The study of the installation damage of flexible geogrids

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ABSTRACT: This study involves the exhuming of two different strengths of PVC-coated PET flexible geogrids from five different typical soils for the purpose of evaluating the amount and degree of installation damage. A series of single rib strength tests (GRI-GG1) and in-isolation junction strength tests (GRI-GG2) was performed to evaluate the strength of reduction due to the installation procedure in the study. The results of the study indicated that installation damage to a flexible geogrid is a function of grain size distribution and angularity of backfill materials, compaction effort and lift thickness, and type and weight of construction equipment's. Based upon the test results, the tensile strength retained for flexible geogrid placed within fine grained soil, sandy soil, gravel with some fine soils, and crushed stone gravel are 83% to 99%, 85% to 96%, 66% to 95%, and 57% to 88%, respectively. The partial factor of safety for tensile strength due to installation damage is significantly related to soil type and varies from 1.01 to 1.70. The strength of junction retained for flexible geogrid is ranging from 71% to 100% for various type soils. The partial factor of safety for junction strength due to installation damage varies from 1.00 to 1.41 for different type of soils.

1 INTRODUCTION

The family of Geosynthetics includes geotextile, geogrid, geomembrane, geonet, geocomposite, geopipe, geosynthetic clay liner, and geo-others. These products are generally produced using polymer materials in manufacture and usually consist of a very good quality control process. Since these materials are relatively easier to handle in comparison with conventional construction materials, they have been widely used in the construction site to replace some virgin materials in the areas of transportation, environmental, geotechnical, and hydraulics engineering.

Geogrid is a member of geosynthetic family. The primary function of geogrid is reinforcement and separation. In order to satisfy these functions, geogrids typically are placed within soils with equal spacing and forming a soil/geogrid composite material. The tensile strength of geogrid in combine with the interlocking phenomena within the soil/geogrid system provides the function of reinforcement. As the results, this improves the bearing capacity and the compressive strength of soil-geogrid system.

Geogrids are currently being used in a number of different soil reinforcement applications, such as retaining walls, steep soil slope stabilization, and improve bearing capacity of foundation soils. All of these applications require design procedures that are based on the tensile strength of geogrid. Generally, the wide width tensile strength according to ASTM standard D-4595 or the single rib tensile strength according to GRI-GG1 specification would be measured in the laboratory. Such laboratory-measured strength is not the allowable value to be used in the final design. The as-received materials test specimens usually do not include such items as installation damage, long term creep, chemical degradation, etc. Thus the design value must be suitably reduced so as to reflect the anticipated in-situ behavior. The allowable strength can be related to one another on a site-specific basis as follows (Koerner 1998):

$$T_{allow} = T_{ult}\left[\frac{1}{RF_{ID} \times RF_{CR} \times RF_{CD} \times RF_{BD}}\right] \quad (1)$$

Where T_{allow} = allowable wide width tensile strength for use in design; T_{ult} = ultimate wide width tensile strength on the as-received material; RF_{ID} = reduction factor for installation damage; RF_{CR} = reduction factor for creep deformation; RF_{CD} = reduction factor against chemical degradation; RF_{BD} = reduction factor against biological degradation.

This paper focuses on providing a database for the installation damage of flexible geogrids for retaining wall and steep soil slope applications and similar reinforcement situations. PVC-coated PET geogrids are used in the study. The manufacture design strength of the test geogrids are 60 kN/m and 150 kN/m. Five different soils were used in the study, which include a low plasticity silty clay, a poorly graded fine sand, a poor graded silty gravel, a clayey gravel, and a well graded gravel. The test geogrids were placed parallel and perpendicular to the compaction roller traveling direction with 15 cm and 30 cm lift thickness. The compaction effort of the test soils was evaluated by the sand cone method or the nuclear density gage method after each layer of compaction. The strength behavior of the geogrids before installation and after exhuming was evaluated according to the Geosynthetic Research Institute test standards GG1 and GG2. The comparison of the single rib tensile strength, elongation at failure, and junction strength before and after installation was also performed. The partial factor-of-safety for installation damage for the flexible geogrid was also evaluated.

Note that the term has been called "survivability" by Christopher and Holtz (1984) and is defined as the "resistance to damage during construction and initial operation". Up to now, a number of studies related to the survivability of geotextiles and geogrids had been performed; for example see Bonaparte, et al. (1998), Koerner and Koerner (1990), Koerner et al. (1993), Rainey and Barksdale (1993), Rickardson (1998), and Troost and Ploeg (1990). However, geotextiles and rigid geogrids are the primary materials used in those studies. Thus, the objective of the study is to fill the gap of the current database and to provide the test data of the installation damage of flexible geogrids. The concern of this paper is not focused on "durability" which can be defined as "resistance to damage by long-term degradation of biological, chemical or aging mechanisms".

2 FHWA/AASHTO SURVIVABILITY CRITERIA

Recent work by FHWA has led to development of installation damage reduction factor to reduce the allowable tensile strength of geosynthetic reinforcement used in retaining wall and slope-stabilization applications. Table 1 gives current FHWA presumptive installation-damage reduction factors for a variety of geosynthetics. Recommended values from IFAI's Geotextile Division (now the Geosynthetic Materials Association, GMA) also are shown. These installation-damage reduction factors reflect potential stone/stone applications.

Table 1. FHWA degradation-reduction factors for geosynthetics.

Geosynthetic	Degradation Reduction Factors		
	FHWA Recommendation		IFAI recommendation
	Type 1. Backfill Max. size 100mm D50 about 30mm	Type 2. Backfill Max. size 20mm D50 about 0.7mm	Type 3. Backfill Max. size 20mm 0.1mm＜D50＜ 0.5mm
HDPE Uniaxial Geogrid	1.20-1.45	1.10-1.20	1.05-1.15
PP Biaxial Geogrid	1.20-1.45	1.10-1.20	1.05-1.15
PVC-coated PET Geogrid	1.30-1.85	1.10-1.30	1.05-1.20
Acrylic-coated	1.30-2.05	1.20-1.40	1.15-1.30
Woven Geotextiles (PP and PET)	1.40-2.20	1.10-1.40	1.05-1.20
Nonwoven Geotextiles(PP and PET)	1.40-2.50	1.10-1.40	1.05-1.20
Slit-film woven PP Geotextile	1.60-3.00	1.10-2.00	1.10-1.75

PP = polypropylene, PVC = polyvinyl chloride,
PET = polyester, HDPE = high density poluethylene

3 FIELD SURVIVABILITY TEST PROGRAM

The field survivability study was performed during the development of an industry park near Shin-Chun, Taiwan in the middle of September 1999. Five different test pits were prepared for each test soil. The test soils included a low plasticity silty clay (CL), a poor graded fine sand (SP), a poor graded silty gravel (GP-GM), a clayey gravel (GC), and a well-graded gravel (GW). The gradation curves of the test soils are shown in Figure 1.

Two different tensile strength uniaxial geogrids were used in the study. The tensile strengths of the test geogrids are 60 kN/m and 150 kN/m. The manufacture roll width is 3.8 meters. The size of test sample is 1.9 m wide and 2.9 m long. In order to evaluate the effect of roller traveling direction on the strength of geogrid, the warp ribs of test sample were placed parallel (MDC test) and perpendicular (XMC test) to the roller traveling direction for these two types of geogrids. The schematic view of the placement of geogrid for MDC and XMC tests is shown in Figure 2. Totally 8 pieces of test samples were placed within each test pit. Thus, the minimum size of test pit is 8 meters by 11 meters.

First of all, the entire test site was compacted to reach a minimum 95% of the standard compaction density. A lift of 15 to 20 cm test soils was then placed and compacted to the desired density. The eight pieces of test samples were placed in the desired arrangement as shown in Figure 3. Thereafter, the test soils were carefully placed over the test geogrid samples with the lift thickness of 15 cm or 30 cm by using a backhoe and a dozer. During the placement, the doze was not allowed to make any significant turns on the geogrids. Then the test soils were compacted using a vibratory steel wheel compactor. The density of the cover soils was then evaluated by the sand cone method and the unclear density gage method. The compaction density of the test soils was found in the range from 91% to 97 % of the standard compaction density. Exhuming of the geogrids at each test pit and under different lift thickness consisted of dozing off the upper materials and then carefully hand shoveling the remaining thickness, about 10 cm covers. Due to short time interval between placement and exhuming of the geogrids, which varied from 1 to 4 hours, there was no bonding of geogrids to the soil beneath or above them. Thus, it was assumed that whatever damage may have occurred to the geosynthetics was done during the backfilling and compaction process, i.e., it is “installation damage” and not due to any other possible types of long-term degradation.

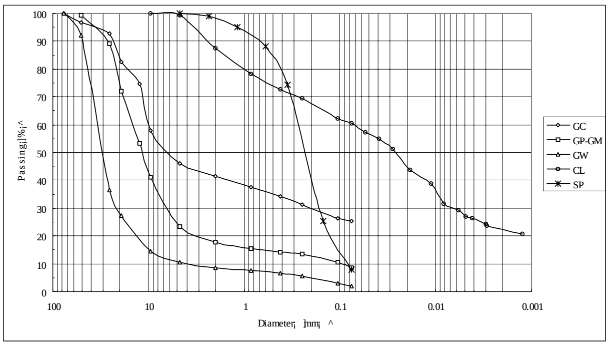

Figure 1. Grain size distribution of the test soils.

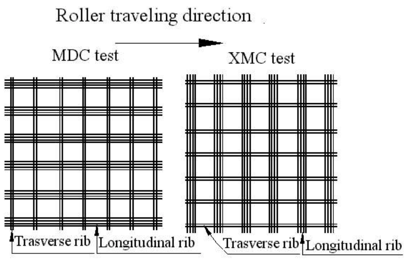

Figure 2. Schematic view of geogrid layout for the installation test.

Figure 3 Typical geogrid samples layout.

4 TEST DATA AND RESULTS

Upon exhuming the installed geogrids, a visual damage survey was made. The number of ribs broken per square was reported. The exhumed geogrid samples were then labeled and shipped back to laboratory for testing. The single rib tensile strength test and junction strength test according to GRI-GG1 and GRI-GG2 test standards were performed. For each geogrid sample, 20 specimens were tested for both test methods.

4.1 *Single rib tensile strength*

Generally tensile strength is the most important design parameter for geogrid reinforcement applications, and ASTM D-4595 and GRI-GG1 are the most common test methods in the design. For simplicity, the standard test method for single rib tensile strength (GRI-GG1) was used in the analysis. In addition, the elongation at failure and 5% strain tensile strength were also examined. The results of these tests were then compared to the average test values obtained from the pre-construction geogrid samples. The result of such a comparison is the retained percentage for each different conditions of evaluated. Finally, the inverse of this value will be the partial factor of safety for installation damage.

4.2 *Test data for pre-construction samples*

Due to time constrain, only two types of geogrids were analyzed in the study. The manufactured tensile strength of the analyzed geogrids was 60 kN/m and 150 kN/m. The manufacture roll width of the test samples is 3.8 meters. A number of 124 warp ribs are counted for the raw samples (equivalent 32 warp ribs per meter). The rib opening is about 2 cm by 2 cm, and the opening area is about 47%. In order to understand the effect of preload on tensile strength of geogrid, a series of single rib tensile tests with various preloads was performed for these two types of geogrids. Typical test results for various preload conditions are shown on Figure 4. As shown on the figure, the tensile strength versus elongation curves for 1% and 2% preload conditions are quite similar. In addition, the results of statistic analysis for the single rib tensile tests of 60-kN/m geogrid under various preload conditions are shown in Table 2. It is very clear to us, the test results obtained from 2%

preload condition consist the lowest measurement uncertainty and 95% confidence interval. Thus, 2% preload was used for the rest single rib tensile tests. The junction strengths of the pre-construction geogrid samples are shown on the Table 3. The average junction strength efficiencies vary from 9.5% to 11.5% for the test samples.

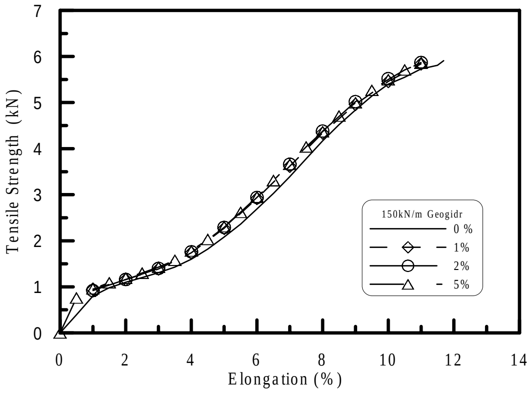

Figure 4. Typical single rib tensile strength test results for 150-kN/m geogrid under various preload conditions.

Table 2. The results of statistic analysis of typical single rib tensile tests for 60-kN/m geogrid under various preload conditions.

Preload	0%	1%	2%	5%
Tensile Strength(kN)	1.488	1.457	1.525	1.497
Standard Deviation(kN)	0.031198	0.062548	0.028191	0.041110
Measurement Uncertainty(kN)	0.009865	0.019779	0.006304	0.013000
Confidence Level (kN)	0.022318	0.044744	0.013194	0.029408
Elongation(%)	10.677	14.798	12.0375	11.421
5%Strain Strength(kN)	0.570	0.357	0.5005	0.511

Table 3. Typical junction strengths for the pre-construction geogrid samples.

Geogrid Type	Single Junction Strength (N)	No. of Junction (No./m)	Junction Strength (kN/m)	Junction Strength Efficiency (%)
60kN/m	145.582	40	5.823	9.546
150kN/m	693.79	32	22.201	11.582

4.3 *Tensile strength of the geogrid placed in the poor graded silty gravel*

As mentioned earlier, 20 test specimens were used for the tensile tests of each test condition. The single rib tensile strength of the 150 kN/m geogrid samples placed in the poor graded silty gravel (GP-GM) with 30 cm cover thickness under XMC test condition in comparison with the average tensile strength of the pre-construction samples is shown in Table 4. As shown in the Table, the average retained percentages for the ultimate and 5% strain tensile strength are 86.0% and 85.0%, respectively. The average elongation at failure is about 90.0% of pre-construction sample. In addition, the tensile strength of the test samples possesses the smallest confidence interval among these three variables. The results of 150 kN/m geogrid samples placed under the poor graded silty gravel for different thickness of soil cover and compaction direction are summarized in the Table 5. As shown in the Table, the compaction direction has very low influence on its tensile strength and elongation at failure. However, the percent strength retained associated with 15-cm lift thickness are relatively less than those associated with 30-cm lift thickness. The percentages strength retained are ranging from 81.4% to 86.0% for various conditions.

Table 4. The comparison of single rib tensile test results between pre-construction and installed samples (150 kN/m) placed 30 cm under the poor graded silty gravel with XMC condition.

Items	Tensile Strength Test Result (kN)	Tensile Strength Retain Percentage (%)	Elongation Test Result (%)	Elongation Retain Percentage (%)	5% Strain Strength Test Result (kN)	5% Strain Strength Retain Percentage (%)
Average Value	5.149	85.95993	10.2275	90.03081	1.954	84.95652
Standard Deviation	0.348544	5.81877	1.091454	9.607872	0.181177	7.87728
Interval	1.36	22.70451	3.61	31.77817	0.72	31.30435
Min. Value	4.33	72.28715	8.53	75.08803	1.59	69.13043
Max. Value	5.69	94.99165	12.14	106.8662	2.31	100.4348
Total	102.98	1719.199	204.55	1800.616	39.08	1699.13
Confidence Level	0.163124	2.723269	0.510816	4.496624	0.084794	3.686682

Table 5. Summary of the test results between the pre-construction and installed samples (150 kN/m) placed under the poor graded silty gravel for various test methods and test conditions.

Compaction Type	Cover Thickness	Tensile Strength Retain Percentage	Elongation Retain Percentage	5% Strain Strength Retain Percentage	Junction Strength Retain Percentage
MDC	15cm	81.386	88.050	80.304	91.926
	30cm	84.958	89.969	83.587	75.116
XMC	15cm	83.402	89.979	79.840	76.086
	30cm	85.960	90.031	84.957	87.355

4.4 *Comparison of tensile strength for the five backfill materials*

In order to provide complete data base for the installation damage of flexible geogrids, the percents strength retained and the partial factor of factors for the 150 kN/m woven geogrids placed within the test soils for MDC and XMC test conditions are summarized in the Table 6 and 7, respectively. The data shown in the tables were obtained base upon the results analyzed from the single rib tensile tests. As seen, the average tensile strength, the average elongation at failure, and the average 5% strain tensile strength are listed. In conclusion, the percent strength retained for the 150-kN/m geogrid ranges from 92% to 99% for fine-grained soils, 90% to 93% for sands, and 76% to 89% for gravels. The percent strength retained and reduction factors for 60-kN/m geogrid installations within the test soils are summarized in Tables 8 and 9. It was found that both test geogrids consisted similar installation damage behavior.

4.5 *Elongation at failure*

Compatibility is an important principle in the geogrid reinforcement application. Therefore, the rib elongation and tensile strength at desire strain are the important mechanical properties of geogrid. The elongations at failure of the 150-kN/m geogrid samples installed in the five different test soils are also shown in Tables 6 and 7. Based upon the test results, the average elongation values at failure for the 150-kN/m and 60-kN/m pre-construction samples are about 11.4% to 12.0%. Generally, elongation at failure will be reduced due to the installation process. For example, the elongation at failure is reduced from 11.4% to 9.7% and 12.0% to 9.3% for the150 kN/m and 60 kN/m geogrid samples installed in the poor graded silty gravel (GP-GM), respectively. By comparing the data shown in Table 6 and 7, it is found that the lift thickness of the test soils generally has no significant effect on the elongation at failure for the conditions tested. By further analyzed the data, it is found that the compaction roller traveling direction is also having no significant effect on the single rib elongation at failure.

Table 6. The test result and retained percentages of the 150 kN/m geogrid under five different soils and various cover thickness (MDC test).

Soil Type	Cover Thickness	Tensile Strength		Elongation		5% Strain Strength	
		Test Value (kN)	Retained Percentage (%)	Test Value (kN)	Retained Percentage (%)	Test Value (kN)	Retained Percentage (%)
CL	15cm	5.938	99.12	1.979	105.67	12.005	86.04
	30cm	5.781	96.50	2.132	100.44	11.411	92.67
SP	15cm	5.601	93.50	1.943	99.03	11.250	84.48
	30cm	5.449	90.96	1.934	94.98	10.790	84.07
GW	15cm	5.266	87.90	1.856	93.68	10.642	80.67
	30cm	4.555	76.04	1.990	82.21	9.339	86.52
GC	15cm	5.322	88.84	1.765	95.56	10.856	76.72
	30cm	5.119	85.45	1.809	94.14	10.695	78.63
GP-PM	15cm	4.875	81.39	1.847	88.05	10.003	80.30
	30cm	5.089	84.96	1.923	89.97	10.221	83.59

Table 7. The test result and retained percentages of the 150 kN/m geogrid under five different soils and various cover thickness (XMC test).

Soil Type	Cover Thickness	Tensile Strength		Elongation		5% Strain Strength	
		Test Value (kN)	Retained Percentage (%)	Test Value (kN)	Retained Percentage (%)	Test Value (kN)	Retained Percentage (%)
CL	15cm	5.540	92.48	10.881	95.78	1.929	83.87
	30cm	5.599	93.47	10.964	96.51	2.042	88.76
SP	15cm	5.426	90.58	10.153	89.38	2.218	96.41
	30cm	5.371	89.66	11.071	97.45	1.752	76.17
GW	15cm	4.429	73.94	9.241	81.34	1.910	83.02
	30cm	4.905	81.89	10.047	88.44	1.888	82.07
GC	15cm	5.057	84.42	10.618	93.47	1.750	76.07
	30cm	5.360	89.47	10.268	90.38	2.084	90.61
GP-GM	15cm	4.996	83.40	10.22	89.98	1.836	79.84
	30cm	5.149	85.96	10.228	90.03	1.954	84.96

Table 8. The test result and retained percentages of the 60 kN/m geogrid under five different soils and various cover thickness (MDC test).

Soil Type	Cover Thickness	Tensile Strength		Elongation		5% Strain Strength	
		Test Value (kN)	Retained Percentage (%)	Test Value (kN)	Retained Percentage (%)	Test Value (kN)	Retained Percentage (%)
CL	15cm	1.453	95.25	10.626	88.25	0.535	107.00
	30cm	1.442	94.52	11.275	93.65	0.495	99.01
SP	15cm	1.471	96.43	13.451	111.72	0.384	76.80
	30cm	1.392	91.28	10.270	85.30	0.488	97.60
GW	15cm	1.200	78.66	9.781	81.23	0.474	94.70
	30cm	1.148	75.25	9.320	77.40	0.494	98.70
GC	15cm	1.340	87.84	10.850	90.11	0.469	93.70
	30cm	1.326	86.92	10.627	88.26	0.471	94.20
GP-GM	15cm	1.039	68.10	9.540	79.24	0.442	88.30
	30cm	1.205	78.98	9.742	80.91	0.481	96.20

Table 9. The test result and retained percentages of the 60 kN/m geogrid under five different soils and various cover thickness (XMC test).

Soil Type	Cover Thickness	Tensile Strength		Elongation		5% Strain Strength	
		Test Value (kN)	Retained Percentage (%)	Test Value (kN)	Retained Percentage (%)	Test Value (kN)	Retained Percentage (%)
CL	15cm	1.452	95.21	11.277	93.66	0.499	99.70
	30cm	1.455	95.38	11.681	97.02	0.468	93.50
SP	15cm	1.392	91.28	10.270	85.30	0.488	97.60
	30cm	1.467	96.20	13.530	112.37	0.401	80.10
GW	15cm	1.148	75.25	9.320	77.40	0.494	98.70
	30cm	0.973	63.77	8.891	73.85	0.450	90.00
GC	15cm	1.326	86.92	10.627	88.26	0.471	94.20
	30cm	1.298	85.11	11.096	92.16	0.444	88.80
GP-GM	15cm	1.205	78.98	9.742	80.91	0.481	96.20
	30cm	1.004	65.84	8.777	72.90	0.479	95.80

4.6 *Tensile strength at 5% strain*

Variation of the tensile strength at 5% strain for the 150 kN/m geogrid installed in the test soils with 30 cm and 15 cm lift thickness for XMC test condition are shown in Tables 6 and 7. As shown in the tables, the installation process has very minor effect on the tensile strength at 5% strain. Typically, the percent of strength retained varies from 79.6% to 96.4% for the conditions tested.

4.7 *Junction strength*

Commonly, the opening area of geogrid is also an important physical property that controls the interlocking behavior of soil/geogrid system. In addition to surface friction, geogrid, junction strength is another mechanism that will transfer the pullout resistance of geogrid from soil to geogrid. Therefore, junction strength is another important mechanical property for geogrid. Tables 6 and 7 also consisted the junction strength for the 150 kN/m geogrid samples installed in the five different test soils with 30 cm and 15 cm lift thickness for XMC test condition. As mentioned earlier, the average junction strength for the 150-kN/m pre-construction geogrid samples is about 694.6 Newtons. As shown in the table, the average junction strength for the150 kN/m geogrid samples installed with 30-cm cover thickness was generally reduced to 606.1 Newtons. In comparison with the data shown on these two tables, the installation damage was more severe for the samples with 15-cm cover thickness, and the average junction strength is about 527.9 Newtons for the condition with 15 cm cover thickness. In addition, the behavior of junction strength for XMC and MDC test conditions was found to be quite similar to each other. And the junction strength behavior for the 60-kN/m geogrid samples was found to be similar to that associated with the150 kN/m geogrid samples.

5 SUMMARY AND CONCLUSIONS

The installation survivability of flexible geogrids under various conditions was performed. The tensile strength of the tested geogrids were 150 kN/m and 60 kN/m, and the test geogrid samples were placed and compacted in five different soils with 30 cm or 15 cm cover thickness. The samples then were carefully exhumed from the test field and sent to the laboratory for testing. The single rib tensile strength and junction strength tests according to the GRI-GG1 and GRI-GG2 specifications were performed. Base upon the test results, the retained percentage and the partial factor of safety of the rib ultimate tensile strength, the elongation at failure, the tensile strength at 5% strain, and junction strength were obtained.

The results of the study have indicated that installation damage to a flexible geogrid is a function of grain size distribution and angularity of backfill material, compactive effort and lift thickness, and type and weight of compaction equipment. It is also clear that geogrid placed within the angular crushed stone gravel shown greater damage than other backfill materials, while the geogrid placed in a fine sand or fine grained soil shown little damage.

In addition to provide the installation damage database for flexible geogrid, the other goal of the study was to quantify a factor of safety for geogrid installation survivability. Based upon the results of the study, the recommended typical and average partial factor of safety for flexible geogrids placed within various types of soils are listed in Table 10. As shown in the table, geogrid installed in gravel backfill showed more severe damage than same material placed in fine grain soil or fine sand. The typical partial factors of safety of single rib tensile strength for fine grain soil, sandy soil, gravel with some fine soils, and the crushed stone gravel are about 1.01 to 1.20, 1.04 to 1.18, 1.05 to 1.52, and 1.14 to 1.74. %. In addition, the average partial factors of safety of junction strength for fine grained soil, sandy soil, gravel with some fine soils, and the crushed stone gravel are 1.09, 1.08, 1.12 to 1.18, and 1.16, respectively. The recommended values appear to agree with those values recommended by FHWA.

Table 10. Typical recommended partial factor of safety for installation damage of flexible geogrids

Soil Type	Tensile Strength		Junction Strength	
	Range of Partial Factor of Safety	Average Factor of Safety	Range of Factor of Safety	Average Factor of Safety
CL	1.01 ~ 1.20	1.07	1.00 ~ 1.21	1.09
SP	1.04 ~ 1.18	1.10	1.00 ~ 1.31	1.08
GW	1.14 ~ 1.74	1.31	1.00 ~ 1.41	1.16
GC	1.05 ~ 1.19	1.13	1.00 ~ 1.25	1.12
GP-GM	1.13 ~ 1.52	1.28	1.00 ~ 1.40	1.18

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