Design prediction of the strengthened foundation base deformation by field tests data

La prèvision de calcul des déformations de la base des fondements reportès à partir des recherches prises en nature

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ABSTRACT: The paper presents the solution of the complicated practical geotechnical problem of the skeleton structure foundation strengthening. The strengthening was done due to change of the spatial arrangement of a building and essential load increase. The experience of a foundation strengthening with jet grouted piles is described based on results of the base deformations monitoring. The main design principles of the foundations under strengthening are given. The results of the deformation design prediction based on jet grouted piles test and the base deformation measuring are presented.

RÉSUMÉ : Dans cet article on présente la solution d'un problème géotechnique pratique compliqué du renforcement des souches d'un bâtiment en carcasse construit sur les sols de fondation dangereux à cause du karst, en raison du changement lors de la construction de la conception de plan et de volume du bâtiment et de l'accroissement signifiant de charge. L'expérience est décrite du renforcement des souches par des papillons d'injection de forage sur la base des résultats du monitoring des déformations des sols de fondation. Les résultats sont présentés des pronostiques prévisionnelles des sols de fondation des souches renforcées à la base des essais des papillons d'injection de forage et de la mesure des déformations du sol de fondation.

KEYWORDS: foundation strengthening, settlements, pile vertical load test

1 INTRODUCTION

Design prediction of the strengthened foundation base deformation by field tests data was executed for the new shopping centre located in Ufa (Russia). The 500x250m shopping center was designed as a skeleton one-storey building with column spacing 16x8 m. The building construction was started in April, 2007, then restarted in June, 2009 and finished in 2010. Since May, 2008 till August, 2009 the construction at site has been not performed. In 2007…2008 the foundations and the most part of the bearing structures have been constructed. During construction time, the building part was changed (by investor's demand). The column spacing was increased (8x16m to 16x16m or 12x16m) and foundation loads to the moment of construction stoppage 1,2…1,5 times increased the design ones. After construction restarting, other changes of building frame design have taken place. At the significant area the number of stories and floor loads have been increased. As a result, all these changes provoked 30…70% increase of the foundation loads and the further foundation strengthening.

2 ENGINEERING-GEOLOGICAL CONDITIONS

Under the foundation base stiff clays, tough and soft loams occur underlain with water saturated medium coarse sand and gravel at the depth of 8…10 m. (table 3). Maximum predicted ground water level is 2 m under the foundation base. The building site applies to the third category of stability about karst deformations and is divided into sections according to extent of their risk in accordance with Russian Codes. At this site, areas are located that are classified according to their karst risk as potentially not dangerous and potentially dangerous (fig.1) with the probable design diameter of karst hole 7 m.

Due to site severe engineering-geological conditions characterized with lack of homogeneity and karst risk, the following foundations were designed: post- and strip foundations on the bed; piled foundations with the in-situ raft (pile groups); strip foundations on the bed and piled foundations with the strip in-situ raft reinforced considering a karst hole formation.

Severe engineering-geological conditions of site demanded foundation settlement observation and expert investigation of construction.

3 TECHNICAL EVALUATION OF THE STRUCTURAL CONCEPT ON FOUNDATION STRENGTHENING

When design working out and the way of the foundations strengthening selecting, the following was taken into attention.

1. To the moment of the strengthening design development, the building was 1,5 years. In axes 1…15' the bearing structures were completely constructed and at the rest part of the area foundations, columns and floors of the ground floor were built.

2. According to monitoring results (table 1), it was stated that to the moment of strengthening design development (August 2009), the settlements on the whole were stabilized. The settlements of the column foundations with the loads exceeding the design ones already in the process of construction were 6…10cm; the settlements of the rest foundations were 3…4 cm. The settlements data were used to evaluate the coefficients of subgrade reaction of strip- and post foundations bases that demanded strengthening (fig.2, table 2).

Taking into account that the significant part of the structures was constructed and more than half of the base loads have already been transferred, when selecting the method of the foundation strengthening the minimum digging out and dismantling (drilling, cutting, etc.) of the existing foundation should have been provided. Method of strengthening with jet grouted piles was selected with loads transfer from the building through the connection of the reinforced concrete column with the in-situ raft rested on piles.

Table 1

Mark number (fig.1)	Dates of measurement (days) and settlements (mm) from the moment of last measuring												Settlement for 958 days of observation, mm	Strengthening	Foundation type
	Settlement for the previous period, mm	24. 11. 2007	20. 02. 2008	10. 04. 2008	07. 05. 2008	02. 09. 2008	15. 04. 2009	16. 11. 2009	20. 01. 2010	16. 05. 2010	16. 06. 2010	09. 07. 2010			
		7	88	50	27	118	225	217	63	116	31	23			
M7	0	0	1,8	8,0	3,7	0	0	0,5	0	2,1	0	0	16,1	–	post
M14	0	0	2,6	5,8	0	0,9	0	9,7	0,5	1,2	0	0	20,7	–	strip
M26	1	0	0	1,9	2,5	0	2,1	0,7	0	0,9	0	0	9,1	–	strip
M27	1	0	5,4	14,0	6,1	5,9	9,2	21,5	17,0	3,3	0	0	83,4	–	strip
M29	0	0	6,2	11,7	5,2	2,3	10,2	13,8	2,1	1,2	0	0	52,7	–	strip
M31	50	0	0	0	1,4	8,5	7,7	21,8	2,0	1,3	0	0	92,7	JGP	post

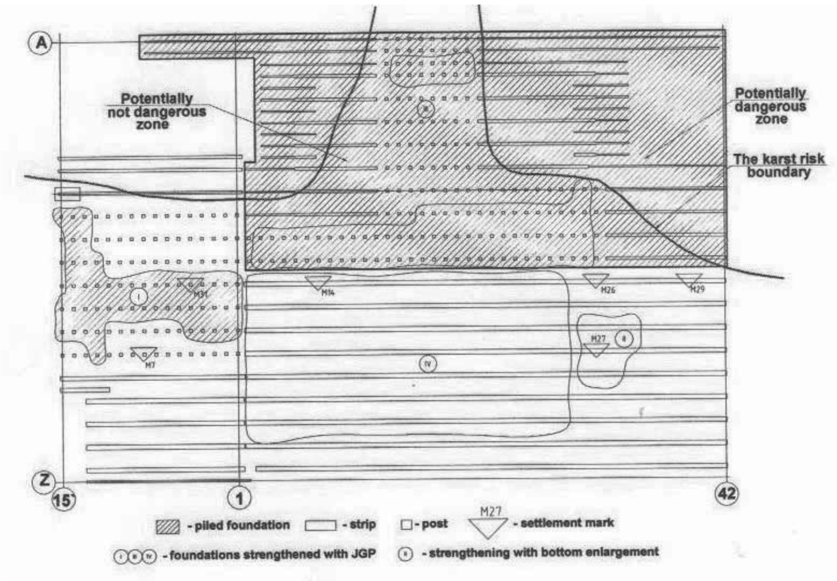


Fig.1. Combined plan of foundations, strengthening constructions and settlement marks

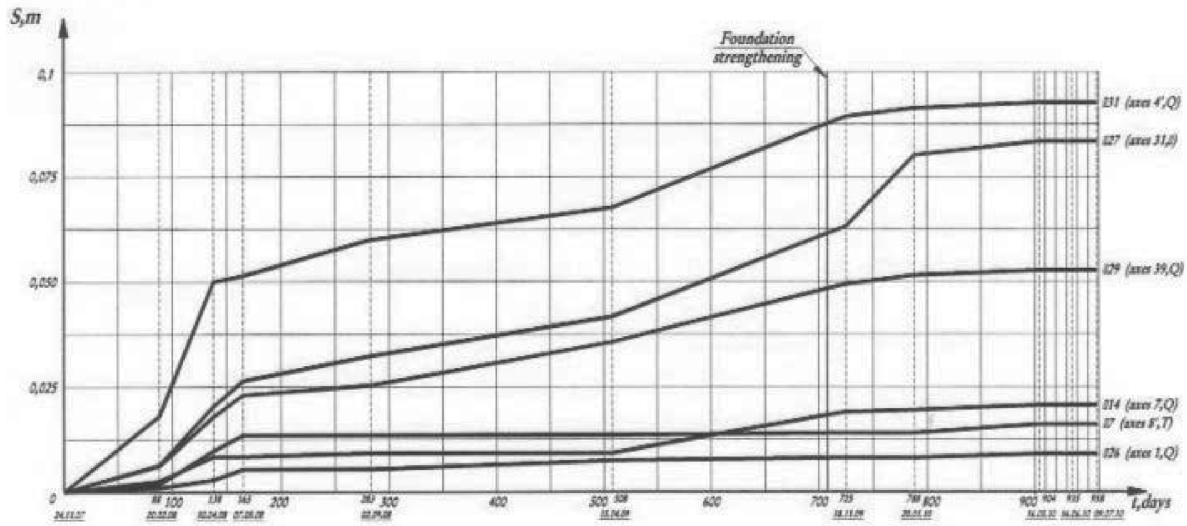


Fig. 2. Monitoring results of foundations settlements

Table 2

Mark number (fig.1)	Foundation type	Settlement before construction restart, mm	Base pressure before construction restart, kH/m^2	Coefficient of subgrade reaction, kH/m^3
M7	post	13,5	64	4700
M14	strip	9,3	114	12200
M26	strip	5,4	114	20000
M27	strip	25,5	114	4400
M29	strip	25,0	114	4500
M31	post	60,0	144	2400

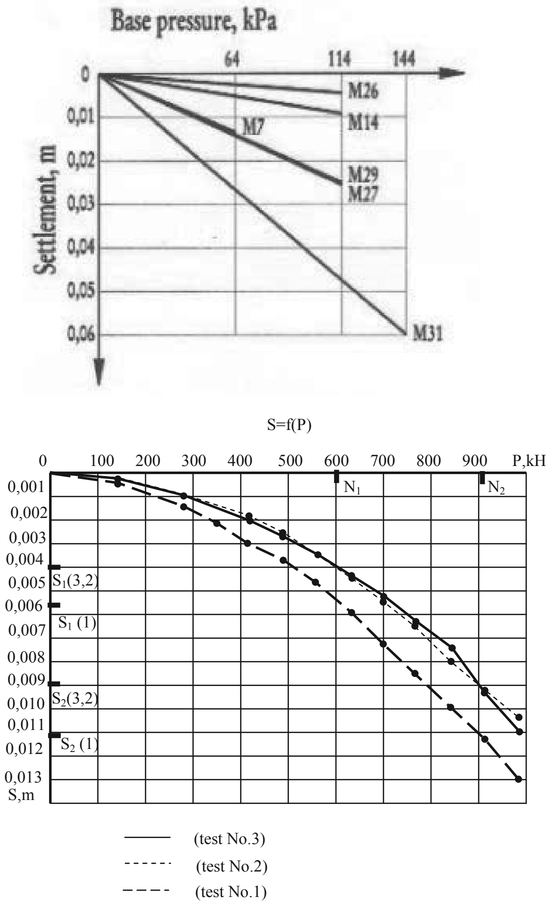
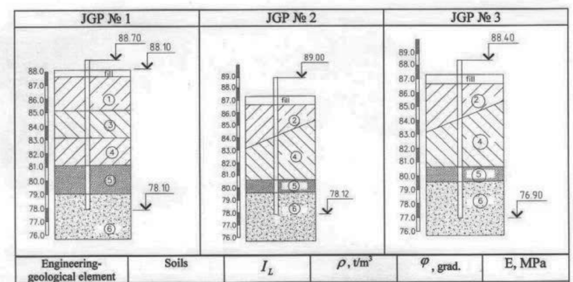


Fig.3. Diagrams of field investigations
a – base pressure-settlement of post- and strip foundations; b– load-settlement of test piles

Table 3



Engineering-geological element	Soils	I_L	ρ, t/m^3	φ, grad.	E, MPa
1	cay	0,1	1,838	16	17(10)
2	cay	0,63	1,59	11	5
3	loams	0,34	1,85	13	12
4	loams	0,64	1,89	11	8
5	sand	-	1,9	29	20
6	gravel	-	2,09	R_0=0,5 MPa	

425 mm diameter and 10…11 m length jet grouted piles were deepened into gravel soil to the depth of 1 m and more. To evaluate the pile design load, the pile vertical load test of trial piles with the diameter 425 mm, 10,6 m length (pile No. 1), 10,88 m length (pile No. 2) and 11,5 length (pile No. 3) (table 3) have been carried out. The piling was realized with the unit SBU 100 GA50.The engineering-geological characteristics of soils are presented in table 3.

Pile vertical load tests have been carried out according to standard method. The limit resistances while testing reached 980 kH. Figure 3 presents diagrams of pile tests.

Considering different structural concepts of the foundations and the building, analysis have been carried out according to these features and four types of the foundations strengthening have been suggested (see figures 1 and 4).

I. Strengthening of *post foundations* of a building in axes 15' – 1. Practically all extra load is taken into account to be transferred to jet grouted piles, i.e. the load is not transferred to post foundation, as the construction of the reinforced concrete raft strengthening is not absolutely stiff.

That's why only insignificant part of the extra load is transferred to the foundation base, so the foundation in combination with the strengthening construction and piles behaves as combined piled foundation.

II. Strengthening of *strip foundations without piles* by means of geometrical dimensions increase with use of technology "HILTI".

III. Strengthening of *pile group foundations* with increased loads was carried out by means of jet grouted piling around the raft and including them into pile group behavior through the reinforced concrete slab fixed with the column and the raft (with the anchors HILTI). With such method of strengthening jet grouted piles start to work in a pile group together with the driven piles.

IV. Strengthening of *foundations without piles* in axes 1 – 29 was carried out by means of insignificant part of load transfer to the foundation. Jet grouted piling use is based on insufficient reinforcing with in situ reinforced concrete strip under the columns, the load of which is more than twice increased compared to design one. Such strengthening construction partially loads the existing foundation including it into work. The jet grouted piles together with the foundation accept the ultimate design load. Pile strengthening is carried out along the whole length of the strips, as otherwise the different stiffness of the strip base will lead to its deterioration.

Irrespective of strengthening type, the main design requirement is continuation of foundations loading only after completion of all works on strengthening considering the terms of strength increase of in-situ concrete of structures.

4 THE MAIN DESIGN PRINCIPLES

Analysis of foundation strengthening has been carried out considering the deformability of the foundation base and jet grouted piles. Due to special features of constructions of the foundations under strengthening and different extent of works completion on above foundations structures construction, the following design assumptions were taken.

While the building *post foundations* strengthening in axes 1'…15', analyses of loads transferred to the foundation after its strengthening were carried out i.e. when construction restarting considering the loads after the building starting (fig.5). Analysis of the column joint and strengthening construction was done for the total design load. Deformability indices of the foundation base and jet grouted piles quantitatively evaluated with the coefficients of subgrade reaction of the foundation base under strengthening and pile stiffness respectively, were determined

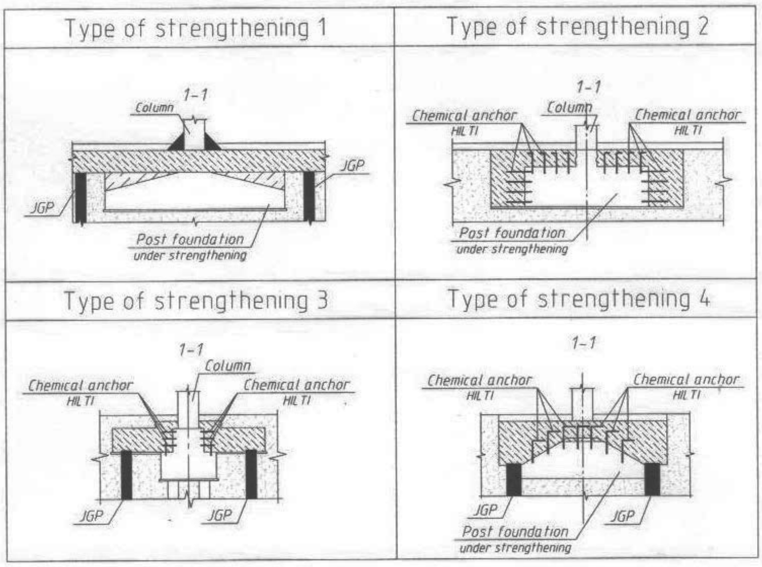


Fig.4 Types of foundation strengthening with jet grouted piles (technical decision)

by results of pile test at site and monitoring of post foundations settlement (tables 2, 4). While analysis of the number of jet grouted piles, the total load was taken to be transferred to those piles, so the coefficient of subgrade reaction of the foundation base under strengthening was taken to be equal 0.

When *piled foundations* strengthening with jet grouted piles, analyses have been carried out for the total design load. Pile stiffness was determined by data of pile vertical load test of the driven- and jet grouted piles.

The authors of the paper made predictions of the foundation settlement in axes 1' 15', P-S due to foundations load increments, strengthened with the jet grouted piles after the construction restart. The deformations are calculated with regard for the different deformability of the post foundation base and a pile. The coefficient of subgrade reaction in the post foundation base (settlement marks M7 and M31 in fig.1) was determined by results of settlements monitoring (table 2, fig.3a) and stiffness coefficient of jet grouted piles – by tests data (table 4, fig. 3b). The design scheme is presented in fig.5. By results of analysis of the base deformation of the most loaded post foundations strengthened with the jet grouted piles, the settlements after the construction restart with regard for the total load were 13,8 and 12 mm, respectively. At present, when the construction of the shopping center is completed, but the building is not put into operation, the measured base deformations of these foundations are 10,5 and 5 mm, respectively. Such conformity of predicted and measured deformations confirms the efficiency of the base strengthening and high accuracy of the analysis methods based on in-place tests.

Table 4

Test number (table 3)	Pile (JGP) length, m	Pile (JGP) length in soil, m	Pile settlement according to test, mm	Stiffness ratio of pile (JGP) base, kN/m $K=\frac{N_2-N_1}{S_2-S_1}$
1	10,6	10	13	50000
2	10,88	10,58	11	60000
3	11,50	11,10	10,35	60000

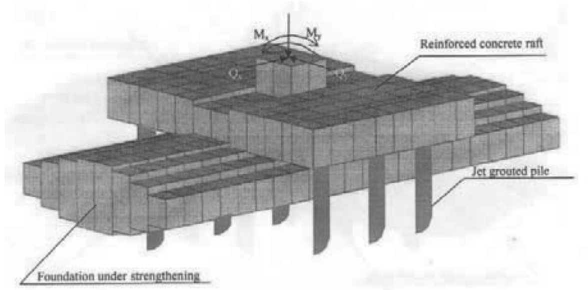


Fig.5. Design diagram of foundation strengthening (strengthening types 1 and 4)

5 CONCLUSION

1. The complicated practical geotechnical problem of strengthening of the skeleton building foundations under construction, the necessity of which was provoked by change of space-planning decision in the process of construction is solved.

Within one 500x250 m building, four types of foundations have been designed: post foundations on the bed without karst protection; strip foundations on the bed designed for 7 m diameter karst hole; piled foundations in kind of pile groups of driven piles without karst protection and pile group foundations combined with karst protected reinforced concrete strips on piles.

2. Four types of foundations strengthening has been developed with the use of jet grouted piles taking into attention loads increase compared to design, acting (already imposed) loads and foundations settlements at the moment of their strengthening, structural concepts of foundations and the extent of karst risk of the base.

3. Analysis of strengthening constructions and base deformations was carried out according to data of jet grouted piles vertical load test and settlements measurements of the foundations under strengthening.

4. The results of the strengthened foundations settlements measurement after the building implementation showed the good precision with analysis data. This proves the correctness of the taken structural and design schemes.