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Assessment of Structural Foundation's Contribution to the Stability of a Site Susceptible to Sliding

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Abstract

Assessment deep foundation structural system's contribution on stability of a site susceptible to sliding when using "top carrier piles" represents the main objective of this paper .
For this, pile-ground interaction was analyzed in case of full mobilization of the shear resistance soil after dangerous surfaces of yielding.
Afterwards, with the aid of the results obtained, the bundle between the number of structural piles and the number of piles necessary for ensuring the stability of settlement in known soil conditions was established.

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Keywords: pile; slope; stress; displacement; level of assurance.

1. Introduction

The case study presented in the paper starts from the necessity of replacing a direct foundation system into a deep foundation system, on piles, for a residential building with basement + ground floor + two floors + one retracted floor (B+G+ 2F+R).

Replacing the originally designed foundation system was determined by the actual characteristics of the soil raised during the execution of excavation works, essentially different to those specified in the geotechnical study.

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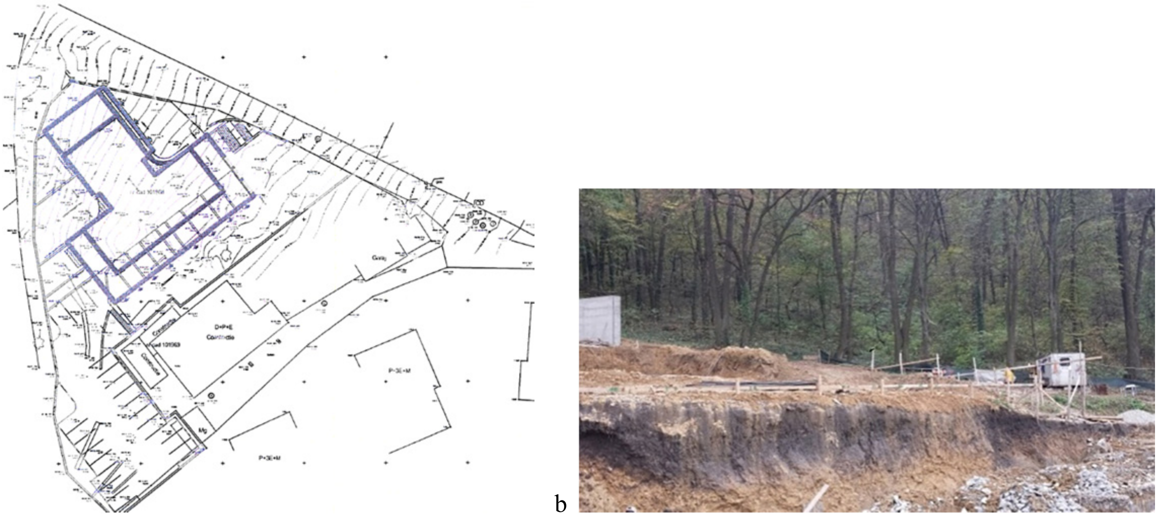
In the situation newly created by soil resumption investigation and interpreting laboratory results obtained on samples of soil taken at the scene, a major risk of loss of stability of the site was revealed and reported, by forming sliding surfaces under the footing.



a b

Fig. 1. (a) Proposed site plan; (b) Overview of the site.

1.1. Description of the location

The site investigated is located in Brasov, on the northern slope of the ”Melcilor hill”, which make part of the ”Postavarul Massif”, at altitudes between 614 and 624 meters. The slope has an average gradient of 17 °: starting from weak inclined slopes (below 7 °) to strongly inclined slopes (over 25 °), see Fig. 1 a and Fig. 1 b.

Landforms have been developed in this area on white-gray limestone, rarely reddish, by reef-genesis, massive or laminated, that reach hundreds of meters thick. ln ”Melcilor hill”, mass limescale deposits are interspersed by Lower Jurassic sandstones represented predominantly by quartz and marl.

On the lithological boundaries and fault lines formed there are highly fractured rocks showing a high level of degradation. As result of disintegration processes and weathering over bedrock toward the ground surface a delluvial blanket was formed, less consolidated, consisting predominantly of clay in consistent or firm state, with fragments of debris included. The thickness of these superficial deposits is small in the western perimeter on strongly inclined slopes where limestone occurs, while on the slopes of low and moderately sloping, delluvial thickness increases considerably, reaching 7.00 m.

The tilted position of the site, the sequence and lithology layers of soil and the hydrostatic level of groundwater determined the extension of the geotechnical study by checking the stability of the massive, highlighting possible slid surfaces.

1.2. Data on the projected building

The building that will be raised on the investigated site has a variable highness, with two withdrawals practiced from downstream to upstream: B+G+ 2F+R.

The directly foundation system, initial designed, was replaced by a deep foundation system, achieved of drilled piles and a network of crossing beams under lamellar pillars and diaphragms.

The superstructure of building is designed of lamellar pillars and concrete reinforced walls, consolidated in horizontal plane by means level floors.

The building is designed on an embankment in stages, separated into two sections. Section 1 of the building is located downstream, on the first two steps of the embankment.

2. Using structural piles for site assessments

Surveying site, lithography and uneven the distribution in vertical and horizontal layers of the soil, shows the technical correctness of using the deep system foundation on pile, with structural role and improvement of conditions of stability slip perimeter built.

*2.1. **Structural foundation system design***

The initial system of foundation was designed under form of isolation/continues foundations of concrete reinforced, settled on a block of plain concrete with variable highness, function of ground characteristics. In the conditions of terrain presented in the geotechnical study effected after the digs works has begun, the directly foundation system, initial designed, is unpassable and the possible surfaces of sliding are situated under the foundation foot.

The new designed foundation system is achieved of ”top carrier piles” settled under a network of crossing beams, orientated after the rows and building axes, Fig. 2.

The design process of the two main components of the system foundation, are aimed at establishing the following elements:

a. For piles:
   - type and diameter of pile;
   - length of pile ;
   - pile's body reinforcement;
   - bearing capacity of the pile.

b. For the crossed beams networks support plate secured to the floor:
   - geometric shape and dimensions;
   - amount of reinforcement and layout of the section

For technological reasons, soil structure and location, it was established “top carrier piles” with a diameter d = 600mm, total length variable established ”in situ” by condition of embedding it in stony ground [1], [2].

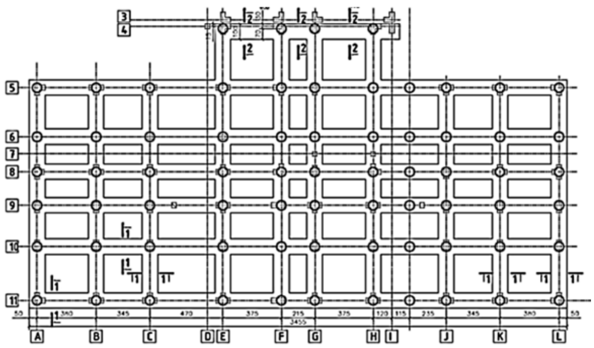


Fig. 2. Plan of the building foundations and disposition of the pile

The reinforcement of the pile consisted of longitudinal and transversal bars. It was dimensioned for maximum sectional efforts along the pile determined by loads of fundamental and horizontal component of the massive land sliding in.

To establish the number of required piles to load transmission to healthy ground static tests ”in situ” were effectuated, on stamp piles, type: ”imposed stress – measured deformation", in order to finalize the bearing capacity of a pile, Fig. 3a .

a  b 

Fig. 3. (a) View during pile's test; (b) Foundation beams networks reinforcement.

The tests made in situ on "piles prove" (see Fig. 3a) have led to establishing of bearing capacity value, for these: $R_{c,d} = 110 \cdot 10^4 N$, superior of value determined by means soil characteristics, respectively: $R_{c,d} = 50.02 \cdot 10^4 N$ [3].

The number of piles structural noted n_p was established by calculation, by means of the relationship:

$$n_p = \beta \cdot N_{b,k} / R_{c,d} \tag{1}$$

Where:

β – coefficient depending on the size resultant vertical eccentricities;

$N_{b,k}$ – the design value of axial compressive efforts to superior level of slab;

$R_{c,d}$ – compressive load bearing capacity of the pile, determined using the equation:

$$R_{c,d} = R_{b,k} / \gamma_t \tag{2}$$

Where:

$R_{b,k}$ –characteristic value of bearing capacity, determined from measurements in the field;

γ_t –partial coefficient for total resistance of the pile

After conducting the calculation, it resulted in a total of 70 piles placed in nodes networks integral foundation beams stiffened by slab support of the ground floor and the intermediate, in case of larges openings.

The design of foundation aimed at increasing the rigidity of the building infrastructure, embracing the reverse beam shape "T", with sole width of 100 cm and height of 110 cm, integral to the upper floor through the support plate. [4]

Reinforcement resulting from the calculation was arranged on the heart and sole transverse beam. The rest was provided as constructive reinforcement, according to the specific technical.

An overview on the foundation reinforcement beams is shown in Fig. 3b.

2.2. Stability assessment of the site

It is a complex issue stabilizing a slope through a field of pilots distributed in 2D. So far as our knowledge has not been consistently analyzed in specified literature. Single pile or row piles behaviour was competently analysed by many authors. As an economic solution, using piles to stabilize slopes is preferred frequently [5], [6], [7], [8], [9], compared to the other retaining wall structures.

Stability analysis of the site was done in two distinct stages, with consideration of two working assumptions.

Stability's calculation was performed of the site built and unbuilt, emphasizing the value for each situation and condition factor of stability, efforts and strains in the ground and piles.

2.2.1. Stability assessment unbuilt of the site

Verification of slope stability by current methods, Bishop, Fellenius, Janbu, Spencer, Morgenstern –Price led to the safety factor value (Fs) between 136-139,8%, with according of a unsatisfactory degree of assurance, and it led to the necessity of replacing the direct system of foundation with a deep foundation system, by means of "top carrier piles", embedded in bedrock [3].

2.2.2. Assessment of structural piles contribution to the stability of the site

For a quick assessment of stability variation a method was conceived that includes some simplifying assumptions:

- Piles' displacements are ineffective.
- Horizontal displacement of the soil do not alter the status of the efforts;
- Piles are distributed in rows;
- The slope is infinite.

The cap piles beam is able to take over any horizontal deformation of piles heads. The superstructure must be designed taking into account these tasks.

We considered that the lateral earth pressure would be similar to the vertical efforts below a foundation, but rotated up to bring it horizontally.

The lateral earth pressure on the first pile row was similar to the weight of soil in vertical loads.

Due to the difficulty of solving the problem we considered that the soil downstream of the first row of piles lacks weight.

Efforts downstream piles are distributed as a pressure bulb, but complementary of the total load (see Fig. 4a).

Overlaying the entire piles field with these horizontal bulbs is found that their surfaces interfere (see Fig. 4b).

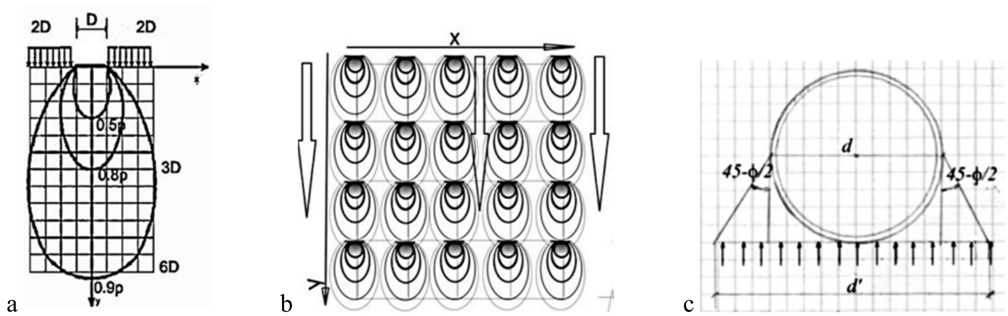


Fig. 4. (a) Shadow's effort distribution behind a pile; (b) Schematic efforts shadows distribution; (c) Effective diameter of a pile, d' diagram of in a field of piles.

The values of the spatial distribution interfering depends mainly by the distance between the piles on the y-axis, then the effective diameter d' of a pile as in Fig. 4c.

Where d' is:

$$d' = d \cdot (1 + \tan(45^\circ - \frac{\varphi}{2})) \qquad (3)$$

Considering two piles seated on the same row, shadows efforts distribution downstream of one pile can estimate the following formulas (similar to the distribution below a strip load - [10]):

$$\sigma_{x1}(x,y) = \frac{p}{\pi}\cdot\left[a\cot\left(\frac{x-\frac{D}{2}}{y}\right) - a\cot\left(\frac{x+\frac{D}{2}}{y}\right) - \frac{D\cdot y\cdot\left(x^2-y^2-\frac{D}{4}\right)}{\left(x^2+y^2-\frac{D}{4}\right)+D^2\cdot y^2}\right] \tag{4}$$

- where σ_{x1} is the horizontal stress that would normally act as vertical under p at the y depth, equivalent of lateral earth pressure; x - distance from the edge of the foundation respectively from the considered edge pile.

For the joined pile on the same X direction, we will replace the variable x with D_{ax}-x, where D_{ax} is the distance between axes of the piles, formula will be:

$$\sigma_{x2}(x,y) = \frac{p(y)}{\pi}\cdot\left[a\cot\left(\frac{D_{ax}-x-\frac{D}{2}}{y}\right) - a\cot\left(\frac{D_{ax}-x+\frac{D}{2}}{y}\right) - \frac{D\cdot y\cdot\left((D_{ax}-x)^2-y^2-\frac{D}{4}\right)}{\left((D_{ax}-x)^2+y^2+\frac{D}{4}\right)+D^2\cdot y^2}\right] \tag{5}$$

Noting with k_3 the variable of equality can write:

$$\sigma_X = p\cdot k_3 \tag{6}$$

The amount of the effort that crosses the shadow of two piles it will be:

$$\sigma_{Sx}(x) = p - \sigma_{x1}(x)k_3 - \sigma_{x2}(x)k_3, \tag{7}$$

Illustration of these efforts can be seen in Fig. 5 (plane distribution) and Fig. 6 (space distribution).

The total value of the passed efforts to subsequent pile row will be:

$$P_I := \int_0^{D_{ax}} \sigma_{SX}(x)\,dx \tag{8}$$

and the average value of this effort will be:

$$p = \frac{P_1}{D_{ax}} \tag{9}$$

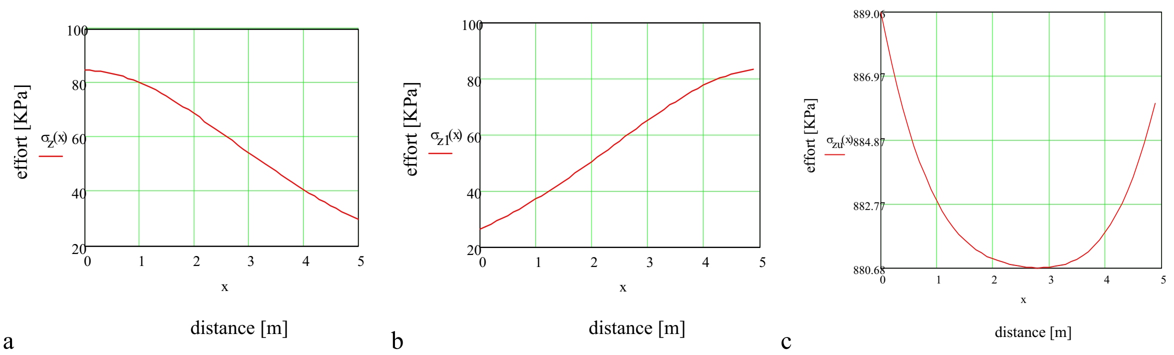


Fig. 5. Efforts among two piles (a – for first pile, b for the opposite pile and c for both of them) depending on the distance between axes in X direction, Illustration for D_{ax} = 5 m and p = 1000 Pa.

An iterative calculation it will be conducted to establish the efforts for the next pile row, initial conditions taking value from the previous row. In the case of granular or partially granular soil, horizontal efforts are decreasing up to the bedrock starting from surface.

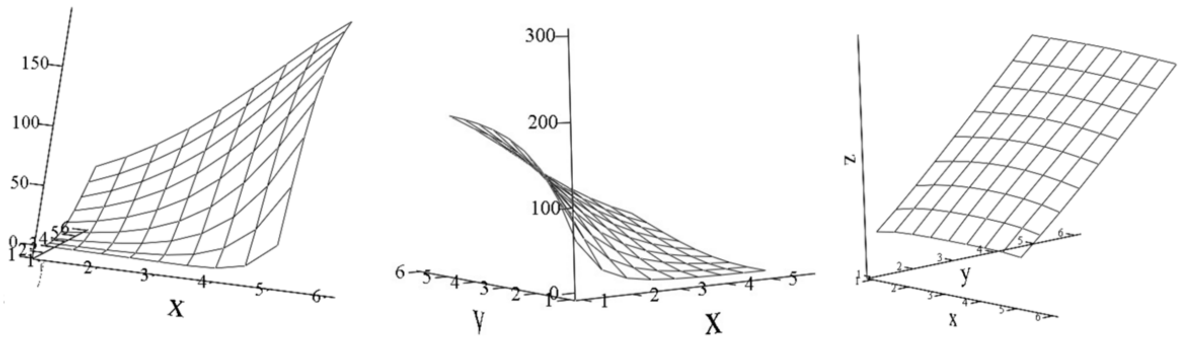


Fig. 6. Efforts among two piles, σ_{x1},σ_{x2} and σ_{Sx} . On X axis – distance between to piles on the same row is figurated, on Y axis distance between to piles on the same column, perpendicular on terrain contour lines, both in meters; on Z axis efforts is figurated in Pa. Illustration for distance between axes D_{ax} = 6 m laterally earth pressure on the first row p = 1000 Pa.

Their variation by depth may be related to internal friction angle which increases up to the bedrock, supposing that the soil is not purely cohesive. It is intuitive that the effort on the alignment parallel to horizontally contour lines is dependent on internal residual friction angle of the soil:

$$\sigma_y = f(\varphi_{rez}) \tag{10}$$

Or, the residual friction angle of the soil, under the assumption adopted in the study case below, varies according to depth:

$$\varphi = f(z) \tag{11}$$

In the case of movements in cohesive soil it is assumed that the variation of shear strength will have a minimum on the slip surface and the relative movement in that plane will be the maximum. In conclusion we can say that each row of piles at a distance of up to 6 meters brings an increase in safety factor of approximate 10%.

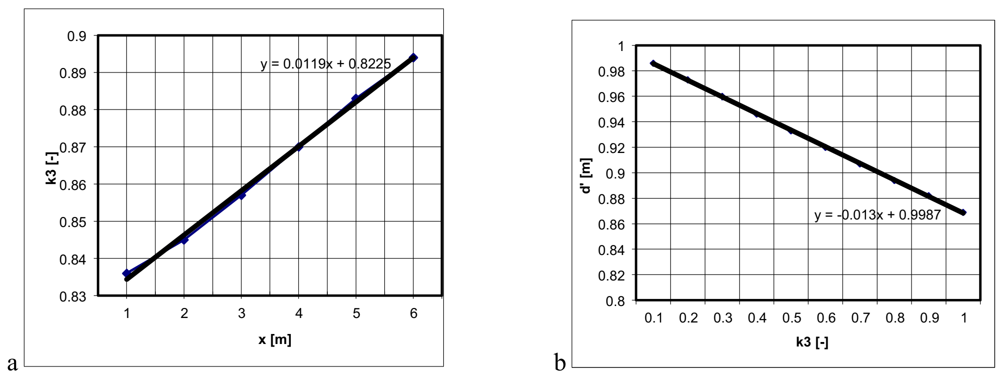


Fig. 7. (a) The variation of efforts by horizontal distance between piles; (b) The variation of efforts by pile's diameter.

Appling (4) and (5) formulas by different values of X, distances between piles on the same row and, on the other hand, by piles' diameter d, we have found different values of k_3. Following a linear regression on these values, transmitted stresses increases with distance from the "edge" of the pile (Fig. 7a and 7b), by formula:

$$y = 0.0199 \cdot x + 0.8225 \quad (12)$$

and depending on the pile's diameter:

$$y = -0.013d' + 0.9987 \quad (13)$$

Following this reasoning we consider that the safety factor of the slope, in the presented study case, increased by about 60% as result of the adoption of this solution foundation.

The calculation algorithm has been applied for various distances of arrangements of the structural piles, for various usual diameters of drilled piles and material's characteristics.

The results led to the formulation of the conclusions about the stability of the site built through structural drivers in percentage limits: 35% - 65%.

3. Conclusions

The presented case study, highlights the contribution of structural system of foundations, by means „top carrier piles" to the stability of a slope susceptible to slip.

The numerical simulations effected and the results obtained by variation of geometric parameters and material characteristics, led to followings conclusions:

- For a distance between structural piles of maximum 6 m, each row of „top carrier piles" maybe to determine an increase of safety factor to slip, up to 10%;
- For a building settled on a slope terrain susceptible to slide, the contribution of a deep foundation structural system by means „top carrier piles", to the growth of stability factor is comprised between (30-60)%, in rapport of ground characteristics, geometrical dimensions and the distance between rows and axes;
- For the presented case study, the structural system of foundation , achieved by means „top carrier piles" insures a growth of safety factor to slip, of approximate 60%

The results and the formulated conclusion can to represent an informative guide regarding the contribution of "top carrier piles" used in designing of deep foundation structural systems for the buildings settled on a terrain slope.

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