

Influence of transport infrastructure on water permeability of soils of Western Siberia

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Abstract. Correctly designed transport infrastructure should support the current economic relations. It should provide a reserve for development of economy of the region in the future. In Western Siberia, new highways are actively being built and major repairs of the operating roads are being conducted. Local materials are often used in the roadbed construction. In the Tyumen region, it is usually sandy silt and clayey sand. The soil has unfavourable physico-mechanical properties. The soil is prone to water and wind erosion. This type of ground gets on the adjacent to the road territory. Studies on the influence of highways on soil permeability were carried out on the basis of the federal highway Tyumen-Omsk. Three types of soils, which are actively used in the agricultural sector, were considered. It is found that the content of particles with the size less than 0.01 mm reaches 32% in the soil used in road construction. It is noted that a part of these particles accumulates on the adjacent to the road territory since it is being washed out from roadbed. The content of physical clay (<0.01 mm) in soils increases by 34-62% relative to the initial values. The width of active accumulation of silt particles reaches 15-20 m along the roads. The soils at the distance up to 10 m from the highway are almost impermeable to water. Absence of a natural hydrological drain, results in the territory bogging. An inverse close correlation was established between the content of physical clay (<0.01 mm) and water permeability ($r = 0.90$).

1. Introduction

Creation of transport infrastructure with use of modern scientific researches provides favorable conditions for functioning of all economy branches. Correctly designed road network supports the current economic relations as well as creates a reserve, that provides economy mobility for the future [1]. The common issue of the transport infrastructure is that its development significantly falls behind with the expansion pace of the economic relations. In order to design an enterprise of the national economy, the demand for transport, transport ways availability, and their capacity are considered. Rationale for transportations influences economy efficiency of the separate enterprises, municipalities and the country as a whole.

The goal of the unified transport infrastructure in Western Siberia was to create road system at minimum expense, providing quick access to the key facility objects [2]. Therefore, construction of the morotways usually passed through the driest territory where high quality soils historically had formed. As long as regions developed, those soils were actively involved in the agricultural system. One of the factors was well-developed transport infrastructure, that had attracted people, which combined with the soil and climate conditions had contributed to the strong region economy boost.



The regional specifics of the soil cover of Western Siberia and, in particular, the South of the Tyumen region is that considerable territories are heavy saturated with water in the spring and fall period. Absence of the hydrological drain leads to the fact that water does not go to the lakes or rivers and stands in the lowlands. Due to the low soil permeability water cannot be absorbed fast enough. It is specific character of the Western Siberia soil cover [3].

Local materials are usually used in construction or repair of the roads. It considerably reduces the cost value [4-6]. However, it often leads to bogging of the adjacent to highways territories, since low water permeability of the soils and lack of the natural hydrological drain. Today part of lands adjacent to highways are boggy and melioration measures are required.

2. The goal of researches

The goal is to study the influence of transport infrastructure on water permeability of the soils of Western Siberia.

3. Materials and Methods

The research was conducted in the south of the Tyumen region. As an object of studying, the soils located near the federal highway Tyumen-Omsk were chosen. Extent of researches was 450 km. In order to determine the types of the soil, the soil shear was conducted. The following soil types were defined: dark grey solodic; leached chernozem; meadow alkaline. In addition, there were found another soil types, that agricultural value is low. Soil samples were selected on various distance from the highway. As control, the sites located in 200 m from the road have been taken. The analysis of particle size distribution of the ground was carried out by a laser particle sizer Analisette-22. At the sampling points, the water permeability of the soil was determined by the Kachinsky method in 6-fold replication. The material used to create the roadway was also selected. The analysis of the physical and chemical properties of the selected soils was carried out in accordance with state standards. Statistical processing and correlation analysis of the collected material were calculated using Microsoft Excel.

4. Results

The analysis of particle size distribution of the ground which is used in construction and repair of roads showed that the soil type relates to sandy silt. The share of particles with sizes less than 0.01 mm was 32% of the total volume (fig. 1). The content of large particles in sandy silt (0.5-1.0 mm) did not exceed 5%. Such material is unfavourable for a roadbed as it is prone to water and wind erosion. Sandy silt and soils, that contain particles of such type, have low water permeability properties. According to G.S. Merentseva and A.O. Hrebtovy sandy silt and clayey sands are of little use for road construction without any binding materials [8]. Certain soils have heaving properties and lose their stability properties as saturated with water. The mineralogical composition of sandy silt is various; usually it consists of basalts, quartz, field spars [9]. Plant fragment are frequently found in it like bark, rootlets of woody plants. In addition, there are humic substances flowing from the upper layers of the soil under the influence of descending currents of water [10].

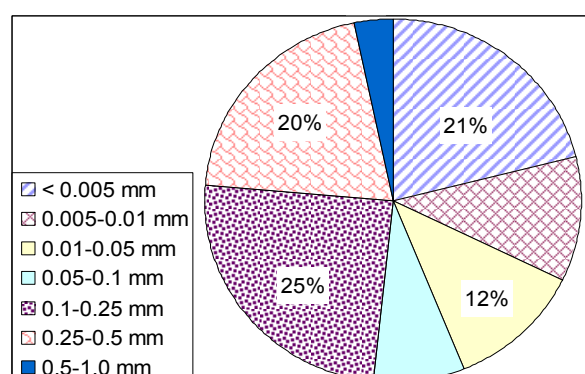


Figure 1. Granulometric composition of sandy silt used

Part of the silty and small dusty particles, which are contained in the roadbed material, is gradually washed away by water. On the territory adjoining the highways there is accumulation of small particles and their partial penetration deep into the soil. Moreover, light particles are blown out and accumulated at a considerable distance from the roads. The accumulation of silty and dusty particles gradually alters the granulometric composition of soils. The studies showed that at a distance of 200 m from the federal Tyumen-Omsk highway, the content of physical clay (particles' size is less than 0.01 mm) in the 0-40 cm layer of leached chernozem reaches 40.4%. This corresponds to a heavy loam variety (Table 1). Analysis of the soil-forming rock showed the complete identity of the sites located at different distances from the road. The content of physical clay in leached chernozem at a distance of 5 m from the road was the maximum and reached 64.6%. This corresponded to a clayey type of soil. The silt fraction (particles' size is less than 0.001 mm) accounted for 45.6%, while at a distance of 200 m their content was 30.4%. Considering the fact that the particle size distribution and the ratio of fractions in the soil-forming rock of these areas are identical, different changes will result from anthropogenic impact. Long-term agricultural use of arable land can also affect the particle size distribution of the soil, but the changes are not so drastic and usually they are the same type within small areas (11).

Table 1. The contents of elementary particles in the soils adjacent to the Federal highway Tyumen-Omsk, (layer 0-40 cm), %

Soils	n*	The distance from the road, m				
		5	10	15	20	200
Physical clay (particles < 0.01 mm)						
Dark grey solodic	30	57.8	54.3	38.5	36.3	35.7
Leached chernozem	35	64.6	60.2	54.6	42.7	40.4
Meadow alkaline	15	65.2	62.1	60.2	46.8	48.7
Silt fraction (particles <0.001 mm)						
Dark grey solodic	30	42.0	40.8	36.6	30.5	28.0
Leached chernozem	35	45.6	46.7	37.4	32.1	30.4
Meadow alkaline	15	50.4	50.0	40.7	38.5	37.2
<i>n – the number of sampling</i>						

n – the number of sampling

The dark grey solodic soil also belongs to the heavy loam type. The content of physical clay in the top layer makes 35.7% from the particles' total. At the distance of 5 m from road granulometric composition is considerably heavier. The content of particles that are <0.01 mm reaches 57.8%, 42.0% of which are the share of silt fraction. The share of small particles gradually decreases, as moving further away from the road, and it reaches 36.3% at the distance of 20 m. The given fact proves the particles washout because when the wind erosion effect is observed, the particle size distribution would be changed at a greater distance from the road.

Meadow alkaline soils are similar to chernozems by morphological character. However, their physical and chemical properties significantly differ. It is expressed in the high level of ground waters, usually not exceeding 1-2 m. Alkaline content makes alkalescent the top layer of the meadow soil. Soil units initially have low water permeability due to their dispergation with sodium cations. At the distance of 200 m from the highway, the content of physical clay in meadow alkaline soil reaches 48.7% what is common for heavy loam types of the saline soils. Emergence in such soils of the particles, which size is less than 0.01 mm, inevitably affects on granulometric composition and accompanying properties. In immediate proximity from road (5 m), the content of physical clay is 65.2% ,50.4% of which relate to silty fraction. It corresponds to the light loam kind of the meadow soils.

The soil particles, which size is less than 0.01 mm, are usually aggregated in water-stable microstructural separateness. Active humic agents and calcium cations promote it. Primary aggregation is a quite long process, therefore, the particles which have got on the surface of the soil start to migrate gradually deep into the soil, thereby deteriorating its water permeability. This process is called illuviation, the result of which is formation of the recondensed horizon that dramatically reduces air and water permeability of the soil.

Chernozems are characterized by high water permeability, despite their heavy particle size distribution. At the distance of 200 m from the road, where there is no possibility of the appearance of solid particles, water absorption occurs at a rate of 4.5 mm / min, which corresponds to high water permeability. As the soil voids fill with water, the water permeability decreases to 2.8 mm / min, remaining at this level for a long time. Such high indices are due to the presence of water-resistant soil aggregates that do not break up into elementary soil particles, thus enabling water to pass deep into the water at the maximum speed. At the distance of 5 m from the Tyumen-Omsk highway, the infiltration coefficient was minimal - 0.4 mm / min, which is 6 times less than the filtration values. This fact indicates a serious change in the water-physical properties of soils adjacent to highways. The prolonged overmoistening of the territories adjacent to the roads inevitably leads to the formation of anaerobic conditions at the depth and the formation of a gley horizon. It is a good retainer and prevents the movement of water deep into the soil. Nowadays, hydrophilic vegetation appears in the areas where natural drain is weak. This indicates bogging of the territory.

Deterioration of chernozem permeability is traced along the distance of 15 m from road. The rate of absorption does not exceed 2.0 mm/min, and filter coefficient is no more than 1.5 mm/minutes. Water permeability of chernozem at distance of 20 m from road is comparable to an areas, located at 200 m.

Dark grey solodic forest soils are comparable to chernozems in water-physical properties. Their water permeability at distance of 200 m from a highway is considerably high: the coefficients of infiltration and filtrations reach 4.0 and 2.4 mm/min respectively. It is considered to be sufficient for water not to stand on the soil surface without a natural drain under conditions of periodical flushing regime. However, in immediate proximity from highway (5 m), the rate of absorption is minimal and comparable to filtration that reaches 0.1 mm/min. Solodization of dark grey forest soil deteriorates the absorption process of water deep into the ground, as water stability of the certain soil units is lower than chernozem ones. This explains lower water permeability of the dark grey forest solodic soils with distance from the road. At the distance of 20 m, rate of absorption and filtration factor reach values of chernozem and areas, that are 200 m away from the road.

Table 2. The permeability of soils adjacent to the Federal highway Tyumen-Omsk, mm/min

Soils	n*	The distance from the road, m				
		5	10	15	20	200
The coefficient of infiltration (absorption speed)						
Dark grey solodic	10	0.2	0.4	1.2	3.5	4.0
Leached chernozem	15	0.4	0.7	1.6	4.0	4.5
Meadow alkaline	12	0.1	0.2	0.8	3.0	3.8
Coefficient of filtration						
Dark grey solodic	10	0.1	0.7	1.6	2.2	2.4
Leached chernozem	15	0.1	1.1	1.5	2.0	2.8
Meadow alkaline	12	0.0	0.4	0.8	1.1	1.6
<i>n – the number of sampling</i>						

n – the number of sampling

Among the studied soils, meadow alkaline type of soil has the lowest water permeability. The filtration coefficient in its natural state is 1.6 mm / min. This is a genetic specific of the soil, because

the contained sodium peptizes down humic substances [12]. In case of the water presence, structural aggregates decay, adversely affecting water permeability. In Siberia, meadow alkaline soils were initially waterlogged and bogged. Therefore, a change in the particle size distribution will inevitably lead to a deterioration in their state. Plots of meadow soil at a distance of 5 m from the road are characterized by the absence of any water permeability properties. Open water surface was seen multiple times, and the vegetation was represented by hydrophytic plants: cattail (*Typha latifolia*); cane (*Scirpus*) and reed (*Phragmites*). At a distance of 15 m from the highway, the infiltration and filtration rates of meadow alkaline soil do not exceed 1.0 mm / min. Some improvement in the water properties of meadow soil occurs only at 20 m and further away from the road. The collected data allowed us to calculate correlation dependences between the particle size distribution and water permeability of the studied soils. Soil absorption rate is inversely proportional to the content of physical clay and clay particles - the correlation coefficient is -0.82 and -0.86 respectively. Generally, the water permeability of soils is characterized by a filtration coefficient, which also depends on the content of elementary soil particles. As the calculations showed, the correlation between them is characterized as inverse and very strong ($k = 0.90$).

5. Conclusion

1. The sands and loams, that are used in construction of transport infrastructure in the Tyumen region, are dusty type soils, where 32% are the particles of sizes less than 0.01 mm.
2. Content of physical clay (particle size is less than 0.01 mm) in the soils adjacent to highways increases by 34-62% comparing to the initial content. The content of physical clay decreases with distance from the highway and reaches initial sizes at 20 m mark.
3. Water permeability of the soils adjacent to the highway at distance no more than 10 m is close to zero, what results in surface bogging and diminishing of fertility of the soils involved in the agriculture. Filtration coefficient of the areas without highway influence varied from 1.6 to 2.8 depending on soil type what refers to high water permeability.
4. The filtration coefficient of the areas adjacent to roads can reach 0 in case of natural factors, which deteriorate soil permeability (solodization, alkalinity), therefore, indicating the formation of impermeable layers and bogging of the surface.

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