Landmarks in Earth Reinforcement, Ochiai et al (eds),
© 2001 Swets & Zeitlinger, ISBN 90 265 1852 8

Practical experience in small scale pullout tests

H. Zanzinger
LGA, Geosynthetic Institute, Nuremberg, Germany

E. Gartung
LGA, Geotechnical Institute, Nuremberg, Germany

G.L. Sivakumar Babu
Civil Engineering Department, Indian Institute of Science, Bangalore, India

ABSTRACT: Pullout response of geogrids in soil is a function of soil type, soil properties, normal stress, type of geogrid, specimen width and length as well as other boundary conditions. Extensive research has been executed in the past into the problem of soil-geogrid interaction, so the fundamentals are well understood. However, the determination of individual project specific design parameters for soil-geogrid interaction analyses cannot be executed with expensive, sophisticated scientific experiments. Simple, inexpensive, small scale pullout tests are recommended for this purpose. The paper points out a number of important details to be observed in routine testing and presents some test results obtained with different material combinations.

1 INTRODUCTION

In geotechnical applications reinforcing geosynthetics (GSY) are typically used as strengthening elements for embankment foundations, for supporting structures, for the stabilisation of slopes, as pavement reinforcement or for other assignments.

The GSY reinforcement sheets are installed between more or less horizontally placed and compacted soil layers. They retain the soil and prevent it from slipping. For this purpose reinforcements are anchored in stable soil zones. The reliability of the anchorage is crucial for the stability of the structure and/or for its performance. Accordingly, the problem of soil-reinforcement interaction and safety assessment of anchorage has been given due consideration in theoretical and experimental studies and there are numerous reports on this subject in the literature.

A special question of soil-reinforcement interaction arises when extensive areas have to be covered with reinforcement sheets and when it is necessary to transmit forces across the boundaries of individual reinforcement sheets. One way of accomplishing this is by sewing the sheets together. The strength of the seam can then be determined experimentally by tensile tests and the ratio of the seam strength to the strength of the reinforcement can be entered into the design calculation as a reduction factor. Another way of transmitting forces across the boundaries of reinforcement sheets is by friction in overlap joints. To evaluate the interaction of the reinforcement sheets with each other and with the soil surrounding them, pullout tests can be carried out, modelling the mechanical performance of the members involved under field conditions.

Since there is a great variety of GSY reinforcement applications and of different soils, it is necessary to determine the required length of reinforcement anchorage or of the overlap for each project individually unless there is past experience with conditions which fit. The most common way to establish the soil-reinforcement interaction in the limit state is by pullout or by direct shear testing. The present paper refers to practical experience with pullout tests.

2 PULLOUT-TESTS

The question about the required minimum anchoring length for the particular application can be answered by pullout tests with GSY specimens of different lengths. Reducing the length of the reinforcement specimen step by step, the length can be found where the GSY just starts slip. Alternatively, a number of wire extensometers can be fixed to the tested GSY specimen, in order to determine the load-displacement performance of the soil-reinforcement system and thus deduce the required anchoring length. Relatively large equipment is needed to carry out these tests. Typical dimensions for such pullout boxes are width B = 0.6 to 1.0 m and length L = 1.0 to 3.0 m (Adanur et al. 1996, Lopes & Ladeira 1996). Tests of this type are quite demanding. That is why they are carried out for research purposes or fundamental studies rather than for day to day construction projects. The costs of such pullout tests are too high for routine applications.

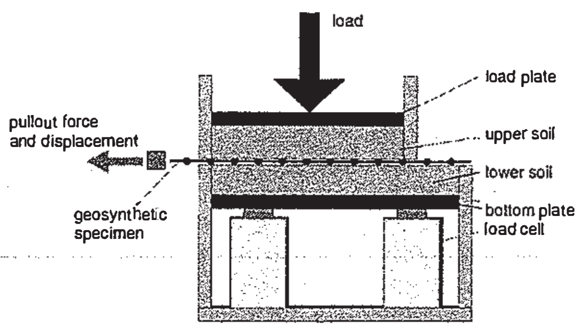

Figure 1: Set-up of a small scale pullout test

To meet practical demands, simpler tests as described in this paper are recommended out with smaller equipment. Shear boxes commonly used for shear tests on GSYs, with dimensions of B = L = 0.3 m, are employed for these routine pullout tests (Figure 1).

In pullout tests of GSY specimens from the soil, two different failure mechanisms may occur. Under the applied tensile force the geogrid may either slip out of the soil or it may lose its integrity before slipping and tear. The normal surcharge loads are increased from test to test, as in direct shear testing and the limit tensile force is measured. It is important that the tensile force is introduced into the geogrid by proper clamping device. The free end of the geogrid projecting from the rear of the pullout box facilitates displacement measurements at the rear side. Displacements are also measured at the front side. So the average strain of the geogrid under load can be determined in the soil contact area. The pullout forces and the normal forces are measured. It is very important not only to measure the applied total normal load, but also to evaluate the actual normal stress in the plane of the GSY sheet during the entire pullout procedure.

The results of pullout tests are commonly presented as plots of average pullout shear stress τ vs. average normal stress σ.

$$\tau = F / (2 \bullet B \bullet L) \quad (1)$$

$$\sigma = N / (B \bullet L) \quad (2)$$

with F = pullout force; B/L = width/length of tested specimen; and N = normal force (corrected for dilatancy).

3 DIFFERENCES BETWEEN DIRECT SHEAR TESTS AND PULLOUT TESTS

It is sometimes stated that routine pullout tests are not needed, because the soil-reinforcement interaction can be determined adequately by direct shear tests. This is correct for woven geotextiles. However, it does not apply to geogrids with open spaces between the strands (Jones 1996).

In shear tests, the resistance acting at a single GSY/soil or GSY/GSY interface is determined. In contrast, with pullout tests two interfaces between the GSY and the soil are involved. Shear tests on soil-geogrid interfaces do not characterise the pullout resistance correctly for the following reason: when shear tests are carried out on geogrids, the soil above the geogrid is only partially in contact with the surface of the geogrid, but probably to a greater extent with the soil beneath, due to the openings of the geogrid. Since the friction angle between soil and GSYs and the angle of internal friction of the soil may be quite different, the results of shear tests may be misleading when applied to the determination of minimum anchoring lengths of geogrid reinforcements. The test results of pullout tests which are discussed subsequently were executed on a routine basis for road and railroad construction projects.

4 FACTORS DETERMINING THE PULLOUT RESISTANCE

4.1 *Normal stresses*

The normal surcharge load is generally applied pneumatically or hydraulically on to the geogrid-soil interface via layers of 5 to 10 cm of soil of well defined compaction and water content conditions above and below the geogrid. The effect of the skin friction between the soil and the walls of the box is compensated by measurements of the load transducers at the bottom of the test set up.

Figure 2 shows an example of a pullout test on a GSY embedded in medium sand. The grid spacing of 30 mm corresponds to the wave length of the waves that show up in the force-displacement curves recorded while the geogrid is pulled out of the soil at a constant rate. The first maximum value of the measured pullout force defines the pullout resistance under the particular normal stress.

Since the test set up does not permit vertical movements of the upper and lower loading plates, considerable increase of normal stress due to dilatancy effects may be observed (Hayashi et al. 1996).

Figure 3 presents an example of a pullout test on a geogrid of 30 mm grid spacing in medium sand. The previously mentioned waves related to the grid geometry can hardly be detected here, but depending on the magnitude of the normal stress an increase of the normal stresses up to about 50% is observed as soon as greater movements do occur. In most geogrid reinforcement applications dilation is not restrained, so the pullout test results have to be corrected accordingly.

If the increase in normal stress due to restrained

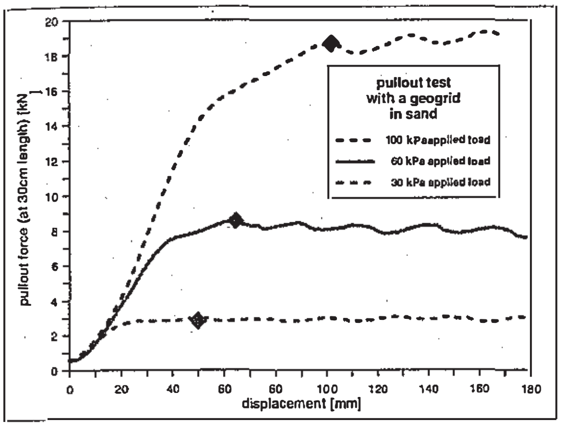

Figure 2. Pullout test of a knitted geogrid, spacing 30 mm, embedded in medium sand

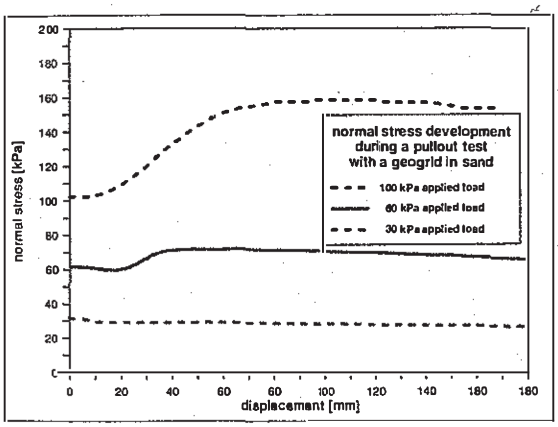

Figure 3. Pullout test with pronounced dilatancy effects

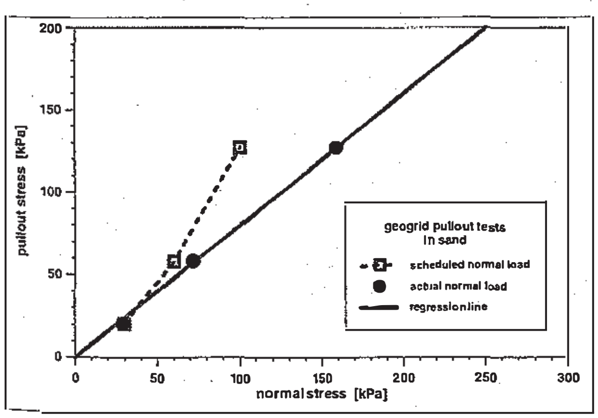

Figure 4. Pullout stress vs. normal stress (example knitted geogrid 30 mm spacing in medium sand)

dilation of up to 50% shown in Figure 3 would not be corrected for, the pullout resistance would be severely overestimated as can be seen on Figure 4. The stress correction for dilation produces outstanding correlations and leads to a linear relationship between pullout resistance and normal load as long as the pullout resistance does not exceed the tensile strength of the geogrid.

4.2 *Geogrid tensile strength*

The pullout resistance can only be measured by the test discussed here, when it is smaller than the tensile strength of the geogrid under the pertinent test conditions.

The purpose of the test is to determine the average composite action of the geogrid-soil system under particular conditions (type and state of soil, normal stress etc.). The test has to be prepared accordingly which may require some standard soil mechanics experiments in advance.

Experience has shown that the distribution of the normal stress acting on the geogrid-soil interface is not uniform. Because of wall friction there is a stress concentration in the middle part. As a result, the central area of the geogrid strip experiences greater normal stresses than the edges which in turn leads to more efficient retention of the reinforcement in the middle part of the strip. The tensile load is therefore concentrated at the central zone of the test specimen. The edges of a wide strip show a tendency to yield first, while the central zone still holds, so the tensile forces are concentrated in the middle. If the strength of the geogrid is overcome, the central strands tear first. This should be taken into consideration in the preparation of the pullout testing programme. In some cases failure of wide geogrid specimens in tension was observed at only 50 to 60% of the nominal strength. This effect can be influenced in practice by testing specimens of smaller width.

4.3 *Geogrid geometry*

The geometrical features of the GSY e.g. the grid spacing and the granular properties of the soil influence the pullout resistance. Figure 5 compares the results of pullout tests carried out on a geogrid with grid spacing of 20 mm with medium sand, grain size 0 to 2 mm and with crushed basalt rock, particle size 16 to 32 mm.

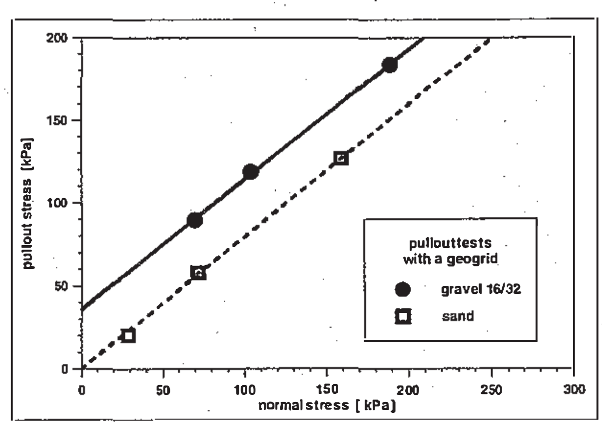

Figure 5. Pullout stress of a knitted geogrid with 20 mm grid spacing in two different soil types

In both cases the pullout resistance of the geogrid was overcome without the tensile strength of the geogrid being reached. In spite of very different soil particle sizes the frictional component of the pullout resistance appeared to be almost identical, but there is a "cohesion" intercept at the crushed rock line. The pullout resistance of the geogrid in coarse crushed basalt at zero normal stress is caused by interlocking. In the test with the much finer sand, no interlocking effect was observed. Obviously geometrical features, grain shape and the relationship between grain size and grid spacing have an important effect on pullout resistance under low normal stresses.

4.4 *Soil types*

For any given geogrid the pullout strength depends on the type of soil and the compaction and water content conditions. As an further example, test results are presented for a woven polyester geogrid, tensile strength 80 kN/m in machine direction and 30 kN/m in cross machine direction with grid spacing of 20 mm. The tests are carried out with gravel, sand and clay soil, the graduation curves of which are shown an Figure 6. The pullout resistance for the geogrid embedded in gravel and in sand shows simi lar patterns (Figure 7) as the one for crushed rock and sand (Figure 5) with a pronounced intercept at zero normal stress for the coarse grained material. Again, the line for sand is parallel to the line for the coarse grained soil like Figure 5. The pullout resistance measured for the stiff clay (water content w = 22%, dry density ρ_d = 1.64 g/cm³) is lower than for the cohesionless soils. Apparently it is controlled by the shear strength of the clay and may depend on the drainage conditions as well as the velocity of pullout.

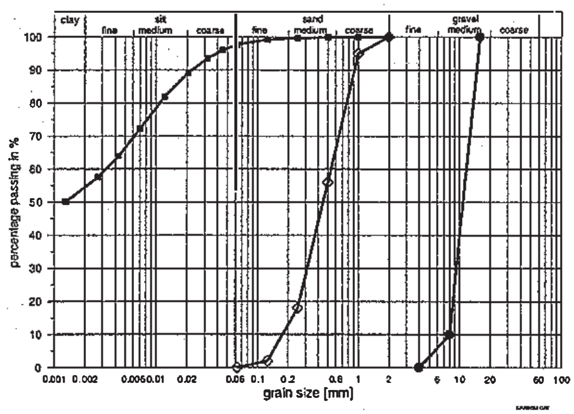

Figure 6. Graduation curves of three soil types

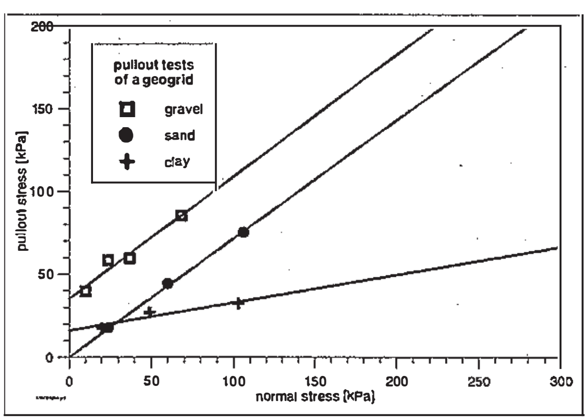

Figure 7. Pullout stress of a geogrid with 20 mm grid spacing

5 OVERLAP JOINTS

Pullout tests can also be used to determine the required overlap width of geogrids when it is necessary to transmit forces across the edges of geogrid sheets. Figure 8 compares the results of two pullout tests. The lower line presents the pullout stress of a single geogrid. The upper line shows the test results of a test with two geogrids of the same type, overlapping in such a way that the lateral strands of the geogrids can interlock. In this configuration the lateral strands of the geogrids that interlock, contribute substantially to the pullout resistance. The geogrid

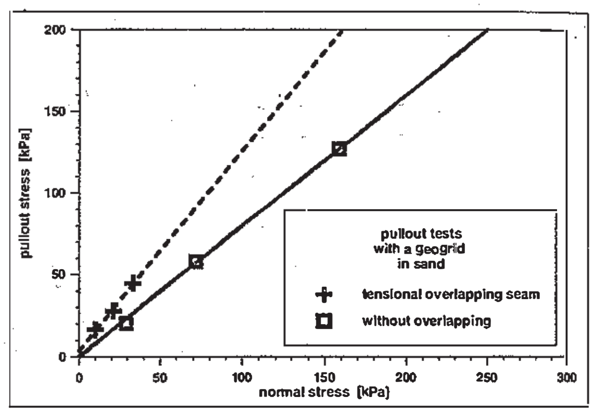

Figure 8. Pullout stress of a tensional overlapping seam of knitted geogrids

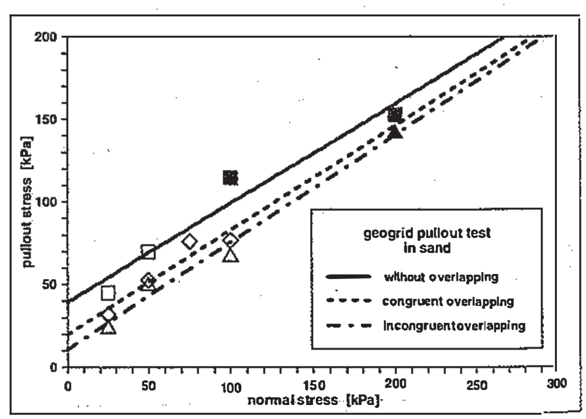

Figure 9. Influence of congruent and incongruent overlapping seams on pullout resistance of knitted geogrids

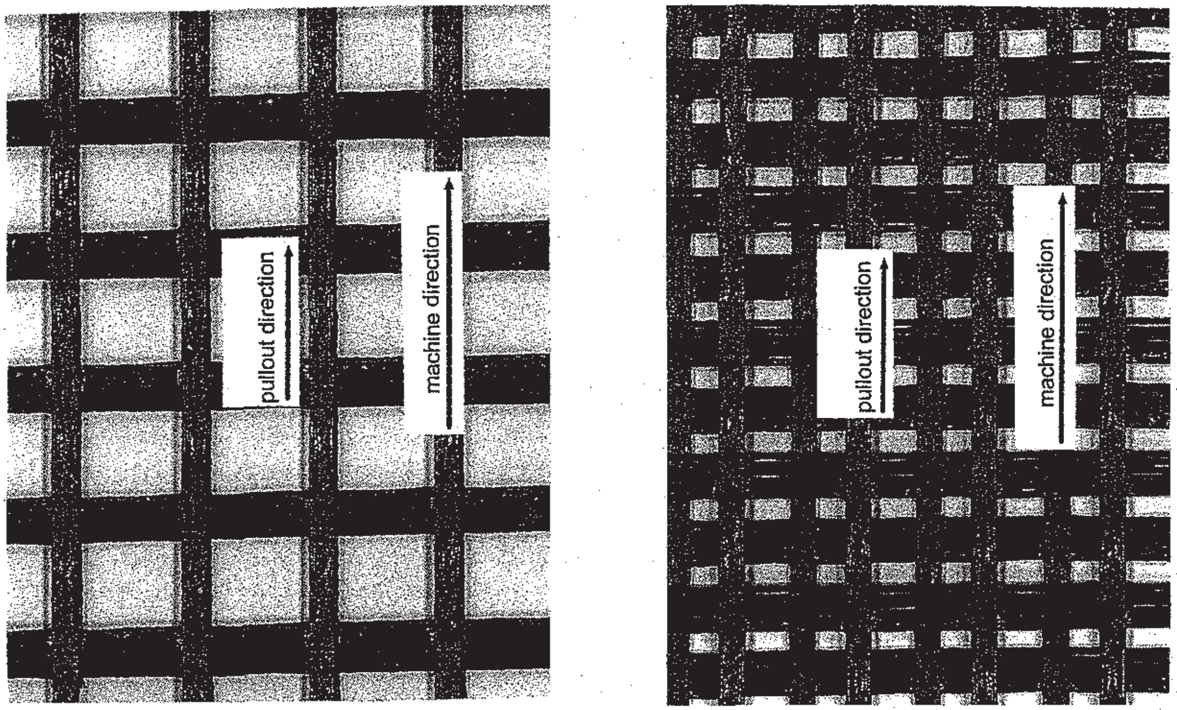

Figure 10. Geogrid overlaps, congruent placement at left, incongruent placement at right hand side

without an overlap joint but otherwise embedded in the same sand shows appreciably less pullout resistance.

However, if the geogrid is installed in such a way that the lateral strands are not facing each other, so there is no interlocking, the smoother sides of the geogrid are in contact with each other, then a reduction of the pullout force is experienced. For the overlap joint this means, that the force to be transmitted by friction is smaller than in the case where interlocking occurs (Figure 9).

When geogrids overlap, they may be placed in such a way that strands are lying on top of each other in a perfect match, they are congruent as depicted on the left hand side of Figure 10. But they may be placed in such a way, that the strands are not on top of each other, being incongruent, as shown on the right hand side of Figure 10. Test results (LGA 1995) on Figure 9 demonstrate that the pullout resistance differs slightly for these different placement conditions. For an assessment of the force that can be transmitted via overlap joints, the more conservative values of incongruent conditions apply.

6 APPLICABILITY TO OTHER GSY

All geogrid pullout tests referred to in the present paper were carried out with knitted and woven geogrids. The manufacturing system for all geogrids was practically of the same type. Tensile strengths ranged from 30 to 400 kN/m. Accordingly, the results are valid for these geogrids. A transfer of the experiences presented here to reinforcing GSY of other types are not justified.

7 SUMMARY AND CONCLUSIONS

Small scale pullout testing of geogrid-soil systems, is a practicable tool for the determination of design parameters of GSY-reinforced soil structures on routine projects. The tests are carried out with the soils from the site in question at the pertinent compaction and moisture conditions. It is inappropriate to estimate the pullout resistance of geogrids on the basis of direct shear tests.

Normal stresses acting on the geogrid-soil interfaces have to be corrected for dilation effects. The distribution of the normal stress in the test set up leads to a stress concentration and an associated concentration of tensile forces in the middle part of the test specimen. This should be considered in the preparation of the tests and the size and shape of the test specimens.

Pullout tests can also be used to determine the transmission of tensile forces via overlap joints.

REFERENCES

Adanur, S., Mallik, S. & Zhai, H. 1996. Analysis of geotextile-soil interaction in pull-out tests. *Proceedings of the International*

Symposium on Earth Reinforcement, Fukuoka, Kyushu, Japan, 12-14 November, Vol. 1, Rotterdam: Balkema. 3-8.

Hayashi, S., Alfaro, M.C. & Watanabe, K. 1996. Dilatancy effects of granular soil on the pullout resistance of strip reinforcements. *Proceedings of the International Symposium on Earth Reinforcement, Fukuoka, Kyushu, Japan, 12-14 November, Vol. 1*, Rotterdam: Balkema. 39-44.

Jones, C.J.F.P. 1996. Earth reinforcement and soil structures. *Thomas Telford Publishing*, London, 379 pp.

LGA 1995. Test reports GE 9408972/A, GE 9408972/B and GE 9408972/C (unpublished) in German.

Lopes, M.L. & Ladeira, M. 1996. Pull-out tests for the assessment of soil-geogrid interaction – Influence of some mechanical and physical parameters. *Proceedings of the International Symposium on Earth Reinforcement, Fukuoka, Kyushu, Japan, 12-14 November, Vol. 1*, Rotterdam: Balkema. 89-94.