A preliminary study on the effects of geotexture upon seepage flow

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ABSTRACT
Based on the theory of geological control and rock hydromechanics, this paper asserts that the geotexture controls seepage flow in rock mass most directly. The geotexture is graded properly with consideration on the characteristics of seepage flow in rocks. Four important effects of geotexture upon seepage flow are proposed: the graded preference effect, the channelling intersection effect, the unsaturation effect and the coupling effect. The basic meaning, interrelationship and engineering significance of these four effects are discussed.

RÉSUMÉ
Basé sur la théorie du contrôle géologique et du rocher hydromécanique, ce texte affirme que la géotexture gouverne le plus directement l'écoulement de la fluide dans le rocher. Tenant compte des caractéristiques de l'écoulement de la fluide dans le rocher, on a échelonné correctement la géotexture. Quatre effets importants de la géotexture sur l'écoulement de la fluide sont proposés: l 'effet de la préférence échelonnée, l'effet d'insersection canale, l'effet de non-saturation et l'effet couplé. Le contenu essentiel, le rapport et l'importance de ces quatre effets sont préliminairement étudiés.

1 INTRODUCTION

The theory of geological control is one of the basic theories for geological engineering. It contains three aspects: control theory of geological (or rock) structure, control theory of engineering geological bodies and control theory of engineering geological processes. Based on a large number of recently published articles in relevant fields, as well as in-depth observation on natural seepage flow in rock mass, I developed a new theory, which can be summarized as "geotexture controls seepage flow", and I believe further study is necessary.

The similar standpoints to the above opinion are typically listed as follows. Firstly, Xiao Nansen proposed as early as in 1956 the point of view "neotectonics controls groundwater activities". Secondly, Zhou Chuangbing and Xiong Wenlin (1996) put forward directly the control effect of rock mass structure upon seepage flow, and held that different rock mass structures were generally corresponding to different flow media types.

This paper proposes the effects of geotexture upon seepage flow, putting more emphasis on the mechanism of seepage flow in rock mass, in other words, trying to clarify how geotexture controls groundwater seepage.

2 THE GRADED PREFERENCE EFFECT

Geotexture, in short, is the structure of geological body which refers broadly to natural rock of any formation type in any geological age. Gu Dezhen and Wang Sijing (1979) divided geological body into such five grades as crustal block, mountain mass, rock mass, block and rock block. Li Zhonglin et al. (1987) divided geotexture into the following five grades: regional crustal structure, regional geotexture, mountain geotexture, rock mass structure and block structure. Huang Dingcheng (1987) divided geotexture even more specifically into regional crustal structure, regional (or areal) geotexture, geotexture of sectional mountain or valley slope, rock mass structure and block structure. In this paper, geotexture is graded with consideration on both advantages of the above grading programmes and characteristics of seepage flow in rock mass (seen in table 1).

The main roles of regional crustal structure in seepage flow include: (1) controlling the invasive modes and sites of mantle fluid upward; (2) controlling the flow characteristics and aggregation state of lithospheric hyperthermal fluid; (3) forming deep hydrogeological structure and controlling deep fluid dynamic characteristics.

The principal effects of regional (or areal) geotexture upon seepage flow are as follows: (1) controlling the distribution of underground oil and gas reservoir; (2) controlling the formation of geothermal, mineral fluid and hot springs; (3) forming regional hydrogeological structure and controlling regional (or areal) hydrodynamic characteristics.

The major structural effects of sectional mountain or valley slope upon seepage flow are: (1) forming different types of hydrogeological structure of mountain or valley slope and controlling the corresponding hydrodynamic characteristics; (2) combined with such factors as terrain, geomorphology and so on, controlling the characteristics of spatial distribution of shallow groundwater recharge, runoff and discharge; (3) through regional (or areal) geological discontinuities, getting certain hydraulic connections with deep groundwater.

The effects of rock mass structure upon seepage flow are mainly as follows: (1) forming different media types of seepage flow and reflecting different permeability of rock mass; (2) combined with such factors as groundwater level, boundary conditions and heavy rain, controlling the flow status and seepage force characteristics in certain engineering zone.

Block structure upon seepage flow shows the following characteristics. (1) Due to a large number of dead-end cracks and gaps exist in blocks, the control effects are weak. (2) Because of the impacts of various external factors, the control effects generally change with time.

From the above analysis, we can see that the basic viewpoints of the graded preference effect of geotexture upon seepage flow can be summarized as follows. (1) Geotexture of higher grade generally possesses more powerful control effect upon seepage flow and greater impact upon the stability of geological bodies. (2) The priority sequence of geotexture controlling seepage flow is the one-by-one sequence from geotexture of senior grade to geotexture of junior grade with the priority of structural planes.

Table 1. Different grades of geotexture and the corresponding engineering significance

Grade	Geotexture	Structural body	Structural plane and its grade		Engineering significance
I	Regional crustal structure	Crustal block (lithospheric fault-block, crustal fault-block)	Regional huge fault (deep fault system)	Regional grade (I)	Regional crustal stability, deep geological stability, regional surficial stability
II	Regional (or areal) geotexture	Stratigraphic block (basement fault-block, caprock fault-block)	Large to medium fault, other structural planes of similar scale	Areal grade (II)-(I)	Deep geological stability, regional surficial stability, reservoir induced seismicity
III	Geotexture of sectional mountain or valley slope	Rock formation block, other geological bodies of similar scale	Medium to small fault, other weak structural planes of similar scale	Sectional grade (III)-(II)	Mountain or valley slope stability, ground stability, leakage stability, mine water gushing and inrush
IV	Rock mass structure	Block, rock block	Small fault, through joint, other structural planes of similar scale	Site grade (IV)-(III)	Rock mass stability, engineering structure stability, seepage stability, in-situ hydrogeological test
V	Block structure	Rock block, rock debris, mud	Part-through or non-through hard surface, micro-cracks, porosity	Block inner grade (V)-(IV)	Block stability, physical & mechanical properties of rock block, suffosion stability, indoor hydraulic test

3 THE CHANNELLING INTERSECTION EFFECT

The channelling effect of geotexture upon seepage flow means the uneven seepage distribution and dominant channelling flow within or between the same or different grade of structural planes. This effect contains the following three levels. (1) Discontinuity network channelling effect, that is, the seepage flow in rock mass selects predominant discontinuity networks for large-scale gathered seepage flow. (2) Surficial channelling effect, that is, the seepage flow on a structural plane continues to choose irregular channels for random preferable seepage flow. (3) Variable active channelling effect, that is, the seepage flow along the irregular channels chooses furtherly different channels for active seepage flow paths when channel connectivity or hydraulic condition changes.

The channelling flow is controlled by aperture, spacing, roughness and filling of discontinuities. The channelling effect is more notable for discontinuities with larger aperture, spacing, JRC, or more uneven filling distribution. In the author's point of view, the channelling effect is determined by such inherent characteristics of seepage flow in fractured media as the tendency of uniform level, selective flow and confluence (Luo Shaohe et al. 1993).

The cross-flow effects of geotexture upon seepage flow include the effects of flow deflection, bias current, local head loss and varying flow resistance in different directions at the crossing of discontinuities, among which the effect of bias current is most important. The cross-flow can be divided into such two types as continuous and discontinuous cross-flow (Hull and Koslow, 1986). Tian Kaiming et al. (1989) and Su Baoyu et al (1997) studied the continuous cross-flow effect deeply, and represented two different academic points of view respectively. Both Hull & Koslow (1986) and Philip (1988) studied the discontinuous cross-flow effect, and also represented two different academic points of view. This paper holds that Tian Kaiming's theory of bias current on the continuous cross-flow effect and Philip's streamline view on the discontinuous cross-flow effect are correct. Su Baoyu's research results are useful in understanding the continuous cross-flow effect, while Hull's method of streamline routing through discontinuous junctions is incorrect.

The cross-flow effect is mainly controlled by the scale, aperture, crossing sub-fractures and filling characteristics of discontinuities. The cross-flow effect is notable for structural planes of senior grade or wide apertures. The crossing sub-fractures are mainly caused by fissures interaction, weathering or other factors, as make cross-flow effect more complicated. As for the influence of filling characteristics, it should contribute to weaken the cross-flow effect to a certain extent. This paper asserts that the cross-flow effect is mainly caused by the interference effect of non-intersectional flow streamlines upon each other.

In fact, the channelling effect and the cross-flow effect are inextricably linked, i.e., they are dependent and restraint on each other, and both are controlled by geotexture, so they can be called together as the channelling intersection effect of geotexture upon seepage flow. Consideration on the priority sequence of geotexture grade should be given to study this effect. In general, if other factors are not considered, the channelling intersection effect of the higher-level geotexture is greater than that of the lower-level geotexture; the channelling intersection effect of the different-grade geotexture is more notable than that of the same-grade geotexture. Studying the channelling intersection effect of geotexture upon seepage flow is of great engineering significance, such as mountain groundwater resource evaluation, karst formation, development and karst collapse forecast, the safe storage of nuclear waste, groundwater pollution control, as well as buried garbage disposal.

4 THE UNSATURATION EFFECT

Generally, any underground multiphase flow with a saturation degree of about 15% ~ 85% for each fluid phase should be regarded as unsaturated seepage flow. The fluid can be divided into such two major categories as the earth's interior fluid and surface fluid, including gas, liquid and melt. This paper simply discusses the water - gas two-phase unsaturated flow in geological bodies.

According to the spatial location the unsaturated flow can be divided into the following three types: (1) unsaturated flow in suspended zone (including capillary zone); (2) unsaturated flow in vadose zone; (3) unsaturated flow in deep geological bodies.

Based on groundwater existence characteristics and seepage flow features, the unsaturated flow can be divided into: (1) unsaturated implicit infiltration of bound water; (2) unsaturated slow percolation of capillary water; (3) unsaturated temporary dynamic flow of gravity water.

Unsaturated seepage is controlled by geotexture, and influenced by lithologic, topographic and morphological characteristics, as well as climate and other factors. It may be a stable or slow-changing unsaturated flow or an unstable transient unsaturated flow. The latter includes the following three types: (1) unsaturated flow when seepage boundary condition changes; (2) unsaturated flow when seepage medium structure varies; (3) unsaturated flow during rainfall infiltration.

The unsaturated flow when seepage boundary condition changes, mainly refers to transient unsaturated seepage when groundwater level changes dramatically, such as the unsaturated flow in reservoir area while water level is rising or falling rapidly. This saturated - unsaturated flow boundary changes transiently, the hydraulic gradient changes transiently in spatial and time distribution as well. It is of great significance studying this transient unsaturated flow in the risk analysis of seepage-induced landslides in reservoir area.

As for the unsaturated flow when seepage medium structure varies, two simple examples are cited as follows. (1) The local transient unsaturated flow in vadose zone through newly connective fissures caused by variation of stress which leads to crack propagation and connection to effective fracture network. This type of unsaturated flow could bring negative impact to certain projects. (2) The severe dynamic circular unsaturated flow caused by expansion of deep underground geological bodies due to variation of surrounding geostress. This type of unsaturated flow may be an explanation about the mechanism of middle to deep-focus earthquakes.

The unsaturated flow during rainfall infiltration is related closely with intensity of rainfall, topographic and morphologic characteristics, as well as seepage media characteristics. Liu Yaping and Chen Chuan (1996) proposed that, in porous media, under certain conditions, the seepage in unsaturated zone is not a simple one-dimensional downward infiltration, but flow along preferential paths across most of the soil space. The preferential flow behaves as the following three forms: large pore flow, funnel flow and finger flow. This paper posits that the first two forms of preferential flow are just the reflection of differences in local structure of porous media. In fractured media, as a result of the characteristics of multiple fracture network systems and their non-uniform connectivity, rainfall infiltration usually forms some transient saturated areas within certain zones above groundwater level, and often converts into surface runoff through penetrating fissures, so that the uniform groundwater level rises very slowly (Zhang Youtian, Liu Zhong. 1997). This is undoubtedly controlled by rock mass structure too.

It is not difficult to understand that the graded preference effect and the channelling intersection effect make the unsaturation effect more notable. Firstly, the graded preference effect may lead to various forms of preferential flow and cause unsaturated seepage more frequent. Secondly, the channelling intersection effect can strengthen the non-connectivity of seepage flow in rock mass and make the unsaturation effect more obvious.

5 THE COUPLING EFFECT

The coupling effect means the effect of geotexture coupled with geo-environment upon seepage flow. This effect combines geotexture with geo-environment as a complex system, and is closely connected with the above mentioned three effects.

Geo-environment is generally composed of geostress, groundwater and geotemperature, that is, stress field, seepage field and temperature field. In the author’s opinion, in geo-environmental three components, stress field and temperature field are pure ubiquitous fields; while seepage field possesses its own unique characteristics. For example, seepage field is not an authentic unified continuous field, so it is contradict with the conception of “field”.

In view of this, the geo-environment discussed here is only limited to geostress field and geothermal field, therefore the coupling effect of geotexture and geo-environment upon seepage flow is the complex physical, chemical, mainly mechanical coupling interactions between geotexture and geo-environment, as well as their common coupling control effects upon seepage flow.

Simply, the coupling effect can be divided into two sub-themes: (1) the control effect of geotexture coupled with geostress upon seepage flow; (2) the control effect of geotexture coupled with geothermal field upon seepage flow.

The control effect of geotexture coupled with geostress upon seepage flow is simply analysed as follows. On one hand, it behaves as stress concentration near geological discontinuities which makes geotexture prone to damage, as a result enhances the local permeability of rock mass. On the other, it behaves as meso-damage and micro-damage caused by geostress variation, which in turn alleviates stress concentration near discontinuities and enhances the local permeability of rock mass.

The control effect of geotexture coupled with geostress upon seepage flow includes two aspects: the coupling interactions between geotexture and geostress; and their common control effects upon seepage flow.

The coupling interactions between geotexture and geostress can be analysed in two ways: (1) the coupling interactions between structural planes and geostress, on which fracture mechanics knowledge can be applied in the research; (2) the coupling interactions between structural bodies and geostress, on which damage mechanics knowledge can be applied in the research.

The common control effects of geotexture coupled with geostress upon seepage flow can also be analysed in the following two ways.

(1) The common control effect of structural planes coupled with geostress upon seepage flow. This effect behaves that the expansion of meso-cracks under variable geostress enhances the connectivity of macro structural planes, which directly improves the overall shape of connective fracture network for seepage flow. This effect can be treated simply by amending the spatial connectivity rate for discontinuities (Yang Yanyi, Zhou Weiyuan. 1991).

(2) The common control effect of structural bodies coupled with geostress upon seepage flow. This effect mainly behaves as the variation of infiltration properties of rock blocks because of the damage of microscopic rocks caused by expansion of meso-cracks. This effect might be researched by introducing a new concept - damage percolation tensor (Zhang Hui et al. 2000).

The control effects of geotexture coupled with geothermal field upon seepage flow are analysed simply as follows.

Different characteristics of heat transfer in geological bodies with dissimilar origins and components may contribute to uneven distribution of thermal stress. Well, heat conduction can arouse the growth and evolution of geological discontinuities. Thus geotexture and geothermal field control seepage flow commonly.

The coupling effect of geotexture and geothermal field upon seepage flow behaves as defining the fluid phase, causing local convection and so on. Whether the hot water in geothermal reservoir is vapour or liquid depends on whether water temperature is higher than local boiling temperature, while boiling temperature depends on local pressure, and local pressure is influenced by local geotexture.

Studying the control effect of geotexture coupled with geothermal field upon seepage flow is of great significance in geothermal reservoir forecast, exploitation and control.

6 DISCUSSION

The graded preference effect of geotexture upon seepage flow emphasizes the heterogeneity and anisotropy of seepage flow. Without consideration on this effect, the seepage control measures will be prone to dangerous conditions.

The channelling intersection effect of geotexture upon seepage flow emphasizes the discontinuity and system complexity of seepage flow. The continuum method is not always appropriate in dealing with some certain discontinuous seepage issues. Of course this effect can be simplified according to the demand of precision, but with no consideration on this effect may also lead the seepage control measures to unsafe conditions.

The unsaturation effect of geotexture upon seepage flow, connected with the suction, may provide a new way for the study on abnormal seepage pressure. This is of certain significance for stability analysis of geological bodies. With no consideration on this effect may bring the seepage control measures into safe or unsafe conditions, depending on specific unsaturated seepage cases.

The effect of geotexture coupled with geo-environment upon seepage flow involves the interaction between geo-environment and geotexture. Its impact on seepage flow is subtle and complex, yet some of the engineering issues should also give proper consideration on it. Otherwise, the invariable understanding of geotexture will possibly make the seepage control measures be one-sided in some extent, and the safety of measures depends on specific engineering problems.

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