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Reinforced embankments over areas prone to subsidence

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ABSTRACT: Using geosynthetics instead of conventional solutions - as there might be concrete slaps or backfilling of subground excavations - economical solutions can be found for the protection of traffic areas against sudden collapse caused by mining voids or earth subsidence. Numerous publications dealing with theoretically based models up to large-scale test results can be found, but less context has been worked out by now. Two design assessments are presented and discussed. Although considerable reductions are made, the design assessment of the BS 8006 gives the opportunity to optimise the construction and to carry out a preliminary design to determine the required geosynthetic by taking care of the specific boundary conditions of the BS 8006 model.

1 EARTH SUBSIDENCE AND MINING VOIDS

The main reason for earth subsidence is the collapse of subground excavations in karstic regions. Geologic karstification can be decisive influenced by anthropogenic processes (e.g. leaching of mineral- or potassium salt for commodity extraction or mining-hydrogeological influences). In opposite to depressions caused by this subground weakness, a void leads to a sudden endangering of traffic (e.g. ≈ 500 occasions in Sachsen-Anhalt since the beginning of recording in 1960).

Taking the frequency rank of the expected diameters into consideration, a protection of traffic areas against sudden occurrence of voids is necessary in coherence to the risk of damage.

2 PROTECTION AND REDEVELOPMENT MEASURE

In the last years the reinforcement of the subgrade by means of geosynthetics with a high tensile strength as a more economic alternative to conventional solutions has been discussed, tested and has already been installed abroad in different countries, mainly in Great Britain.

However, it is not aimed to achieve a durable „bridging" of voids without any deformation, but to achieve a temporary limitation of the surface deformation up to a minimum until an observation of damages is carried out and the trafficking area can be closed.

3 DESIGN ASSESSMENTS AND VERIFICATION

Mainly three functions can be differentiated for modelling a soil layer bridging an area without any bedding:

- Spanning; the geosynthetic is assumed to work as a membrane without taking a reaction of the soil into consideration (just vertical loading/surcharge);
- Composite system with full interaction soil/geosynthetic in analogy to the theory of beams (pressure/shear/tension);
- Arching (dome) theory.

With different weighting the main elements are in every case the characteristics of the geosynthetic (stress-strain behaviour) and of the soil (shear strength, compactness, unit weight) as well as the interaction characteristic soil/geosynthetic.

Figure 1. Void in Neckendorf, Germany (2001)

As far as the first mentioned design assessment does not take the interaction soil/geosynthetic and the capability of the soil into consideration because of the usually unknown characteristics, the second assessment requires the full knowledge of the stress-strain behaviour of the composite system. The at least mentioned assessment does not take the interaction soil/geosynthetic into consideration as well because of the assumption that the indicated strains of the geosynthetic are thus not compatible to the very low deformations of the dome.

4 BS 8006

The analytical assessment of the British standard BS 8006 is subdivided into the determination of the strain of the geosynthetic and the determination of the required tensile strength, given by a closed formula each.

The assessment is based on the membrane concept, arching of the soil is not taken into consideration. Further assumptions are: rigid support, parabolic deflection, no strain outside the deflected shape and the direction of loading is still vertical after deflection occurs.

Calculating the strain of the geosynthetic first, it has to be differentiated between a circular void and a gaping fissure.

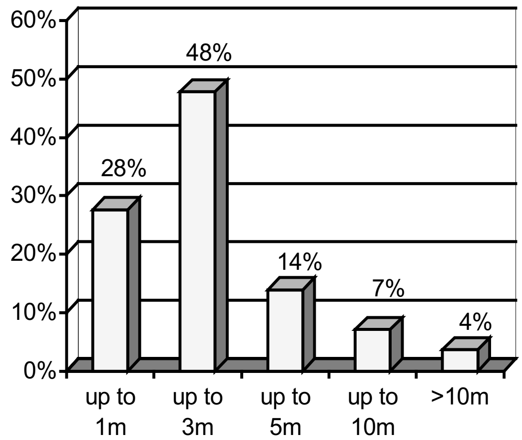

Figure 2. Frequency rank of the top diameter of ≈ 500 sink holes since 1960 (Geologisches Landesamt Sachsen-Anhalt 2001)

Assuming a constant volume of the soil, a defined deflection at the surface is expected (Figure 3). For the definition of the fracture line the internal angel of friction of the soil is used. As a result, this assessment gives a direct correlation between the deflection of the geosynthetic and the surface, using a geometrical relationship indicated by the volume of the rupture cone. The second design step calculates the tensile strength for the determined strain. As far as the strain, calculated by the geometric model as described, shows a strong increase depending on the height of coverage, it has to be checked whether the maximum tensile strain of the geosynthetic becomes decisive (Figure 4). Furthermore the unit weight of the coverage, the surcharge (traffic loading), the diameter of the void respectively the dimensions of a gap and a multiplier λ to consider a uniaxial or a biaxial spanning of the void/gap are initial values for the calculation. As an example, a circular void is overlayed by two orthogonal arranged layers of uniaxial geogrids. In this case the required tensile strength of the uniaxial geogrids can be reduced to 67 % in comparison to a layout with one main reinforcing direction.

Figure 4 shows the results of a calculation for a uniaxial and a biaxial spanning of a void at equal boundary conditions, depending on the height of the coverage and using the formulas as given by the BS 8006.

Following the geometrical assessment for the calculation of the strain, the required strength is decreasing with increasing distance from the reinforcement to the surface. Because of the maximum strain of the chosen geosynthetics, the required strength is increasing again with increasing the coverage height.

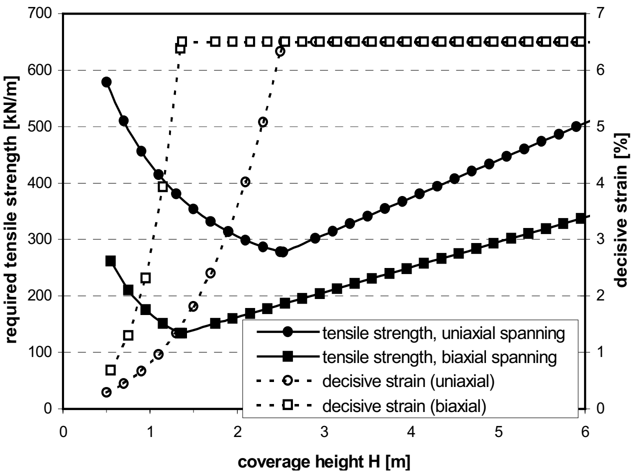

Figure 4. Decisive tensile strain and tensile strength depending on the coverage height, calculating a uniaxial and a biaxial spanning using the BS 8006 assessment (calculation with: D = 3.5 m, d_S/D_S = 1/60, q = 33.3 kN/m², φ′= 32.5°)

Comparing the shown results (Figure 4), the relationship of λ can be seen, influenced by the way of spanning (uniaxial or biaxial). A detailed criticism of the BS 8006 assessment as well as a compilation of the assumptions can be found e.g. by LAWSON et al. (1994).

5 GIROUD ET AL. (1990)

Figure 5 gives an overview of the model as used by GIROUD. In agreement to the BS 8006 the indicated stress of the geosynthetic is calculated using the membrane theory. The main assumptions of the two dimensional GIROUD model are a circular deflection, the direction of the loading is perpendicular to the deformed shape, rigid support, isotropic strength-strain behaviour of the geosynthetic and no strain in the anchoring areas.

A further difference in comparison to design assessments using the membrane theory only is indicated by taking a shear resistance on the fracture planes into consideration, leading to a reduction of the effective stress on the geosynthetic.

It is differentiated between circular and long voids, where the effective vertical load is more reduced at circular failure mechanisms (determination of the shear strength after KEZDI.

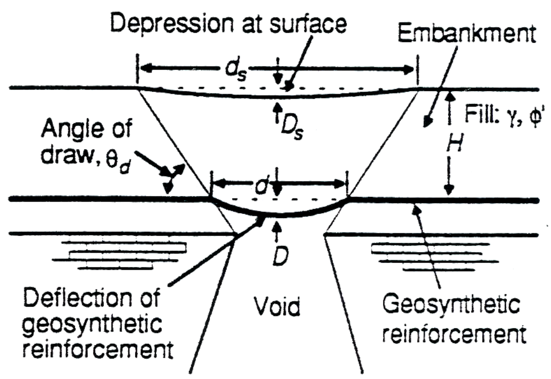

Figure 3. Model as used in BS 8006

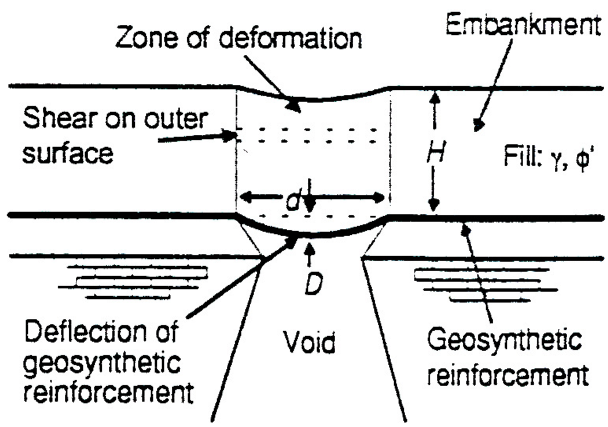

Figure 5. Model after GIROUD et al. (1990) [sketch by LAWSON et al. (1994)]

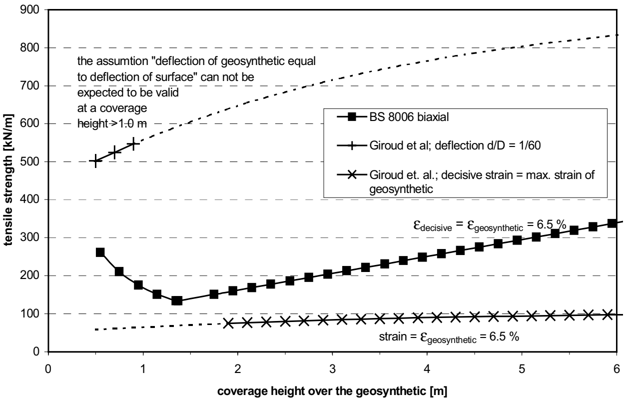

Figure 6. Comparison of required tensile strength calculated for a circular void with a diameter of D = 3.5 m using design approach of the BS 8006 and GIROUD et al. (1994)

The described assumptions show, that there is no direct correlation between the deflection on the surface of the construction and the deflection of the geosynthetic. A correlation can be given for the additional assumption, that the deformations of the geosynthetic are directly transferred to the surface. This assumption can only be valid for very low coverage heights.

In Figure 6 the calculation results as presented in Figure 4 are supplemented by a calculation following the design assessment by GIROUD et al. (1994) under comparable conditions.

The shown calculation results have been determined for two boundary conditions: First, for low coverage it has been assumed that the deflection on the surface is equal to the deflection of the geosynthetic. Second, it has been assumed that the maximum allowable tensile strain, chosen to 6.5 %, is used in total. The direct comparison of the calculations leads to the result that for very low coverage heights the model used by GIROUD requires a significant higher tensile strength as the model of the BS 8006. In opposite to this the required tensile strength following the GIROUD model is significant lower than the results given by the BS 8006 model – in this case the influence of arching of the coverage soil becomes decisive.

For a uniaxial spanning of circular voids with geosynthetics with an anisotropic stress-strain behaviour (nearly all geosynthetics with a satisfying maximum tensile strength belong to this category) a differentiation in two cases is recommended by GIROUD et al. (1994). In case of a relation < 0.5 for the cross direction to the main direction, 50 % of the maximum tensile strength of the main direction may be valid for calculation. In case of a relation > 0.5, the minor of the tensile strength (cross or main direction) may be decisive.

6 NEW CALCULATION METHODS

Beside calculation methods presented in this paper several calculations were worked out with numerical methods in the past years. As an example figure 7 shows a calculation of a reinforcing element over a void worked out with the program PLAXIS.

This program, which is based on the Finite Element Method (FEM), considers the behaviour of the soil under different load conditions as well as the interaction between the geosynthetic and the surrounding soil. Based on our experience the updated mesh material model is most suitable to simulate the above described processes.

To develop and verify this approach, different calculations are made at the moment to compare 2-dimensional with 3-dimensional calculation models. In addition to this, in-situ tests are carried out to make it possible to judge the calculation results with the measured data. This finally leads to an improved design approach.

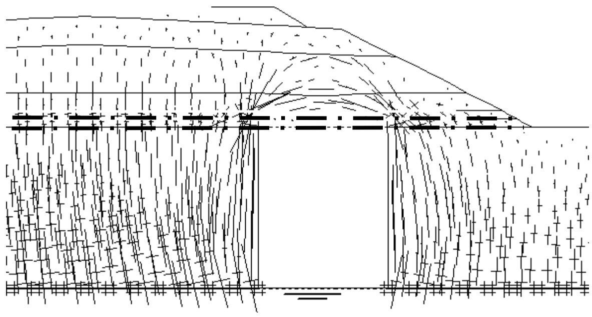

Figure 7. Calculation of a geogrid over a void with PLAXIS (Calculation by BBG, Lemfoerde)

7 CONCLUSIONS FOR DESIGN

7.1 *Geosynthetics*

The used geosynthetics can be divided into three groups:
- woven geogrids and wovens manufactured of polyester yarns
- laid geogrids manufactured of extruded polyester flat bars and
- woven geogrids manufactured of aramide yarns

Due to different product properties, manufacturing processes and raw material the prices of the products are increasing approximately in the above mentioned order. However, there is a clear distance between the aramide wovens and the two other groups. In Figure 8 the typical stress-strain behaviour of the mentioned product groups is shown. Also the pair of values ‘tensile strength’ and ‘assigned strain depending on the fill height’, which are shown as example for an uniaxial reinforcement, are also given. This representation makes clear that not the maximum tensile strength is the decisive criterion but the product property to be able to absorb very large forces already in the case of small strains.

Those geogrids which are manufactured from extruded polyester flat bars facilitate an optimum use of the product strength in construction heights of 1.5 m up to 2.5 m. In the case of very low cover heights of only approximately 1.0 m, until now only aramide wovens or multi-layer systems can apply the required tensile strengths for the corresponding strains. The maximum tensile strength during production is only used to a small extent so that small covers only in exceptional cases can lead to an economic solution.

The statement of the optimum use of the product strength of the geogrid has been supported by examination at the Gropius-Institute in Dessau, Germany. In this examination a Secugrid®-geogrid, which consists of extruded flat bars was laid over a void of 1.6 m diameter.
On top of the geogrid a construction of 0.4 m crushed stone (0/32 mm), 0.95 m sandy gravel (0/8 mm) and again 0.4 m crushed stone (0/32 mm) was put with an intensive compaction of each layer. Finally an asphalt layer of 5 cm was installed, on which a traffic load of a 60 km/h fast truck was simulated by four jacks. Within a loading time of 14 days 310,000 loadings and unloadings have been carried out. At the end of the simulation a maximum deformation on the carriageway surface of 3.9 cm and of the geogrid of 9.3 cm have been measured. The geogrid showed no damages due to overloads or cracks. The maximum strain of the geogrid at the side of the trial pit was 1.46 %. Due to stress transfer from the middle to the sides of the voids an arch has been build in the soil layer over the void.

7.2 *Installation and formation*

A sufficient anchoring length of the geosynthetics at the edge is the premise for bridging the subsidence. In the case of sufficient

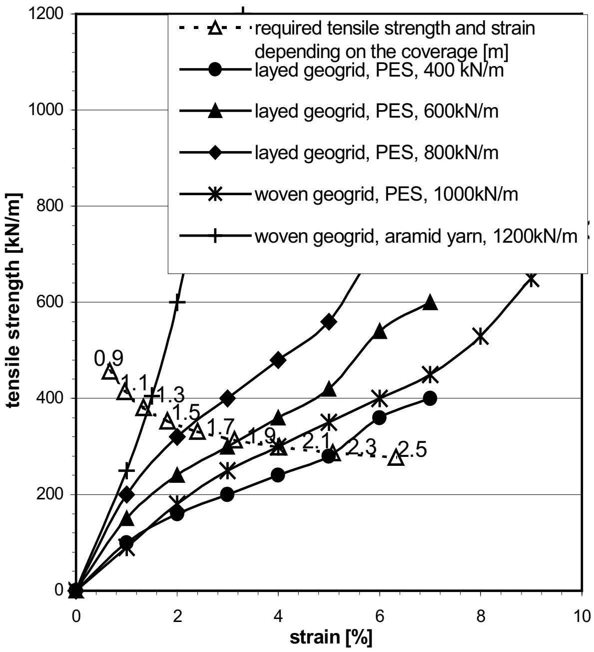

Figure 8. Strength-strain characteristics of different reinforcing products and required strength-strain values depending on the coverage height (taken from Figure 4, uniaxial)

cover and usual diameters of the subsidence it is assumed that a pull-out resistance of the geosynthetic can be calculated.

This cannot be assumed for small covers as the geosynthetics and the topsoil can fail because of sliding. If no sufficient anchoring can be guaranteed, this area has to be protected by means of a reinforcement which works vertically towards the main trajectory motion. Should wovens be used as reinforcing element it must be considered for the dimensioning of the overlaps that the friction of the interface woven/woven is much lower than the friction within the interface soil/woven. The friction values can be increased by placing for example a thin layer of sand.

If -due to the geometry of the subsidence diameters to be expected as well as due to a comparatively large thickness of the cover soil- it cannot be excluded that, in the case of a subsidence, arching within the soil avoids the detection of the subsidence, it is recommended to install a monitoring system which indicates all occurring strains of the geosynthetics and which -should the situation arise- warns of these subsidence.

8 SUMMARY

A lot of publications are well known, dealing with theoretical analyses as well as with praxis orientated design approaches. In direct comparison of two design approaches often used in practice with test results of large scale tests it can be concluded, that the design approach of the BS 8006 allows to perform a practice orientated design (may be preliminary in some cases). The optimum layout for the geosynthetic can be expected by a coverage height of 1.5 m up to 2.5 m from the economic and static point of view, because the strength-strain characteristics of the used geosynthetic can be exploited as far as possible.

The model and the design approach given by the BS 8006 can be judged as useful for standard applications. On the other hand the authors recommend further verification by laboratory modelling and large-scale test to determine the optimum relation of coverage height to the diameter of the void to prevent development of rigid domes.

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