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A COMPARISON OF GEOGRID STRIPS AND METALLIC REINFORCING STRIPS UNDER STATIC AND REPEATED LOADING

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ABSTRACT: This paper summaries the results of a series of large-scale tests on the pull out behaviour of reinforced earth strips under static and slow repeated loading. Comparisons are made between plain smooth steel strips and Tensar SR2 geogrid reinforcement under load with number of alternating load applications. The results clearly demonstrate that the geogrid reinforcement is safer and more load efficient than the steel reinforcement.

1 INTRODUCTION

During the last 25 years the practice of reinforcing soils has increased tremendously. Several types of either relatively inextensible metallic or extensible polymeric reinforcements have been widely used, and for the great majority of situations these elements are subjected to a near constant load. There are, however, a number of cases where the individual reinforcing elements may be subjected to a slow repeated load. These examples include bridge abutments subjected to traffic loads; restraining structures subjected to significant tidal variations; structures subjected to extremes of temperature daily. Extensive literature will be found on the behaviour of elements under static loading but little data are available in which the form of loading is non-static. It is known that the application of an external load causes resistance to be mobilised along the length of the reinforcement, according to the laws of bond and bearing. Questions very often posed by engineers include: (a) what is the difference between a relatively flexible and a relatively rigid reinforcement; (b) how does a repeated load application affect the pull-out capacity and the life of a reinforcement. Work has been in progress for nearly a decade systematically examining how different types of reinforced earth strip behave under a range of loading conditions. This paper presents some of this work in an attempt to give an unbiased assessment of the performance of the geogrid reinforcement relative to smooth steel strips.

2 THE TEST SYSTEM

The test rig comprised a rigid steel container, Figure 1, 0.3m by 0.3m by 4m in length. The internal walls of the rig are smeared with a frictionless grease, allowing a surcharge pressure, applied via a pressure plate loaded through a water bag, to be transmitted through the sand mass. The test reinforcing strip was placed in the middle of the sand mass and can be loaded either statically under constant stress increments, or under slow repeated loading. For the repeated loading the load was changed every 20 seconds to give a square shaped pattern between an upper and a lower load level. The upper and lower load levels were expressed as a percentage of the static pull-out capacity (Pu) of the steel strips and the index load (PI) of the geogrid strip. The index load is the ultimate rupture load as defined by Choek (1985). The two elements tested were a smooth steel strip and a plastic geogrid SR2 strip.

The steel reinforcing strip was made from hard rolled steel of 680N/mm^2 yield stress and 200KN/mm^2 modulus of elasticity. The plastic reinforcement was formed by cutting a row of two ribs in width and 35 bars in length of SR2 geogrid. The width of the strips finally chosen was 32mm to ensure that there were no edge effects from the test rig walls. The steel strip was provided with special load cells, temperature compensated, at 400mm centres, the wires from the cells being carried in grooves machined along the length of the strip to an end terminal. The geogrid was provided with special axial movement gauges at five locations along the strip. The sand was used in a dry state being of medium size and uniformly graded. A raining method of the sand placement gave an average relative density of 0.53.

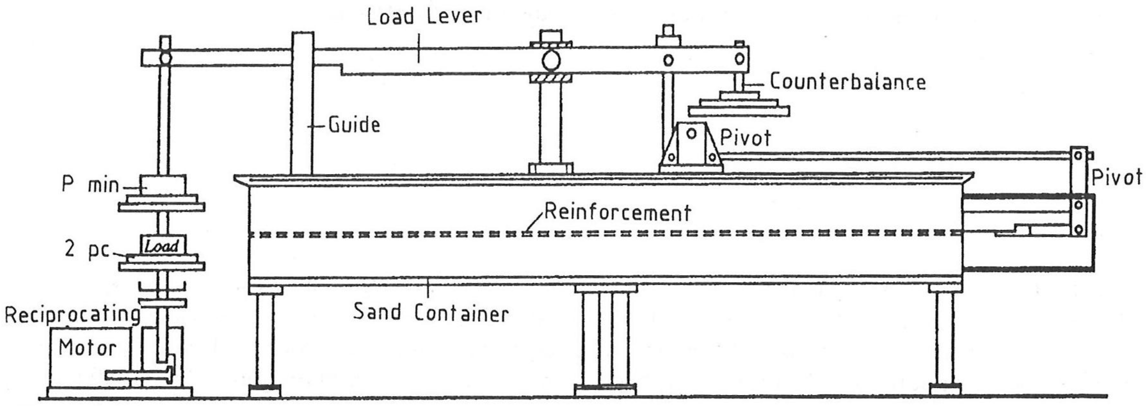

Figure 1. The test rig.

3 STATIC LOAD TEST BEHAVIOUR

Three levels of normal stress, 50, 75 and 100KN/m^2 were applied to the sand surface and the two reinforcement types were loaded statically. The largest pull-out load was generated by the smooth steel strip, the smallest by the geogrid strip. The shapes of the pull-out load displacement curves are given in Figures 2(a) and 2(b). It will be noticed that there are very different modes of behaviour. The smooth strip has a near peak load at a displacement less than 1mm whilst the geogrid plastic strip provided no peak load. The significance of these trends is that a smooth metal strip may pull-out abruptly whereas the geogrid strips do not have such a characteristics. These different trends in load mobilisation with displacement can be attributed to the differences in the mechanisms whereby load is mobilised. For the smooth steel strip load is mobilised essentially by frictional resistance only, whilst for the plastic strip both friction and end bearing on the projections are mobilised.

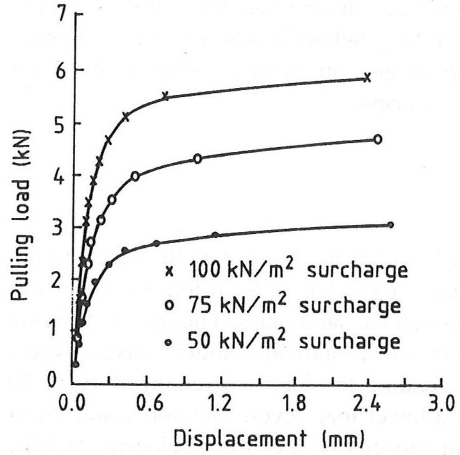

Figure 2(a). Load-displacement relationships, smooth strip.

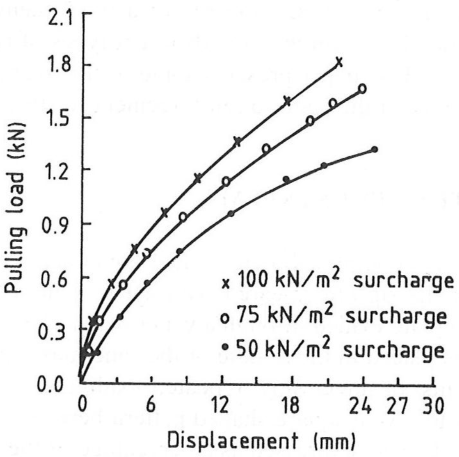

Figure 2(b). Load-displacement relationships, geogrid strip.

Data for the smooth strip are shown in Figure 3 giving the distribution of applied load along the length of the strip. The record movements along the geogrid strip are given in Figure 4. It will be noted with the steel strip that the axial load is gradually mobilised over the full length, whereas the load in the plastic strip was mobilised over the front part of the strip only, the parts towards the distal end being unstrained. This observation would indicate that unless a very low confining stress be used it would be impossible to pull out the geogrid strip. Consequently failure of this strip by rupture appears to be an easier mode.

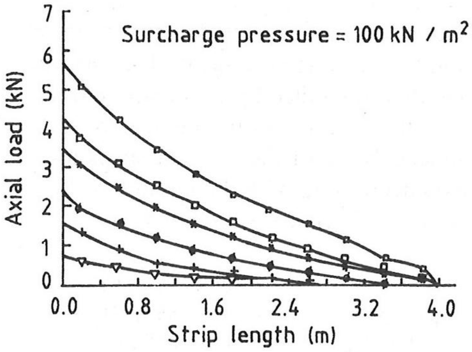

Figure 3. Axial load mobilisation of the smooth strip.

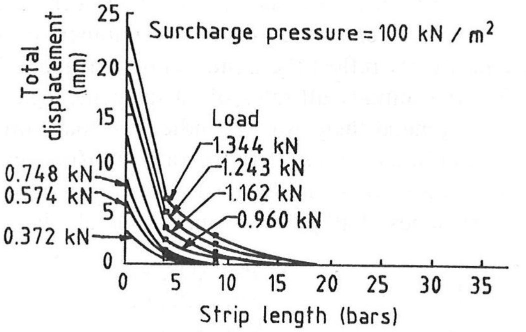

Figure 4. Axial displacement of the geogrid strip.

It is clear that the mechanics of load mobilisation for the steel strip (primarily in side friction) are different from the geogrid (primarily in bearing against the individual bars of the grid). Direct comparison of load carrying capacity between the steel strip and the geogrid is unwarranted because, in use, the grid reinforcement covers the plan area of the ground whereas the individual strips cover a small area only. From knowledge of strips spacing the relative load efficiencies of the grid versus the strip may be established. From a simple consideration it will be found that the geogrid has at least the same load capacity as the steel reinforcement. Also, at reasonable depths of embedment the geogrid will fail structurally rather than pull out.

4 REPEATED LOAD TEST BEHAVIOUR

A wide range of loading levels and amplitudes was chosen to assess their effect on the behaviour and performance of the two test strip elements. In some cases the tests were taken to 100000 load cycles. The cumulative effects of cyclic loading are shown in figures 5(a) and 5(b). There are significant differences in the manner the strips behave. The smooth steel strip was characterised by an initial stable state followed by a short period with an accelerated movement leading to a catastrophic failure. The plastic strip displaced much further under repeated loading, exhibiting a gradual movement and despite the large number of load repetitions this strip did not fail by pulling out.

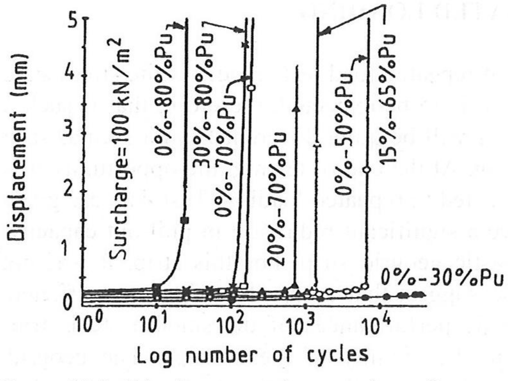

Figure 5(a). Displacement-log number of load cycles, smooth strip.

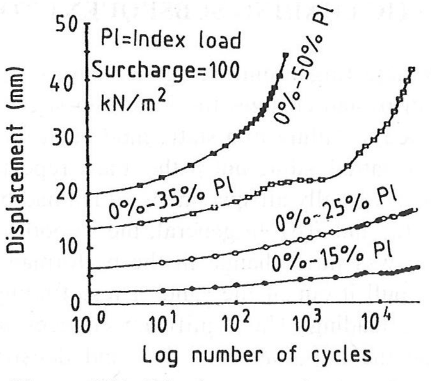

Figure 5(b). Displacement-log number of load cycles, geogrid strip.

This observation would suggest that such strip is much more suitable to resist pull-out repeated loading than the smooth steel strip.

The above data were presented in semi-log form making difficulty in comparing trends between the strips because of different levels of loading, different initial displacements on load and different modes of load mobilisation. Other investigators have successfully used the rate of deformation technique to explain the behaviour of elements subjected to repeated loading. For example, Lashine (1973) showed that an accelerated rate of displacement for repeated tests on a granular soil usually was irreversible and indicative of failure once such a stage had been reached. The present data are replotted in this form of rate of displacement/cycle against the number of cycles on a log-log scale (figure 6(a)). The smooth strip data clearly reflect the trends shown in figure 2, namely that all strips failed by eventually pulling out although initially all rates of displacement kept decreasing with increases in the number of load cycles. In general there was no indication that failure was imminent. None of the geogrid strips tests indicated failure (Figure 6(b)), the rate of displacement in all cases decreasing with the number of load cycles increase. Also, there is no abrupt change in the reinforcement's behaviour. An interesting feature is that the slopes of all plots are approximately the same.

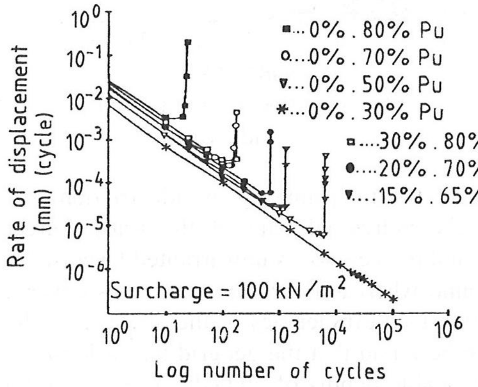

Figure 6(a). Rate of displacement-number of cycles, smooth strip.

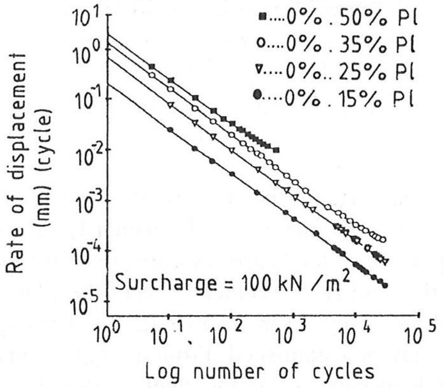

Figure 6(b). Rate of displacement-number of cycles, geogrid strip.

The test data clearly demonstrate the complex nature of repeated loading response of foundation elements. From a fundamental point of view the deterioration in the performance of a strip appears to be related to several partly understood factors including, (i) changes in load transfer along the strip length, (ii) Changes in the locked-in stress after each load cycle, (iii) compaction of the sand due to local shear reversals causing breakdown of particles, (iv) changes in the normal confining stress along the strip with increase in the number of load repetitions leading to a significant deterioration of the skin friction resistance. In order to understand these complex and interrelated factors it will be necessary to carry out a wide range of further testing and calculations.

5 STATIC LOADING SUBSEQUENT TO REPEATED LOADING

The act of subjecting a reinforcing element to a package of repeated load tests modifies the stress state along the strips and changes the locked-in stress regime. It is to be expected, therefore, that if such a strip is loaded to failure in a static mode that its behaviour will be quite different from a similar strip subjected to static loading but without any repeated loading. At the end of testing, the opportunity was taken to load statically all specimens which had been subjected to repeated loading. Test data are given in figures 7(a) and 7(b). In general, the smooth strip gave a significant reduction in pull-out capacity, whilst there was little change in the performance of plastic geogrid strip. For this strip, it was not possible to pull it out of the sand. These findings would suggest that a smooth strip is not efficient under cyclic loading. The significant changes in the static performances of the smooth steel strips demonstrate the importance of the sand densification in the vicinity of these strips. The geogrid, because of the very large reserve length unloaded, behaved in a similar manner to first time loading and, undoubtedly, is a much more reliable reinforcement if the applied loading is of a slow cyclic form.

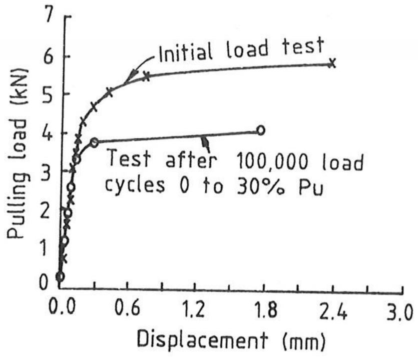

Figure 7(a). Load-displacement relationship before and after repeated loading, smooth strip.

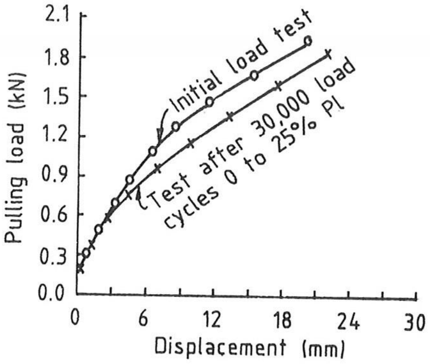

Figure 7(b). Load-displacement relationship before and after repeated loading, geogrid strip.

6 CONCLUSION

These large-scale laboratory experiments demonstrate that the mechanics of load mobilisation for the steel strip (primarily in side friction) are different from those of the geogrid strip(primarily in bearing against the individual bars of the grid). Because the ultimate pull-out load levels are quite different for the two strips it is very dangerous to make any generalisations about their usefulness, but it is clear to us that the geogrid strip is much more efficient tensile resisting member than the smooth steel strip, especially under repeated loading. A particular feature was the inability of the geogrid to pull out of the sand, failure being by rupture of the reinforcement material. In many cases deformation of the reinforcement will control.

REFERENCES

1. Choek, Y.K. (1985). The behaviour of polymeric grids used for soil reinforcement. Thesis, University of Strathclyde, UK.
2. Lashine, A.K.F. (1973). Deformation characteristics of a silty clay under repeated loading. *Proceedings of the 8th International Conference on Soil Mechanics and Foundation Engineering*, Moscow, Vol. 1, pp. 237-244.