Performance Summary Of The Tanque Verde Project-Geogrid Reinforced Soil Retaining Walls

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Abstract

The long-term performance of geogrid reinforced soil wall structures is investigated and documented through the examination of a specific project constructed in 1984 and 1985, in the Sonora Desert. The mechanical performance of a wall on this project has been monitored with an instrumentation program. Results of this instrumentation program, that has been on-going since construction, are summarized herein. Additionally, the findings of a recent investigation on the chemical and biological stability of the geogrid reinforcement used in these structures is summarized. The mechanical monitoring program and durability investigation documents that the mechanical and physical properties of the polyethylene geogrid soil reinforcement have not changed over time.

Introduction

The use of geogrid reinforced soil walls in the U.S.A. has increased dramatically since their first use just a decade ago. Government agencies and private owners are now extensively specifying and using these cost-effective wall structures. However, some specifiers and government agencies have expressed concerns with the ability of the designers of geosynthetic structures to predict long-term performance of the geosynthetic material and the affect, if any, on the wall structure performance. It was, therefore, deemed useful to summarize the performance to date of one of the first major geogrid reinforced soil retaining wall projects in the U.S.A.

The performance of the 10-year old Tanque Verde Project wall structures is summarized herein. Performance is quantified with results from a mechanical

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instrumentation program and from chemical analyses of recently exhumed geogrid material.

The mechanical response of the geogrid reinforced soil wall during construction, immediately after construction, and over time is the focus of this instrumentation program. The mechanical instrumentation program has been on-going since construction of the instrumented wall in 1985. An investigation into the durability of the geogrid reinforcement was initiated in 1993. Specimens of geogrid were retrieved from the project in August 1993 for laboratory testing. The retrieved specimens have been in-service since the wall construction in 1985.

<u>Project Description</u>

In 1984 and 1985, forty-six (46) separate geogrid reinforced soil walls were constructed in Tucson, Arizona as part of the Tanque Verde Grade Separation Project. Four cross-section wall geometries, as illustrated in Figure 1, were used in the 46 wall structures. The geogrid reinforced soil walls for this project are situated within limited rights-of-way at two grade separated interchanges. The walls extend approximately 1550 lineal meters and vary in height from 0.3 to 6.6 meters. The wall facing on this project consists of full-height precast concrete panels, 150mm thick and 3 meters wide.

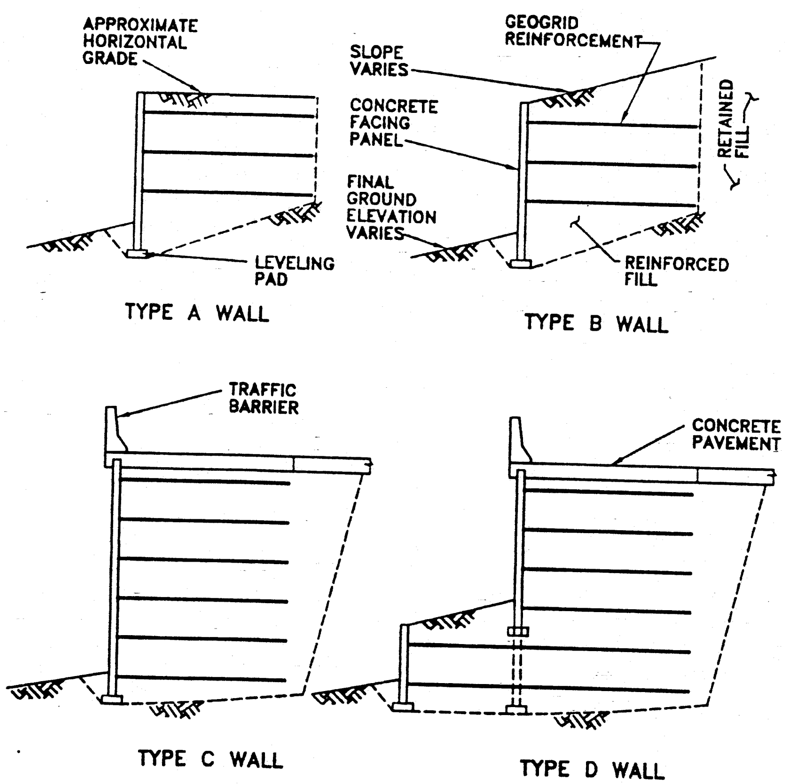

Figure 1. Typical Geogrid-Reinforced Wall Cross-Sections

Design

At the time these structures were designed there were no government agency guidelines for the design of MSE walls. The walls were designed using a tie-back wedge analysis procedure (Jones, 1985). Lateral loads and failure plane location used in design were determined using Rankine lateral earth pressure theory. In the design it was conservatively assumed that the reinforced soil mass responded to the external loads as a rigid body. Stresses within the reinforced soil mass were calculated as the sum of the overburden pressure plus overturning stresses due to externally applied retained backfill pressures. A trapezoidal stress distribution was used for computing internal and external overturning stresses. The external stresses were also used in assessing bearing loads. The minimum factors of safety for stability used in design were:

External Stability

- Sliding, $FS_s = 2.0$
- Overturning, $FS_o = 1.5$
- Bearing capacity, $FS_{bc} = 1.5$
- Global stability, $FS_g = 1.5$

Internal Stability

- Tensile Failure, $FS_t = 1.5$
- Pullout, $FS_p = 1.5$

The design life for this project was established by the Owner to be 75 years. This was based on the fact that the mechanically stabilized earth (MSE) walls were permanent, critical structures.

Geogrid Material Properties

The allowable design strength of the geogrid reinforcement was based on creep at the anticipated in-service temperature, which is a function of the polymer type and manufacturing process used to produce the geogrid, and on the effects of construction on the geogrid. The allowable design tension of the geogrid was determined by dividing the allowable tension based on creep by a reduction factor to account for construction effects.

Tensar structural geogrids, SR2, manufactured by punching, reheating and drawing extruded sheets of high molecular weight, high density polyethylene (HMW HDPE) were used as the soil reinforcement for this project (Figure 2). The geogrid composition by weight and constituents is 97+% HMW HDPE, 2+% carbon black, plus antioxidant(s).

For this geogrid, the allowable tension based on creep is 29 kN/m at 10% strain after 120 years at 20°C. A safety factor of 1.5 was applied to the creep limited strength to determine the long-term design tension of the geogrid (19 kN/m). The value of 1.5 was used to address an in-service temperature greater than 20°C, installation damage, material and load variations, construction tolerances, and unknowns.

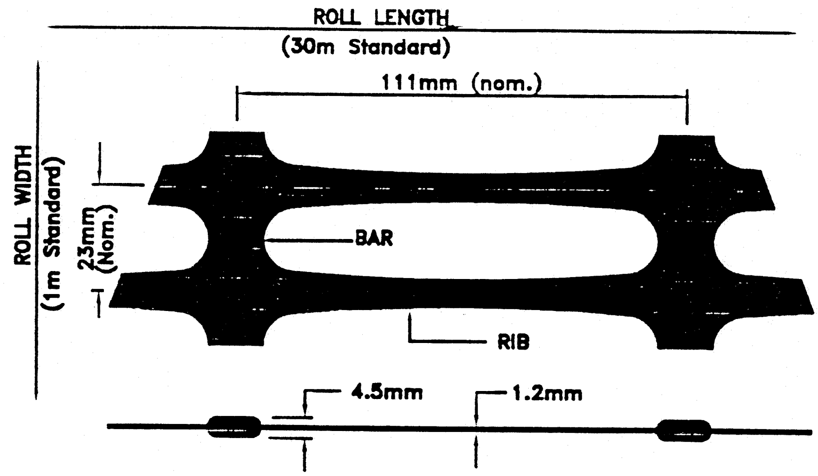

Figure 2. SR2 Geogrid

Soils

The friction angles and unit weight of the fill in the reinforced zone, retained fill and foundation soils used in the stability analysis of these MSE walls are listed below:

	Friction Angle	Unit Weight (kN/m^3)
Reinforced Fill	34°	19.6
Retained Fill	30°	18.1
Foundation Soil	30°	18.1

The maximum soil strength parameters for the reinforced fill and retained backfill soils were dictated by the U.S. Federal Highway Administration guidelines. The actual peak angle of internal friction of the soil used for both the reinforced fill and retained backfill is in the range of 36° to 38°. This estimate is based upon soil type, field densities, and local experience.

Construction

The precast concrete facing panels were set on cast-in-place concrete leveling pads. The wall panels were braced during backfilling and the tops of the adjacent panels were temporarily clamped together to minimize differential movement of adjacent panels during construction. Sand wall fill was placed and compacted up to the elevation of the first geogrid layer. Fill within three feet of the wall face was compacted with hand operated light-weight vibratory compactors. At each reinforcement level the geogrid reinforcement was connected to a geogrid tab cast into the facing panel with a 25mm diameter PVC pipe connector (Figure 3). The geogrid tabs were formed by embedding a short section of geogrid into the wall panels during casting, such that a "C" shaped tab protruded from the back of the wall face. This connection was used with the intent of being able to withstand differential settlement between the panel and the reinforced fill without over stressing the facing panel or the geogrid to facing panel connection.

The connections to the wall face were pretensioned by placing timber wedges between the PVC pipe and the wall facing to remove slack in the "C" shaped tabs (Figure 3). The main length of geogrid reinforcement was also pretensioned by inserting steel "T" forks through the apertures of the geogrid at the tail of the layer and pulling them taut.

Sand fill was placed on the geogrid and spread with a front end loader. After a lift of fill (200mm loose) was placed, the steel "T" forks and timber wedges were removed. When the fill height reached approximately two-thirds the height of the wall, the erection braces were removed from the outside of the wall. Fill and geogrid placement continued in this manner until the wall was complete.

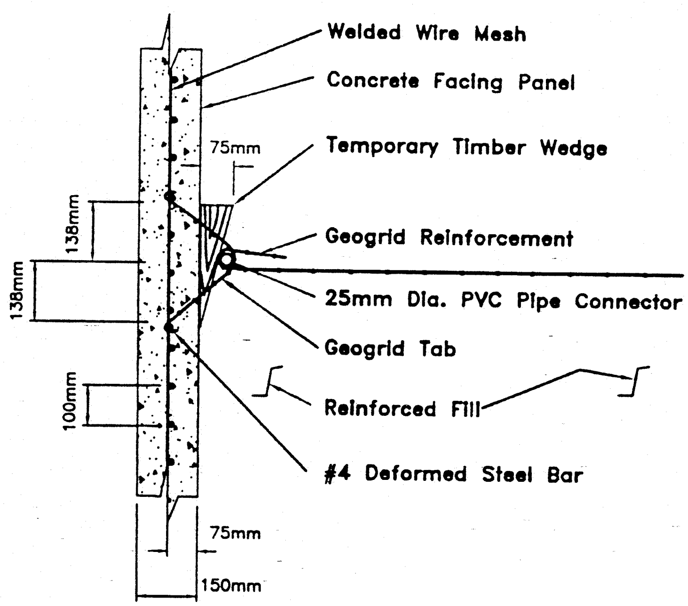

Figure 3. Geogrid Facing Panel Connection (from Berg et. al., 1986)

Mechanical Instrumentation

A long-term performance monitoring program was established for this project, with the objective of measuring strain to use in computing stress in the geogrid reinforcement with time. Two of the type D wall sections (Figure 1) were instrumented in September of 1985. The instrumentation program included: resistance strain gages, horizontal load cells, inductance coils, and resistance thermometers. The typical instrumentation layout for the monitoring system used is shown in Figure 4. These panels were selected for instrumentation because of their height, independence of three dimensional effects (i.e., near bridge abutments) and time of construction. The goals of the instrumentation program were to determine stresses and strains within the reinforced soil mass, movements of the wall panels, external and internal wall temperatures and to make an overall assessment of the performance of the wall. End of construction, 2 year results, 4 year results, and 7 year results have been presented by Berg et. al. (1986), Fishman et. al. (1989), the FHWA (1990) and Collin and Berg (1992) respectively.

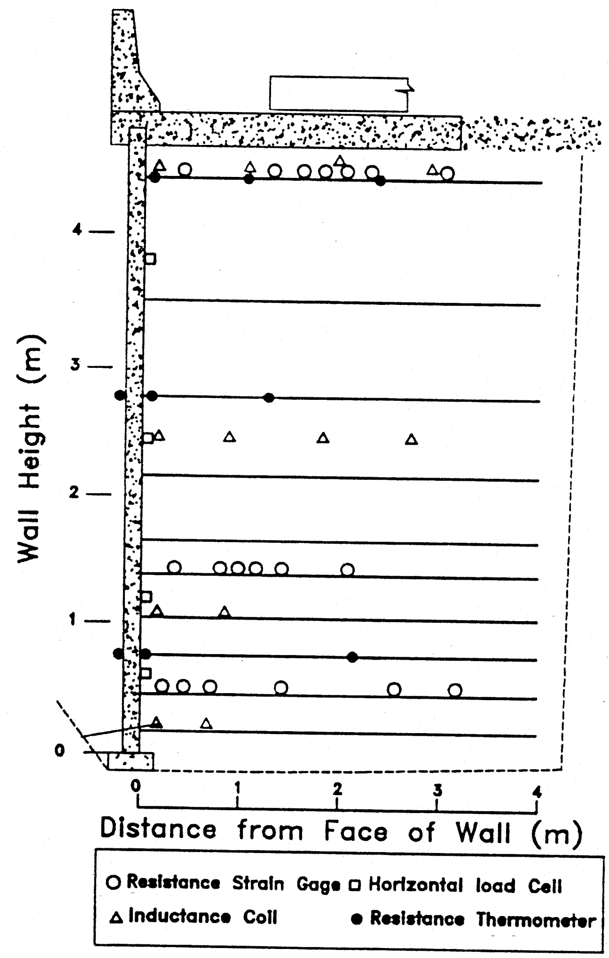

Figure 4. Instrumentation Plan (from FHWA EP-90-001-005)

Performance

Mechanical Instrumentation

The strain along the length of the reinforcement as well as the strain at the connection were monitored for this project. Strains were measured with resistance strain gages mounted on the connections tab "C" loops (Figure 3). Figure 5 presents results from one of the instrumented wall sections. Results of geogrid strains within the reinforced soil mass are presented in Figures 6 and 7. From these figures it is clear that geogrid strains over a seven year period of time are stable. The maximum measured strain in the reinforcement is below 1% for all layers of geogrid for both instrumented wall sections. The maximum strain at the connection between the geogrid reinforcement and wall face is stable with time, again with a maximum measured strain below 1%. The geogrid reinforcement, for this project, was designed based on an allowable strain of 10% defined by in-isolation laboratory testing.

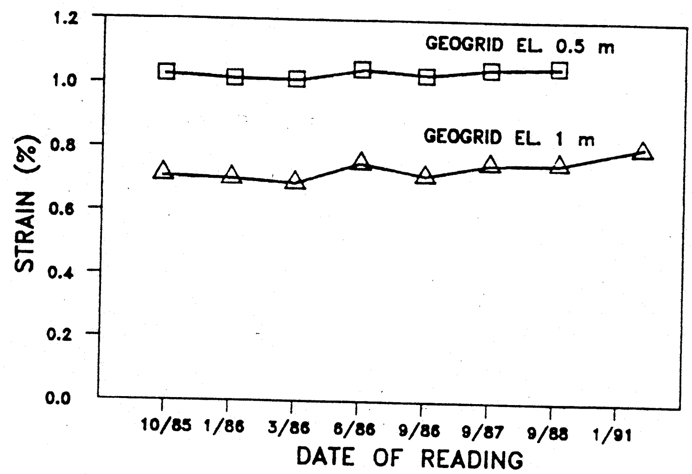

Figure 5. Geogrid Wall Face Connection Strain Gage Data (Wall 26-30) (from Collin and Berg, 1992)

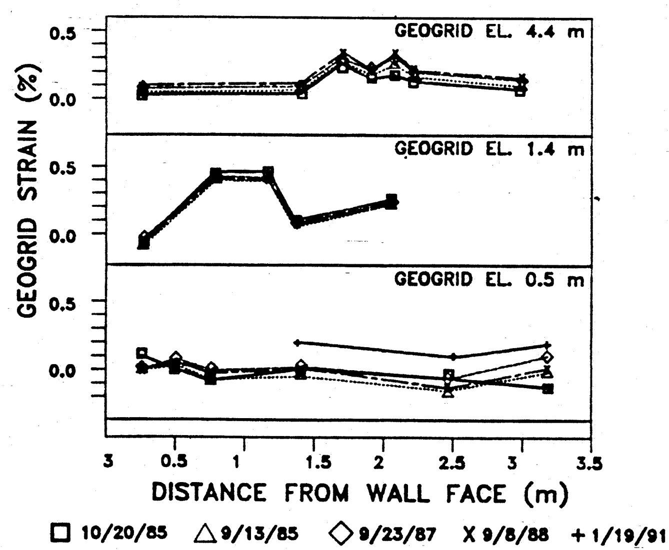

Figure 6. Geogrid Strain Gage Data (Wall 26-30) (from Collin and Berg, 1992)

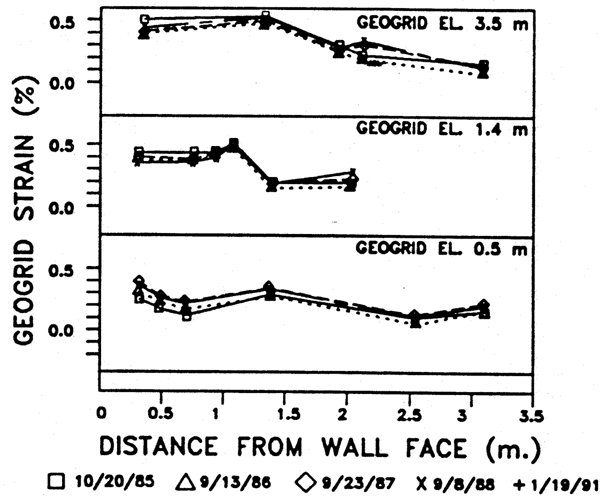

Figure 7. Geogrid Strain Gage Data (Wall 26-30) (from Collin and Berg, 1992)

Figure 8 shows typical temperature readings for the instrumented wall panels. The readings taken in the late summer reflect the build up of temperature within the reinforced soil mass which reached as high as 36° C. Elevated temperature environments for polymer reinforcements is a potential design concern because an increase in temperature accelerates mechanisms of degradation.

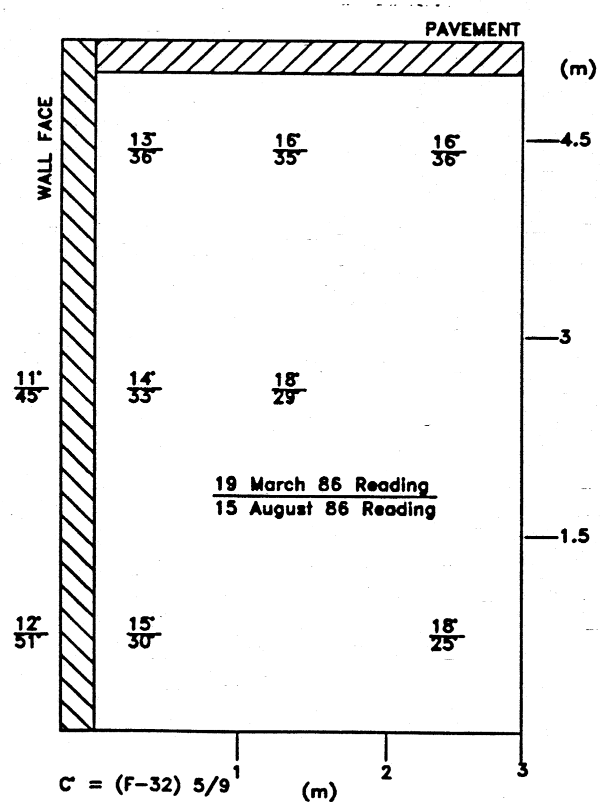

Figure 8. Temperature Reading (after FHWA EP 90-001-005)

Geogrid Durability Evaluation

The geogrids in this project have been in service for 8 to 9 years in an elevated temperature environment. Since elevated temperatures accelerate the mechanisms of degradation, analysis of the properties of exhumed samples of the reinforcement was deemed appropriate. Details of the August 1993 geogrid sample exhumation have been presented by Bright et. al. (1994).

In order to quantify the amount of degradation that occurred in the geogrid, mechanical tests were conducted and the properties of the exhumed geogrid, used in the Tanque Verde Project, were compared with those from an archived roll of SR2 geogrid manufactured during the same era (within 1 year). Because the archived geogrid is not from the same lot as the exhumed geogrid, some slight variation in the values of measured properties is likely between the two geogrid samples.

Deterioration of geosynthetics may occur due to physical damage (i.e., installation damage), mechanical deformation (i.e, dimensional change, tensile/elongation behavior, creep), thermal degradation (i.e., oxidation), and biological degradation (i.e., attack by macro and micro-organisms). The evaluation process thus requires that visual, physical, mechanical, thermal and compositional tests be performed on specimens from the archived and exhumed geogrid samples.

Visual analysis, using photographic records, assesses the presence and extent of installation, exhumation, and macro-organism damage across the surface topology. Scanning electron micrographs show the extent of such damage, (i.e. surface degradation) due to attack by oxidation (surface dullness), soil chemistries, and micro-organisms. Physical tests assess dimensional stability due to annealing, as well as subsequent densification via geogrid shrinkage due to prolonged exposure to an elevated temperature environment. Mechanical tests assess retention of tensile and elongation properties and the behavioral response to a constant sustained load. But, these tests cannot necessarily differentiate between the mechanisms of mechanical deformation. However, thermal tests may assess any significant changes in morphological status of the HMW HDPE that may relate to changes in mechanical properties. Composition tests indicate the residual amount of the principal additive (i.e., carbon black). Comparison to original formulations documents any concentration changes, thus indicating the duration of long-term stability.

Test Results

Physical and mechanical test results and resin properties are summarized in Table 1. For tests employing multiple specimens, results in Table 1 are reported as arithmetic averages with standard deviations noted. Behavioral response of archived and exhumed geogrid in tension creep is shown in Figure 9.

Particle size distribution of a soil sample taken from the exhumation site is given in Figure 10. Soil pH was 8.0 and 8.7 in distilled water, and 7.6 and 7.8 in a 0.01 Molal solution of $CaCl_2$, respectively.

Parameters	Archived Average Value	Archived Standard Deviation	Exhumed Average Value	Exhumed Standard Deviation
Mass / Area (g/m2) Rib Thickness (in) Junction Thickness	912. 0.054 0.178	 0.009 0.002	930. 0.054 0.177	 0.004 0.001
Single Rib Strength (kN/m) Max. Load/Max % Strain Load @ 5% Strain Load @ 2% Strain	 85.0/15.2 46.8 26.2	 1.79/1.15 0.85 0.65	 85.0/14.0 48.6 25.9	 0.45/0.64 0.35 0.29
Junction Strength (kN/m) Max. Load/Max % Strain Load @ 5% Strain Load @ 2% Strain	 84.6/16.4 46.1 26.1	 0.63/0.59 0.40 0.42	 83.6/16.0 47.0 25.9	 0.42/0.55 0.57 0.41
Wide Width Strength (kN/m) Max. Load/Max % Strain Load @ 5% Strain Load @ 2% Strain	 78.0/15.3 44.6 25.6	 3.0/1.28 0.40 0.45	 78.0/14.0 43.3 23.6	 2.2/1.21 0.30 0.37
Density (g/cc) Melt Flow Index (g/10 min)	0.9561 0.225	0.0005 0.007	0.9595 0.207	0.0002 0.004
Carbon Black Concentration (%)	2.06	0.020	2.96	0.031

Table 1. Physical and Mechanical Test Results and Resin Properties (from Bright et. al., 1994)

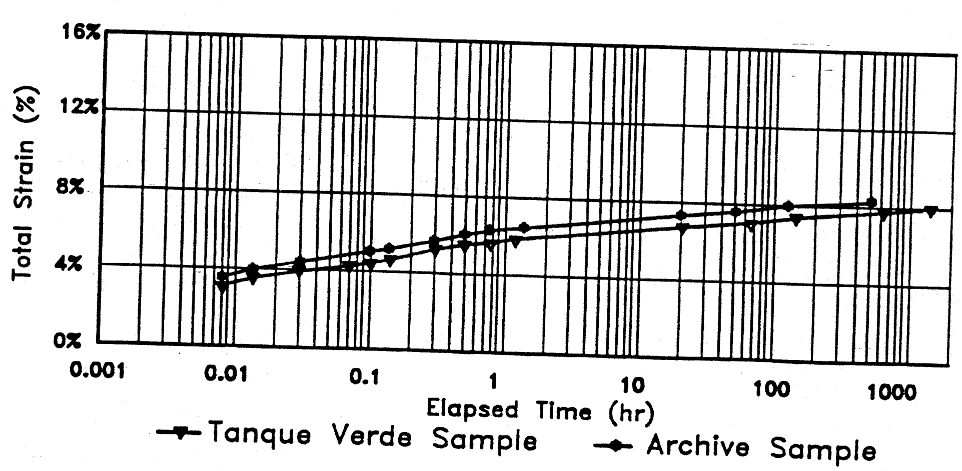

Figure 9. Creep Test Results (from Bright et. al., 1994)

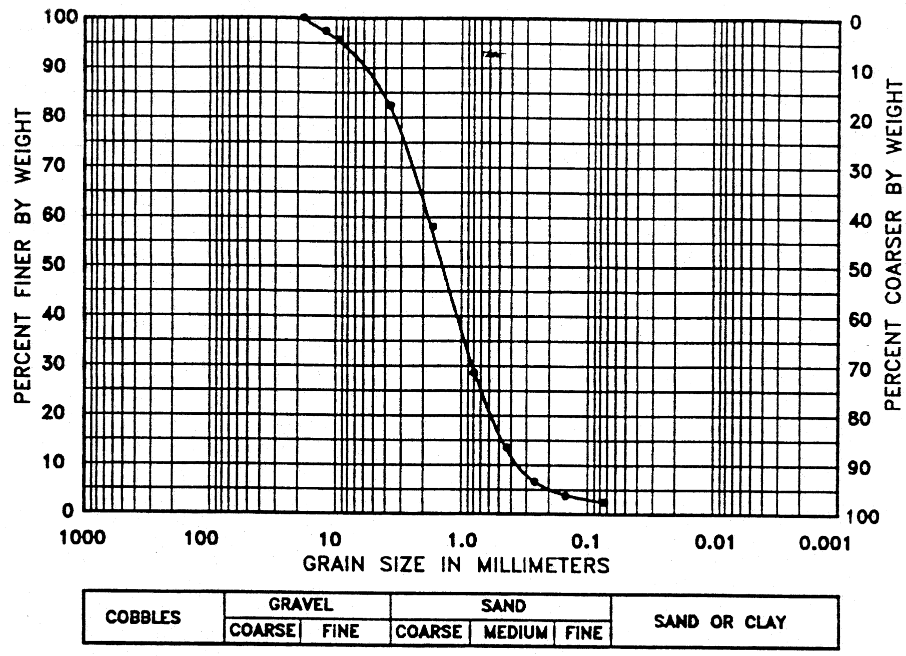

Figure 10. Reinforced Backfill Grain Size Distribution

A visual inspection of the exhumed geogrid showed that there were no broken or cut ribs over its surface. This sample experienced no significant installation or exhumation damage. There was no surface degradation due to attack by the resident ant colony; apparently the ants were simply not interested in a geogrid of HMW HDPE. Typically, oxidation starts on the surface and progresses inward. An oxidized surface of a polyolefin, like polyethylene, will appear dull. Surface quality of the exhumed sample was glossy, indicating no oxidative degradation in progress. Thus, topological analysis by scanning electron microscopy was not warranted.

Physical test results show no significant change in dimensional properties over 8+ years. Rib and junction thicknesses exhibit zero change. The change recorded for mass per unit area is within the variance of specification for SR2 geogrid manufacture.

Test results show no significant change in tensile strength measured at 2% and 5% strain levels, and at maximum load between the two samples of geogrid. There is no significant change in single rib, junction, or wide width tensile strengths between archived and exhumed geogrid manufactured during the same era (with 1 year). The ultimate strength values for a single rib are above the 79.0 kN/m product specification, and the differences in strain values recorded at maximum loading between samples per strength test are within a standard deviation. Thus, there is no indication of lost ductility, or embrittlement of the exhumed geogrid with time.

The behavioral response of archived and exhumed geogrid specimens in unconfined tension creep at a 29 kN/m width loading is shown in Figure 9. This loading results in a total strain response of less than 10%. At about 1000 hours, the two specimens are becoming asymptotic to less than 8.5% total strain. The two response curves are essentially parallel, indicating that the mechanism by which creep occurs within the two geogrid specimens is the same. Although these two geogrids are from different lot numbers as discussed earlier, their response with time to a constant, sustained load is essentially the same. In addition, the mechanism by which they respond is identical and thus, it may be concluded that the creep mechanism has not changed over an 8+ year duration.

Resin density was determined from the extrudate from the melt flow index tester; no significant changes in morphology occurred over the 8+ year duration. Melt flow index values indicate no change in the molecular weight of the resin over the 8+ year duration. Any significant change in molecular weight would be reflected in corresponding changes in mechanical strength and there were no changes. However, a 0.022 g/10 min. difference does indicate the samples came from different production lots, also indicated by the values on carbon black (CB) concentration.

CB specification for SR2 was 1-3% by weight in 1984 and 2+% is known and accepted to be sufficient to retard long-term degradation for HDPE due to exposure to ultraviolet light (which is of no concern for in-ground applications). The difference in CB concentration has not affected mechanical properties of the exhumed geogrid relative to the archived geogrid. A higher CB concentration would, if anything, lower mechanical properties initially. Any significant change in ductility or embrittlement, would increase strength values with a corresponding decrease in strain values. As discussed earlier, such has not occurred.

Discussion and Conclusions

The field measurements for the instrumented wall sections on this project show that at relatively high in-soil temperatures (+36°C), the HMW HDPE geogrid experienced a maximum strain of approximately 1% and is stable with time. Also, in-isolation creep testing of the exhumed and the archived sample showed similar performance, however, at substantially higher strain than the measured field strain.

The exhumed and archived samples, through creep testing, are shown to have the same long-term strength after 8+ years of service, even though the exhumed sample was subjected to elevated temperatures which hypothetically could cause oxidation. Oxidation of the HMW HDPE has apparently not occurred with time as evidenced by the creep performance of the tested samples.

Analytical measurements have shown that there was no measurable oxidation. The surface of the geogrid is, therefore, relatively unchanged with time. Strain of the reinforcement as seen from the field measurements is constant. One can conclude that the soil/geogrid interaction which is dependent on the surface characteristics of the geogrid and the long-term creep strength of the geogrid is, therefore, unchanged with time.

The creep behavior of the archived, and the exhumed Tanque Verde geogrids is essentially identical and their commonness in creep response indicates that the mechanical properties of the geogrid did not change over the 8+ years in service. The measured creep of the reinforcement at the instrumented sections of the wall over the 8+ year period is negligible and maximum strain in the geogrid reinforcement of approximately 1%.

A long-term monitoring program and chemical analysis of recently retrieved geogrid specimens for the first use of geogrid reinforcement along with precast facing panels in a major transportation related MSE application in North America, has demonstrated that the mechanical and physical properties of the reinforcement have not changed over a 9 year time frame. The HMW HDPE geogrid experienced insignificant installation and exhumation damage, no biological attack and no surface oxidation.

Acknowledgments

The authors would like to acknowledge the many other engineers and researchers who have been involved in this project over the last decade, they include Dr. Rudy Bonaparte, Ron Anderson, Vickey Chouery-Curtis, Dr. Ken Fishman, Professor C.S. Desai, Dr. Robert Sogge, Barry Berkowitz, John Walkinshaw and Ali Fermawi. The original field instrumentation program was contracted with Desert Earth Engineering with participation from the Department of Engineering and Engineering Mechanics at the University of Arizona in Tucson.

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Key Words

Case Reports
Earth reinforcements
Earth Structures
Geosynthetics
Instrumentation
Monitoring
Performance Evaluation
Polymers
Reinforcement
Retaining Walls