Influence of Lateral Limited Uniaxial Tensile Strain on Opening Sizes

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Abstract. Nonwoven geotextiles are widely used for seepage prevention, foundation improvement and reinforcement materials. They are usually under lateral limited uniaxial tension in engineering, which results in changing behaviour of the opening size of geotextiles. According to theoretical analysis of pore parameters people studied before, the equivalent pore size ($D_{95}$) of nonwoven geotextiles under the lateral limited uniaxial tensile strain are derived in this paper. Two different nonwoven geotextiles were stretched under lateral limited uniaxial tensile strain of 3%, 5% and 10% respectively. Dry sieving tests were exerted in order to eliminated electrostatic effects and measure the change of pore size of nonwoven geotextiles. The results show that theoretical solutions are good for predicting the change law of pore sizes for non-woven geotextiles. Pore size of nonwoven geotextiles increases with increasing of the lateral limited uniaxial tensile strain.

Keywords. Nonwoven geotextiles, lateral limited uniaxial tension, opening size, dry sieving test.

1. Introduction
Nonwoven geotextiles are widely used in construction sites for embankment maintenance, seepage prevention and foundation reinforcement. Pore size is one of the most important parameter in filtration design, soil retention and anti-clogging for geotextiles [1-3]. In fact, geotextiles applied in projects are mostly under stretching. Rowe et al. [4] measured that tensile strain in the direction perpendicular to embankment is almost 10% while it is relatively small in the direction along the embankment. Geotextiles in this condition is considered to be under lateral limited uniaxial tensile strain. Won et al. [5] conducted a long-term monitoring of reinforced walls and found that the maximum tensile strain of geotextiles was around 6.05%.

Changing behavior of pore sizes varies in different experimental conditions. Wu et al. [6] suggested an increasing trend of equivalent pore size according to permeability tests and gradient ratio tests as uniaxial tensile strain increased for thermally bonded non-woven geotextiles. She Wei et al. [7] showed that pore size decreased with uniaxial tensile strain increasing in wet sieving test for needle-punched nonwoven geotextiles. Tang Lin et al. [8-9] measured that pore size decreased as uniaxial tensile strain increased while it increased with biaxial tensile strain increasing for needle-punched nonwoven geotextiles.

Geotextiles are stretched in different stress states because of the complexity of soil deformation [10]. Geotextiles are confined in the soil due to normal loads imposed by soils on both sides [11]. Palmeira et al. [12] showed that overburden loads limited deformation of pore size due to plane strains.
for nonwoven geotextiles. And geotextiles were considered to be under lateral limited tensile strain when overburden loads were large.

Equivalent pore size of nonwoven geotextiles is defined as the diameter of particles that can pass through fibers of each layer [2]. Giroud et al. [13] proposed a mathematical model based on the geometry of the pore size of nonwoven fabrics. Wei She et al. [7] derived the theoretical equivalent pore size \( O_{95}^{ltu} \) of nonwoven geotextiles under uniaxial tensile strain. Tang Lin et al. [9] extended the theoretical solution to biaxial tensile strain.

In this paper, the theoretical equivalent pore size \( O_{95}^{ltu} \) of nonwoven geotextiles was derived under lateral limited uniaxial tensile tests, with fibers being stretched in tensile direction while fabrics being fixed in orthogonal direction. The speed of two longitudinal extensometers were set to 5mm/min and two weft clamps were fixed during the whole tensioning stage. Two kinds of needle-punched nonwoven fabrics were stretched and dry sieving tests were exerted when tensile strains were 0, 3%, 5% and 10% respectively. The results present a good prediction for changing rules in pore size with lateral limited uniaxial tensile strain increasing for nonwoven geotextiles.

2. Theoretical Analysis of Equivalent Pore Size \( O_{95}^{ltu} \) Under Lateral Limited Uniaxial Tensile Strain

Giroud et al. [13] proposed the theoretical equivalent pore size \( O_{95}^{ltu} \) before tensioning, \[ \frac{O_{95}}{d_f} = \frac{1}{\sqrt{1-n}} - 1 + \frac{10n}{(1-n)t_{GT}/d_f} \] (1)

where \( n \) is porosity of nonwoven fabrics, \( d_f \) is diameter of fibers, and \( t_{GT} \) is thickness of nonwoven geotextile.

\[ n' = 1 - \frac{1}{(1+\varepsilon_x)(1+\varepsilon_z)} \times \frac{\mu_{GT}}{\rho_f t_{GT}} \] (2)

Figure 1. Deformation of nonwoven geotextiles under lateral limited uniaxial tensile strain.

She et al. [7] assumed that nonwoven geotextiles were isotropic and they were under plane strains during uniaxial tensile tests. The assumption is proper for nonwoven geotextiles used in lateral limited uniaxial tensile strain in this paper. Figure 1 shows the length of nonwoven geotextile sample is \( b \), the width of sample is \( a \). The thickness and porosity of sample is \( t_{GT} \) and \( n \) respectively.

The plane strain in tensile direction is \( \varepsilon_x \) which is equal to \( \varepsilon_x \), \( \varepsilon_y \) in direction perpendicular to \( \varepsilon_x \) is equal to 0 and \( \varepsilon_z \) in direction of thickness is equal to \(-v' \varepsilon_x/(1-v')\). \( v' \) is Poisson's ratio during stretching for nonwoven geotextiles.

Width \( a \) maintains the same during tensioning because of fixed two sides of each fabric sample. Length \( b' \) of sample during tensioning can be expressed by \( b(1+\varepsilon_x) \). Thickness of sample in lateral limited uniaxial tensile test \( t_{GT}' \) can be expressed by \( t_{GT}(1+\varepsilon_z) \).

The mass per unit area of nonwoven geotextile under lateral limited uniaxial tension test \( \mu_{GT}' \) is equal to \( \mu_{GT}/(1+\varepsilon_x) \), where \( \mu_{GT} \) is the initial mass per unit area.

The initial porosity \( n \) can be expressed by \( 1 - \mu_{GT}/(\rho_f t_{GT}) \), where \( \rho_f \) is the initial density of fibers. The porosity \( n' \) in lateral limited uniaxial tensile test can be expressed by equation (2),
The ratio of volume for nonwoven fabrics before tensioning and during tensioning is represented by equation (3).

\[
\frac{V'}{V} = (1 + \varepsilon_x)(1 + \varepsilon_y)(1 + \varepsilon_z) = 1 + \frac{1 - 2\nu'}{1 - \nu} \varepsilon + \frac{\nu'}{1 - \nu} \varepsilon^2
\]  

(3)

Since the value of tensile strain \( \varepsilon \) is small, volume ratio is near to equation (4),

\[
\frac{V'}{V} \approx 1 + \frac{1 - 2\nu}{1 - \nu} \varepsilon
\]  

(4)

where \( \nu \) is Poisson’s ratio before stretching.

Since equation (3) is almost equal to equation (4), there is relationship between \( \nu \) and \( \nu' \) expressed by equation (5),

\[
1 - \frac{\nu'}{1 - \nu} \varepsilon = 1 - \frac{\nu}{(1 - \nu)(1 - \varepsilon)} \varepsilon
\]  

(5)

The equivalent pore size of nonwoven geotextiles under lateral limited uniaxial tensile strain can be derived as equation (6),

\[
O_{bs}^{lu} = \left( \frac{\sqrt{(1 + \varepsilon)(1 - \nu - \varepsilon)}}{\sqrt{(1 - n)(1 - \nu)(1 - \varepsilon)}} - 1 \right) \times d_f + \frac{1 + \varepsilon}{1 - n - (1 - \nu)(1 - \varepsilon)} 10 d_f^2 \]  

(6)

3. Experimental Results of Dry Sieving Test

3.1. Dry Sieving Test

Test samples are two kinds of staple fiber needle-punched nonwoven fabrics with mass per unit area of 150 g/m² and 250 g/m² respectively. They are named NW150 and NW250. The main physical and mechanical parameters of the two nonwoven fabrics are shown in table 1.

|               | \( \mu_{GT} \) (g/m²) | \( t_{GT} \) (mm) | \( \rho_f \) (g/cm³) | \( d_f \) (μm) | \( \nu \) |
|---------------|-----------------------|-------------------|-------------------|-----------|-----|
| NW150         | 156                   | 1.21              | 1.32              | 23        | 2.6 |
| NW250         | 254                   | 2.08              | 1.32              | 23        | 2.6 |

The pore size distribution in dry sieving test of NW150 and NW250 when tensile strain is 0, 3%, 5% and 10% respectively are suggested in figure 2. The curves move to right as lateral limited uniaxial tensile strain increases, it shows that pore size increases with tensile strain increasing.

![Figure 2. Pore size distribution in dry sieving test for NW150 and NW250 under lateral limited uniaxial tensile strain.](image-url)
Three characteristic pore sizes \( O_{95} \), \( O_{50} \) and \( O_{30} \) corresponding to lateral confined uniaxial tensile strains of 0, 3%, 5%, and 10% for NW150 and NW250 are measured by interpolation which are listed in the table 2 in. It can be seen from the table 2 that three characteristic pore sizes for NW150 vary in a larger speed, \( O_{95} \) varies from 152 \( \mu m \) to 195 \( \mu m \), which increased by 28%. Characteristic pore sizes for NW250 increase gradually. \( O_{95} \) varies from 90 \( \mu m \) to 104 \( \mu m \), which increased by 16%. All of nonwoven fabrics increase with the increase of confined uniaxial tensile strain.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Tensile strain (%) & \( O_{95} \) (\( \mu m \)) & \( O_{50} \) (\( \mu m \)) & \( O_{30} \) (\( \mu m \)) \\
\hline
NW150 & & & \\
0 & 152 & 105 & 84 \\
3 & 155 & 110 & 87 \\
5 & 180 & 113 & 89 \\
10 & 195 & 119 & 92 \\
\hline
NW250 & & & \\
0 & 90 & 68 & 45 \\
3 & 94 & 70 & 48 \\
5 & 101 & 73 & 50 \\
10 & 104 & 75 & 53 \\
\hline
\end{tabular}
\caption{Measured characteristic opening sizes of stretched nonwoven geotextiles.}
\end{table}

3.2 Theoretical \( O_{95}^{th} \) and Results of Dry Sieving Test
Substituting the basic parameters of the test material's initial porosity, fiber diameter and fabric initial thickness into equation (6), the corresponding equivalent pore size can be calculated and compared with the results of dry sieve test, as shown in figure 2.

Figure 3 suggests that the theoretical equivalent pore size \( O_{95} \) predicted an increasing trend as lateral limited uniaxial tensile strain increased for NW150 and NW250. The correlation coefficients between the experimental values and theoretical values are 0.94 and 0.93, respectively, indicating a better prediction for theoretical equations.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Theoretical solutions of \( O_{95}^{th} \) and experimental \( O_{95} \) of dry sieving.}
\end{figure}

4. Conclusions
Lateral limited uniaxial tensile tests were exerted on two different thick fabrics. Dry sieving tests were deducted when tensile strain is 0, 3%, 5% and 10% respectively. Compared experimental result \( O_{95} \) with the theoretical solution \( O_{95}^{th} \), two conclusions are obtained:
(1) The pore size distribution curve of the nonwoven fabric moves to right as lateral limited uniaxial tensile strain increases, indicating that pore sizes increase with increasing of lateral limited uniaxial tensile strain.

(2) The theoretical solution $O_{95u}$ predict well in changing law of characteristic pore sizes for two nonwoven geotextiles under lateral limited uniaxial tensile strain. $O_{95u}$ is a little smaller than $O_{95}$.

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