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Research on the Long-term Tensile Strength of Geogrid in Reinforced Soil Structure

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Abstract: The long-term tensile strength of reinforcement in geogrid reinforced soil structure is an important design parameter. The reduction factors of geogrid, such as installation damage, creep, chemical and micro-biological degradation during construction and operating in the soil must be considered to decide the long-term tensile strength. According to the lab test results, the strength of geogrid in soil and air is compared, and the tensile properties of HDPE geogrid with different strain rates have been studied. In addition, the installation damage reduction factors in five poorly-graded granular fill have been put forward. The creep test method and creep reduction factor have been raised. Finally, the durability reduction factor is discussed in this paper. These results can be used as a reference for future design of geogrid reinforced soil structure.

1. Introduction

Geogrid reinforcement has been proved to be an impressing improvement to the soil, which it can put the compressive strength of geogrid and tensile strength of soil together by friction between soil and geogrid. And it can limit the lateral deformation of soil and improve the strength and overall stability of reinforced soil structures. The friction between geogrid reinforcement and soil also includes the friction between surface of geogrid and soil, the end bearing force between the soil particles and the ribs of geogrid, and surface friction between soil mass inside and outside of geogrid mesh [1].

Generally, reinforced soil structure operates under a long-term load, so the long-term tensile strength of geogrid is one of the most important indicators in the engineering design. To determine the long-term tensile strength of geogrid reinforcement, it involves the tensile strength of the material and its various reduction factors in the process of the engineering application [2]

At present, the standards of all countries around the world, carried out the provisions for the value method of long-term strength of geosynthetic reinforced materials. Generally, the ultimate tensile strength has been multiplied by the reduction factors such as the construction damage, creep and aging.

$$T_a = \frac{T_{ult}}{RF} = \frac{T_{ult}}{F_{iD}F_{CR}F_D} \tag{1}$$

Where: T_a is the long-term strength of geogrid; T_{ult} is the ultimate tensile strength of geogrid; R_F is the reduction factor of strength; F_{iD} is the reduction factor of construction damage; F_{CR} is the reduction factor of creep; F_D is aging reduction factor consideration of the influence of microbial, chemical, thermal oxidation.

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Although some countries made some correlation studies on the reduction factor and put forward different recommendation values, the wide range of values brings inconvenience for the design. The paper related a lot of experimental research carried out by the author to make a systematic study about the long-term strength of HDPE uniaxial tensile plastic geogrid which were widely used in the reinforced soil structure in engineering [3].

2. Determination of geogrid ultimate tensile strength

The tensile strength of geogrid is expressed by the tension of unit width, which is kN/m. The tensile strength of geogrid is associated with the width, shape, and constraint condition of specimen, which must be determined under the standard conditions. At present, the procedure of which is in the *Geosynthetics-Plastic geogrid* (GB17689-2008) is mainly base on the test of strength of single rib or wide. As the *Pecification for test and measurement of geosynthetics* (SL235-2012) ruled about the single rib method, each sample should not be less than 5 ribs, and the tensile rate is 20%/min. As for the method in *Test Methods of Geosynthetics for Highway Engineering* (JTGE50-2006), it stipulates that single rib or multiple ribs can be used in tensile test, and the tensile rate is need to set up for 20%/min of the measuring length [4].

2.1 Analysis of the geogrid tensile properties in different medium

When the geogrid reinforcement material embedded in the compacted soil, it is their interaction with soil to enhance to structure. The tensile properties in the air medium and the engineering properties in the soil medium will be different. The influence factors of geogrid properties in the soil medium include tensile rate and confining pressure. Ding Jinhua studied through the tensile tests that put the uniaxial geogrid in the weathered sand under different vertical loads and test under different tensile rates, and came out that in the lateral restraint, the overlying load is larger, and the secant modulus of geogrid is higher. Geogrid in certain tensile rate in soil showed a higher tensile strength than in the air medium, but it gradually decreases with the decreasing of strain rate. When the strain rate is 3mm/min, the secant modulus of reinforcing material in the air and soil are roughly equal (Figure 1). Thus, under working stress state, the secant modulus of geogrid in soil medium is about 5% larger than it in air medium. For geotechnical engineering, it is acceptable, the tensile test results of geogrid in air medium can applied to soil medium environment.

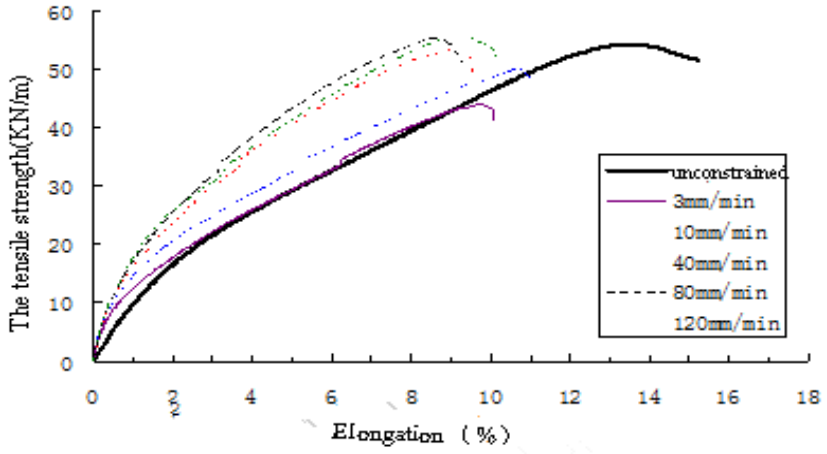


Figure 1. Geogrid tensile stress and strain under sand-confined σ_1=100kPa.

2.2 Analysis of geogrid tensile properties in different tensile rate

Plastic tensile geogrid has been composed of high molecular polymer with damping viscosity; and stretching rate will affect the tensile modulus. Under the low strain rate, molecular position in the structure has enough time to adjust, part of the energy is converted into heat, the other absorbed by the

damping structure, lead to the tensile strength of material to decrease. Therefore, different tensile rates will lead to different tensile properties of the geogrid [5].

In order to analyze the effect of tensile rate on the tensile properties of geogrid, the author carried out the geogrid tensile test under the different tensile rate (50 mm/min, 10 mm/min, 1 mm/min, 0.1 mm/min, and 0.05 mm/min). The test method is the single rib, performed at 20±2℃.

Test results show that, the tensile strength and secant modulus of geogrid decreases with the reduction of tensile rate, peak strain increases with the decrease of tensile rate, so the tensile rate is a factor that affects the tensile properties of geogrid. When the strain rate is fixed, the tensile strength corresponds with 2%, 5%, 10% strain, and the peak strain increases, while the tensile modulus is decreased in turn.

3. Construction damage reduction factor of geogrid

The geogrid of reinforced soil structure will produce some damage in the laying and the process of filling compaction, which will reduce the strength of geogrid. Lots of experiments showed that the construction damage of geogrid can generally divided into four types:

1. General wearing due to friction caused by small particles of fillers in contact with the surface of the reinforcement. 2. Reinforcement rib wearing caused by the large grain fillers. 3. Small cracks caused by the local cracking of longitudinal rib. 4. The shearing destruction of the ribs caused by the longitudinal ribs sharp saw tooth [6].

In order to discuss the construction damage of HDPE uniaxial geogrid in different gradation packing medium and define strength reduction factor of construction damage, the construction damage field test of geogrid was conducted.

3.1 Test methods

Considering the non-uniformity of the field filler of reinforced soil structure, five kinds of fillers with different particle size and bad gradation were blunt, the maximum diameter was 10mm, 20mm, 50mm, 75mm, 125mm, Qingdao quarry crushing granite as the filler, the grading curve as shown in Fig.2.

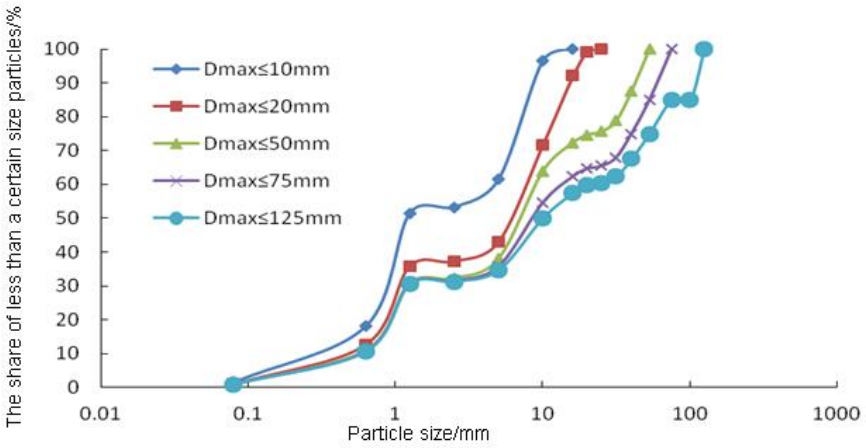


Figure 2. Grading curve of granular fill.

The five kinds of filler above were paving on a flat ground that divided into five regions. After the roller was completed, laying different tensile strength of geogrid in each region. Then the roller began paving and rolling the filler again with the geogrid below. Filler's pseudo thickness is 187.5mm and compaction thickness is about 175mm. Using YZ-12 vibratory road roller to compact at the speed of 2km/h. A total of three cases of compaction were carried out: standard compaction-rolling for 4 times, excessive compaction-vibration roller for 8 times, and thick compaction-pseudo thickness 37.5 cm, vibration roller for 4 times. Then, dig out samples of the geogrid after the compaction, and analyze the phenomena of apparent and test of tensile.

3.2 Analysis of the experiment results

The excavated geogrid sample showed different degrees wear and tear; most have bruises, rib cracking rarely, no rib fracture. The test results showed that the degree of construction damage of one type of geogrid increase with the filler particle size increase. Through the indoor standard tensile test of excavated geogrid sample and corresponding to the same batch geogrid without test show: the larger particle size of filler, the more serious of geogrid construction damage, strength reduction caused by construction damage is smaller, the loss of strength of different type geogrid is basically identical, the extensibility of construction injury geogrid sample lower than the standard sample, and reducing with the increase of the damage degree. After the statistics, construction damage reduction factor of HDPE uniaxial geogrid as shown in table 1.

4. Creep reduction factor of geogrid

Plastic geogrid composed of polymer with creep properties will have an influence on the long-term behaviour of reinforced soil structure. The creep phenomenon of reinforcement will lead to stress redistribution in reinforced soil structure so that present overall instability or excessive horizontal deformation. Three stress of the creep process-the transition point critical temperature of strain stage is glass transition temperature T_g (transition point of elastic phase and viscoelastic phase) and the melting point temperature T_m (transition point of viscoelastic phase and fluid phase).When the ambient temperature $T<T_g$, geogrid behaved as elastic properties. When $T_m>T>T_g$, geogrid behaved as viscoelastic (creep) properties. In terms of HDPE, Geogrid will exhibit creep characteristics when the surrounding temperature of soil medium is 10~30℃.

Table 1. Test result of geogrid installation damage reduction factor

Maximum Particle Size	$D_{max}\leq10$ mm $D_{50}\approx1.2$ mm	$D_{max}\leq20$ mm $D_{50}\approx6.0$ mm	$D_{max}\leq50$ mm $D_{50}\approx7.0$ mm	$D_{max}\leq75$ mm $D_{50}\approx8.5$ mm	$D_{max}\leq125$ mm $D_{50}\approx10$ mm
Reduction Factor	1.05	1.09	1.09	1.13	1.13

In order to study the creep characteristics of HDPE uniaxial geogrid and analyze the creep reduction factor, the experimental research on the typical tensile of plastic HDPE geogrid was carried out. The test in accordance with the "*Creep testing and evaluating method on plastic georids*"(QB/T2854-2007).

The creep test of geogrid has been calculated using the long-term strength of geogrid through the relationship under different temperature, strain of geogrid under different load and time, and shift factor and extrapolation depend on time. The engineering design is using deformation amount 10% in 100 a for the design life, in order to increase the reliability of extrapolation of experimental data, it should remove the strain data that within 1h to reach 10%, at the same time, it must also have the strain data collected that more than 1000h to reach 10% to ensure the credibility. The creep test results of typical geogrid have shown in Fig.3-Fig.5.

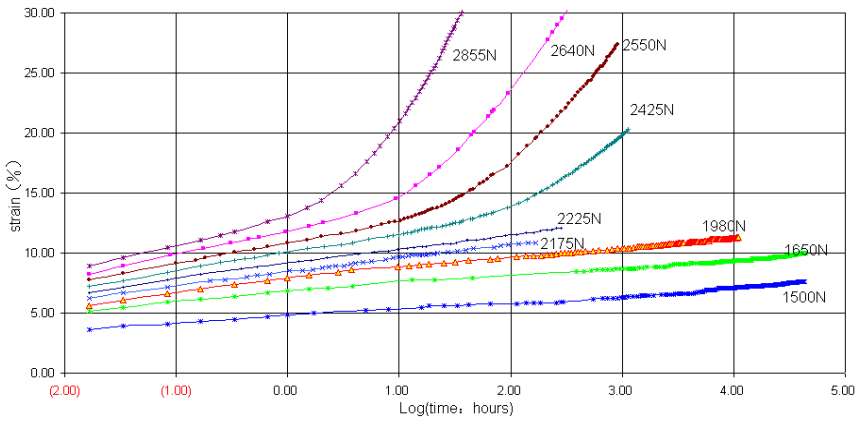


Figure 3. Deformation curve of EG50R under 20℃.

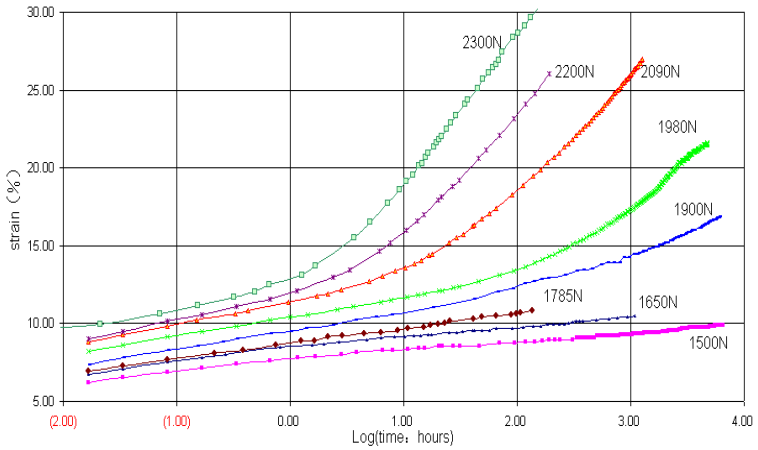


Figure 4. Deformation curve of EG50R under 40℃.

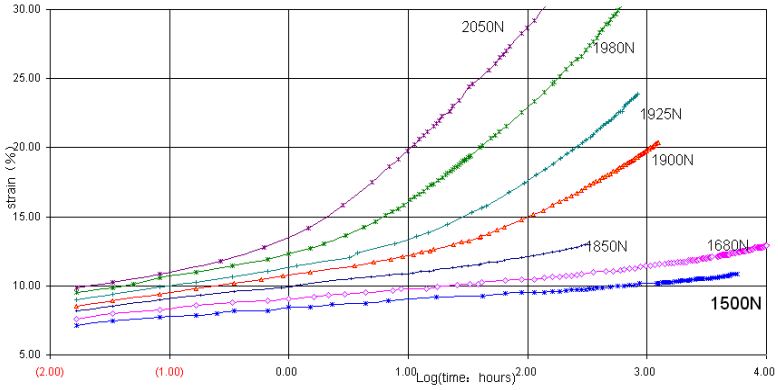


Figure 5. Deformation curve of EG50R under 50℃.

According to the principle of time temperature equivalence, we can get extrapolation time-load curve and equation below 20℃ of EG50R, as it is shown in Fig.6.

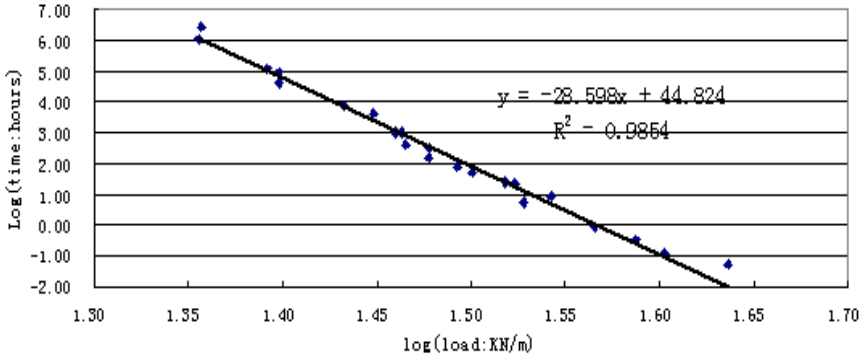


Figure 6. Extrapolate curve and equation of EG50R.

For example, when calculated the long-term strength of geogrid of 60 and 120 a, the EG50R geogrid creep strength reduction factor is 2.32 and 2.37, respectively.

5. Aging reducing factor

Geogrid composed of polymer with chain structure will withstand long-term microbial, chemical (acid, alkali) in reinforced soil structures and the effect of thermal oxidation, the degradation reaction and exchange reactions occurs easily, which may cause the decrease of tensile strength. Therefore, the

aging resistance reduction factor of geogrid is an important part of its long-term design strength. The arrangement of molecules in polymer has a certain effect on durability of geogrid. Table 2 is the comparative of durability of four typical raw materials.

Table 2 Performance Comparison of High-Molecular Polymer of Geosynthetics

	Light Degradation	Thermal Oxidation	Hydrolysis	Acid Degradation	Alkali Degradation	Microbial Degradation
PP	medium	bad	good	good	good	superior
PA	good	good	medium	medium	good	good
PET	superior	superior	bad	good	medium	medium
PE	medium	medium	good	superior	superior	superior

Design code for applications of geosynthetics on subgrade of railway (TB 10118-2006) suggested that the strength reduction factor of the reinforced soil structure considering chemical damage, biological damage is 1.0~1.5. *Standard for applications of geosynthetics in hydraulic and hydro-power engineering* (SL/T225-98) recommend that for the geogrid reinforced soil retaining wall chemical damage factor is 1.0~ 1.5 and biological damage factor is 1.0~ 1.3. The HDPE geogrid is produced by BOSTD Gwosynthetic Qingdao LTD. in accordance with European standards to take the aging test. The oxidation test for 56 days under the condition of 100 ℃, microbial degradation test continuous for 16 weeks and chemical degradation test in acid and alkali environment, experimental results show that the strength of the material has no decay, aging reduction factor is 1.0.

6. Conclusion

Based on the analyses of a large number of experimental results and research about long-term strength of the reinforcement in geogrid reinforced soil structure, drawing the following conclusion,

1) The geogrid reinforced soil structure modulus is different in soil and air within 5% stress in the working state. Tensile test results of geogrid in air medium can be applied to soil medium environment in the design procedure.

2) Stretching rate is a factor that affects the tensile strength, ductility of geogrid and the secant modulus.

3) Construction damage strength reduction factor of HDPE uniaxial geogrid is about 1.05-1.13.

4) Creep reducing factor of HDPE uniaxial geogrid is about 2.3-2.4.

5) Aging reducing factor of HDPE uniaxial geogrid is about 1.0.

Acknowledgement

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