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Temperature Affects on the Connection Strength of MSE Walls

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ABSTRACT: The affect of elevated temperatures (i.e., > 23°C) on the connection strength between a concrete wall face and geosynthetic reinforcement is investigated. This investigation includes the review of two field monitoring programs, one in the southeastern United States and one in the desert environment of the southwestern United States. These field monitoring programs measured both the ambient and in situ temperatures at the wall face and within the reinforced soil mass. In addition, the results of a laboratory investigation into the affects of elevated temperatures (38°C) on the connection strength between the wall face and geosynthetic reinforcement are presented.

1. INTRODUCTION

In North America, the use of geogrid reinforced soil retaining walls has gained wide acceptance as an economical alternative to both conventional cast-in-place concrete retaining walls and mechanically stabilized earth (MSE) walls using metallic reinforcements. Procedures for determining the internal and external stability of geosynthetic reinforced MSE structures, and for determining the long-term allowable design strength of the reinforcement have become well established state-of-the-practice procedures over the last decade. However, with the rapid growth in the last five years in the popularity of geogrid reinforced, segmental concrete faced MSE walls, the need for a rational connection strength design criteria has arisen. Collin and Berg (1993) presented a procedure for determining the long-term connection design strength between the geosynthetic reinforcement and wall face. This procedure states that the allowable design strength of the connection should be determined at the in-situ service temperature, and, if no information is provided the assumed temperature shall be taken as 38°C.

2. CONNECTION DESIGN CRITERIA

The design of the connection between soil reinforcing elements and facing units is a critical component of any MSE retaining wall structure. The procedure outlined below was developed by Collin and Berg (1993) and follows the generalized criteria documented in the Task Force 27 guidelines (1990) for evaluation of the long-term allowable strength of geosynthetic soil reinforcement. Both serviceability and limit state criteria are considered when quantifying the design connection strength of a system.

2.1 Serviceability Criterion

The allowable connection strength based upon a serviceability criterion is determined as follows:

$$T_{cs} = \frac{T_{wconn}}{FD \times FC}$$

where:

T_{cs} = long-term allowable connection strength based upon a serviceability criterion (kN/m);

T_{wconn} = geosynthetic tensile load at 20mm displacement, measured at the back of the facing unit, at the design temperature (kN/m);

FD = a reduction factor for geosynthetic durability in the connection environment (dimensionless); and

FC = a reduction factor for geosynthetic installation damage of connection construction (dimensionless).

Task Force 27 guidelines do not specifically address the maximum elongation between reinforcement and wall face; it does, however, limit the amount of overall elongation of the reinforcement embedded in soil during pullout to less than 20mm. This deformation is measured with a quick (e.g. displacement rate of 1mm/minute) pullout test. Collin and Berg (1993), therefore, established a 20mm deformation as determined with a quick connection strength test as the maximum allowable movement of the connection. This criterion is intended to assure that post-construction movement of the wall face is limited to an acceptable level.

2.2 Limit State Criterion

The ultimate strength of the connection must also be evaluated. The allowable design connection strength, based upon the limit state criterion, is determined as follows:

$$T_{cl} = \frac{T_{lconn} \times R_D}{FD \times FC \times FS}$$

where:

T_{cl} = long-term allowable connection strength based upon a limit state criterion (kN/m);

T_{lconn} = limit state tensile load of the connection, where the accumulated creep strain-rate continues to decrease with log-time at the design temperatures (kN/m);

R_D = reduction factor (dimensionless); and

FS = overall factor of safety to account for uncertainties in structure geometry, fill properties, reinforcement properties and externally applied loads (dimensionless), usually taken as a minimum value of 1.5.

The limit state tensile load should be determined from creep tests (minimum duration of 1,000 hours) of representative connections. This minimum duration is acceptable only if the rate of creep at termination of the test is approximately equal to that derived from creep testing of the geosynthetic itself (Collin and Berg, 1993).

A reduction factor R_D has been incorporated into the equation for the determination of the long-term allowable connection strength. The addition of this factor allows the designer to reduce the required tensile load at the connection.

Task Force 27 guidelines require that the connections of geosynthetic reinforcements be designed to carry 100% of the maximum design load at all levels of reinforcement within the wall. A R_D = 1 meets this requirement. However, tensile loads in the reinforcement at the wall face may not reach the maximum reinforcement design load, and may only be some portion of the ultimate design load for any layer. Thus use of a R_D value less than one may be appropriate. Both the serviceability and limit state connection strengths are a function of the normal pressure applied at the connection. The connection strength should, therefore, be evaluated at the anticipated range of overburden pressures.

These two equations enable a designer to quantify the long-term performance of a critical component of an MSE wall, the connection between the reinforcement and facing unit.

3. TEMPERATURE AFFECTS

Geosynthetic reinforcements are manufactured from polymers which are thermoplastic materials. The strength of these materials is in part dependent upon temperature. For example, the ultimate strength of a geosynthetic reinforcement tested at 23°C will be higher then the ultimate strength of the same reinforcement tested at 40°C. The consideration of the in-service temperature of the reinforcement is, therefore, an important consideration when evaluating the long-term design strength of the reinforcement or the long-term design strength of the connection between reinforcement and wall facing units.

In North America, the state-of-practice when determining the long-term allowable strength of the reinforcement for MSE structures is to assume that the temperature of the in-service environment is 23°C. This temperature is the assumed average temperature of the reinforcement over the life of the structure (75 years) and is believed to be a conservative number based on the insulating characteristics of soil. However, the connection between the reinforcement and facing unit may be exposed to higher temperatures at the face of a wall than within the reinforced soil mass for short-term periods, in some geographic locations. Task Force 27 guidelines require that the allowable design strength of the connection be determined at the in-situ service temperature. If no information is provided as to the actual in-situ temperature, the assumed temperatures shall be taken as 38°C.

4. ELEVATED TEMPERATURE CONNECTION TESTING

The results of a limited laboratory study of the affect of elevated temperature on the connection strength between a high molecular weight, high density polyethylene geogrid and a segmental concrete facing unit is presented below. A test temperature of 38°C and a quick tension test at 1mm/minute (serviceability criterion test condition) was used. As discussed in the following sections this represents an extreme temperature scenario for the United States. The procedures used for this testing program are the same as those followed by the lead author in previous testing programs (Chewning and Collin, 1991), with the exception that the wall face was heated from approximately 23°C to 38°C with radiant heat (Figure 1). This temperature was reached and held constant for four hours prior to applying tension on the geogrid. The four hour heating cycle is believed to conservatively represent the maximum duration a wall will experience 38°C temperatures during a daily cycle. The elevated temperature condition is generally a short-term condition (3-4 hours per day for a couple of months per year). As such, elevated temperature effects on the serviceability state connection criteria are evaluated. The limit state strength is evaluated at 23°C.

Three connection strength tests (one control test at 23°C and 2 elevated temperatures tests at 38°C) were conducted using an extruded geogrid with an ultimate strength (ASTM D4595) of 80 kN/m and a creep limited strength (ASTM D5262) of 33.6 kN/m.

The results of the connection strength tests as a plot of connection force versus displacement are shown in Figure 2. A serviceability connection strength at 38°C (tension at 20mm displacement) of 28.1 kN/m and an ultimate strength

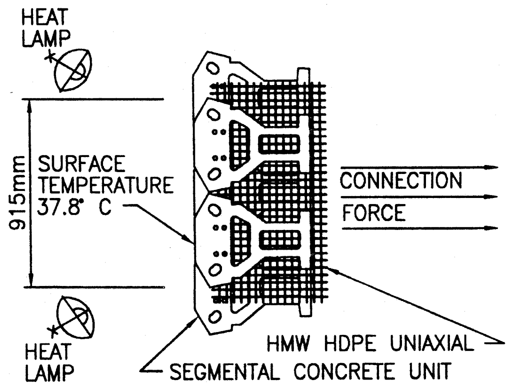

Figure 1 Laboratory Connection Strength, at Elevated Temperature, Test Apparatus

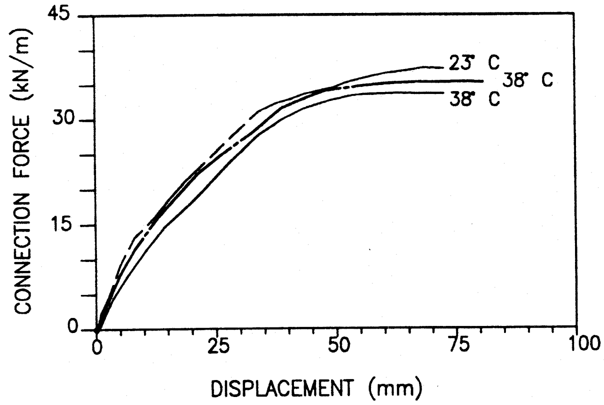

Figure 2 Connection Strength Testing HMW HDPE Geogrid in Segmental Concrete Unit

of 46.6 kN/m (average of two tests) were measured as compared to 30.8 kN/m and 50.6 kN/m respectively at 23°C, The affect of elevated temperature on the connection strength of this particular combination of geogrid with the segmental concrete facing unit shown in Figure 1 was to reduce the serviceability connection strength by less than 9 percent.

Even at this reduced connection strength the serviceability connection is well above the long-term allowable strength of the geogrid (i.e. 21.3 kN/m). For this particular combination of geogrid reinforcement and segmental concrete facing unit, the elevated temperature (38°C) at the connection has not affected the design of the structure as the long-term allowable strength of the reinforcement (21.3 kN/m) is lower than the serviceability connection strength (28.1 kN/m) and governs the design.

5. FIELD MONITORING PROGRAM

To evaluate the actual in-situ temperature of geogrid reinforced MSE walls, two projects were identified and monitored. The first project located in the Sonora Desert was extensively instrumented and monitored under the FHWA Demonstration Projects Program. Detailed results of this monitoring program were reported by Berg et. al. (1986), Fishman et. al. (1991), Collin and Berg (1992) and a government report (1989) entitled "EXPERIMENTAL PROJECT 1, Ground Modification Technique, Technology Transfer, Tensar Geogrid Reinforced Soil Wall, Grade Separation Structures on the Tanque Verde - Wrightstown - Pantano Roads Intersection, Tucson, Arizona". The wall facing for this project consisted of full-height (3 m wide by 15 cm thick) precast concrete panels. Temperature measurements on the face of the wall, immediately behind the wall face and within the reinforced soil mass are shown in Figure 3. A maximum temperature of 36°C was measured immediately behind the facing panel in the reinforced fill with temperatures up to 46°C measured on the exterior surface of the concrete panels.

Geogrid strains were also monitored as part of this instrumentation program. Both strains at the connection and along the length of the reinforcement were recorded. As previously discussed, an increase in temperature would be expected to be seen as increased geogrid strains. However, no increase in strains at the connection were observed during wall monitoring. Conclusions (FHWA, 1989) from the project were:

"The evidence to date indicates that the elevated summertime temperatures of the Sonora Desert environment have no significant effect on the performance of geogrid reinforcement behind the wall facing".

The second project selected for monitoring is located in Atlanta, Georgia and is a wall varying in height from 3 to 6 meters. The facing for this wall utilizes dry cast segmental concrete units that are 20 cm wide, 30 cm high and 30 cm deep (Figure 4). One cross-section of the wall, approximately 4.2 meters high, was monitored with two sets of three thermistors. One located approximately 0.6 meters above the bottom of the wall and one located approximately 1.2 meters above the bottom. At each elevation a set of three thermistors were installed; one within the precast unit; one 25 cm behind the back of the unit; and one approximately 1 meter behind the back of the unit.

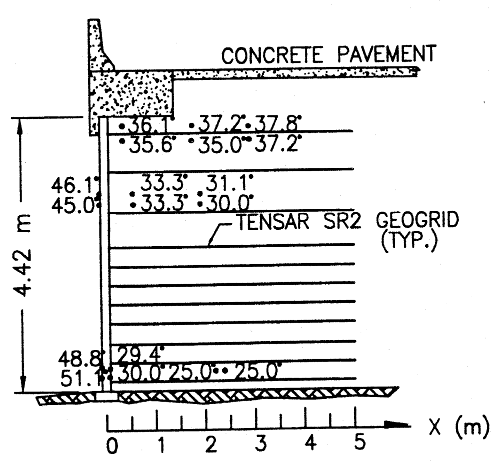

Figure 3 Temperature measurements on Tucson Wall

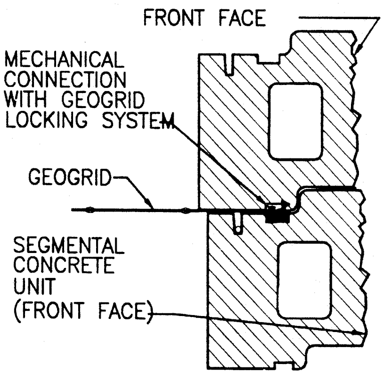

Figure 4 Geogrid Segmental Concrete Unit Connection

The highest temperature within the connection was 33°C. It was recorded in late July following four weeks of daily high temperatures ranging between 32 and 38°C.

The connection for this particular combination of geogrid with high junction strength and segmental concrete unit is a mechanical connection. The maximum temperature of 33°C was measured at the point of this mechanical connection and can be considered to represent the connection temperature for design.

6. DISCUSSION

The information provided in the previous sections of this paper represent a limited study. Additional research should be conducted to evaluate the sensitivity of frictional connections to various normal pressures under elevated temperatures. For mechanical connections, the variation in normal pressure has a much smaller affect on connection strength. Only one type of geogrid was tested at elevated temperatures. The procedure proposed is believed to be appropriate for both singular and composite geogrids. Further research should be conducted to evaluate the affect of high temperatures on connections which utilize composite (coated) geogrids.

7. CONCLUSIONS

The affects of in-situ temperatures on the connection strength between geosynthetic reinforcement and wall facing for MSE walls should be considered when evaluating the performance of the connection. A procedure has been presented for conducting elevated temperature connection tests. The results of a limited testing program on a specific combination of facing unit and reinforcement has demonstrated that the serviceability strength of the connection was reduced by approximately 10% for an elevated temperature environment of 38°C (compared to 23°C).

This, however, does not control the design of MSE walls constructed with these specific components as the long-term design strength of the geogrid reinforcement is less than the connection strength between the reinforcement and segmental concrete unit even at an elevated temperature of 38°C.

Field monitoring of two geogrid reinforced MSE walls in the southeastern and southwestern portions of the United States have shown that maximum short-term elevated temperatures at the geogrid facing unit connection of these structures was 33° and 31° respectively. The Task Force 27 requirement for elevated temperature connection testing at 38°C appears to be appropriate for the majority of the United States.

REFERENCES

Collin, J.G., and Berg, R.R., "Connection Strength Criteria for MSE Walls", Transportation Research Record, Transportation Research Board, 72 Annual Meeting, January 10-14, Washington D.C., 1993.

Berg, R.R., Bonaparte, R., Chouery, V. C., and Anderson, R. P., Design, Construction, and Performance of Two Geogrid Reinforced Soil Retaining Walls, Proceedings of the IIIrd International Conference on Geotextiles, Vienna, Austria, 1986, pp. 401-406.

Fishman, K.L., Berg, R.R., and Desai, C.S., Geosynthetic-Reinforced Soil Wall: 4-Year History, Transportation Research Record No. 1330, Behavior of Jointed Rock Masses and Reinforced Soil Structures, Transportation Research Board, Washington, D.C., 1991, pp. 30-39.

Collin, J.G., and Berg, R. R., Permanent Geogrid Soil Retaining Walls - U.S. Experience, International Symposium on Recent Case Histories of Permanent Geosynthetic Reinforced Soil Retaining Walls, University of Tokyo, Japan, 1992.

Chewning, R.J. and Collin, J.G. "Evaluation of Geogrid to Wall Facing Connections for Modular Block Earth Retaining Wall Systems," Proceedings Ohio River Valley Soils Seminar XXII, Lexington, Kentucky, 1991.

Task Force 27, AASHTO-AGC-ARTBA Joint Committee, 1990, "Design Guidelines for Use of Extensible Reinforcements (Geosynthetics) for Mechanically Stabilized Earth Walls in Permanent Applications", AASHTO, Washington, D.C.

Tensar Geogrid-Reinforced Soil Wall, Grade-Separation Structures on the Tanque Verde-Wrightstown-Pantano Roads Intersection, Tucson, Arizona, Experimental Project 1, Ground Modification Techniques, FHWA, 1989, 119 p.