Jacked Pile Interaction with Strengthened Foundation

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Abstract. During the reconstruction old, often historical heritage, buildings are changing their working conditions. Therefore, in most cases the foundations need to be strengthened. One of the reasons is, because the actions on foundations are changing. Other reason is building state for the foundations deformation. Foundation bearing capacity can be increased by strengthening the foundation ground or changing of the foundation construction. Reliable and effective method of strengthening is to use the jacked piles. This method must be assessed in the two approaches. One is the influence on building structures and foundations during installation, the other, relationship between piles and foundation after reconstruction. In the article is given simulation of the actions on foundation during reconstruction and load distribution between the foundation and piles. It also assesses influence of the piles stiffness on load distribution between the strengthened foundation and piles.

Keywords: underpinning, jacked pile, pile stiffness, displacement, stress distribution, pile force.

Conference topic: Foundation construction.

Introduction

At present, significant increase of the old buildings renovation works in the capital and other cities. Undergoes renovation, not only the buildings which have historical heritage, but also many other older buildings in city centres. The high cost per square meter useful area in urban center has stimulated the old buildings renovation. Very often, when is changing the usage purpose of the renovating building, may lead to changes in their foundation load. For this reason it is necessary to strengthen the foundations of the building, choosing the most suitable and cost-effective strengthening methods of the foundation or ground beneath them. Foundation bearing capacity can be increased by strengthening the foundation ground or changing of the foundation construction.

In the reconstructed building in Maironio str. 1 in Vilnius will be equipped a hotel. In the supporting structures the architects has provided a number of changes. The changes have included underground structures as well. One of these changes was to deepen basement and a 17.5 m long bearing wall (Fig. 1) in the basement to replace by four columns.

Underpinning construction

The designing load of the foundation columns was 2890 – 3180 kN. In the technical project had provided such work sequence: cut out slot in the basement wall, install the foundation plate, set up the column. This sequence had been provided for each column installation. After the columns installation, the wall had been demounted. Dimensions of columns plate had been designed 3.0×3.0 m, height of 0.80 m, foundation pad 0.30 m below the water level. This relatively dangerous

solution did not fit for the builders. It will be difficult to implement this solution. Builders had desired more reliable and simple solution. It was suggested to install continuous 0.50 m height beams on the both sides of the existing foundation with impacted eight piles for each column (Fig. 1).

Fig. 1. Strengthening of the wall foundation with the beams on the both sides of foundation

This is effective and often used method of the foundation strengthening. Beneath the strengthening foundation or near them the piles are installed. The pile can take over the whole load or part of the load that transmitted onto the existing foundations. Perhaps the most reliable type of piles is a jacked pile. The piles are

pushed into the ground. Pile's section length depends on the type of equipment. Pushing is completed, when pushing force achieve design value and pile stops swoop. Piles are pressed into the soil by jacks without any noise or vibration. The equipment is simple and small, therefore to install piles are easy both outside and inside of the building. The foundation is strengthened in two phases. In the first stage is concreted raft with openings and loops for the piles installation, the second stage takes place after concrete hardening. At this stage the piles (159 mm diameter metal pipes) are pressed in and filled with concrete after impact. The installation of jacked piles requires 1.5÷3.0 times less power than the installation of other types of piles (Perley, Gdalin 1990). The pressing force and depth are being checked during installation. The pressing is finished after reaching the proper depth and pressing force. Vertical forces acting raft beam as pliers will press the existing foundations (Fig. 2), because the bending moment from the vertical forces are greater than of horizontal forces. Connective rod must withstand the effect of bending moment that will appear from impact action, piles action and horizontal force.

Fig. 2. Action of vertical forces: 1 – existing foundation; 2 – grillage beam; 3 – key; 4 – connective rod; 5 – longitudinal reinforcement

Usually during compression, the effect acting the strengthening foundation is greatest. Impaction force must be greater than the design pile load (Medzvieckas, Sližytė 2005):

$$F_{imp} = F_{cd} \times \gamma_p, \quad (1)$$

where: F_{imp} – impact force; γ_p – empirical coefficient between the compression force and the pile bearing capacity (1,7 for fine saturated sand, 1,4 for medium and coarse sand); F_{cd} – design pile load.

Numerical simulation

To assess effects for a foundation and foundation displacements of the reconstructed building the calculations using PLAXIS 3D program had been fulfilled. All construction stages of renovation were modelled. When beams on both sides of the existing foundation were concreted, the openings had been cut out and columns installed. After columns installation the wall was disassembled. The existing foundation pad is rested on dense gravel (angle of internal friction $\phi = 39^\circ$, Young's modulus $E = 79$ MPa) above ground water level (Fig. 3). Beneath gravel was detected up to 3.8 m dense (internal

friction angle $\phi = 36^\circ$, Young's modulus $E = 48$ MPa), deeper from 5.4 to 6.0 m very dense (internal friction angle $\phi = 38^\circ$, Young's modulus $E = 82$ MPa) fine sand. Beneath was found very dense gravelly sand (internal friction angle $\phi = 40^\circ$, Young's modulus $E = 63$ MPa). In 2015, the investigation was carried out by Ltd "GEO-TESTUS".

Numerical modelling has shown that the pressure beneath the existing foundation had no significant changes (Fig. 4). In the cross section near the second column the average pressure beneath the foundation pad changed from the initial (1st stage) 720 kPa to 749 kPa after the wall demolishing for the second column installation (3rd stage). After installation of the second column and wall demolishing between first and second columns (4th stage) pressure decreased till 722 kPa, after the dismantling of the wall for the third column installation increased (5th stage) till 763 kPa, after the third and fourth column installation (6÷8th stage) pressure changed insignificantly 744÷746 kPa.

The largest settlements occurred just after the building construction. According to the calculation, the initial foundation settlements could be 32–37 mm (Fig. 5). The cutting out openings for columns, columns

Fig. 3. Geological situation: 1 – back-fill; 5 – gravel middle dense; 6 – gravel very dense; 2 – fine sand dense; 3 – fine sand dense very dense; 4 – gravelly sand very dense

Fig. 4. Pressure changes in cross-section near the second column: 1st stage – initial phase of the reconstruction; 2nd stage – 1st column installation and part of the wall demolition; 3d stage – wall demolition for the 2nd column; 4th stage – 2nd column installation and the wall demolition between the 1st and 2nd columns; 5th stage – wall demolition for the 3–s column; 8th stage – 4th column installation and demolition of the last part of wall

installation and walls disassembling, will create additional displacements. Additional displacements that will be after columns installation is shown in Figure 5. The works order was such: primarily was installed first column and dismantled part of the wall near column, then cut out openings for the second column and installed the second column. The same sequence was for third and fourth columns installation. After columns installation the rest part of the wall was disassembled.

Fig. 5. Foundation displacement

After the first column, installation between 2.6÷3.5 m and from dismantling part of the wall the unloaded foundation part will rise up. Because 4th column was placed between 16.0÷17.0 m this part will sink down. The beam on both side of the foundation warrant small foundation displacements and slight variation of the pressure beneath foundation pad. As the pressure after the foundation pad was changed little, piles will take over only a small load. Calculations show that underpinning could be without piles.

The foundations on a naturally formed mineral soil, very often there is no need to strengthen, as the base bearing capacity are higher than the renovated building foundations loads. The degree of ground strength exploitation is often no more than 0.5 rarely to 0.8, therefore reconstructed building ground can take over a considerable additional load without soil strengthening and without increasing the dimensions of the foundations. Moreover, after the long-term building exploitation the soil beneath foundation acquire new properties (Konovalov 1986). Underlay is compressed, however, as the research suggests not much and depending on buildings age and the foundation pressure. Thickness of compacted soil layer beneath the foundation pad can be about from 1.0 to 2.0 foundation width (Konovalov 1986). However, when in the renovated building is changing the structural scheme, the load on foundations redistributes. In most cases the foundations must be reinforced with piles. The piles load depends on the pressure change beneath the foundation and the stiffness of the piles. When the foundations of renovated building are unloading a few, the pressure beneath foundation is changing slightly (Table 1) and the piles

stiffness has little effect. The 1st row is represented the stress distribution after a reinforced foundation without the piles. The arrows have shown the piles location in the reinforced foundation. Piles stiffness has little effect on stress distribution under foundation.

When during renovation the foundation is not unloaded, the force acting piles is not big and depends on the stiffness of the piles (Table 2). The foundation displacements are depending from the pile stiffness. The changes of foundation displacements get a small.

Calculations were carried out to assess the influence of the foundation unloading. If at the initial phase of the renovation the foundation unloading, piles stiffness has more influence on the pressure distribution after the foundation (Table 3).

Table 1. Pressure under foundation (kPa)

Beam				Foundation			Beam		
Initial	↑			-728	-670	-732	↑		
1	-44	-68	-74	-765	-706	-768	-87	-69	-45
2	-44	-68	-74	-765	-706	-768	-87	-69	-44
3	-43	-67	-74	-765	-706	-768	-87	-69	-44
4	-41	-66	-73	-764	-705	-767	-86	-68	-41
5	-35	-63	-70	-761	-702	-764	-83	-64	-35

Table 2. Pile force depending on pile stiffness and foundation displacement

No.	Pile force	Pile stiffness	Displacement
	kN	kN/m	mm
1	0.0	0	0.434
2	0.6	2000	0.425
3	1.2	4000	0.416
4	5.3	20000	0.372
5	64.0	400000	0.324

Note: *stiffness 0 – without pile.

Table 3. Pressure under foundation (kPa)

Beam				Foundation			Beam		
Initial ↑ Unload				-728	-670	-732	↑		
				23	-135	23			
1	-153	-327	-314	-301	-437	-303	-315	-330	-135
2	-159	-308	-293	-279	-417	-281	-295	-311	-140
3	-164	-291	-275	-260	-400	-262	-277	-294	-145
4	-171	-250	-234	-217	-360	-218	-235	-254	-152
5	-161	-201	-190	-171	-319	-171	-190	-204	-157
6	-131	-145	-140	-119	-273	-120	-141	-146	-128
7	-24	-20	-37	-14	-176	-14	-37	-19	-27

In 1st row is represented the distribution of stresses in the strengthened foundation without the piles. Stress distribution after the strengthened foundation depends from the piles stiffness. Increasing the piles stiffness stress after foundation decreases. The force on piles and foundation displacements size depends from the pile stiffness (Table 4).

Table 4. Pile force depending on pile stiffness and foundation displacement

No.	Pile force kN	Pile stiffness kN/m	Displacement mm
1	0	0	13.48
2	25	2000	12.57
3	46	4000	11.78
4	98	10000	10.00
5	156	20000	8.03
6	225	40000	5.85
7	374	400000	1.26

Note: 0 – without poles.

With increasing piles stiffness, the force acting piles increase while foundation displacements decrease. Minimal additional settlements of the foundation are an important motivation for the using the jacked piles for the foundation strengthening. Allowable additional displacements of the foundation depend on the building condition and architectural and historical value (Iljichiov *et al.* 2001).

Foundation displacements depending from the stiffness of the piles:

$$u = \frac{F_p}{k_p}, \quad (2)$$

where: k_p – piles stiffness (kN / m); F_p – force acting on the pile.

After analyzing the piles test data in sands, Meyerhof (1959) suggested the relationship between the settlement of the piles and the piles diameter, when the load does not exceed one third of the limit value. According this relationship the piles stiffness will be equal:

$$k_p = \frac{F_u \cdot 30n}{d_b}, \quad (3)$$

where: d_b – diameter the pile base; F_u – pile limit load; n – relation between limit load and design load ($n \geq 3$). Poulos and Davis (1980) suggest the load settlement ratio of pile in terms of coefficient, I . The coefficient I is obtained from a number of other coefficient that reflect features such as the pile-soil stiffness ratio, the value of Poisson's ratio for soil and so forth. Piles stiffness then can be determined in accordance with equation:

$$k_p = \frac{d_b \cdot E_L}{I}, \quad (4)$$

where: d_b – pile pad diameter; E_L – Young's modulus of soil at pile tip level.

Fleming *et al.* (2008) proposed the equation for calculation of the piles displacements, when obtain linear dependence on the load. Under this dependency piles stiffness will be equal to:

$$k_p = \frac{2d_b G_b}{(1-\nu)} + \frac{2\pi \bar{G} L}{\zeta}, \quad (5)$$

where: d_b – pile pad diameter; G_b – shear modulus of soil below pile tip level; $\bar{G}$ – average shear modulus of soil over the embedment depth, L , of the pile; ζ – parameter can be found as natural logarithm of ratio between the radius of soil deflection around the pile and pile radius. This parameter is depending from variation of soil shear modulus with embedded depth and ratio between pile embedment depth L and diameter d .

When the load – the normalized settlement curve is fitted to the Weibull curve (Takagi *et al.* 2007), this curve always passes the same yield point at R_y/R_u of 0.63. Experiments show that when the load on the pile not exceeds 0.5–0.6 the ultimate load, the settlement increases linearly within the increase of the load, and the stiffness remains approximately at a constant value (Cheng 2011).

When there are used jacked piles stiffness can be assessed in accordance with the piles compressing graph, which is drawn up during the pushing. After the pile are unloaded and again loaded in stages, by measuring the displacement of the pile.

Under submitted piles stiffness calculation dependencies, piles stiffness should be between 150 000 and 280 000 kN/m, close to the piles material stiffness. However, when the load is close to the limit, the stiffness of the piles should be much lower 10 000 and 40 000 kN/m. Urbonas *et al.* (2016) carried out analyses of piles stiffness based on the static test. Calculated piles stiffness values when settlements varied from 0.97 to 4.89% of the piles diameter were obtained respectively from 125 000 to 38 000 kN/m.

Conclusions

Installation of the beams on both sides of the existing foundation reduces differences of the foundation settlements, due to load redistribution, changing bearing structure. The calculated additional foundation displacements were less than 0.5 mm. When the columns were installed instead the wall, no splits were observed in wall above the basement.

The load that takes over the piles is depending on load change during the reconstruction of foundation. If the foundation during reconstruction is unloaded slightly, the piles will take over small load. The foundation will be taken over the greater part of load.

If the foundation during reconstruction will be unloaded considerably and loaded again, then the piles will take over a larger load. The load size will depend on the stiffness of piles. As the piles stiffness is high (> 100000 kN/m), the piles will take over the big part of the load.

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