Zvoimir Šepac dipl ing , Zvoimir Šepac mag.ing.aedif

Stability and earthquake-resistant engineering structures

Scope of stability and earthquake-resistant engineering structures

Earthquake-resistant foundation stability structures – Laying the foundation on insufficiently load-bearing soil – RES Retaining Engineering Structure– Laying the foundation on sloping, or landslide-prone terrain

Case history

***** A conventional earthquake-resistive design method may include a pseudo-static analysis, or dynamic analysis, wherein the latter may include a response at which an earthquake-resistive matches an external vibration-force. The conventional earthquake-resistive design method may not provide an exact earthquake force, that needs to be balanced with an amount of a resistive force of a horizontal connecting surface arranged between a foundation and a building structure.
As shown by the pictures of the recent earthquake events in Turkey and Taiwan, the collapse of most of the mostly shallow-founded structures was caused in most cases by the yielding of the foundation or the yielding of the resistive of the structural connection of the structure to the foundation. Both are the result of an unsubstantiated earthquake force. Buildings that have collapsed and have not been demonstrated to be stable with the added effect of kinetic forces from the earthquake could have occurred even with compliance with current regulations, because the regulations do not require "primary" proof of the impact of kinetic forces or "mechanical impedance". All previous evidentiary procedures have a secondary character because their approximation to the real state of equilibrium is indirect. In the case of earthquake-resistant various basic building structures, there is a large difference in a dimensioned earthquake force compared to previous calculations, that it is a sufficient cause of global earthquake disasters.
Thus, the conventional earthquake-resistance design method may not provide an exact earthquake resistance of the building structure.

****** Laying the foundation on insufficiently load-bearing soil has already been solved in ancient times by the construction collectively named "piling", implying aggregate action, or resistance. Thomas Whitaker (1976) said, "Piling is a form of construction of great antiquity, and an almost instinctive trust in piles for overcoming difficulties runs throughout foundation work".
To this day (2024), "piling" does not have a better purposeful alternative, and the alternative "is not even necessary", because, at the same time, it is the best eathquake-resistant construction. The said building construction has not been represented with a primary structural approach so far.
In most cases, it is unnecessary and irrational, and in terms of earthquakes also harmful, to search for a deep load-bearing layer using "piers or caissons" as a substitute for "piling", unless liquefaction is present.

*** The excavation stability in water-bearing and a not water-bearing soil has so far been solved according to the least resistance principle in seeking solutions, so that the horizontal action is stabilized by horizontal "long" anchors, or heavy gravity walls, or disruptive supports. Neither can be considered an engineering solution due to the obvious spatial awkwardness in dimensions, weight, and reactive stability adverse activity.
The new solution applied by us, the new "Retaining Engineering Structure" construction (European patent, EP 3827133) eliminates anchors and gravity walls. It is introduced into the regular construction practice.

**** Laying the foundation on sloping, or landslide-prone terrain, has so far been solved similarly as the excavation stability, with inevitable harmful consequences. The new construction, "Retaining Engineering

Structure", simultaneously solves the foundation stability, and earthquake-resistant action. Such a stable combination is impossible to achieve with any other construction. This solution is particularly relevant for infrastructure facilities – roads and railways, which, in natural conditions of increased landslide instability, require the upgrade of basic solutions.

Approach

A stability engineering construction is a set of elements or forces [F], which is simultaneously in the mass gravity element [γh], forming together the energy field [Fs] of elements or forces.
Elements or forces of such an energy field [Fs] can therefore be expressed in equilibrium state as energy stress, inertial and gravitational forces [Nm].
If such a statement is made for known characteristic energy points or field surfaces, then it is possible to write balance equations of energy forces for these points or surfaces, by solving which we get the scalar magnitudes of forces [N], necessary to dimension the equilibrium state of the structure in the field [Fs].
Known energy points or surfaces are simply those, for which we know some of the characteristic energy values, displacement, velocity, or acceleration.
If the energy field elements [Fs] receive kinetic energy, such as an earthquake, then a kinetic energy force [Nm/s] is attached to the field element. Since it is a kinetic energy force, in this case the question of the character of the interaction of these forces in the field [Fs] arises.

If the field element velocities differ, then the interaction expression of these forces is no longer possible based on the elements' rigidity,
F=K x $\boldsymbol{\delta}$ [N], K=F/ $\boldsymbol{\delta}$ [N/m]
but based on the elements' impedance,
F=Z x v [N], Z=F/ v [N s/m]
where Z represents a specific force impulse [N s/m], not rigidity [N/m].

Earthquake

An earthquake is an earth mehanical wave, which consists of a cyclic exchange of potential and kinetic energy of particles of a wave material, particle mass flow $\boldsymbol{q}$ [kg/s], particle velocity $\boldsymbol{v}$ [m/s] and acceleration $\boldsymbol{a_g}$ [m/s^2].
This change propagates in the form of a wave, longitudinally or transversely at constant velocity $\boldsymbol{C}$ [m/s] according to the well-known law of elasticity,

$$\frac{d^2u_n}{dt^2} = \frac{C_n^2 \cdot d^2u_n}{dx^2}, \qquad C_n = \left[\frac{E}{\rho}\right]^{\frac{1}{2}}$$

$$\frac{d^2u_t}{dt^2} = \frac{C_t^2 \cdot d^2u_t}{dx^2}, \qquad C_t = \left[\frac{G}{\rho}\right]^{\frac{1}{2}}$$

The inertial force F_1 of a building structure, which response to the acceleration of the earthquake wave a_g is transferred to the building structure as a further acting active force of the building structure. At the same time, the inertial force F_2 is created in a wave field, thus creating impedance conditions of the two elements, a first element 1 and second element 2.

In the field of forces, there are the following elements of a stability construction:

- **Object 1- a first element 1 of the field** being the building structure - an element with a mass M_1, received force F_1 from the earthquake wave, acceleration a_1, velocity v_1 and displacement u_1
  F_1, a_1, v_1, u_1
- **Horizontal connecting surface 3 – common element of the field** being an element with resultant confrontation force Q or a resultant **earthquake force**,

- **Object 2 - a second element 2 or transmission medium of the field –** an element with a mass M_2, transferred force F_2 from the first element, acceleration a_2, velocity v_2 and displacement u_2
  F_2, a_2, v_2, u_2

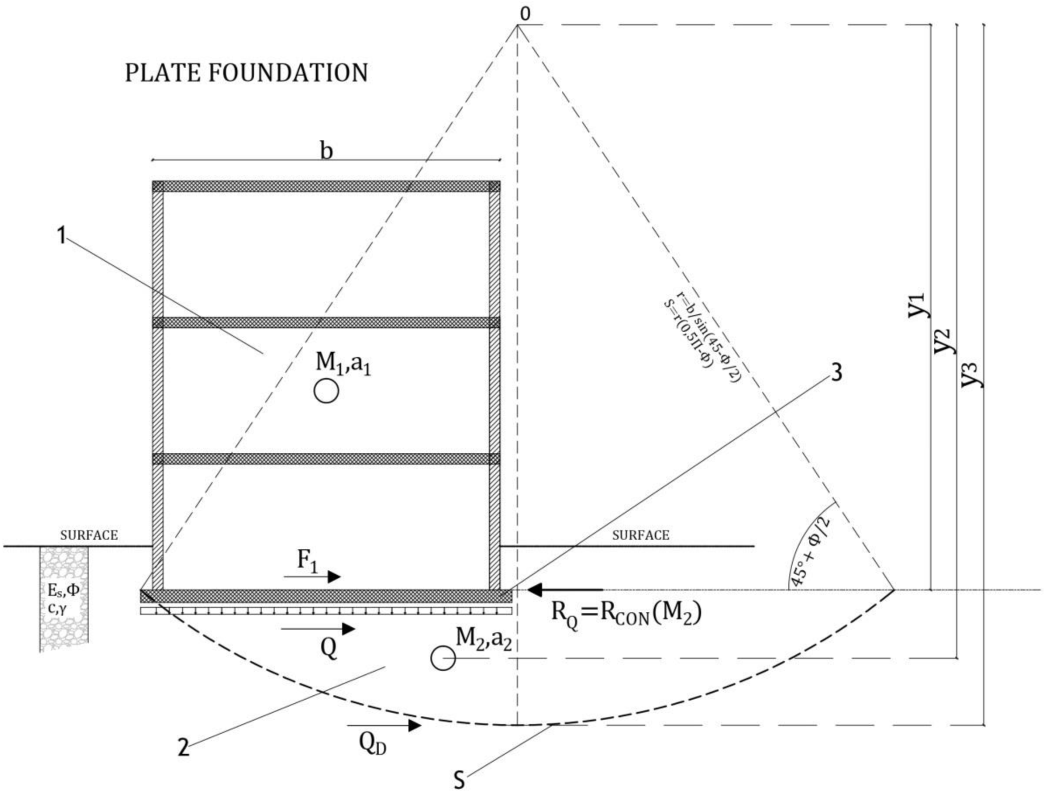


FIG. 1

In accordance with the present invention and as illustrated in the figure 1, the first element 1 of the field relates to the building structure , the horizontal connecting surface 3 , connecting the first 1 and second element 2 of the field.

In accordance with the balance of forces on a basis of known characteristic energy points or surfaces, a resultant earthquake force $\boldsymbol{Q}$ is known, since the following can be applied;
In a state of equilibrium, two bodies with different velocities cannot stand in the same place at the same time, the velocities on the horizontal connecting surface of these two bodies must be "**forcibly**" unified, otherwise destruction or breakdown will occur.
To prevent destruction or breakdown of the building structure, the following condition at the horizontal connecting surface 3 must be satisfied:

$$\boldsymbol{v} = \boldsymbol{v_1} = \boldsymbol{v_2} \qquad [1]$$

where $\boldsymbol{v}$ is velocity of the horizontal connecting surface 3, $\boldsymbol{v_1}$ is velocity of the first element 1 of the field and $\boldsymbol{v_2}$ is velocity of the second element 2 of the field.
A shear stress $\boldsymbol{\sigma_S}$ on a layer, will turn any straight line originally perpendicular to the layer through an angle γ, the angle γ is a relative shear. Upon elastic deformations, the angle γ is very small, and tg (γ) $\approx \gamma$, consequently the relative shear is equal to an angle of shear γ, so that

$$\sigma_s = G_S \, tg\, \gamma$$

The coefficient G_S depends only on the properties of a material is the shear modulus which equals such a tangential stress at which the angle of shear will be 45° (tg (γ) =1), if an elastic limit was not exceeded at such large deformations. The shear modulus G_S is measured in pascals [Pa].
A force $\boldsymbol{F_n}$ on a layer in a ground will generate a shear force $\boldsymbol{F_s}$, so that

$$F_s = F_n \, tg\, \phi$$

where an angle of internal friction „ϕ" depends only on properties of the ground.
The transition of the acceleration of the earthquake wave force into the building structure 1 through the horizontal connecting surface 3 of two elements of different dominant material constants M_2 (ϕ) *i* M_1 (G_S), where there is an initial wave interaction,

earthquake wave M_2, $a_g \rightarrow$ horizontal connecting surface $\rightarrow$ element M_1, a_1

$$\begin{gathered} M_1 \cdot a_g = M_1 \cdot a_1\, tg\, \Phi \\ a_1 = \frac{a_g}{tg\, \Phi} \\ F_1 = a_1 \cdot M_1 \end{gathered} \qquad [2]$$

The question arises as to what is the resultant force Q in the confrontation with earthquake action and how to find the parameters necessary for the calculation of the resultant force Q.
We know with which parameter values the event "occurred", but we do not know with which parameter values in the future the event "will occur". It remains to apply one computationally possible parameter with a value of which we can unambiguously express the balance and at the same time satisfy an impedance condition.
The value with which it can be unambiguously expressed the balance and at the same time to satisfy the mechanical impedance condition is calculated value of an acceleration of the earthquake wave a_g for a certain area. The acceleration of the earthquake wave a_g is expressed from the spectrum of the acceleration with respect to time of the earthquake wave, the possibility of which appears in some period of time in the life time of the building structure 1. It is based on the actual accelerogram, a strong-motion record or acceleration time-history. Accelerographs record the acceleration of the ground with respect to time.
The resultant force Q appears on the horizontal connecting surface 3, as a factor of velocity merging, which is balanced with the second element 2 having the mass M_2. When this force becomes greater than the strength of the horizontal connecting surface 3 can withstand in the equilibrium state, then the building structure breaks down, therefore the structural second element 2 is proved to the limit state of a highest expected resultant force Q, and the first element 1 having the mass M_1 to the limit state of the force F_1.
The mechanical impedance Z is a measure of how much a structure resists motion when subjected to a kinetic force. It relates forces with velocities acting on a mechanical system.
If we start from the fact that the impedance Z of two elements with different velocities but with a common horizontal connecting surface occurs, then it is clear that a force on the horizontal connecting surface 3 or in this case the earthquake resultant force Q can be calculated.
According to the definition of the mechanical impedance:

$$\begin{gathered} F_s = F_1 + F_2 = Z_1 \cdot v_1 + Z_2 \cdot v_2 \\ v = v_1 = v_2 \\ \left[\frac{\mathrm{M}_1 \cdot a_1}{v_1} + \frac{\mathrm{M}_2 \cdot a_2}{v_2}\right] \cdot v = Z \cdot v = Q \\ Z_1 + Z_2 = Z \\ Q = \mathrm{M}_1 \cdot a_1 + \mathrm{M}_2 \cdot a_2 = Z \cdot v \end{gathered} \qquad [3]$$

where Q is the "earthquake or seismic resultant force" that needs to be balanced with an amount of a resistive force R_{Q2} at the horizontal connecting surface 3 of the second element 2, having the mass M_2, and the inertial force F_1 as a resistive force with the first element 1, having the mass M_1.
If the transmission medium i.e. the second element 2 with defined mass M_2, which defines its mass for transmitting the earthquake force mainly on the basis of the shear modulus "G_S", as in the case of a foundation made of concrete or rock, then the mass M_2 is determined by geometric dimensions of the second element 2.

In the case when the transmission medium i.e. the second element 2 with defined mass M_2 is the ground 2 with the dominant characteristic being the angle of internal friction ϕ, as in the case of a slab foundation, then the mass M_2 of the second element 2 is determined with the mass discontinuity limit line that forms the inertial force F_2.
For the foundation slab structure 2 the mass M_2 is calculated by determining a border of a discontinuity of the mass M_2, wherein the discontinuity of the mass M_2 is determined by a circular segment defined with a circle S having a center of rotation 0 of the mass M_2. The mass discontinuity occurs on a line of equalization of the angle of internal friction ϕ and the angle of the direction of the resultant stress. Since it is a rotational movement, the border of the mass discontinuity is a circle defined by two known tangents. The first tangent is arranged at a starting point where an angle between the horizontal connecting surface 3 and of a sliding surface is $45\text{-}\phi/2$, the starting point is arranged at a edge of the foundation slab structure 2 where the inertial force F_1 acts on the mass M_2, and the second tangent is arranged at a bisector of the circular segment where the tangent must be horizontal, where a radius r of the center of rotation 0 equals b/sin($45\text{-}\phi/2$) where b is a width of the building structure 1. The acceleration a_2 of the foundation structure 2, is a function of the inertial force F_1 and the angle acceleration ε of the mass M_2. The acceleration a_2 of the foundation structure 2 and the inertial force F_2 may be calculated, and the mass M_2 with the angular acceleration ε, and the horizontal acceleration a_2 is determined and the earthquake resultant force Q for the foundation slab structure may be calculated as follows

$$\begin{gathered}
\boldsymbol{\varepsilon} = \frac{\boldsymbol{M_0}}{\boldsymbol{I_2}} = \frac{\boldsymbol{a_2}}{\boldsymbol{y_2}} \\
\boldsymbol{M_0} = \boldsymbol{F_1} \cdot \boldsymbol{y_1} + \boldsymbol{Q_d} \cdot \boldsymbol{y_3} \\
\boldsymbol{I_2} = \mathbf{M_2} \cdot \boldsymbol{y_2^2} \\
\boldsymbol{F_1} = \mathbf{M_1} \cdot \boldsymbol{a_1}, \qquad \boldsymbol{F_2} = \mathbf{M_2} \cdot \boldsymbol{a_2} \\
\boldsymbol{Q_d} = \boldsymbol{F_1} - \boldsymbol{F_2} \\
\frac{\boldsymbol{F_1} \cdot \boldsymbol{y_1} + (\boldsymbol{F_1} - \mathbf{M_2} \cdot \boldsymbol{a_2}) \cdot \boldsymbol{y_3}}{\mathbf{M_2} \cdot \boldsymbol{y_2^2}} = \frac{\boldsymbol{a_2}}{\boldsymbol{y_2}} \\
\boldsymbol{a_2} = \frac{\boldsymbol{F_1} \cdot (\boldsymbol{y_1} + \boldsymbol{y_3})}{\mathbf{M_2} \cdot (\boldsymbol{y_2} + \boldsymbol{y_3})} \\
\boldsymbol{Q} = \mathbf{M_1} \cdot \boldsymbol{a_1} + \mathbf{M_2} \cdot \boldsymbol{a_2}
\end{gathered} \tag{4}$$

where y_1 is a distance between the center of rotation 0 and the horizontal surface 3, y_2 is a distance between the center of rotation 0 and a center of the mass M_2, y_3 is a distance between the center of rotation 0 and a horizontal tangent of sliding surface, y_3 equals radius r of the center of rotation 0. Q_d is a resultant shear force at the sliding surface defined by circle S, M_0 is an angular momentum, ε is the angular acceleration and I_2 is a moment of inertia of M_2.
Q represents the earthquake resultant force calculated for the foundation slab structure to which it is necessary to dimension resistance characteristics R_{Q2} of the horizontal connecting surface 3, where the following condition at the horizontal connecting surface 3 must be satisfied

Distribution of shear inertial forces F_i along the height of the building structure 1 may be calculated as follows (see reference [XI])

$$\boldsymbol{F_i} = \boldsymbol{F_1} \cdot \frac{\boldsymbol{z_i} \cdot \mathbf{M}_i}{\sum \boldsymbol{z_J} \cdot \mathbf{M}_J} \qquad \mathrm{M}_{moment} = \int \boldsymbol{F_i}\, \boldsymbol{dz}$$

where M_i (M_j) are floor masses and z_i (z_j) are heights of the masses above the connecting surface 3.

Distribution of force Q by possible resistive forces R_{Q2} of foundation structures must be as follows

$$\begin{gathered}
\boldsymbol{Q}[\boldsymbol{N}] < \boldsymbol{R_{Q2}}[\boldsymbol{N}] \\
\boldsymbol{R_{Q2}} = \boldsymbol{R_{CON}}(\mathbf{M_2})
\end{gathered} \tag{5}$$

$\boldsymbol{R_{Q2}} = \boldsymbol{R_{CON}}(\boldsymbol{M_2})$ is the resistive force of the horizontal connecting surface 3 and in the foundation slab structure may be calculated as follows:

$$\boldsymbol{R_{Q2}} = \boldsymbol{R_{CON}}(\mathbf{M_2}) = \mathbf{M_1} \cdot \boldsymbol{g} \cdot \boldsymbol{tg\,\Phi}$$

with added passive resistance where $\boldsymbol{R_{CON}}$ may be calculated as follows [6]

$$\boldsymbol{R_{Q2}} = \boldsymbol{R_{CON}}(\mathbf{M_2}) = \mathbf{M_1} \cdot \boldsymbol{g} \cdot \boldsymbol{tg\,\Phi} + \boldsymbol{R_{PAS}}$$

where $\boldsymbol{R_{PAS}}$ is gravitational resistive force of the passive resistance. Said $\boldsymbol{R_{PAS}}$ is resistive force existing in a case when the first element 1, i.e. above ground object comprises underground structures such as garages or/and basements, said underground structure generates gravitational resistive force $\boldsymbol{R_{PAS}}$.

$\boldsymbol{R_{Q2}} = \boldsymbol{R_{CON}}(\boldsymbol{M_2})$ in the foundation slab structure may be reinforced with adding a Retaining Engineering Structure - RES where $\boldsymbol{R_{Q2}} = \boldsymbol{R_{CON}}(\mathbf{M_2})$ may be calculated as follows

$$\boldsymbol{R_{Q2}} = \boldsymbol{R_{CON}}(\mathbf{M_2}) = \mathbf{M_1} \cdot \boldsymbol{g} \cdot \boldsymbol{tg\,\Phi} + \boldsymbol{R_{RES}} \qquad [7]$$

where $\boldsymbol{R_{RES}}$ is a resistive force generated by a Retaining Engineering Structure.
The Retaining Engineering Structure is described in European patent application no. 18 759 997.2 which application is incorporated herein in its entirety by reference.
According to the present invention, the Retaining Engineering Structure is implemented for the building structure 1 without underground structures, and in addition to the foundation slab structure 2.
Thus, the resistive force $\boldsymbol{R_{RES}}$ is present when in addition to the foundation slab structure 2 the building structure 1 comprises the retaining engineering structure, wherein the retaining engineering structure is implemented for the building structure 1 without underground structures.

Individual foundation structure

Fig. 2 illustrates a cross section through the foundation with the support structure according to the invention with above ground building structure arranged thereon.
The transmission medium, i.e. the second element 2 is the foundation with the support structure 2, which defines its mass for the transmission of the force of the seismic wave dominantly on the basis of solid cohesion of the material, such as concrete. The mass $\boldsymbol{M_2}$ is determined by geometric dimensions of the foundation with the support structure 2. When force $\boldsymbol{F_1}$ acts on the first element 1, the mass $\boldsymbol{M_2}$ of the second element 2 gets angular acceleration $\boldsymbol{\varepsilon}$ and acceleration $\boldsymbol{a_2}$. The acceleration $\boldsymbol{a_2}$ of the foundation with the support structure 2 is a function of the inertial force $\boldsymbol{F_1}$ and the angle acceleration $\boldsymbol{\varepsilon}$ of the mass $\boldsymbol{M_2}$.

INDIVIDUAL FOUNDATION

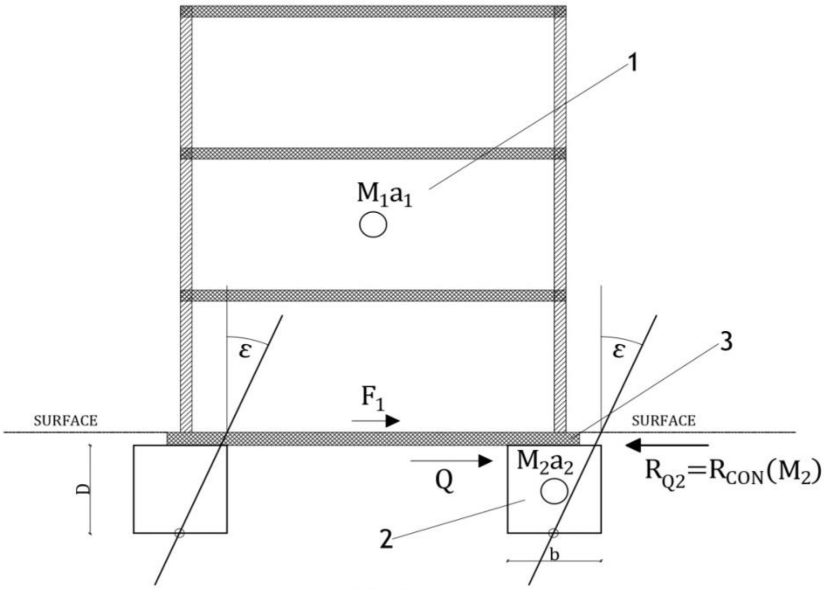


FIG. 2

$$\boldsymbol{F_1} = \mathbf{M_1} \cdot \boldsymbol{a_1} \qquad \boldsymbol{F_2} = \boldsymbol{a_2} \cdot \mathbf{M_2}$$
$$\boldsymbol{\varepsilon} = \frac{\boldsymbol{M_0}}{\boldsymbol{I_2}} = \frac{\mathbf{2} \cdot \boldsymbol{a_2}}{D}$$
$$\boldsymbol{a_2} = \frac{\boldsymbol{M_0} \cdot D}{2 \cdot \boldsymbol{I_2}}, \qquad \boldsymbol{M_0} = \boldsymbol{F_1} \cdot D, \qquad \boldsymbol{I_2} = \frac{\mathbf{M_2} \cdot \mathrm{D}^2}{\mathbf{4}} \quad , \ \boldsymbol{a_2} = \frac{\mathbf{2} \cdot \boldsymbol{F_1}}{\mathbf{M_2}} \tag{8}$$
$$\boldsymbol{F_2} = \boldsymbol{a_2} \cdot \mathbf{M_2}$$
$$\boldsymbol{Q} = \mathbf{M_1} \cdot \boldsymbol{a_1} + \mathbf{M_2} \cdot \boldsymbol{a_2}$$

where $\boldsymbol{D}$ is a height of the foundation with the support structure 2, $\boldsymbol{b}$ is a width of the foundations with the support structure 2, $\boldsymbol{Q}$ is earthquake resultant force calculated for the foundation with the support structure 2 to which it is necessary to dimension resistance characteristics $\boldsymbol{R_{Q2}}$ of the horizontal connecting surface 3, where the following condition at the horizontal connecting surface 3 must be satisfied

$$\boldsymbol{Q}[\boldsymbol{N}] < \boldsymbol{R_{Q2}}[\boldsymbol{N}]$$
$$\boldsymbol{R_{Q2}} = \boldsymbol{R_{CON}}(\mathbf{M_2}) \tag{9}$$

where $\boldsymbol{R_{Q2}} = \boldsymbol{R_{CON}}(\boldsymbol{M_2})$ is the resistive force of the horizontal connecting surface 3 according to the embodiment of the foundation with the support structure 2.

Piling foundation structure

When piles are necessary to avoid heavily controlled subsidence, it is historically implied that this is the resistant action of a pile group or piling.

Piles are vertical columns, built with the purpose of transfer the load of the building into deeper better-bearing soil layers. To avoid difficult-to-control soil settlements, due to the resistive action of a group of piles it is necessary to use pile foundations.

With reference to figure 3, the building structure 1 arranged above the connecting surface 3 is the first element 1 with defined mass $\boldsymbol{M_1}$, the group of piles 2 arranged below the connecting surface 3 is the

second element 2 with defined mass M_2, where an outer perimeter of the group of piles 2 structure determines the mass M_2.
Piles in the constructive group are determined with space ***s x s,*** depth ***D,*** pile diameter ***d,*** anchored depth of pile $h_s = D/3$,
and with pilot-ground sliding surface with resultant angle amount, Φ

where ***s*** is distance between piles, ***D*** is embedment depth of piles, ***d*** is diameter of piles and,

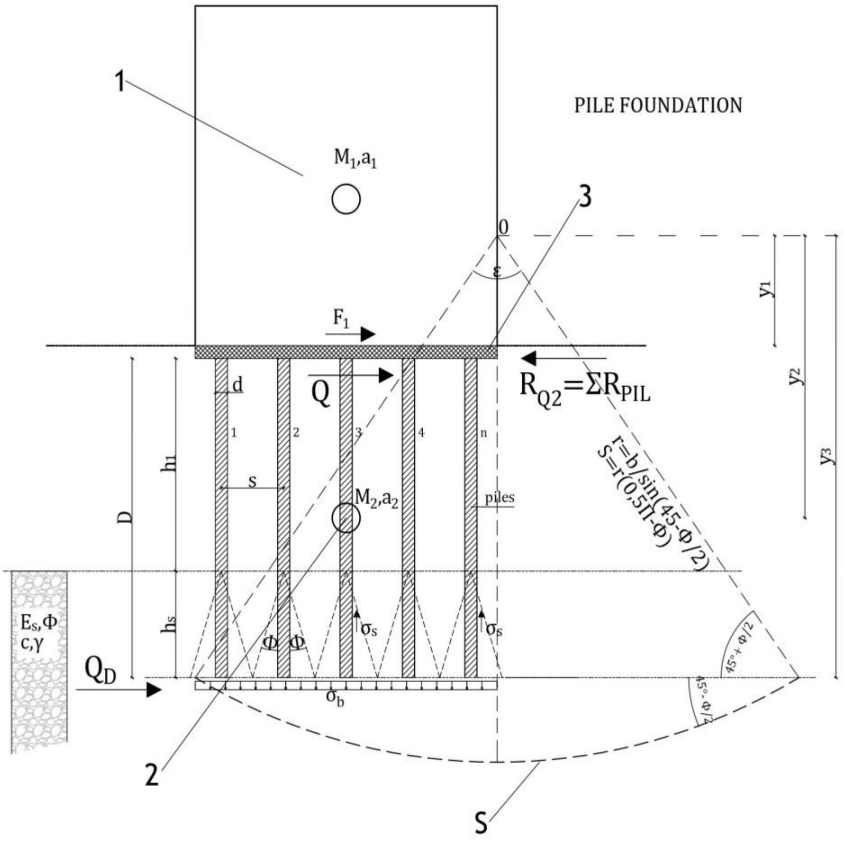


FIG. 3

where deformation – tension force $\boldsymbol{\delta}$- $\boldsymbol{N_P}$ for one pile may be calculated as follows ,

$$\boldsymbol{\delta} = \frac{3 \cdot N_P \cdot ln\frac{s}{d}}{2 \cdot h_s \cdot \pi \cdot E_s} \qquad [10]$$

$\boldsymbol{N_P}$ [N] a tension force in one pile may be calculated as follows

$$N_P = \int \frac{\sigma_s \cdot d^2 \cdot \pi}{2} dh_s \qquad [11]$$

Equilibrium equations on a surface where y=D may be calculated as follows

$$W_{work}(h_s) = U_{pot}(base) \qquad [12]$$

$$\Delta = \Delta_{hs} + \Delta_b$$

$$\boldsymbol{\Delta_{hs}} = \frac{3 \cdot N_p \, ln\frac{s}{d}}{2 \cdot \pi \cdot h_s \cdot E_s}, \qquad \boldsymbol{\Delta_b} = \frac{e_b \cdot h_b}{2}$$

$$\frac{3 \cdot N_P^2 \cdot ln\frac{s}{d}}{4 \cdot \pi \cdot h_s \cdot E_s} = \frac{\sigma_b \cdot e_b \cdot s^2 \cdot h_b}{4}$$

$$h_b = \frac{3 \cdot N_P^2 \cdot ln\frac{s}{d}}{\pi \cdot h_s \cdot E_s \cdot \sigma_b \cdot e_b \cdot s^2}$$

$$\Delta_b = \frac{3 \cdot N_P^2 \cdot ln\frac{s}{d}}{2 \cdot \pi \cdot h_s \cdot E_s \cdot \sigma_b \cdot s^2}$$

$$\Delta = \frac{(1 + \frac{N_P}{\sigma_b \cdot s^2}) \cdot 3 \cdot N_P \cdot ln\frac{s}{d}}{2 \cdot \pi \cdot h_s \cdot E_s}$$

where $\boldsymbol{\Delta}$ is deformation of the group of piles 2, $\boldsymbol{\Delta_{hs}}$ is deformation of the group of piles 2 at along a depth $\boldsymbol{h_s}$ and $\boldsymbol{\Delta_b}$ is deformation of the group of piles 2 at its base, where the base of the group of piles 2 is arranged at a bottom of the group of piles 2 at the embedment depth of piles $\boldsymbol{D}$. Further, $\boldsymbol{e_b}$ is specific deformation of a base of piles 2 at the bottom of the group of piles 2, $\boldsymbol{E_s}$ is elasticity modulus of pile elements along length $\boldsymbol{h_s}$, where $\boldsymbol{h_s}$ is anchoring length of the piles, and $\boldsymbol{\sigma_b}$ is stress at the base of the group of piles 2.
Vertical stability of the group of piles 2 may be calculated as follows

$$\Delta < \Delta_{admisible}$$

$$\sigma_b < q_R$$

$$\sigma_b = p + \gamma \cdot D$$

$$q_R = c \cdot N_c + q \cdot N_q + \frac{1}{2} \cdot \gamma \cdot B \cdot N_\gamma$$

$$\sigma_s = \frac{N_p}{d \cdot \pi \cdot h_s}, \qquad \sigma_{su} = \sigma_b \cdot tan\,\Phi + c \qquad [13]$$

$$s = 2 \cdot h_s \cdot tan\,\Phi$$

$$h_s = \frac{N_p}{d \cdot \pi \cdot \sigma_s \cdot tan\,\Phi}$$

$$3 \cdot h_s < D$$

$$N_{PU} = h_s \cdot d \cdot \pi \cdot \sigma_{su} \cdot tan\,\Phi$$

$$N_P < N_{PU}$$

where $\boldsymbol{N_{PU}}$ is ultimate tension force in each pile.

In the earthquake case of the pile foundation , we have forces and element field, [$\boldsymbol{M_2}$ (piling), $\boldsymbol{M_1}$ (G_S), $\boldsymbol{F_1}$, $\boldsymbol{F_2}$ and $\boldsymbol{Q}$].
The transition of the acceleration of the wave force into the object through the connecting surface 3 of the elements 1 and 2, there is an initial wave confrontation that may be calculated as follows

$$M_1 \cdot a_g = M_1 \cdot a_1 \, tg\,\Phi$$

$$a_1 = \frac{a_g}{tg\,\Phi}$$

If the pile is designed as complete transmitter of the horizontal load, then $\boldsymbol{tg\,\Phi=1}$ otherwise $\boldsymbol{tg\,\Phi<1}$

$$F_1=M_1 \cdot a_g$$

For the pile foundation structure 2 the center of rotation ***0*** of the mass M_2 is determined by the circular segment defined with the circle ***S,*** the circular segment is defined with two tangents, the first tangent is arranged at the starting point where the angle between horizontal surface of the bottom of the group of piles 2 and of the sliding surface is *45-ϕ/2*, the starting point is arranged at a bottom edge of the group of piles 2, and the second tangent is arranged at the bisector of the circular segment where the tangent must be horizontal, where the radius ***r*** of the center of rotation ***0*** equals b/sin(*45-ϕ/2)* and ***b*** is the width of the pile foundation structure 2.
The mass M_2, is calculated by determining a volume forming an outer circumference formed by the pilot structure pile foundation structure 2.

$$\begin{gathered}
\boldsymbol{\varepsilon}=\frac{\boldsymbol{M_0}}{\boldsymbol{I_2}}=\frac{\boldsymbol{a_2}}{\boldsymbol{y_2}} \\
\boldsymbol{M_0}=\boldsymbol{F_1}\cdot\boldsymbol{y_1}+\boldsymbol{Q_d}\cdot\boldsymbol{y_3} \\
\boldsymbol{I_2}=\mathbf{M_2}\cdot\boldsymbol{y_2^2} \\
\boldsymbol{F_1}=\mathbf{M_1}\cdot\boldsymbol{a_1}, \qquad \boldsymbol{F_2}=\mathbf{M_2}\cdot\boldsymbol{a_2}, \qquad \boldsymbol{Q_d}=\boldsymbol{F_1}-\boldsymbol{F_2} \\
\frac{\boldsymbol{F_1}\cdot\boldsymbol{y_1}+(\boldsymbol{F_1}-\mathbf{M_2}\cdot\boldsymbol{a_2})\cdot\boldsymbol{y_3}}{\mathbf{M_2}\cdot\boldsymbol{y_2^2}}=\frac{\boldsymbol{a_2}}{\boldsymbol{y_2}} \\
\boldsymbol{a_2}=\frac{\boldsymbol{F_1}\cdot(\boldsymbol{y_1}+\boldsymbol{y_3})}{\mathbf{M_2}\cdot(\boldsymbol{y_2}+\boldsymbol{y_3})} \\
\boldsymbol{Q}=\mathbf{M_1}\cdot\boldsymbol{a_1}+\mathbf{M_2}\cdot\boldsymbol{a_2}
\end{gathered} \qquad [14]$$

where y_1 is a distance between the center of rotation ***0*** and the horizontal surface 3, y_2 is a distance between the center of rotation ***0*** and a center of the mass M_2, y_3 is a distance between the center of rotation ***0*** and a total depth of the pile foundation 2, i.e. a bottom of the piles.
Q represents the seismic resultant force calculated for the pile foundation structure to which it is necessary to dimension resistance characteristics $\boldsymbol{R_{Q2}}$ of the horizontal connecting surface 3, where the following condition at the horizontal connecting surface 3 must be satisfied

$$\begin{gathered}
\boldsymbol{Q}[\boldsymbol{N}]<\boldsymbol{R_{Q2}}[\boldsymbol{N}] \\
\boldsymbol{R_{Q2}}=\boldsymbol{R_{CON}}(\mathbf{M_2})=\sum\boldsymbol{R_{PIL}}
\end{gathered} \qquad [15]$$

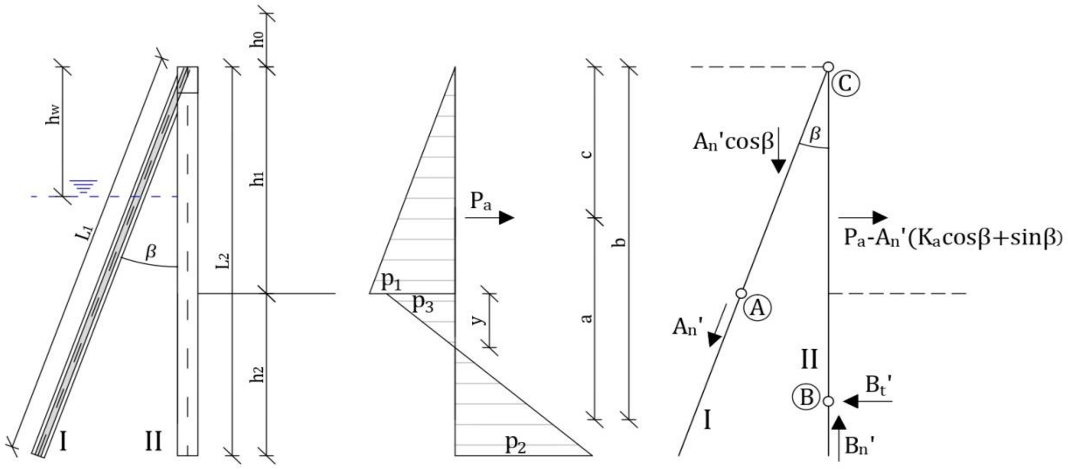
where $\boldsymbol{R_{Q2}}=\boldsymbol{R_{CON}}(\boldsymbol{M_2})$ is the resistive force of the horizontal connecting surface 3 where $\sum\boldsymbol{R_{PIL}}$ is sum of the horizontal resistive forces in the pile foundation structure 2.

RES – Retaining Engenering Structure

The excavation stability, by using a stabilizing oblique pile and vertical structure, is a construction shift in the stable, spatial, and rational aspect, which, in prior practice of the same constructions, was not used. The oblique pile I, positioned with an angle β =15-20 to the vertical structure II, becomes a basic stable element. The bearing capacity of this pile is composed as the sum of two external influences, the first, as the resistance $A_n(h_s)$ in the h_s part, the second, as the load $A_n(h_1)$ in the h1 part, only to result in the force C_n at the construction junction point C.
In the stability calculation, $A_n(h_s)$ is obtained if the minimum possible value of the vertical load $A_n(h_1) = A_n(h_s)$ is introduced as a favourable impact, and the P_a value as an adverse impact. If the pile possesses transverse rigidity EI, it accepts the horizontal component $of\ A_n \sin\beta$ from the total horizontal load.
Finally, the horizontal effect on vertical structure II in the amount of $K_a A_n \cos\beta$, i.e., $A_n[K_a \cos\beta + \sin\beta]$ is reduced if the oblique pile possesses axial EA and transverse rigidity EI.

The ratio **δ - A_n** of the oblique pile is according to,

$$\delta = [3\, A_n /2\, h_s\, \pi\, E]\, \log_e(s/d) \text{----------------} \; [III]$$
$$A_n = \int N_p\, dh_s,\quad N_p = \sigma_s\, d^2\, \pi /2,\quad \sigma_s = A_n / d\, \pi\, h_s \qquad [16]$$



Picture 4

Equilibrium equations

$$\mathbf{A'_n b \tan\beta + \; 0,5 h_1 \tan\beta\, A'_n \cos\beta - a[\, P_a - A'_n(K_a \cos\beta + \sin\beta)]=0}$$
$$\mathbf{B'_n h_1 \tan\beta - 0,5 h_1 \tan\beta\, A'_n \cos\beta - (b - h_1)B'_t - h_1[P_a - A'_n(K_a \cos\beta + \sin\beta)]/3=0}$$
$$\mathbf{B'_t = c[P_a - A'_n(K_a \cos\beta + \sin\beta)]/b}$$
$$\mathbf{C'_n = \; a[P_a - A'_n(K_a \cos\beta + \sin\beta)]/b \tan\beta}$$
[17]

Deformation of system △s, element resistance and load,

$$\triangle s = \triangle I_n / \cos(90 - \beta), \triangle I_n = 3\, A_n \ln(s_1/d)\, /2\, h_s\, \pi\, E \text{---------} \; [III]\, ,$$
$$M_{\max I} = \Phi(u) M_I,\; M_I = \frac{h_1}{14} A_n \sin\beta,\; [\, u^2 = A_n h_1^2/4\, E_I I_I] \text{----------------} [VII]$$
$$M_{\max II} = \Phi(u) M_{II}, M_{II} = p\, (\, h_1 + y)^2/14, [\, u^2 = B_n\, (\, h_1 + y)^2/4\, E_{II} I_{II}] \text{---} \; [VII]$$
$$[\, P_a - A'_n(K_a \cos\beta + \sin\beta)]/\, (\, h_1 + y) = p$$
$$A_{n,q,R} = \sigma_q\, d\, \pi \tan\varphi_d\, L_I/2$$
$$B_{n,q,R} = \; h\, \gamma\, N_q\, A_b + c_d N_c A_b \;\; B_{t,q,R} = (P_p + B'_n \tan\varphi_d) s_2$$

Horizontalno aktivno opterećenje $\mathbf{P_a} = \sum\, (p_a \times h_{p_a})$

$$p_1 = [\gamma'(h_1 - h_w) + \; \gamma_{uns}(h_w + h_0)]K_a + (h_1 - h_w)\gamma_w - p_{ca}, [h_w < h_1]$$
$$p_3 = p_1 - p_{cp},,\; p_{ca} = 2cK_a^{0,5}\; p_{cp} = 2cK_p^{0,5}$$
$$z = \gamma' \times (K_p - K_a), y = \frac{p_3}{z}, b = \frac{2h_S}{3} + h_1, c = \frac{2h_1}{3}, a = b - c\, ,$$
[18]

Stability display

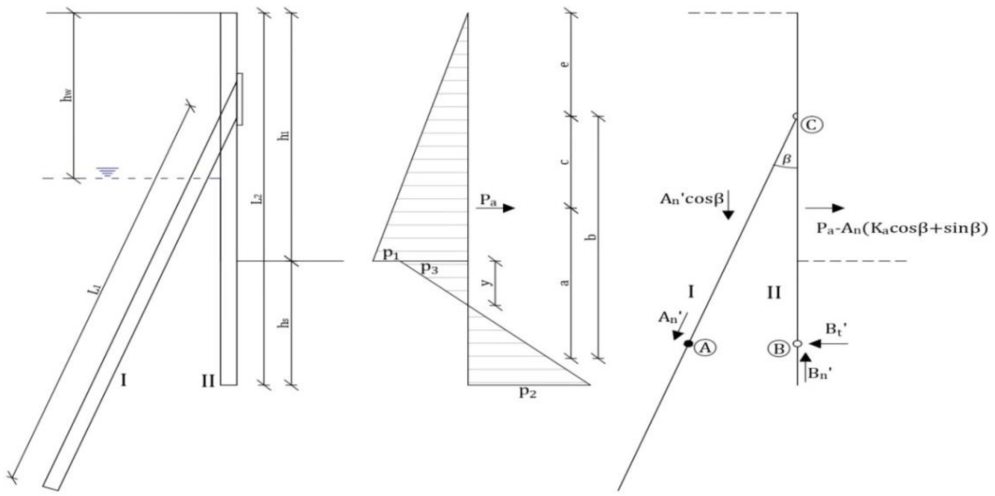
$$\triangle s < \triangle s_{,\,adm}$$
$$A_n = A'_n \times s_1 < A_{n,q,R}, C_n = \; C'_n x\, s_1 < C_{n,c,R}$$
$$B_n = B'_n \times s_2 < B_{n,q,R,} B_t = B'_t \; \times s_2 < B_{t,q,R}$$
$$M_{\max I} < M_{I,R}, M_{\max II} < M_{II,R}$$
$$r_p > A_n/2\, h_s\, \Pi\, \sigma_{sa}$$
[19]

RES – Retaining Engenering Structure in more severe waterproof condition and greater depths

When the excavation is deeper, it includes a waterproof vertical structure–diaphragm, and the oblique pile is placed at a statically optimal height relative to the vertical structure, which requires a special bond of these two elements.
The ratio δ - A_n of an oblique pile is according to,

$$\delta = [3\ A_n /2\ h_s\ \pi\ E]\ \log_e(s/d) \text{------------- [III]}$$

$$A_n = \int N_p\, dh_s,\quad N_p = \sigma_s\, d^2\, \pi /2,\quad \sigma_s = A_n / d\, \pi\, h_s$$



Picture 5

Equilibrium equations

$$A'_n \cos\beta\ \ b\tan\beta + \ 0,5\ b\tan\beta\ x\ A'_n\cos\beta - a[\ P_a - A'_n(K_a\cos\beta + \sin\beta)]=0$$
$$B'_n\ \ b\tan\beta - 0,5\ b\tan\beta\ x\ A'_n\cos\beta \text{ - } a\ [P_a - A'_n(K_a\cos\beta + \sin\beta)]=0$$
$$B'_t = c[\ P_a - A'_n(K_a\cos\beta + \sin\beta)]/b$$
$$C'_n = a[P_a - A'_n(K_a\cos\beta + \sin\beta)]/b\tan\beta$$

[20]

Deformation of system$\triangle_S$, resistance of elements, and load

$$\triangle_S = \triangle I_n / \cos(90-\beta), \triangle I_n = 3\ A_n \ln(s_1/d)\ /2\ L_s\ \Pi\ E \text{--- [III] ,}$$
$$M_{max\,I} = \Phi(u)M_I, M_I = \frac{b}{14}\ A_n\ \sin\beta, [\ u^2=A_n\, b^2/4\ E_I\, I_I] \text{--- [VII]}$$
$$M_{max\,II} = \Phi(u)M_{II}, M_{II} = p\ b^2/14, [\ u^2=B_n\, b^2/4\ E_{II}\, I_{II}] \text{--- [VII]}$$
$$[\ P_a - A'_n(K_a\cos\beta + \sin\beta)]/\ (\ h_1+y) = p$$

$$A_{n,q,R} = \sigma_q\ d\ \pi\ \tan\varphi_d\ L_I/2$$
$$B_{n,q,R} = \ h\ \gamma\ N_q\ A_b + c_d N_c A_b\ \ B_{t,q,R} = (P_p + B'_n\tan\varphi_d)s_2$$

Horizontalno aktivno opterećenje $P_a = \sum(p_a \times h_{p_a})$ $b = \frac{2h_s}{3}$+(h$_1$-e), c=$\frac{2h_1}{3} - e$, a=b – c ,

[21]

Stability display

$$\triangle_S < \triangle_{S,\,adm}$$
$$A_n = A'_n \times s_1 < A_{n,q,R}, C_n = \ C'_n x\ s_1 < C_{n\ ,c,R}$$
$$B_n = B'_n \times s_2 < B_{n,q,R,} B_t = B'_t \times s_2 < B_{t,q,R}$$

$$\Phi_{(u)} M_{I} = M_{I\,max} < M_{I,R}, M_{II\,max} < M_{II,R}$$
$$r_p > A_n/2\ h_s\ \pi\ \sigma_{sa}$$
[22]

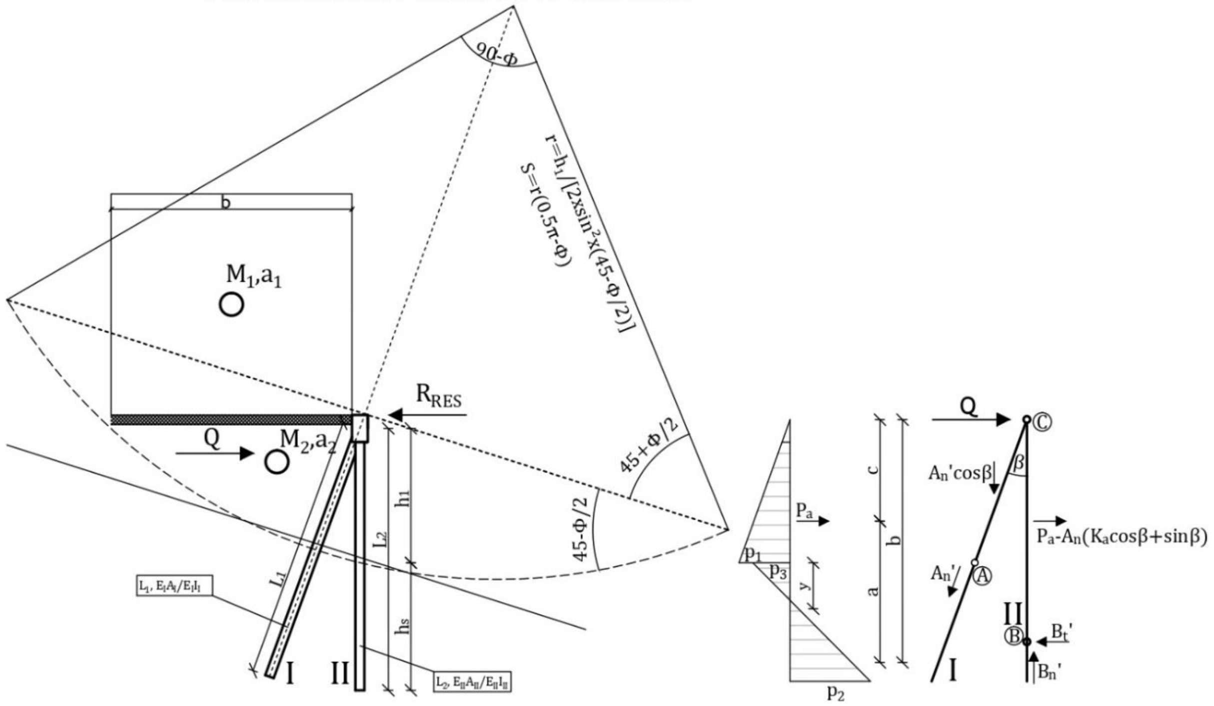
RES – Retaining Engenering Structure in laying the foundation on sloping or landslide terrain

An object on a slope with insufficient stability potential is secured by adding the RES construction, of resistance M_{RES}, after which the system solution is a semi-infinite Rankine's state of equilibrium.
The positive difference in energy forces $\triangle$ **M**, action, and overall resistance with the RES construction $\mathbf{M_{RES}}$, represents the required stability potential.

$$\triangle\, \mathbf{M = 0.5(\sigma_b\, tg\, \varphi + c)\, r\, S + M_{RES} - p\, b[0,5b + (r - h_1)\sin\beta] - P_a\left(r - \frac{h_1}{3}\right) - Q\,(r - h_1)}$$
$$\mathbf{M_{RES} = A_{n,q,R}\ x\ h_1 tg\ b\ ,\quad P_a = \sum(p_a \times h_{p_a})\ ,\quad Q = M_1\, a_1 + M_2\, a_2}$$

[23]

FOUNDATION ON SLOPE GROUND



Equilibrium equations

$$\mathbf{A'_n \cos\beta\ \ h_1 \tan\beta + \ 0,5\ h_1 \tan\beta\ A'_n \cos\beta - b\ Q\ - a[\ P_a - A'_n(K_a \cos\beta + \sin\beta)] = 0}$$
$$\mathbf{B'_n h_1 \tan\beta - 0,5 h_1 \tan\beta\ A'_n \cos\beta - \ h_1 Q - (b - h_1) B'_t - h_1[P_a - A'_n(K_a \cos\beta + \sin\beta)]/3 = 0}$$
$$\mathbf{B'_t = c[P_a - A'_n(K_a \cos\beta + \sin\beta)]/b}$$
$$\mathbf{C'_n = \ \ a[P_a - A'_n(K_a \cos\beta + \sin\beta)]/b \tan\beta + Q\ b/\ b \tan\beta}$$
[24]

Deformation of system $\triangle_S$, resistance of elements, and load

$$\triangle_S = \triangle I_n\ /\cos(90 - \beta), \triangle I_n = 3\ A_n \ln(s_1/d)\ /2\ L_s\ \pi\ E\text{--- ----------[III]} ,$$
$$M_{max\,I} = \Phi(u) M_I,\ M_I = \frac{h_1}{14}\ A_n\ \sin\beta,\ [\ u^2 = A_n h_1^2/4\ E_I I_I]\text{--- ----------[VII]}$$
$$M_{max\,II} = \Phi(u) M_{II}, M_{II} = p\ (\ h_1 + y)^2/14,\ [\ u^2 = B_n\ (\ h_1 + y)^2/4\ E_{II} I_{II}]\text{--- [VII]}$$

$$[\,\mathbf{P_a} - \mathbf{A'_n}(\mathbf{K_a}\cos\boldsymbol{\beta} + \sin\boldsymbol{\beta})]/\,(\mathrm{h_1{+}y}) = \mathbf{p}$$
$$\mathbf{A_{n,q,R}} = \boldsymbol{\sigma_q}\,\mathbf{d}\,\boldsymbol{\pi}\tan\boldsymbol{\varphi_d}\,\mathbf{L_I}/2$$
$$\mathbf{B_{n,q,R}} = \mathbf{h}\,\boldsymbol{\gamma}\,\mathbf{N_q}\,\mathbf{A_b} + \mathbf{c_d N_c A_b} \quad \mathbf{B_{t,q,R}} = (\mathbf{P_p} + \mathbf{B'_n}\tan\boldsymbol{\varphi_d})\mathbf{s_2}$$
$$M_{RES} = A_{n,q,R} \times h_1 tg\,\beta$$
Horizontal aktive load $\mathbf{P_a} = \sum(\mathbf{p_a} \times \mathbf{h_{p_a}})$, $\mathbf{b} = \frac{2\mathbf{h_s}}{3} + \mathbf{h_1}$, $\mathbf{c} = \frac{2\mathbf{h_1}}{3}$, $\mathbf{a} = \mathbf{b} - \mathbf{c}$

[25]

Stability display

$$\triangle_s < \triangle_{S,\,adm}$$
$$\mathbf{A_n} = [(\mathbf{A'_n} \times \mathbf{s_1}) + \mathbf{M_Q}/\,\mathbf{b}\tan\boldsymbol{\beta})] < \mathbf{A_{n,q,R}},\ \mathbf{C_n} = \mathbf{C'_n} \times \mathbf{s_1} < \mathbf{C_{n,c,R}}$$
$$\mathbf{B_n} = [(\mathbf{B'_n} \times \mathbf{s_2}) + \mathbf{M_Q}/\,\mathbf{b}\tan\boldsymbol{\beta})] < \mathbf{B_{n,q,R}},\ \mathbf{B_t} = \mathbf{B'_t} \times \mathbf{s_2} < \mathbf{B_{t,q,R}}$$
$$\Phi_{(u)}\,M_I = M_{max\,I} < M_{I,R},\ M_{max\,II} < M_{II,R}$$
$$r_p > A_n/2\,h_s\,\pi\,\sigma_{sa}$$

[26]

conclusion

By using the known energy equilibrium equations on these stability and earthquake-resistant constructions, the supporting stability solutions exposing the primary nature of the equilibrium state are obtained.

***For the earthquake-resistant stability constructions, the difference in supporting stability potential by using the new approach is over 30-50%. Unfortunately for these constructions, it bears a negative sign; it is therefore necessary and urgent to revise the eartquake-resistant regulatory procedure for laying the foundations of buildings.**

****Regarding the basic piling construction, the real values of its constructive parameters can finally be proven, which bear a positive sign in terms of stability potential by using the said approach. This confirms the ancient and univerasal value of the said construction.**

*****Unlike these two procedures, the third one, the Retaining Engineering Structure or RES,** EP 3827133, **thanks to the discovered stability potential being over 30-50%, but with a positive sign, is already in practical application and implementation, and has references.**

Notation:

RES – Retaining Engineering Structure
R[N] **-** resistive force
$\mathbf{R_{RES}}$ [N] **-** resistive force of the Retaining Engineering Structure
$\mathbf{R_{CON}}$[N] **-** resistive force of the horizontal connecting surface
$\mathbf{R_{PAS}}$**[N] -** gravitational resistive force
u [m], **v** [m/s], **a** [m/s^2], **g**[m/s^2]-displacement, velocity, acceleration, gravitational acceleration
M [kg] = **W/ g** = V**r**[kg] - mass of an element of the field
W[N]**= g M** = **V ρ g** [N] - gravitational force
F= a M [N], N [kg m/s^2], **F= q** x **v** [N] - inertial force
$\boldsymbol{a_g}$ - calculation value of earthquake wave acceleration

$\boldsymbol{\varepsilon}$ **[**1/s^2**] -** angular acceleration **-** rotational motion
N$_P$[N]**, -** tension axial force of the pile
$\boldsymbol{Q}$=Z v [N] - shear force/ seismic resultant force
Z=F/ v [N s/m] **-** impedance of elements
$\triangle$ **-** deformation of the structure
δ- deformation of elements of the structure
K=F/δ[N/m] **-** stiffness of the element
ρ [kg /m^3], **q**[kg/s], **γ=ρ g** [kN/m^3] - density, mass flow rate and specific weight
$\boldsymbol{C_n}$ **=[E/ r]$^{1/2}$** [m/s] **-** wave velocity of a longitudinal wave
$\boldsymbol{C_t}$ **=[G/ r]$^{1/2}$** [m/s] **-** wave velocity of a transverse wave
W_{work}, U_{pot}, K_{kin}, [J]**,** J [kg m^2/s^2] - work and energy
E_s =**σ/e** [kN/m^2] **-** modulus of elasticity of the element
e= $\boldsymbol{\delta}$ **/L** [m/m] - specific deformation
G_S **=E_S/2(1+μ)** [kN/m^2] shear modulus
μ - Poisson's number
σ_s σ_n, [σ_{su} σ_{nu}] --- [kN/m^2] - stresses, shear and normal, [ultimate]
I_{sec}[m^4]**, I_{rot}**[kg m^2] – cross section and rotation characteristics
$\boldsymbol{\phi}$**, c** [kN/m^2], **γ_{uns}, γ_{sat}** [kN/m^3] **-** angle of internal friction, cohesion and soil/ground weight

References:

[I] Biot, M. A. *Proc.Natl.Acad. Sci.1933*
[II] Bowles, J.E. "*Foundations Analysis and Design, Fifth Edition ", 1996.*
[III] Cooke, R. W. *The settlement of friction pile foundations* 1974
[V] Cyril M. Harris & Charles E. Crede "*Shock and vibration handbook "*, 1976.
[IV] Poulos, H.G. & Davis, E.H.: *Pile Foundation Analysis and Design 1980.*
[VI] S.P.Timoshenko &, D.H. Young "*Theory of Structures, Second Edition"*, 1965.
[VII] Timoshenko, P. S. "*Strength of Materials, Third Edition "*, 1958.
[VIII] S. Timoshenko & D.H. Young "*Advanced Dynamics, Fourth Edition "*, 1948.
[IX] S. Timoshenko & J.N. Goodier "*Theory of Elasticity, Second edition "*, 1951.
[X] Whitaker, T. "*The Design of Piled Foundations, Second edition "*, 1976.
[XI] EUROCODE 8 *"Design of structures for earthquake resistance"*