Geosynthetic-Reinforced Soil Wall: 4-Year History

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A geogrid-reinforced earth-retaining wall using full-height precast concrete wall facing was instrumented in Tucson, Arizona. Construction on the wall was completed in October 1985. Instruments were monitored during construction, at intervals during the year after construction, and once a year thereafter. Tensile strains measured during construction indicate that during compaction of the wall fill, a tension force was induced in the geogrids that is low in comparison with safe working loads. Measurements of tension in the geogrids are compared with tensions computed by limit equilibrium analysis. In general, this comparison is satisfactory. In addition, a study of measured geogrid response over a 4-year period reveals that rates of creep strain are not appreciable.

A geogrid-reinforced earth-retaining wall using full-height precast concrete wall facing was instrumented in Tucson, Arizona. The purpose of the instrumentation was to study the response of the wall system and compare it with design assumptions and calculations applied to wall systems using strip reinforcements and articulated wall facing. Instruments were placed to measure geogrid strains, lateral earth pressure transferred to the wall face, strains in the reinforced wall fill, vertical stress, and the distribution of temperature within the reinforced wall fill.

Construction on the wall was completed in October 1985. Instruments were monitored during construction at intervals during the year after construction and once a year thereafter. Readings taken during 1990 represent the sixth year of the wall-monitoring program, but these data are not available for presentation. The purpose of this paper is to present measurements taken since initial construction of the wall through the end of 1988. In this manner the performance of the geogrid-reinforced wall system over a long period of time may be discussed. The presentation in this paper is derived from various previous publications (*1–4*).

DESCRIPTION OF WALL SYSTEM

The wall system serves as a grade separation for a highway project; it was considered as an alternative to a conventional cantilevered retaining-wall system or a mechanically stabilized earth wall system using steel strips as reinforcement. Schematics of the instrumented earth-reinforced retaining wall are shown in Figures 1 and 2, which refer to separate wall panels that were instrumented. In this paper "height" refers to the vertical elevation and "depth," to the horizontal distances into the fill measured from the wall face. The instrumented wall panels were 15.5 ft (4.72 m) high. Wall facing consisted of precast concrete panels 6 in. (15.24 cm) thick and 10 ft (3.05 m) wide. Geogrids were mechanically connected to the concrete facing panels (Figure 3) at the elevations shown and extended to a depth of 12 ft (3.66 m). On the top of the wall fill, a pavement structure was constructed that consisted of a 4-in. (10.16-cm) base course covered by 9.5 in. (24.13 cm) of portland cement concrete.

The specified soil reinforcement was Tensar's SR2 geogrid, which is made of extruded high-density polyethylene, uniaxially oriented to obtain a high tensile strength equivalent to that of mild steel. It is reported to be resistant to chemical substances normally existing in soils. The geogrids have a maximum tensile strength of 5,400 lb/ft (79 kN/m) and a tension modulus at 2 percent elongation determined from unconfined "quick" (2 percent strain/min) tension tests of 75,000 lb/ft (1094 kN/m). A long-term allowable tensile strength of 1,986 lb/ft (29 kN/m) based on extensive creep testing has been reported. This value was reduced by an overall factor of safety equal to 1.5 to compute a long-term design tensile strength of 1,324 lb/ft (19 kN/m) for use in design.

Construction Methods

Construction methods can have a major impact on the performance of the wall system. The construction procedures used on this project are discussed in detail elsewhere (*1,2,4*). Brief details are given in the following.

Full-height precast concrete wall facing panels were hoisted and set vertically on a leveling pad. The panels were stabilized with struts so that they were initially battered inward.

As placement proceeded, geogrids were secured to the wall face at proper elevations and stretched to take up the slack. Fill was placed and spread onto the geogrid with a front-end loader. The fill was placed up to the next geogrid elevation and compacted. Compaction near the wall face was performed using a jumping jack; further from the wall face, however, a self-propelled vibratory compacter was used. As the height of the wall increased, struts on the outside of the wall were loosened, allowing the load to be transferred to the geogrids. This process was repeated for each geogrid level until the top of the wall was reached.

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Description of Instrumentation

The instrumentation program was designed to measure

1. Movements of wall faces by surveying the fronts of the concrete facing panels,
2. Strains in the reinforcement by resistance strain gages and inductance coils fastened to the geogrid reinforcement,
3. Horizontal and vertical strains in the soil with inductance coils placed in the reinforced wall fill,
4. Lateral earth pressure against the wall face and the distribution of vertical stresses along a geogrid with pressure cells installed in the reinforced wall fill, and
5. Distribution of temperature within the reinforced soil mass with resistance thermometers.

Locations of instruments are shown in Figures 1 and 2. All elevations referred to in this section are with respect to the base of the wall. The instrumented wall panels were 10 ft apart; they are denoted as 26-30 and 26-32. In general, instrument locations in the two walls were similar, to provide a cross-check; some differences in instrument layout allowed for acquiring additional information, such as geogrid strains at different elevations or the measurement of vertical stress and lateral earth pressures against the wall facing.

Details of instrument calibration, performance, and installation can be found in a preliminary instrumentation report (*1*).

DESIGN EQUATIONS

The wall was designed in accordance with available reinforced-soil methodology (*5*). A value engineering study performed by Dames and Moore (*6*) provides a detailed description of the design for this particular project. A summary of parameters used in the analysis is presented in Table 1.

Considering the internal stability of a soil wall constructed with frictional fill, as was the case with the instrumented wall

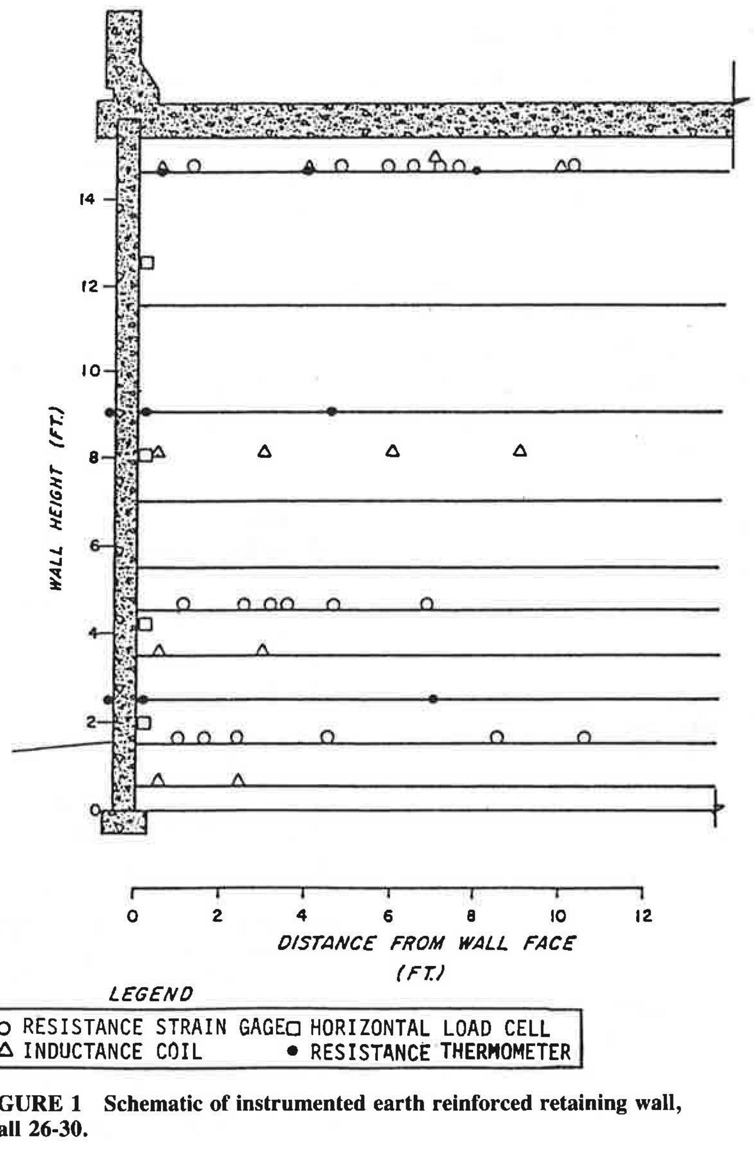

FIGURE 1 Schematic of instrumented earth reinforced retaining wall, Wall 26-30.

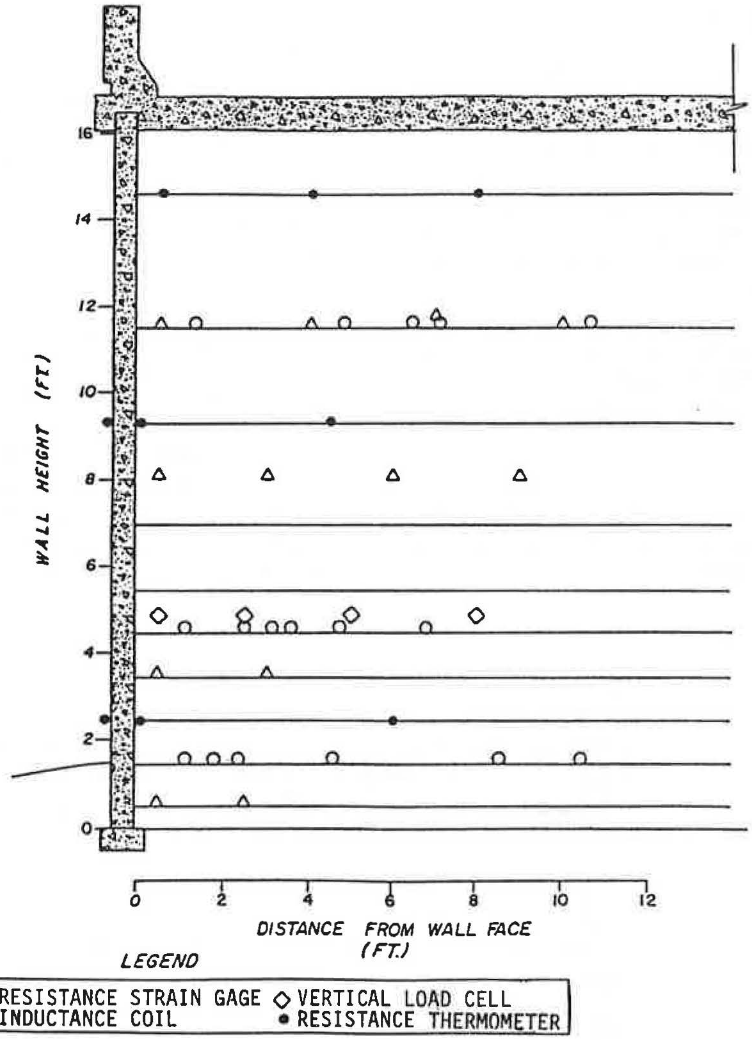

FIGURE 2 Schematic of instrumented earth reinforced retaining wall, Wall 26-32.

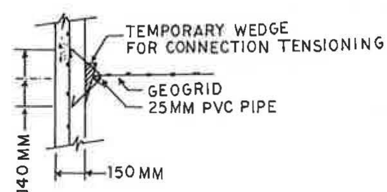

FIGURE 3 Measurements of strain in connection between geogrids and wall facing.

panels, the tensile force in the geogrid at level i (T_i) per unit width of wall is given by

$$T_i = K_{aw} \sigma_{vi} V_i \quad (1)$$

where

V_i = vertical spacing of the geogrids,
σ_{vi} = maximum vertical stress at level i obtained by assuming a linear variation of vertical stress (*5*), and
K_{aw} = Rankine coefficient of active earth pressure for the wall fill.

COMPARISON BETWEEN MEASUREMENTS AND DESIGN QUANTITIES

In general, good agreement was obtained between maximum tensions in the geogrids computed with Equation 1 and those obtained from measurements with gages attached to the grids. Measured strains were converted to geogrid loads using a stiffness modulus considering both the time-dependent stress-strain response of the viscoelastic polymer composing the geogrid and the increased stiffness that results from in-service soil confinement. Isochronous tension strain curves for Tensar SR2 geogrid (*5*) indicate that for the low levels of strain realized in this project, most time-dependent deformation occurred within the first 100 hr after load application. The 100-hr isochronous modulus relating strain to load in the geogrid is about one-third of the modulus determined from a "quick" tension test performed on the material. However, this reduction in stiffness is counteracted by the tendency of in-service soil confinement to increase the stiffness modulus. Results from tension tests performed on model plastic geogrids reported by Juran and Christopher (*7*) indicate that the confined stiffness modulus is about three times the unconfined

TABLE 1 SUMMARY OF PARAMETERS USED IN ANALYSIS

Parameter	Material		
	Wallfill	Backfill	Geogrid
Internal Friction	34°	30°	---
Cohesion	0	0	---
Unit Weight, lb/ft^3	125	115	---
(kN/m^3)	(19.6)	(18.0)	
Longterm Allowable Tension, lb/ft			1986
(kN/m)			(29.0)
Longterm Design Tension, lb/ft			1324
(kN/m)			(19.3)

stiffness modulus. When effects of both time and soil confinement were considered coincidentally, the stiffness modulus determined from unconfined quick tension testing was used to convert strains measured in the field to geogrid loads. However, further study is required to better establish confined behavior of in-service materials.

Measurements indicate that tensile strains in the geogrids are in the range of 0.3 to 0.8 percent, corresponding to a load of 225 to 600 lb/ft (3.28 to 8.75 kN/m) in the geogrids. Comparing this load with the ultimate tensile strength of the geogrids, which is 5,400 lb/ft (79.0 kN/m), the grids are loaded to between only 4 and 11 percent of the ultimate load level. At this low load level, significant creep is not expected.

Maximum tensions in the geogrids computed with Equation 1 and measurements from instrumented geogrids are compared in Figures 4–8. Tensile strain is depicted in these figures, and Equation 1 is used to compute the maximum tensile forces in the geogrids, which are then converted to strains. Results are presented for geogrids at elevations of 0.5, 1.5, 3.5, 4.5, and 11.5 ft (0.15, 0.46, 1.07, 1.37, and 3.51 m). Development of strain in the geogrids due to successive placement of lifts over the grids, indicated by fill placement height, is displayed. Results are presented for wall panels 26-30 and 26-32 when measurements from both walls are available, and in general, the results from the two wall sections are consistent.

Measurements include strains induced during compaction of the first lift of fill over the geogrid (with compaction) and measurements that do not include compaction strains (post compaction). Compaction strains are not shown for measurements made with inductance coils at elevations of 0.5, 3.5, and 11.5 ft (0.15, 1.07, and 3.51 m), because these measurements were deemed to be unreliable at such low strains. It appears that compaction did induce some additional tensile strain, roughly between 0.1 and 0.2 percent. These strain levels correspond to a tension load between 75 and 150 lb/ft (1.1 and 2.2 kN/m), which is considered small when compared with the design working load level of 1,324 lb/ft (19.4 kN/m).

Results presented for geogrids at the lower elevations of 0.5 and 1.5 ft (0.15 and 0.46 m) are shown in Figures 4 and 5. Strain measurements taken during the early part of construction when the height of fill over the grids was low are relatively close to those predicted by Equation 1. As construction proceeded and the height of fill over the geogrids increased, strains predicted by Equation 1 became higher than those that were measured. Results for geogrids located at higher elevations are shown in Figures 6–8. Here, strain measurements appear to be in good agreement with predicted strains throughout the construction process, indicating closer agreement between Equation 1 and measurements with respect to geogrids at these higher elevations.

A possible explanation for the response of the lower geogrids is related to the pinned connection between the precast concrete wall facing and a strip footing at the base of the wall. The connection may have allowed a small amount of initial translation between the wall facing and footing while the first few lifts of backfill were placed. Displacements were such that load transfer between the soil and geogrid reinforcement was possible. Further displacement at the bottom of the wall facing was restricted by the pinned connection, so load transfer to

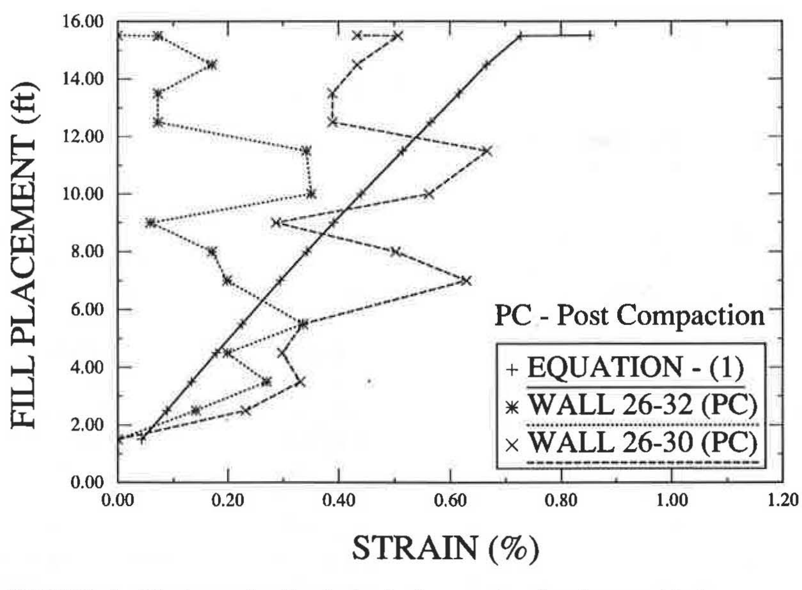

FIGURE 4 Maximum tensile strain during construction in geogrid at elevation 0.5 ft (0.15 m).

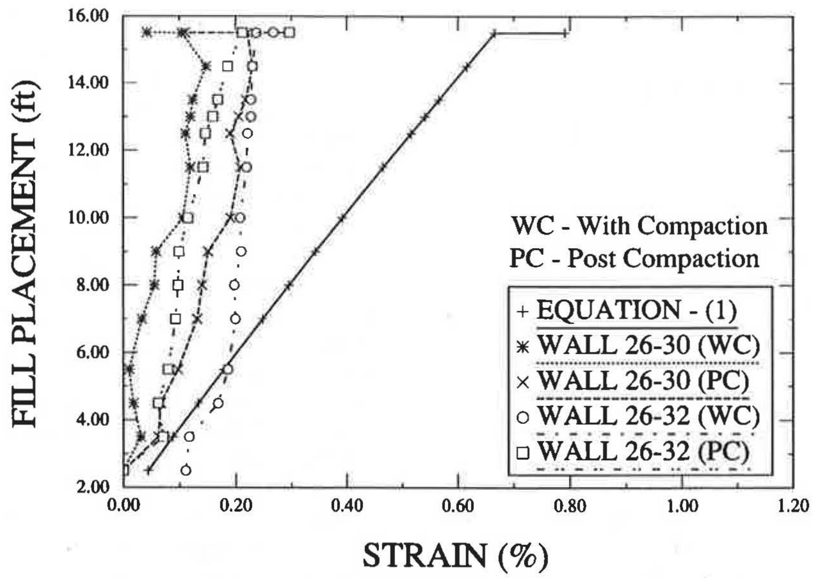

FIGURE 5 Maximum tensile strain during construction in geogrid at elevation 1.5 ft (0.46 m).

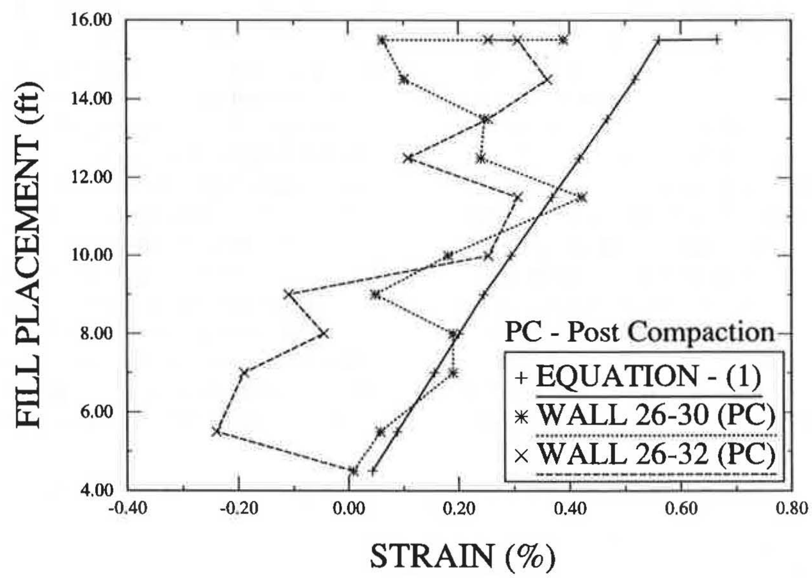

FIGURE 6 Maximum tensile strain during construction in geogrid at elevation 3.5 ft (1.07 m).

the geogrids was not possible while backfill was being placed at higher elevations. Perhaps increased lateral earth pressure was then applied to the wall face, as indicated by pressure measurements at the wall face.

LONG-TERM BEHAVIOR

Fluctuations in readings from pressure cells and inductance coils throughout the first year after construction of the wall appear to well represent the seasonal temperature fluctuations within the reinforced soil mass. These fluctuations may be due to the temperature effects on the wall sytem or to the effect of temperature on the instruments. Temperature compensation was provided for resistance strain gages, and no significant or consistent fluctuations with temperature variation throughout the year were observed.

Creep effects were not apparent for the year during which readings were taken. The effects of the creep may have been masked by temperature effects. However, the level of tension in the geogrids may be so low that creep effects are insignificant.

Figures 9–14 present results of geogrid strain measurements taken with resistance strain gages along the length of grids at elevations of 1.5, 4.5, 11.5, and 14.5 ft (0.46, 1.37, 3.51, and 4.42 m). Readings acquired at the end of construction of the wall (October 1985) are compared with readings taken annually in 1986, 1987, and 1988. Data from resistance strain gages were not obtained during 1989 because of equip-

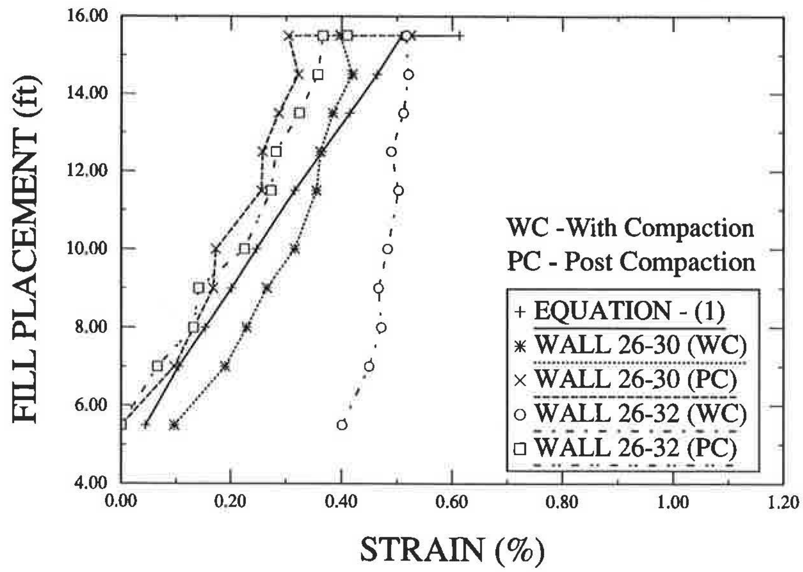

FIGURE 7 Maximum tensile strain during construction in geogrid at elevation 4.5 ft (1.37 m).

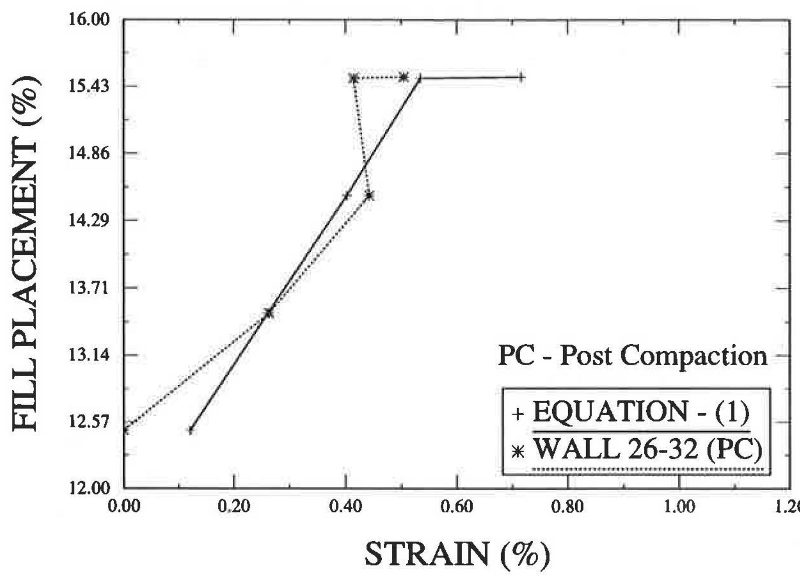

FIGURE 8 Maximum tensile strain during construction in geogrid at elevation 11.5 ft (3.51 m).

ment difficulties. Information shown in Figures 9–14 reveals that subsequent readings display little change from previous readings and no consistent pattern. Creep or a change in strain with time is not indicated.

Figure 15 shows results from measurements of strain in the connection between geogrids and the full-height precast concrete wall facing. The connection consists of pieces of geogrid embedded in the precast concrete wall panels to form a loop through which the ends of geogrids are inserted. The connection is illustrated in Figure 3. Measurements are from resistance strain gages mounted to the top portion of the loops. A small increase in strain over time is revealed from measurements taken with gages mounted on loops at elevations 0.5, 1.5, and 3.5 ft (0.15, 0.46, and 1.07 m). The small increase in strain, which may be due to settlements that occurred in the wall fill, appears to have stabilized between 1987 and 1988. The decrease in strain recorded from measurements taken at elevation 11.5 ft is most likely due to a loss of bond between the strain gage and the geogrid material.

CONCLUSIONS

This study is unique in its focus on field measurements of geogrid-reinforced retaining walls with full-height precast concrete facing. Tensile strains measured during construction of the wall indicate that during compaction of the wall fill, a tension force was induced in the geogrids that is low when

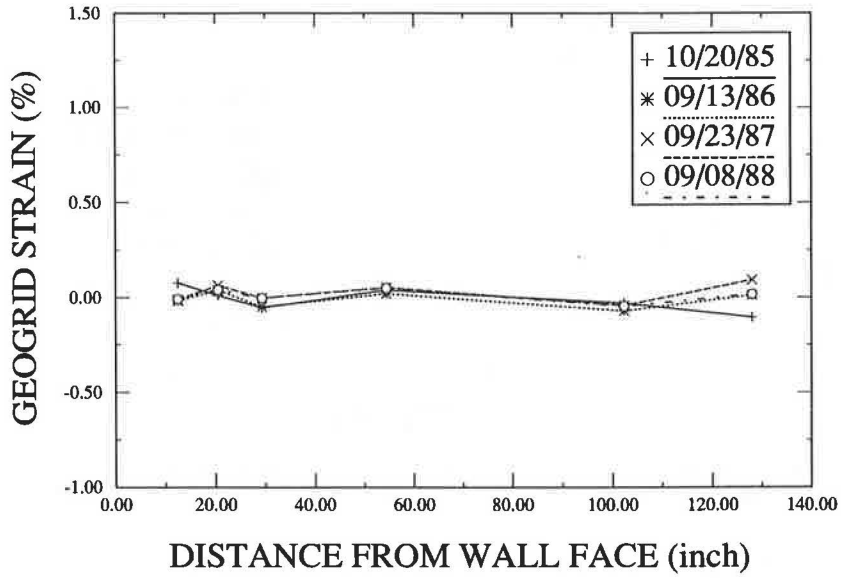

FIGURE 9 Annual measurements of strain along geogrid at elevation 1.5 ft (0.46 m), Wall 26-30.

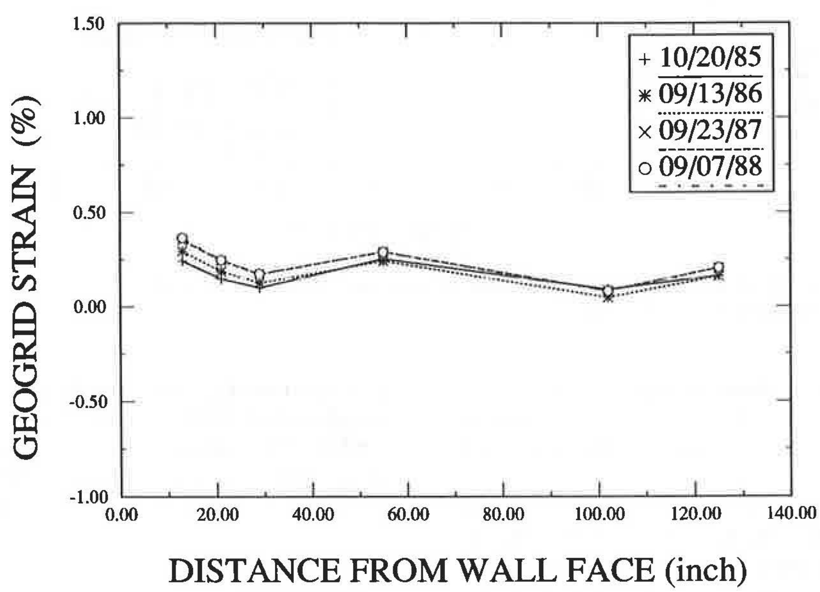

FIGURE 10 Annual measurements of strain along geogrid at elevation 1.5 ft (0.46 m), Wall 26-32.

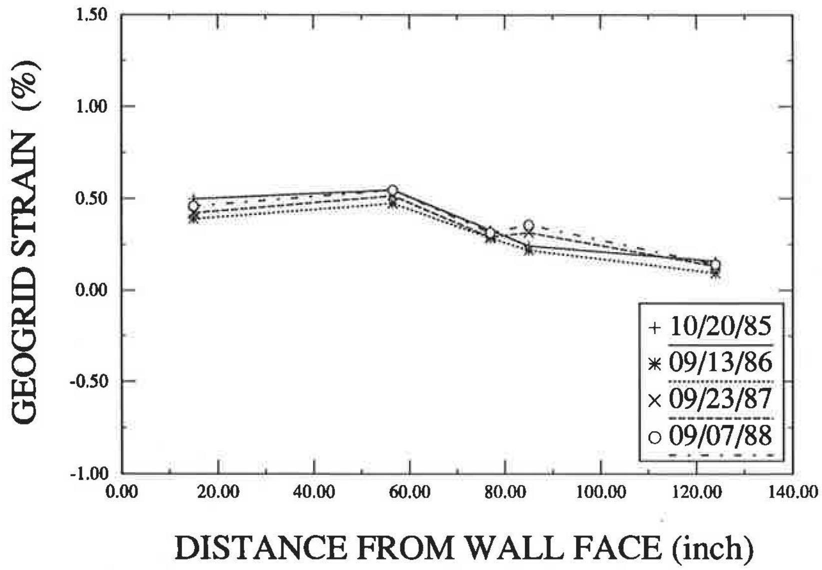

FIGURE 13 Annual measurements of strain along geogrid at elevation 11.5 ft (3.51 m), Wall 26-32.

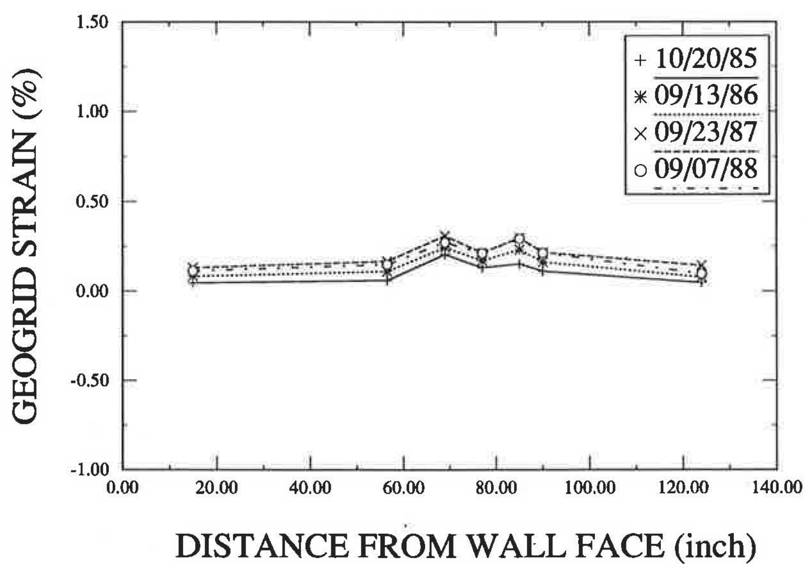

FIGURE 14 Annual measurements of strain along geogrid at elevation 14.5 ft (4.42 m), Wall 26-30.

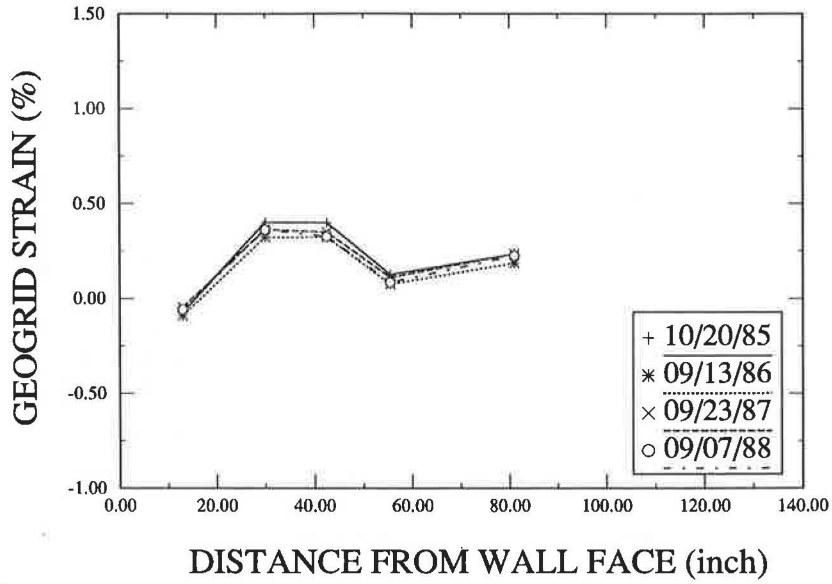

FIGURE 11 Annual measurements of strain along geogrid at elevation 4.5 ft (1.37 m), Wall 26-30.

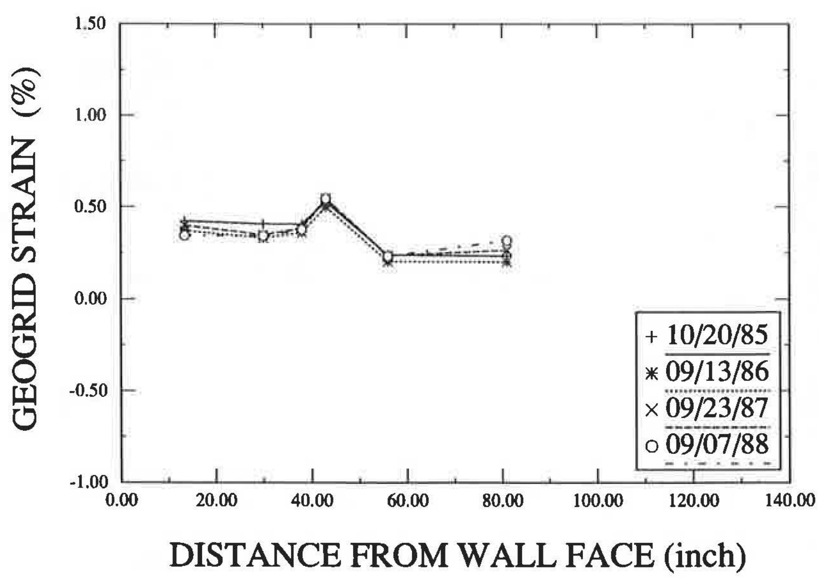

FIGURE 12 Annual measurements of strain along geogrid at elevation 4.5 ft (1.37 m), Wall 26-32.

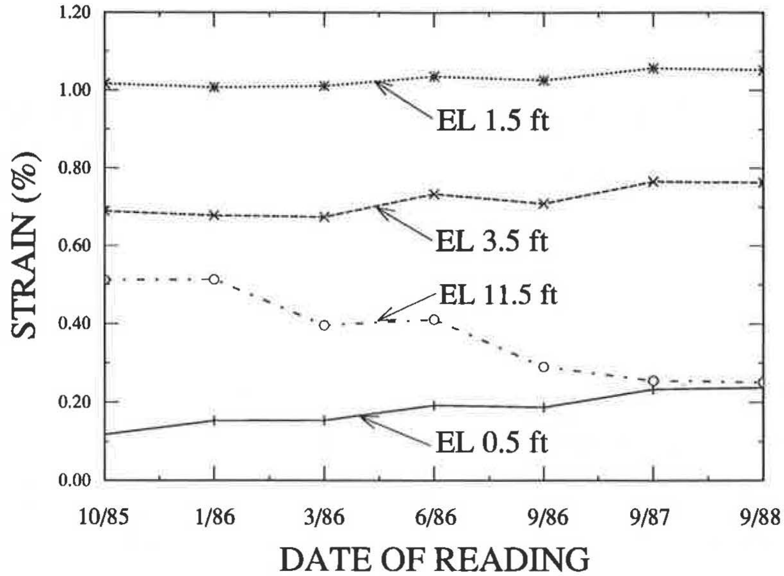

FIGURE 15 Detail of connection between geogrids and wall facing (*8*).

compared with safe working loads. Geogrid strains measured during and after construction demonstrate that the computation of maximum tension in the reinforcement using Equation 1 was in general satisfactory.

In addition, this project is especially important because of its duration. Survivability of the instruments installed in this project has allowed the observation of the long-term behavior of geogrids in service. Data obtained so far indicate that appreciable rates of creep strain are not evident. Although this conclusion lends credibility to the use of strain-hardened polyethylene materials for long-term applications, it should be noted that the level of tension that prevailed in the geogrids was far below the design tensile strength. Future studies should focus on the behavior of geogrids installed in systems such that the geogrids are loaded to working stress levels.

ACKNOWLEDGMENTS

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REFERENCES

1. Desert Earth Engineering. *Tensar Earth-Reinforcement Wall Monitoring at Tanque Verde–Wrightstown–Pantano Roads, Tucson, Arizona.* Preliminary report to Pima County Department of Transportation and Flood Control District, Tucson, Ariz., 1986.
2. Desert Earth Engineering. *Tensar Earth-Reinforcement Wall Monitoring at Tanque Verde–Wrightstown–Pantano Roads, Tucson, Arizona.* Final report to Pima County Department of Transportation and Flood Control District, Tucson, Ariz., 1987.
3. K. L. Fishman, C. S. Desai, and R. L. Sogge. Field Behavior of Instrumented Geogrid Soil Reinforced Wall. *Journal of the Geotechnical Engineering Division*, ASCE, submitted March 1990.
4. *Tensar Geogrid Reinforced Soil Wall.* Experimental Project 1, Ground Modification Techniques. FHWA-EP-90-001-005. FHWA, U.S. Department of Transportation, Jan. 1989.
5. *Guidelines for the Design and Construction of Reinforced Walls Using Tensar Geogrids.* Netlon Ltd., Blackburn, England, 1984.
6. Dames and Moore. *Tensar SR2 Reinforced Retaining Walls for Tanque Verde Road, Tucson, Arizona.* Study for Pima County Department of Transportation and Flood Control District, Tucson, Ariz., 1984.
7. I. Juran and B. Christopher. Laboratory Model Study on Geosynthetic Reinforced Soil Retaining Walls. *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 115, No. 7, July 1989.
8. R. R. Berg, R. Bonaparte, R. P. Anderson, and V. E. Chouery. Design, Construction, and Performance of Two Geogrid Reinforced Soil Retaining Walls. *Proc., 3rd International Conference on Geotextiles*, Vienna, Austria, 1986.

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