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Effect of ground temperature fluctuations in reinforced embankment studies

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ABSTRACT: The use and the calibration of strain gages on polyethylene geogrids in a geogrid reinforced embankment research are described. Laboratory studies on the calibration of strain gages for ground temperature fluctuations, as prevalent in cold climates, revealed that the temperature affects the strain gage readings more than presumed. The results of this study showed an increase in gage readings resulting from the combined thermal properties of the strain gage, the adhesive and the geogrid specimens for decreasing temperatures, independent of applied axial-stress. It implies that the strain gage may record higher strain than the actual strain when exposed to temperatures below its installed room temperature. The study emphasizes that it is imperative to calibrate the strain gages for temperature variations.

1 INTRODUCTION

The existing research on soil reinforcement interaction has attempted numerous approaches to study several proposed limit equilibrium design concepts. This study carried out in July 1990 on the campus of the University of New Brunswick, Fredericton investigated the performance of one such geogrid reinforced embankment based on the equal force theory. The 6m high geogrid reinforced slope was instrumented with 36 strain gages on five geogrids at four levels, two thermocouples, an inclinometer and an open stand pipe. Field monitoring was carried out during and after construction of the slope (Randeniya, 1991).

The study stressed considerably on the observations of the strain gages and the analysis of its data to examine the soil-reinforcement interaction. However, at the outset it was envisaged that the temperature influenced the monitoring of the strain gages in the present field program. The yearly recorded ambient temperature range for the Atlantic Canada is in the range of 34 ^{0}C to -25 ^{0}C. Therefore, to measure the anticipated variations in ground temperature two thermocouples were installed in the proximity of the instrumented geogrids. Hence, a study was undertaken to calibrate for the temperature variations in addition to the routine tensile strain calibration.

2 STRAIN GAGE TYPE AND INSTALLATION

The preference of strain gages in this study to measure longitudinal compressive or tensile strains at a selected point was based on the ease of installing these at a relatively lower cost. The foil type EA-13-125BT-120 strain gages manufactured by M-M Measurements Group Inc., Raleigh, NC (USA) were installed in a similar fashion as described by Bathurst (1990) on the geogrid.

In the preparation of samples with strain gages, the methodology for installation was same as for the field program and these were installed on the top and bottom of rib sections of geogrid (Figure 1). The surface was sanded and cleaned; the bondable terminal type CEG-75C (Measurements Group, Inc., USA) and a strain gage was placed next to each other in the longitudinal direction with the terminals facing upwards. A piece of cellophane tape was place on top to hold both strain gage and terminal in place and the unit was placed on the cleaned geogrid surface. Strain gage adhesive M-Bond GA-2 (epoxy resin) and curing agent 10A (diethylene triamine) manufactured by Measurement Group, Inc. were employed for the purpose. The specified mix was applied between gage and terminal and the geogrid surface. To ensure good bonding, clamps were used with Teflon pads as protective cushions to prevent damage to the gage. The clamps were left in place for approximately 12 hours before they were removed.

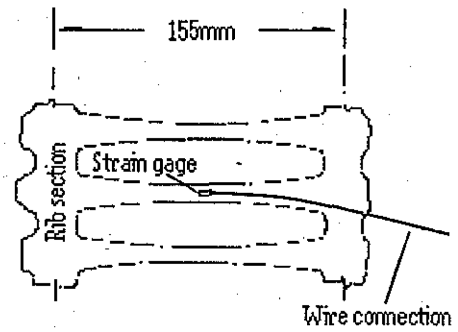

Figure 1 Arrangement of strain gage on the geogrid strip

The adhesive is the recommended type for bonding gages to the base material and also its selection resulted from its performance after several trials against another commercially available adhesive. Short transformer wires (15mm long) were used to connect each terminal to the strain gage. These were soldered with great care to avoid damaging the gages. A M-Coat D Air drying acrylic waterproof coating (Measurements Group Inc.) was applied to cover all connections and circuits.

The recorded room temperature range at which the installations were carried out was between 20 ^{0}C to 24 ^{0}C, the significance of this is detailed later. The Wheatstone bridge circuitry that was produced for the measurement of strain was a quarter bridge circuit using three resistors available in the strain measuring device VISHAY/ELLIS 20 digital strain indicator unit.

3 CALIBRATION TESTS

The calibration tests also stemmed from the following facts: 1) information relevant to the behavior of strain gages and adhesive with respect to temperature change can only be used for 2024-T4 Aluminum surfaces as given in ***M-M Engineering Data Sheet for Precision Strain Gauges*** and 2) lack of research documents pertinent to the performance of the adhesive on High Density Polyethylene (HDP) geogrid surfaces. The ASTM-E251 (1990) recommended procedure for calibration was not considered since no allowance for the temperature variations is made as in this case.

For the calibration it was fundamental to consider the complications emerging from the two variables, the tensile force and the temperature, transpiring simultaneously in the field. A simplistic approach was adopted to exclude one of the variables by maintaining one variable constant while the other was varied. In this instance the temperature was varied with the possibility of two constant conditions being applicable; either zero force or a constant tensile force.

The combined response to temperature of all three components: the strain gage, the adhesive and the HDP geogrid was viewed as having independent expansion and contraction properties relative to the temperature variation. However, since the objective of this study was to find calibration factors to analyze the field

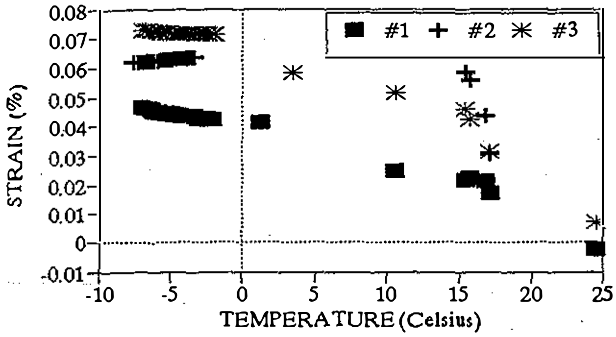

Figure 2 Measurement of 3 samples for varying temperature

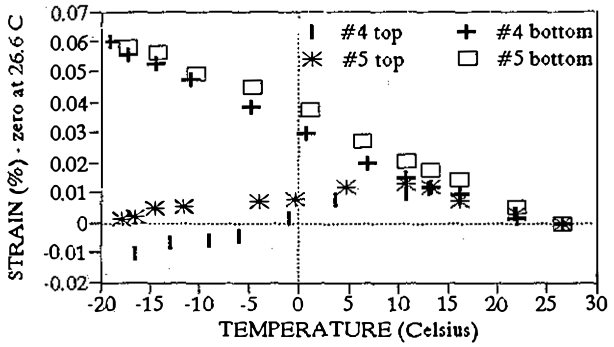

Figure 3 Measured variation of the two dual gage samples

readings it was decided not to consider their individual thermal reaction which may if considered may complicate the calibration. A series of tests were carried out to evaluate the combined behavior of the strain gage, the adhesive and the geogrid as one unit, for a range of temperatures from 30 °C to -20 °C, extending well beyond the measured ground temperature variations.

3.1 Test series I

The Test series 1 (with no axial force) was conducted on three geogrid strips with gages on one side. The specimens were placed horizontally on a level surface inside the temperature controlled chamber with gages facing upwards. A pair of thermocouples was attached to the strips as consistent with the field program. These were connected to the same strain indicator and thermometer which were used for the field monitoring in order to eliminate any indifference between the field readings and laboratory measurements.

The temperature in the chamber was increased to 24.4 °C and the strain gages were balanced. Thereafter, the temperature was reduced to -8 °C and the strain was recorded as a function of decreasing temperature at a constant rate of about 2 °C per minute.

The results are presented in Figure 2. It indicates that for decreasing temperatures the strain increases with a sudden change at about 16 °C. This can be inferred as the non-instrumented surface contracting at a faster rate than the instrumented surface, creating compression and a curling or bending effect. It is suspected that the instrumented upper surface experienced tension as indicated by the increase in strain gage readings. Test series 2 was undertaken to confirm this supposition.

3.2 Test series 2

Two additional samples were prepared with strain gages attached to both sides and the three samples from Test series 1 were also used in this test . It was intended here to provided equal thermal expansion or contraction properties on both sides of the geogrid, thus reducing the suspected curling effect. All five samples were tested in the same way as Test series 1, and the temperature range this time was 26.2 °C to -20 °C.

Figure 3 show the results of Test series 2. The strips with dual strain gages measured both compression and tension confirming the earlier finding. As observed before, a significant change occurs around 16°C for the single strain gage sample and close to 12 °C for the dual gage samples.

The HDP begins to curl significantly more at this temperature range and it is apparent that the rising indicator readings up to these temperatures are no longer a function of the thermal properties of the HDP but a combined function of the adhesive and the strain gage.

An integral part of both Tests 1 and 2 was the natural tendency of geogrid strips to remain partially curled under any working environment. Consequently, this may have further enhanced the observed curling or the bending behavior of the strips. However, questions were raised whether the same would occur under field conditions where such curling effects can not be anticipated due to the applied static loads. Test series 3 was performed with the application of axial force to the strips to eliminate such curling effects.

3.3 Test series 3

The strategy for this test series involved the application of load(s) to the geogrid strips primarily to eliminate any natural curling effects which may be occurring during the temperature changes. Application of a constant load to the specimen appeared sufficient to give an affixed value on the strain indicator for that load (Figure 4). It was viewed that any noticeable change on the strain indicator during the temperature change must be attributed to the thermal behavior of the adhesive which holds both the strain gage and polyethylene in place.

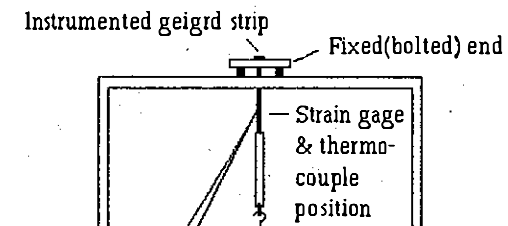

Figure 4 Test apparatus for test series 3

The loads applied to the samples were determined from the tensile tests. From these tests, it was decided to apply loads of 5, 10 and 20 kgs per strip. (The weight of the hanger was 0.45 kg and this was included in the applied load). This is equivalent to loads of 2.06, 4.12 and 8.24 KN/m (ie. 56% of design load) applied on the reinforcement. However, the work done by Greenwood (1990) on Tensar SR2 indicate that for 50-60% of design load a strain as low as 2.5% for short term load of 1 hour shows a difference of 1.2% with the 10,000 hour load test. Therefore, proportionally the intended loads for the calibration test on the strips of SR1 would be sufficiently within this limit and should exhibit a similar behavior.

Test series 3 required newly installed strain gage geogrid samples, with rib sections to serve as grips for the applying tensile load. As for Test series 1, the strain gages were placed only on one side as no curling or bending was anticipated. In all, five samples were prepared for this test series.

The arrangement for testing involved placing a loading frame in the temperature chamber. Several methods of load application were considered, drawing from the fact that the smooth HDP geogrid surface could cause slippage at the grips under applied load. There were two ideal possible alternatives, to have rough or spiked grip or to make a small hole in the center of the rib. The latter approach was adopted. The size of the hole (3.5mm) to be drilled was resolved after compromising between the available space for bolts and several trial holes made on similar geogrid samples, and loading them to examine if the opening would undergo any deformation.

The initial load of 5 kg was placed on the hanger. The gage readings were recorded and this value was compared with the value from the tensile tests to examine whether the gage was performing within the expected limits. The comparison showed that it was sufficient to continue the test.

The balancing of the gage and the indicator was done at room temperature of 18 ^{0}C without any load. This meant increasing the temperature and subsequently lowering it to calibrate for the test range. (Attempts were made by reversing the process to observe whether the increase in temperature from the lowest temperature would produce the same outcome. The results gave inconsistent readings and the attempt was abandoned).

The procedure was repeated for the remaining four samples for further loads of 10 and 20kg. The obtained results are presented in Figure 5.

The results presented a good relation among all samples for the applied loads. In order to correlate with the tensile test calibration and for the eventual use in the calibration of field data a reference indicator reading at 20 ^{0}C was taken as zero.

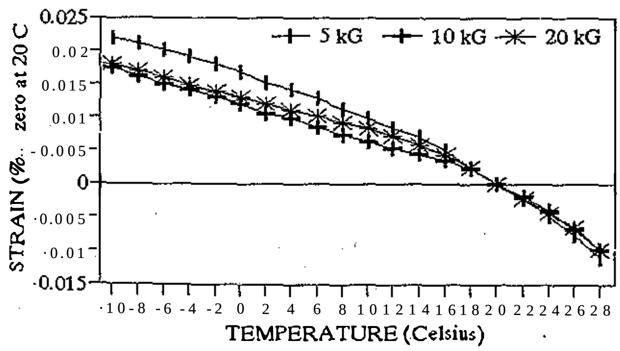

Figure 5 Mean variation of 5 samples for applied loads 5, 10 and 20 kgs respectively

This test also confirmed a change in the slope around 16 ^{0}C, which was much more prominent than observed in test series 1 and 2.

4 DISCUSSION

From Test series 1 and 2 it was inferred that the increase in gage readings resulted from indifferent contraction rates of the gage, adhesive and the HDP. Test series 3 indicated the sensitivity of the entire unit to temperature variation as required for calibration purposes in this research. Additionally, this test series also confirmed the findings of the previous two tests, fostering the view that the polyethylene may have a lower thermal contracting property than both the strain gage and the adhesive.

An explanation to the observations lies in the role of the adhesive which acts as the intermediary medium in transferring the strain from the geogrid to the gage. Under a constant temperature environment the behavior of the unit is conventional, all movements are thus relative. The hypothesis of this study, however, is that in the event of any temperature decrease the adhesive contracts at a faster rate than the gage causing it to contract along with the adhesive. The manner in which this phenomenon could accommodate within the thin element is for the gage to bulge while being adhered to the adhesive by overcoming the contraction character of the strain gage,thus increasing its length to indicate tension.

The apparent change around 16 ^{0}C (Figures 5) can not be adequately explained at present without performing comprehensive tests. However, this change was not considered sufficiently relevant to hinder the overall outcome of the study, nevertheless it was seen as an inherent property of the entire unit.

The findings of this study were confirmed from the field monitoring program where the slope was not subjected to any external pressures throughout the monitoring. The observations of the strain gages continued to increase in small amounts with decreasing ground temperature (Figure 6). Although the ground temperature did not fall below 4 ^{0}C the field observations were within the laboratory measurements for the monitored temperature range.

The apparent changes heavily depended on the type of gage and the adhesive and could be prominent. A large percentage of today's geogrid research seeks to investigate the failure criteria

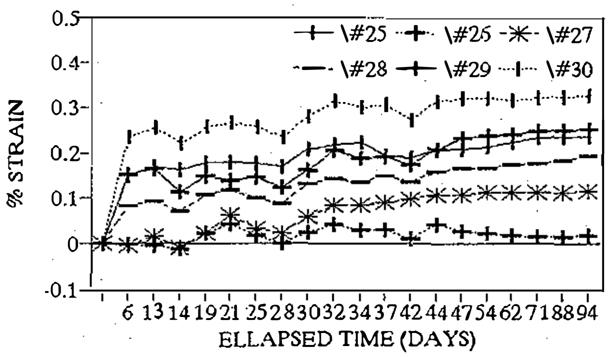

Figure 6 Observed strain profile of individual gages of an instrumented geogrid placed at mid section of the slope

and ensue the soil-geogrid interaction at the limit state. In such research where geogrid strains are measured, and presuming that temperature changes exist, the measured readings may give rise to misleading interpretations.

It is worth underlining that this study comprised of limited equipment to model the prevailing ground temperature variations with better flexibility of selectable rates of temperature change. Therefore, it is difficult to envisage how the unit would behave under transient temperature environments. Nevertheless, it is understood that in most circumstances geogrid research is not carried out in environments where sudden temperature change occur. As the field observations of this study suggest the ground temperature change is slow and gradual, and no temperature change greater than 3 ^{0}C per day could be anticipated.

5 CONCLUSION

This study demonstrated that use of strain gages in any geogrid research where the temperature is a factor in the environment, the gage readings are considerably affected by change in temperature.

Its significance may be most distinct when measuring critical strains. The tests described in this paper are preliminary and therefore, further tests are necessary to establish exact cause for the observed behavior. The study emphasizes that it is imperative to calibrate the strain gages for temperature variations in addition to routine tensile tests.

REFERENCES

ASTM 1990: Standard test methods for performance characteristics of bonded resistance strain gages. E251-67, 428-444.

BATHURST, R. J. 1990. Instrumentation of Geogrid-Reinforced Soil Wall. Transport Research Record No. 1277,National Research Council, Washington, D.C.

GREENWOOD, J. H. 1990. The creep of geotextiles. Proceedings, 4th International Conference on Geotextiles, Geomembranes and Related Products, Hague, Holland, pp. 645-650.

MICRO - MEASUREMENT ENGINEERING DATA SHEET. General information on EA series precision strain gages. Measurements Group, Inc. Releigh, NC, USA.

RANDENIYA, R. 1991. Performance and Predictions of an Instrumented Geogrid Reinforced Embankment. MScE. Thesis, University of New Brunswick, Canada.