

# THE ENVIRONMENTAL PROBLEMS CONNECTED WITH HIGHWAY CONSTRUCTION AND MAINTENANCE

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***Abstracts:** In the paper the environmental problems connected with road construction and maintenance, trends and ways of their solving are formulated and presented. The problems with deformation of the road embankment slopes are considered.*

***Key words:** ecological safety of roads; parameters of ecological safety, road embankment, slope of road embankment*

## I. ENVIRONMENT PROBLEMS ON ROADS

The increase in the traffic volume (up to 40-70 and more thous. cars per day at the large cities exits and 10-20 thous. on the majority of the federal roads), construction of new and reconstruction of the existing roads have aggravated the problem of environmental protection. When considering the ecological problems in Russia considerable attention is traditionally and deservedly paid to the automobiles. The result of it is the significant progress in the sphere of engine-building accompanied by the sharp reduction in emission of harmful substances. In the years coming Europe is planning to introduce standard EURO -5, Russia - standard EURO-2 and later on - standard EURO-3. In the USA the President George Bush announced the development of the new ecologically friendly car engine. But apart from the cars there are other factors that contribute to the environmental pollution. The most significant of them are highways affecting the level of pollution coming from traffic. Moreover, the road itself has negative influence with the roadside territory. Such influence is exerted by:

- Road engineering elements: roadbed, bridge crossings and flyovers, water intake structures and culverts.
- Separate road engineering structures: pavement, roadbed, shoulders.
- Road infrastructure units: rest area, gasoline stations, food stations, public transport stations.

The above listed sources of highway influence over the environment affect all the nature elements: air, soil, water, biosphere. Air pollution over the highway is influenced by the roadbed, pavement surface material and texture, even interchanges design and peculiarities of traffic. The roadbed in the form of a high embankment affects the thermal, humidity and wind conditions of the roadside territory.

Roadway paving influences the quality and composition of the automobile exit gases, the quantity of wear debris of the automobile parts, including automobile tires, air pollution by the wear debris of the roadway covering, dust and garbage and it is an important factor of the formation of the level of traffic noise. Constructional features of the road crossing, means and methods of organization and traffic control of automobiles also influence the quantity of the exit gases released by the automobile engines.

The impact of automobile road on soil and water is no less diversified. The landscape of the area changes as a result of exemption of territory for the engineering constructions of the roads, careers, earth-deposits, construction sites, industrial approaches. As a consequence of development of the road network there occurs the fragmentation of the territory, change of terrain and flora. The construction of grade level, bridges and crossovers is followed by deformation of sub-base, development and strengthening of erosion processes. The regime of runoff of surface and ground offers is often broken, which is followed by drainage or overdamping of territories, up to formation of marshes. It often leads to the erosion of the bed of the water streams, formation of ravines. The soil gets contaminated not only by the components of the exit gases of the automobiles but grade level erosion products, wear of roadway covering, by the materials used during the winter maintenance of roads (antiglaze reagents). Water contamination of rivers and lakes occurs as the result of pollutant emission and impact of erosion products, wear of roadway coverings and automobile tires, dust, garbage, oil-products and human wastes (in the locations of infrastructure facilities).

Such kind of impact also has its consequences in biosphere: flora, fauna, including humans. The habitat of plants is limited as a result of the change of the regime of soil watering, drainage or underflooding of the territories, change of soil fertility as well as the presence of contaminative chemical agents. In the locations of rest areas occurs trampling and vegetation damage, repacking of soil. The habitat of animals limits, natural migration ways change, acoustic environment becomes more complicated.

According to the law «On environment protection» in Russia the following items are subject to protection from contamination, depletion, degeneration, damage, extermination and other negative impact of economic and other activity:

- Land, the Earth's interior, soils.
- Surface and underwater.
- Forests and plants, animals and other organisms and their genetic heritage.
- Ambient air.

Automobile roads belong to the objects of environmental threat. Depending on the level of environmental threat they are divided in three classes. The first class are large objects, which considerably influence the environment: federal and regional motorways and speedways of the I and II technical categories with not less than four lanes and constructive works on them, separate bridges and crossovers with the length of more than 500 m. According to the International standards and Federal documents the construction of road objects of the first class belongs to ecologically destructive activity categories. The second class represents the objects, which considerably influence the environment. They include the roads of II and III categories with predicted (perspective) rate of traffic more than 2000 veh. per day and the constructions on their surface, separate areas of other roads in population centres and particularly protected areas. The third class is represented by the objects which have insignificantly influence, local action on the environment: automobile roads with predicted traffic rate less than 2000 veh. per day transport constructions on their surface, repair works.

Under environmental threat (safety, environmentally safe state) of the automobile road there is understood the ability of the road to provide the minimum of hazardous, formed by engineering constructions and constructions of the automobile road, impacts and pollution of nature of the areas attached to the roads, their influence on the work of the road transport. The level of environmental threat (safety) of the automobile road depends on its technical condition and the technical state of the road buildings, the level of contamination of the natural environment of the wayside, as well as influence of the technical condition of the road on the pollutant emission of the road transport.

With the purpose of quantitative estimation of the level of environmental security (environmentally safe state) of the road there are proposed special rates, which are divided into two groups – ecological and ecologically significant. The ecological ones include the rates, which characterize the level of air, water, soil pollution, bioenvironmental effect (human, flora, fauna) and reflect the cooperative effect on the nature of road transport as well as engineering constructions of automobile road. Ecologically significant rates include those, which characterize the technical condition of elements (constructions) of roads or maintenance works, which reflect the influence and environmental effect of the road and the effect of the latter on the ecological rates of road transport. The level of ecological safety of the road is evaluated by comparing factual and regulatory values of ecological and ecologically significant rates, stated in quantitative or qualitative form.

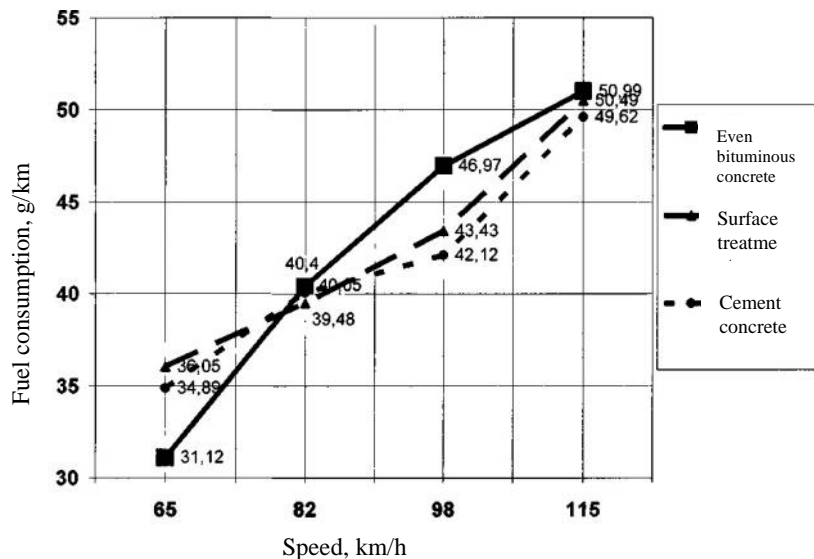
The state of road will be considered environmentally safe if:

- There is no violation and pollution of the roadside territory, formed and caused by engineering constructions and road constructions, or they are as low as practicable with the existing technologies and modern requirements.
- There are created conditions, which provide the minimal possible (with the existing technologies and modern requirements) impact on nature from the side of road transport, which is at the road.

Quantitative values and qualitative assessments of the environmentally safe state of road, its engineering facilities and constructions are represented in the branch regulatory document «Rates and norms of ecological safety of the road», prepared by the Road Agency of Ministry of Transport of the Russian Federation and set in force since January 1, 2003.

With the purpose of environmental safety improvement of the roads in Russia there have been worked out the rules and norms of environmental design of road elements and roads constructions. The examples of such rules are the rules and standards of design and construction of rest areas at the roads. The rules efficient up to the present moment both in Russia and abroad are made solely on the basis of requirements of road traffic safety ensuring. However the growth of traffic volume lead to the fact that rest areas are overloaded by road transport, the environment of roadside territory cannot resist the excess human load. As a result rest areas do not carry the assigned functions – provide rest neither for the drivers nor for pedestrians and, by this means, do not contribute to safety improving of road traffic.

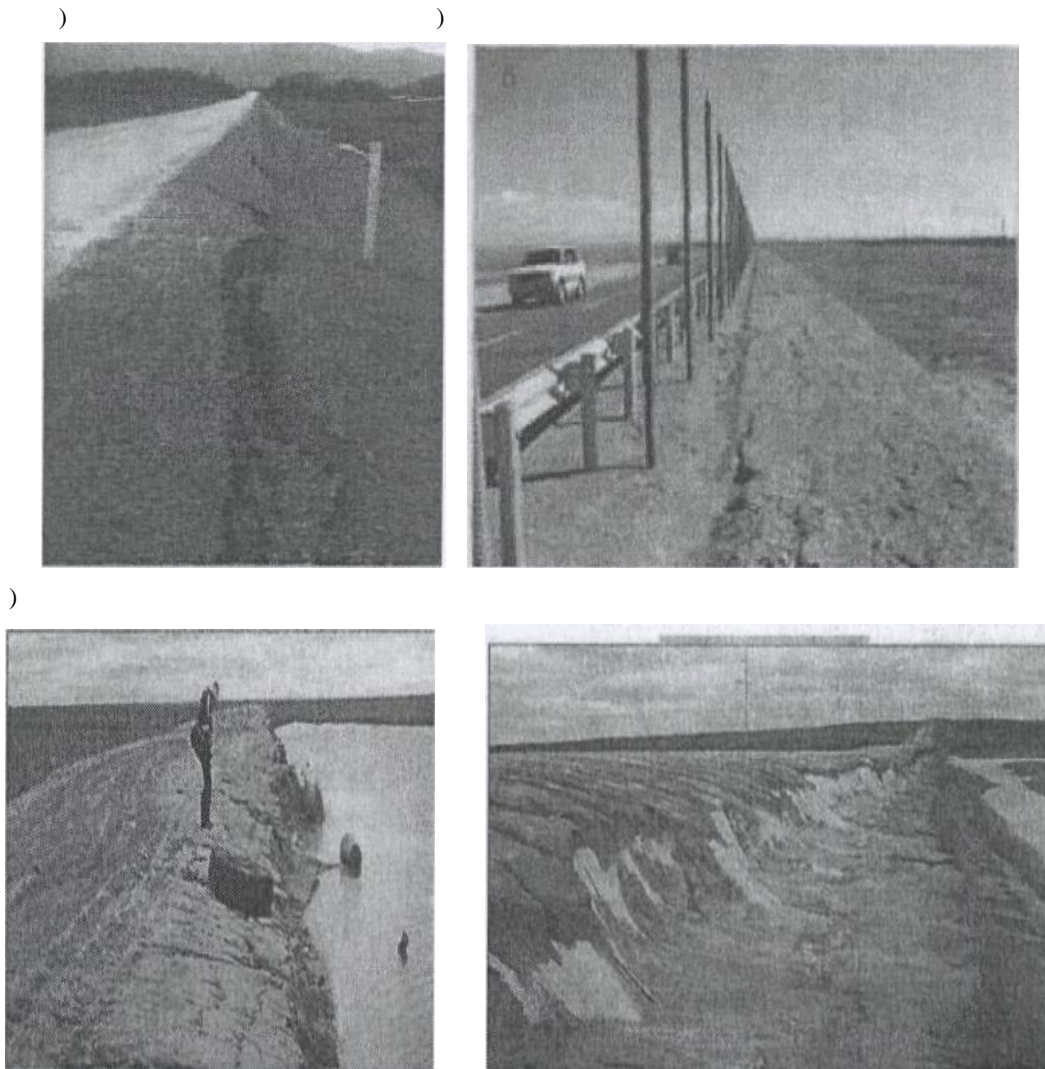
The research of the recent years showed the significant impact of roadway coverings on the fuel consumption of automobile engines, and, in such a way, on the volume of exit gases. Beside the environment-oriented values the right choice of the material and texture options of pavement also has an energy-conservative value. The research carried out, the results of which are presented on the Fig. 1, revealed quite a complicated character of interrelation between the material and surface texture and fuel consumption in the whole actual speed ranges of automobile traffic. It is estimated that, on the road sections with the average speed of traffic of 80 and more km/hour the minimum fuel consumption are observed on the cement -concrete pavement in comparison with the asphalt-concrete. In case of traffic motion of less than 80 km per hour there is observed quite an opposite picture.



*Figure 1. Impact of the material and texture options of the roadway covering on the motor car fuel consumption*

## II. DEFORMATION OF THE ROAD EMBANKMENT SLOPES

The practice of construction and reconstruction of roads showed that the basic types of deformation of the earth embankments (roadbed), made from granular materials (sands, sand and gravel ground etc.) are surface erosion and local shear deformations in the form of landslides, earthflows, caused by the impact of water on the ground. Such kind of deformation one may see in the regions with quite a cold climate, in the regions with snow falls, snowstorms and cold winter. This is the Northern and Central parts of the European territory of the Russian Federation, the whole territory of Siberia and Far East of the Russian Federation, Alaska (USA), high mountain areas of China (Tibet). It is confirmed by the observations of numerous authors (Fig. 2) [1,2,3,4].



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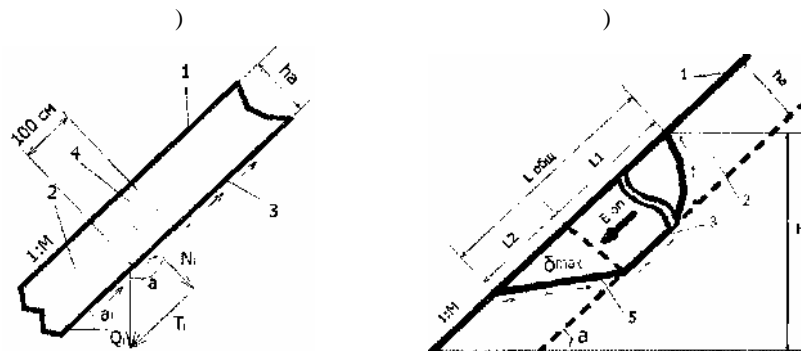
**Figure 2.** Local deformations of subgrade embankment:

) road in Alaska [4]; ) Qinghai - Tibet railroads [3]; ) Russia - road «Yamal» [1]; ) Russia - road «Don» 104 km [1]

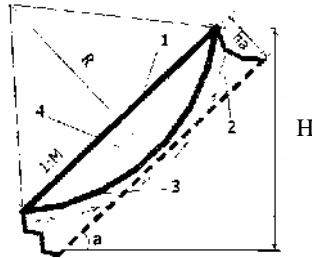
Deformations of grade level, caused by water erosion, are developed in the period, when the surface of formation is still not hardened and caused by considerable overspeeding of the water flowing from the ground surface (usually during the rains) of the standard (not eroding) speeds for the ground. The ways of prevention of such kind of deformations are well-known – it is timely embedment of the traffic way, waysides and slopes of grade level with the materials, which are highly resistant to the washaway.

The situation is more difficult with the deformations of the second type – shifts on the slopes. Local deformations of this type can be observed on the embankment slope of all types of ground. What is particularly interesting is the fact of appearance of shear deformations on the fill slopes from the cohesionless soil. Besides such deformations develop on the slopes of even high fills (up to 8 and more m), with asphalt and cement-concrete pavements at the carriageway and shoulders, with good grassy turfs at the slopes. Particularly often these deformations occur in the first 1-3 years of grade level service.

The possible schemes of local deformation developments are presented at the Fig. 3. In all cases there are slip lines of the definite coat massif of soil in the coating surface of the slope:



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. 3. Development scheme of shear deformations on the fill slopes [6]:

- due to identity element;
- inplane slip with uplift;
- destruction of the whole slope in the belt of weathering on the circular cylindrical surface ; 1 - face of slope; 2 – capacity of the active zone ha; 3 – shift surface; 4 – assumed blocks; 5 - retaining prism in uplift zone

The condition of the slope stability is the balance or excess of restraining forces over the shear forces. Stability coefficient is:

$$R = \frac{Z_i \text{tg} \varphi_n + \frac{C_n}{Z_i}}{Z_i \text{tg} \alpha} = \frac{\text{tg} \varphi_n + \frac{C_n}{Z_i}}{\text{tg} \alpha}$$

where  $\rho$  - soil density;  $Z_i$  - running coordinate of the active zone capacity of the slope perpendicularly its surface;  $\text{tg} \alpha$  - coefficient of soil shift of the active zone h at depth  $Z_i$ ;  $\text{tg} \varphi_n$ ,  $C_n$  - correspondingly calculated values of angle of repose and soil cohesion at depth  $Z_i$ ;  $\alpha$  - rate of slope.

The analysis of the complex of restraining force showed that, the main role in the loss of local soil stability on the slopes is played by water, which causes decrease of angle of repose and cohesion between the particulates and dynamically effects the soil grains.

Structural cohesion in graded materials takes place only in case of high density and soil compactness and predominantly in case of low homogeneity on grain -size classification and is predetermined, mainly, by interlocking grain arrangement [9].

**Table 1.** Dependence of cohesion and angle of internal friction of soil from its porosity [9]

Type of refuse stone	Cohesion ( P ) and angle of internal friction $\varphi$ (grade) with the porosity factor $\varepsilon$			
	0,45	0,55	0,65	0,75
Gravel and coarse sand	0,02	0,01	-	-
	43	40	38	-
Sands of average coarseness	0,03	0,02	0,01	-
	40	38	35	-
Fine sand	0,06	0,04	0,02	-

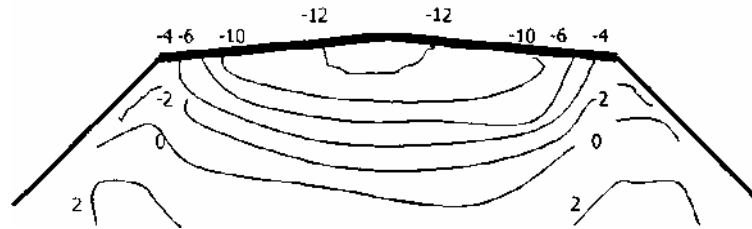
	38	36	32	28
Dust sand	0,08	0,06	0,04	0,02
	36	34	30	26

*Note: Upper line - cohesion, lower - angle of repose.*

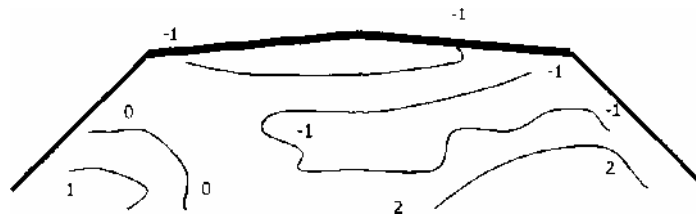
The water gets into the soil on the slopes as a result of percolation in case of storm event and snow melting.

In winter the soil of grade level freezes (after the temperature fall below  $-5^{\circ}$  ). Isothermal curve of zero temperature falls lower and lower from the surface of grade level. Temperature distribution in depth gives evidence of the character of the soil straight-freezing: maximal under the roadway paving and lesser on the slopes of fills (Fig. 4 /8/).

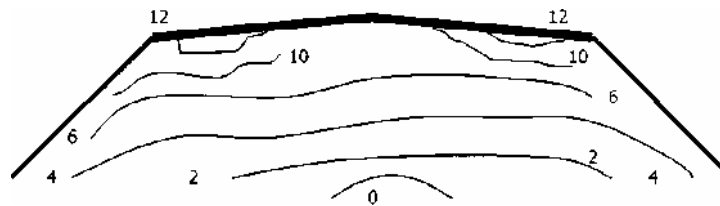
Isotherm of February



Isotherm of March



Isotherm of April

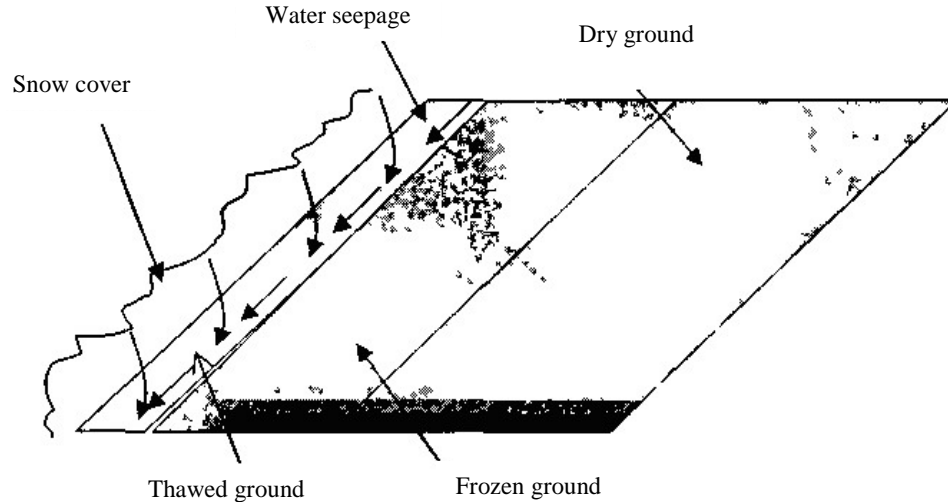


**Figure 4.** Isotherms ( $^{\circ}$ ) of the coat of grade level during the winter -spring months  
(Moscow and Moscow region)



In spring there is started a constant soil temperature rise in the upper part of the grade level. Heat current changes its direction, moreover before the start of melting. Soil frost retreat starts from two sides: from above, from the surface of grade level, and from below, from the side of thawed ground (in the mass or the ground of the grade level). The speed of frost retreat from above is more or less identical on all the areas and averages (for Moscow region) to 4 cm/day. Frost retreat from within averages to 0,6-0,7 cm/day. On the whole the thickness of layer, melted from within, amounts - in relation to the whole thickness of frost-bound layer - to 7 up to 34%.

After the start of snow melting the water from the upper coating of the snow cover, subject to the forces of gravitation, passes through the snow to the soil slope. Under the influence of melt-water there is started gradual coat frost retreat. The part of melt-water gets into the pores of the unfrozen soil, the remaining part flows through the slope – through the face of slope, under the snow cover. As the snow melts and the soil thaws the major part melt-water gets into the soil pores and the smallest part of it flows down the slope surface. At last there comes a moment, when the depth of the melted soil-work at the slope surface reaches the value, wherein the all amount of melt-water which enters the soil goes to the soil pores. The flow down the surface of the slope stops. Melt-water through the soil pores under the gravity forces reaches the surface of the soil still not melted. In case of quite a large openness there appears the water flow in the soil. Gradually takes place the formation of seepage, which flows in the soil above the border of the section «thawed ground - frozen ground» (Fig. 5.)



**Figure 5.** Formation of the seepage on the slopes of the grade level during the snow melting

As a result there happens a considerable soil overwetting, followed by the decrease of forces, which secure the soil grains from the shift. In the zone of water filtration on soil grains operates the hydrodynamic head  $h_B$ , which appears as the result of penetration of elementary

rate of water flow  $q$ , and the following formation of seepage with the rate  $Q = \sum q_i$ . Elementary rate of flow  $q_i$  is formed by water, which penetrates into the soil during the snow melting on the slopes, and, in case of storm event, rainwater. The water flows through the surface of aquifuge – the surface of still frozen soil-work (in spring) or the surface of a more solid soil-work which lies lower (in summer and in autumn).

The melting surface is not plain. That is why in some places, because of the outflow obstacle, the local additional body of water may occur, which increases weighing water impact and therefore decreases restraining forces.

The water of rains which fall during the snow melting period accelerates and increases the process of snow melting, therefore leveling up the water flow in the coat. The rainwater itself also penetrates into the soil pores (because of the infiltration) increasing more the filtration flow and soil dampness. Because of the accelerated snow melting and soil frost retreat in the zone of the shelf of grade level there is possible a situation, when the water from the overdamping zone under the roadway paving through the unfrozen coat under the wayside and the upper part of fill slope comes into the filtration flow, which flows in the surficial belt of the slope.

At some time the soil overdamping reaches the level when, the shearing force exceed restraining forces. So there happens a shift - local deformation in the form of slope gutter.

As regards sand the possibility of shift deformation is worsened by its tendency to attenuation in aqueous state. Attenuation often happens [5] under the influence of filtration flow on the sand structure, in particular in case of dynamic character of filtration forces. Recently settled refuse stone of earthworks is very sensitive to the dynamic forces. Dynamic effects usually cause small shift of sand-grains, which cause sand fluidization.

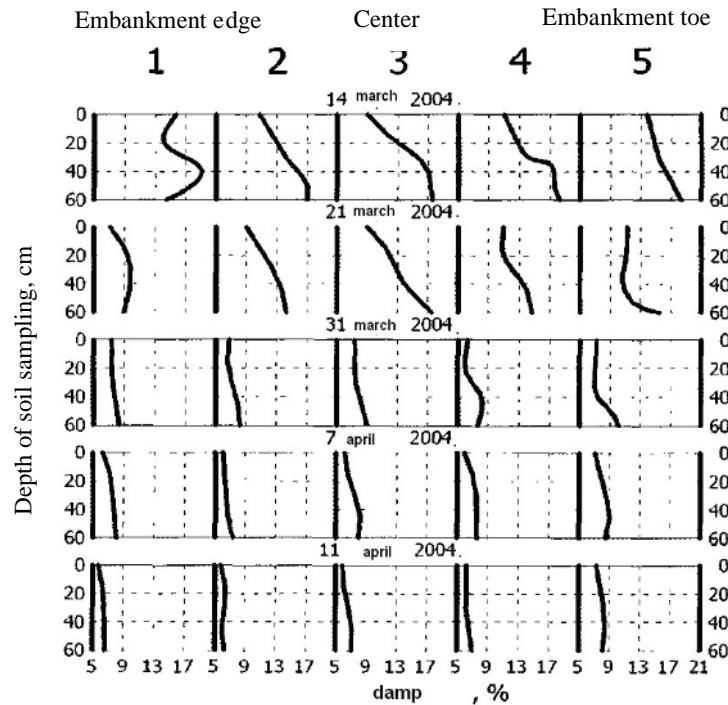
In case of sand fluidization on the slopes, instead of vertical displacement of sand-grains in the process of sand settlement, there occurs considerable relative flat and vertical displacement of values as a consequence of running ground dispersion. In case of sufficient surface slope the burdens rush in the form flows to the lower areas, forming the covers, filling the cavities and hollows.

Deformation ratio depends on the rate of dynamic effects. Earthquakes can cause passing of sand into dilute state on the large area. The effects of explosions and vibration are caused only by local fractures of area structure, quite close to the whence of dynamic effects. Very often the fluidization event happens in comparatively small scales, for example, in the event of people walking or vehicle passing over the surface of loose water-saturated sands [5].

Fluidization is native to all quite loose granular soils of any grain size. However due to a larger permeability to water the retention time of coarse-grained soils in dilute state is less, than that of compact-grained and that is why the fluidization practically never occurs there.

The danger of fluidization for the resistibility and structural competence is defined not by the fact of fluidization, but by the character of its flow. The dwelling time of sand in dilute condition and toughness of burdens influences the possible construction displacement.

The rightfulness of theoretical considerations concerning the reasons for formation of local deformations on the slopes of grade level of roads was confirmed by the results of full-scale measurements of water content and soil (sand) density on the fill slopes of roads «Don» (km 103-104), built from fine sand of the borrow pit «Martemianovo» of Tula region (filtration coefficient 1-3 m/day, gradation factor -1,67). Embankment height- from 1,5 to 8 m. The research was carried out in the years 2001-2005. Water content and soil density on the slopes were defined at depth 0, 20, 40 and 60 cm. during different times of the year. The depth was counted from the lower surface of top soil. The research was carried out in field and laboratory conditions with the use of certified appliances. The character of coat moisture gradient of the slope part during the spring months is shown on Fig. 6.



6. Coat moisture gradient of the slope part of grade level in spring 2004 year. km 104 /r «Don». 1 -5 - point on slope contour: 1 – on the edge, 5 - embankment foot, 2-3 - passing points

**Table 2.** The character of placement of thawed and frozen layers on the slope of the fill in the first half of the day March, 2004, km. 104 /r «Don», depth of fill 8 m, slope ratio 1:1,75. Slope orientation - south, air temperature at night  $-10^{\circ}$  , day  $+ 5^{\circ}$

layer	Soil state in the layer	Layer height, m
1	Frozen ground	0,03-0,05
2	Hydromorphic soil	0,05-0,10
3	Fluidity soil	0,05-0,10
4	Frozen soil	0,15-0,20
5	Non frozen soil	-

The fact of water flow in the soil (filtration flow) was photographed (Fig. 7)



**Fig 7.** Water filtration on the border of frozen and unfrozen soil (km 104 / r «Don», 14.03.2004)

Density measurements, carried out simultaneously with the humidity estimation showed that the soil on the slopes is in quite friable state (table 3).

**Table 3.** Soil density and humidity of the fill slope on 104 km road «Don» (average rates). Slope orientation - south. 14.03.2004

measurement point	Depth of measurement point, cm	Coat density g/cm <sup>3</sup>	Coat humidity %
1	0	1,83	14,5
	-20	1,80	13,8
	-40	1,76	17,3
	-60	1,87	15,7
2	0	1,85	10,0
	-20	1,85	12,5
	-40	1,83	15,1
	-60	1,87	15,7
3	0	1,83	9,1
	-20	1,80	12,5
	-40	1,76	16,0
	-60	1,87	17,5
4	0	1,83	10,9
	-20	1,80	12,2
	-40	1,76	15,6
	-60	1,87	15,0
5	0	1,76	13,0
	-20	1,83	14,0
	-40	1,83	16,2
	-60	1,85	17,5

*Note:* Optimum density for this sand is 1,89 g/cm<sup>3</sup>, optimum humidity - 10,9%.

Actual values of compacting factors (0,93-0,95-0,97) during the first 2,5 years of slope work (0,93-0,95-0,97) turned out to be lower than regulatory value (min 0,99), which certifies soil high porosity on the fill slopes.

The research of dynamic effects of automobile transport on the soil of the slope fill parts was carried out at 104 km /r «Don» (depth of sand fill - 6-8 m) 9 !4km R (depth of sand fill 2 m). On the /r «Don» convulsion in coat generated by passage of single -unit truck of the mass 22 t with the speed of 50, 60 and 80 km/h, at Moscow Ring Motorway there was moving a real traffic flow with the intensity (in one direction) 6480 veh/h (km 9) and 7200 veh./h (km 14). The carriageway of the road «Don» has 4 lanes (two lanes in each direction), at Moscow Ring Motorway - 4 lanes in each direction. Shoulder s at 1,0 m from the upper edge of embankment are hardened by plant formation. In both cases the the road pavement made of asphaltic concrete, the roadbase - of low cement content concrete, base – of sand.

Vibrational impact of automobiles on the soil of grade level was studied in dry weather, in July under the temperature of + 23° and in November under the temperature of +4° . There were registered mean square and peak heights (X, Y, Z) of vibration acceleration. Axle X is directed perpendicularly to the road axle. The measurement time amounted to 5 to 10 minutes and included the automobile drive to the measurement point and automobile removal.

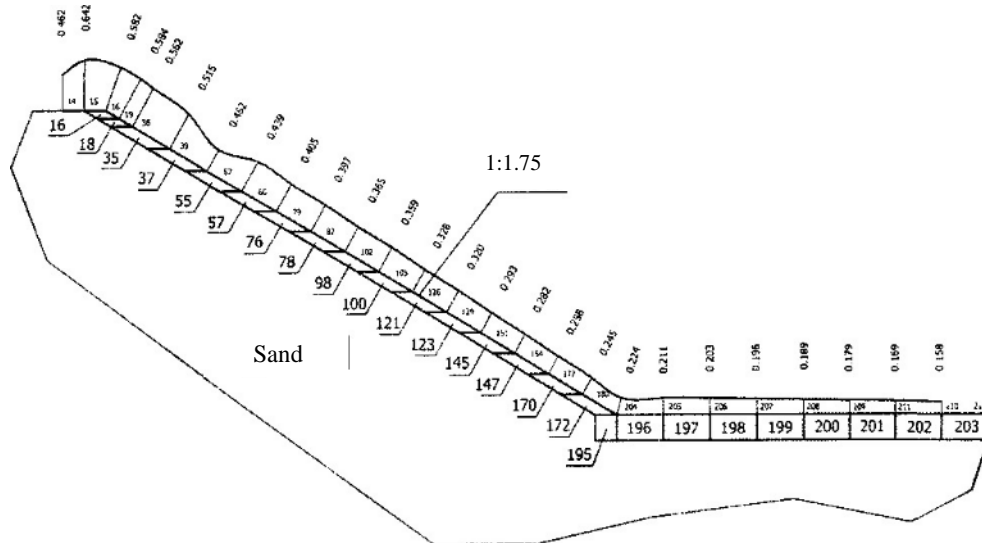
There were made measurements (the values of vidroaccelerations), processing of the results received according to the finite element method enabled to define, that the vibration impact on the slopes for the conditions discussed in case of problem solving on normal stress amounted, average, from 0,1 up to 0,044 kg/cm<sup>2</sup>, tangentially - from 0,04 to 0,001 kg/cm<sup>2</sup>. Value peaks fall within the upper and lower slope part, which suggests the increased load in these zones. The movement of soil parts amounts to 0,6 up to 0,2 mm and on the whole uniformly decreases in proportion to the standing off pumping source (from the cover of the road) (Fig. 8).

### III. CONCLUSION

The results of the research carried out enables to make a conclusion that local soil deformation on the embankment slopes are determined by the combination of the range of factors: low soil density in the slope surficial belt, high soil moistening in spring period, the presence of filtration stream of melted (and rain – in case of rain fall) water in the slope part of the roadbed. Vibrations generated in the soil of the roadbed by the cars passing by contribute to the disturbance of equilibrium of restraining and shearing forces.

Only one from the abovementioned factors is subject to control by the roads constructors - soil density of slope parts of embankment. However at the present time the embankment construction method implies that the slope soil is not compacted The technology of soil compacting of slope of embankments still is not worked out. The recommendations concerning the following overcutting of the unconsolidated slope soil, which one may find in references, cannot be considered as rational due to many reasons. As a consequence, the tools for the works

execution on slope soil stabilization are not available (one cannot view a small road roller, which rolls down the slope as a major compaction tool).



8. Curve of the soil particles flow (mm) as a result of operation of single load. Summary constituent, disturbing frequency 10 Hz

## References

- [1]. *Evdokimov V.I.* The nature of Yamal and roads: complicated interaction. The Journal «Russian Roads of XXI century», , 2005.
- [2]. *Kupachkin B., Radkevich .* Introduction to the new soil mechanics. The Journal «Russian roads of the XXI century», 1, 2006
- [3]. *Kondratiev V.G.* Qinghai-Tibetan railroads: new experience of the construction of grade level on deep-frozen soil. The Journal «Transport construction», 4, 2005.
- [4]. *G.Grondin, A. Guimond, G. Dore* Impact of permafrost thaw on airfield and road infrastructures in Nunavik - Quebec. «ROADS» (PIARC), 332, 2006.
- [5]. *Ivanov P.L.* Dilution of sandy ground. ., SEI, 1962
- [6]. *Nemchinov .V., Men'shov .S.* Influence of vibration of the road transport on the local slope stability of road bed. The Journal «Science and Engineering for Roads», 4, 2005.
- [7]. *Men'shov .S.* Provision of local slope stability of high fills of roads made of granular soil. Ph.D. Thesis. oscow, DI(S U), 2006.
- [8]. *Zolotar' I. ., Puzakov N. ., Sidenko V. .* Aquatic- heating parameters of the grade level and roadway paving. ., Publ. House "Transport", 1971
- [9]. SNiP 2.02.02-83. Base of buildings and constructions. ., 1985
- [10]. *Beliaev D.S., Yushkov B.S., Kychkin V.I., Rukavishnikova N. .* Development and approbation of the valuation method of technical condition of the grade level of the coats of transport works. The Journal «Russian Roads of the XXI century», 3, 2005 ♦