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Influence of strain rate on geosynthetic reinforcement properties

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ABSTRACT: Strength properties of geosynthetics are often obtained by performing ASTM D4595 wide width tensile tests or GRI-GG1 single rib tensile tests. However, the actual rate of loading of the reinforcement in the field during reinforced earth structure construction may be five or six orders of magnitude slower than the standard ASTM D4595 and GRI-GG1 testing rate. In an effort to investigate the strain rate effects on the engineering properties of different geosynthetic materials, the authors performed strength tests on ten different materials under different strain rate conditions. In this paper, typical results of strain rate controlled strength tests of different geosynthetic reinforcements were summarized and discussed. Suggested low strain rate adjustments of various geosynthetics reinforcement materials were proposed as well. Results of this study is hoped to improve design and performance prediction of geosynthetic structures.

1 INTRODUCTION

Strength properties of geosynthetic reinforcement are often obtained by performing ASTM D4595 wide width tensile tests or GRI-GG1 single rib tensile tests. However, the actual rate of loading of the reinforcement in the field during general geosynthetic reinforced soil (GRS) structures are often five or six orders of magnitude slower than the standard ASTM D4595 and GRI-GG1 testing rates. Lee (2000) proposed low strain rate adjustments for moduli of different woven geotextiles manufactured using different polymer materials based on the low strain rate wide width tensile test results (Boyle et al., 1996). The proposed modulus adjustments were found to be of great help in predicting performance of GRS retaining walls (Lee et al., 1999; Lee 2001). It was found that moduli of geosynthetic reinforcement had to be adjusted for the low strain rate conditions in order to correctly analyze the stress/strain distributions inside GRS structures.

However, only certainly polypropylene (PP) and polyester (PET) woven geotextiles had been studied for low strain rate effects on their strength properties so far (Boyle et al., 1996). Stain rate effect on nonwoven geosynthetic reinforcement and geogrids has not been well investigated. In an effort to obtain better understandings of the strain rate effect on the engineering properties of different geosynthetic reinforcement materials, the authors performed strain rate dependent strength tests on eight different materials including nonwoven geotextiles, woven geotextiles, as well as flexible and rigid geogrids. The testing strain rates are ranged from 50mm/min to 0.05mm/min. Polymer types of tested materials include polypropylene, polyester, and high density polyethylene (HDPE).

In this paper, results of strain rate dependent strength tests are presented. Strain rate effects on different geosynthetic reinforcement materials are also summarized and discussed. Finally, low strain rate adjustments of various geosynthetic reinforcement materials are proposed as a conclusion of this on going study. Results of this study is hoped to improve design and performance prediction of geosynthetic structures.

2 STRAIN RATE DEPENDENT STRENGTH TESTS

2.1 *Test plan*

In this study, both the ASTM D4595 wide width tensile test and the GRI-GG1 single rib tensile test were used to obtained strength properties of geosynthetic reinforcement products. Tables 1 and 2 show the test methods, controlled strain rates, index properties, polymer types and manufacture engineering properties of the tested geosynthetic reinforcement materials.

Table 1 Properties and test plan of geogrid reinforcement material.

Sample Name	Rigid Grid, RG1	Flexible Grid, FG2	Flexible Grid, FG3	Flexible Grid, FG4
Test Method	GRI-GG1			
Controlled Strain Rate	50, 10, 1, 0.1, 0.05 (mm/min)			
Polymer Type	HDPE	PET	PET	PET
Unit Weight (g/m^2)	598.0	222.4	457.7	503.3
Thickness (mm)	1.35	1.58	2.08	1.05
Manufacture T_{ult} (kN/m)	80	50	115	145

Table 2 Properties and test plan of geogrid reinforcement material.

Sample Name	Woven Geotextile, WG1	Woven Geotextile, WG2	Non-Woven Geotextile, NWG1	Non-Woven Geotextile, NWG2
Test Method	ASTM D4595			
Controlled Strain Rate	10, 3, 1, 0.1, 0.05 (mm/min)			
Polymer Type	PP	PP	PP	PP
Unit Weight (g/m^2)	239	318	403	706
Thickness (mm)	0.94	0.78	6.22	10.01
Manufacture T_{ult} (kN/m)	60	40	30	40

2.2 *Test apparatus and sample preparation*

The INSTRON multi-function test machine equipped with video extensometer, computer controlled rate controller, and multi-channel data acquisition panel was used to perform both wide width and single rib strength tests. Figure 1 shows the test setup and the camera of the video extensometer.

Figure 1 Test setup and the video extensometer.

For wide width tensile strength tests (woven and nonwoven geotextiles), the specimens were prepared with a size of 200mm wide by 200mm long. The additional 50 mm length on each end of the specimen was reinforced with an epoxy resin to prevent possible damage by the clamps. Geogrid specimens of the single rib strength tests were prepared to have enough length for two completed junctions between the roller clamps. This approach was used to prevent close-clamp failures of the geogrids at large loads.

3 TEST RESULTS

3.1 *Original test data*

Figures 2 to 5 show the typical test results of various geogrids, and geotextiles. As shown in these figures, strength properties of geosynthetic reinforcement materials were found to be very sensitive to the strain rates. The ultimate strength and general stiffness (average slopes of the strength-strain curves) values of all tested geosynthetic reinforcement materials decrease as the controlled testing strain rates decrease. Furthermore, the ultimate strains of tested geosynthetic reinforcement materials increase as the strain rates decrease.

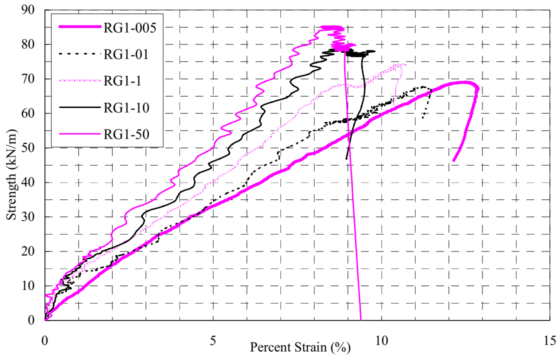


Figure 2 Typical test results of rigid geogrid (RG1).

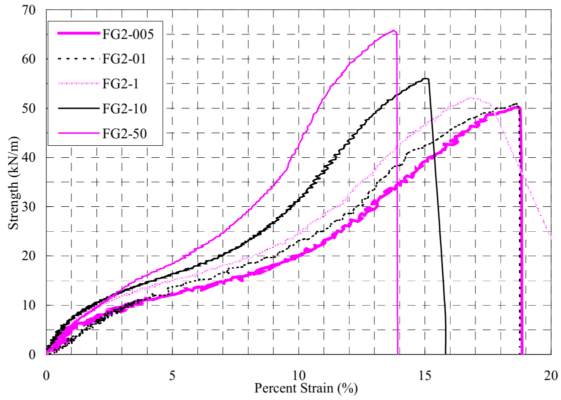


Figure 3 Typical test results of flexible geogrid (FG2).

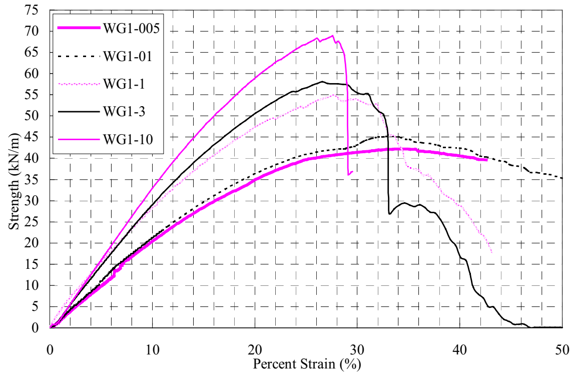


Figure 4 Typical test results of woven geotextile (WG1).

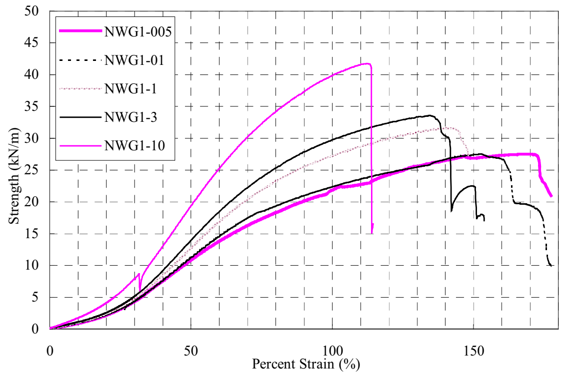


Figure 5 Typical test results of non-woven geotextile (NWG1).

As shown in Figures 2 and 3, the ultimate strengths of geogrids decrease about 20% as the testing strain rate decreases from 50mm/min to 0.05mm/min. For geotextiles, test results shown in Figures 4 and 5 indicate an average 32% reduction of ultimate strengths of geotextiles when the testing strain rate decreases from 10mm/min to 0.05mm/min.

3.2 *Modulus*

Figures 6 and 7 summarize the 5% strain and ultimate strain secant moduli of tested geogrid under different strain rate conditions. As shown in Figure 6, an average 32% reduction of the 5% strain secant modulus was found when the testing strain rate was lowered from 50mm/min to 0.05mm/min. Furthermore, ultimate strain secant moduli of Geogrids RG1, FG2, and FG3 show an average 40% reduction when testing strain rate was lowered from 50mm/min to 0.05mm/min. However, Geogrid FG4 (average T_{ult} = 160 kN/m at strain rate 50mm/min) shows only a 30% ultimate strain modulus reduction when testing strain rate was lowered from 50mm/min to 0.05mm/min.

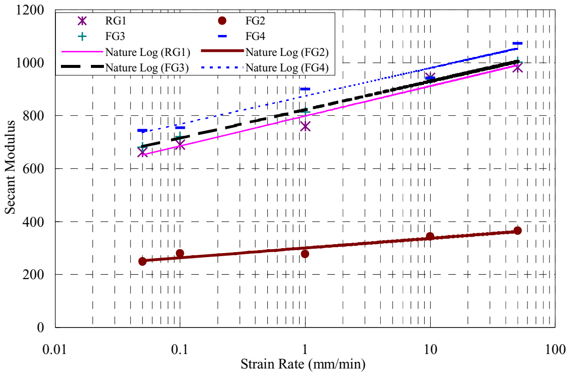


Figure 6 5% strain secant moduli of geogrids under various strain rate conditions.

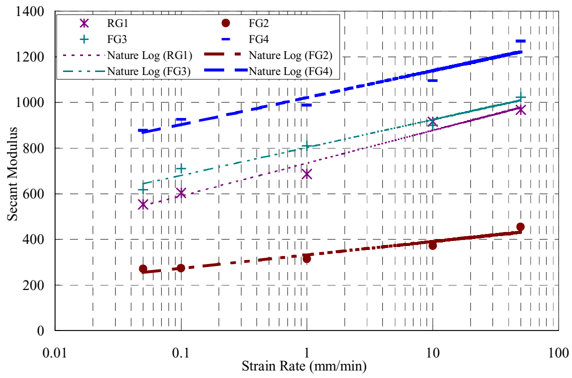


Figure 7 Ultimate strain secant moduli of geogrids under various strain rate conditions.

Similar tendency was also observed from the test result of polypropylene geotextiles. Results shown in Figure 8 indicates an average 42% reduction of 5% strain secant modulus of Geotextiles WG1, WG2, NWG1 and NWG2 when strain rates decreased from 10mm/min to 0.05mm/min. For ultimate strain modulus of geotextiles, an average 50% low strain rate reduction factor was observed from the test results (Figure 9).

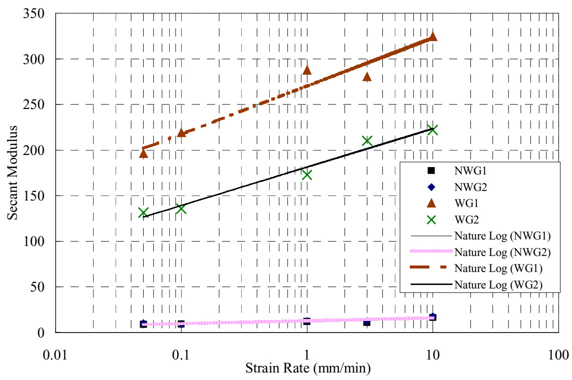


Figure 8 5% strain secant moduli of geotextiles under various strain rate conditions.

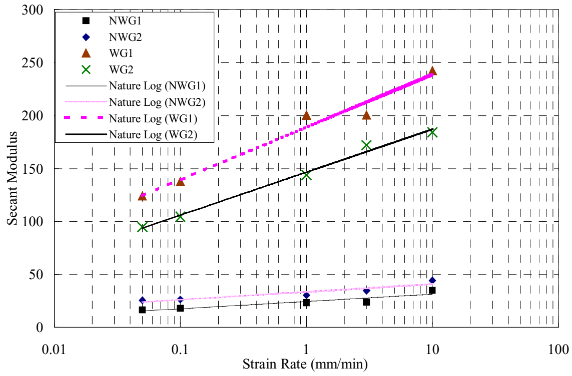


Figure 9 Ultimate strain secant moduli of geotextiles under various strain rate conditions.

Boyle et al. (1996) reported a 40% low strain rate modulus reduction factor for the PP woven geotextiles and a 20% reduction factor for the PET woven geotextiles. Test results described above verifies Boyle's research results of PP geotextiles, yet it indicates that PET geogrids have a larger low strain rate modulus reduction factor (32%) than PET geotextiles do.

3.3 *Ultimate strain*

Another engineering property of geosynthetic reinforcements that is also affected by strain rate is the ultimate strain. As shown in Figure 10, ultimate strains of both rigid and flexible geogrids increase as the testing strain rate decreases. For rigid grid, the ultimate strain increases 40% as the strain rate decreases from 50mm/min to 0.05mm/min. For flexible grid, the ultimate strain increases 35% as the strain rate decreases from 50mm/min to 0.05mm/min.

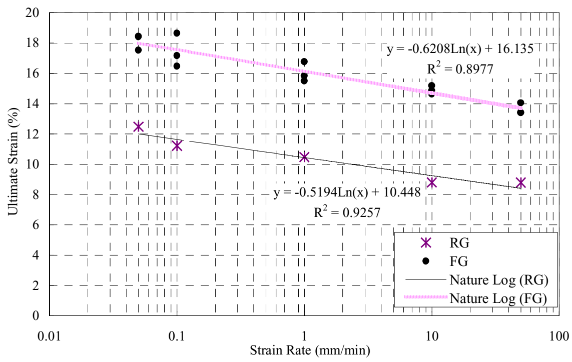
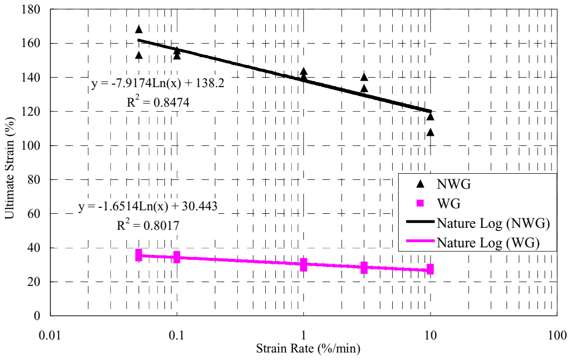


Figure 10 Ultimate strains of geogrids under various strain rate conditions.

Figure 11 summarizes the low strain rate effect on ultimate strains of woven and nonwoven geotextiles. As shown in the figure, ultimate strain of woven geotextiles increase only 30% as strain rate decreases from 10mm/min to 0.05mm/min. However, ultimate strain of non-woven geotextiles increase as many as 45% when strain rate decreases from 10mm/min to 0.05mm/min.

Figure 11 Ultimate strains of geotextiles under various strain rate conditions.



4 CONCLUSION AND DISCUSSIONS

1. Engineering properties such as ultimate strengths, moduli, and ultimate strains of geosynthetic reinforcement materials including rigid geogrids, flexible geogrids, woven geotextiles and nonwoven geotextiles were all found to be very sensitive to the strain rate. These observations not only further verified the previous test results done by Boyle et al (1996), but also proved that strain rate has similar effects on the strength properties of nonwoven geotextiles and geogrids as it has on the woven geotextiles.

2. Table 3 summarizes the low strain rate adjustments of various geosynthetic reinforcement materials proposed by Lee (2000) and the authors. The proposed modulus reduction factors should be carefully considered when performing design or performance prediction of geosynthetic reinforced soil structures.

Table 3 Proposed low strain rate reduction factor of geosynthetic reinforcement modulus

Polymer	Geosynthetics	Lee (2000)	This Study
HDPE	Geogrid	50%	35%
PET	Geogrid	-	35%
	Woven Geotextile	20%	-
PP	Woven Geotextile	50%	45%
	Nonwoven Geotextile	-	55%

3. Low strain rate seems to have similar influence on the engineering properties of both rigid (HDPE) and flexible (PET) geogrids.

4. Geosynthetic reinforcement materials made of polypropylene are found to be most sensitive to the low strain rate. These geosynthetics have larger ultimate strength and modulus reductions as well as ultimate strain increase as the strain rate decreases.

5. For polyester geosynthetic reinforcement materials, the geogrids are found to be more sensitive to the strain rate than the geotextiles. This result might be caused by the different fabric structures between geogrids and geotextiles.

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