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The construction damage of flexible geogrids under 5 different backfill materials

Les dommages de construction de geogrids flexible au-dessous de 5 différents remblayent des matériaux

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ABSTRACT: A comprehensive on-site full-scale construction damage test of flexible geogrids from a single manufacture was performed. The reduction rates of geogrid tensile strength placed within clayey soil, sandy soil, clayey gravel, poor graded silty gravel, and well-graded crushed stone gravel are 1% to 17%, 4% to 15%, 5% to 16%, 12% to 34%, and 12% to 42%. The retained strength of junction (GRI-GG2) for flexible geogrid is ranging from 71% to 100% for various types backfill materials. Additionally, 2% of the maximum load is recommended as the preload for single rib tensile strength test (GRI-GG1). The wide width tensile strength (ASTM D4595) of the test geogrids generally is about 5% to 15% lower than those obtained from single rib tensile tests (GRI-GG1). The difference of tensile strength obtained from these two test methods increases as the construction damage effect increases.

RÉSUMÉ: Un essai complet sur place complet de dommages de construction des geogrids flexibles d'une fabrication simple a été réalisé. Les cadences de réduction de la résistance à la traction de geogrid placée dans le sol argileux, le sol arénacé, le gravier argileux, le gravier silty évalué pauvre, et le gravier en Pierre écrasé bien-évalué sont de 1% à 17%, 4% à 15%, 5% à 16%, 12% à 34%, et 12% à 42%. La force maintenue de la jonction (GRI-GG2) pour le geogrid flexible s'étend de 71% à 100% pour différents types remblayent des matériaux. Supplémentaire, 2% du chargement maximum est recommandé comme charge initiale pour l'essai simple de résistance à la traction de nervure (GRI-GG1). La résistance à la traction large de largeur (ASTM D4595) des geogrids d'essai est généralement environ 5% à 15% inférieurs à ceux obtenus à partir des essais de tension de nervure simple (GRI-GG1). La différence de la résistance à la traction obtenue à partir de ces augmentations de méthodes de deux essais à mesure que l'effet de dommages de construction augmente.

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):

$$Tallow = Tult\left(\frac{1}{RF_{ID} \times RD_{CR} \times RF_{CD} \times RF_{BD}}\right) \quad (1)$$

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.

Up to now, a number of studies related to the survivability of geotextiles and rigid geogrids has been performed (Koerner and Koerner 1998, Koerner et al. 1993, Richardson 1998, Troost and Ploeg 1990). Recent work by FHWA and IFAI has led development of reduction factor 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.

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. PVC-coated PET geogrids produced by a local manufacture are used in the study. The manufacture design strength 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 size of test sample is 1.9 m wide and 2.9 m long. 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 size 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 reported. The exhumed geogrid samples were then labeled and shipped back to laboratory for testing. The strength behavior of the geogrids before installation and after exhuming was evaluated according to the Geosynthetic Research Institute test standards GG1, GG2, and ASTM standard D4595. 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, single rib tensile strength test (GRI-GG1) was used as the primary test method to evaluate the installation survivability of the test samples. In addition, elongation at failure and junction strength before and after installation was also analyzed. 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. The reduction factor for installation damage for the flexible geogrid was also evaluated.

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

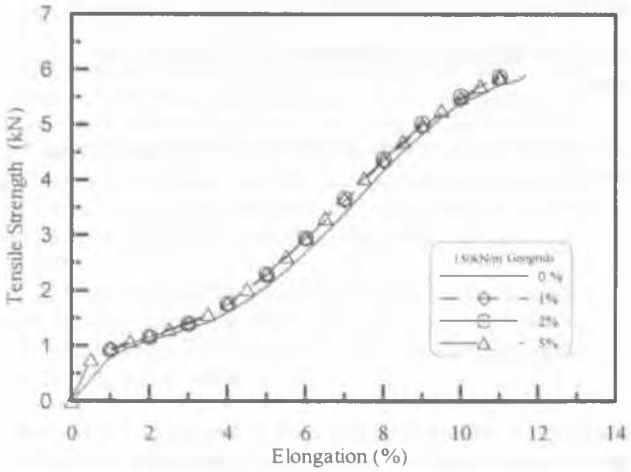

Figure 1. Typical single rib tensile strength test results for 150-kN/m geogrid under various preload conditions.

Table 1 The results of statistic 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

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 single rib tensile tests.

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

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 directions 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.

3.3 *Comparison of Tensile Strength for Five Different Backfill Materials*

In order to provide complete database for the installation survivability of flexible geogrids, the average test values and percentages strength retained for the 150-kN/m woven geogrids placed within the test soils for XMC and MDC test conditions are summarized in the Table 3. Since the effect of soil cover thickness on rib tensile strength is not very 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 shown in the table were obtained base upon the results analyzed from the single rib tensile tests and junction strength tests. In conclusion, the percentages strength retained for the 150-kN/m geogrid are about 79% to 81% for well graded gravels, 88% to 91% for clayey gravels, and 79% to 80% for poor graded silty gravels. Due to limited space, the test values and percentages strength retained for 60-kN/m, 100-kN/m, and 200-kN/m geogrids installed within the test soils are not shown in the paper. It was found that those test geogrids consisted similar installation damage behavior.

Table 3 The test results and retained percentages of the 150-kN/m geogrid under five different backfill materials for XMC and MDC test conditions. (Single rib tensile tests)

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

3.4 *Tensile Strength at 5% Strain*

The variation of the tensile strength at 5% strain for the 150-kN/m geogrid installed in the test soils 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 78% to 89% for the conditions tested. By evaluating the entire data, the effect of installation process on tensile strength at 5% strain is relatively more significant for the geogrids with higher tensile strength.

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 150-kN/m geogrid samples installed in the five different test soils are also shown in Table 3. Based upon the test results, the installation process would reduce the elongation of the test sample at failure. By further analyzed the data, it is found that the compaction roller traveling direction has 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 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. The average retained percentage junction strength for the 150-kN/m test geogrid samples is ranging from 80% to 85% shown in Table 3. 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 grip is required perform the wide width tensile test. Typically, a pair of roller grip is weighted over 60 kilograms.

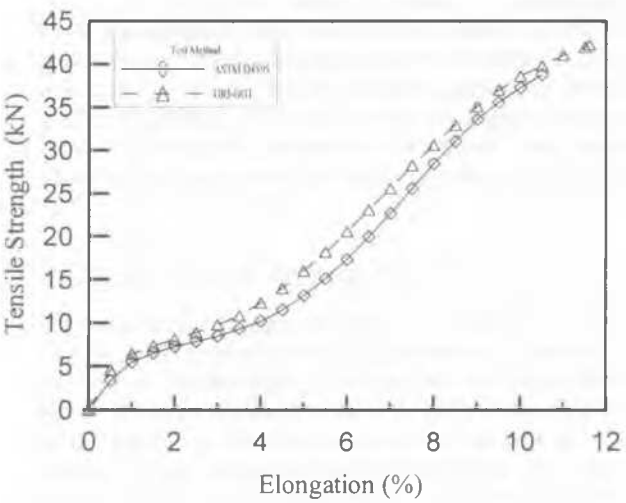

Figure 2. Comparison of single rib and wide width tensile test results for pre-construction geogrid samples (150 kN/m)

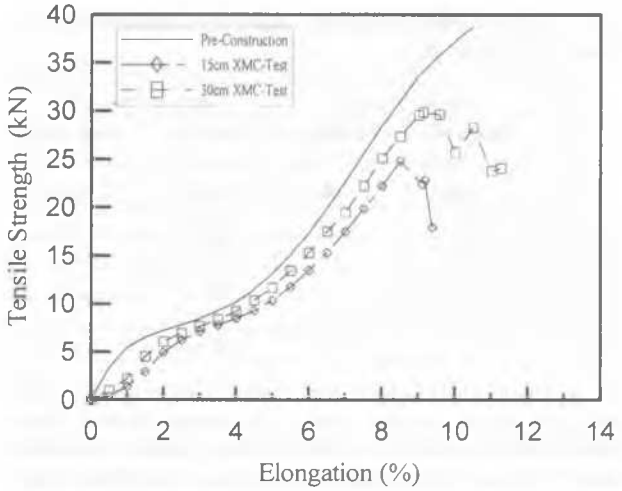

Figure 3. Tensile strength versus elongation curves (150-kN/m) of the pre-construction and exhumed samples under well-graded gravel for different test conditions

Table 4. Comparison on the average tensile strength retained percentages for single rib and wide width tensile tests of 150-kN/m geogrid samples placed under five different backfill materials for different 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	95.38	97.58	99.59	71.30	87.65
SP	90.48	93.97	95.30	97.93	70.51	87.26
GW	89.35	92.59	92.93	96.57	72.81	85.11
GC	89.04	92.11	91.70	94.96	74.74	88.24
GP-GM	88.55	91.12	91.34	94.71	74.68	85.18

Therefore, to perform a wide width tensile test is more complex and time consume in comparing with performing single rib tensile test. In order to evaluate the difference between these two test methods, a series of wide width tensile tests of 60-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 150-kN/m 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. Typical tensile strength versus elongation curves between the pre-construction and exhumed samples (XMC condition) under well-graded gravel for 150-kN/m test samples are shown in Figure 3. As shown in the figure, the ultimate strength and elongation for the exhumed samples are significantly less those for the pre-construction samples. The comparison of the tensile strength retained percentages for the 150-kN/m test samples placed under the test soils for single rib and wide width tensile tests are shown on Table 4. As shown on the tables, the retained percentages of wide width tensile strength, elongation at failure, and the tensile strength at 5% strain are about 5% to 15% less than the values for single rib tests.

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 material, compactive effort and lift thick-

Table 5. Typical recommended reduction factors for construction damage of flexible geogrids

Soil Type	Tensile Strength		Junction Strength	
	Range of Partial Factor of Safety	Average Partial Factor of Safety	Range of Factor of Safety	Average Partial Factor of Safety
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

ness, and type and weight of compaction equipments. It is also clear that geogrid placed within the angular crushed stone gravel shown greater damage than other backfill materials. Geogrid placed within backfill materials containing more greater than No. 4 sieve materials shown greater construction damage. As the construction damage of geogrid test sample increases, the elongation at failure of the test sample would reduce.

A 2% of the maximum load is recommended as the preload for single rib tensile test. If wide width roller grip is not available, single rib tensile test with more than 10 specimens can be used to evaluate the tensile strength of geogrid also.

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 the study, the recommended typical and average reduction factors for flexible geogrids placed within various types of soils are listed in Table 5. As shown on 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. 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 5% to 15% 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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