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# Seepage properties of geomembrane faced sandy-gravel dams with different dam heights due to defect-induced leakage

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**Keywords:** Sandy-gravel dams, geomembrane, defect-induced leakage, phreatic line, seepage flux

**Abstract.** The unsaturated seepage theory was employed to calculate the seepage field of geomembrane faced sandy-gravel dams with different heights. The influences of the location and size of defect on the phreatic line and seepage flux of dam were analyzed particularly. The results revealed that the change trends of the phreatic line and seepage flux of dams with different heights are basically the same. However, the height of phreatic line and the seepage flux both decrease with increasing defect location in geomembrane. In addition, the size of the defect has little influence on the phreatic line and seepage flux.

## Introduction

As a kind of polymer material, geomembrane is widely employed in anti-seepage project such as dikes, cofferdams, reservoir basins, channels, landfills, as well as sandy-gravel dams, for its high elongation, low permeability, high construction period and low cost [1,2]. However, in the short- and long-terms, due to poor quality assurance during placement and diurnal environmental temperature variations, damage often occurs and defects are easy to develop in the geomembrane, which will have negative effect on the anti-seepage performance [3].

Extensive research has been undertaken into seepage properties due to geomembrane defects. Giroud provide a comprehensive calculation method to evaluate leakage through geomembrane defects in composite liners, which is applicable to a wide range of liquid heads on top of the composite liner [4]. Foose used three-dimensional numerical models to analyze leakage through circular defects and two-dimensional numerical models to analyze leakage from defective seams [5]. The results showed that existing equations and analytical models all have limitations and no universal equation or method is available for predicting leakage rates. Various parameters on the leakage flow through defects in the geomembrane is studied by Saidi through numerical modelling and the results revealed that the interaction between two adjacent square defects does not result in an important reduction of the flow rate and wetted areas can be approached by an ellipse or by an 8-shape depending on the distance separating adjacent defects [6].

In this study, unsaturated seepage theory was employed to analyze the seepage field of a sandy-gravel dam with impervious geomembrane barrier considering different dam heights, locations of defect and sizes of defect in geomembrane barrier. The changes of phreatic line and seepage flux are presented, which can be the reference for engineering design.

## Layout of geomembrane in sandy-gravel dams

Similar to the concrete face rockfill dam, geomembrane can be placed on the upstream surface of a sandy-gravel dam as impervious barrier, which is the main impervious layout type (Fig. 1). According to the different upstream dam slope ratios, there are two different layout methods of geomembrane. For the gentle slope such as a sandy-gravel dam, the geomembrane can be directly placed on the dam surface and stabilized by its own friction. However, for the steep slope, the geomembrane cannot maintain stability through friction alone. Thus, specific adhesive should be employed to stick the geomembrane on the dam surface.

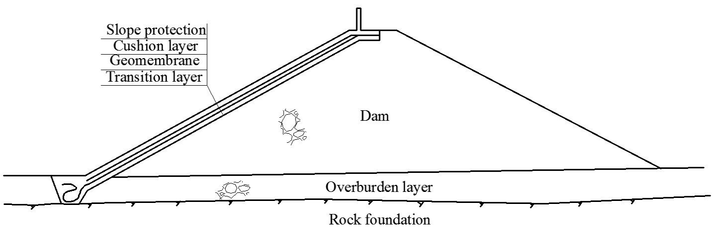



Fig.1 A typical sandy-gravel dam with geomembrane barrier on dam surface

## Seepage calculation method

**Permeation mechanism and defect-induced leakage of geomembrane** Polymeric geomembrane is not absolutely impermeable. Typical coefficient of permeability of geomembrane is in the range of 1×10-10 to 1×10-13 cm/s [1]. The water flowing through the geomembrane can be inferred as laminar for the reason that the water flows through these micro-pores or fractures with a quite small velocity (about 10-9 m/s). Thus, the Darcy's law can be assumed to be employed to analyze the geomembrane seepage behavior. In addition, as the thickness of geomembrane is quite small, the geomembrane is usually treated as porous medium and the thickness is magnified to a certain value according to the identical seepage flux assumption [7].

**Unsaturated seepage behavior of dam material** As excellent low permeability of geomembrane, the phreatic line in a sandy-gravel dam with geomembrane barrier is low, and the dam body is mostly in unsaturated zone. Considering that the seepage velocity and Reynolds number in unsaturated zone are small, the seepage can be also treated as laminar flow. Thus, unsaturated or saturated seepage theory is suitable for the seepage field calculation of a sandy-gravel dam with geomembrane barrier. In this paper, the unsaturated seepage theory was adopted for the seepage field analysis.

## Influence of the geomembrane defect on the seepage field of sandy-gravel dams

**Calculation model** A typical sandy-gravel dam model with impervious geomembrane barrier is built for calculation. The upstream and downstream dam slope ratios are both 1:1.7 and the thickness of cushion layer is 50 cm (Fig. 2). The height of the dam is set as 30 m， 50 m， 100 m and 200 m, respectively, with the corresponding reservoir level of 28 m，48 m，98 m and 197 m. In the seepage field calculation by finite element method, the geomembrane barrier with thickness of 1 mm is treated as porous medium with thickness of 10 cm. The defect is assumed to locate at the upper, middle or lower part of the geomembrane, respectively, with the diameter of 5 cm, 10 cm, 15 cm and 20 cm, respectively. The saturated coefficient of permeability of the cushion layer and dam body are $4.5\times10^{-4}$ cm/s and $1.2\times10^{-3}$ cm/s, respectively. Table 1 lists the change of permeability and saturation with the matric suction of dam material.

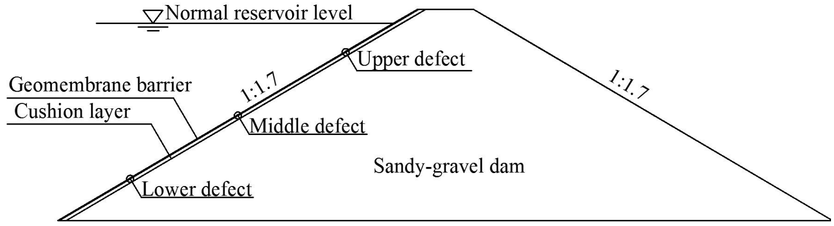
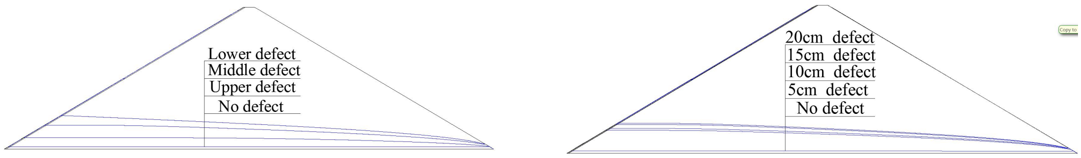



Fig. 2 Calculation model

Table 1. Unsaturated seepage characteristics of dam materials

| matrix suction (kPa) | | 0.01 | 0.1 | 1 | 10 | 100 | 1000 |
|---|---|---|---|---|---|---|---|
| permeability (m/s) | dam body | 1.00E-5 | 9.20E-6 | 3.15E-6 | 1.74E-9 | 4.33E14 | 9.54E-19 |
| | cushion layer | 1.05E-7 | 1.00E-7 | 7.87E-8 | 1.36E-8 | 1.20E-11 | 1.72E-15 |
| saturation | dam body | 1.0000 | 0.9988 | 0.8922 | 0.2072 | 0.0624 | 0.0314 |
| | cushion layer | 1.0000 | 0.9999 | 0.9949 | 0.8414 | 0.2509 | 0.0910 |

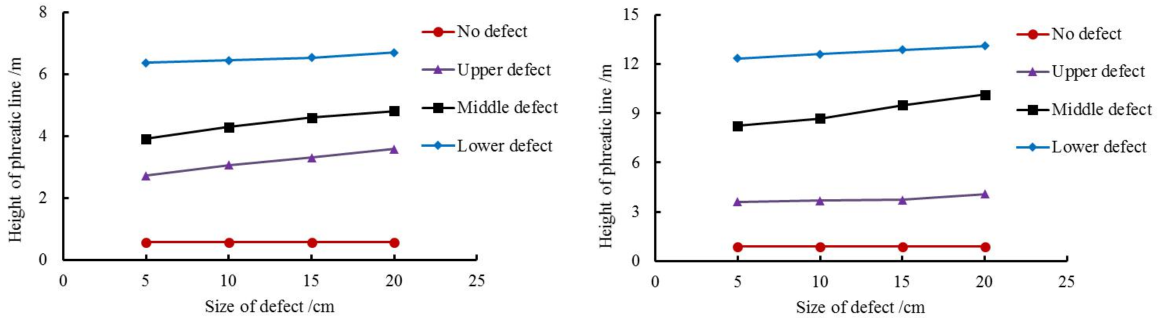
**Result analyses** Fig. 3 shows the distributions of phreatic line considering different sizes and locations of the defect for a 100 m high dam. It can be observed that the location of defect has obvious influence on the phreatic line. When there is no defect, the phreatic line is quite low as the low permeability of geomembrane. When the geomembrane barrier is with defect, the lower the defect is, the higher the phreatic line is. In contrast, the size of the defect has little influence on the phreatic line distribution.



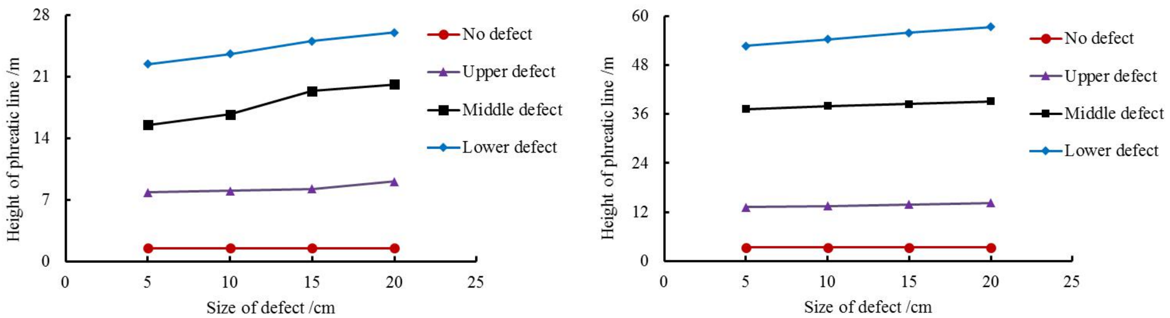

(a) Influence of defect location (10 cm defect) (b) Influence of defect size (middle defect)

Fig. 3 Change of phreatic line for a sandy-gravel dam with height of 100 m

Fig. 4 shows the change of phreatic line height after the geomembrane with the size of defect. It is obvious that the intact geomembrane (no defect) can effectively lower the phreatic line in dam body. Once defect appears in the geomembrane barrier, the location of phreatic line will rise obviously. The variations of the phreatic line in dams with different heights are basically the same, which are only different in numerical values.



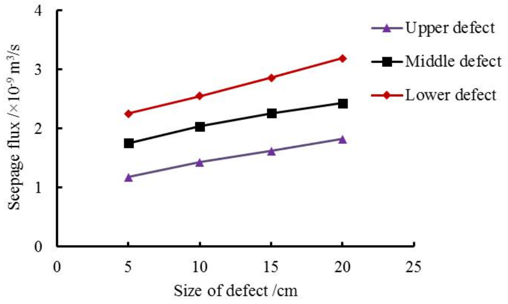

(a) 30 m (b) 50 m



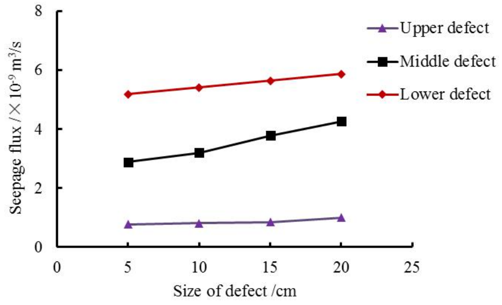

(c) 100 m (d) 200 m

Fig. 4 Change of phreatic line of sandy-gravel dams with different heights

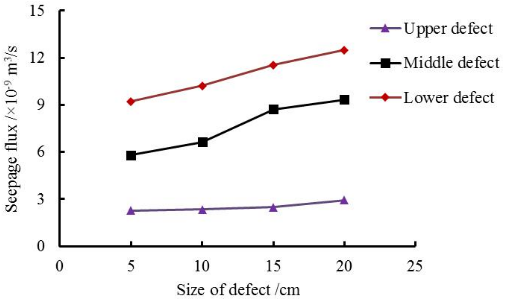
The influence of defect on the seepage flux is shown in Fig. 5. With increasing size and decreasing location of defect, the seepage flux increases gradually, but is still in the same order of magnitude. The height of the dam has little influence on the change law of seepage flux.



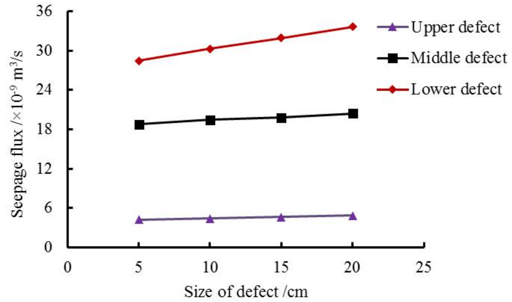

(a) 30 m




(b) 50 m




(c) 100 m




(d) 200 m

Fig. 5 Change of seepage flux of sandy-gravel dams with different heights

## Conclusions

Based on the unsaturated seepage theory, a numerical model of a sandy-gravel dam with geomembrane barrier was built to investigate the influence of defect on the seepage field in dam body. The following conclusions can be drawn.

(1) The geomembrane barrier with low permeability can effectively lower the phreatic line and decrease the seepage flux of the dam when the geomembrane is intact. However, due to influence of manufacturing or construction, defects are easy to occur in the geomembrane, which will significantly change the distribution of phreatic line in dam body.

(2) The change trends of the phreatic line and seepage flux due to different dam heights are basically the same, but different in numerical values. With increasing defect location, the height of phreatic line and the seepage flux decrease, but the size of the defect has little influence on the phreatic line distribution and seepage flux of the dam

(3) According to the calculation results, it is noted that the influence of the defect on seepage field in a sandy-gravel dam with geomembrane barrier cannot be underestimated, especially the location of the defect. If the numbers of defect in geomembrane can be effectively controlled in practical engineering, the severe defected-induced leakage can be avoided and the safety of a sandy-gravel dam can be ensured.

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