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Determination of maximum allowable load and anchorlength of polyester geogrids

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ABSTRACT: This paper describes the method to establish the allowable design strength of a reinforcing fabric or a geogrid and the latest results of research, to optimize the various reduction factors. Results are presented of pullout tests on Fortrac geogrids. These tests lead to identification of minimum anchorlengths for specific pull-out loads. Design charts based on this research are presented.

1. Allowable design strength

The allowable design strength of a reinforcing mat is the rupture tensile strength devided by factors for temperature effects, chemical or bacteriological attack, mechanical damage during installation, etc.
For a safe design it is required that all these factors be determined correctly and used in the proper way.
Nowadays the allowable design strength of reinforcing mats or geogrids is mostly calculated with the equation:

$$P_{all} = P_c \left[\frac{1}{f_d} \cdot \frac{1}{f_{env}} \cdot \frac{1}{f_m} \cdot \frac{1}{f_c}\right] \quad \text{.... eq.1}$$

with

P_c = ultimate breaking strength with respect to time and extension
f_d = reduction factor for mechanical damage
f_{env} = reduction factor for biological and environmental environment
f_m = factor for extrapolation deviations or material factor
f_c = factor of safety

This equation is now used for several years and many publications can be found of research projects where reduction factors were established for certain phenomenea. Greenwood and Jewell6) published a good overview of the various effects. In this paper the effects on Stabilenka reinforcing fabrics and Fortrac geogrids are outlined. The reduction factors are based on research executed at the Akzo Research Laboratories or at other institutes under Akzo funding.

1.1. Ultimate tensile strength

The ultimate tensile strength is determined in a standard tensile strength test facility. The clamps should be able to transfer the load onto the fabric in such a way that all yarns are loaded equally. Elongations should be measured preferably between two points on the fabric, measurements of the movements of the clamps are not acceptable because of lack of accuracy.
Furthermore the width and length of the sample, the test speed and temperature at testing are important (ref. Myles3) and Veldhuijzen van Zanten1)).

1.2. Creep

Creep is an extension of the material increasing with time and under a constant tensile force. After a certain time the material will break under that force.
The rupture strength is defined as a characteristic strength for a certain lifetime.
The results are combined in the stress-rupture line of Figure 1, where the characteristic strengths for different design life periods can be found as a percentage of the ultimate tensile strength.

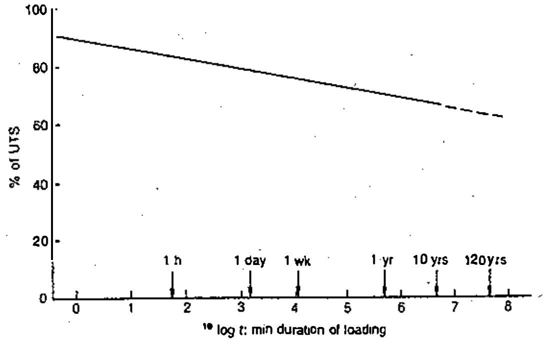


Figure 1 : Stress-rupture line of Stabilenka and Fortrac

Extrapolation covers one time period on the log scale. It is important to notice this because of the effects that extrapolation has on the factors of safety as recommended by Jewell and Greenwood [4]. The value of P_c of equation 1 for a specific design lifetime can be found by means of the graph of Figure 1.

P_c = % stress ratio . UTS eq.2

% stress ratio is the factor of the applied load divided by the ultimate tensile strength (UTS) of that material.

1.3. Mechanical damage factor

The dumping and compacting of fill on top of a reinforcing mat may result in cut yarn fibres or surface abrasion and then affect the mat's strength.
To find the effects of this mechanical damage many full-scale tests have been performed with various types of fills.

Table 1 : Mechanical damage factors

Soil Type	Well graded fill of maximum Particle Size mm	Recommended Partial Reduction Factor f_d			
		Stab. ≤ 300*	Stab. > 400*	Fortr. ≤ 55*	Fortr. > 55*
Cobbles	200	1.40	1.40	1.2	1.05
Gravels	60	1.35	1.14	1.15	1.03
Sand	2	1.17	1.10	1.10	1.02
Clays	0.06	1.10	1.10	1.05	1.02

* Ultimate tensile strength in kN/m.

1.4. Reduction factor for biological and environmental attack

The favourable effect of a coating on top of the yarns on the mechanical damage factors can be clearly seen in Table 1. Tests at Sikkens Laboratories in Holland and by Dr. L. Wichter at FMPA in Germany have shown that polyester is not affected by biological attack.
At several research institutes, polyester yarns and fabrics have been tested in the past decades for the effects of hundreds of different chemicals in various combinations[9]. While the pH value is often used to indicate the type of chemical we found that it is not always reliable though. In general, the above institutes arrived at the same conclusions. In normal soil conditions no strength reduction has been found (pH 9 - 4). At high acidic levels, a reduction has been found and a reduction factor of 1.05 is advised (pH ≤ 4). In alkaline condition (pH ≥ 10), polyester is affected by hydrolysis.
This occurs at higher temperatures (above 30 ... 40°C) and in combination with water and in a highly alkaline environment.
Under normal soil conditions no hydrolysis effects are to be expected. For pH ≥ 9 we advise a reduction factor of 1.15. In any extreme condition, especially if the soil contains alkaline chemicals and temperature might exceed the normal ground temperatures it is advisable to contact the polyester producer for detailed information.

Table 2 : Recommended partial reduction factors for biological and chemical environment

Chemical condition	Partial factor
pH ≥ 9	1.15
pH 9 - 4	1.0
pH ≤ 4	1.05

1.5. Factors for extrapolation deviations

Jewell and Greenwood[6] recommend factor f_m to compensate for any uncertainties resulting from deficient test data or an extrapolation covering more than 1 log cycle.
This factor may vary between 1.3 and 2.2.
For Stabilenka and Fortrac this factor is 1.3 for a design lifetime of 10 years and 1.5 for a design lifetime of 100 years.

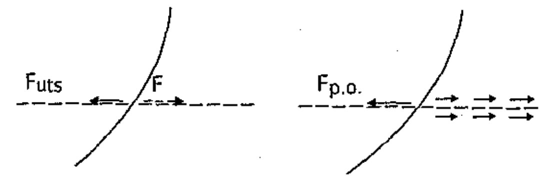
1.6. Safety factor

Depending on the calculation method used, the safety factor may be introduced in the allowable strength calculation of the reinforcing mat or when load factors are used in the geotechnical calculation of the structure.
No safety factor is required in this equation.

2. Pull out resistance

The function of a geogrid used as soil reinforcement has 2 failure modes:

- ultimate tensile strength of the material (the material breaks)
- pull-out mechanism: there is not sufficient anchor length to develop the maximum force by friction. As a consequence, the material is pulled from the anchoring zone.



Tensile strength failure Pull-out failure

Figure 2.: Failure modes

The pull-out mechanism of the anchor by means of a pull-out test. To this end a geogrid specimen is placed in a modified shear box and pulled out of it while being subjected to various vertical loads.
On the basis of the pull-out force/length/vertical load ratio the Coefficient of Interaction or the bond factor is determined.

$$COI = \frac{F_{\text{pull-out}}}{2.b.L.\sigma' \,.\, \tan\varphi} \quad .... \text{ eq.3}$$

However, from recent publications it is becoming increasingly clear that, being dependent on the vertical load under which the test is conducted, the COI value is not constant7). Furthermore, the dimensions of the pull-out box and the elongation of the grid itself have a considerable effect on the results. The materials used may have an elongation at break of over 10%. The elongation measured at the front of the box will largely be the result of an elongation of the material and not of pulls. However, this elongation, which - depending on the distance to the pull-out box front - decreases to zero, induces friction. As the Coefficient of Interaction values may show a scatter of more than 50%, pull-out box test results are not easy to analyse. In my opinion, such a scatter is inadmissible.

2.1. Failure modes

The pull-out resistance of a geogrid may be composed of various components7).
G. Richardson8) describes them as:

- Frictional restraint

The full material pressed against the surface of the geogrid elements provides the frictional restraint that resists pull-out of the reinforcing element. For this mechanism the pull-out restraint is a function of the developable surface area of the geogrid and the soil-polymer coefficient of interaction. Mechanically interwoven grids primarily develop their resistance from frictional restraint acting in the longitudinal element. The coefficient of friction may vary dramatically with both polymer and surface finish. Softer surface material like the coating on Fortrac provides maximum friction.

- Bearing capacity

A significant percentage of the ultimate restraint in extruded geogrids is built up by the bearing capacity provided by the transverse elements. These elements develop a similar mechanism of passive resistance as the ribs on steel strips in the traditional reinforced earth design, provided that the dimensions of the ribs have sufficient profile.

- Strike through

When the transverse elements provide very little surface area and when the coefficient of interaction between fill and grid is low, the restraint is developed in another way, i.e. by soil particles that by projecting through the openings of the grid prevent the transverse elements being pulled out. This mechanism functions as a "cheese slicer" and requires significant junction strength. All three components will contribute to the pull-out resistance to an extent that greatly depends on the properties of the geogrid. After an extensive study R. Jewell has developed a formula by which the bond factor of a geogrid can be calculated depending on such factors as coefficient of friction between fill and polymers, mesh size, and surface area of bearing members9).
Nowadays, engineers often apply this

formula to calculate the bond factor (coefficient of interaction between fill and geogrid) instead of going by the results of tests performed under specific conditions.

2.2. Junction strength

It will be clear by now that a minimum junction strength value of a geogrid is not easily determined.
This is explained by this value being dependent on the mechanism that induces the "bond" resistance, this mechanism itself being dependent on the shape and type of geogrid.
For some types of grid with a low frictional restraint the contribution of the bearing capacity of the transverse members will be much higher than for other types. And for a standard geotextile under similar conditions, the contribution will almost entirely be made by the friction between the fill and geotextile[10].
Therefore, it is impossible formulate a general minimum requirement for the junction strength of geogrids.

2.3 Test program pull-out

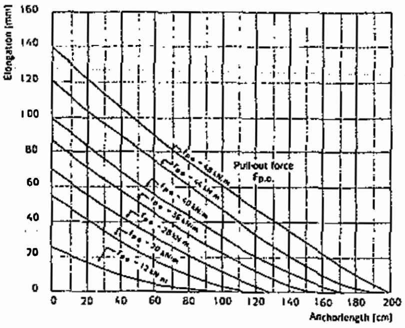
In order to gain insight into the behavior of mechanically bonded geogrids during pull-out, Mr. Wichter[11] of the Forschung- und Materialprüfungsanstalt (FMPA) in Baden-Würtenberg in Germany subjected Fortrac Geogrids to an extensive test program. The principle of these tests was to perform pull-out tests under various loads and for several soil types, not by pulling out the specimen from the pull-out box, but by ensuring that the specimen length inside the pull-out was such that the ultimate tensile strength of the geogrid would be reached outside the pull-out box.
The relative movement of various points of the geogrid inside the pull-out box was measured. Conducted in this manner, the pull-out test is in accordance with the standard procedures. Most standards stipulate a minimum specimen length inside the pull-out box of 1.00 m. For the test under consideration lengths of 2 m were used. The disadvantage of a pull-out test using a shorter length, e.g. 1 m, is that it usually results in pull-out. During pull-out the specimen is being drawn across a long distance through the soil out of the box. This renders any conclusions about the integrity of the junctions impossible. Therefore, the exact failure mechanism at pull-out is unknown. It may very well be that the shear resistance between the geogrid and the surrounding soil has been exceeded; or that the interaction between the soil and geogrid is such that two sliding surfaces just above or just underneath the grid have formed in the soil; or that the crushing of certain elements of the grid has initiated failure. The effect of deformation of the grid inside the pull-out box cannot be determined either. Part of the grid moves across a considerable distance as a result of the grid's elongation, while in its rear end no appreciable moving occurs. As a consequence, the Coefficient of Interaction in the moved part will decrease relatively to that of the part that has hardly moved.
Furthermore, the coefficient of interaction calculated on the basis of a test that resulted in complete pull-out, depends on the effective stress applied during this test. If a pull-out test is performed in the manner described above, the result of said effects is that no accurate values are found for the Coefficient of Interaction. The greatest drawback of this method is that it does not tally with reality. In reality the allowable strength in the geogrid is far below its ultimate tensile strength, while a safety coefficient ensures that the anchor length applied is higher than the calculated length. This means that only limited elongation takes place and therefore the failure mode is completely different from pull-out.

2.4. Execution of tests and results

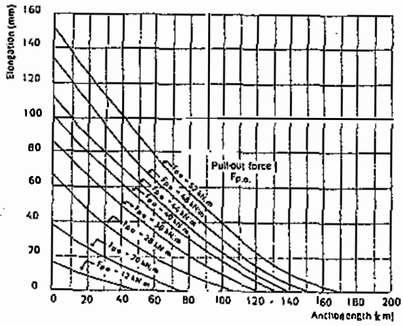
The tests have been executed in sand (SE), clayey sand (ST)and gravel (GW). The type of soil is identified according to the classification in DIN 18196. A typical set of test results is presented for the test: Fortrac 55/30-20 in gravel (GW).

Test data:
a. sample dimensions:
   0.5 m (width) x 2 m (length)
b. - d_{50} of gravel : 6 mm
   - 30% of mix : dia. ≤ 1 mm
   - 25% of mix : dia. ≥ 16 mm
   d_{60}/d_{10} : 27.5
   gamma : 20 kN/m^2
   phi : 35°

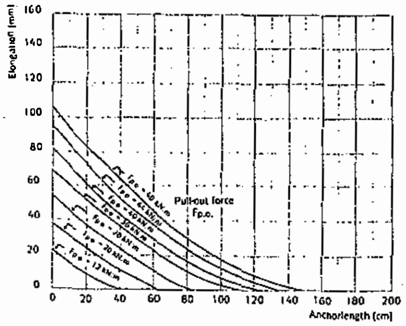
By means of measuring wires attached to the geogrid at mutual distances of 32 cm the movements of the corresponding measuring points at the rear of the pull-out box were read off. No junction failure was observed after any of the tests performed. The results of the test are illustrated in the form of charts in which the movements of the measuring points at various pull-out forces and at a given effective stress are plotted.



Surcharge: 4.5 kN/m



Surcharge: 29.5 kN/m

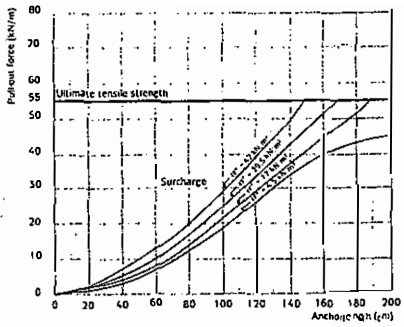


Surcharge: 42 kN/m

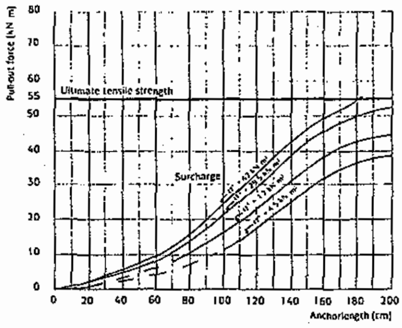
Figure 3: Fortrac 55/30-20, gravel
Elongation vs. Anchorlength

2.5 Results

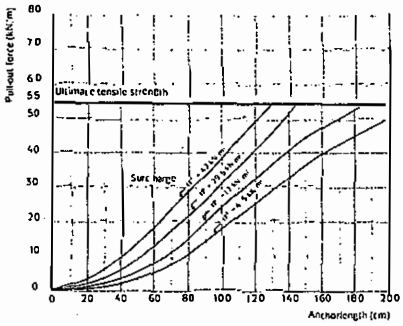
The results can be shown together in one chart, in which the pull-out force is plotted relatively to the mobilized anchor length for a given combination of type of Fortrac and soil. The graphs for Fortrac 55/30-20 and 80/30-10 in 3 types of soils are presented.



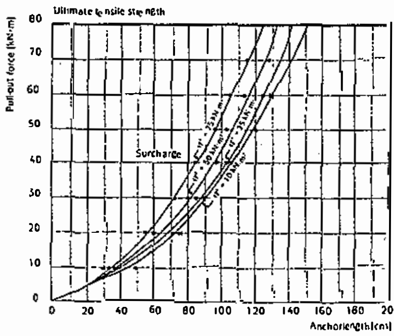
Fortrac 55/30-20 Sand (SE)



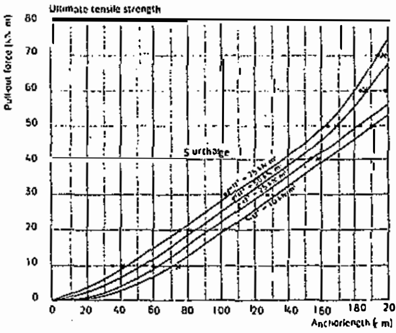
Fortrac 55/30-20 Clayey sand (ST)



Fortrac 55/30-20 Gravel (GW)



Fortrac 80/30-10 Sand (SE)



Fortrac 80/30-10 Clayey sand (ST)

Fortrac
80/30-10
Gravel (GW)

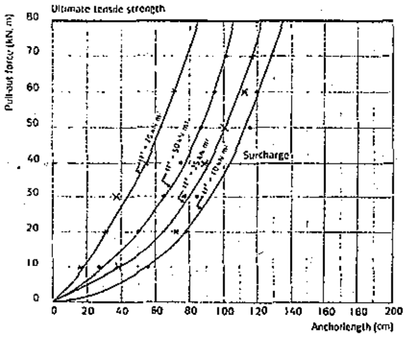


Figure 4: Fortrac 55/30-20 and 80/30-10
Pull-out force vs. Anchorlength

2.6. Discussion

If we analyze the results, we see the following:

- The lines in figure 3 do not run parallel to each other. From this it follows that the Coefficient of Interaction is dependent on the effective stress and no constant value.
- If the test had been executed using a sample length of, e.g. 100 cm, pull-out would have occurred at 18 kN/m, at an effective stress of 4.5 kN/m^2, and at 39 kN/m, at an effective stress of 42 kN/m^2. The corresponding coefficients of interaction vary by a factor of 5 (Figure 4);
- At a pull-out force of, for example, 30 kN/m, the anchor length mobilized at an effective stress of 4.5 kN/m^2 is 130 cm and that mobilized at an effective stress of 42 kN/m^2, 82 cm. Here, there is no linear connection either. At the maximum pull-out force (ultimate tensile strength of the material), here 55 kN/m, the mobilized anchor lengths are 200 and 120 cm, respectively. The charts can easily be used to determine the required anchorlength for a specific design condition. At an effective stress of 29.5 kN/m^2 and an allowable load of 25 kN/m for the grid you will find a mobilized anchor length of 87 cm. Observing anchor length safety factors between 1.5 - 2, you will select anchor lengths of 130 and 174 cm, respectively. Furthermore, you can read off that, when the ultimate tensile strength of this grid (55 kN/m^2) is reached, the mobilized anchor length is 133 cm. So, when prescribing an anchor length of, for example 150 cm, you will know that the safety factor at a working load is 1.72. However, if there were a strength increase in the grid, no pull-out would occur, because then the grid would have reached its ultimate strength.

2.7. Conclusion

Pull-out tests on geogrids conducted by the procedures described above yield design charts that are useful and offer much insight to engineers. The test procedures are fully in accordance with the prevailing standards. All inaccuracies that occur with Coefficients of Interaction are eliminated. The anchor lengths actually realized under various conditions are also indicated. Further one should realize that in many cases, but especially when a geogrid is used beneath road foundations or in low embankments, its length is also determined by practical circumstances. The anchor length available is often many times longer than the length calculated in theory, which is usually less than 2 m.

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