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TECHNICAL DESIGN AND STABILITY ANALYSIS PROCEDURE FOR HORIZONTAL STABILITY CONSTRUCTION OF ROADS AND RAILWAYS

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Abstract

Unstable sections of predominantly vertical roads and railways are usually stabilized by viaducts, while predominantly horizontal unstable sections of the same structures are regularly stabilized by special structures which have a common feature of spaciousness or massiveness, and which proportionally also require peculiarity in all aspects of the construction.
The goal of the new solution is to avoid the highlighted structural peculiarity, that is, to apply a solution that will be more of a constructive element of roads and railways, like a viaduct in an approximate sense. There is such a solution, and that is the low-rise stable structure, which in a naturally appropriate way counteracts horizontal instabilities on low-rise objects. The horizontal effect on the object is converted to a vertical direction via this construction by means of pile coupling, while this effect is greatly reduced due to the effect of static interaction between the components of the coupling. If, instead of various vertical structures with horizontal anchors or mass structure retaining walls, we apply the slope-pile coupling at an optimal angle in the range of 15 to 20 degrees, then, by activating the external horizontal effect, i.e. instability, the primary axial resistance in the oblique pile is simultaneously activated through circumferential friction. The vertical component of this resistance decreases the active horizontal component, while the horizontal does the same, provided that the pile has a transverse static EI feature. This approach has not been used thus far in engineering practice and therefore represents a novelty. Therefore, it can be argued that by constructing a low-rise stable structure, we can achieve at least approximately the same structural impression that we enjoy regarding the viaduct construction for predominantly vertical instabilities.

Keywords: retaining engineering structure, batter pile, vertical piling structure, active soil pressure, suspended weight, pile skin resistance, natural slops instabilities

1 Introduction

Batter piles and a vertical pile walls are coupled with a head beam, as a horizontal load-bearing structures. The batter pile is performed at an angle of 20˚, using “in situ” pile technologies. The batter pile achieves the load-bearing capacity with a part of its length as a kind of catenary and partially as a anchoring. Along the entire length “L_1“, the profiled steel core “A_S“ is installed.

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As a conclusion, the load-bearing capacity of the batter pile is not only conditioned by the value of activating its axial deformation, but by the activation of the weight suspended on it as well. There is no activation of the horizontal load of the sistem without the activation of the suspended weight on the batter pile.
Suspended weight on it, then no longer creates horizontal pressure but is displaced as a vertical pressure of the vertical element of the structure. With such a design and equal dimension quantity, the structure achieves the goal of reducing spatiality and increasing the load-bearing potential.
The batter pile can be considered as an element composed of two lenghts, the span "CA" and the anchoring part "L_1 – CA". One end of the span "CA" is supported by the vertical structure while the other end is anchored by the axial tensile force "A_n".
On the base of this statements , equilibrium equations for stability analysis can be performed for the system of structural elemets or for the system of the finite elements method , with characteristics "E_I , A_I , I_I " , for batter pile and " E_{II} , A_{II} , I_{II} " for vertical structure...

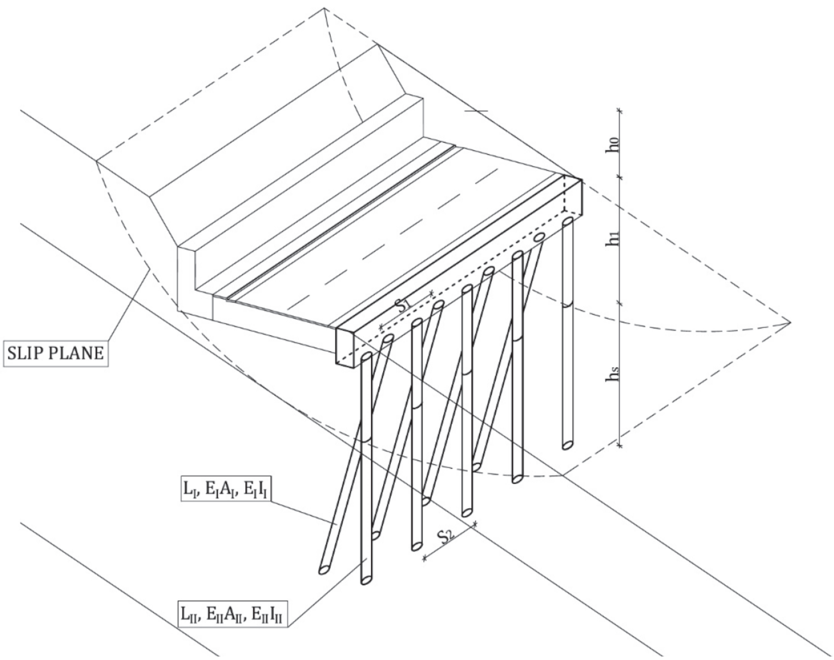

Figure 1 Road on slope - Construction model

Construction is modeled as 3-joint bracing, Figure 2.
a) Vertical load of element I, A_n'cosβ
b) Horizontal resistance of element I, A_n'sinβ
c) Bending resistance I, composite bearing capacity A_n',M_I' of the pile's section
d) Axial resistance in point A of element I, A_n'
e) Horizontal load on the element II, P_a-A_n'(K_a cosβ+ sinβ)
f) Transversal and axial resistance in point B of element II, B_t', B_n'
g) Bending resistance of element II, composite bearing capacity B_n', M_{II}' of the pile's section
h) Axial deformation of element I, ΔI_n
i) Axial deformation of element II, ΔII_n
j) Bending deformation of element II, ΔII_t
k) Horizontal deformation of the sistem, Δ_S

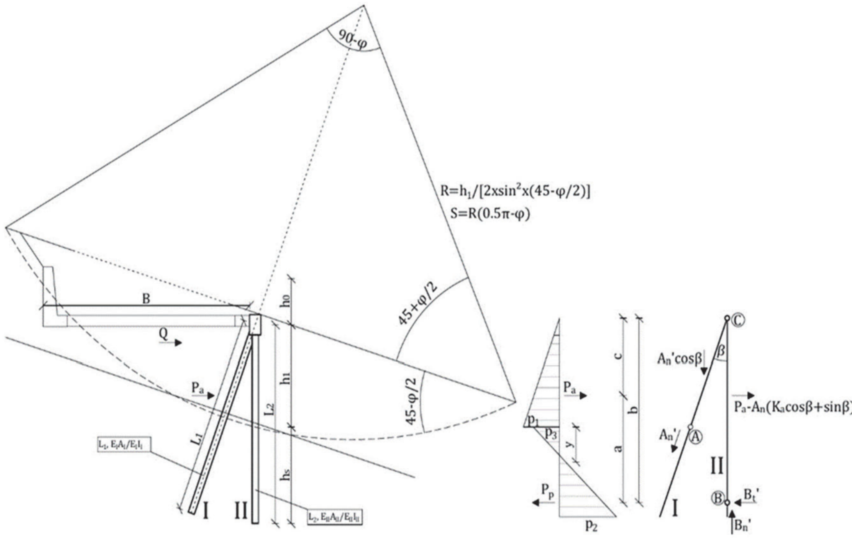

Figure 2 Road on slope - Stability model

2 Construction equilibrium equations

The equilibrium equations for the construction elements can be obtained from the stability model shown in Figure 2.

$$A_n' \times b \times \tan\beta + \frac{h_1 \times \tan\beta \times A_n' \times \cos\beta}{2} - a \times \left[P_a - A_n'\left(K_a \times \cos\beta + \sin\beta\right)\right] = 0 \quad (1)$$

$$B_n' \times h_1 \times \tan\beta - \frac{h_1 \times \tan\beta \times A_n' \times \cos\beta}{2} - \left(b - h_1\right) \times B_t' - \frac{h_1 \times \left[P_a - A_n'\left(K_a \times \cos\beta + \sin\beta\right)\right]}{3} = 0 \quad (2)$$

$$B_t' = \frac{c\left[P_a - A_n'\left(K_a \times \cos\beta + \sin\beta\right)\right]}{b} \quad (3)$$

$$C_n' = \frac{a\left[P_a - A_n'\left(K_a \times \cos\beta + \sin\beta\right)\right]}{b \times \tan\beta} \quad (4)$$

Activated horizontal load

$$p_1 = \gamma_{sat} \times h_1 \times K_a - p_{ca} \quad (5)$$

$$p_3 = p_1 - p_{cp} \quad (6)$$

$$y = \frac{p_3}{z} \quad (7)$$

According to the Figure 2:

$$b = \frac{2h_s + y}{3} + h_1 \tag{8}$$

$$c = \frac{2h_1}{3} \tag{9}$$

$$\mathrm{a = b - c} \tag{10}$$

$$z = \gamma \times \left(K_p - K_a\right) \tag{11}$$

$$p_2 = z \times \left(h_S - y\right) \tag{12}$$

$$P_a = \mathring{a}(p_a \times h_{p_a}) = \frac{p_1 \times h_1 + p_3 \times y}{2} \tag{13}$$

$$P_p = \mathring{a}\left(p_p \times h_{p_p}\right) = \frac{p_2 \times \left(h_S - y\right)}{2} \tag{14}$$

3 Deformation equilibrium state

Kinematic equations can be obtained from the stability model shown in Figure 2.

$$\Delta I_n = A_n \times \left[\frac{s_1}{4h_{s1}d\pi G_s} + \frac{L_1 - h_{s1}}{A_I E_I}\right] \tag{15}$$

$$\Delta II_n = B_n \times \left[\frac{s_2}{4h_{s2}d\pi G_s} + \frac{L_2 - h_{s2}}{A_{II} E_{II}}\right] \tag{16}$$

$$\Delta s = \frac{\Delta I_n + \Delta II_n}{\tan \beta} \tag{17}$$

3.1 Composite bearing capacity of the pile’s section of element I

$$\Delta \mathrm{I_t} \begin{cases} \mathrm{A_n} \\ \Phi(u)\mathrm{M_{Imax}} \end{cases} \tag{18}$$

$$\Phi(u) M_{\mathrm{I}max} = \Phi(u) A_n \frac{h_1}{12} \sin \beta \tag{19}$$

$$u^2 = \frac{A_n h_1^2}{4E_I I_I} \tag{20}$$

3.2 Composite bearing capacity of the pile’s section of element II

$$\Delta II_t \begin{cases} B_n = nA_c f_c \\ M_{I\,\mathrm{I}max} = mA_c h f_c \end{cases} \tag{21}$$

4 Stability evidence

4.1 Stability evidence of construction elements

$$A_n = A_n^{'} \times ds_1 < A_{n,q,R} \tag{22}$$

$$A_t = A_n^{'} \times \sin\beta \times s_1 < A_{t,q,R} \tag{23}$$

$$B_n = B_n^{'} \times s_2 < B_{n,q,R} \tag{24}$$

$$B_t = B_t^{'} \times s_2 < B_{t,q,R} \tag{25}$$

$$\Phi(u) M_{I\max} = M_{I,R} \tag{26}$$

$$M_{II\max} < M_{II,R} \tag{27}$$

$$\Delta s < \Delta s_{adm} \tag{28}$$

4.2 Stability evidence of road on slope

Stability of the system is ensured by setting the adding reactive shear forces $\Delta R_{,req}$ in the slip plane, after which the system is solved as Rankine's semi-infinite equilibrium condition. Calculation of the adding reactive section force R_{req}:

$$\Delta R_{req} < 0.3 \times R_{soil} = 0.3\left(c_d + \gamma_{sat} \times h_1 \times \tan\varphi_d\right) S \tag{29}$$

$$\Delta R_{req} < \left(A_{t,q,R} + B_{t,q,R}\right) \tag{30}$$

Main stress at slide plane,

$$\sigma_b = \gamma \times h_1 \tag{31}$$

Diference stress of ultimate resistence stresses and loads stresses,

$$\Delta R_R = \frac{\left[\left(\sigma_b \tan\varphi + c\right) RS + \left(A_{t,q,R} + B_{t,q,R}\right) R - H\left(R - h_1\right)\right]}{0.5B^2 + B\left(R - h_1\right)\tan\alpha} - p_0 \tag{32}$$

If, Δq_R, positive, then we have sliding – seizmic resistance potential,

$$H = P_a + Q \tag{33}$$

5 Construction elements characteristics

5.1 Element I

Batter pile lenght L_1, where:

d - pile diameter
s_1 - axial distance between piles
h_{s1} - anchor part of L_1
A_l - profiled steel core of a pile
γ_R,γ_S,γ_C - partial safety factors
σ_q - soil pressure
σ_s - steel core strenght
K_p - coef. passive earth pressure
φ_d - angle of internal friction of the soil
$A_{n,q,R}$ - axial tensile bearing capacity of element I, with regard to the soil
$A_{t,q,R}$ - lateral bearing capacity of element I, with regard to the soil

$$N_{s,R} = \frac{\sigma_s A_l}{\gamma_s} \quad (34)$$

$$A_{n,q,R} = \frac{\sigma_q d \pi h_{s1} \tan \varphi_d}{\gamma_R} \quad (35)$$

$$A_{t,q,R} = \frac{\gamma \left(h_1 + h_{s1} \right) K_p d h_{s1}}{2 \gamma_R} \quad (36)$$

5.2 Element II

Vertical pile wall length L_2, where:

d - pile diameter
s_2 - axial distance between piles
h_{s2} - anchor part of L_{12}
P_p - passive soil resistance
$B_{n,q,R}$ - vertical bearing capacity of element II in point B
$B_{t,q,R}$ - horizontal bearing capacity of element II in point B
N_q, N_c - bearing capacity of the soil

$$B_{n,q,R} = \frac{h \gamma N_q A_b + c_d N_c A_b}{\gamma_R} \quad (37)$$

$$B_{t,q,R} = \left(P_p + B_n^{'} \tan \varphi_d \right) s_2 \quad (38)$$

5.3 Element III

Connection element for connection and anchoring of the batter piles with vertical pile structure as a reinforced concrete head beam.

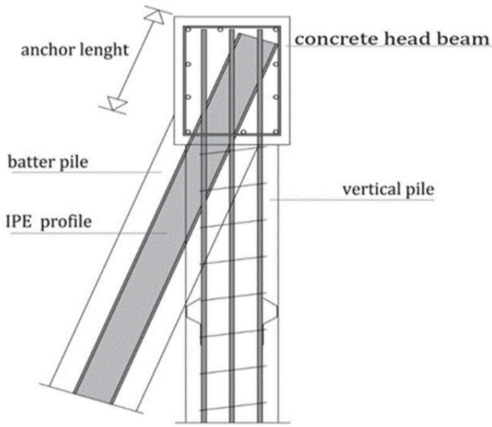

Figure 3 Connection element detail

6 Conclusion

According to the goals set and with the use of known static and structural settings, naturally acceptable and at the same time more rational and based on its function more stable construction is gained. This construction and its resistance elements give the optimal response to the state of strain caused by the construction of the road or railways on the slopes, without introducing new elements of instability, which are presently caused by the weight of massive elements or the anchoring position of anchor systems. In addition, interactions among the elements of our construction are optimized, so the rationality is substantially increased for the same safety factor. This will enable a single standard solution for construction on the slopes, bringing us closer to the goal set for the construction. Concerning stability analysis, carried out on the basis of equilibrium equations, based on the mobilized resistance of structural elements or less on the basis of finite structural elements equilibrium, in one and the other case, as can be seen in the stability analysis procedure, the influence of the wrong estimation of the calculation parameters is minimized. Therefore, this approaches leads to consolidation of constructions at horizontal instabilities, as well as slope sliding and earthquake

References

[1] Berezantzev, V.G., Khristoforov, V., Golubkov, V.: Load Bearing Capacity and Deformations of Piled Foundations, Proc. 5th Int. Conf. S.M. & F.E., 1961

[2] Bowles, J.E.: Foundations Analysis and Design, Fifth Edition, 1996.

[3] Broms, B.B.: Lateral Resistance of Piles in Cohensionless Soils, J.S.M.F.D., ASCE, 90 (1964), SM3:123-156

[4] Poulos, H.G., Davis, E.H.: Pile Foundation Analysis and Design, 1980.

[5] Simović, V.: Građevna Statika I, Građevinski institut, Zagreb, 1988.

[6] Šepac, Z.: Patent cooperation treaty, PCT, Int. Aplication No. PCT/HR2018/0000

[7] Terzaghi, K., Peck, R.B.: Soil Mechanic in Engineering Practice, 1967.

[8] Timoshenko, P.S.: Strength of Materials, Third Edition, 1958.

[9] Tomičić, I.: Priručnik za proračun armiranobetonskih konstrukcija, 1983.

[10] Whitaker, T.: The Design of Piled Foundations, Second edition, 1976.