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## ON THE VELOCITY OF WATER MOVEMENT IN A POROUS FIELD

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*Research area:* hydraulics, irrigation and drainage engineering

### ABSTRACT

In the scientific literature and practice, the geometrical distance and the mean velocity relative to it is assumed as movement of water particles in a porous field (environment, surroundings) between two cross sections of filtration flow. In fact, in a porous field (soil) the water particles move along porous grooves (channels) of curved trajectories circumambulating the particles of the field. Each of these trajectories has a different length and upon given specific conditions – type and condition of the porous field - have certain repetitiveness.

This treatise considers the real velocity of filtration flow in a porous field (soil), i.e. the velocity of the water movement along porous grooves, where the process of interaction between the filtration flow and the field takes place, which predetermines its condition of rest or erosion. This process cannot be observed, predicted and controlled through the mean velocities of filtration flow only.

For the adopted initial conditions in the treatise, an analytical dimensioning relationship has been established to determine the real velocity of filtration flow in porous grooves.

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## 1. Introduction

In the literature [1,2,8], the velocity of water movement in a porous field (environment, ground) or soil is determined by the formula:

$$V = Q/F, \quad (1)$$

where  $Q$  is the water quantity of the filtration flow under consideration;  
 $F$  – initial cross area of the porous medium (Fig. 1).

The velocity can also be determined by the basic law of filtration:

$$V = KJ, \quad (2)$$

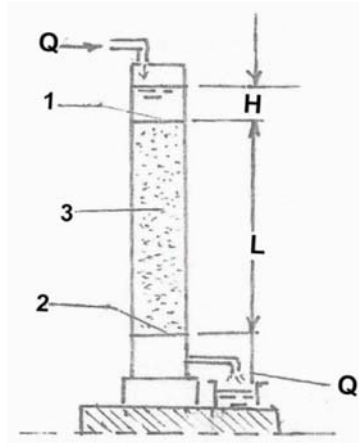
where  $J$  is the pressure gradient;  $J = H/L$ ;

$H$  – water pressure;

$L$  – geometric distance between the inlet and the outlet cross section of the field under consideration, Fig. 1;

$K$  – coefficient named “coefficient of filtration”.

Fig. 1 presents the classic experimental formulation model given in the literature mentioned, for determination of the  $Q$ ,  $V$ ,  $J$  parameters of filtration flow for any porous field.



**Fig. 1. Experimental formulation model for filtration flow**

**1 – inlet cross section plane; 2 – outlet cross section plane; 3 – porous area of the field**

The filtration flow passes through the porous area of the field's cross section –  $F_{por}$ . It is well known that  $F > F_{por}$ , in size reaching up to 30% for a sandy (highly permeable) field. Consequently,  $V$  is fictive velocity, considerably smaller than the flow's mean velocity –

$$V = Q/F_{por}. \quad (3)$$

The movement of the filtration particles takes place along porous curved grooves (channels) [Chertowsov M. [3]]. The length of the latter in the field (environment) considered, depending on the random arrangement of the hard (soil) particles for the respective physic-mechanical indices and condition, is irregularly variable. The individual length of each groove, limited by the inlet and the outlet plane (fig. 1) is different, of certain repetitiveness, resp. percentage of their total number. The sum-total of all individual lengths

is an area, which has a lower envelope of length equal to the geometric distance  $L$  between the inlet and the outlet planes of the field considered, as well as an upper envelope of the maximal possible length, with dimension given in the literature. [4], [7]. Under the action of the water pressure  $H$  (Fig. 1), of equal size for all inlet openings of the porous grooves, the water particles fall into a groove of smaller or greater length, wherefore the flow velocity in them differs. The nature of alteration and the size of the latter is predetermined by the irregular alterations of the grooves' length. These velocities are the filtered flow's real velocities and they predetermine the flow's impact on the medium, respectively on its condition.

The interaction between the filtration flow and the field is a continuous process and is carried out and takes place in the porous grooves by the real velocities of the water. This process cannot be directly established, observed, controlled by knowing the fictitious velocity via formula (1) or by the mean velocity via formula (3). It is inadmissible that this interaction disrupt the threshold equilibrium of the field, causing erosion, slide and disastrous ruin of buildings and facilities.

According to the flow's active force, which is different in the various grooves, and the field's resistant force, reduced to utmost non-furrowing (non-eroding) velocity, it is possible that there occur:

- A state of utmost equilibrium, whereupon the utmost non-eroding velocity is equal to or greater than the velocity of the flow in the groove considered.
- A state of disrupting the utmost equilibrium of the field. In these cases, the utmost velocity is smaller than that in the groove. Depending on what part of the field (the probability distribution curve) where erosion occurs, anti-erosion measures will be applied.
- A state in which the flow velocities are lesser than the silting ones. For this state, there occurs silting or decrease in the permeability capacity of the field, water intake facilities, wells, etc. decrease in their flow rate or dry out.

This brief exposition shows that studying the state and dynamics of the interactions between the force of the flow in the porous grooves and the field's resistance is a important topical problem.

The present treatise's subject of consideration is the real velocity of the filtration flow in a porous field, i.e. the velocity of the flow in porous grooves.

## **2. Initial data**

To establish the flow velocity in any porous groove, use is made of initial conditions and data, as follows:

- The water movement in a porous field is steady;
- The water pressure at the inlet opening of all porous grooves has a permanent size;
- The water pressure at the outlet opening of any groove is zero – free water outflow;
- The cross section of the grooves is reduced to a round section of permanent diameter;
- The characteristics of the porous field (soil) are known;
- The water temperature, resp. the value of the hydrodynamic viscosity coefficient has a permanent value along the flow.

### 3. Inference of analytical relationship for determination of the flow velocity

The water movement, for the conditions mentioned, has a laminar regime. The energy spent (pressure loss) in the interval from the inlet to the outlet of any porous groove, is determined by relationship [4], [7]:

$$h_{\text{loss}} = \frac{64}{v d} \frac{L_i}{d} \frac{v^2}{2g} \quad (4)$$

where, after a simplification, it assumes the following form

$$h_{\text{loss}} = \frac{32}{g} \frac{v}{d^2} L_i V_i \quad (5)$$

where  $Re = \frac{v_i d}{v}$  – Reynold's number for the flow in a porous groove;

$V_i$  – flow velocity in groove "i";

$d$  – diameter (reduced) of the cross section of any porous groove;

$v$  – cinematic coefficient of the water viscosity;

$L_i$  – length of groove "i".

For the conditions considered, the  $d$ ,  $v$ ,  $h_{\text{loss}}$  and  $g$  quantities have permanent value and the following relationship can be laid:

$$\frac{32}{g} \frac{v}{d^2} = \text{const} = C \quad (6)$$

Consequently

$$h_{\text{loss}} = C L_i V_i \quad (7)$$

The length of any porous groove, resp. of any trajectory from the flow, is always greater than the geometric distance between the inlet and the outlet planes of the porous field considered, through which passes the filtration flow (Fig. 2). From investigations by the author, presented in the literature [4], the length  $L_i$  is determined by the relationship:

$$L_i = \frac{L}{1 - 2,58 A_L} + |M| \sigma \quad (8)$$

where  $A_L = \frac{\sigma}{L_{\text{av}}}$ ;

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (\Delta)^2}{n}} \quad \text{– average quadratic deviation;}$$

$\Delta = L_i - L_{\text{av}}$ ,  $L_{\text{av}}$  – average arithmetic length of the porous grooves in the field considered;

$M$  – coefficient by the normal law of distribution, named "probabilistic coefficient".

The values of this probabilistic coefficient  $M$  [6] are positive and negative and are presented in Table 1. in function of probability of occurrence  $P$  by the law of normal

distribution of Gauss. For example, for  $P = 0.90$ ,  $M = 1.65$ , which means that  $(1-0.90) \cdot 100\% = 10\%$  of the total aggregate of grooves from the positive sector have length equal to or greater than the one calculated by formula (8). The practical interval of  $M$  is from  $M=0$  to  $|M|=2.58$ . In the interval  $|M| > 2.58$  there is a length of the grooves lesser than 1% and their ignoring is admissible.

**Table 1. Values of the M coefficient for probability of occurrence P from P=0 to P=0.99**

<b>P</b>	0,0	0,10	0,30	0,50	0,60	0,70	0,80	0,90	0,95	0,99
<b>M</b>	0,0	0,126	0,384	0,675	0,840	1,040	1,28	1,65	1,960	2,58

The system of equations (7) and (8) is then solved to obtain:

$$V_i = \frac{h_{\text{loss}}}{C (L_{\text{av}} + |M| \sigma)}, \quad (9)$$

- a dimensioning relationship for determination of the flow's real velocity in any porous groove "i" from the positive sector, i.e. in the interval from  $M=0$  to 2.58 and from the negative sector, i.e. in the interval from  $M=0$  to  $-2.58$ , where

$$L_{\text{av}} = L + 2.58 \sigma, \quad (10)$$

$L$  – geometrical distance between the inlet and the outlet section of the filtration flow considered.

On expressing  $V_i$  without the participation of  $L_{\text{av}}$ , dimensioning relationship (9) assumes the following form:

$$V_i = \frac{h_{\text{loss}}}{C (L + \sigma (2,58 + |M|))}. \quad (11)$$

Of particular practical interest is the maximal and minimal flow velocity in the porous grooves.

By formula (11) is establishing:

- minimal velocity

$$V_{\text{min}} = \frac{h_{\text{loss}}}{C (L + 5,16 \sigma)}, \quad (12)$$

in porous grooves, which are smaller than 1% of all in the sector considered.

- maximal velocity

$$V_{\text{max}} = \frac{h_{\text{loss}}}{C L}. \quad (13)$$

in a porous groove, the length whereof equals the geometrical distance between the filtration flow's cross sections considered.

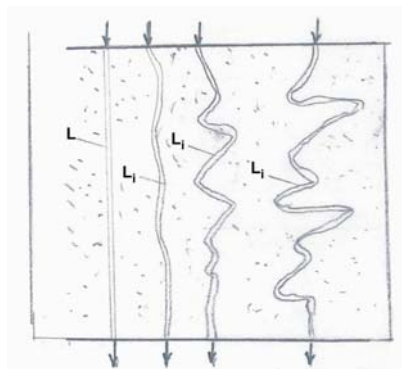


Fig. 2. The length of porous grooves -  $L_i$  and the geometric distance -  $L$

#### 4. Conclusions

1. The movement of the filtration water particles takes place along porous grooves, where the length of the latter depends on the random and irregular arrangement of the hard (soil) particles for the respective physic-mechanical indices and states of the field.
2. The real velocities are the filtration flow velocities in the porous grooves. Based on the latter, there can be predicted and assessed the occurrence and development of the erosion process.
3. The interaction between the filtration flow and the field is a continuous process and is carried out and takes place in the porous grooves by the real water velocities. This process cannot be established, observed, controlled and predicted by use of the fictitious velocity and the mean velocity.
4. Established is an analytical relationship (11) for determination of the filtration flow velocity in any porous groove. For the conditions considered, the real velocity depends on the coefficient  $M$  (Table 1.) and on the average quadratic deviation of the latter.

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## ВЪРХУ СКОРОСТТА НА ДВИЖЕНИЕ НА ВОДАТА В ПОРЪОЗНА СРЕДА

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*Ключови думи:* хидродинамика, филтрационни течения

*Научна област:* хидравлика, хидромелиорации

### РЕЗЮМЕ

В научната литература и практиката за движението на водните частици в поръозна среда между два напречни разреза на филтрационно течение се приема геометричното разстояние и средната скорост спрямо него. Но реално, при движение в поръозна среда (почва) водните частици се движат по поръозни каналчета с криволинейни траектории заобикалящи частиците на средата. Всяка една от тези траектории има различна дължина и при дадени конкретни условия – вид и състояние на поръозната среда, имат определена повтаряемост.

В настоящата работа се разглежда реалната скорост на филтрационно течение в поръозна среда (почва), т.е. скоростта на движението на водата по поръозни каналчета, където протича процеса на взаимодействие между филтрационното течение и средата, който предопределя нейното състояние на покой или ерозиране. Този процес не може да бъде наблюдаван, прогнозиран и управляван само чрез фиктивната или средната скорости на филтрационното течение.

При приетите изходни условия в разработката е установена аналитична оразмерителна зависимост за определяне на реалната скорост на филтрационното течение в поръозни каналчета.

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