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Durability of geogrid reinforcement from a sloped retaining wall after 25 years in-service

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ABSTRACT: This study presents a durability assessment of geogrid samples that were exhumed from a sloped retaining wall 25 years after completion of construction. The durability assessment is based on visual inspection and a series of index and strength tests, focusing on the identification of possible physical damage and/or degradation. The assessment lends confidence in the use of isochronous load-strain-time data for predicting the long-term strain of geogrid reinforced soil structures for design practice. This research belongs to the few well-documented long-term studies on geogrid durability.

1 INTRODUCTION

The determination of a long-term value of tensile strength for stability analysis of a geosynthetic reinforced soil structure involves use of a separate reduction factor to account for (i) the potential for damage of the reinforcement during installation and (ii) the durability of the reinforcement over the service life of the structure. The two factors account for any strength loss that may occur and appear in design guidelines and codes of practice (see for example, BS-8006). A limited number of field trials have sought to quantify durability from strength testing of specimens retrieved after long-term burial. They encounter a common difficulty in being able to distinguish between strength loss due to installation damage and change in strength arising from material durability, see for example Harney and Holtz (2006), Wayne *et al.* (1997), Onodera *et al.* (2004), and Jenner and Nimmesgern (2002).

Given a very limited body of data on geosynthetics after more than 20 years in-service, and recognizing that differentiation between a strength change due to installation damage and durability has not always been feasible, this contribution reports on the durability of geogrid exhumed from a sloped reinforced soil wall near Oslo, Norway, about 25 years after completion of construction. Little or no installation damage was anticipated in the geogrid reinforcement because of the practices used in construction of this instrumented research structure. Accordingly, the objectives of this study are to (i) assess exhumed samples for installation damage based on visual observations, (ii) quantify any changes in material properties in terms of geometry, composition, and tensile strength from isochronous load-strain testing, and (iii) based on the findings, comment upon the implications for consideration of durability in design practice.

2 THE NORWEGIAN SLOPED REINFORCED SOIL WALL

The structure is located 25 km northeast of Oslo, Norway. The steep (2V:1H) sloped wall is 20 m long and 4.8 m high (see Figure 1). It comprises two sections, termed Sections ‘J’ and

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'N', each of which is 10 m long and with a different arrangement and spacing of Tensar SR 55 geogrid reinforcement (Fannin & Hermann 1990).

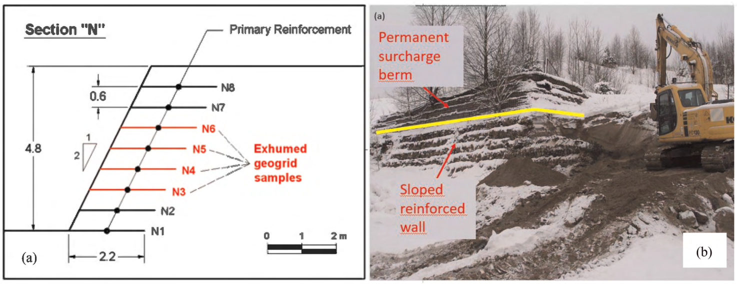

Figure 1. Section "N": (a) exhumed geogrid layers and (b) preparation for field sampling activities.

2.1 *Construction details*

The sloped wall seats into an existing slope in a borrow pit used by the local road authority. The backfill is a uniformly graded clean sand with trace of fine gravel, with median grain size d_{50} = 0.2 mm and coefficient of uniformity C_u = 2.6, obtained from the same borrow source. Construction took place in July 1987. Backfill sand was placed using a front-end loader, prior to spreading with a mini excavator to a minimum loose lift-thickness of approximately 350 mm. Thereafter it was moisture-conditioned to a water content $5 \leq w \leq 10\%$, and compacted using a vibrating plate to a thickness of approximately 300 mm and dry density greater than 92% of the maximum value from the Standard Proctor test (ASTM D698).

Eight layers of uniaxial geogrid were used in Section 'N' (termed layers N1 to N8, see Figure 1a). They were placed at a uniform vertical spacing of 0.6 m that equates to two finished compaction lifts. The length L = 2.2 m of the geogrid reinforcement does not satisfy modern design guidance: it was purposively chosen for Section 'N' as a parametric variable for investigation in the original field trial that predated regulatory design guidance by several years.

The front-end loader was not permitted to drive on the reinforced soil zone, and the mini-excavator was only permitted to move onto that zone after pushing a loose layer of backfill sand over it to a working-platform thickness of 350 mm. The commensurate supervision of all equipment operation afforded little or no opportunity for construction-related installation damage.

2.2 *Service life*

Following a month of self-weight loading commencing in July 1987, a single load-unload cycle of surcharge loading was applied to the crest of the structure over a period of nearly 2 months using water-tanks that were filled in August 1987 and subsequently emptied and removed in September 1987. Permanent surcharge loading was subsequently imposed on the sloped wall by means of a 3 m high berm that was constructed in October 1987 and then left in place. Upon completion, instrumentation established a maximum tensile load per unit width $T_{max} \approx 1.4$ kN/m the lowermost (N1) layer of geogrid, and values of $2.1 \leq T_{max} \leq 3.0$ kN/m in the other (N2 to N8) layers above it; the companion values of maximum tensile strain were in the general range $0.2 \leq \varepsilon_{max} \leq 0.8\%$. Although the force mobilized in the geogrid layers is relatively small, it was demonstrated entirely consistent with a geotechnical analysis informed by the frictional strength of the sand backfill (Fannin & Hermann 1990). The average temperature in the reinforced soil zone varied between 7 and 9°C, depending on location, with the near surface locations experiencing a seasonal range between 0 and 20°C. Long-term performance monitoring over a period of 10 years established that the tensile force per unit width in each layer remained essentially constant. The associated strain exhibited a time-dependent increase: the invaluable time-series record of field data for independent measurements of load-strain-time to almost 90,000 h was found very consistent with laboratory creep test data for the geogrid to 100,000 h (Fannin 2001).

3 FIELD SAMPLING

A program of field sampling was conducted about 25 years after completion of construction in February 2013. Section 'N' was selected for sampling of the backfill sand and geogrid reinforcement because the site layout provides for easier access to that end-location of the structure.

3.1 *Soil*

Excavation proceeded in a 'top-down' direction from the crest of the structure near the lateral toe of the surcharge berm (see Figure 1b). Three grab samples of soil were taken at the mid-height between layers N8-N7, N7-N6, and N6-N5, respectively (see Figure 1a). At the time of construction, the backfill soil was classified as a uniformly graded sand with trace gravel and trace silt. Scanning Electron Micrograph (SEM) images of sand in the grab samples (see Figure 2a) suggests a generally angular to very angular grain shape. XRD analysis established the mineralogy as approximately 70% quartz, 20% feldspar, 5% mica, and 5% others. Index testing to ASTM 4972 established a pH of 8.3, believed consistent with the predominantly silicate content of the sand.

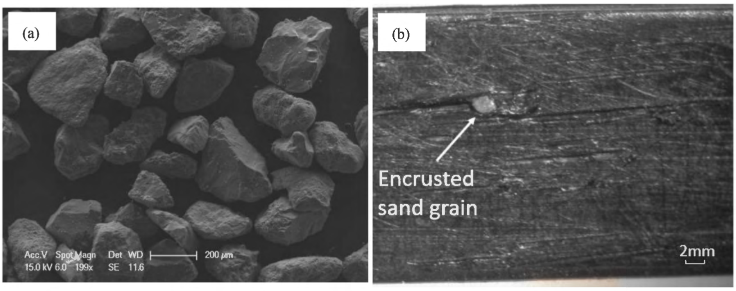

Figure 2. Sampled materials (a) sand grains and (b) geogrid reinforcement.

3.2 *Geogrid*

The backfill sand was carefully removed by machine-excavation, in a series of horizontal cuts. When the backfill cover thickness reduced to approximately 15 cm, the rest was then removed by hand-excavation using a shovel to move the bulk of the sand, and a combination of spade and soft-sweep push-broom to remove all of the remaining sand and expose the top surface of a geogrid layer for sampling. Four layers, N6 to N3 (see Figure 1a), were exhumed from the structure. The backfill was frozen to over a distance of approximately 0.75 m into the reinforced soil zone behind the slope-face, thus field exhumation yielded samples of geogrid reinforcement that were approximately 1.25 m long and 1.0 m wide. Hand-held visual assessment established no evidence, on any of the geogrid samples, of adverse damage that could be attributed to installation at the time of construction in 1987 or the process of field sampling.

SEM inspection of the N6 specimens (Quinteros 2014) identified a high frequency of low magnitude abrasions: they took the form of surficial scratches of variable length, typically less than 0.1 mm deep. A very low frequency of medium-size abrasions was detected: they took the form of pits and gouges that were typically 2 to 15 mm long and 0.2 to 0.5 mm deep (see Figure 2b). The absence of any damage is attributed to the supervision of all equipment operation resulting in no opportunity for installation-related damage during construction of the instrumented field-trial.

4 CHARACTERIZATION OF THE GEOGRID AFTER 25 YEARS IN-SERVICE

The exhumed geogrid was characterized with reference to geometry, material composition, and analysis of its load-strain-time response in creep testing. Creep test data for the exhumed specimens are compared directly with typical data for the same product reported by the manufacturer. Given the absence of any observed installation damage, the methodology enables an assessment of material durability.

4.1 *Tensile strength*

Rapid loading creep (RLC) tests were performed to ISO 13431:1999 at the Tensar International laboratory at Atlanta, USA, with oversight by an independent third-party inspector. Test specimens were taken from the exhumed samples of layer N3 and N5 geogrid material. A constant tensile load per unit width of 8.8, 15.4, 17.8, 19.8, or 24.2 kN/m was applied to five layer N3 specimens, and a loading magnitude of 8.8, 17.8 or 24.2 kN/m to three layer N5 specimens. The RLC tests were performed at a constant temperature of T = 20 ± 2°C, and all eight specimens were loaded to a total elapsed time of 10,000 h. The tests yield load-strain-time data, and are presented in the form of isochronous curves at t = 1, 10, 100, 1,000, and 10,000 h (see Figure 3).

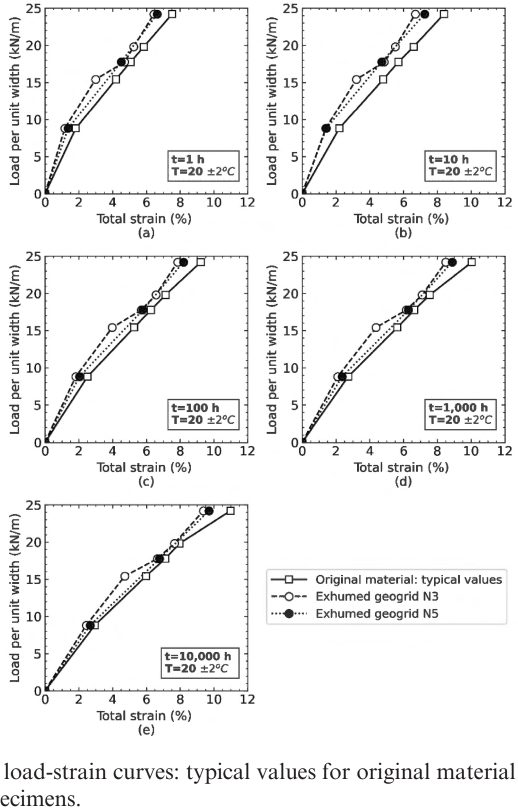

Figure 3. Isochronous load-strain curves: typical values for original material and results for exhumed layer N3 and N5 test specimens.

There is generally good agreement in the load-strain response with time for the exhumed N3 and N5 specimens. For example, at the largest magnitude of load per unit width (24.2 kN/m), the difference in total strain between the N3 and N5 test specimens is: 0.1% strain at t = 1 h; 0.5% strain at t = 10 h; 0.3% strain at 100 h; 0.3% strain at 1,000 h; and 0.2% strain at 10,000 h.

A comparison of the isochronous curves of the current study with curves reported by the manufacturer for the same Tensar SR55 geogrid product, termed herein typical values, indicates a plotting position for the exhumed N3 and N5 material that is consistently associated with relatively smaller values of total strain (see Figure 3). To investigate further the nature of the difference between the measured values for the exhumed field material and typical values for the same product, the magnitude of strain increment between isochronous load-strain curves was calculated for RLC test data on the exhumed material ($\Delta\varepsilon_{\mathrm{exh}}$) and from the typical curves for original product type ($\Delta\varepsilon_{\mathrm{typ}}$) as illustrated schematically in Figure 4a.

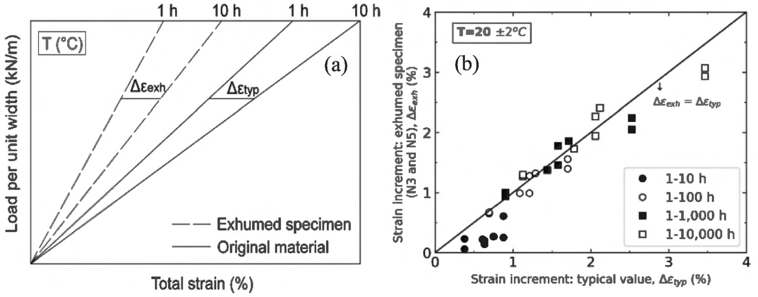

Figure 4. RLC test data: (a) schematic illustration of strain increment $\Delta\varepsilon$ (t = 1 to t = 10 h) and (b) comparison of data for field samples with typical values for the original product.

Results are reported for the four increments of 1 to 10, 1 to 100, 1 to 1,000, and 1 to 10,000 h (see Figure 4b). Strain increments for specimens of the exhumed geogrid at 1 to 10 h exhibit the least good agreement, while the data for increments of 1 to 100, 1 to 1,000, and 1 to 10,000 h are in good agreement with the typical values. The 32 data points establish $\Delta\varepsilon_{\mathrm{exh}} = 1.03 \cdot \Delta\varepsilon_{\mathrm{typ}}$. Strain increments in rapid load creep testing of the exhumed specimens are thus believed very similar to those for the original product type. Taken collectively the evidence in Figure 3 and Figure 4 suggest the isochronous load-strain response of the exhumed geogrid compares very well with the typical behaviour reported by the manufacturer. The finding implies no degradation of strength or stiffness of the geogrid over the 25 year service life in the sloped reinforced soil wall at the Skedsmo location, near Oslo, Norway.

The British Standard (BS-8006) gives explicit consideration to a serviceability limit state, which is expressed as a limit value on the magnitude of permissible post-construction strain over the service life of a structure. Isochronous load-strain curves are used for purposes of estimating the post-construction strain in a reinforced soil retaining structure. The difference between ‘the end of construction total strain’ and ‘the design life total strain’ defines the strain increment of interest. The observed excellent agreement between strain increments in this study for exhumed and original uniaxial geogrid reinforcement lends strong support to the use of isochronous load strain curves for estimating long-term values of reinforcement strain in design to BS-8006.

5 CONCLUSIONS

Geogrid samples were exhumed from a sloped wall structure to investigate the material durability after 25 years in-service. Based on the results of this study, following conclusions are drawn:

(a) visual inspection and microscopic imaging revealed no installation damage of any significance, a finding that is attributed to the good quality of the backfill soil and the close inspection of all construction activities for this research structure. Accordingly, it is reasonable to compare properties of the exhumed material with typical values for the original product and attribute any changes to durability phenomena over the service life of the structure near Oslo, Norway;
(b) rapid loading creep test data to 10,000 h show excellent agreement between incremental strain in specimens of the exhumed geogrid and typical values for the original product type, with a finding of $\Delta\varepsilon_{\mathrm{exh}} = 1.03 \cdot \Delta\varepsilon_{\mathrm{typ}}$ that implies no degradation of strength or stiffness of the sampled geogrid;
(c) in the absence of any installation damage, the excellent agreement in rapid loading creep test data is believed indicative of no concern for durability manifesting itself as degradation in the strength or stiffness of the geogrid reinforcement after an elapsed time of 25 years; and,
(d) the finding lends confidence to the use of isochronous load-strain-time data for predicting the long-term tensile strain of geogrid in reinforced soil structures.

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