Liquid filtration properties in gravel foundation of railroad tracks

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Abstract. Railway bed gravel foundation has a constant permanent impact on urban ecology and ground surface. It is only natural that larger objects, such as railway stations, make broader impact. Surface run-off waters polluted by harmful substances existing in railroad track body (ballast section) flow along railroad tracks and within macadam, go down into subterranean ground flow and then enter neighbouring rivers and water basins. This paper presents analytic calculations and characteristics of surface run-off liquid filtration which flows through gravel multiple layers (railroad track ballast section). The authors analyse liquids with various density and viscosity flowing in multi-layer porous medium. The paper also describes liquid stationary and non-stationary weepage into gravel foundation of railroad tracks.

1. Introduction

The Primary equations for liquid filtration in porous medium are considered [1, 2] to be the equation of continuity $\partial(\rho m)/\partial t + div(\rho\vec{u}) = 0$ and Darcy's law $-grad(p) + \rho\vec{g} - \mu\vec{u}/k = 0$ in which ρ is liquid density; m is medium porosity (that is relative proportion of open cells in a certain material); $\vec{u}$ is liquid filtration speed ($\vec{u} = m\vec{v}$ here $\vec{v}$ is liquid motion average speed in porous medium); t is time; p is liquid pressure; $\vec{g}$ is free-fall acceleration; μ is absolute viscosity of liquid; k is porous medium penetration (or penetration coefficient).

The optimal solution for this set of equations is $p = 0$, $\vec{u} = C(\vec{g}/g)$, where $C = k\rho g/\mu$ is liquid filtration coefficient in a certain medium. It is clear that this solution shows liquid free-flow in porous medium under the action of gravity. This solution makes clear the two physical meanings of the filtration coefficient. Firstly, C is speed of this liquid free-flow gravitational filtration in a certain porous medium. Secondly, C is the liquid maximum volume in a definite unit of time (discharge) on a definite area unit which is capable of free-flow filtration in this medium. Porosity and water filtration coefficient of different media typical value (measured by the researchers) are given in Table 1.

Table 1. Porosity and filtration coefficient of different media typical value

Material	m, %	C, m/s	Material	m, %	C, m/s
Broken granit 40x70 mm	46.0	0.01	River sand 1 mm	15.0	$0.51x10^{-3}$
Broken granit 20x40 mm	45.2	0.004	Fluvial soil	60.0	$0.40x10^{-5}$
Broken granit 5x20 mm	44.8	$0.18x10^{-2}$	Sand clay	75.0	$0.22x10^{-5}$
Quartz sand 2-3 mm	30.0	$0.10x10^{-2}$	Clay	50.0	$0.23x10^{-7}$

2. Atmospheric precipitation filtration

Let us assume that this area precipitation rate is q_{20} [5]. It is evident that liquid accumulation (puddles) on porous medium surface can be non-existent only under the condition $q_{20} < C$. Let us compare q_{20} = 70 l/(s·ha) = $0.7 \cdot 10^{-5}$ m/s (typical for Samara region) with the data presented above in Table 1. We realize that no matter what real precipitation rate is there is no liquid accumulation on either sand or gravel surface. Puddling is possible only if the surface is fluvial soil, sand clay or clay. On the other hand, railroad track ballast section is multi-layer porous medium in itself. Its upper layer is gravel, the next under-layer is sand, then there is geofabric which is deposited above main soils [1] (usually these soils are fluvial soil, sand clay or just clay). It leads us to the assumption that rain water flows immediately through ballast section gravel and sand layers and comes down to the main soils.

The most likely scenario then can unfold in either if the following ways:

- if the main soils are water-permeable (sandy) rain water drains down to the nearest waterproof layer;
- if the main soils are not water-permeable enough (either clay or fluvial soil or sand clay) rain water starts accumulating on the border between sub-ballast and the main soils. This underground liquid accumulations slowly leak water down into the soils.

If we put water-permeable geofabric on the border between sub-ballast and the main soils it will change nothing. But if we put waterproof geofabric on the border between sub-ballast and the main soils it would prevent water from leaking further down. Thus, we make a kind of water-bearing layer. It makes liquid flow horizontally up to the geofabric edge. Then this liquid flows out of ballast section in lateral direction generating road-side puddles which later sink into soils.

3. Quasistationary anthropogenic (man-made) water discharge (leakages) filtration

Let us consider a situation when there is some stationary liquid weepage (that is usually very polluted water) in a certain area. It punctually drenches ballast section surface, its volume flow rate being Q ($m^3/(m^2s)$=m/s). In this case there is a filtration channel developing gradually under the leakage point, its radius being $R = (Q/\pi C)^{1/2}$. The filtration channel radius depends on porous medium character. The channel in gravel is narrower than it is in sand, and the channel in sand is narrower than it is in soils: $R_{gr} < R_{sand} < R_{soils}$.

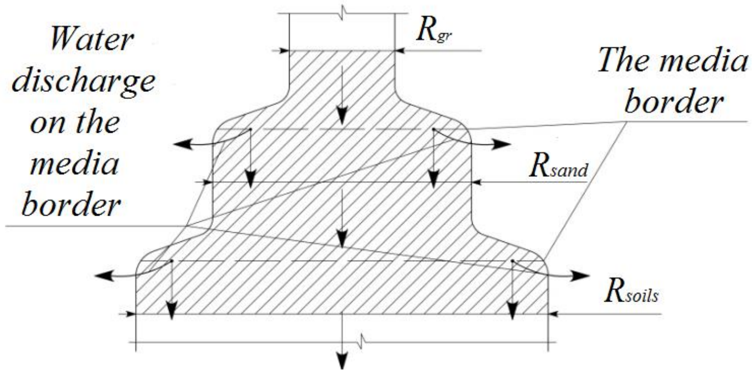

Fig. 1. Liquid filtration channel widening and water discharge on the media border

For this reason a filtration channel widens both on the border of gravel and sand and on the border of sub-ballast and soils (as seen on Fig. 1). When some part of the filtration channel goes beyond railway embankment it leads to liquid discharge in lateral direction (either on the border of gravel and sand or on the border of sand and soils).

Let us consider $R_{\max}$ to be a filtration channel the maximum permissible radius (that is a distance between the center of one 11.7 m railroad track, the railroad here being double track to the edge of the railway embankment, $R_{\max}$=11.7/4 = 2.925 m [4, 6, 8]). In this case the maximum permissible liquid leakage up to the point of its discharge in the lateral direction is $Q_{\max} = \pi C R_{\max}^2$.

The researchers calculated the maximum permissible liquid leakage basing upon the filtration coefficient typical values. While calculating we assume the main soils to be sand clay, sand foundation to be of river sand, its upper layer to be broken granite of 40×70 mm. At $Q < Q_{soils}$ =0.059 l/s water gradually flows through gravel, sand and soils within the railroad embankment. At 0.059 l/s= $Q_{soils} < Q < Q_{sand}$ =14.0 l/s water flows through gravel, sand and soils within the railroad embankment, a lateral discharge of water originating on the border of sub-ballast and gravel (some water flowing farther into the soils outside the railroad embankment). At 14.0 l/s = $Q_{sand} < Q < Q_{gr}$ =269.0 l/s water flows through gravel within the railroad embankment. There is a lateral discharge of water originating on the border of gravel and sand. Some water goes on flowing farther through the sand. There is the second lateral discharge of water originating on the border of sand and soils. At $Q > Q_{gr}$ =269.0 l/s some water flows down the gravel and some – through the gravel within the railroad embankment. There is a lateral discharge of water originating on the border of gravel and sand. Some water goes on flowing farther through the sand. There is the second lateral discharge of water originating on the border of sand and soils. The process is schematically shown on Figure 2.

4. Petroleum products filtration

Now we consider petroleum products filtration (e.g. crude oil) when split on railroad tracks [7, 10]. All equations presented in the previous part of our research work here as well. There are, though, some quantitative changes, which are due to greater viscosity of petroleum products.

In fact, water viscosity (at 20° C) is approximately 10^{-3} Pa*s, its density being 10^3 kg/m^3. Crude oil viscosity is (100…200)*10^{-3} and more Pa*s, its density being (0.8 ...1.0)*10^3 kg/m^3. There is very littler difference in there density while their viscosity is 100 ... 200 times as different. One should also take into account that oil viscosity dramatically rises at low temperatures (that is in spring, autumn and winter) and that some petroleum products viscosity (e.g. industrial fuel oil) is even greater than that of crude oil.

Penetration coefficient of the media does not depend on the properties of liquid [1, 2]. That is why penetration coefficients co-relation for one and the same liquid in different media does not depend on the properties of liquid either. It means that the geometric formula for filtration channel widening (given above) are the same both for water and petroleum products. It is important, though, that time required for petroleum products filtration is μ_{oil} / μ_{water} approximately 100 ... 200 ... times longer. In other words, petroleum products filtration goes on the same way as water filtration but it takes 100 ... 200 times longer. As a result, critical values for leakage leading to a lateral discharge of petroleum products from ballast section are 100 ... 200 times less than those values for water discharge. In case of a stationary leakage, a lateral discharge of petroleum products originates on the border of sub-ballast and soils when $Q > Q_{soils}$ =(0.059 l/s)/(100...200)=(0.6...0,3) ml/s. In this case the sub-ballast ends up to be heavily polluted everywhere along its ballast section. When $Q > Q_{sand}$ =(14.0 l/s)/(100...200)=(140...70) ml/s there is another lateral discharge of petroleum products on the border of gravel and sand. In this case it is not only the sub-ballast which ends up to be heavily polluted everywhere along its ballast section but also the gravel layer. It is quite clear that in this case ballast section mechanical properties are seriously affected and it becomes dangerous to go on using this railway tracks.

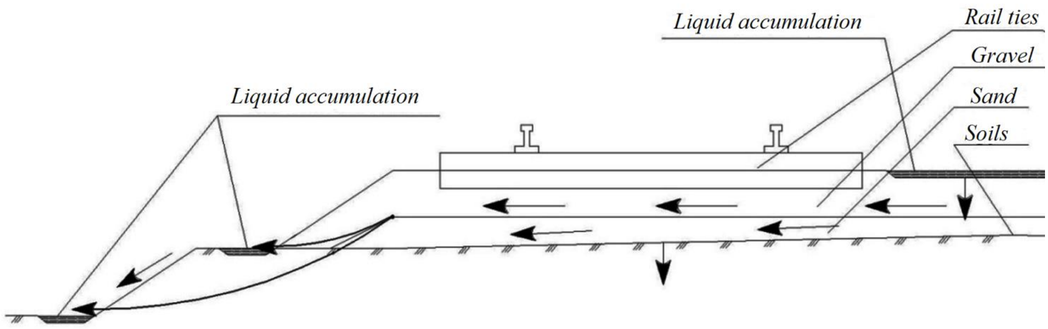

Fig. 2. Fluid weepage, outlet and discharge on different environment border

5. Conclusions

The research proves that any liquid which lands on railroad tracks goes on flowing down the railway embankment and then turns in the lateral direction. It happens either on the border of ballast section and sub-ballast or on the border of sub-ballast and soils.

Thus, we can conclude that if ballast section pollutants (discharged in the lateral direction) are properly collected and then utilized or disposed, environmental damage arising of railroads use can be reduced to a minimum. It is also very important that in this case ballast section reliable performance grows upward as well.

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