Development of A Strain Monitoring System for Use with Buried Geogrids

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ABSTRACT: The paper describes the development of a method, based on the direct measurement of extension or contraction over a 100mm gauge length, for measuring the in-situ strain in geogrids. The direct method of strain monitoring is carried out by a device consisting of an LVDT protected within a sliding guide tube. This type of strain monitoring system was developed because of its robustness during installation and, unlike electrical resistance gauges, the strain readings are unaffected by disconnections, which is an important requirement in field studies. The system has a high degree of resolution and is capable of measuring strains up to 20%. The system has been applied successfully in large-scale laboratory tests and also in full-scale field trials. The strain monitoring system is shown by the results presented from laboratory tests, to be a reliable, safe and cost effective method of measuring strain in buried geogrids.

1 INTRODUCTION

In recent years there has been a considerable interest in the use of geotextiles to provide surface protection in areas of shallow mineworkings. This interest has been reflected in research activity, much of which has centred on theoretical studies. For example, Poorooshasb (1991) has reported on a theoretical study of the load settlement response of a compacted fill layer supported by a geotextile overlying a void. Similarly, Kempton (1992) has reported on the use of geotextiles to support road embankments over areas subjected to mining subsidence and concluded that such a design solution is cost-effective compared with the traditional pressure grouting solution. The same area of application for geogrids has been investigated recently by the authors of this paper. The full experimental study is reported in a companion paper (Bridle, Jenner and Barr 1994), whereas this paper reports on the development of the strain monitoring system used in the study.

The main objective of the experimental work carried out in the full study was to investigate the use of geogrids to provide protection against sudden collapse in lightly loaded areas such as landscaped recreation areas, footpaths, car parks and local access roads. Full-scale test beds were constructed in which geogrids (in one or two layers) were placed beneath 600mm of compacted Type 1 aggregate which was loaded in turn with a uniformly distributed surcharge of either 5 or 7.5kN/m². Voids of 3m or 5m were developed in the test beds in a controlled manner and the strains developed in the geogrids were monitored for a minimum period of 12 hours.

A review of existing strain monitoring systems was carried out prior to the development of the system reported here. Full consideration was given to systems already on the market and under development. However, on the basis of the costs of existing systems and the delay in waiting for systems under development, it was decided to proceed with the purpose-built system of strain monitoring reported here. Some thought was also given to the direct measurement of strain in the geogrids since the voids were to be developed in a controlled manner. This approach was also rejected, primarily on safety grounds.

The above details for the test programme, extracted from a companion paper (Bridle, Jenner and Barr 1994), resulted in the following requirements for the strain monitoring system:

- the system must be able to measure large strains, possibly well in excess of 5%
- strain measurements in a number of locations were required and, hence, a data logging system was necessary
- the system had to be robust during installation
- the system should be unaffected by disconnections during the study of creep in the test bed
- the system should maintain its accuracy throughout the test period and be safe, relatively cheap and easy to use.

The above requirements were satisfactorily met by the strain monitoring system reported here.

2 SYSTEM DEVELOPMENT

Considerable difficulty was encountered during the early stages of the study in locating a suitable cheap strain measuring system for the proposed experimental work. Various commercially available systems together with systems under development were considered but rejected on either cost or delivery time. Hence, it was decided to develop a purpose-built system, based if possible on direct strain measurements during tests.

Initially, a number of laboratory tests were carried out on strips of geogrid which was to be used in the test beds. Various techniques of measuring strain were investigated and the results compared with the strain output gained via the testing machine. The original intention was to drill small holes in the intersections of the grids and to locate the equivalent of Demec type pips at these locations. However, this system was abandoned since the holes reduced significantly the load carrying capacity of the geogrid and only small strains could be measured with the equivalent Demec system. The use of callipers to provide direct strain measurement was also investigated. Although callipers could be used to measure large strains the system was rejected on the grounds of safety. The problems encountered by drilling holes at the intersections led to the notion of using spring-loaded grips to locate the strain gauge positions.

The method of strain measurement finally adopted is illustrated in Fig.1. The method is based on the direct measurement of extension or contraction over a 100mm gauge length by means of an LVDT. The LVDT is protected by a sliding guide tube as shown. Both the LVDT and the guide tube are fixed to the geogrid by spring-loaded clips so that their position on the geogrid is maintained during elongation of the material and corresponding reduction in the cross-sectional area. The system has a high degree of resolution and is capable of measuring strains of up to 20%. It is a relatively cheap monitoring method which can be readily installed and is a safe method of gaining strain readings.

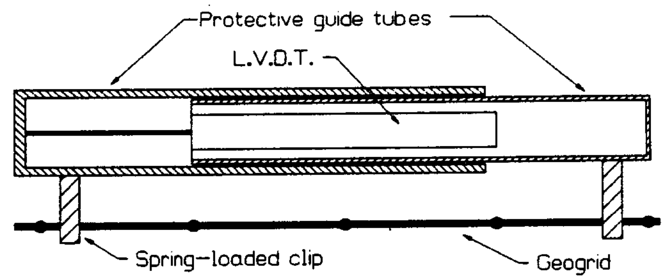

Fig. 1 Schematic view of strain monitoring device (Strains measured over 100mm gauge length via extensometers containing Sangamo DCR 15 LVDT displacement transducers with an extension range of ± 15mm)

The only potential problem with the system reported here is that the LVDT may become locked within the guide tube. Hence, some care is required during the installation of the gauges. In this study each strain measuring device was surrounded by approximately 20-25mm of sand to provide protection during the compaction of the Type 1 aggregate used in the test beds. Sufficient gauges were installed in each test so that any failure of a particular gauge would not invalidate the overall output from the monitoring system. Up to 24 gauges were used at any one time in the study and the results were recorded on a data logging system.

In this study, only one gauge length of 100mm was used. However, other gauge lengths could be readily adopted with the strain monitoring system developed. After use, the LVDTs can be salvaged and used in other studies.

3 LABORATORY STUDIES

The strain measuring system has been used to monitor the strains in full-scale tests and in laboratory studies. The application of the system in the laboratory studies is reported here to illustrate the main features of the system. The laboratory studies were developed to investigate the effect of void diameter on the development of strains in the supporting geogrids.

Fig.2 illustrates the test bed construction used in the laboratory studies. Incidentally, Fig.2 also illustrates the test bed details adopted in the full-scale field trials.

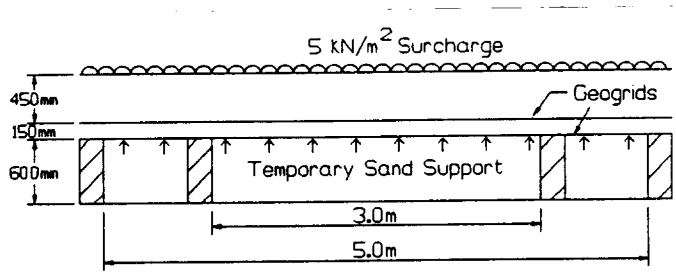

Fig. 2 Section illustrating test bed construction

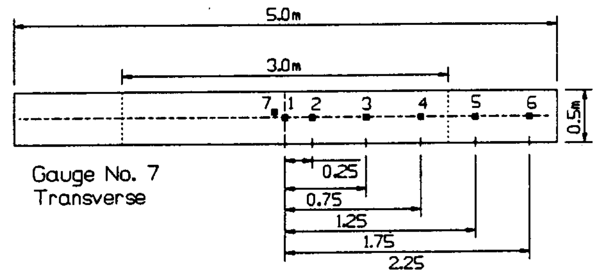

Fig. 3 Location of strain gauges

The bottom half of the laboratory test bed consists of two 600mm high walls, 0.5m wide, with a sand infill providing initial support. 25mm of sand was placed over the entire bottom half of the test bed prior to the bottom layer of geogrid being placed in position. 150mm of Type 1 sub-base was then compacted over the bottom layer of geogrid. The second geogrid was then placed in position and the remaining 450mm of Type 1 sub-base was placed and compacted in layers. Finally, a series of 20kg weights were placed on the top surface of the test bed to simulate a surcharge of $5kN/m^2$.

The strain measuring gauges were protected during installation with sand being provided in their immediate vicinity. The cables leading from the LVDTs to the data logging system were looped within the sub-base to try to prevent their destruction during the test. The locations of the strain monitoring gauges are illustrated in Fig.3.

Once the imposed loading had been placed in position the process of creating the void was initiated. A series of 25mm diameter holes had been created in the formwork supporting the sand in the area to be voided. The sand in the void zone was removed over a period of approximately 4 hours with regular readings of strains taken throughout this time. The sand was removed until the level was well clear of the geogrid holding the pavement in position. Sufficient sand was removed in each case to ensure that the creep of the geogrid would not be affected by the remaining sand in the void.

A large amount of data was gathered during the tests. In addition to the strain measurements, the following information was also recorded:

- deflection at centre-span (both grids)
- deflections at quarter-spans (both grids)
- position of tensile cracking over the supports

The tests were continued over a period of 3 to 4 days. Creep was observed to take place during this period of time for most of the tests carried out. The creep was observed from both the strain measurement and also from the deflections at mid and quarter spans. In most tests, the geogrids successfully held the imposed loads after the creation of the voids for the minimum period of 12 hours specified in the brief. Typical results are presented in the next section.

4 TYPICAL STRAIN RESULTS

Typical results for the measured strains developed over a period of three days are illustrated in Figs. 4 & 5. In this particular test the void area developed was 2m in length and two geogrids were placed in the pavement, one at the level where the void was to be created and the second at a distance of 150mm above the bottom grid. Since the void length was 2m, only gauges 1, 2 and 3 in the bottom layer and the corresponding gauges in the second layer were over the void area i.e. the remaining gauges were over the support piers.

Fig. 4 shows the strains developed in the bottom layer. Significant strains were developed in gauges 1, 2 and 3 but gauges 4, 5 and 6 showed that no strain had been developed in the grid in this location. The strains in the central gauges (1 and 2) were very similar in their initial magnitude and during the creep strain developed. A slightly reduced strain level was recorded by gauge 3 which was approximately 0.25m away from the support. It is interesting to note that virtually no strain was recorded by gauges 4, 5 and 6. Thus it can be concluded that the strain in the geogrid at this level within the test bed is dissipated rapidly once the grid passes over a supported area.

The strains in the top grid are illustrated in Fig. 5. Again, similar results in both magnitude and creep performance are observed for the gauges over the void area. A lower level of strain is observed in the gauge which is 0.25m beyond the support and thereafter the strain reduces more gradually than that observed for the bottom grid.

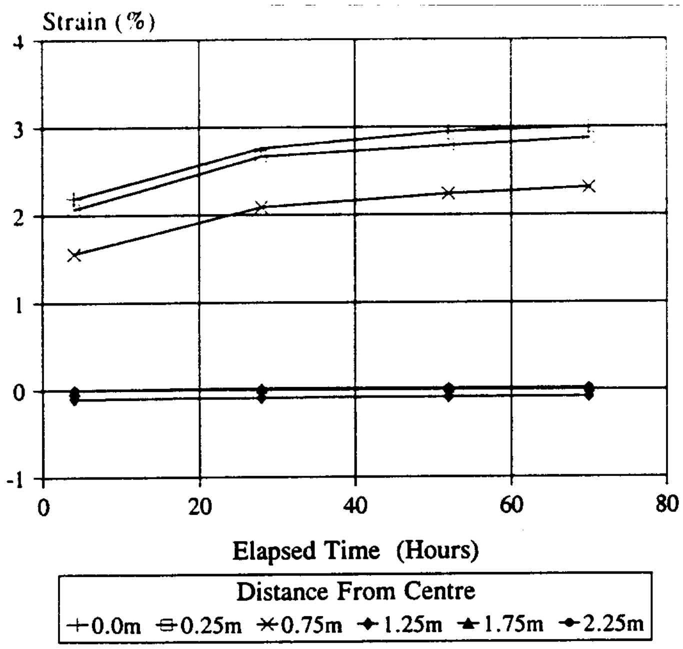

Fig. 4 Strains in base layer of geogrid for 2m void

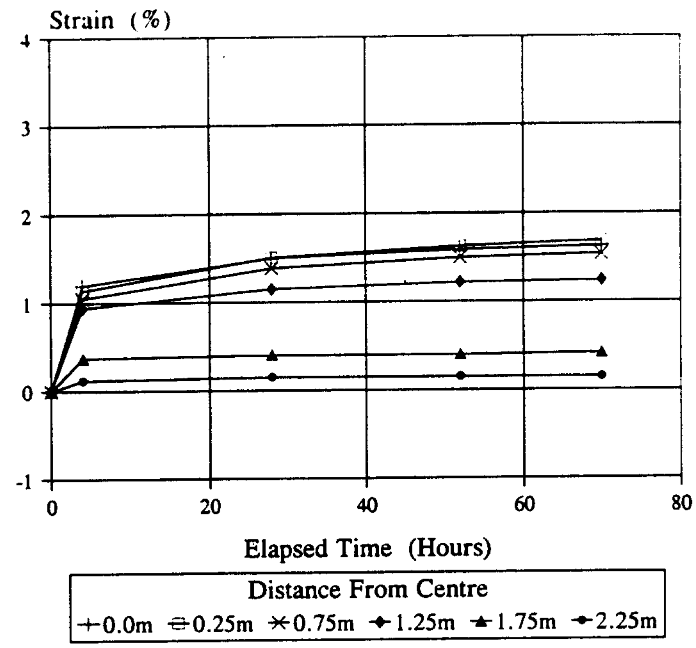

Fig. 5 Strains in upper layer of geogrid for 2m void

Figs.4 & 5 show clearly the creep strain developed in the geogrids over a period of three days. The creep strain in gauges 1 and 2 after three days was of the order of 40% of the initial strain developed over a period of approximately three hours during the excavation of the void. Large creep strains were expected to take place in the geogrids which had fulfilled their function in sustaining the imposed load over a period of 12 hours.

The strains developed in the top layer were of the order of half those developed in the bottom grid. Furthermore, the dissipation of strain over the support area was much more gradual in the case of the top grid. The information gathered in this study can be used in a back analysis of the forces developed in the test bed. Since the deflected shape of the geogrids was also monitored during the three days of testing, a full description of the geometry, loading and strains is available for analysis of the test bed. The information gained will be used to develop and refine future design procedures.

5 CONCLUSIONS

A simple, cheap robust system of direct measurement of strain in geogrids has been developed and used successfully in field trials and laboratory studies. The system is based on the direct measurement of extension or contraction over a 100mm gauge length by means of a LVDT protected by a sliding guide tube. The system has a high degree of resolution and is capable of measuring strains of up to 20%.

The strain monitoring system was developed because of its robustness during installation and, unlike electrical resistance gauges, the strain readings remain unaffected by disconnections. This is an important consideration for field investigations when a complete strain history is required but where it is impractical to leave data recording equipment permanently attached.

Typical strain results acquired during some of the laboratory testing programme are presented. The laboratory tests were carried out primarily to study the effects of varying void diameter, in the range 2m to 4m, and the number of layers of geogrids to be used in typical pavements. The strain monitoring system provides a full record of the development of the strains during void formation together with the creep history of the geogrids. The information provided, together with deflection measurements, allows a full back analysis to be carried out on the test beds investigated.

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