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Geogrid reinforced road subgrade stabilization design methodology.

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Abstract

Nowadays an increasing number of unpaved roads and traffic areas are build using geotextiles. These unpaved structures are composed of a base layer placed on a subgrade soil and reinforced with one or several layers of georids. For a subsoil with insufficient bearing capacity, stabilization and improvement of subsoil charasteristics is necessary. The bearing capacity can be increased by excavation and replacement of the soft material, chemical stabilization by using chalk or by using geosynthetics. Placed between the subgrade and base course, or within the base course, the geosynthetic improves the performance of unpaved roads carrying channelized traffic and unpaved areas subjected to random traffic. This paper presents a design methodology for stabilizing a road subgrade using geogrid reinforcement.

Rezumat

În zilele noastre, un număr mare de drumuri sunt construite folosind geogrilele. Aceste structuri sunt alcătuite dintr-un strat de bază aşternut peste un teren natural de fundare şi ranforsate cu unul sau mai multe straturi de geogrile. În cazul unei fundatii care nu prezintă o capacitate portantă suficientă este necesară stabilizarea şi îmbunătăţirea caracteristicilor acestuia. Capacitatea portantă poate fi mărită prin excavări şi înlocuirea materialului moale, stabilizarea chimică care se face folosind calcar sau materiale geosintetice. Aşezând materialul geosintetic între stratul de fundare şi stratul de bază sau în interiorul acestuia, se îmbunătăţeşte starea drumurilor nepavate care suportă un trafic dirijat şi a zonelor nepavate. Această lucrare prezintă o variantă de proiectare pentru stabilizarea unei fundatii de drum prin folosirea ranforsării cu geogrile.

Keywords: Geosynthetics, unpaved and paved roads, geogrid-reinforcement, road design, road subgrade, bearing capacity.

1. Functions of geosynthetics in unpaved roads

Geosynthetics have been used for subgrade stabilization and base course reinforcement for construction of unpaved structures roads and areas since the 1970s. Geosynthetics in roadstructures can have a reinforcement, separation and filtration function. Because of the reinforcement function significant higher shear stresses can be observed at the interface subbase - geosynthetic - subsoil (Figure 1). The separation function prevents contamination of the gravel with the small particles of the soft subsoil.

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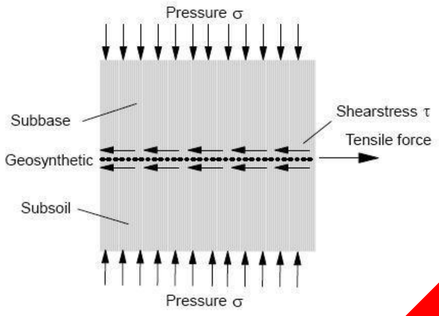

Figure 1: Reinforcement function of geosynthetics

Tensile force is only created when displacement occurs below the geosynthetic. A membrane effect will then be developed when enough interaction between soil and grid is developed (Figure 2). This mechanism creates an extra stiffness in the road structure and prevents further settlement. When a geosynthetic develops high tensile strength at very low elongation (i.e. a high modulus), less settlements will occur at the (unpaved) surface of the road structure.

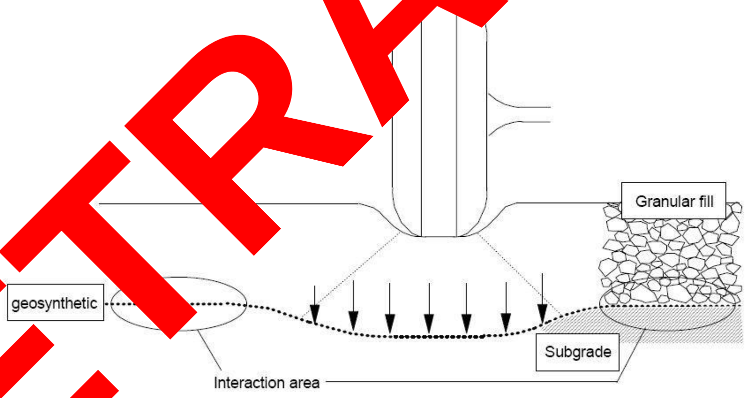

Figure 2: Membrane-effect after Giroud and Noiray

The increase of bearing capacity is mainly attributed to the reinforcement function. As the separation effect substantially contributes to the long term stabilization, it is useful to combine both functions in one product. An other important issue is that the stresses should be taken up by the geosynthetic also for a longer period without significant strain. During the construction of the unpaved road the geosynthetic will be pretensioned according to the Membrane-effect theory. With this pretensioning effect the foundation of the road possesses a higher stiffness which has a positive effect on the lifetime of the road. Geosynthetics for permanent unpaved and paved roads should possess good long term performance to act as a reinforcement and/or as a separator during the total road life.

2. Functions and behavior of unpaved roads

Function of base course in unpaved roads

An aggregate base course is required where the strength of a soil is insufficient to directly support vehicle wheel or track load. The soil overlain by a base course is referred to as the subgrade soil or, simply, the subgrade. The base course material must have sufficient strength to support the load without shearing internally. It must also have sufficient thickness to distribute the vertical load over a larger area of the subgrade such that the vertical pressure is reduced to less than the bearing capacity of the subgrade soil.

Performance of unreinforced unpaved structure

A base course may need to carry only a few load applications where it functions as a working platform on a construction site, or many load applications where it functions as a temporary or permanent road. Significant surface rutting, e.g., 50–100 mm, is often acceptable for temporary unpaved roads that can be readily maintained by adding material and regrading. However, deep rutting in the subgrade can cause contamination of the base course material with subgrade soil, which may require complete replacement of the base course.

Surface rutting is a result of one or more of the following mechanisms:

-Compaction of the base course aggregate and/or subgrade soil under repeated traffic loading.

-Bearing capacity failure in the base course or subgrade due to normal and shear stresses induced by initial traffic.

-Bearing capacity failure in the base course or subgrade under repeated traffic loads resulting from a progressive deterioration of the base course material, a reduction in effective base course thickness from base course contamination by the sub-grade soil, a reduction of the ability of the base course to distribute traffic loads to the sub-grade, or a decrease in sub-grade strength due to pore pressure buildup or disturbance.

-Lateral displacement of base course and subgrade material due to the accumulation of incremental plastic strains induced by each load cycle.

Behavior of geogrid-reinforced unpaved roads

Geogrid reinforcement is used to prevent or reduce rutting caused by bearing capacity failure of the base or subgrade and by the lateral movement of base course or subgrade material.

Influence of geogrid on base course behavior

Aggregate base course material interacts with a geogrid principally by interlocking within the apertures. The ribs of the geogrid confine the aggregate and resist lateral movement of the aggregate when the base course is loaded at the surface. Perkins (1999) attributes four benefits to base course material confinement for asphalt paved roads. These four benefits also exist for unpaved roads. They can be summarized as follows:

-Prevention of lateral movement of the base course material, which results in reducing surface rutting.

-Increase of stiffness of the base course material, which reduces vertical strains within the base course.

-Improvement of flexural stiffness of the base course, which distributes the traffic loads and reduces the maximum vertical stress on the subgrade.

-Reduction of shear stress transmitted from the base course to the subgrade, which increases the bearing capacity of the sub-grade.

For unpaved roads, there are additional potential benefits to the base course provided by reinforcement:

-Prevention of shear failure within the base course.

-Tensioned membrane direct support of traffic load after significant rutting where traffic is channelized.

-Prevention of tension cracking at the bottom of the base course, which minimizes contamination of the base course material with subgrade soil as the layer flexes under load.

-Prevention of loss of base course aggregate into soft subgrade soil.

Influence of geogrids on subgrade soil behavior

Geogrids can improve the performance of the subgrade soil through four mechanisms: prevention of local shearing of the sub-grade, improvement of load distribution through the base course, reduction or reorientation of shear stresses on the subgrade, and tensioned membrane effect. These four mechanisms are discussed below.

-Prevention of local subgrade shear. In unreinforced roads, if the vertical stress on the subgrade exceeds the elastic limit of the soil, some limited or ''local'' permanent shear occurs. The base course material punches into the subgrade and permanent deformation results. Under repeated loading, the shear zones grow, the base course deteriorates, critical stress levels increase, and surface ruts develop. Eventually, the plastic limit, or ultimate bearing capacity, of the subgrade soil is reached and a complete shear failure results. Adequate reinforcement between the base course and subgrade prevents development and growth of local shear zones and allows the subgrade to support stresses close to the plastic limit while acting as if it is still within its elastic limit (Giroud and Noiray 1981).

-Improvement of load distribution. As discussed previously, geogrid reinforcement increases the ability of the base course to distribute wheel loads and reduce the maximum normal stress on the subgrade. Thus the factor of safety against bearing capacity failure is increased.

-Reduction or reorientation of shear stress at subgrade interface. According to Milligan et al. (1989a) and Perkins (1999), one of the beneficial effects of geosynthetic reinforcement at the interface between base course and subgrade soil is to carry the shear stresses induced by vehicular loads at the interface. It is important to understand that the shear stresses transmitted from the base course to the subgrade can be directed outward or inward. According to a classical result of the theory of plasticity, outward shear stresses decrease the bearing capacity of the subgrade whereas inward shear stresses increase the bearing capacity of the subgrade. The shear stresses induced by vehicular loads tend to be directed outward, which decreases the bearing capacity of the subgrade. The interlocking between the geogrid and the base course aggregate results in two beneficial effects: (i) lateral movement of the base course aggregate is reduced or eliminated and, as a result, no outward shear stresses are transmitted to the subgrade; and (ii) the bottom surface of the base course, with confined aggregate striking through geogrid apertures, provides a rough surface that restrains lateral movement by the subgrade, which generates inward shear stresses that increase the subgrade bearing capacity.

-Tensioned membrane effect. Rutting at the subgrade surface is accompanied by adjacent heaving if the subgrade soil starts to shear. A geosynthetic layer at the interface takes a wavelike shape that stretches and tensions it. When a stretched flexible material has a curved shape, normal stress against its concave face is higher than normal stress against its convex face. This is known as the ''tensioned membrane effect'' (Giroud and Noiray 1981). Under the wheel, in the trough of the wave, the tensioned membrane carries some of the wheel load and reduces normal stress on the subgrade. Outside the loaded area, over the adjacent crests of the wave, the tensioned membrane presses down on the subgrade and increases the normal stress (''confining pressure'') where it serves to resist shear failure. A tensioned membrane thereby both decreases the applied stress and increases the bearing capacity. The tensioned membrane effect is significant only if traffic loads are channelized and rut depths are relatively large (Giroud et al. 1985); this is a major difference between unpaved roads and unpaved trafficked areas.

3.Design methodology for unpaved roads

Based on the results of the trials and the membrane theory of Giroud and Noiray design graphs are developed for multifunctional-geogrids in unpaved and temporary roads which are also presented by Jaecklin and Floss. Boundary conditions are the allowable rut depth, the axle load, the number of axle passes, the conditions of the subsoil and the quality of the aggregate. From the graphs the designer can read the thickness of the base without geosynthetic (Du), the reduced thickness when using a geosynthetic(Dr) and a reduction(ΔD). Figure 3 shows the design graph based on a rut depth of 75 mm and a geogrid with an ultimate tensile strength of 20kN/m.

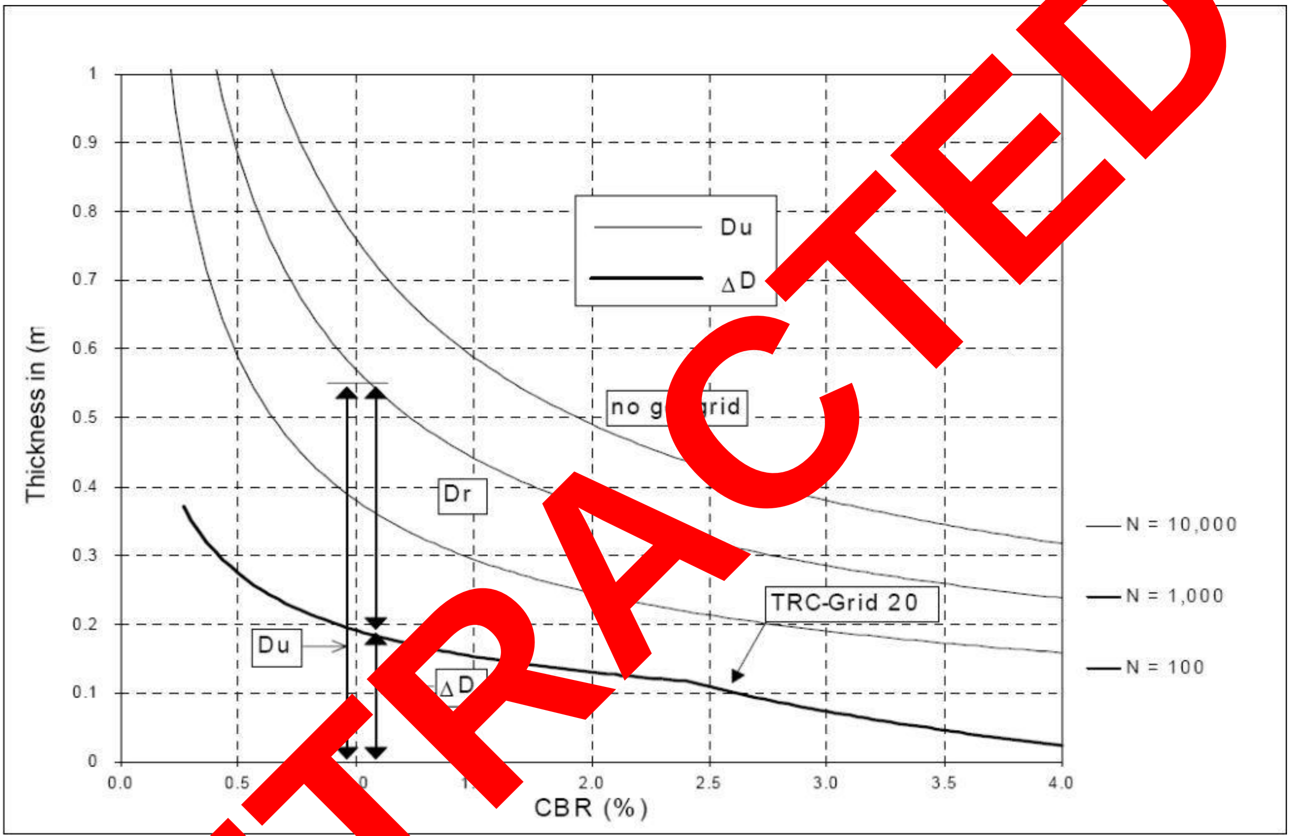

Figure 3:Designing the base thickness for unpaved roads based on the allowable rut depth(75 mm), axle load(80kN) and axle passes according to the membrane theory.

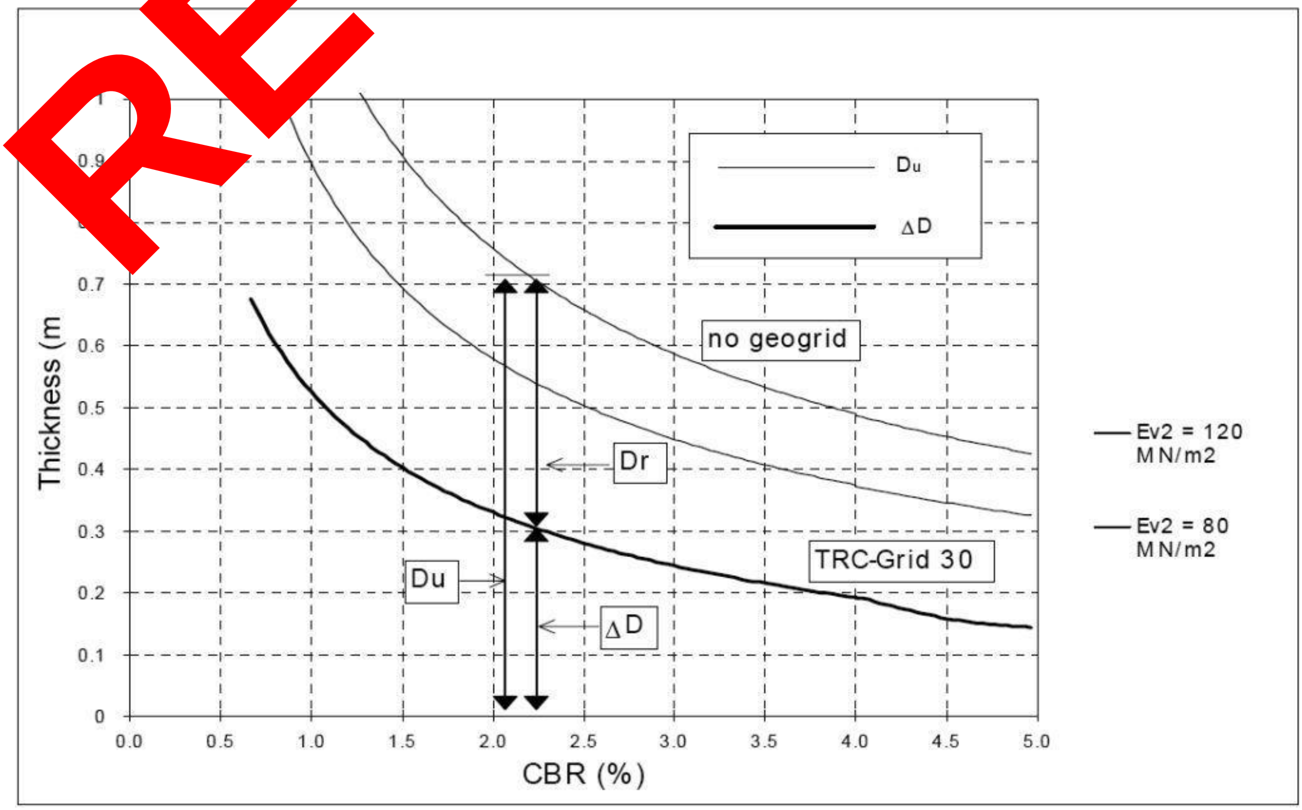

Figure 4:Designing the base thickness for unpaved roads on the bearing capacity on the top of the base (in this case crushed gravel 0/56mm)

The rut depth is just one indication for the load and deformation taken up by the reinforcing element (geosynthetic). On trafficked areas other then temporary roads the bearing capacity is normally measured by plate bearing test where a plotted graph shows the relation between the applied pressure and the deformation; the deformations are often very small (< 5mm).

A design graph (Figure 4) presents design curves for the thickness of the base course (crushed aggregate 0/56 mm) to achieve a required Ev2 value on top of the layer (often a frost protection layer). The bearing capacity of the subsoil is given as a CBR value(California Bearing Ratio) as the plate bearing test on soft soil is very hard to perform. The investigation for the thickness of that layer was based on these very small deformation. The design curves are based on normal loads due to construction traffic and compaction which induce tension forces in the geogrid.

The results of the plate bearing tests reflects only short term behavior of the geosynthetic interlayer. When an unpaved road is build for a longer period the long term behavior of the geosynthetic (during the life time of the road) should be taken into account. The tensile strength will be reduced due to creep, mechanical damage and other mechanisms.

Paved roads

For using geosynthetics in paved road structures (surface layer existing of asphalt or concrete) the long term behavior has to be taken into account. The measures bearing capacity on top of the base should be maintained during the total design life of the road. To consider the long term behavior of a geosynthetic the reduction factors should be taken into account. For example, the strength of the high modulus geogrid is based on the aramid yarns, which have a reduction factor A1 of 1.58 for a 100 years design life. The special configuration of the multifunctional geogrid provides a permanent separation to prevent contamination of the subbase and preventing losses of the bearing capacity on the long term.

For paved roads the calculated thickness of the unpaved situation is checked for spreading the load in such a way that the vertical pressure on the subsoil is not exceeding the bearing capacity of the subsoil.

The design for a paved road starts with the unpaved situation during construction and only then goes on to consider the paved situation. It therefore integrates the results of calculation for the unpaved road with those for the paved structure (with asphalt or concrete). Calculation for the unpaved situation gives the thickness of granular fill when using a reinforcement. Before placing the asphalt layer the granular fill should be compacted to project specifications. This compaction is usually given as a Proctor Density (%).

To design the surface layer general accepted design charts or standard programs are available. While the usual pavement designs have some layers of different asphalt types, the total surface layer thickness is used in this design method. Note that the surface layer has no influence on bearing capacity and only functions to spread the load. Figure 5 illustrates the mechanism.

The top-layer of the total pavement structure is considered to be elastic and isotropic and only spreads the wheel load. It has no influence on the road's total bearing capacity. Instead of using asphalt, it is also possible to calculate with a concrete pavement. In this case the load spreading angle of the top layer and the density should increase.

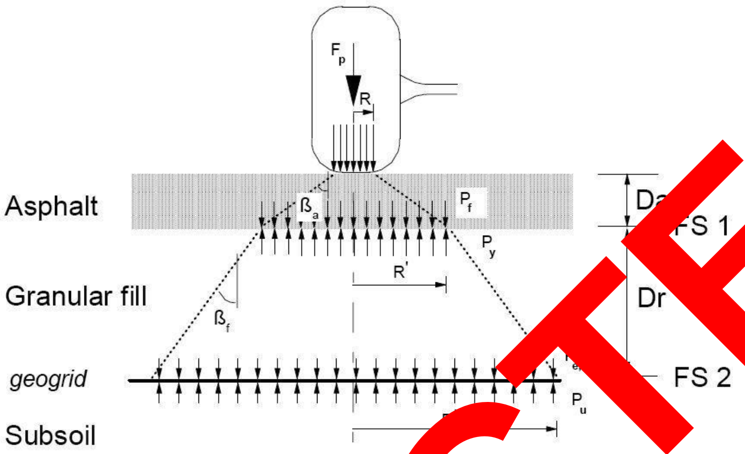

Figure 5: Forces and pressures in the paved situation

To check whether the complete structure is stable for [illegible] life, the maximum bearing capacity of the granular fill and the subsoil should be calculated and these should be compared to the actual stresses. The factors of safety (FS) for a stable structure are:

$$\frac{Py}{Pf} > 1.1 \qquad \text{(FS 1)}$$

$$\frac{Pu}{Pe,s} > 2 \qquad \text{(FS 2)}$$

in which:
Pf = pressure on the fill
Py = bearing capacity of the fill
Pe,s = equivalent pressure on the subsoil
Pu = bearing capacity of the subsoil

FS 1
-The design method assumes a completely elastic surface layer that has no effect on the rigidity of the total structure. In practice, of course, the surfacing does impart additional rigidity
-Compaction of the granular fill is likely to raise the bearing capacity of the fill to a certain maximum, and limited or no differential settlement in the fill will therefore take place.

FS 2
During the life of the structure, differential settlements may occur in the subsoil due to its low CBR value and to dynamic wheel loads. The geogrid raises the bearing capacity of the subsoil and reduces the chances of differential settlement, the most critical failure mechanism. Hence the higher safety factor.

Design methodology

STEP 1
Calculate the thickness of granular fill for the unpaved situation (Dr). The selection of the geogrid type depends mainly on the CBR-value of the subsoil but can also be done in relation with the expected traffic.

STEP 2

The contact area between the tire and the road surface is considered to be circular (wit... dius R). R is being calculated as R = √{Fp / (π Pt)} with Fd the wheel load and Pt wheel pres...re.
R' and R'' determined:

$$R' = R + Da \times \tan \beta a \quad (1)$$

$$R'' = R' + Dr \times \tan \beta f \quad (2)$$

in which:
R = radius of area of contact between tire and road surface
R' = radius of distributed load between tire asphalt and granular fill (...ure 5)
R'' = radius of distributed load between granular fill, T... Grid and su...ade (Figure 5)
Da = thickness of surface layer (e.g. asphalt)
Dr = thickness of granular fill using a geogrid
βa = load spreading angle of the surface layer
βf = load spreading angle of the granular fi... after comp...)

When using two or more layers of different ...an... ...types in the road foundation, keep in mind that the different load angles and d...ies ma... ...ve an influence on the outcome.

STEP 3

Determine the pressure on ...e ... ...ill (...) from:

$$Pf = \frac{Fp}{\pi(R')2} + \gamma a \times ... \quad (3)$$

In which:
Fp = maxi...n w...el load for the paved situation
γa = density ... e surf...e layer

S...EP 4

C...ul... th... ...ximum bearing capacity of the granular fill (Py) using the following formula *Ho... ...y and Jewell* :

$$Py = 0.6 R' \times \gamma f \times N\gamma \quad (4)$$

This expression uses a shape factor of 0.6 for an axial symmetry together with the theory of Vesic. The bearing capacity factor Nγ for a rough based footing can be expressed approximately as Nγ =2(Nq+1)tanφ', and finally the bearing capacity factor Nq us given by the exact expression $Nq = \{(1+ \sin\varphi')/(1- \sin\varphi')\}e^{\pi\tan\varphi'}$.
φ' is the internal angle of friction.

CHECK 1

The stability of the fill can be checked by calculation the ratio:

$$\frac{Py}{Pf} > 1.1$$

If it exceeds 1.1, the bearing capacity of the fill is sufficient. If the ratio is less than 1.1:

-increase the thickness of the surface layer, or
-use a different type of surface layer to increase the load spreading angle, or
-increase the compaction of granular fill to obtain a higher angle of friction, or
-use a different granular fill with a higher angle of friction.

STEP 5

Estimate the number of loaded wheel passes for the life of the paved road (Np). This is equal to the number of loaded axles passes during the road life. Two load carrying axles per truck is assumed.

STEP 6

Calculate the equivalent wheel load Fe. The dynamic loadings during the road life may have an influence on the differential settlements in the subsoil. To take these repetitive loading patterns into account for the bearing capacity check of the subsoil, calculate an equivalent wheel load (Fe). This Fe will replace the single wheel load Fp. Using the number of passes for the life of the paved structure (Np) (STEP 5), the Fe is derived from the equation (De Groot et al.,):

$$Fe = Fp\ (\sqrt[6.2]{Np}) \qquad (5)$$

STEP 7

Calculate the equivalent pressure on the subsoil (Pe,s) using the formula:

$$Pe,s = \frac{Fe}{\pi (R'')^2} + \gamma a \times Da + \gamma f \times D[illegible] \qquad (6)$$

This equivalent pressure is the result of the equivalent wheel load (STEP 6) and the weight of the surface layer and the granular fill.

STEP 8

Calculate the maximum bearing capacity of the subsoil (Pu) using the formula:

$$Pu = Nc \times CBR \times 3[illegible] \left[\frac{R''}{R}\right]^2 \qquad (7)$$

Nc is the bearing capacity factor of the subsoil. For axial symmetry the Nc value for a reinforced structure is 5.69. For an unreinforced structure this value is value is 3.14.

CHECK 2

Check the subsoil stability by calculation the ratio:

$$\frac{Pu}{Pe,s} > 2.0$$

If this ratio is higher than 2.0, the mechanical stability of the subgrade is guaranteed. If the safety factor is less than 2.0:

-increase the thickness of the granular fill, or
-increase the compaction of the granular fill to achieve a higher load spreading angle, or
-use different granular fill with a higher load spreading angle, or
-increase the CBR value of the subsoil by artificial consolidation.

4. Conclusions

This paper presents a new design for unpaved and paved roads based on the lateral restraint theory. Extensive static and dynamic plate bearing tests on different conditions have been executed which showed an significant increase of bearing capacity when using geogrids. Several roads have already been designed and executed according to the present design method and presented good results so far, and further fieldtests will continue to verify and calibrate the new design method.

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