Influence of Mechanical Indices for Soil Basement on Strength of Road Structure

Influence des paramètres mécaniques de la couche de fondation sur la résistance d'une structure de chaussée

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ABSTRACT: It has been observed that at present insufficient attention has been paid to the consideration of moisture and mechanical indices variety for soil basement while designing of highways. Peculiarities have been analyzed for moisture variety of soil basement for the highway "Astana-Burabai". Peculiarities for indices variety of stress-deformed condition of road structure with cement concrete pavement have been calculated and determined.

RÉSUMÉ : Il a été observé que les variations de teneurs en eau et des paramètres mécaniques des couches de base sont généralement insuffisamment prises en compte lorsqu'on dimensionne des chaussées. Des particularités ont été analysées pour différentes teneurs en eau du sol de fondation de la route "Astana-Burabaï". Des variations des paramètres de comportement contraintes/déformations de la couche de fondation ont été également prises en compte et analysées lors du dimensionnement de la chaussée en béton de cette route.

KEYWORDS: highway, soil basement, cement concrete pavement, moisture, deformation, stress.

1. INTRODUCTION

Main elements for modern highways are pavement and soil basement. They have been operated jointly in the highway. Therefore while designing of highways calculation for pavement and soil basement strength has been carried out jointly (SN RK 2005).

As mechanical impact from car wheels, as well as climatic factors (temperature, moisture and so on) has been made over longevity and strength of road structures. Moisture of soil basement can be one of the main climatic factors, influencing greatly over highways with cement concrete pavement.

The following assumptions have been made in Kazakhstan present standard provisions for calculation of rigid pavements for strength (SN RK 2005):

- maximum moisture of soil basement has been observed in spring, when its complete thawing occurs, and the weakest condition of road structure complies with that time moment;
- theoretically soil basement has constant moisture value during overall service period for road structure (from 16 to 20 years for highways of I-III technical categories).

Fundamentals of present method of road structures for strength (SN RK 2005) were established in 60s-70s of the last century. At that time the above assumptions were accepted to simplify calculations. At present there are high performance computers and powerful software's, which allow to carry out very complicated calculations, considering seasonal moisture varieties, therefore, deformation and strength characteristics of soil basement.

2. HIGHWAY "ASTANA-BURABAI"

Express highway "Astana-Burabai" connects the capital of Kazakhstan, Astana city, with resort zone Burabai, and is a part of international automobile route "Atana-Kokshetau-Petropavlovsk-border of Russian Federation". Total length of the road is 224 km. It has 6 lanes with the width of 3.75 m each. Start (50 km) and final (47 km) road sections have cement concrete pavement, road section in the middle of the road (127 km) is pavement from crushed stone mastic asphalt concrete. Reconstruction of the road was fully completed in November 2009.

Pavement structure consists of: cement concrete, 25 cm; crushed stone optimum mix, 25 cm; coarse-grained sand, 30 cm.

To investigate the peculiarities of temperature and moisture variety temperature and moisture sensors were placed into soil basement of that road section in October 2010. Depth for placement of those sensors from the surface of cement concrete pavement was 80, 115, 150, 185 and 220 cm.

Soil basement of the road consists of light pulverescent clay loam: moisture at the border of rolling W_p = 15.0 %; moisture at the border of fluidity W_T = 25.4 %. Granulometric content of soil has been shown in the Table 1.

Table 1. Granulometric content of light pulverescent clay loam

Full residue (%) in sieves with size of cells (mm)					
2.0	1.0	0.5	0.25	0.1	0.05
6.8	8.4	10.9	17.3	28.2	29.4

Underground waters lay in the depth (below than 3.0 m from the land surface).

3. MOISTURE OF SOIL BASEMENT

Diagrams have been represented in the Figures 1 and 2, showing moisture variety during time period in different points of soil basement. Analysis of the mentioned diagrams has shown that character of moisture variety in various depths of soil basement is different. The surface of soil basement (80 cm) has proved to be very sensitive to seasonal climate variety: the biggest values of moisture (21-23 %) have been observed in spring and autumn seasons of the year, and in summer, due to the dry weather moisture reduces to 8-8.5 %, which can be explained by transferring of part of the liquid moisture into soil condition (ice) with negative temperatures.

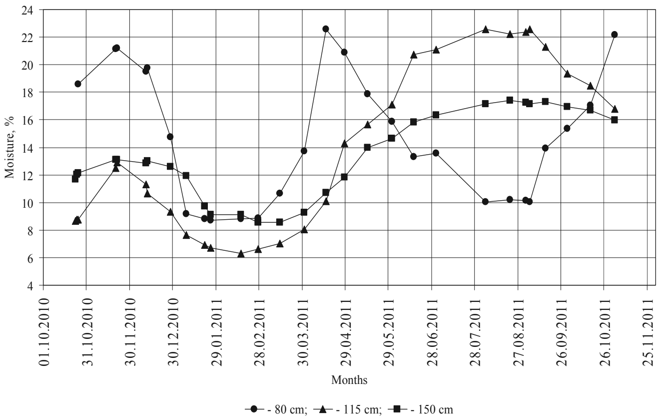

Figure 1. Moisture variety in soil basement of the highway "Astana-Burabai", road section with cement concrete pavement
(2010-2011)

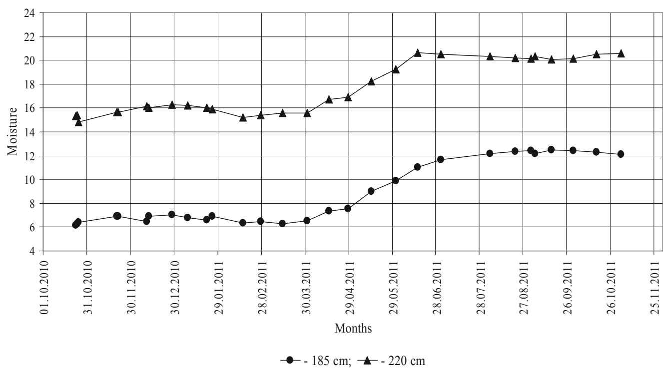

Figure 2. Moisture variety in soil basement of the highway "Astana-Burabai", road section with cement concrete pavement
(2010-2011)

Moisture increase in the depths of 115 cm and 150 cm occurs in summer and autumn seasons of the year (17-22 %) compared with spring (10-13 %). Moisture reduces to 6-9 % in winter season.

Moisture has not been reduced evidently in the depths of 185 cm and 220 cm in winter season. It can be explained by the fact that in the depths, mentioned above, negative temperature has small values. Moisture value was 15-16% in the depth of 220 cm in autumn 2010, moisture increase up to 20-21% occurred in spring 2011, which in future was practically constant. Moisture was of similar character of variety in the depth of 185 cm: moisture was 6-7% in autumn 2010; it was increased to 12% in spring 2011, and was practically constant in summer and autumn 2011. One can see from Figure 2, that the difference in moisture values of soil in the depth of 185 cm and 220 cm (8-10 %) during overall annual cycle is practically constant. Meanwhile, moisture in the depth of 220 cm is larger than in the depth of 185 cm, which can be explained by close location of the depth in 220 cm to underground waters.

Qualitative and quantitative analysis, carried out above, for moisture variety in points, located in different depths, has shown complicated character and non-homogeneous of moisture distribution in soil basement of the highway. In such cases it is convenient to use averaged moisture indices. Therefore, Figure 3 represents diagram, showing average moisture variety for soil basement of the highway. It reflects the following important peculiarities for moisture variety of soil basement according to its depth and time:

- it represents average value of liquid moisture at any reviewed time moment;
- moisture decrease occurs on winter season due to transfer of liquid moisture into solid condition (ice) with negative temperatures;
- initial moisture, observed in autumn 2010,with coming spring in 2011 has gradually been increased and further (in summer and autumn) remains practically constant.

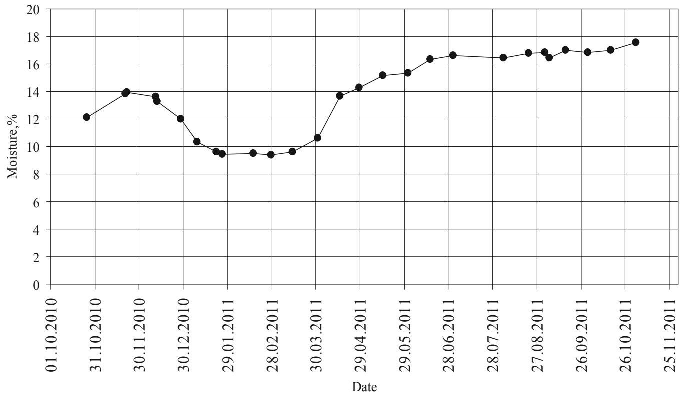

Figure 3. Average moisture variety in soil basement of the highway "Astana-Burabai", road section with cement concrete pavement (2010-2011)

4. STRENGTH-DEFORMED CONDITION OF ROAD STRUCTURE

4.1. Mechanical characteristics

Mechanical characteristics for materials of pavement layers have been represented in the Table 2.

Table 2. Calculated values of elasticity modulus and Poisson's coefficient for pavement layers

Material	Thickness h, cm	Elasticity modulus E, MPa	Poisson's coefficient
Cement concrete	25	37500	0.2
Crushed stone sand mix C 6 (40)	25	200	0.3
Coarse-grained sand	30	120	0.3

Mechanical characteristic of soil basement vary for a year. Their calculated values (Table 3) has been determined considering average moisture variety of soil basement (Figure 3). Meanwhile elasticity modulus value for soil in winter season has been determined based on the results of Prof. N.A.Tsytovich (Tsytovich 1973), and during other seasons of the year – based on recommendations of standard provisions (SN RK 2005). Due to the absence of reliable data, Poisson's coefficient value for soil has been accepted constant and equal to 0.35.

4.2. Calculated scheme and mathematical model for road structure

Calculated scheme for road structure has been represented in the Figure 4. This figure shows components for stress-deformed condition of road structure, which causes its destruction (sagging of the surface for cement concrete pavement ℓ, tensile stress σ_r and tensile deformation ε_r in cement concrete pavement, vertical compressed deformation for the surface of soil basement ε_{z0}).

Table 3. Calculated values of elasticity modulus for soil – light pulverescent clay loam

Calculated date	Average moisture W, %	Average temperature, ^{0}C	Elasticity modulus E, MPa
19.11.2010	13.9	7.0	90
24.01.2011	9.5	-4.6	6500
26.02.2011	9.4	-5.2	7200
14.04.2011	13.7	-0.4	500
16.06.2011	16.3	12.3	58
29.09.2011	16.9	14.7	51

Note: Only content of unfrozen moisture has been shown in winter season

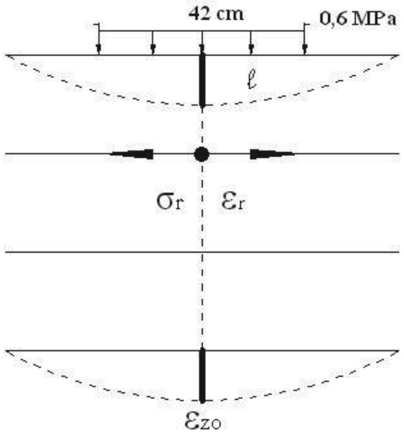

Figure 4. Calculated scheme of road structure

Mathematical model of multi-layer elastic half-space under influence of axle-symmetric load has been used to calculate the above components for stress-deformed condition of road structure (Privarnikov 1973). Load q = 0.6 MPa within circle with diameter of D = 42 cm influenced over the surface of concrete pavement. Such load corresponds to axle load of the truck Q = 13 tons.

4.3. Stress-deformed condition

The results of calculation of indices for stress-deformed condition of the road structure have been represented in the Figures 5 and 6. Analysis of the obtained dependencies has shown that sagging of the surface for cement concrete pavement, tensile stress and vertical deformation on the surface of soil basement have qualitatively similar character of variety in annual cycle. Thus, their least values have been determined in winter months (January, February), when upper part of soil basement is in the most frozen condition (average temperature in January and February is -4.6 ^{0}C and -5.2 ^{0}C respectively), due to this fact soil basement has the increased rigidity (ranging from 6500 MPa to 7200 MPa). With coming of warm season the rigidity of soil basement reduces, which results in the value increase of the above indices for stress-deformed condition (SDC) of pavement. Their biggest values were obtained during the period from June to September. Their values, obtained in the month of November, proved to be comparable with those ones obtained during the period from June to September. Therefore, the reviewed case shows that sagging of cement concrete pavement and vertical deformation of the surface for soil basement, during long period in annual cycle – from June to November – preserves the biggest values, which are higher in 6.0-6.5 times, compared with winter season.

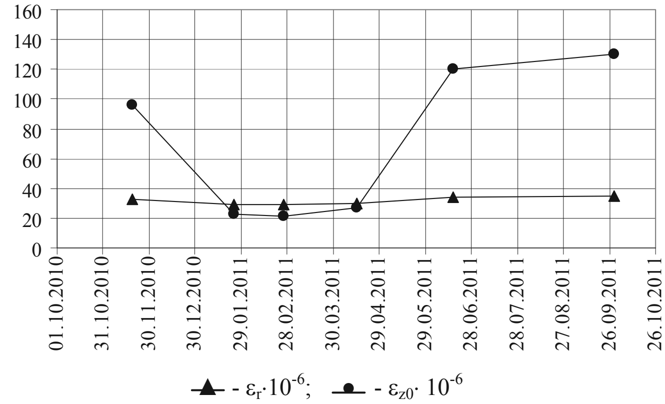

Figure 5. Tensile deformation (ε_r) in cement concrete pavement and compression deformation (ε_{z0}) on the surface of soil basement

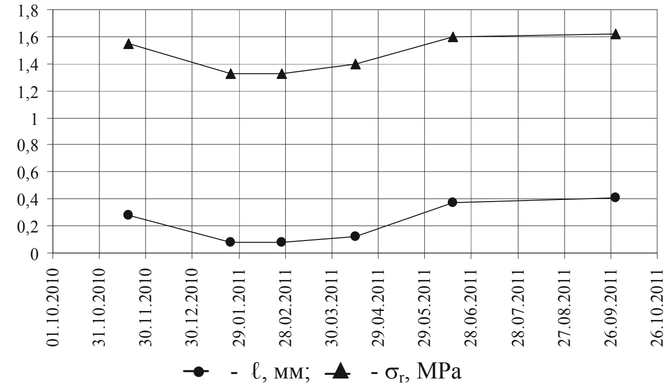

Figure 6. Sagging (ℓ) and tensile stress (σ_r) in cement concrete pavement

It should be mentioned that tensile stress value varies little in annual cycle. Thus, tensile stress value (1.6 MPa at average), occurring during overall summer-autumn seasons, is bigger only for 19 % of its least value, occurring in winter season (1.3 MPa at average). It can be explained by the fact that with big rigidity of cement concrete slab (E=37 500 MPa), which is bigger than rigidity of soil basement in 735 times in autumn season (E=51 MPa), rigidity increase in winter in 141 times (up to 7200 MPa) has not greatly influenced over tensile stress value.

Character of tensile deformation variety in cement concrete pavement differs substantially from the indices analyzed above. Tensile deformation value varies little in annual cycle ($2.9 – 3.5{\cdot}10^{-5}$), which also can be explained by big rigidity of cement concrete slab.

It should be mentioned that cement concrete slab has been calculated for sagging of pavement in spring, and sagging increase in summer and autumn seasons can be the cause of destruction of cement concrete slabs in the form of longitudinal, transversal and oblique cracks (Figures 7-9).

5. CONCLUSIONS

The results of experimental investigation for moisture variety of soil basement and calculations for indices of stress-deformed condition for road structure, obtained the work, allow making the conclusions as follows:

1. Moisture value and its phase content in soil basement of the highway vary substantially in annual cycle and according to the depth of basement.

2. Qualitative character of variety for sagging, tensile stress in cement concrete pavement and vertical compressed deformation of the surface for soil basement in annual cycle

Figure 7. Longitudinal crack in cement concrete pavement of the highway "Astana-Burabai"

Figure 8. Transversal crack in cement concrete pavement of the highway "Astana-Burabai"

Figure 9. Oblique crack in cement concrete pavement of the highway "Astana-Burabai"

is similar. Their maximum values occur in summer and autumn seasons, which are substantially bigger than in spring calculation season and can be the cause for appearing of longitudinal, transversal and oblique cracks in cement concrete pavement. Tensile deformation of cement concrete pavement varies little in annual cycle.

3. The issue of further investigation of peculiarities for moisture variety of soil basement for highways in different climatic conditions is topical.

4. Calculated values for mechanical characteristics of soils should be determined in laboratory and field conditions.

5. Carrying out of profound analysis for stress-deformed condition of road structures using reliable calculated values for mechanical characteristics of soils and considering value variety and phase content of moisture for soil basement in different climatic conditions is important for practical purposes.

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