Study on geomembrane seepage property of earth-rock dams

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Abstract. As an anti-seepage material, geomembrane is widely used in earth-rock dams engineering. However, the seepage calculation of geomembrane earth-rock dams has not been studied theoretically. According to the permeation mechanism of geomembrane, it can be divided into two categories: one is the permeability of itself; the other is the defect leakage flow. Based on the feedback analysis of the observation data of geomembrane of earth-rock dam, the average permeability coefficient of geomembrane is obtained. Finally, the error sources of clay emulation in seepage calculation of geomembrane earth-rock dams are discussed. The counting error is analyzed and the mathematical model is modified.

1. Introduction
Impervious structure is one of the key parts of earth-rock dams, which is prone to leakage damage. At present, geomembranes are widely used in earth-rock dams[1]. However, geomembranes are vulnerable to damage during installation and throughout their life, in the form of perforations and tears. These defects affect the effectiveness of geomembrane as a permeable barrier resulting in leakage of geomembrane lining into the dam. The benefits of composite geomembrane in dams include minimizing seepage, improving stability and long-term performance, and minimizing construction costs. Because of the high cost of transportation, the cost of materials used to build dams can increase significantly without suitable soil[2]. Geomembrane liners can be an economical and effective alternative to industrial products. Even with defects, geomembranes reduce the amount of leakage through the soil. A new equation for defect leakage of composite lining system is established. The Finite element method analysis shows that a geomembrane dam with defects will not produce pore pressure similar to that of an unlined dam[3].

This paper starts from the seepage characteristics of geomembranes. In this paper, the seepage is divided into two categories: one is the permeability of the geomembrane itself; another is leakage flux. Based on the feedback analysis of the measured data, the average permeability coefficient is obtained, which solves the problem that it is difficult to determine the defect of geomembrane.

2. Seepage mechanism of geomembrane
According to some experimental results reported in technical literature, the main results obtained and the understanding of geomembrane are as follows[4]: (1) geomembrane is a low permeability barrier compared to other materials rather than an absolutely impermeable barrier; (2) water can diffuses into the geomembrane; (3) seepage in geomembrane because of there are pores inside.

Geomembrane is a new type of impermeable material completely different from traditional impermeable material. It is a non-granular soil and non-porous media. However, the seepage
calculation of geomembrane earth-rock dams has not been studied theoretically. In this paper, geomembrane seepage is divided into two categories: (1) permeation; (2) leakage defects. There are fundamental differences in seepage mechanism, which need to be analyzed separately[5].

2.1. Permeation calculation of geomembrane
According to Darcy's law, the numerical model of the seepage of geomembrane leaching fluid is established. The model is solved by Finite element method[6].

\[ Q = k_g \cdot i \cdot A = \frac{k_g \Delta h A}{T_g} \]  

(1)

Where \( A \) is permeation area ;  
\( k_g \) is permeability coefficient ;  
\( i \) is hydraulic gradient;  
\( \Delta h \) is waterhead;  
\( T_g \) is thickness.

According to the results of permeability test, the permeability coefficient is a numerical area rather than a fixed value. As shown in figure 1, the permeability coefficient of geomembranes changes with the change of pressure. Generally speaking, the permeability coefficient is very low.

![Permeability coefficient of geomembrane](image)

Figure 1. Permeability coefficient of geomembrane

2.2. Leakage calculation of geomembrane
According to Brown's test results, if the material's permeability coefficient is greater than \( 10^{-3} \text{ m/s} \), it can be considered as freely permeable. Then Bernoulli equation is used to calculate the leakage of geomembrane[7]:

\[ Q = \mu a \sqrt{2gH} \]  

(2)

Where \( H \) is waterhead;  
\( g \) is gravitational acceleration;  
\( d \) is diameter of the hole;  
\( \mu \) is discharge coefficient;  
\( a \) is defect area per unit area.

2.3. Comparative analysis
However, geomembranes are vulnerable to damage during installation and throughout their life, in the form of perforations and tears. Through Giroud survey and statistical analysis, the average pore
density is 1 geomembrane per 4000 m$^2$. The diameter of the hole varies from 1mm to 5mm. Considering the specific situation in China, the actual density is greater than the above density. In addition, the pore density per 4000 m$^2$ of geomembrane is 1, which is the statistical average value[8].

The calculation of geomembrane seepage is compared with that of seepage by an example.

Example:
waterhead $H=10m$,
permeability coefficient $k_g=1\times10^{-11}cm/s$,
thickness of $T_g=0.5mm$,
the hole density is 1 per 4000m$^2$, the hole diameter is 3mm.
The calculation results: permeation flow is $8\times10^{-6}m^3/s$ (12% of the total), and defect leakage is $6\times10^{-5}m^3/s$ (88% of the total).

The example show that both seepage and leakage are not negligible.

3. Seepage analysis of geomembrane earth-rock dams
Taking the geomembrane earth-rock dam on solid foundation as an example (shows in figure 2), the seepage flow of impervious body is calculated by hydraulic method:

$$ q = k_e \cdot \frac{H_1^2 - h_e^2 - (\delta \cos \alpha)^2}{2\delta \sin \alpha} $$

Where $\delta$ is thickness,
$k_e$ is permeability coefficient,
$H_1$ is upstream water levels,
h$_e$ is overflow point after impervious body,
$\alpha$ is upstream slope angle.

![Figure 2. Schematic of geomembrane earth-rock dam](image)

In the case of small thickness of geomembrane, the thickness of geomembrane $\delta$ is proportional to the permeability coefficient of geomembrane $k_g$ according to the model of clay, usually 1000 times, so that the equivalent thickness is made up to 0.5m–1.0m, which is easy to calculate. After magnification, because the thickness of geomembrane increased many times and the magnification was 1000 times, we could not ignore it. Based on the above analysis, the source of seepage error in emulation calculation of geomembrane earth-rock dams is discussed. The counting error is analyzed and the mathematical model is modified.

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4. Conclusions
According to the seepage mechanism of geomembranes, the seepage of geomembranes can be divided into two categories: one is the permeability, another is leakage flux. Their seepage mechanisms are completely different and should be treated differently. The calculation results show that seepage and leakage are not negligible. Based on the feedback analysis of the measured data, the average permeability coefficient is obtained, which solves the problem that it is difficult to determine the defect of geomembrane. Finally, the source of seepage error in emulation calculation of geomembrane earth-rock dams is discussed. The counting error is analyzed and the mathematical model is modified.

Acknowledgments
This work was financially supported by the National Natural Science Foundation of China (Grant No. 51879146).

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