ARTICLE IN PRESS

Geotextiles and Geomembranes xxx (2017) 1–11

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

A method for correcting field strain measurements to account for temperature effects

Christopher L. Meehan*, Majid Talebi

University of Delaware, Dept. of Civil and Environmental Engineering, 301 DuPont Hall, Newark, DE 19716, USA

A R T I C L E I N F O

Article history:
Received 30 June 2016
Received in revised form
20 February 2017
Accepted 26 February 2017
Available online xxx

Keywords:
Geosynthetics
Geosynthetic reinforced soil
Foil strain gauge
Wire
Temperature effects
Thermistor
Wheatstone bridge

A B S T R A C T

Measurements of deformation and strain are of critical importance for the structural health monitoring of geosynthetic reinforced soil (GRS) structures. For some commonly used wiring configurations and sensors, field strain measurements can exhibit apparent strains that are caused by changes in wire temperature or changes in gauge temperature, which do not correspond to changes in actual strain in the geosynthetic. Correcting for these effects is important for separating out real structural behavior from wiring and sensor issues, and is imperative for avoiding false trigger warnings in automated instrumentation reporting systems. The current paper consequently presents a method for correcting field strain measurements to account for temperature effects. Data collected from sensors embedded in a heavily-instrumented GRS abutment over a two-year monitoring period is presented. The distributed thermistor array embedded in the GRS abutment is shown to be particularly useful for understanding temperature effects on the measured foil strain gauge data. The presented approach and associated framework for data correction are useful for practicing engineers and other researchers, as the general concepts from this study can be applied to data collected from many instrumented geosynthetic field projects.

1. Introduction

Field sensors play an increasingly important role in civil engineering projects, as advances in data acquisition techniques and wireless (cellular) data logging approaches have allowed for remote, real-time structural health monitoring (e.g., Brownjohn, 2007; Fraser et al., 2009; Hu et al., 2013). Measurements of deformation or strain have historically played a critical role in assessing the behavior of geotechnical structures in the field, and may even allow for development of "early warning" systems that can provide indications about a catastrophic failure before it occurs (e.g., Lee and Wu, 2004; Intrieri et al., 2012; Lehtonen et al., 2015; Ong et al., 2015). Proper signal processing algorithms and corrections for the effect of temperature are critical for accurate reporting of measured field strains, and are essential to avoid reporting of "false positives" during structural health monitoring – i.e., the reporting of incorrect large displacement or high strain events that are in fact due to electrical or temperature issues (e.g., Hall and Deighan, 1986; Khan and Wang, 2001; A-iyeh, 2013). These type of "false positive" events can lead to mistrust of the accuracy of a field monitoring system post-installation, which can reduce attention to future system warnings, and increase response time if a failure event is impending or in the process of occurring.

Numerous failures of reinforced earth structures such as mechanically stabilized earth (MSE) walls, geosynthetic reinforced soil (GRS) walls, or geosyntethic reinforced slopes have been documented in the engineering literature (e.g., Yoo and Jung, 2006; Hossain et al., 2011; Liu et al., 2012; Xue et al., 2014; Miyata et al., 2015). The use of these structures has generally become quite widespread for many different retained soil applications, due to their many performance and cost saving benefits (e.g., Adams et al., 2011; Yonezawa et al., 2014; Costa et al., 2016). Unfortunately however, the failure rate of these structures is generally significantly higher than other geotechnical engineering structures, which is generally attributed to poor design, poor construction, poor backfill compaction, or the existence of internal or external water (e.g., Koerner and Koerner, 2013; Valentine, 2013). Consequently, the use of structural health monitoring systems for reinforced earth structures may provide many practical benefits for owners or engineers that are responsible for the performance of the

* Corresponding author.
E-mail addresses: cmeehan@udel.edu (C.L. Meehan), mtalebi@udel.edu (M. Talebi).

http://dx.doi.org/10.1016/j.geotexmem.2017.02.005
0266-1144/

structure over the long-term.

When performing internal strain monitoring of reinforced earth structures, it is common practice to measure the strain of the reinforcing elements at various locations, whether they be metal strips, geogrids, or woven or non-woven geosynthetics (e.g., Walsh et al., 2009; Leshchinsky et al., 2010; Stuedlein et al., 2010; Warren et al., 2010; Horpibulsuk et al., 2011; Jiang et al., 2016; Nicks et al., 2016). A variety of strain gauge technologies have historically been utilized for this purpose, including vibrating wire strain gauges (electrically based), foil strain gauges (electrically based), and fiber Bragg grating gauges (fiber optic based) (e.g., Ma and Wu, 2004; Briançon et al., 2006; Allen and Bathurst, 2013a, 2013b). Various strain gauge attachment techniques have been employed to affix the sensors to the reinforcement, which generally correspond to the type of strain gauge that is being used, and the type of reinforcement material that the gauge needs to be attached to (e.g., Sluimer and Risseeuw, 1982; Leshchinsky and Fowler, 1990; Berkheimer, 2007; Won and Kim, 2007; Walsh, 2009).

This paper presents localized strain results measured for a heavily instrumented geosynthetic reinforced soil (GRS) bridge abutment, which was constructed as part of an integrated bridge system (IBS) (e.g., Adams et al., 2011). More detailed information about this project, the first GRS-IBS structure deployed in the state of Delaware, is available in Talebi et al. (2014a, 2014b). Foil strain gauges were selected for strain monitoring for this project, following recommendations made by Warren et al. (2010). Given the difficulty that has historically been observed with attaching strain gauges to GRS-IBS reinforcement (e.g., Warren et al., 2010), two different strain gauge attachment techniques were utilized for this project (Leshchinsky and Fowler, 1990; Wu et al., 2013), with each strain gauge point of monitoring having two independent measurements of strain. Temperature measurements were also made at each strain monitoring location using embedded thermistors.

Data collected using the embedded strain gauges and thermistors, ambient temperature monitoring instrumentation, and a variety of other sensors together provided extremely useful information about the overall performance of the GRS-IBS (Talebi, 2016). Using the recorded data, a method for correcting field strain measurements to account for temperature effects was developed. The presented approach is useful for engineers that need to correct measured foil strain gauge results for the effect of temperature under complex field conditions.

2. Project details

Talebi et al. (2014a, 2014b) present details about the design and construction of the first GRS-IBS project in Delaware, which was built in 2013. Fig. 1 shows a cross-section through the west GRS abutment that was constructed for this project, along the roadway centerline. The geosynthetic that was utilized for this project was a polypropylene woven fabric geotextile, which had an ultimate tensile strength of 70 kN/m in both the machine and cross-machine directions (Product HPG-57, which was provided by Hanes Geo Components, of Winston-Salem, North Carolina). A custom-built structural health monitoring system was deployed for this project, with more than 100 sensors being monitored during construction and over an extended period of time post-construction (Talebi et al., 2014a, 2014b; Talebi, 2016). Strain and temperature monitoring locations in the west abutment are shown in Fig. 1, with all of the points that are shown being located along the roadway centerline.

At each monitoring point shown in Fig. 1, two different strain gauges and attachment techniques were utilized to instrument the geosynthetic reinforcement layers, with the goal being to have

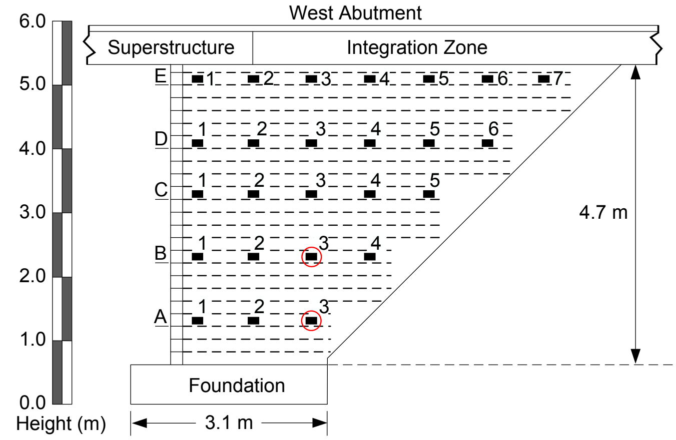

Fig. 1. Typical section of the west GRS-IBS abutment, along the roadway centerline. Strain and temperature monitoring locations along select geosynthetic layers are shown.

independent and complimentary measures of strain (as shown in Fig. 2 for location B1). For the first strain monitoring technique, a "long" strain gauge (5.71 cm, Vishay Micro-Measurements EA-06-20CBW-120) was attached following the general methodology outlined by Leshchinsky and Fowler (1990). For the second strain monitoring technique, a "short" strain gauge (0.95 cm, Vishay Micro-Measurements EP-08-250BG-120) was attached following the general methodology outlined in Talebi (2016), in accordance with recommendations made by Wu et al. (2013). Step-by-step photos of the attachment process and additional details about the adhesives and other materials used for gauge attachment and waterproofing are discussed in more detail in Talebi (2016).

A thermistor was also installed at each monitoring location shown in Fig. 1, to investigate the effect of soil temperature changes on the strain readings. Ambient air temperature conditions were measured using a thermistor positioned at the location of the project dataloggers. In total, these sensors provided an accurate picture of spatial changes in the temperature within the GRS abutment that occurred in response to changes in ambient temperature conditions, on a daily and seasonal basis.

3. Measuring geosynthetic strains using foil strain gauges

Traditional foil strain gauges relate physical deformation over the length of the gauge (strain) to changes in electrical resistance across the gauge resistor (Fig. 3a). Changes in temperature of the gauge itself alter its inherent electrical resistance, leading to different relationships between strain and resistance for different gauge temperatures (e.g., Vishay Micro-Measurements, 2007). Consequently, it is necessary to correct measured resistance values for the effect of temperature to get consistent and accurate measurements of strain from the gauge. Additionally, in common usage, strain gauges are part of a larger electrical circuit that involves an input signal wire, an output signal wire, and a datalogger (Fig. 3b). Changes in temperature of the input and output wires also affects their internal electrical resistance, leading to changes in the overall resistance values that are measured by the datalogger; these changes in temperature also need to be corrected for to get accurate strain measurements.

For typical levels of strain in civil engineering applications, changes in resistance (in ohms) across a foil gauge are typically quite small. Consequently, foil strain gauges are commonly used in a Wheatstone bridge configuration with a voltage excitation source, to more accurately capture small changes in resistance (Fig. 4). Two

Please cite this article in press as: Meehan, C.L., Talebi, M., A method for correcting field strain measurements to account for temperature effects, Geotextiles and Geomembranes (2017), http://dx.doi.org/10.1016/j.geotexmem.2017.02.005