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REINFORCED WALLS OF NATURAL REINFORCED SOIL

Ina Popova

University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria

ABSTRACT
When excavations are picked, especially in more depth excavations, often is necessary to reinforce the slopes. The well known technologies are applied – slurry walls, pilots, sheets, etc. In recent years another type reinforcement is being used, which consist in driving the steal rods in slopes at definite angle on determined intervals and with determined lengths. A result is a conditional reinforced wall of natural reinforced soil, which can provide considerable depths of excavations in vertical or low-pitched slopes. The theory of determination of static diagram of the walls is based on the theory of earth pressure, but with alternations that admit the specific of interaction between walls of reinforced soil and surrounding massif. The most important part of these alternations is inclusion of cohesion between soil of the wall and soil massif. This interaction is not considered in classical theory of Coulomb and leads to considerable reduction of soil pressure to values, that could be taken by the walls of reinforced soil. Assumptions and methods of determination of corrected values of earth pressure in such type walls and peculiarities of their accomplishment are given in the report.

When excavations are picked, especially excavations with greater depth, it is not always possible to carry out the reinforcement of slopes in compliance to geo-technology requirements. This applies mostly where construction in built-up city areas is performed and a number of restrictions arises, due to the existence of roads and underground communications such as water supply systems, electrical and phone cables, etc. in close proximity. An important requirement is not to disturb the transport and life cycle in the areas surrounding building sites. In all these occasions reinforcement of the slopes, especially for relatively deep hollows is needed. This reinforcement is carried out by well-known technologies such as slurry walls, pilots (usually borehole), short passive or deep pre-stressed anchors, sheets, etc. In recent years a new type of reinforcement, comprising of driving steel rods with a certain length into slopes at defined intervals, is implemented (fig. 1). As a result a conditional reinforced wall of natural reinforced soil, which can provide for considerable depth of excavations in vertical or light slopes is created.

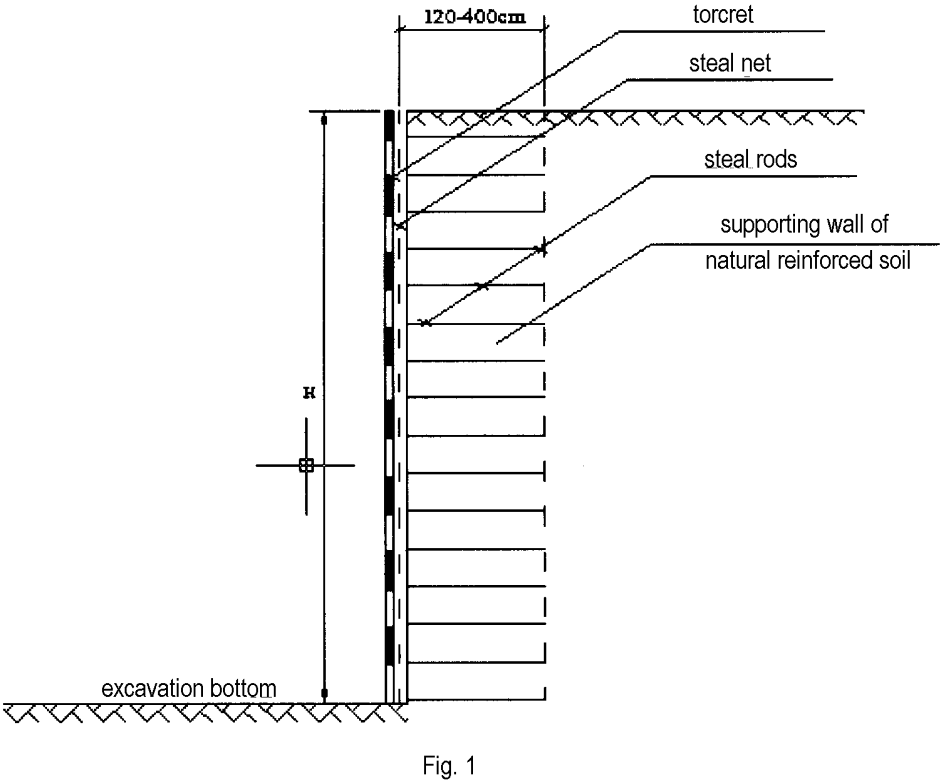

Fig. 1

The theory for determination of the static diagram of such walls of natural reinforced soil is based on the earth pressure theory, but with alternations, taking into consideration the specific character of the interaction between reinforced soil walls and the surrounding massif. An essential part of these alternations is the provision for of cohesion between the soil of the thus constructed walls and the rest of the soil massif. This interaction is not accounted for in Coulomb's classical theory and leads to significant reduction in the soil pressure quantity to a value that could be supported by reinforced soil walls.

In the classical theory on earth pressure, created by Coulomb (in 1773), and prerequisites sufficiently quoted in specialised literature, /the soil volumetric mass and the internal friction angle are homogeneous, earth pressure is a result of the soil wedge sliding along the plane, the bridging over the shearing strength takes place simultaneously along the entire failure plane, and there is no soil cohesion/ (fig.2), earth pressure is calculated by dependence [1]:

$$E = \frac{G\sin(\upsilon_a - \varphi)}{\sin(\theta + \delta + \varphi - \upsilon_a)} \tag{1}$$

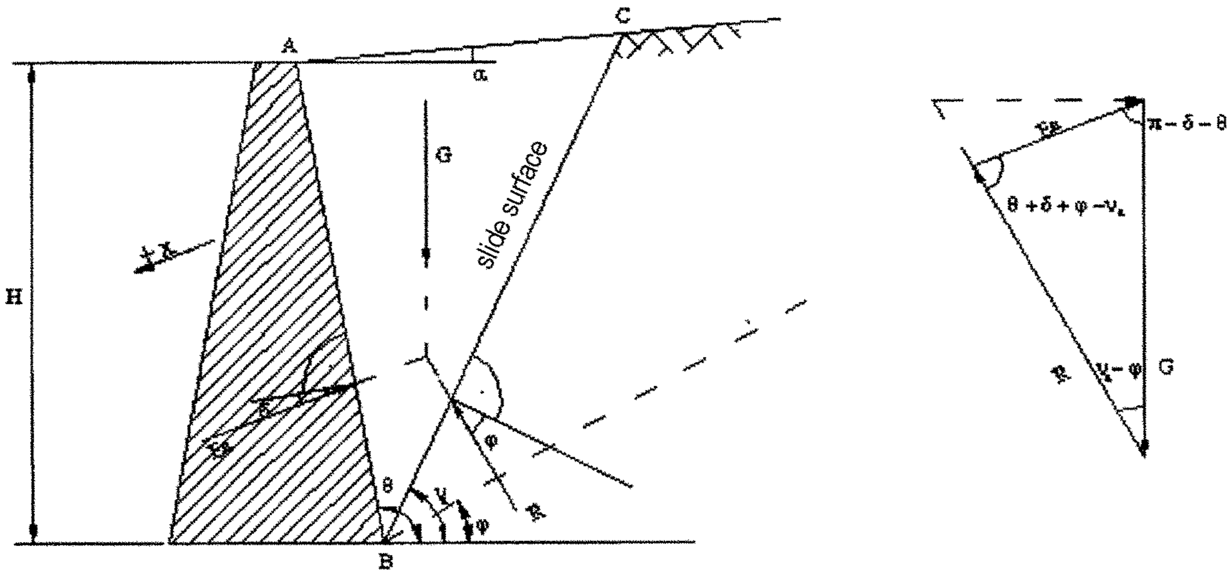

Fig. 2 Calculation scheme of the active earth pressure

The meaning of separate values is presented in the figure.

One of the essential problems is related to determination of the slope angle of the sliding surface - ν_a. According to theory this angle is determined by the condition for obtaining the peak of active earth pressure, an element of the theory for peak value of a function. Following performance of the specific operations, which shall not be subject of this study, an angle value ν_a is reached. It is a complex function of ground slope's angle, the wall's rise, the angle of the soil's internal friction and the friction angle between wall and soil [1]. By substitution of the value reached for ν_a by formula (1), the final value of the earth pressure E_a is calculated.

In dimensioning the scale of reinforcing constructions of excavations of significant depth, dependencies are reduces by admitting for horizontal ground and vertical back wall of the reinforcing works - α=0, θ=π/2. In more accurate calculations the angle of friction between wall and soil - δ is accounted for, and in some more specific cases – the rise of the back of the wall $\theta \neq \pi 2$ is also accounted for. In analytical expressions for determining the horizontal component of active earth pressure the following formula is applied:

$$E_a = ½.\gamma.H^2 \tag{2}$$

Where: γ is the average volumetric mass of soil in the soil wedge sliding along the sliding surface, H is the wall height, and K_a is the side earth pressure factor. K_a is calculated by formulas, presented in specialized literature, such as formula [1].

In more typical cases the inclusion of friction between soil and wall may lead to a reduction of earth pressure by 20 or more than 20 %. If this friction, as well as the influence of the back of the wall's rise are disregarded, as is the normal practice in construction, the formula for calculation of the side earth pressure factor is reduced and the classical type of Rankin's minimum state of tension is reached:

$$K_a = tg^2\left(45 - \frac{\varphi}{2}\right) \tag{3}$$

Cohesion is not included in all the above mentioned formulas. The cohesion influence is taken in consideration also on the basis of Rankin's state of tension, where the constant speed P_c is eliminated from the earth pressure diagram:

$$P_c = 2c\sqrt{K_a} \tag{4}$$

Cohesion, despite its changing value, has a significant influence on earth pressure, therefore it should be accounted for, especially for temporary constructions, such as reinforcing constructions of excavations of greater depth, because following construction of the underground parts of buildings their interaction in the static diagram of buildings is usually disregarded. Cohesion may be directly accounted for in the earth pressure values by directly including its interaction in the sliding surface of the soil wedge. In the case of reinforced walls of natural soil, the cohesion influence may be taken into consideration also in the interaction between wall and soil, because for such walls, due to their nature, there is always adhesion between conditional reinforced soil wall and the rest of the soil massif.

In order to account for this influence, the force triangle in fig. 2 is considered. The effect of tilting earth pressure to the angle of friction between soil and wall may be accounted for approximately by the figure, where its vector is determined to be horizontal. If the cohesion action is included, which has not been done previously, another force, that is approximately vertical and for one linear meter of the wall length has a value of:

$$C = cH \tag{5}$$

should be included in the force triangle, where c is the cohesion value, and H is the wall height. The inclusion of the force C may be synonymous, due to the fact that the direction of the force R is known, as well as the direction of the earth pressure E_a. Following recording of the force C, the force polygon is of the type presented in fig.3. Obviously this leads to significant reduction of earth pressure and this fact makes it possible to understand the way walls thick 1.2 m to 2.0 m may hold in vertical slopes with a height of up to 7 – 8 m.

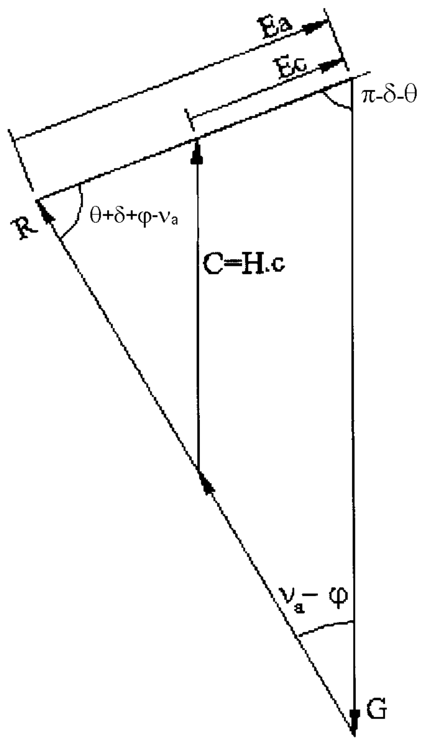

Fig. 3

The determination of the new corrected value of earth pressure may be carried out by general dependencies, known from trigonometry, by using all other dependencies and quantities, known from classic solutions. By applying the prerequisite that forces G and C are parallel, where the backs of walls are vertical and approximately parallel in all other cases, the dependencies for similar triangles, presented in fig.3, may be applied. The weight of soil prism G is easy to calculate due to the fact that the slope angle of the sliding surface is known. The value of earth pressure is also calculated by classic methods. The corrected value of the earth pressure by including the action of soil cohesion in the back surface of the soil wall E_c is calculated by the equation:

$$\frac{cH}{G} = \frac{E_a - E_C}{E_a} \tag{6}$$

Or more clearly, the value of E_c may be calculated by the formula:

$$E_C = E_a\left(1 - \frac{cH}{G}\right) \tag{7}$$

Following reduction, the formula may be presented as:

$$E_C = E_a K_c \tag{8}$$

where K_c may be defined as factor of reduction of earth pressure by reporting cohesion between the reinforced soil wall and the surrounding ground. This factor is in all cases lower than 1. An additional prerequisite is $c.H \leq G$.

This formula can be applied for all cases of earth pressure, for random values of the quantities, included in the formulas for its determination. The question for additional inclusion of cohesion, in compliance to Rankin's postulates, by elimination of the value of P_c from the earth pressure diagram determined by formula (4), still poses a problem. It is based on the same reasoning, as the basis for its performance, independent of the reading of the angle of friction between the soil and the reinforced wall.

The effect of inclusion of cohesion between soil massif and the wall of natural reinforced soil may be easily determined. This determination is carried out by implementing the most widely used of Rankin's examples for determination of earth pressure under the condition that the back of the wall is vertical, the ground is horizontal and the friction angle between soil and wall is $\delta = 0$. In this case the sliding surface of the soil wedge is rising to the horizon under an angle of $\upsilon_a = \frac{\pi}{4} + \frac{\varphi}{2}$, the weight of the soil prism is, as follows:

$$G = 1/2H^2\gamma tg\left(\frac{\pi}{4} - \frac{\varphi}{2}\right) \tag{9}$$

and the active earth pressure E_a is calculated by the formula:

$$E_a = 1/2\gamma H^2 tg^2\left(\frac{\pi}{4} - \frac{\varphi}{2}\right) \tag{10}$$

The factor of reduction of earth pressure as a result of reporting the cohesion between wall and soil shall be:

$$K_c = 1 - \frac{2c}{\gamma H tg^2\left(\frac{\pi}{4} - \frac{\varphi}{2}\right)} \qquad (11)$$

Numeric example:

Determine the earth pressure on a wall of natural reinforced soil using the following values:

Excavation depth (height of slope)	H=6 m
Angle of internal friction of the soil	φ=22°
Soil cohesion	c=15 kPa
Volumetric mass of the soil	γ=20 kN/m^3

The earth pressure, determined by the classic method shall be:

$$E_a = 1/2.20.6^2 \, tg^2\left(45 - \frac{22}{2}\right) = 163{,}79 \text{ kN/m}$$

The factor of reduction of earth pressure, as a result of reporting the cohesion between soil and wall shall be, as follows:

$$K_c = 1 - \frac{2.15}{20.6.tg^2\left(45 - \frac{22}{2}\right)} = 0{,}45$$

The corrected value of earth pressure is as follows:

E_c = 163,79.0,45 = 73,7 kN/m

The reduction of earth pressure is 55%, which is significant.

In other cases this reduction may be different, but most often it is significant, as may be seen from the numeric example. In all cases the solving must be carried out carefully, using reduced cohesion values, for example reduced 2 – 2.5 times, in order not to calculate a drastic and unrealistic value of the corrected earth pressure, despite the correct postulate of the theoretical solution.

After calculation of the earth pressure, the same procedure shall be followed in the dimensioning of the reinforced wall, as with all other walls. The diagram of earth pressure shall be constructed, reduction as a result of the cohesion action – Rankin's example and control of the wall for tensions in the base plane, sliding and conversion shall be used.

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