

Laboratory Evaluation of Connection Strength of Geogrid to Segmental Concrete Units

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Segmental concrete retaining wall systems reinforced with geogrid are gaining wide acceptance because of their economic and aesthetic appeal. Guidelines have been established for some aspects of design and construction; other aspects are still being reviewed and require further study. One area still being developed involves the connection between the geogrid and the segmental concrete units. The results of a laboratory study to investigate the connection strength and deformation characteristics are presented. Eight retaining wall systems using five segmental concrete units and two geogrids were tested. Test results were analyzed with respect to suggested guidelines for design of the connection. Both maximum connection strength and strength at a limiting deformation were considered.

Segmental concrete retaining walls reinforced with geogrid are gaining acceptance because of economic and aesthetic advantages in certain applications. Berg presents a concise description of these retaining systems (1), and design and construction guidelines have been presented (2-5); although some aspects remain under review and require further study. One of these areas relates to the strength of the connection between the geogrid reinforcement and the concrete facing units. Current connection strength requirements are those established by AASHTO-Associated General Contractors (AGC)-American Road and Transportation Builders Association (ARTBA) Task Force 27 (5).

The Task Force 27 guidelines state that the extensible reinforcement connections to the facing should be designed to carry 100 percent of the maximum design load at all levels within the wall and that a representative section of the connection be load tested. The guideline also states that the allowable design strength of the reinforcement cannot exceed the measured connection strength. However, no criteria are provided for determination of the connection strength. Chewing and Collin (6) have presented the results of some connection strength testing and have proposed the following criteria:

- Serviceability: limit the movement in the connection between the geogrid and modular block to 1.91 cm (0.75 in.).
- Limit strength: establish a factor of safety of 2.0 between the allowable connection strength and the peak connection strength measured in the testing.

Laboratory testing of the connection strength for five retaining wall systems was conducted recently at the University of Wisconsin-Platteville. Individual systems were tested under separate contracts and were sponsored by the manufacturers of the respective systems. Testing was conducted over 2 years, and the procedures evolved somewhat with experience. At the time of testing no standard test procedures were available, so comparing test results for different wall systems is not advisable. Results related to peak or maximum strength have been published (7,8), and results related to the serviceability criterion are presented in this paper.

RETAINING WALL SYSTEMS TESTED

Segmental Concrete Units

Five types of segmental concrete unit were used in the test program. The systems all employ some type of interlocking mechanism between units including pins, clips, and lips as shown in Figure 1. The geogrid, which is positioned between the units, is held in place by the action of the interlocking mechanism and friction. Some of the units have hollow cores filled with crushed stone, which provides stability and also contributes to the strength of the connection between the units and the geogrid.

Geogrid Reinforcement

Test results for two geogrids are reported in this paper. One is a stiff uniaxial geogrid formed of extruded polypropylene. The other is a flexible woven geogrid composed of polyester yarns. Geogrid properties are described in their respective design manuals (3,4). The configuration of the flexible geogrid has been modified since the tests reported in this paper were conducted.

Test Program

Test results are presented for the systems presented in Table 1. The combinations of segmental concrete units and geogrid reinforcements were those requested by the program sponsors. A series of tests was conducted on each system to determine the connection strength over a range of normal loads. Three replicate tests were conducted at each normal load.

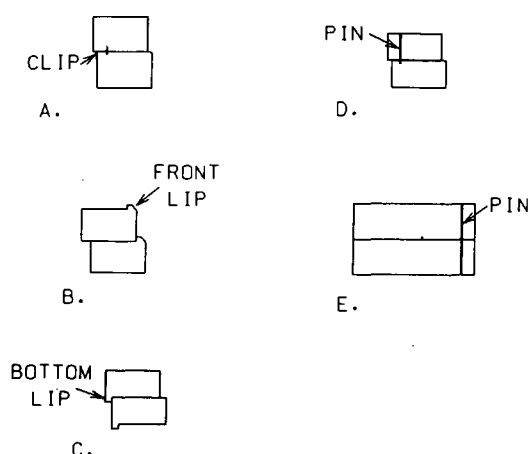


FIGURE 1 Retaining wall systems tested: (a) Stonewall, (b) Allan, (c) Diamond, (d) Versa-Lok, (e) Rockwood.

TEST PROCEDURES

Apparatus

All testing was conducted in the materials laboratory at the University of Wisconsin-Platteville. A schematic of the test apparatus is shown in Figure 2. Two layers of segmental concrete units were positioned with the geogrid in between. The concrete units were restrained from moving by a vertical steel plate placed at the rear of the units. The free end of the geogrid extended through a slot in the plate to connect to a clamping device. The free length of the geogrid specimens was 25.4 cm (10 in.), and the embedded lengths varied from 30.5 to 68.6 cm (12 to 27 in.), depending on the size of the concrete units. The widths of the geogrid specimens were also dependent on the size of the concrete units; they varied from 40.6 to 121.9 cm (16 to 48 in.). Specimen widths for each test series are given in Table 2.

The horizontal pullout force was distributed uniformly across the width of the geogrid by a clamping device consisting of two pieces of wood, 5 cm (2 in.) thick and 25 cm (10 in.) wide. The length of the wood corresponded to the size of the

geogrid specimen. The geogrid was placed between the two wood pieces and a double row of bolts used to fasten the system together. The bolt spacing was 10 cm (4 in.) in each row. No slippage was observed between the clamp and the geogrid during testing.

Vertical loads normal to the geogrid were applied by dead weights acting on a hanger arrangement that extended through holes in the test floor. Pullout forces were applied at a constant displacement rate of 1.27 cm/min (0.5 in./min) using a 44 500-N (10,000-lb) MTS closed-loop hydraulic testing machine. Forces were determined with an electrical resistance load cell, and a force-displacement graph was plotted with an XY recorder.

Procedures

The first step was to place the bottom layer of units, consisting of either two or three units, on the test floor. When applicable, depending on the system, the hollow cores were filled with

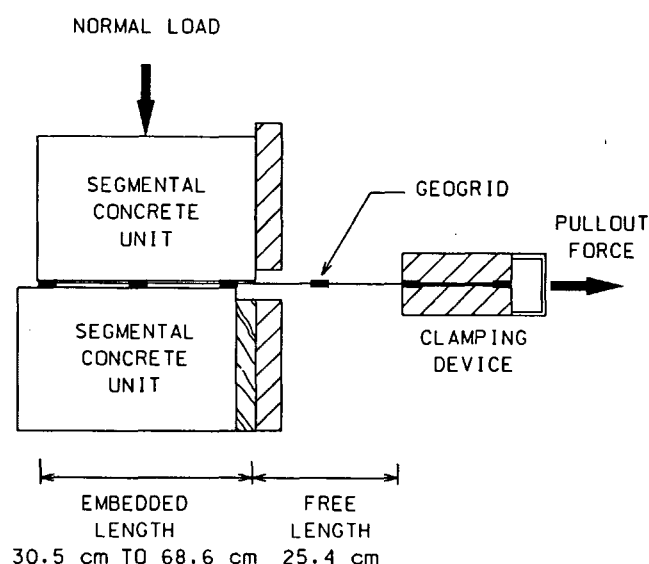


FIGURE 2 Connection strength apparatus.

TABLE 1 Retaining Wall Systems Tested

Test Series	Segmental Concrete Units			Geogrid ^a
	Name ^a	Size ^b cm:cm:cm	Weight ^c N	
A1	Diamond	15x41x30	329	Miragrid 5T
B1	Versa-Lok	15x41x30	365	Miragrid 5T
C1	Rockwood	20x61x69	498	Miragrid 5T
D1	Stonewall	20x41x30	267	Miragrid 5T
A2	Diamond	15x41x30	329	Tensar UX1400
B2	Versa-Lok	15x41x30	365	Tensar UX1400
C2	Rockwood	20x61x69	112	Tensar UX1400
E2	Allan	20x41x30	267	Tensar UX1400

^a Segmental concrete units and geogrid are proprietary and/or patented.

^b Size is height x width x depth.

^c Weight includes units alone without gravel fill.

1 cm = 0.394 inches

1 N = 0.225 pounds

TABLE 2 Specimen Widths

Test Series	Width of Segmental Concrete Units cm	Width Of Geogrid Specimens cm
A1	40.6	40.6
B1	40.6	81.2
C1	61.0	122.0
D1	40.6	40.6
A2	40.6	40.6
B2	40.6	81.2
C2	61.0	122.0
E2	40.6	40.6

1 cm = 0.394 inches

crushed stone and the pins or clips put in position. The geogrid was placed to interlock with the pins or clips or the crushed stone. In all cases the test sections were constructed to represent the way that the particular systems would be constructed in the field. The top layer of units, which consisted of one unit less than the lower layer, was positioned in running bond configuration. The normal load was then applied to the top of the system, and the horizontal pullout force was applied.

Geogrid Extension Testing

Representative samples of the geogrid were tested in tension to determine their deformation characteristics. The samples were 25.4 cm (10 in.) long and 40.6 cm (16 in.) wide. Test apparatus consisted of a clamping device at both ends of the geogrid sample. Rate of loading, loading apparatus, and measurement instrumentation were the same as those used for the connection testing.

TEST RESULTS

Data Analysis

The raw data obtained from each test consisted of pullout resistance versus hydraulic piston movement plotted by an XY recorder. The pullout resistance represents the tensile force developed in the geogrid as the test was carried out. Hydraulic piston movement consists of two components: (a) the elongation of the geogrid over the free length and (b) the relative movement of the embedded length of the geogrid with respect to the concrete units. This relative movement of the embedded length is called the connection deformation.

Values of pullout resisting force were read for each 0.25 cm (0.1 in.) of piston movement from 0 to 5 cm (2 in.). The elongation of the geogrid in the free length was subtracted from piston movement values to determine the connection deformation. Typical results from analysis for both rigid and flexible geogrids are shown in Figure 3.

Normally three replicate tests were conducted at each normal load for each wall system tested. Results of the replicate tests were plotted together, and a regression analysis was conducted to determine the best-fit curve to the data. The equation used for the analysis was of the form

$$y = Ax/(B + x) \quad (1)$$

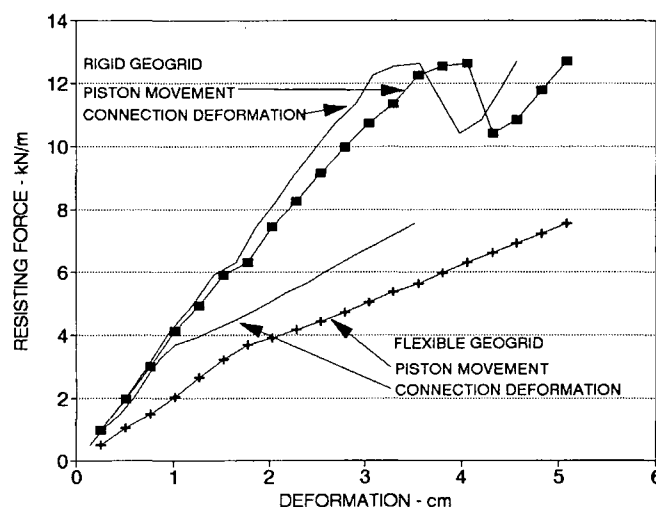


FIGURE 3 Effect of free length deformation.

where

y = resisting force,
 x = connection deformation, and
 A, B = constants of best fit.

Results of a set of three replicate tests are shown in Figure 4. The coefficient of correlation, a statistical indicator of how well the regression curve fits the actual data, was .929 for the data in Figure 4.

Coefficients of correlation were determined for each test and are presented in Figure 5. Factors that influence the repeatability of the results include roughness of the modular concrete block surfaces, variability of the gravel fill, placement of the geogrid with respect to the connecting pins, and variability of the geogrid specimens. The three tests for which the coefficient of correlation is less than 0.6 were at relatively low normal loads. In general, test results were more repeatable at higher normal loads.

Connection Strength

According to Chewing and Collin (6), two criteria for connection strength should be considered: maximum connection strength and connection strength at a deformation of 1.91 cm

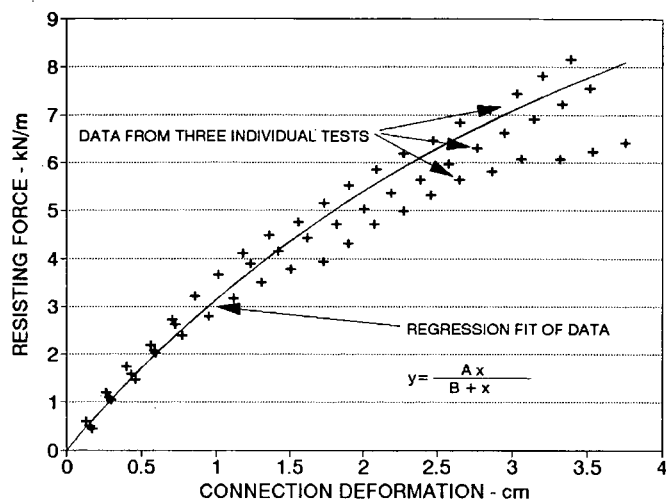
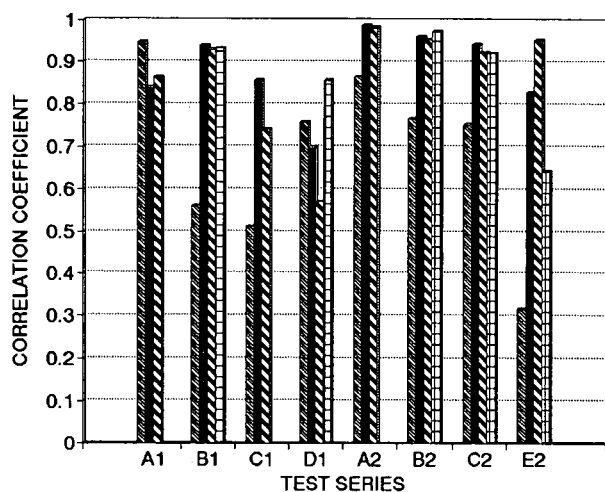


FIGURE 4 Regression fit of load-deformation data.



For each test series, normal loads increase from left to right

FIGURE 5 Statistical accuracy of procedure.

(0.75 in.). These two values of connection strength were determined for each test series and are presented in Table 3.

To illustrate the relative values of maximum strength compared with strength at a limited deformation, a resistance ratio—defined as the maximum connection strength divided by the connection strength at 1.91-cm deformation—was determined for each test series. The resistance ratios for the systems using the flexible geogrid are presented in Figure 6, and those for the rigid geogrid, in Figure 7. The values range from 1.2 to 2.0 for the flexible geogrids and from 1.4 to 2.7 for the rigid.

The significance of the resistance ratio may be related to the factor of safety applied to the maximum connection strength. If a factor of safety of 2.0 as suggested by Chewning and Collin (6) is applied to the maximum connection strength, then the limit strength criterion will control the design for resistance ratios of less than 2.0. Conversely, for resistance ratios greater than 2.0, the serviceability criterion would control.

Three factors have been identified for determining design connection strength:

- Long-term design strength of the geogrid,
- Maximum connection strength, and
- Connection strength at a serviceability deformation of 1.91 cm.

A factor of safety of 1.5, as suggested by GRI Standard of Practice GG4, was applied to the long-term design strength to account for design uncertainty. A factor of safety of 2.0 was applied to the maximum connection strength as suggested by Chewning and Collin. A factor of safety of 1.0 was applied to the serviceability criterion. Values of these three strengths are tabulated in Table 3 for each of the wall systems. The indicated factors of safety were applied and the smallest value designated as the design strength of the connection, which is also indicated in Table 3.

The limit strength criterion was controlling for each of the systems tested with flexible geogrids, whereas for the rigid geogrid systems tested, each of the three criteria was critical depending on the situation.

Deformation at Maximum Strength

The deformation within the connection corresponding to the maximum strength was estimated for each test series. These deformations range from about 2 to 8 cm (0.8 to 3.2 in.), illustrating the finding that significant movement is required to develop the maximum strength in some segmental wall connections.

SUMMARY

A laboratory testing program was conducted to investigate the strength of the connection between segmental concrete retaining wall units and the geogrid reinforcements. Test results were analyzed with respect to three design criteria: the long-term design strength of the geogrid, a limit strength criterion, and a serviceability criterion. The limit strength criterion states that the allowable design strength must be less than the maximum connection strength divided by a factor of safety of 2.0. Serviceability states that the connection must be limited to a deformation of 1.91 cm (0.75 in.).

Eight retaining wall systems were tested, including five segmental concrete units and two geogrids. For the systems tested, limit strength was the critical factor for the flexible geogrids. For the rigid geogrids tested, the critical factor varied between the long-term design strength of the geogrid, the serviceability criterion, and the limit strength criterion.

Test procedures evolved over the 2 years encompassing the testing reported in this paper. Standard test procedures are being developed and will enhance future test programs.

A factor of safety of 2.0 was used for the limit strength criterion, and a limiting deformation of 1.91 cm (0.75 in.) was used for the serviceability criterion. The appropriateness of these values requires further study.

TABLE 3 Comparison of Design Criteria

TEST SERIES	LONG TERM DESIGN STRENGTH ^a kN/m	NORMAL FORCE kN/m	NORMAL STRESS kPa	CONNECTION STRENGTH AT 1.9 cm kN/m	MAXIMUM CONNECTION STRENGTH kN/m	DESIGN STRENGTH ^b kN/m
A1	10.31	3.98	13.0	5.98	7.95	3.98 L
		7.70	23.2	10.03	11.63	5.82 L
		10.60	34.8	8.89	11.16	5.58 L
B1	10.31	1.99	6.5	2.37	3.53	1.77 L
		4.76	15.6	4.67	6.64	3.32 L
		9.17	30.1	5.26	8.41	4.20 L
		13.03	42.8	6.99	10.42	5.21 L
C1	10.31	5.20	7.6	8.94	13.25	6.63 L
		8.14	11.9	9.45	16.62	8.31 L
		10.72	15.6	9.87	19.39	9.70 L
D1	10.31	1.22	4.0	2.94	4.48	2.24 L
		4.21	13.8	7.80	10.28	5.14 L
		6.42	21.1	8.67	11.16	5.58 L
		8.64	28.4	9.87	11.87	5.93 L
A2	10.45	3.98	13.0	3.27	6.01	3.00 L
		7.07	23.2	4.65	9.84	4.65 S
		10.60	34.8	8.05	13.03	6.52 L
B2	10.45	1.99	6.5	4.87	8.17	4.09 L
		4.76	15.6	5.23	10.95	5.23 S
		9.17	30.1	7.20	14.99	7.20 S
		13.03	42.8	6.64	17.90	6.64 S
C2	10.45	6.30	9.2	8.41	14.37	7.19 L
		9.98	14.6	13.53	18.71	9.36 L
		13.66	19.9	15.40	23.31	10.45 G
		17.82	26.0	14.43	24.49	10.45 G
E2	10.45	1.00	3.3	1.75	3.83	1.75 S
		4.14	13.6	4.71	8.47	4.23 L
		8.55	28.1	8.86	14.55	7.27 L
		10.76	35.3	7.42	13.40	6.70 L

^a Long term design strength from manufacturers' recommendations with a design uncertainty factor of 1.5 applied.

^b The design strength is the minimum of: the long term design strength (G), the connection strength at 1.9 cm deformation (S), or the maximum connection strength divided by a factor of safety of 2.0 (L). The governing criterion is indicated by G, S, or L.
 1 kN/m = 68.5 pounds/foot
 1 kPa = 20.9 pounds/foot²

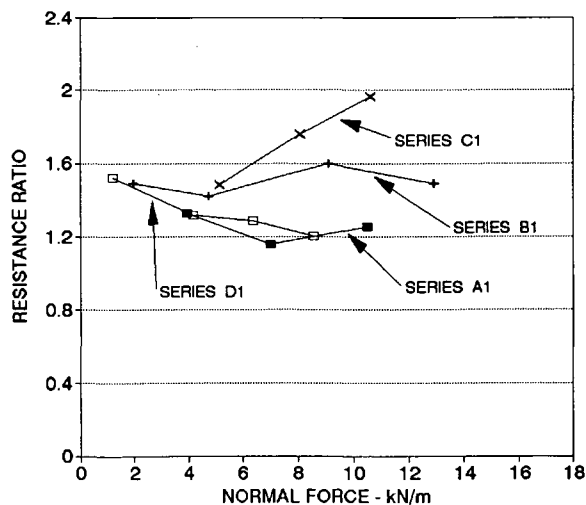


FIGURE 6 Resistance ratio for flexible geogrid.

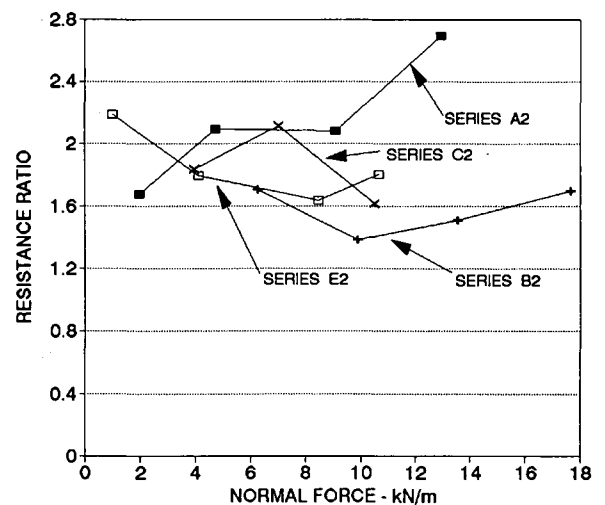


FIGURE 7 Resistance ratio for rigid geogrid.

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