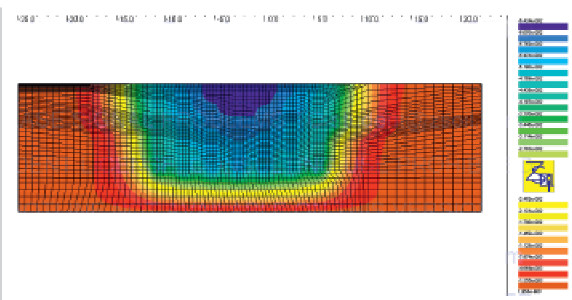

Figure 9.
Displacement Y – ground improvement technique – Vibro Stone Columns (Z-Soil software) [1]

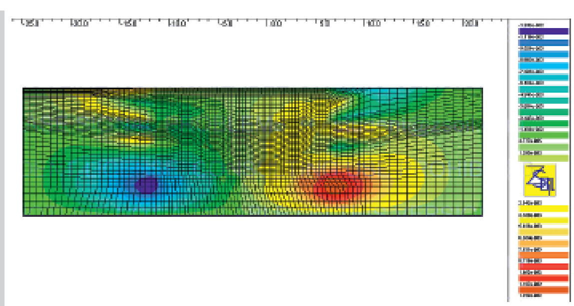

Figure 10.
Displacement X – ground improvement technique – Vibro Stone Columns (Z-Soil software) [1]

Based on the presented diagrams from FEM analysis and simplified calculations it is recommended to make both analyses during a design phase of the investigation. There could appear small differences in the results but in FEM model some interesting aspects can be visible, which is impossible in simplified method.

4. CONCLUSIONS

According to presented simplified calculations and cost calculation, a few compared aspects of the presented methods were schematically shown in Fig. 11÷14.

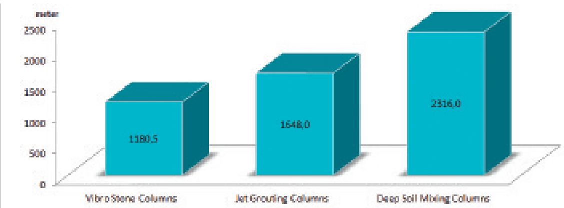

Figure 11.
Total length of various types of columns [m] [1]

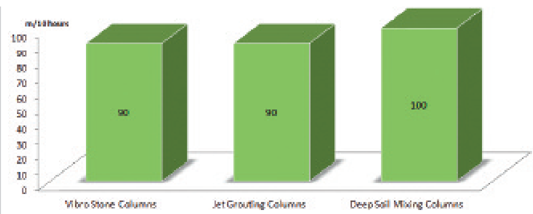

Figure 12.
Possible daily realization of various types of columns [m/10hours] [1]

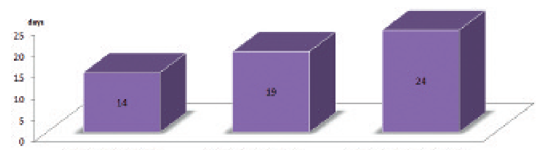

Figure 13.
Time of realization of various types of columns [days] [1]

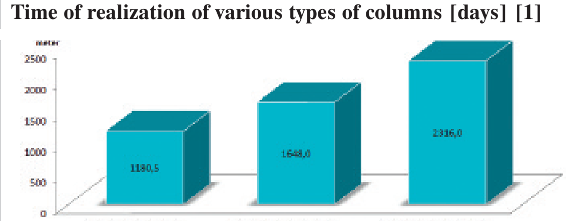

Figure 14.
Total costs of forming various types of columns [PLN] [1]

According to the presented results it can be said that Vibro Stone Columns have a lot of advantages. Forming a column in this technology is cheap, quite easy and, what is most important, the column has got relatively good bearing capacity. They cannot be used everywhere, but for soil conditions presented in this paper for sure it is a good option.

To summarize the paper it is worth saying that in all the presented methods the possible day realization (in the range of 90 100 m/day) and the costs of forming the column (in the range 100 120 PLN/m) are similar, and depend on the same factors such as: weather, equipment used, soil conditions, number of columns, etc. The main difference is in the unit material cost and in the methods of calculation, which gives the real necessary amount of columns. To compensate the second aspect new research should be made. It will make the calculation procedure more clear and could help to avoid such huge safety factors.

REFERENCES

[1] *Zielińska K.*; Various types of columns used nowadays in geotechnical engineering, Master thesis, Gliwice, 2011

[2] www.zamki.pl

[3] www.gizycko.pl/zamek-krzyzacki.html

[4] Geotechnical documentation for Castle complex in Giżycko; Zakład Badań Geologicznych, Toruń, 2008

[5] *Żmudziński Z., Motak E.*; Ocena obliczeniowa nośności pali wykonywanych metodą wysokociśnieniowej iniekcji strumieniowej (Design procedures for calculation of bearing capacity of jet grouting piles), Sesja naukowa, Gdańsk, 1995

[6] PN-B-03264:2002 Konstrukcje betonowe, żelbetowe i sprężone. Obliczenia statyczne i projektowanie (Plain, reinforced and prestressed concrete structures. Analysis and structural design), Polski Komitet Normalizacji, Miar i Jakości, Wydawnictwo Normalizacyjne, Warszawa, 2002

[7] *Kempfert H.G.*; Ground improvement methods with special emphasis on column-type techniques, Institute of Geotechnique. University of Kassel, Germany, 2003

[8] *McCabe B. A., McNeill J. A., Black J. A.*; Ground improvement using the vibro stone column technique, The Institution of Engineers of Ireland, 2007

[9] PN-81/B-03020 Grunty budowlane. Posadowienie bezpośrednie. Obliczenia statyczne i projektowanie (Building soils. Foundation bases. Static calculations and design), Polski Komitet Normalizacji, Miar i Jakości, Wydawnictwo Normalizacyjne, Warszawa, 1981

[10] *Wiłun Z.*; Zarys geotechniki (Geotechnical outline), Wydawnictwo Komunikacji i Łączności. Warszawa, 2007