EFFECT OF SOIL TEMPERATURE CHANGES ON GEOGRID STRAINS

S.Zarnani[1], J.D.Scott[2] and D.C.Sego[3]

[1]M.Sc. Student, Geotechnical Group, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada, T6G 2G7, PH (780) 492-8097; FAX (780) 492-8198; email: szarnani@ualberta.ca

[2]Professor Emeritus, Geotechnical Group, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada, T6G 2G7, PH (780) 492-2636; FAX (780) 492-8198; email: jdscott@ualberta.ca

[3]Professor, Geotechnical Group, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada, T6G 2G7, PH (780) 492-2059; FAX (780) 492-8198; email: dave.sego@ualberta.ca

Corresponding Author: J.D.Scott, Professor Emeritus, Geotechnical Group, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada, T6G 2G7, PH (780) 492-2636; FAX (780) 492-8198; email: jdscott@ualberta.ca

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ABSTRACT

Temperatures were measured along instrumented geogrids to determine thermal strains and their changes with seasonal temperatures. The geogrids did not undergo thermal strains because of soil confinement and instead developed thermal stresses.

Key words: Temperature, Geogrid, Thermal strain, and Thermal stress

INTRODUCTION

The first author is presently performing a graduate student research thesis on the long-term performance of instrumentation installed in a geogrid test embankment in 1986. Vertical and horizontal inclinometers and extensometers, settlement points and piezometers monitored the behavior of the soft silty-clay fill while electrical wire resistance (EWR) strain gauges, Bison induction coil strain gauges and thermocouples monitored the behaviour of the geogrids. Three different types of geogrids were installed in the 12 m high test embankment at different test sections and three layers of each geogrid were instrumented. Monitoring of the embankment continued to 1990 when soil and geogrid deformations had reached a steady state condition. The present research program was initiated in 2003 to determine how the instrumentation had survived over the past 13 years and if sufficient instrumentation was still operational, how the test embankment and geogrids had performed during this period.

TEST EMBANKMENT AND GEOGRID PROPERTIES

Details of the geometry and construction of the test embankment and the instrumentation are given in Liu *et al.* (1994) and in Zarnani *et al.* (2004b). The properties of the three geogrids are summarized in Table 1. The nine instrumented geogrid layers each contained from 9 to 12 strain gauges for a total of 97 strains gauges. Of these, only 14 are not working now for a survival rate of 85%. Details of the EWR gauges and their installation are given in Zarnani *et al.* (2004a). The analysis of the geogrid performance during the last 13 years is presently being performed.

TEMPERATURE CHANGES IN THE TEST EMBANKMENT

Thermocouples were installed with each strain gauge to measure the temperature whenever strain gauge readings were taken. Their purpose was to allow the strain readings to be corrected for thermal strains so the strains from the tensile forces in the geogrids could be isolated. These strains could then be used to calculate the tensile forces in the geogrids.

Temperatures in the Edmonton area are from a high of 35°C in the summer to a low of –35°C in the winter. These temperature changes are of course moderated with depth in the embankment. Figure 1 shows four typical temperature measurements on one of the geogrids. Temperature changes take place along the full 12 m length of the geogrid. The temperature variation with depth is shown in Figure 2 for all nine instrumented geogrid layers. At each test section, instrumented geogrids are at heights of 1 m, 3 m and 5 m above the base of the embankment. The values in Figure 2 were averaged from more than 20 sets of readings at different times of the year. The temperature varies about 18°C one-half meter into the fill and beyond 8 m into the fill, the variation is only about 5°C. A considerable time lag in temperature change between the air temperature and the soil temperature occurs with distance into the embankment as shown in Figure 3.

At 1 m it is about 25 days while at 11 m it is over 200 days. This complex temperature variation with distance from the slope surface indicated that the pattern of thermal strains along the geogrids would be constantly changing and would necessitate detailed corrections to the measured strains.

DUMMY EWR STRAIN GAUGES

EWR strain gauges were attached to short pieces of geogrid following the same procedures as used on the instrumented reinforcement and installed in the fill in the same manner. The purpose of these gauges was to evaluate the influence of the wet soil environment, the soil confining stresses, the temperature and the readout instrument on the performance of the gauges and to provide correction factors for the geogrid gauges associated with these environmental influences. These dummy gauges were places at each instrumented geogrid layer at 0.5, 1.0 and 5.0 m from the slope surface. As for the geogrid strain gauges, the first reading following placement of a 15 cm soil layer on the geogrid was taken as an initial reading and is subtracted from all subsequent readings. The dummy gauges were placed adjacent to thermocouples so temperature influences could also be evaluated.

Figure 4 (a) shows the change in strain readings on one EWR dummy gauge at a 1 m depth during the 17 years since it was installed. Note the change in the time scale for the 13 years when no readings were taken. These readings are the actual readings with no correction for thermal strains due to temperature changes. The variation in readings is only ±0.10% strains. Figure 4 (b) contains the actual temperatures at the dummy gauge.

In order to estimate thermal strains developed in geogrids due to variations in temperature, thermal expansion tests were conducted in the laboratory. EWR strain gauges were bonded to pieces of geogrid material in the same manner as they were bonded for use in the test fill. Strains were measured at different temperatures under stress free condition (without any soil confinement and tension of the geogrid). The linear coefficients of thermal expansion of the geogrids obtained in these tests are shown in Table 1.

To compensate for the thermal expansion or contraction of the geogrid, the thermal strain was calculated by multiplying the change in temperature by the linear coefficient of thermal expansion. This thermal strain was then subtracted from the measured strain. Figure 4 (c) shows the corrected strain readings for the gauge in Figure 4 (a). These corrected strains are a mirror image of the temperature and show more variation than the uncorrected readings

All 27 dummy gauges worked well during construction and are still giving consistent readings. These dummy gauges show that the gauges, leads, connection boxes and readout box are all performing satisfactorily during this 17-year period. Figure 5 shows all the readings to date without any temperature correction. Variation in readings after 17 years is only ± 0.10% strain. Figure 6 shows all the readings with the temperature correction applied. The variation in readings is ± 0.30% strain. Therefore, when the dummy gauge readings are corrected for geogrid thermal expansion and contraction the variation in strain readings in considerably larger. It appears that a geogrid temperature correction is not applicable. The confining stress of the soil must prevent the geogrid from undergoing thermal expansion or contraction and as a result the strain of the geogrid is over or under estimated when a temperature correction is applied.

EFFECT OF SOIL CONFINING PRESSURE

As with much research, when the results are finally achieved they appear obvious. The linear coefficients of thermal expansion of all 3 geogrids are listed in Table 1 and vary from 11 x 10^{-5} to 27 x 10^{-5} per °C. Soils and rocks generally have a linear coefficient of thermal expansion of about 1 x 10^{-5} per °C only a small fraction of that of polymers. If no slippage occurs between the soil and geogrid, then the geogrid cannot significantly change length from temperature change. The water in the soil has a volumetric coefficient of thermal expansion of about 21 x 10^{-5} per °C but the temperature changes occur so slowly that flow of the water into air voids in the unsaturated compacted soil can take place. This volumetric change of the water may have an effect on the pore fluid pressures in the soil but not significantly on the soil volume.

As the geogrids are prevented from undergoing thermal strain by the confining soil, they will develop thermal stresses. The thermal stress, σ_t, can be calculated from the following equation:

$$\sigma_t = \frac{E\alpha}{(1-\nu)} \Delta t \quad \text{kN/m}$$

where E = elastic modulus in kN/m

α = linear coefficient of thermal expansion

ν = Poisson's ratio

Δt = change in temperature

The elastic moduli for strains below 1% are given in Table 1 for the three geogrids and vary from 500 to 1800 kN/m. These values were obtained from the tensile force – strain test results shown in Figure 7. For most polymers, Poisson's ratio is about 0.4. For a temperature change of 18°C, the thermal stress will vary from 1.6 kN/m to 14.6 kN/m as shown in Table 1. The actual thermal stress will depend on the temperature change from the time of installation of a geogrid and could be compressive or tensile.

CONCLUSIONS

1. Geogrids confined with soil do not undergo thermal expansion or contraction from temperature change if slippage between the soil and geogrid cannot occur.
2. Thermal stress or thermal force will occur in the geogrids with the magnitude depending on the elastic properties, temperature change and linear coefficient of thermal expansion.

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Zarnani, S., Scott, J.D. and Sego, D.C., 2004a, "Long Term Performance of Geogrid Strain Gauges." 57th Canadian Geotechnical Conference, Quebec City, Canada, In Press

Zarnani, S., Scott, J.D. and Sego, D.C., 2004b, "Geogrid and Soil Strains in a Reinforced Slope." GeoFrontiers 2005 Conference, Austin, Texas, In Press

List of Tables:

Table 1. Properties of Geogrids

Geogrid		Signode TNX5001	Paragrid 50S	Tensar SR2
Type of Polymer		Polyester	Polyester polypropylene	High Density Polyethylene
Structure		Rectangular grid	Square grid	Uniaxial grid
Junction Type		Welded	Welded	Planar
Aperture Size (mm)	Machine Direction	89.7	66.2	99.1
	Cross Machine Direction	26.2	66.2	15.2
Open Area (%)		58	78	55
Linear Elastic Modulus 0 to 1% strain (kN/m)		1800	500	1100
Linear Coefficient of Thermal Expansion (°C×10^{-5})		27	11	17
Thermal Stress from $\Delta T=18°C$ (kN/m)		14.6	1.6	5.6

List of Figures:

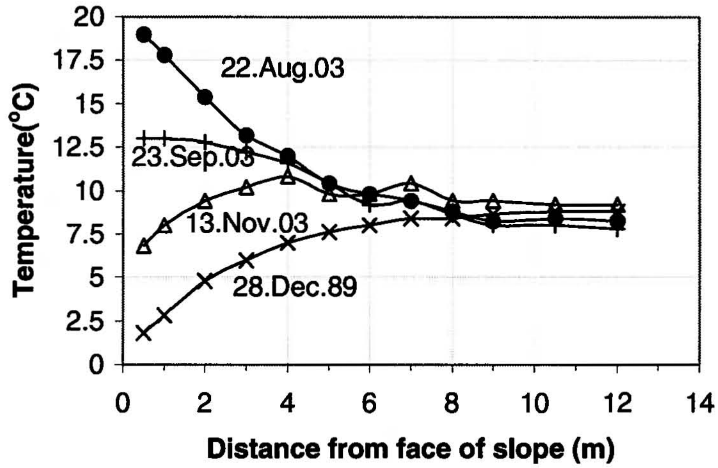


Figure 1.Temperature variation along a geogrid

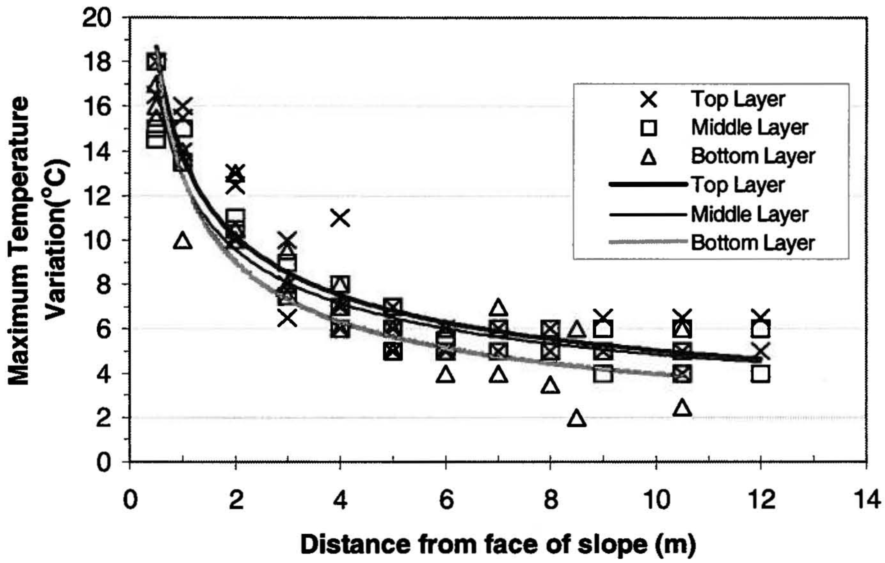


Figure 2. Maximum Temperature Variation Along Geogrids

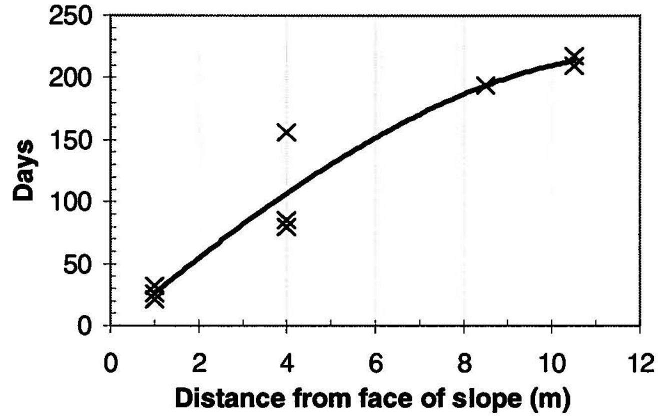
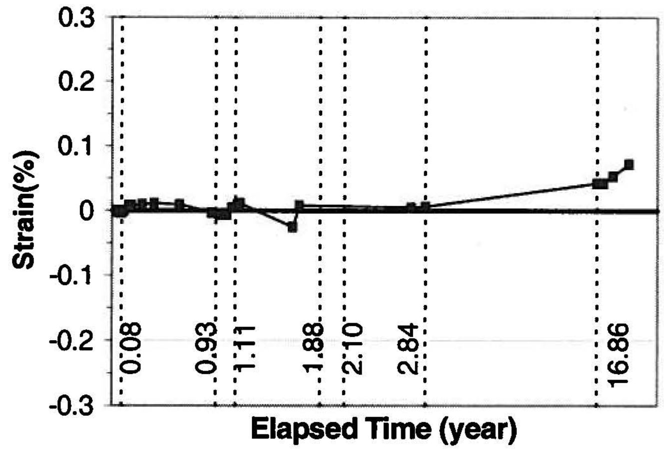
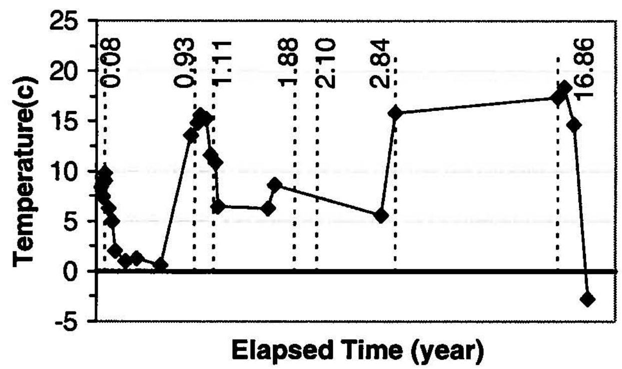


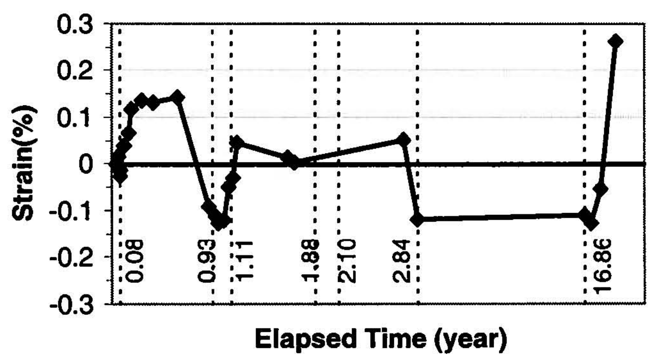
Figure 3. Time Lag of Temperature Change



a) Strain without temperature correction



b) Temperature



c) Strains with temperature correction

Figure 4. Dummy Gauge at 1 m from Face of Slope

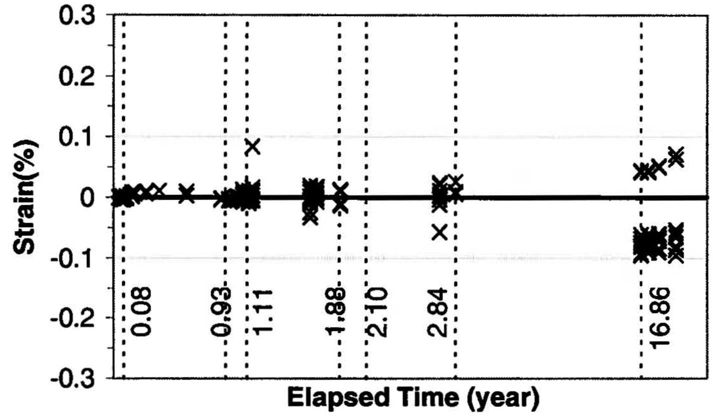


Figure 5. All dummy gauges without temperature correction

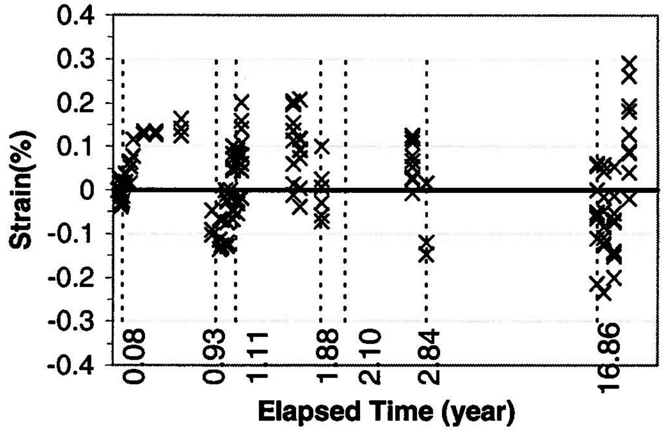


Figure 6. All dummy gauges with temperature correction

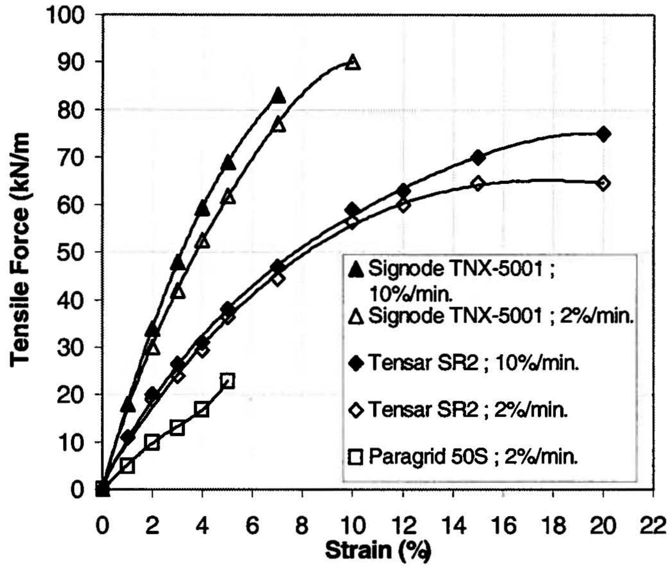
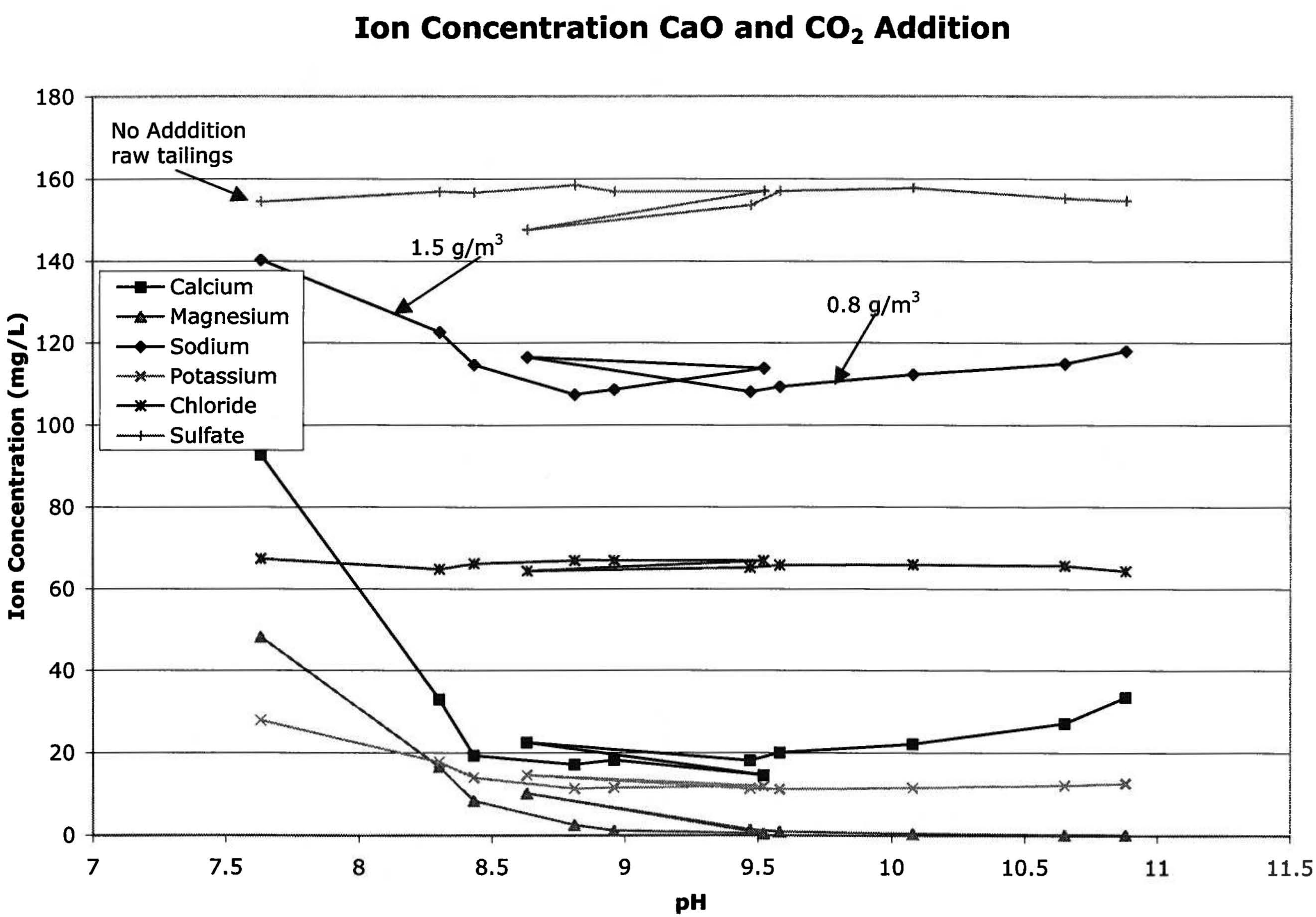


Figure 7. Force-Strain Tests on Geogrids


Ion Concentration CaO and CO2 Addition
No Adddition
raw tailings
1.5 g/m3
0.8 g/m3
Calcium
Magnesium
Sodium
Potassium
Chloride
Sulfate
Ion Concentration (mg/L)
pH
180
160
140
120
100
80
60
40
20
0
7
7.5
8
8.5
9
9.5
10
10.5
11
11.5