structure

M.V. NEMCHINOV
A.S. MEN'SHOV

Moscow State Automobile
& Road Technical University, Russia
uchsovet@madi.ru

ROAD SUBGRADE EMBANKMENT DEFORMATION

Abstract

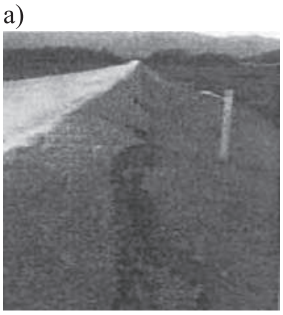
The impact of snow melting on slope's stability on the roads in cold regions is presented. Examples from Russia are given and the analysis of the results of investigation is presented. The authors point out to lack of modern tools and the lack of adequate preventive technologies.

Keywords: asphalt concrete, low viscosity bitumen, asphalt weather resistance, LTOA, STOA, AASHTO T283, PANK 4303

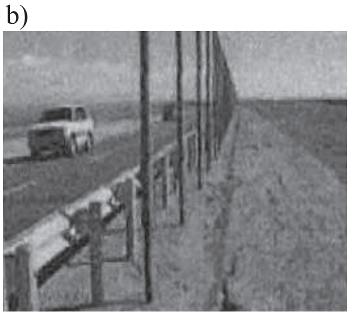
1. Introduction

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 suffered erosion and local shear deformations in the form of landslides, earthflows, caused by the impact of water on the ground. Such a 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. 1) [1, 2, 3, 4].

a)



b)



c)

d)

Fig. 1. Local deformations of subgrade embankment: a) road in Alaska [4]; b) Qinghai - Tibet railroads [3]; c) Russia – road «Yamal» [1]; d) Russia – road «Don» 104 km [1]

2. Forms of local deformation of the slope

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 Figure 2. In all cases there are slip lines of the definite coat massif of soil in the coating surface of the slope:

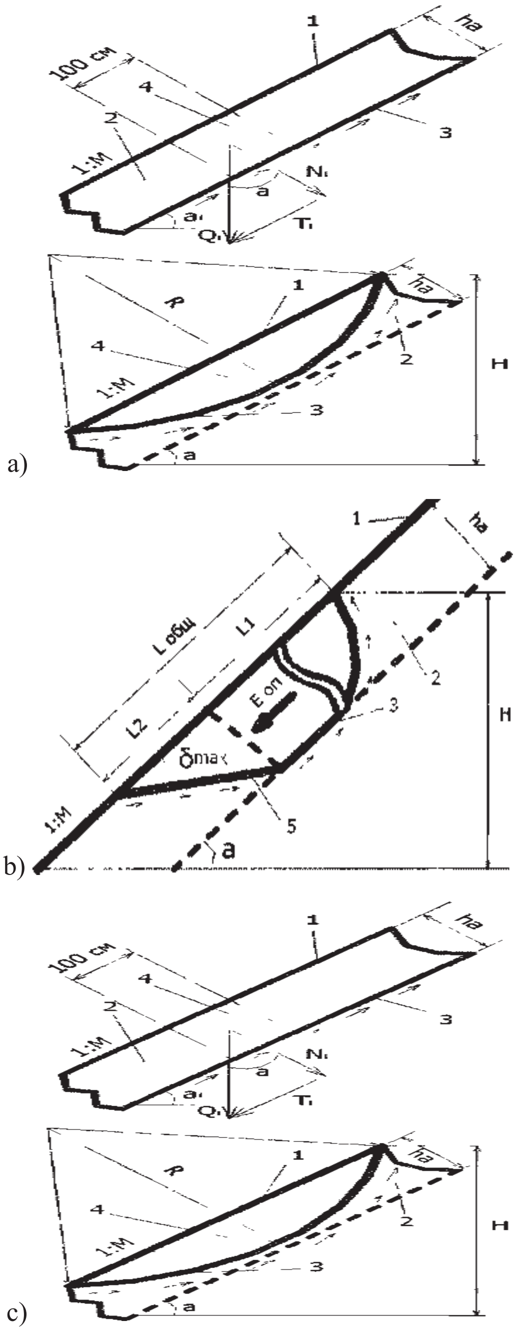


Fig. 2. Development scheme of shear deformations on the fill slopes [6]: a) due to identity element; b) inplane slip with uplift; c) destruction of the whole slope in the belt of weathering on the circular cylindrical surface; 1 – face of slope; 2 – capacity of the active zone ha; 3 – shift surface; 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:

$$R_{zap} = \frac{\gamma_{Zi} tg\varphi_n + C_n}{\gamma_{Zi} tg\alpha} = \frac{tg\psi_{Zi}}{tg\varepsilon}, \quad (1)$$

$$tg\psi_{Zi} = tg\varphi_n + \frac{C_n}{\gamma_{Zi}}, \quad (2)$$

where: γ – soil density; Zi – running coordinate of the active zone capacity of the slope perpendicularly its surface; $tg\psi_{Zi}$ – coefficient of soil shift of the active zone h at depth Zi; $tg\varphi_n$, C_n – correspondingly calculated values of angle of repose and soil cohesion at depth Zi; α – rate of slope.

2.1. The water and it role in losing stability of the 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 decreasing of angle of repose and cohesion between the particulates and dynamically effects the soil grains.

Structural cohesion C_n 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 C (MPa) and angle of internal friction φ (grade) with the porosity factor ε			
	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°C). 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. 3 [8]).

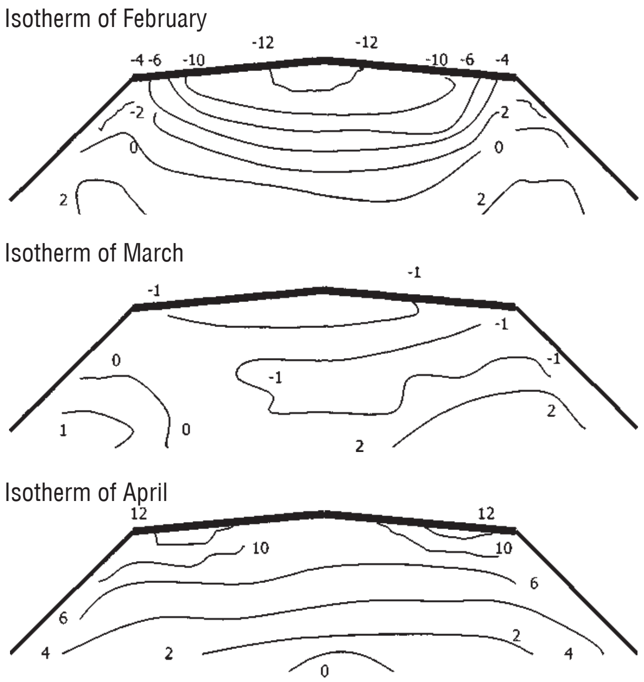


Fig. 3. Isotherms (°C) of the coat of grade level during the winter-spring months (Moscow and Moscow region)

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 mess 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. 4).

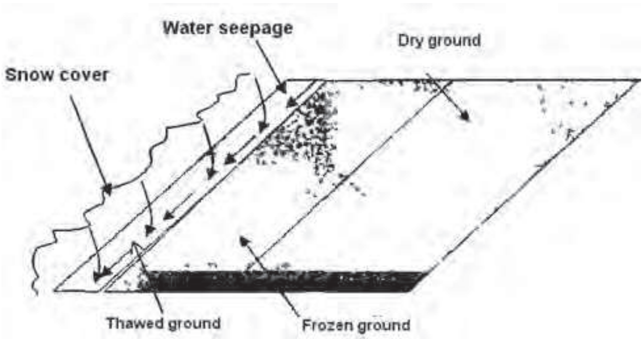


Fig. 4. Formation of the seepage on the slopes of the grade level during the snow melting

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 $Q = \Sigma q_i$. Elementary rate of flow qi 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 Figure 5.

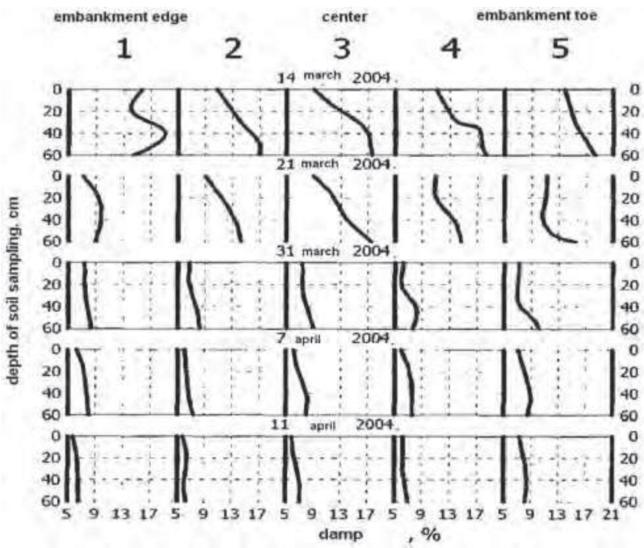


Fig. 5. Coat moisture gradient of the slope part of grade level in spring 2004 year. km 104 a/r «Don». 1-5 – point on slope contour: 1 – on the edge, 5 – embankment foot, 2-3 – passing points

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 a/r «Don», depth of fill 8 m, slope ratio 1:1.75. Slope orientation - south, air temperature at night -10°C, day +5°C

№ 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. 6).

Fig. 6. Water filtration on the border of frozen and unfrozen soil (km 104 a/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/cm³	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/cm³, 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 a/r «Don» (depth of sand fill – 6-8 m) and 94 km MKAR (depth of sand fill 2 m). On the a/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. Shoulders 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°C and in November under the temperature of +4°C. 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.

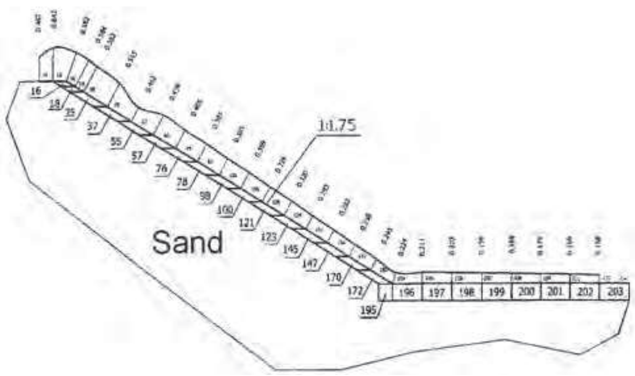


Fig. 7. Curve of the soil particles flow (mm) as a result of operation of single load. Summary constituent, disturbing frequency 10 Hz

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/cm², tangentially – from 0.04 to 0.001 kg/cm². 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. 7).

3. Conclusions

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).

References

[1] Evdokimov V.I. (2005): *The nature of Yamal and roads: complicated interaction*. The Journal «Russian Roads of XXI century».

[2] Kupachkin B., Radkevich A. (2006): *Introduction to the new soil mechanics*. The Journal «Russian roads of the XXI century», № 1.

[3] Kondratiev V.G. (2005): *Qinghai-Tibetan railroads: new experience of the construction of grade level on deep-frozen soil*. The Journal «Transport construction», № 4.

[4] Grondin G., Guimond A., Dore G. (2006): *Impact of permafrost thaw on airfield and road infrastructures in Nunavik - Quebec*. «ROADS» (PIARC), № 332.

[5] Ivanov P.L. (1962): Dilution of sandy ground. M., SEI.

[6] Nemchinov M.V., Men'shov A.S. (2005): *Influence of vibration of the road transport on the local slope stability of road bed*. The Journal «Science and Engineering for Roads», № 4.

[7] Men'shov A.S. (2006): *Provision of local slope stability of high fills of roads made of granular soil*. Ph.D. Thesis. Moscow, MADI(STU).

[8] Zolotar' I.A., Puzakov N.A., Sidenko V.M. (1971): *Aquatic- heating parameters of the grade level and roadway paving*. M., Publ. House "Transport".

[9] SNiP 2.02.02-83. Base of buildings and constructions. M., 1985.

[10] Beliaev D.S., Yushkov B.S., Kychkin V.I., Rukavishnikova N.E. (2005): *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.

M.V. Nemchinov
A.S. Men'Shov

Deformacje skarp nasypów drogowych

Praktyka konstruowania i modernizacji budowli ziemnych pokazuje, że podstawowe typy deformacji nasypów ziemnych, wykonanych z granulowanych materiałów, spowodowane są zjawiskiem erozji powierzchniowej poddanej lokalnym deformacjom spowodowanym ścinaniem. Sytuacja ta pojawia się na osuwiskach, gdzie występuje oddziaływanie wody w gruncie. Przeprowadzone wyniki badań umożliwiły sformułowanie wniosków, że lokalne deformacje gruntów na skarpach nasypów są spowodowane poprzez oddziaływanie następujących czynników: mała gęstość objętościowa pasów nasypów, wysoka wilgotność gruntu w okresie wiosennym, lokalne przenikanie wody w okresie topnienia lodu w korycie drogi. Drgania generowane w korycie drogi poprzez oddziaływanie ruchu pojazdów przyczynia się do zakłóceń w równowadze pomiędzy naprężeniami ścinającymi a hamowaniem. Aktualna wiedza dotycząca konstruowania skarp nasypów obecnie nie jest jeszcze usystematyzowana.