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VENEER SLOPE STABILITY WITH GEOGRIDS

Authors:
Branimir Bratoev - **PhD, CEng., Sofia**
Ivan Doikov - **Associate proffersor, PhD, Sofia**

ABSTRACT

The use of geosynthetic materials in infrastructural, industrial and civil construction is widespread worldwide. Many of the commercially available geogrids can be effectively used to reinforce steep slopes. The appropriate selection of geogrids and their correct application and anchoring is of utmost importance to ensure the local stability of sloping terrains. This article gives insight into the geogrids used in practice and the possibilities for their tensile strength design and anchoring when ensuring veneer slope stability. Alternative approaches to reinforce steep slopes using other geosynthetic materials are outlined.

1. Types of geogrids applicable to reinforce steep slopes and mechanism of action

Geogrids are a geosynthetic material in which transverse and longitudinal ribs cross most often at right angles, forming square or rectangular openings of different sizes. Geogrids are mainly manufactured from four polymers – high density polyethylene, polypropylene, polyester or polyvinyl alcohol. Depending on the production technology there are several types of geogrids: extruded, woven and laid geogrids. According to their tensile strength at break, geogrids are divided into mono-oriented (monoaxial) - with dominant strength in one direction and bi-oriented (biaxial) - with equivalent strength longitudinally and transversely to the direction of production. The production technology and the polymer used are the main characteristics on which the reduction coefficients depend, which in turn determine the long-term tensile strength of the geogrids. To strengthen steep slopes, mono-oriented geogrids are most often used, and the type of polymer from which they are produced should be selected in such a way that it is resistant to the aggressiveness of the topsoil.

Geogrids work by wedging with an interlocking mechanism. The holes in the geogrid allow the bulk material to pass through, after which it is wedged between individual ribs. Due to the stiffness and strength of the geogrid ribs, the bulk material above the geogrid stays above it and does not flow down. [4] From this point of view, it is extremely important to make an appropriate selection of the openings of the geogrid in relation to the grain size of the bulk material. This is of particular importance in cases where the geogrid is laid horizontally or close to it.

Unlike bulk material, geogrids have high tensile strength. This allows them to transmit the stresses caused by permanent and temporary loads over a larger area than without the presence of a geogrid. At the same time, with a good wedging of the loose material in the geogrid, it can provide resistance against slipping of the covering layer on steep slopes.

Fig. 1 Interlocking effect of the geogrid with soil

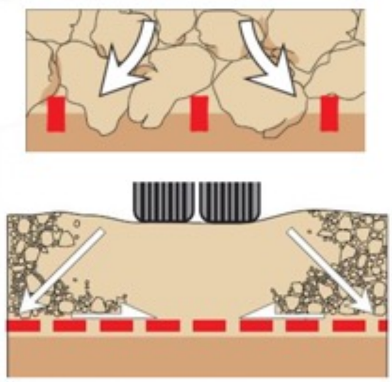

Fig. 2 Mechanism of absorption of tensile stresses by the geogrid

2. Purpose and scope of the study

Very often, in practice, it is necessary to build slopes steeper than those that the characteristics of the soil and bulk materials allow. Similar tasks may arise in the construction of a lower and upper insulating screen of landfills and tailing ponds, construction of roads and railways in deep trenches, and in strengthening of coastlines. This solution offers a number of (or several) advantages:

• It reduces the need for expropriation of land related to the construction of the corresponding facility.

• It allows for the use of local soil for the construction of slopes.

• It reduces the costs of building the corresponding facility.

One of the possible solutions is related to the use of a geogrid in areas of the surface where slippage between the individual soil layers and corresponding veneer slope failure is expected to occur. The geogrid should be dimensioned in such a way as to ensure that it will absorb the forces that arise within it, both from the weight of the embankment placed on it as well as from the temporary loads associated with construction machinery, live load, snow, etc. At the same time, adequate anchoring of the geogrid at the crest of the slope is essential to prevent failure.

3. Methodology for designing the required tensile strength at break of the geogrids and type of anchoring

3.1. Determination of the required tensile strength at break of the geogrid

Slopes covered with bulk material should be designed to prevent slippage of the topsoil layer. Due to the low shear strength of the topsoil, loss of stability may occur due to gravity forces, live loads, overburden, slope wetting and/or seismic forces. According to Koerner and Soong [2], the slope can be divided into two zones – an active wedge that breaks away from the top of the slope and a smaller zone at its heel (passive wedge) that resists the sliding of the active wedge. Adhesion between the cover layer and the base and/or the friction angle between the cover layer and the base are the main factors that ensure the stability of the slope, in cases where it is not reinforced with a geogrid or other geosynthetic material. In the formulation thus proposed, it is assumed that the passive wedge resists sliding through the cohesion in the overlying layer and the friction of the passive wedge when sliding along the surface of the material laid in the heel of the slope.

Impacts in the active wedge can be expressed as follows:

$$W_a = \gamma . h^2 \left(\frac{L}{h} - \frac{1}{tan\beta} - \frac{tan\beta}{2} \right)$$

$$W = W_a + S + Q$$

$$N_a = W.cos\beta$$

$$C_a = c_a . \left(L - \frac{h}{tan\beta} \right)$$

Equalizing impacts in a vertical direction:

$$E_a.sin\beta = W - N_a.cos\beta - \left(\frac{N_a.tan\delta + C_a}{FS} + T \right).sin\beta$$

$$E_a = \frac{FS.(W - N_a.cos\beta - T.sin\beta) - (N_a.\tan\delta + C_a).sin\beta}{sin\beta.FS}$$

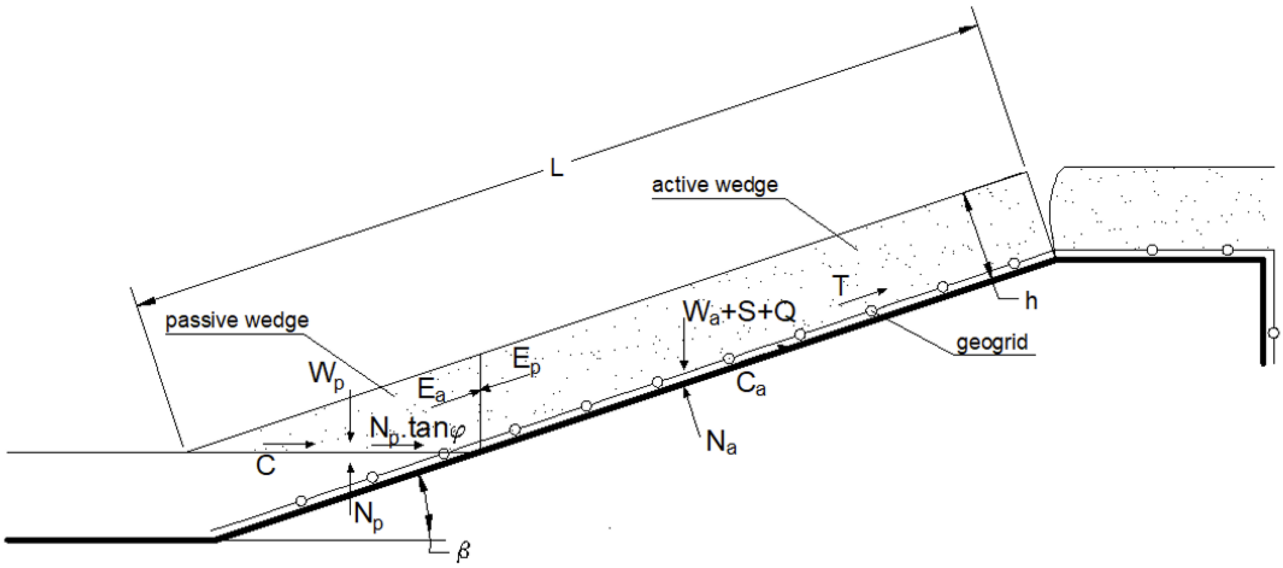

Fig. 3 Forces occurring in geogrid-reinforced slopes

Analogous (or similar) calculations can be performed for the passive wedge:

$$W_p = \frac{\gamma . h^2}{\sin 2\beta}$$

$$N_p = W_p + E_p . sin\beta$$

$$C = \frac{c.h}{sin\beta}$$

Equalizing impacts in a horizontal direction:

$$E_p . cos\beta = \frac{C + N_p . tan\varphi}{FS}$$

$$E_p = \frac{C + W_p . tan\varphi}{FS . cos\beta - sin\beta . tan\phi}$$

Because E_a and E_p are equivalent:

$$E_a = E_p$$

$$a.(FS)^2 + b.(FS) + c = 0$$

$$a = (W_a - N_a . cos\beta - T . sin\beta). cos\beta$$

$$b = -\left((W_a - N_a . cos\beta - T . sin\beta). sin\beta . tan\varphi + (N_a . tan\delta + C_a). sin\beta . cos\beta + sin\beta .(C + W_p . tan\varphi)\right)$$

$$c = (N_a . tan\delta + C_a). sin^2 \beta . tan\varphi$$

In cases where the reinforced slope is located in (or is in) a seismic zone, the seismic forces in the active and passive wedge should be taken into account. This can be done by using the coefficient of horizontal seismic action for the particular seismic (or seismic) zone ah.

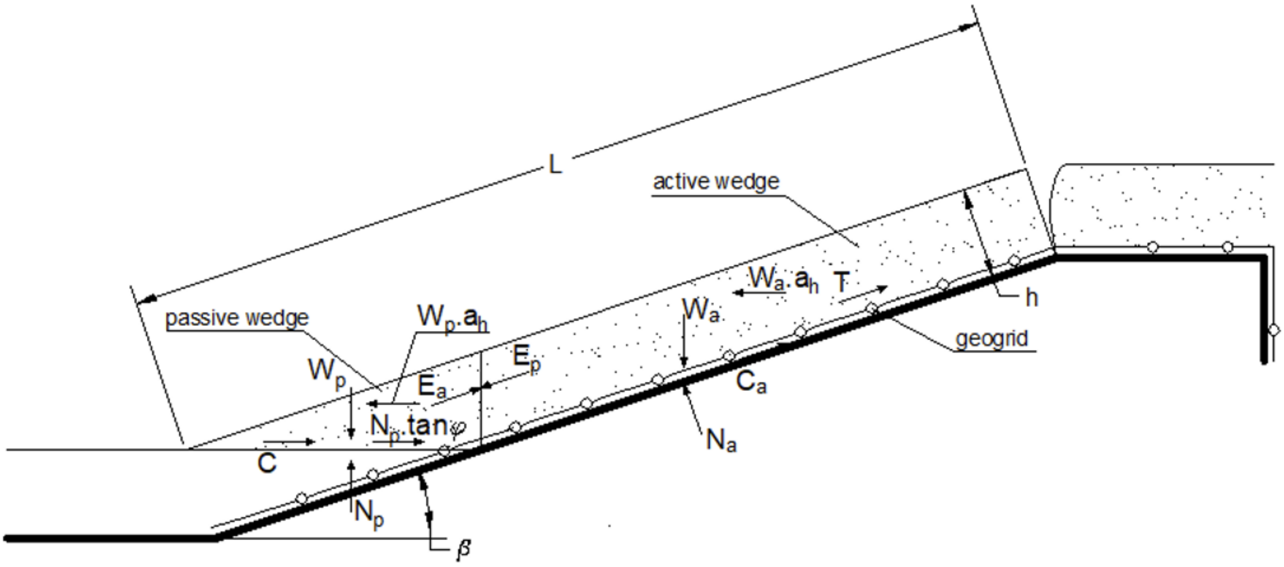

Fig. 4 Impacts occurring in geogrid-reinforced slopes in the presence of seismic impacts

In this case, temporary loads should not be taken into account (or considered) and a, b, and c acquire the following type:

$$a = (a_h.W_a + N_a.sin\beta - T.cos\beta).cos\beta + a_h.Wp.cos\beta$$

$$b = -\left((a_h.W_a + N_a.sin\beta - T.\cos\beta).sin\beta.tan\varphi + (N_a.tan\delta + C_a).cos^2\beta + (C + W_p.tan\varphi).cos\beta\right)$$

$$c = (N_a.tan\delta + C_a).cos\beta.sin\beta.tan\varphi$$

The factor of safety for the corresponding slope can be determined as follows:

$$FS = \frac{-b + \sqrt{b^2 - 4ca.c}}{2.a}$$

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, where

W_a – total weight of the active wedge

W_p – total weight of the passive wedge

N_a – normal force for the active wedge perpendicular to the failure plane

N_p – normal force for the passive wedge perpendicular to the failure plane

S – impact due to snow cover for the slope

Q – impact due to temporary loads on the slope from mechanisation, manpower and equipment

γ – compacted density of the covering layer

h – thickness of the covering layer

L – slope length

b – slope angle

φ – angle of internal friction of the covering layer

δ – angle of friction between the covering layer and the base

ca – adhesion between the covering layer and the base

C_a – force due to the adhesion between the active wedge and the base

c – cohesion of the covering layer

C – force due to cohesion of the covering layer in the passive wedge's destruction zone

E_p – internal force acting on the active wedge

E_p – internal force acting on the passive wedge

T – long-term tensile strength of the geogrids, taking into account (or considering) reduction factors

a_h – coefficient of horizontal seismic impact

FS – safety factor for sliding of the cover layer relative to the base [2], [3].

In case the safety factor is greater than 1.0, it can be considered that the slope will remain stable. Appropriate safety reserves should be taken into account (or considered) according to the local standards, project specifics and loading combination used. FS less than 1.0 requires the use of a reinforcing geosynthetic material if not used in the calculations up to this point or the use of one with a higher long term tensile strength.

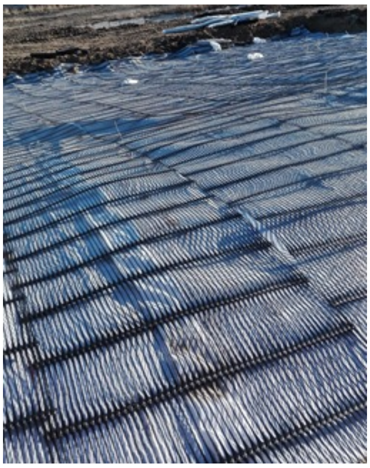

Fig. 5 Landfill remediationslope to be backfilled, reinforced with mono-oriented HDPE geogrid laid over drainage geocomposite

3.2. Determining the type of anchorage

Determining the appropriate type of anchorage for the geogrid is very often critical to achieving stability of the slope. There are mainly two types of geogrid anchoring – with or without an anchoring trench.

3.2.1. Anchoring without an anchoring trench

Very often there is no need to dig the anchor trench for the geosynthetic material, resulting in lower costs. However, the relevant calculations should be carried out in order to (or to) prove this. In this case, the safety factor is accounted for with the geogrid because the calculations use its tensile strength at break without considering the reduction factors for the material. The same approach is adopted in the case where the geogrid is anchored in an anchoring trench. This approach should be used carefully as reduction factors for some geogrids available on the market are significant thus leading to an excessive safety factor.

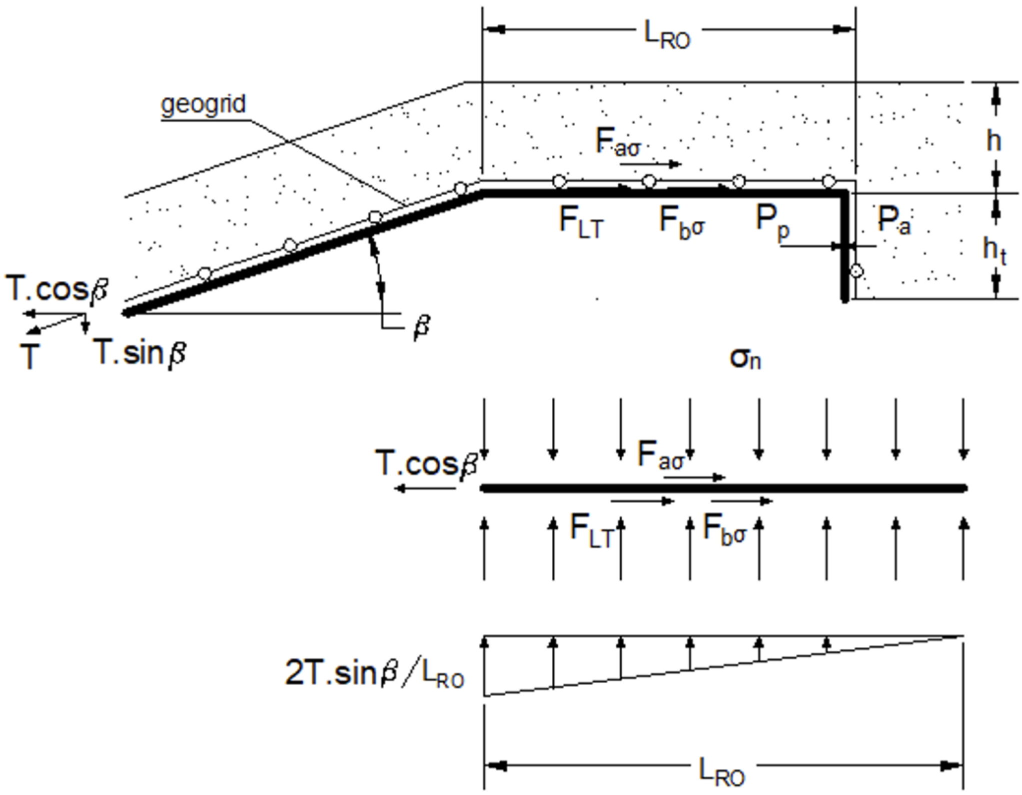

Fig. 6 Forces and stresses occurring when anchoring a geogrid without anchoring trench

The covering layer of the berm at the top of the slope exerts (or applies) pressure on the geogrid:

$$\sigma_n = \gamma.h$$

After equating the effects acting in a horizontal direction, we get:

$$T'.\cos\beta = F_{a\sigma} + F_{b\sigma} + F_{LT}$$
$$F_{a\sigma} = \alpha.\sigma_n.L_{RO}.C_{fa}.C$$
$$F_{b\sigma} = \alpha.\sigma_n.L_{RO}.C_{fb}.C$$
$$F_{LT} = 0{,}5.\alpha.\left(\frac{2.T'sin\beta}{L_{RO}}\right).L_{RO}.C_{fb}.C = \alpha.T'sin\beta.C_{fb}.C$$

Therefore, the required minimum geogrid anchor length is:

$$L_{RO} = \frac{T'(\cos\beta - \alpha.\sin\beta.C_{fb}.C)}{\alpha.\sigma_n.C.(C_{fa} + C_{fb})}$$

σn – normal stress on the geogrid from the covering layer

$F_a\sigma$ – force on the geogrid as a result of the interaction between the geogrid and the covering layer

Fbσ – force under the geogrid due to the interaction between the geogrid and the foundation on which it is laid

F_{LT} – force under the geogrid due to the action of the vertical component of T'

L_{RO} – required anchorage length

C_{fa} – pullout resistance factor above the geogrid. It is assumed to be equal to 0 because the covering layer does not contribute against the pullout of the geogrid, due to the fact that it moves with it, which undoubtedly leads to deformations and cracks in the soil

C_{fb} – coefficient of resistance to pullout under the geogrid. It is assumed to be equal to 2/3.tanφ in cases where the geogrid is in contact with the earth foundation, where φ is the angle of internal friction of the soil.

C – effective width of action for a geogrid equal to 1.0, as the calculations are carried out for one linear meter of slop width

α – correction factor equal to 0.8 for geogrids

T' – short-term tensile strength of a geogrid without taking into account reduction factors [1], [3], [5].

3.2.2. Anchoring with an anchoring trench

In cases where the required anchoring length of the geogrid is too large or there is not enough space for it, it is recommended to use an anchoring trench. Then, horizontal forces act on the part of the geosynthetic material located in the anchoring trench and the active pressure of the earth, which helps to tear the geogrid out of the trench, and passive pressure of the earth, which holds the geosynthetic material.

Equating the impacts acting in a horizontal direction and according to figure 7, an equation results with two unknowns: the anchoring length LRO and the depth of the anchoring trench h_t:

$$T'.\cos\beta = F_{a\sigma} + F_{b\sigma} + F_{LT} - P_a + P_p$$
$$P_a = 0{,}5.(\gamma_t.h_t).K_a.h_t + \sigma_n.K_a.h_t = (0{,}5.\gamma_t.h_t + \sigma_n)K_a.h_t$$
$$P_p = 0{,}5.(\gamma_t.h_t).K_p.h_t + \sigma_n.K_p.h_t = (0{,}5.\gamma_t.h_t + \sigma_n)K_p.h_t$$
$$K_a = tan^2(45 - \frac{\varphi_t}{2})$$
$$K_p = tan^2(45 + \frac{\varphi_t}{2})$$

Therefore, the required minimum geogrid anchorage length for a given depth of anchoring trench is:

$$L_{RO} = \frac{T'(\cos\beta - \alpha.\sin\beta.C_{fb}.C) + (0{,}5.\gamma_t.h_t + \sigma_n).(K_a - K_p).h_t}{\alpha.\sigma_n.C.(C_{fa} + C_{fb})}$$

In case the anchoring length is chosen, and it is necessary to establish the minimum depth of anchoring of a trench, use a quadratic equation to solve for h_t based on equation 32, where:

P_a – impact of active earth pressure in the anchoring trench

P_p – impact of passive earth pressure in the anchoring trench

K_a – coefficient of active earth pressure in the anchoring trench

K_p – coefficient of passive earth pressure in the anchoring trench

h_t – depth of the anchoring trench

γ_t – volumetric weight of the material in the anchoring trench

φ_t – angle of internal friction of the material in the anchoring trench [1], [3], [5].

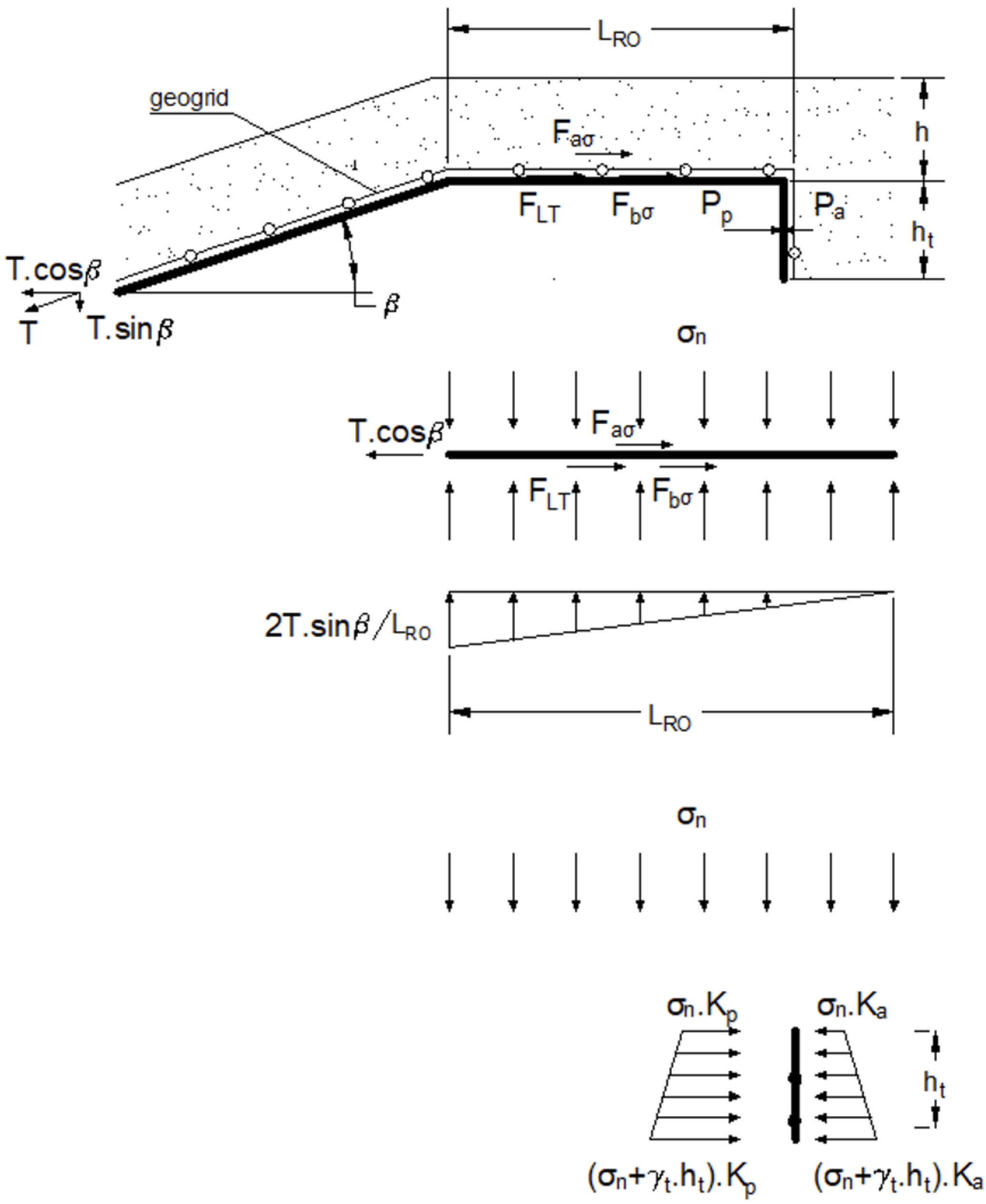

Fig. 7 Forces and stresses occurring when anchoring a geogrid with anchoring trench

4. Other possible solutions for reinforcing steep slopes with geosynthetic materials

Another possible approach to reinforcing steep slopes is the use of a geocell system or reinforcing geocomposites consisting of erosion control material and geogrid or non-woven needle-punched geotextiles with factory built-in pockets to hold the cover layer. Geocells are a geosynthetic material produced from polymer strips welded together, which, when stretched, form openings that can be filled with the covering layer. This method allows the slope of the slope to significantly exceed the angle of internal friction of the covering layer. It should be noted that this method has two serious limitations. The first is related to the fact that most often geocells are produced with a thickness of up to 30 cm, which in turn limits the thickness of the covering layer. The other disadvantage is related to the fact that the geocell system should be anchored with steel J -shaped anchors through a certain distance in the slope itself, which is not allowed in the presence of a waterproofing screen. However, in these cases it is possible to anchor the geocells at the top of the slope through ropes and special devices that transmit stresses from the geocell to the ropes.

Reinforcing geocomposite materials are designed in such a way that a significantly better coefficient of friction with the covering layer is achieved compared to that of geogrids. In this case, the probability of slippage of the covering layer relative to the reinforcing geocomposite is insignificant. At the same time, the strength parameters of the reinforcing geocomposites are not inferior to the geogrids available on the market. When designing tensile strength and anchoring length of geocomposites to reinforce steep slopes, the methodology outlined for geogrids can be used.

5. Conclusion

Reinforcing sloping terrain with geogrids is a common and effective approach. Installation of geogrids is a fast and economical construction process that is practically independent of weather conditions. In addition, the methods of anchoring the material do not require the use of additional anchoring devices and fixtures in the slope area, which are very often inapplicable, especially in cases where there is a geomembrane layer under the geogrid. The proposed methodology makes it possible to design the necessary long-term tensile strength of the geogrids and determine the type and parameters of anchoring the material in the top of the slope.

However, the method has limitations related to the possibility of constructing slopes to angles not exceeding certain values which mainly depend on the internal friction angle of the covering material and the other input parameters with an appropriate safety factor, i.e., the solution is limited to a certain angle of the slope. It should not be overlooked that a geogrid and cover layer should be selected that have a good coefficient of friction relative to each other. The latter is of extreme importance and a basic prerequisite for the described set-up for designing the geogrids and anchoring them.

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