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GROUND ANCHORS IMPACT ANALYSIS ON ADJACENT BUILDINGS

BY

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Abstract. Often ground anchors need to be executed under existing buildings, especially in urban zones. By introducing an anchor in the stress zone of a footing and by loading the anchor, the soil is influenced both the foundation and ground anchor, which may induce a changing of state for the foundation. In this case is analysed strictly the loaded bond length influence on nearby foundation, without taking into consideration the retaining wall moving. Was analysed a single case, using an isolated footing, under which a row of prestressed ground anchors were modelled, in three situations determined by the distance from bottom of foundation to the bond length. A close view is pointed on the foundation movement, registering the settlement, translation and rotation values calculated. The computation was made using finite element method and after making the comparison between the initial state of the foundation and the state after anchor loading, some useful conclusions, which can be used as guidelines for this situation, were underlined.

Key words: anchor load; settlement; rotation; finite element method; stress intersection.

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1. Introduction

Currently, in urban areas, for the execution of deep excavations, it appears the issue of installing prestressed ground anchors outside the property limit, especially under existing foundations. From this comes the necessity of determining the behavior of the active zone for the existing foundation and the foundation itself, when are executed and prestressed ground anchors with the bond length in the soil volume influenced by the foundation. Was started from the assumption that the following situations may occur:

a) grater absolute settlements, when ground anchors are installed under entire surface of footing;

b) grater relative settlements, when ground anchors are installed with inclination;

c) bearing capacity changing of the foundation soil;

d) loss of foundation stability due to rotational movement.

To determine the impact of ground anchors installed under existing buildings, is considered a finite element calculation model (FEM) for a hypothetical situation.

To draw a conclusion, is compared the initial state (foundation without ground anchors in the stress zone) with the final state (foundation with ground anchors in the stress zone), analyzing the states strain, displacement.

2. Modeling the Hypothetical Situation

2.1. Input Information

a) *Reinforced concrete foundation*

Was considered an isolated foundation with the following characteristics: dimensions in plane of the footing: $L \times B = 4 \times 4$ m; foundation level: $D_f =$ $= -1.5$ m from surface; net pressure at foundation base: $p_{\text{net}} = 100$ kPa; type of foundation: elastic foundation.

b) *Prestressed ground anchors*

b_1) length of anchor, $L_{\text{anc}} = 13$ m;

b_2) length of bond anchor sector, $l_b = 7$ m;

b_3) length of free anchor sector, $l_l = 6$ m;

b_4) diameter of bond length, $d = 0.2$ m;

b_5) number of strands, 3 pcs;

b_6) strand diameter, 15.7 mm;

b_7) strands sectional area, 3 × 150 mm = 450 mm;

b_8) inclination angle of anchors, 10^0;

b_9) elasticity modulus of strands, $E = 195{,}000$ N/mm^2;

b_{10}) aAxial rigidity of strands, EA = 195,000 × 450 = 8,775 × 10^7 N = = 87,750 kN;

b_{11}) friction resistance of bond length, $\tau = 120$ kPa;

b_{12}) prestressing force, $P = 300$ kN;

b_{13}) horizontal distance between anchors, $d_a = 1.5$ m.

c) *Description of calculation model*

Is analysed strictly the influence of bond length on foundations under which are executed, considering that the stress zone of foundation is not influenced by the movement of retaining wall.

The calculation model has the dimensions $L \times B \times H = 20 \times 20 \times 10$ m (Fig. 1).

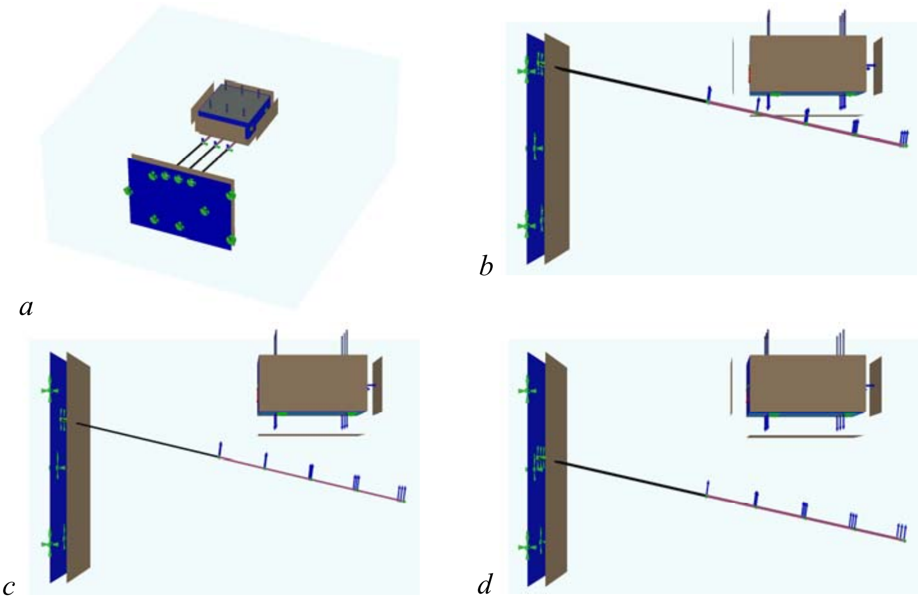


Fig. 1 – View of models. *a* – 3-D view; *b*, *c*, *d* – lateral view of the three situations (see Table 1).

Table 1

Centralizer of Analysed Situations

No. of situation	Type of soil	Level of anchor head, [m]	Minimum distance from bottom of foundation to bond length, [m]
Situation 1	Clayey silt	–0.68	0.5
Situation 2	Clayey silt	–1.68	1.5
Situation 3	Clayey silt	–2.68	2.5

Note: Levels are measured from surface.

The foundation is centred with the ground anchors, on the heads direction.

The deflection of anchor head is limited by blocking the degrees of freedom on the three space directions (u_x, u_y, u_z) of the respetive nodes, and also by introducing a plate, which connects all the anchor heads and which also has all the degrees of freedom blocked.

For the interaction of surface elements with the ground, have been introduced interfaces between them.

The load on the foundation can be placed either in the form of uniformly distributed load or in the form of punctiform load. Was chosen uniformly distributed load, the stresses that could appear in the foundation not being subject of this paper.

The connection between the bond length and free length is rigid for direct transmission of prestressing force from free length to bond length.

Looking at the stress distribution in soil when loading a standard anchor (axial force in anchor decreases from beginning of bond length to the end); (standard anchor = anchor with strands, prestressed, with single bond length), is expected that the beginning of bond length will affect more the foundation.

Rigidities of the surface elements have been chosen relatively large in order to maintain the simplicity of the model.

The calculation was performed for three situations, described by moving the ground anchors at three different depths, in order to underline the variation of anchor impact on foundation (see Fig. 1).

d) *Geotechnical parameters input*

In this case, was used a single type of soil for the entire soil volume, with the characteristics from Table 2.

Table 2
The Model and Geotechnical Characteristics of Soils Used

Parameter	Name	Clayey silt
General		
Model of material	Model	Hardening soil
Type of drainage	Type	Undrained *A*
Unit weight above phreatic level, [kN/m^3]	γ	18
Unit weight below phreatic level, [kN/m^3]	γ_{sat}	20
Geotechnical parameters		
Secant stiffness for CD triaxial test, [kN/m^2]	E_{50}^{ref}	6,000
Tangent oedometer stiffness, [kN/m^2]	E_{oed}^{ref}	6,000
Unloading/ reloading stiffness, [kN/m^2]	E_{ur}^{ref}	24,000
Power for stress level dependency of stiffness	m	1
Cohesion, [kN/m^2]	c'_{ref}	20
Friction angle, [º]	φ'	15
Dilatacy angle, [º]	ψ	0
Poisson’s ratio	ν'_{ur}	0.2
Interfaces		
Interface strength	–	Manual
Interface reduction factor	R_{inter}	0.6
Initial		
K_0 determination	–	Automatic

Ground water level was chosen at –4 m from surface.

2.1. Calculation Steps Presentation

The finite element calculation was performed in the followings steps:

S t e p 1. Calculation of foundation settlement, without ground anchors installation.

S t e p 2. Analysis of ground anchors, without foundation, for which the deformation of soil was registered (horizontal and vertical direction).

S t e p 3. Combined analysis, using both foundation and anchors.

Steps 2 and 3 were performed for each one of the three situations. In this way can be made a comparison of ground anchors effect on adjacent foundations, comparing initial state of the foundation with the new state affected by anchors, and also can be remarked an influence of foundation on ground anchor behavior.

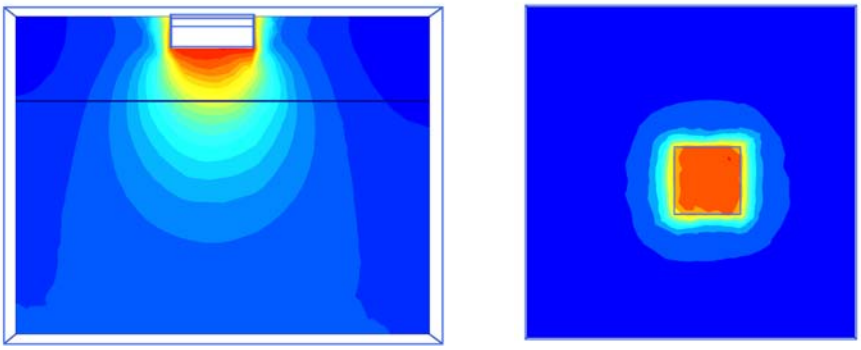


Fig. 2 – Settlement of single footing, without anchors; cross section and plan view at level –1.51 m (1 cm below the bottom of foundation).

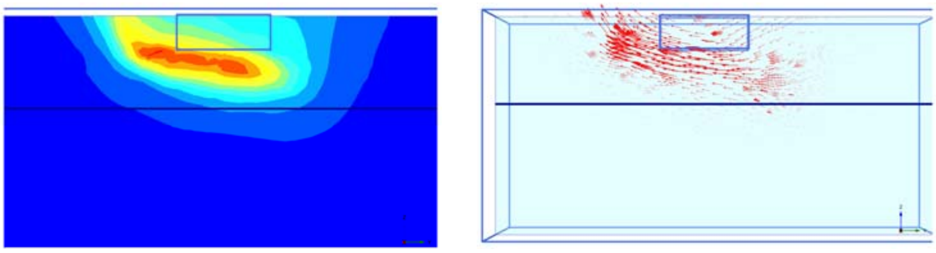
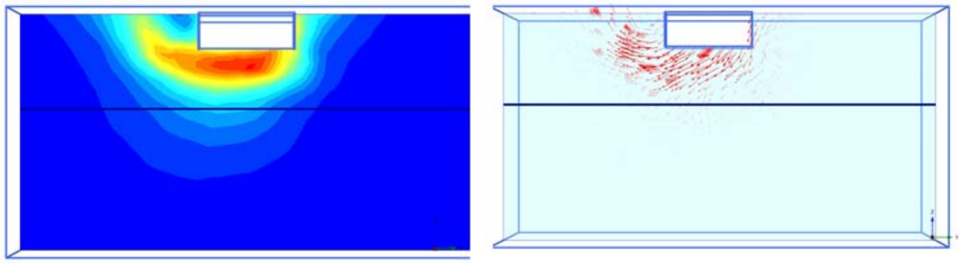


Fig. 3 – Only ground anchor analysis: left – deformation of soil together with bond length displacement; right – directions of soil deformation.

The Figs. 2,...,4 show the general representation of systems behavior, with remark on soil deformation together with element displacements (settlement, translation) and rotation, only for the first situation (see Table 1). The values are presented in the Table 3.



a *b*

Fig. 4 – Analysis of foundation together with ground anchors: *a* – deformation of soil together with bond length displacement and foundation movement; *b* – directions of soil deformation.

Table 3

Presentation of Values Calculated for Steps 2 and 3

	$\lvert u_1 \rvert$	u_{1y}	u_{1z}		$\lvert u_2 \rvert$	u_{2y}	u_{2z} level –1.51 m		u_{2y} level –1.51m	u_{2y} level –1.50m	u_{2y} level –0,1m
	max	max	min	max	max	max	min	max	max	max	max
Sit. 1	20.24	20.18	–3.87	11.93	40.97	36.88	–30.67	17.46	32.43	32.24	11.44
Sit. 2	11.09	10.84	–1.5	4.68	25.45	23,45	–24.59	10.51	12.54	12.32	5.18
Sit. 3	8.36	8.13	–1.27	2.97	19.36	13.73	–19.35	4.35	7.45	7.32	3.33

In Table 3 $|u_1|$ is the total maximum displacement of soil influenced only by the anchors; u_{1y} – displacement on *y*-direction of soil volume influenced only by the anchors; u_{1z} – displacement on *z*-direction of soil volume influenced only by the anchors; $|u_2|$ – total maximum displacement of soil influenced by the foundation and anchors; u_{2y} – displacement on *y*-direction of soil volume influenced by the foundation and anchors; u_{2z} – displacement on *z*-direction of soil volume influenced by the foundation and anchors; *y* – horizontal direction; *z* – vertical direction.

In order to illustrate easely the effects appeared, is used a tabular representation, where is calculated the differences between the final state and the initial state of the foundation (see Table 4).

Table 4

Comparative Presentation of Results with Calculation of Effect in Terms of Displacements

	Isolated foundation			Prestressed anchors		
Situation	Absolute settlement mm	Relative settlement mm	Displacement u_y, [mm]	Displacement u_z, [mm]	Displacement difference Δu_z mm	Displacement u_y [mm]
Sit. 1				min = –4 max = 4	8	20
Sit. 2	17	0	0	min = –1.2 max = 2.4	3.6	6
Sit. 3				min = –0.75 max = 0.25	1	5

	Isolated foundation and prestressed anchors		
Situation	Absolute settlement, [mm]	Relative settlement, [mm]	Displacement u_y, [mm]
Sit. 1	min = –8 max = –32	24	32
Sit. 2	min = –14 max = –24	10	12
Sit. 3	min = –18 max = –14	4	7.5

Notes: the initial relative settlement and initial dispacement on y-direction of the foundation are considered 0; displacement on u_y-direction represents the movement on anchor direction, with positive values on prestressing force direction; the displacement on u_y-direction is calculated at level –1.51 m, 1 cm below foundation bottom level; the values presented in Table 3 are values for the entire soil volume and the values for Table 4 are strictly for the footing, on its footprint.

4. Conclusions

1. *Conclusions on the calculation model used*

a) In order to model the entire ensemble, is recommended like each component to be modeled separately first, tested and in the end followed by combination of all.

b) Displacement of bond length together with soil deformation around it depends on prestressing force, depth of bond length from the surface and on the skin resistance.

c)To highlight the unfavourable situations can be said that is better to use a simple model in order to establish simple guidelines.

2. *Conclusions on the interaction anchorage – foundation*

After calculations, the following conclusions can be drawn:

a) *Absolute settlement* of the foundation increases with anchor loading because of the overlap of stresses in soil given by anchor and foundation, overlap which leads to stress increasing in a point, translated in higher deformation of soil and higher settlement of foundation.

By changing the level of anchor row was desired to highlight the dependence of soil deformation *vs*. distance between the two elements (foundation and anchors) and more exact to see which soil volume is influenced by those two and what are the stress intensities.

Thus can be said that, for the analysed case, the ground anchors influence in unfavourable way the single footing, when anchors are at distances relatively small from footing. It can be observed that the absolute foundation settlement with anchors is almost equal to the absolute foundation settlement without anchors when these are placed at 2.5 m from the footing base. Of course, this distance can vary and may be influenced by a multitude of factors, like: the width of the foundation, the net pressure at the base footing, prestressing force in anchor, geotechnical parameters of the soil, etc. Therefore it was considered a soil with relatively low geotechnical parameters to highlight the anchor influence on foundations.

b) *The relative settlement* of the foundation is given mainly by soil volume deformation when ground anchors are prestressed and can be observed clearly from the analysis of singular anchors, without foundation, the directions of deformation and displacements of soil volume. Thus can be observed a lifting of soil in the zone of connection between free length and bond length, because the maximum stresses in soil given by the anchor are in that zone and because the anchor has an inclination of 10^0. Also can be seen that there is a zone of soil diving at the end of anchor.

The two directions of deformation are rising from the rotation movement of the soil volume above the row of anchors, movement favored by low geological load. At deeper levels of anchor row, is observed a decreasing of this rotational movement and the trend to balance the induced stresses from above bond length with the below induced stresses. This probably comes from the high difference between the stresses induced by anchor and the ones from geological charge. Referring directly to the foundation, the potential of relative settlement appearance because of ground anchors installation decreases with increasing depth of anchors row level and also with the increasing of geological charge. The analysed case singular, but the relative settlement which can appear depends on the position of anchors under foundation and also by the moments at top of foundation.

It is obvious that an anchor positioned under the edge of a foundation or in a corner of it will induce a relative settlement greater than the analyzed situation where the three anchors cover the footprint of foundation in a balanced way.

c) *The translation movement of footing* in the anchor loading direction.

By intersection of the two zones of influence together with the prestressing force, is produced a deformation and displacement of the soil. Basically this horizontal movement is the response of soil acted by the new loads (prestressing force → skin friction → stresses in soil → deformations → displacements), and if in that soil there is a foundation, it will automatically be influenced more or less, according to the pressure at the base of foundation (if the pressure is higher the horizontal displacement of the foundation is lower).

Was analysed the horizontal movement of the foundation at its base and 10 cm below the surface and they are not equal, the difference coming from the decreasing of anchor influence with distance. This horizontal displacement difference translates into rotation of the foundation, all three elements (absolute settlement, relative settlement, rotation) being closely related.

d) *The bearing capacity of the foundation soil*. Due to soil overload by a foundation and prestressed anchors, there is the possibility of loss of stability and possibly anchor pullout but this has low probability, this situation could appear if the pressure at the base footing would be at the limit below bearing capacity and when introducing the anchors would lead to a decrease of bearing capacity below the foundation pressure.

e) *Bond length displacement*. Similar to piles, there is a close connection between the anchors bearing capacity, displacements when loading, their zone of influence and the distance between anchors, but this is not subject of this paper.

Through the analysis presented in this paper can be said that at design of ground anchors which will be placed under adjacent buildings, should be taken into consideration also the influence of bond length on existing foundations and that is necessary a detailed analysis for each situation in order to establish a minimum distance between the bond length and the footing base, so that for adjacent construction, its strength, stability and its functionality will not be affected.

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ANALIZA IMPACTULUI ANCORAJELOR DE TEREN ASUPRA CONSTRUCŢIILOR ÎNVECINATE

(Rezumat)

Deseori ancorajele de teren trebuiesc executate sub clădirile existente, în special în zonele urbane. Prin introducerea unei ancore în zona activă a unei fundaţii şi prin încărcarea ancorei, pământul este solicitat atât de fundaţie cât şi de ancoraj, ceea ce poate conduce la modificări în modul de comportare al fundaţei. În acest caz este analizat strict impactul lungimii de ancorare (bulb) asupra fundaţiilor învecinate, fără a lua în considerare deplasarea peretelui de sprijin. S-a analizat un singur caz, folosind o fundaţie singulară, sub care s-a modelat un rând de ancoraje pretensionate, în trei situaţii determinate de distanţa dintre talpa fundaţiei şi lungimea de ancorare. O privire atentă trebuie acordată mişcării fundaţiei, înregistrând valorile calculate pentru tasare absolută şi relativă, deplasare în plan orizontal precum şi rotire. Calculul a fost efectuat folosind metoda elementului finit şi după realizarea comparaţiilor între starea iniţială a fundaţiei şi starea ei după încărcarea ancorajelor, au fost trasate câteva concluzii ce pot fi folositoare ca linii de urmat la întâmpinarea situaţiilor de acest fel.