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Installation survivability of flexible geogrids as earth reinforcement materials

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ABSTRACT: An in-situ installation survivability study was performed for the purpose of evaluating the amount and degree of installation damage of PVC-coated PET flexible geogrids placed in five types of commonly used backfill materials. The reduction factor for tensile strength due to installation damage is significantly related to soil type and varies from 1.01 to 1.74. The reduction factors for junction strength due to installation damage varies from 1.00 to 1.40 for different type of soils. Additionally, 2% of the maximum load is recommended as the preload for single rib tensile strength test (GRI-GG1). In comparison of the test results, wide width tensile strength (ASTM D4595) of the test geogrids is about 10% to 20% lower than those obtained from single rib tensile strength tests (GRI-GG1). The difference of tensile strength obtained from these two test methods increases as the construction damage effect increases.

1 INTRODUCTION

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. The allowable strength can be related to one another on a site-specific basis as follows (Koerner 1998):

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

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.

Up to now, a number of studies related to the survivability of geotextiles and geogrids had been performed (Koerner and Koerner 1990, Koerner et al. 1993, Rainey and Barksdale 1993, Richardson 1998, and Troost and Ploeg 1990). Recent work by FHWA and IFAI has led development of reduction factors for installation damage of Geosynthetic used in reinforcement applications (Suits, 1996). 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 flexural rigidity values is less than 1000g-cm measured using ASTM D1388 test method).

2 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 backfill materials. The test soils included a low plasticity silty clay (CL), a poor graded fine sand (SP), a clayey gravel (GC), a poor graded silty gravel (GP-GM), and a well-graded gravel (GW).

PVC-coated PET geogrids produced by a local manufacture are used in the study. Four types of uniaxial geogrids with different tensile strengths were used in the study. The tensile strengths of the test geogrids are 60 kN/m, 100 kN/m, 150 kN/m, and 200 kN/m. The manufacture roll width 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%. The dimension of test sample is 1.9 meters by 2.9 meters. In order to evaluate the effect of compaction 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 four types of geogrids. Totally 8 pieces of test samples were placed within each test pit. Thus, the minimum dimension of test pit is 8 meters by 11 meters.

3 TEST DATA AND RESULTS

Upon exhuming the installed geogrids, a visual damage survey was made. The number of ribs broken per square meter was recorded. The exhumed geogrid samples were then labeled and shipped back to laboratory for testing. The single rib tensile strength test, junction strength test, and wide width tensile test according to GRI-GG1, GRI-GG2, and ASTM D4595 test standards were performed. For each geogrid sample, 20 specimens were tested for GG1 and GG2 test methods, and 5 specimens were used for wide width tensile tests. For simplicity, the standard test method GRI-GG1 was used as the primary test method to evaluate the installation survivability of the test samples. By comparing the test values obtained from pre-construction and post-construction test samples, the retained percentage for each test conditions can be obtained. By inversing of this value, the reduction factor for installation damage will be obtained. In addition, the difference between the test results obtained from single rib tensile tests and wide width tensile tests is also discussed in the subsequent section of the paper.

3.1 *Test data for pre-construction samples*

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 four types of geogrids. Typical test results for various preload conditions are shown in Figure 1. 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 statistical analysis for the single rib tensile tests of 150-kN/m geogrid under various preload conditions are shown in Table 1. 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 of the single rib tensile tests.

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

As mentioned earlier, 20 test specimens were used for the rib tensile tests of each test condition. The results of 150 kN/m geogrid samples placed under the poor graded silty gravel for different cover thickness and compaction roller traveling direction are summarized in the Table 2. The average retained percentages for the ultimate and 5% strain tensile strength for XMC test condition with 30 cm cover thickness are 86.0% and 85.0%, respectively. The average of elongation at failure is about 90.0% of pre-construction sample. In addition, as shown on the table, the compaction direction has no significant influence on rib tensile strength. However, the percentages of retained strength associated with 15-cm lift thickness are slightly less than those associated with 30-cm lift thickness. The percentages of retained strength are ranging from 81.4% to 86.0% for various conditions.

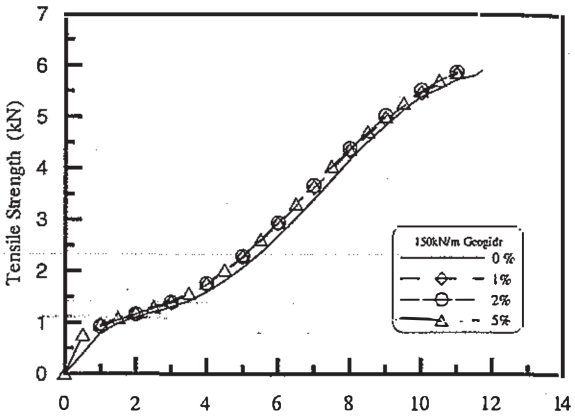

Figure 1. Typical single rib tensile strength test results for 150-kN/m geogrid under various preload conditions.

3.3 *Comparison of tensile strength for five different backfill materials*

The average test values and percentages of strength retained for the 60 kN/m woven geogrids placed within the test soils for XMC and MDC test conditions are summarized in the Table 3. Since the effects of soil cover thickness on rib tensile strength were not significant for the tested conditions, the data shown in the table are the average values for conditions associated with both 15-cm and 30-cm cover thickness. The data were obtained based on the results from single rib tensile tests and junction strength tests. The percentages of strength retained for the 60-kN/m geogrid are about 95% for the silty clay, 94% for the poor graded fine sand, 69% for the

Table 1. The results of statistical analysis of typical single rib tensile tests for 150-kN/m geogrid under various preload conditions.

Preload	0%	1%	2%	5%
Tensile Strength (kN)	5.937	5.945	5.991	6.052
Standard Deviation (kN)	0.120743	0.143159	0.142474	0.173192
Measurement Uncertainty (kN)	0.038182	0.045271	0.045054	0.054768
Confidence Level (kN)	0.086374	0.102410	0.101920	0.123894
Elongation (%)	11.628	11.237	11.361	11.476
5%Strain Strength (kN)	2.034	2.314	2.305	2.315

Table 2. 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.

Compactor 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

Table 3. The test result and retained percentages of the 60-kN/m geogrid under five different soils for XMC and MDC test conditions.

Soil type	Test condition	Tensile Strength		Elongation		5% Strain Strength		Junction Strength	
		Test Value (kN)	Retained Percentage (%)	Test Value (%)	Retained Percentage (%)	Test Value (kN)	Retained Percentage (%)	Test Value (N)	Retained Percentage (%)
CL	XMC	1.453	95.30	11.479	95.34	0.483	96.60	139.48	95.81
	MDC	1.447	94.89	10.950	90.95	0.515	103.01	132.65	91.12
SP	XMC	1.430	93.74	11.900	98.84	0.444	88.85	139.70	95.96
	MDC	1.438	94.31	11.992	99.60	0.431	86.15	138.18	94.92
GW	XMC	1.060	69.51	9.105	75.63	0.472	94.35	114.19	78.44
	MDC	1.037	68.02	9.062	75.27	0.461	92.10	117.18	80.49
GC	XMC	1.330	87.24	10.938	90.84	0.459	91.78	125.61	86.28
	MDC	1.376	90.25	12.178	101.14	0.426	85.25	125.63	86.29
GP-GM	XMC	1.141	74.82	9.464	78.60	0.482	96.34	116.47	80.00
	MDC	1.025	67.20	9.207	76.47	0.460	91.95	110.02	73.70

well graded gravels, 87% to 90% for the clayey gravels, and 67% to 75% for the poor graded silty gravels. The test values and percentages of strength retained for 100-kN/m, 150-kN/m, and 200-kN/m geogrids installed within the test soils are summarized in Tables 4, 5, and 6, respectively. Results showed that these geogrids had similar installation damage behavior as the 60-kN/m geogrid.

3.4 *Tensile strength at 5% strain*

The variation of the tensile strength at 5% strain for the 60-kN/m geogrid installed in the test backfill materials for XMC and MDC test conditions are shown in Tables 3. As shown in the table, the effect of installation process on the tensile strength at 5% strain is relatively less than that on ultimate rib tensile strength. Typically, the percent of strength retained varies from 85% to 96% for the conditions tested. By evaluating the data shown in tables 4 to 6, the effect of installation process on tensile strength at 5% strain various for different conditions.

3.5 *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 60-kN/m geogrid samples installed in the five different backfill materials are also shown in Table 3. Based upon the test results, the average elongation values at failure for the various type pre-construction samples range from about 11.4% to 14.5%. The elongations at failure for various types geogrids and different test conditions are also shown in tables 3 to 6. For the great majority conditions, the data shown in the tables indicated that the installation process would reduce the elongation of test sample at failure. The amount of reduction of strength could be related to the type of damage of geogrid rib due to installation damage. 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.

4 JUNCTION STRENGTH

Commonly, the opening area of geogrid is also an important physical property that controls the interlocking behavior of the soil/geogrid system. In addition to provide 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 3 to 6 also consisted the junction strength for the tested geogrid samples installed in the five different backfill materials for XMC and MDC test conditions. The average junction strength for the 150-kN/m preconstruction geogrid samples is about

Table 4. The test result and retained percentages of the 100-kN/m geogrid under five different soils for XMC and MDC test conditions

Soil type	Test condition	Tensile Strength		Elongation		5% Strain Strength		Junction Strength	
		Test Value (kN)	Retained Percentage (%)	Test Value (%)	Retained Percentage (%)	Test Value (kN)	Retained Percentage (%)	Test Value (N)	Retained Percentage (%)
CL	XMC	4.043	93.36	12.13	103.70	1.258	71.47	616.85	97.38
	MDC	4.009	92.59	11.98	102.45	1.253	71.20	591.50	93.38
SP	XMC	3.810	87.99	11.43	97.75	1.276	72.49	659.81	104.16
	MDC	3.889	89.81	11.90	101.82	1.231	69.94	596.14	94.11
GW	XMC	3.419	78.95	11.15	95.38	1.124	63.87	618.98	97.71
	MDC	3.507	81.00	11.83	101.22	1.034	58.77	599.60	94.66
GC	XMC	3.828	88.41	11.42	97.70	1.292	73.41	624.74	98.62
	MDC	3.955	91.32	13.31	113.88	1.014	57.62	552.39	87.20
GP-GM	XMC	3.420	78.97	10.30	88.11	1.250	71.03	553.40	87.36
	MDC	3.483	80.45	10.61	90.79	1.272	72.28	568.76	89.79

Table 5. The percentages and retained reduction factors of the 150-kN/m geogrid under five different soils for XMC and MDC test conditions

Soil type	Test condition	Tensile Strength		Elongation		5% Strain Strength		Junction Strength	
		Test Value (kN)	Retained Percentage (%)	Test Value (%)	Retained Percentage (%)	Test Value (kN)	Retained Percentage (%)	Test Value (N)	Retained Percentage (%)
CL	XMC	5.569	92.98	10.92	96.14	1.985	86.32	588.35	84.80
	MDC	5.859	97.81	11.71	103.06	2.055	89.36	599.55	86.42
SP	XMC	5.412	90.35	10.63	93.61	1.984	86.26	555.48	80.06
	MDC	5.516	92.09	11.04	97.18	1.928	83.81	586.06	84.47
GW	XMC	4.667	77.91	9.64	84.89	1.899	82.54	555.14	80.01
	MDC	4.910	81.97	9.99	87.94	1.923	83.60	566.76	81.69
GC	XMC	5.208	86.94	10.44	91.93	1.917	83.34	589.19	84.92
	MDC	5.290	88.32	10.92	96.10	1.791	77.89	592.08	85.34
GP-GM	XMC	5.073	84.68	10.22	90.00	1.895	82.40	566.97	81.72
	MDC	4.982	83.17	10.11	89.01	1.885	81.95	579.46	83.52

Table 6. The percentages and retained reduction factors of the 200-kN/m geogrid under five different soils for XMC and MDC test conditions

Soil type	Test condition	Tensile Strength		Elongation		5% Strain Strength		Junction Strength	
		Test Value (kN)	Retained Percentage (%)	Test Value (%)	Retained Percentage (%)	Test Value (kN)	Retained Percentage (%)	Test Value (N)	Retained Percentage (%)
CL	XMC	7.433	90.75	12.625	87.07	2.099	105.99	669.19	89.25
	MDC	7.587	92.63	12.634	87.13	2.206	111.41	743.46	99.15
SP	XMC	7.321	89.38	12.844	88.58	1.844	93.12	707.01	94.29
	MDC	7.275	88.83	13.358	92.12	1.855	93.66	725.08	96.70
GW	XMC	6.688	81.66	11.622	80.15	1.977	99.84	669.44	89.28
	MDC	6.571	80.23	10.254	70.71	2.387	120.53	688.14	91.78
GC	XMC	7.052	86.10	11.824	81.54	2.092	105.67	733.50	97.83
	MDC	7.386	90.19	13.046	89.97	1.896	95.73	695.89	92.81
GP-GM	XMC	6.866	83.83	45.486	90.26	1.735	87.61	663.75	88.52
	MDC	6.508	79.46	44.172	81.20	1.916	96.78	741.07	98.84

693.8 Newtons. As shown on Table 6, the average junction strength for the 150-kN/m geogrid samples was generally decreased from 693.8 Newtons to the range between 555 Newtons and 592 Newtons. 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 others type of geogrid samples is quite similar to that associated with the150 kN/m geogrid samples.

5 WIDE WIDTH TENSILE TESTS

Since geogrids commonly consist of high tensile strength, a pair of roller grips is required to perform the wide width tensile test. Typically, a pair of roller grips is weighted over 100 kilograms. Therefore, a wide width tensile test is more complex and time consuming to perform in comparing with performing single rib tensile test. In order to evaluate the difference between these two test methods, a series of

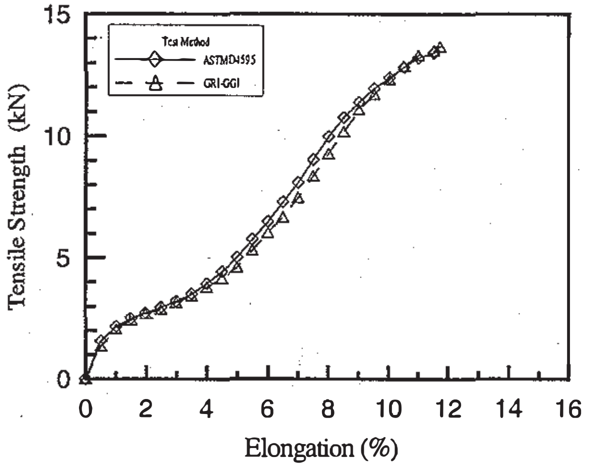

Figure 2. Comparison of single rib and wide width tensile test results for pre-construction geogrid samples (60 kN/m).

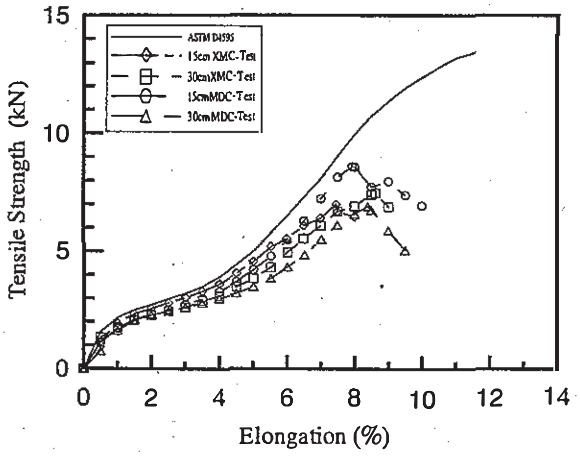

Figure 3. Tensile strength versus elongation curves (60-kN/m) of the pre-construction and exhumed samples under well-graded gravel for different test conditions.

wide width tensile tests of 60-kN/m, 100-kN/m, and 150-kN/m pre-construction and exhumed geogrid samples is performed. Figure 2 shows the typical test results of single rib and wide width tensile tests for the pre-construction samples. For the test geogrid, the wide width tensile test specimen consists of 7 ribs, the GRI-GG1data shown on the figure equivalent the single rib tensile test data multiplied by 7. As shown on the figure, the tensile strength versus elongation curves is quite similar to each other. In addition, the wide width tensile test results of pre-construction and exhumed samples under well-graded crushed stone gravel for different test conditions are shown on Figure 3. As shown on the figure, the tensile strength and elongation of the exhumed samples are significantly less than the test data for the pre-construction samples.

The comparison of the retained percentages for the 150-kN/m test samples placed under well-graded crushed stone gravel for single rib and wide width ten-sile tests is shown on Table 7. As shown on the table, the retained percentages of wide width tensile tests are generally 2% to 22% less than those for single rib tensile tests. Since the retained percentages for different test conditions are quite similar to each other, the average retained percentages for the test backfill materials are summarized in Table 8. As shown on the table, the retained percentages of wide width tensile strength, elongation at failure, and tensile strain at 5% strain are about 3% to 10%, 2% to 14%, and 0% to 17% less than the values for single rib tests, respectively.

6 CONCLUSIONS AND SUGGESTIONS

The results of the study have indicated that installation damage of a flexible geogrid is a function of grain size distribution and angularity of backfill materials, and lift thickness. It is also clear that geogrid placed within the angular crushed stone gravel shown greater damage than other backfill materials. Due to the time constrain, the degree of compaction, the type and weight of compaction equipments are not examined as the variables in the study. It is also believe that, the PVC coating thickness and method of coating has some effect on the ultimate tensile strength and the survivability of the geogrid. However, based upon the limited database, these effects are not analyzed in this study.

The wide width tensile test (ASTM D4595) is the most representative of the loss of strength due to installation procedure. However, if wide width roller grip is not available, single rib tensile test with more than 10 specimens could be used to evaluate the tensile strength of geogrid also. A 2% of the maximum load is recommended as the preload for single rib tensile test.

Table 7. Comparison of the retained percentages of single rib and wide width tensile tests for 150-kN/m geogrid samples placed under well-graded gravel for different test conditions.

Cover thickness	Test condition	Tensile Strength Retained Percentage (%)		Elongation Retained Percentage (%)		5% Strain Strength Retained Percentage (%)	
		Wide Width Test	Single Rib Test	Wide Width Test	Single Rib Test	Wide Width Test	Single Rib Test
15 cm	MDC	78.465	87.905	76.186	93.675	89.118	80.674
	XMC	69.021	76.035	80.668	82.205	76.482	86.522
30 cm	MDC	52.563	73.940	75.659	81.342	61.185	83.022
	XMC	74.246	81.886	78.822	88.438	73.761	82.065

Table 8. Comparison on the average retained percentages for single rib and wide width test tests placed under five different backfill materials for different test conditions.

Soil type	Tensile Strength Retained Percentage (%)		Elongation Retained Percentage (%)		5% Strain Strength Retained Percentage (%)	
	Wide Width Test	Single Rib Test	Wide Width Test	Single Rib Test	Wide Width Test	Single Rib Test
CL	92.11	95.39	97.58	99.60	71.30	87.84
SP	88.55	91.221	91.34	95.398	74.68	85.034
GC	68.57	79.94	77.83	86.41	75.14	83.07
GW	80.22	87.63	80.71	94.01	81.58	80.61
GP-GM	78.13	83.93	80.62	89.51	72.87	82.17

Table 9. Typical recommended reduction factor for installation damage of flexible geogrids.

Soil Type	Tensile Strength		Junction Strength	
	Range of Reduction Factor	Average Reduction Factor	Range of Reduction Factor	Average Reduction Factor
CL	1.01□1.20	1.10	1.00□1.21	1.11
SP	1.04□1.18	1.11	1.00□1.31	1.16
GW	1.14□1.74	1.44	1.00□1.41	1.21
GC	1.05□1.19	1.12	1.00□1.25	1.12
GP-GM	1.13□1.52	1.33	1.00□1.40	1.20

In addition to provide the installation damage database for this type of flexible geogrids, the other goal of the study was to quantify a reduction factor for geogrid installation survivability. Based upon the results of this study, the recommended typical and average reduction factors for flexible geogrids placed within various types of soils are listed in Table 9. As shown in the table, geogrid placed in well-graded crushed stone gravels showed more severe damage than gravel with some fine grain soils. The typical reduction factors of single rib tensile strength for clayey soil, sandy soil, clayey gravels, poor-graded silty gravels, and well-graded crushed stone gravels are about 1.01 to 1.20, 1.04 to 1.18, 1.05 to 1.19, 1.13 to 1.52, and 1.14 to 1.74, respectively. In addition, the average reduction factors of junction strength for clayey soil, sandy soil, clayey gravels, poor-graded silty gravels, and well-graded crushed stone gravels are 1.11, 1.16, 1.12, 1.20, and 1.21, respectively. The recommended values appear to agree with those values recommended by FHWA.

In general, wide width tensile strength of flexible geogrid is about 10% to 20% lower than that obtained from single rib tensile test. The difference of tensile strength obtained from wide width tensile test and single rib tensile test increases as the construction damage of the geogrid samples increases.

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