

# Analysis of Uplift Failure for Large Lined Canals based on Seepage-Stress Coupling Theory

Quanhong Liu<sup>1,2</sup>, Zhengzhong Wang<sup>1,2,\*</sup>, Jingsheng Zhu<sup>1,2</sup>, Kun Cai<sup>1</sup>, Zhanchao Li<sup>1,3</sup>

<sup>1</sup>Cold and Arid Regions Water Engineering Safety Research Center, Northwest A & F University, Yangling, Shaanxi 712100

<sup>2</sup>Key Laboratory of Arid Region Agricultural Water-Soil Engineering of Ministry of Education, Northwest A & F University, Yangling, Shaanxi 712100

<sup>3</sup>School of Hydraulic, Energy and Power Engineering, Yangzhou University, Yangzhou 225009, Jiangsu, China

\*Corresponding author: Zhengzhong Wang

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## Abstract

The foundation under large-scale water delivery canals is saturated because of long-term leakage. Uplift failure could be occurred by the excessively reverse seepage pressure gradient in the soil foundation and linings when an emergency water stop. To systematically explain the mechanism of this uplift failure and the process of destruction, a seepage-stress coupled was established with the assistance of COMSOL software. Moreover, the permeability resistance of the geomembrane was conduct with non-thickness interface element. Then cast in place and prefabricated lining canals with the increase of permeability of geomembrane were conduct in this paper. The result calculated based on practical engineering indicate that either intact geomembrane or intact concrete liner exhibit well impermeability so as to prevent uplift failure. The critical value of permeability for avoiding uplift failure is between  $1 \times 10^{-8}$  m/s and  $1 \times 10^{-10}$  m/s for prefabricated lining canals. The seepage deformation of foundation soil has a significant effect on the lining stress. These research results can provide reference for further research and prevention on uplift failure problems.

**Keywords:** Uplift of canal, uplift failure, seepage and stress coupling, geomembrane permeability resistance

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## I. INTRODUCTION

Xinjiang of China is an arid and semi-arid as well as typically seasonal alpine permafrost region (arid and cold region). White sandstone and mudstone with weak permeability are widely distributed, which are easy to degrade in water and sensitive to frost heaving. The annual minimum temperature is -32.9 - 42.2 °C, and the maximum depth of frozen earth is 133 - 150 cm. At the same time, Xinjiang is in shortage of water resources, with average water volume of only 53000 m<sup>3</sup> for every km<sup>2</sup>, ranking last but two throughout the country, and is the main point of water distribution in the western route

project of the South-to-North Water Diversion Project.

Open canal has many advantages, including strong water supply capacity, low frictional head loss, low cost and easy construction and maintenance, and is the major water conveyance structure for long-distance water diversion project. Most of the canals for water conveyance in Xinjiang are seasonal water supply channels, in which water flows in spring and summer, and is cut off in autumn and winter. As for newly built canals, due to their intact seepage prevention structure and the deeply buried underground water, the effect of frost heaving is not

significant. However, after many years' operation, due to the seepage of canals, the water content of foundation soil increases year by year. Especially for the canal foundation soil with low permeability, due to its weak water permeability, the water content of foundation soil fails to infiltrate downward quickly under the effect of gravity; when the water content of foundation soil reaches the water content of frost heaving, the canal foundation will produce frost heaving deformation, causing damage to the lining and anti-seepage body (such as geomembrane). Due to the vicious circle of periodic "leakage-frost heaving", the water head of foundation earth behind the anti-seepage body will increase year by year. When the water head of foundation soil behind the anti-seepage body reaches a certain limit and encounters the water inside the canal which descends quickly or emergency subsiding water, uplift pressure failure (or uplift failure) will happen to the lining structure of the canal because the water pressure of foundation soil cannot dissipate timely. It shows that, frost heaving and uplift of large canals in arid and cold regions are twinned. Once frost heaving happens, it is accompanied by uplift.

At present, many research achievements have been obtained regarding frost heaving of canal, such as mechanics models of concrete lining damage of canal [1-3], coupling model of moisture-heat-force of frozen earth canal [4-6]. However, the uplift of canal in arid regions mainly focuses on the whole leakage estimation of canal [7-9] and the whole anti-uplift checking calculation of hydrostatic pressure [10-13] etc., and no report can be found about the systematic research on its mechanism.

Uplift failure of canal (hereinafter referred to as uplift) refers to a form of failure caused by lining canal when the water conveyance of canal is cut off. The reason for uplift is mainly that when long-term leakage in water conveyance of canal happens or external water source infiltrates, which saturates the canal foundation of white sandstone with low

permeability. When water is cut off and the water level of canal descends quickly, the uplift force behind the anti-seepage body is too big, resulting in the continuous rise of a large area of canal bottom and slope toe lining. Uplift mainly happens to the bottom of excavated canal and within a certain scope from the slope toe upward along the slope surface, as shown in Fig. 1.



Uplift failure at the bottom of prefabricated lining canal



Uplift failure in cast-in-situ lining canal slope

Fig 1: Uplift failure of a diversion engineering in Xinjiang

On-site survey shows that, most of the main canals with uplift failure in Xinjiang have partly lining swelling and fracture, and no fine-grained soil can be found in the leakage water, and the canal slope has no overall slippage. Therefore, we think the root cause for uplift failure is not seepage failure such as piping in foundation soil or flowing soil, nor overall anti-uplift of lining structure or the anti-sliding stability of side slope does not meet the

design requirement, but the structure failure of lining under the effect of uplift force due to its thin structure.

As for the research progress of uplift pressure, Jin and Liang [14] have made detailed summary. At the moment, the pore theory of uplift [15] has gradually been accepted in the field, which holds the view that hydrostatic pressure is a kind of volume force applied to the permeating body. Pan [16] pointed out that uplift force consists of uplift pressure and seepage pressure. Zhang [17] conducted a large number of tunnel seepage observations and the results proved that when the external water pressure of lining is considered as surface force, the effect of water load will be overestimated, while when we consider concrete lining as permeable medium and uplift force as volume force, the real stress condition of lining can be well reflected. Hence, if we just obtain the water pressure on the boundary of anti-seepage body through seepage analysis and then conduct overall anti-uplift checking calculation or partial anti-uplift checking calculation, it cannot reflect the stress condition of lining reasonably.

Based on this, this paper uses COMSOL commercial finite element software, and considers the permeability resistance effect of geomembrane by non-thickness boundary element. Based on the premise that both lining and geomembrane are permeating body, it establishes seepage—seepage pressure coupled finite element model. By changing the permeability coefficient of anti-seepage body (lining and geomembrane), it systematically analyzes the permeation rules of white sandstone canal foundation with low permeability and replacement of coarse particles for lining canal, as well as stress distribution characteristics of lining. Besides, it further reveals the mechanism of uplift failure of lined canal of white sandstone canal foundation with low permeability and provides theoretical basis for engineering practice.

## II. METHODOLOGY

### Basic Assumption

Both concrete lining and geomembrane are permeable medium;

The seepage of concrete lining and geomembrane comply with Darcy's law;

The lining and foundation soil are isotropic and the water cannot be compressed.

### Seepage Equation

According to Darcy's law and continuity equation, the equation of water motion of two-dimensional porous medium can be described as follows:

$$C(h) \frac{\partial h}{\partial t} = \nabla \cdot (k \nabla (h + y)) \quad (1)$$

Where:  $h$  is pressure head, m;  $C(h)$  is specific water capacity,  $1/m$ ;  $k$  is the permeability coefficient of medium,  $m/s$ ;  $y$  is the space coordinate in vertical direction (take straight up as positive).

In this paper, as for the specific water capacity of concrete material and geomembrane, take 0 for each  $C(h)$ , and constant value for permeability coefficient. The specific water capacity of saturated soil –unsaturated soil of canal foundation  $C(h)$  and permeability coefficient  $k$  are related to matric potential. According to the van Genuchten model [18] commonly used in geotechnical engineering, we have

$$C = \begin{cases} \frac{\alpha m}{1-m} (\theta_s - \theta_r) S_e^{\frac{1}{m}} \left(1 - S_e^{\frac{1}{m}}\right)^m & h < 0 \\ 0 & h \geq 0 \end{cases} \quad (2)$$

$$k = k_s S_e^{0.5} \left[1 - \left(1 - S_e^{\frac{1}{m}}\right)^m\right]^2 \quad (3)$$

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \begin{cases} \left(1 + |\alpha h|^{\frac{1}{1-m}}\right)^{-m} & h < 0 \\ 1 & h \geq 0 \end{cases} \quad (4)$$

$$\mathbf{f}_g = \begin{cases} f_{gx} = 0 \\ f_{gy} = -\gamma \end{cases} \quad (8)$$

where:  $S_e$  is equivalent degree of saturation;  $k_s$  is saturated permeability coefficient of soil, m/s;  $\theta$ ,  $\theta_s$  and  $\theta_r$  are volume water content, saturated volume water content and residual volume water content, respectively;  $\alpha$  and  $m$  are the fitting parameters of soil-water characteristic curve, respectively.

### Constitutive Equation

Assume that lining and foundation soil are ideal elastomer, and according to Hooke's law, the relation between stress and elastic strain can be described as

$$\boldsymbol{\sigma} = \mathbf{C} : \boldsymbol{\varepsilon} \quad (5)$$

The relation between strain and displacement is

$$\boldsymbol{\varepsilon} = \frac{1}{2} [\nabla \mathbf{u} + (\nabla \mathbf{u})^T] \quad (6)$$

From the balance condition of static force we can get

$$\nabla \cdot \boldsymbol{\sigma} + \mathbf{F} = 0 \quad (7)$$

where:  $\boldsymbol{\sigma}$  is Gaussian stress tensor, Pa;  $\boldsymbol{\varepsilon}$  is finite strain tensor;  $\mathbf{u}$  is displacement vector, m;  $\mathbf{C}$  is four-order rigidity tensor, Pa;  $\mathbf{F}$  is the force per unit volume, N/m<sup>3</sup>.

From the view of microcosmic seepage, soil mass, rock mass and concrete can be regarded as porous medium, and a large number of pores can be found between particles or frameworks of these materials. Under the effect of hydraulic gradient, water flows between pores. At this moment, the seepage pressure is not a boundary force but a field force [17]. Therefore, the volume force in the model consists of two parts: one is the volume force  $\mathbf{f}_g$  that is produced by buoyancy:

Another is the seepage volume force  $\mathbf{f}_s$  that is applied to the space under the underground water level in the form of seepage field force:

$$\mathbf{f}_s = \begin{cases} f_{sx} = -\gamma_w \frac{\partial h}{\partial x} \\ f_{sy} = -\gamma_w \frac{\partial h}{\partial y} + \gamma_w \end{cases} \quad (9)$$

where:  $\gamma$  is the volume weight of material, N/m<sup>3</sup>;  $\gamma_w$  is water volume weight, N/m<sup>3</sup>; the direction of gravitational acceleration is the negative direction of y-axis.

So far, we can solve the problem through simultaneous equations (1) - (9) if boundary condition and initial condition are determined.

### Geomembrane Seepage Resistance Model

The anti-seepage geomembrane is a kind of flexible thin-film material. The thickness of geomembrane used in engineering is usually 0.5 - 3 mm, which is far less than the thickness of lining board that is 6 - 15 cm, and can be ignored in the model of numerical analysis. But the permeability coefficient of geomembrane is usually 3 or above orders of magnitude lower than that of intact concrete. If we take the permeability coefficient of concrete as reference, the equivalent thickness of concrete obtained according to the principle of equivalence of anti-seepage effect of geomembrane is appropriately 50-300cm. At this moment, if we adopt equivalent thickness to establish the model of numerical analysis, the previous cross-section dimension of canal will change, which cannot reflect the real stress rule of lining.

For this reason, this paper adopts the non-thickness resistive seepage model for geomembrane, and the schematic diagram of calculation is shown in Figure 2.

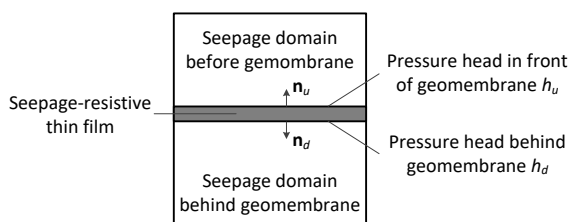


Fig 2: Schematic diagram of resistive seepage model for geomembrane

In the finite element model, we attach a layer of non-thickness interface element to the boundary of geomembrane, and establish the boundary in front of and behind geomembrane in the same spatial position. Through equality constraint equation, the boundaries in front of geomembrane and behind geomembrane are respectively equal to the corresponding pressure heads of seepage area in front of and behind geomembrane. Meanwhile, assume that seepage inside the geomembrane complies with Darcy's law, and we can establish mass conservation equation of pressure head in front of and behind geomembrane:

$$-\mathbf{n}_u \cdot (-k_u \nabla h_u) = -\frac{h_d - h_u}{R_s} \quad (10)$$

$$-\mathbf{n}_d \cdot (-k_d \nabla h_d) = -\frac{h_u - h_d}{R_s}$$

$$R_m = \frac{d_m}{k_m} \quad (11)$$

where  $R_s$  is seepage resistance,  $s$ ;  $k_m$ ,  $k_u$  and  $k_d$  are permeability coefficients of seepage area in the geomembrane, in front of it and behind it respectively,  $m/s$ ;  $h_u$  and  $h_d$  are pressure heads in front of and behind the geomembrane respectively,  $m$ ;  $\mathbf{n}_u$  and  $\mathbf{n}_d$  are outward normal vectors in front of and behind the geomembrane respectively;  $\nabla h_u$  and  $\nabla h_d$  are pressure gradients of seepage area on the boundary in front of and behind the geomembrane respectively;  $d_m$  is the thickness of geomembrane,  $m$ .

### III. MODELING AND SIMULATION

#### Project Overview

In a large water diversion project in north Xinjiang, the canal section of 19+550-52+53 is trapezoidal cross section, the bottom width is 4m and side slope is 1:2 and height of canal is 7.5 m. The lining structures of side slope are respectively: base level, 30 mm M10 mortar for leveling, 0.6mm polyethylene plastic film, 30 mm M10 mortar for protection, 60 mm concrete lining board. The canal foundation soil consists of sandstone and mudstone of Tertiary System and the permeability is  $10^{-6}$ - $10^{-7}$  m/s, belonging to weakly permeable stratum, and the canal is mainly excavation.

The normal operating water level of canal is 5.6 m; the starting time of water flow is May 1 every year, the cutting-off time of water flow is October 1 every year, and there are 5 months for water flow every year.

#### Finite Element Model and Parameter Selection

##### Establishment of finite element model

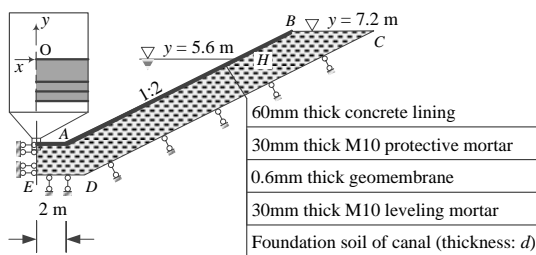
Canal project is a kind of linear project, the calculation of which can be simplified as plane strain. Considering the symmetry of real canal, take 1/2 of the canal cross section and use the cross-section dimension of canal prototype to establish finite element model, as shown in Figure 3.

Set the origin of coordinates of finite element model on the surface of lining in the middle of canal, the maximum size of unit partition along the direction of thickness of foundation soil is 5 cm.  $\Gamma_{OA}$  is the boundary of pressure head,  $\Gamma_{EDC}$  is the boundary of flux, take the product of the

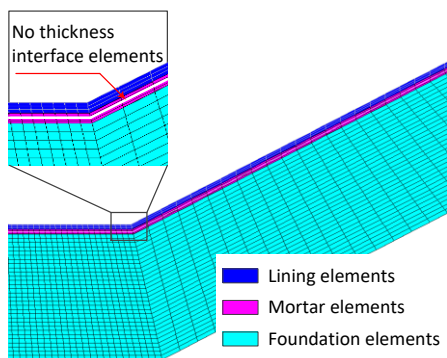
permeability coefficient of previous foundation soil and unit gradient, and the residual is impermeable boundary;  $\Gamma_{OE}$  is symmetry constraint and  $\Gamma_{EDC}$  is normal constraint. Considering the fixtures at the slope toe of canal, fixed constraint was set for the boundary between base slab and the slope slab in this model.

The model calculation does not take into account settlement and deformation caused by dead weight, namely water outside the canal has consolidated before infiltrating into the canal. The initial ground stress of canal is calculated by dead weight balance.

The calculation of canal seepage—stress analysis consists of two parts: a) the water level outside the canal is constantly 5.6 m, and the initial water content is the transient seepage analysis of canal foundation soil of natural water content lasting for 5 months (150 days); b) take the result of the last moment for calculating transient seepage as the initial seepage field, and analyze seepage-stress analysis when the water level of canal suddenly changes to 0.



(a) Schematic diagram of geometric dimensioning and boundary condition of canal cross-section



(b) Grid chart of local finite element

Fig 3: Numerical calculation of cross-section diagram

### Value of material parameter

In the model calculation, ignore the dead weight of geomembrane, and take  $1.0 \times 10^{-11}$  m/s for the permeability coefficient of intact geomembrane. Fit the constants of soil-water characteristic curve of previous foundation soil by referring to literature [5]; take the values of the constants of soil-water characteristic curve of coarse-grained soil (Aeolian sand) by referring to the value of medium-fine sand in literature [19]; initial water content refers to the natural water content in the project in north Xinjiang; as for other parameters, take approximate value according to statistical data of project observation. As for the parameters of mechanics of materials of different parts of canal, see Table 2 and Table 3.

## IV. RESULTS AND DISCUSSION

The model first analyzes the basic seepage characteristic and distribution characteristic of normal stress on the surface of lining under different conditions of film damages for existing canal project. Then, it analyzes the change rule of water level behind the geomembrane and distribution characteristic of normal stress on the surface of lining for cast-in-situ canal and prefabricated plate canal respectively after replacement and transformation by Aeolian sand, and with the change of permeability coefficient of geomembrane and thickness of replacement.

Table 1. Constants of soil-water characteristic curve of different foundation soils

Characteristic of soil	$\alpha$			$m$
	$\theta_s$	$\theta_r$	$\theta_0$	
White sandstone	0.25	0.068	0.203	0.8
Coarse-grained soil	0.35	0	0.145	3.875

Table 2. Value of physical and mechanical parameters

Medium	$\rho_d$ (kg/m <sup>3</sup> )	$E$ (MPa)	$\nu$ (m <sup>3</sup> /m <sup>3</sup> )	$k_s$ (m/s)
Concrete	2300	$2 \times 10^4$	0.167	$1.2 \times 10^{-9}$
Cement mortar	2000	$0.5 \times 10^4$	0.167	$1.0 \times 10^{-5}$
Previous foundation soil	1900	14	0.2	$5.6 \times 10^{-7}$
Coarse-grained soil	1600	20	0.4	$0.9 \times 10^{-5}$

To take into reasonable consideration the effect of seepage in the joint of prefabricated plate, this paper conducts equivalence of permeability coefficient of prefabricated plate to the percentage of length (approximately 10% in actual project) of mortar along the perimeter, and takes  $10^{-6}$  m/s.

### Characteristic of Uplift Failure of Uniform White Sandstone Canal

(1) Characteristic of normal stress distribution on lining surface

Take the normal stress distribution on lining surface when the permeability coefficient of geomembrane is respectively  $10^{-8}$  m/s and  $10^{-6}$  m/s, as shown in Fig. 4. From the level of pulling stress on lining surface we can see, uplift failure of sandstone canal with low permeability first occurs in the middle of canal, and next in the lower part which is 12% of the slope board. Besides, the bigger the permeability coefficient of geomembrane is, the bigger pulling stress on lining surface will be.

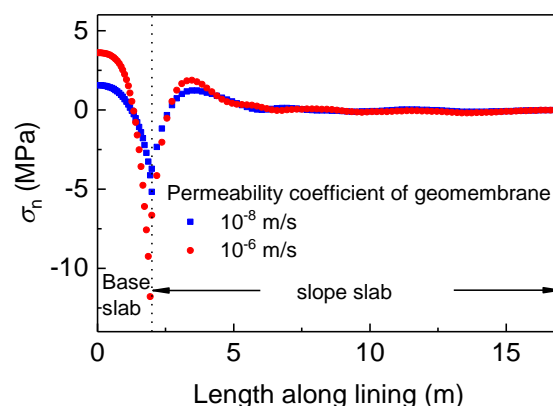


Fig 4: Normal stress distributions on lining surface in typical uplift failure conditions for white sandstone canal

(2) Relation between permeability coefficient of geomembrane, lining stress and depth of infiltration

The seepage of white sandstone mainly includes vertical infiltration and infiltration of foundation soil. As for certain permeability coefficient of geomembrane, the depth of infiltration of foundation soil is basically in direct proportion to the water head behind the geomembrane, and the depth of infiltration in the foundation soul under the canal is the biggest. With the change of different permeability coefficient of geomembrane, the change rule of maximum depth of infiltration at the canal bottom and the change rule of the maximum normal stress on lining surface are shown in Fig. 5.

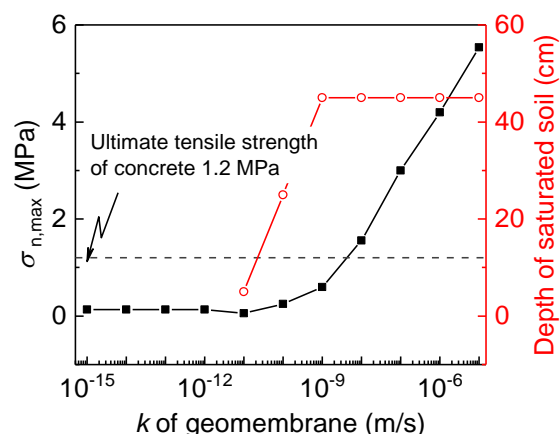


Fig 5: The maximum normal stress on lining surfaces and the seepage depths at the bottom of canal for white sandstone canal foundation

The results of calculating indicate that, when the permeability coefficient of geomembrane is smaller than  $10^{-11}$  m/s, the water content of anti-seepage body protection of foundation soil behind the geomembrane is not saturated and the seepage stress produced is limited, and further reducing the permeability coefficient of geomembrane will not have a significant effect on the prevention of uplift failure. When the permeability coefficient of geomembrane increases to  $10^{-9}$  m/s, the seepage depth of foundation soil shows a linear increase with the increase of permeability coefficient of geomembrane, and finally becomes stable at about 45cm. The overall result shows a laddering change rule.

When the seepage depth of foundation soil increases gradually, the normal stress on lining surface also increases, and exceeds the ultimate tensile strength of concrete when the permeability coefficient of geomembrane is  $10^{-8}$  m/s (the seepage depth of foundation soil reaches 12cm), and uplift failure occurs.

### (3) Influence of seepage deformation of foundation soil on lining stress

The source of lining stress includes deformation due to dead weight, seepage deformation jacking of foundation soil and stress deformation under the effect of volume force of seepage water pressure gradient. In order to further analyze the influence of seepage deformation of canal foundation of white sandstone on the stress deformation of canal lining, this paper analyzes the specific value of stress of seepage deformation of foundation soil and that of overall canal seepage deformation, as shown in Fig. 6.

The results of calculating in Fig. 5 show that the influence of seepage deformation of foundation soil on the stress of lining surface is related to the degree of saturation and seepage depth of foundation soil. When the foundation soil gradually

changes from unsaturated state to saturated state, its seepage deformation increases quickly; when the seepage depth becomes stable, it still increases, but can be ignored compared with the lining deformation caused by water pressure behind the geomembrane. If the geomembrane is intact (permeability coefficient is  $<10^{-12}$  m/s), there is no saturated area of stagnant water in the foundation soil, thus the contribution of seepage deformation of foundation soil is 0. When the permeability coefficient of geomembrane is  $10^{-12}$  m/s -  $10^{-8}$  m/s, the foundation soil starts to become saturated, and with the increase of saturated depth of foundation soil, the effect of seepage deformation becomes bigger, which has a supporting effect on the lining. But when the degree of geomembrane damage continues to increase, the saturated depth of foundation soil remains stable seepage deformation, and the resulting lining stress also tends to be stable (0.29 MPa), occupying only 10% of the whole seepage deformation of canal.

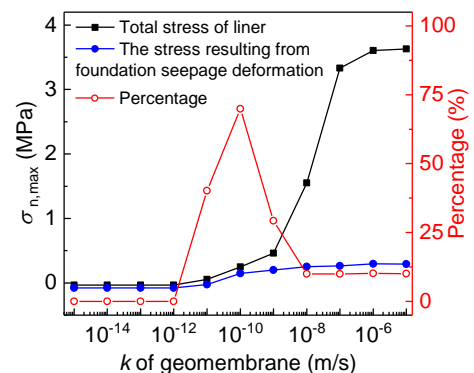


Fig 6: Influence of seepage deformation of white-sandstone foundation on the maximum normal stress on lining surfaces

### Characteristic of Uplift Failure of Replacement of Coarse-Grained Soil for Canal

From above result of calculating we can judge that the amount of water infiltrating into the foundation soil is small, and the effect of seepage deformation on the stress of lining board is small. Therefore, the replacement and filling only considers the result of seepage stress of anti-seepage body and replaced

layer, excluding the effect of seepage deformation of white sandstone laid under the replaced layer.

(1) Relation between normal stress on lining surface and the change of permeability coefficient of geomembrane and thickness of replacement

Whether it is cast-in-situ lining canal or prefabricated board lining canal, when uplift failure occurs, the distribution rule of normal stress on lining surface accords with the result in Fig. 4, and we will not give more details here.

Variation of the maximum value of normal stress on concrete lining surface of cast-in-situ lining canal with the change of permeability coefficient of geomembrane and replacement thickness is shown in Fig. 7 (a). The result of calculating shows that when the lining body (including geomembrane) is intact, the anti-seepage effect of concrete itself can meet the requirement of prevention of uplift failure. Specifically, as for the listed calculation condition, the normal stress on lining surface is between 0.2 - 0.75 MPa, which is lower than the ultimate tensile strength of concrete that is 1.2 MPa. In addition, the smaller the replacement thickness is, the more significant the effect of change of permeability coefficient of geomembrane on the normal stress on lining surface. Namely, when the permeability coefficient of geomembrane is smaller than 10-11 m/s, the less the replacement thickness is, the smaller the normal stress on lining surface will be; while when the permeability coefficient of geomembrane is more than 10-10 m/s, the effect of permeability coefficient of geomembrane on the normal stress on lining surface is not significant.

Variation of the maximum value of normal stress on concrete lining surface of prefabricated board lining canal with the change of permeability coefficient of geomembrane and replacement thickness is shown in Fig. 7 (b). The result of calculating shows that the effect of permeability coefficient of geomembrane on the prefabricated

board lining canal is especially significant. When the permeability coefficient of geomembrane is smaller than 10-12 m/s, the replacement thickness has little influence on the normal stress on lining surface. When the permeability coefficient of geomembrane is bigger than 10-12 m/s, the maximum normal stress on lining surface increases quickly, and when the permeability coefficient of geomembrane is 10-9 m/s, only the thickness of replacement that is below 75cm can meet the requirement that the normal stress on lining surface is smaller than the ultimate tensile strength.

(2) Variation of water level behind the geomembrane of lining canal with the change of permeability coefficient of geomembrane and the replacement thickness

The result of calculating is shown in Fig. 8. From the figure we can find that, when the permeability coefficient of geomembrane is small, the replacement thickness is small and the water level behind the geomembrane is low, the overall distribution rule accords with the statistical law in Fig. 7 (b). Besides, we can find that the smaller the replacement thickness is, the lower the water head behind the geomembrane is. It shows that when the replacement thickness is 50 cm and 75 cm, the maximum water level behind the geomembrane it can sustain is 5.595 m, slightly lower than the water level outside the canal, which is 5.6 m. When permeability coefficient of geomembrane is bigger than 10-10 m/s, the effect of replacement thickness on the water level behind the geomembrane can be ignored.

The water level behind the geomembrane is a comprehensive index that reflects the anti-seepage ability of lining body and geomembrane. From the present result analysis, when the canal in cold regions adopts big replacement thickness to prevent uplift failure, suitable drainage facility should be laid in the canal, and make sure the water level

behind the geomembrane is below 4m when water flow is cut off in the canal.

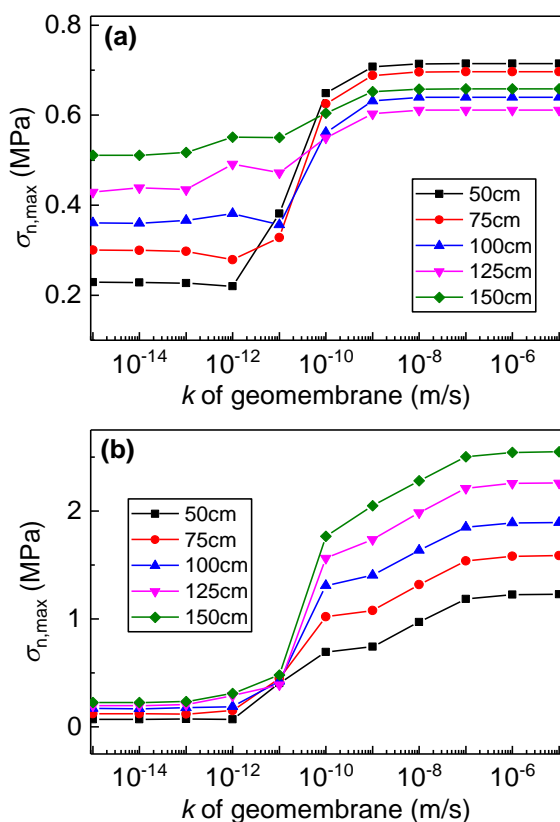


Fig 7: Variation of the maximum normal stress along the lining surface with the change of geomembrane permeability coefficient and replacement thickness.

(a) Cast-in-situ lining canal

(b) Prefabricated lining canal.

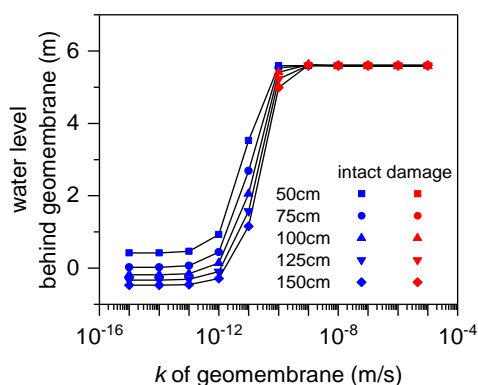


Fig 8: Variation of the water table under the geomembrane with the change of geomembrane permeability coefficient and replacement thickness

## V. CONCLUSION

This paper uses COMSOL multi-physical coupling software to develop a non-thickness interface unit for the geomembrane seepage, and establishes lining-geomembrane-foundation soil integrated trapezoidal canal seepage—stress coupling model. Besides, it carries out systematic analysis of uplift failure and transformation scheme of a water diversion project in Xinjiang. The following conclusions have been drawn:

(1) Intact concrete lining and geomembrane have independent anti-seepage ability. Cast-in-situ lining canal does not have a significant effect on geomembrane damage. When the permeability coefficient of geomembrane is lower than  $10^{-11}$  m/s for prefabricated board lining canals, uplift failure will not occur.

(2) Without drainage condition, foundation soil of uniform white sandstone with low permeability can easily produce uplift failure, and the outward seepage pressure is in direct proportion to the vertical infiltration depth.

(3) When the canal foundation soil with low permeability is replaced and filled with coarse-grained soil, the position of uplift failure is the same as that without replacement, namely in the middle of the canal bottom and the lower part of 12% of the canal slope.

(4) Setting a layer of replacement with a certain thickness and good permeability behind the geomembrane can relieve uplift failure, but too thick replacement is not beneficial for preventing uplift failure. When there is no effect drainage, the maximum replacement thickness should be smaller than 75 cm.

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