

Seasonal features of temperature and moisture distribution in pavements and subgrade of highways in the South Kazakhstan

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ABSTRACT: Physical, mechanical and other characteristics of materials of pavement layers and soil bases, therefore the mechanical behavior of roads depends on the distribution of temperature and moisture at different points in time. In the study of temperature and moisture changes in structural elements of roads, experimental methods are important, which allow obtaining and accumulating reliable information in specific conditions (pavement structure, soil base, climate, weather, hydrogeology, etc.). In this paper we experimentally study seasonal changes and distributions of temperature and moisture in pavements and soil bases of roads located in the south region (Almaty and Shymkent cities) of Kazakhstan. Temperature and moisture values were measured using a special measuring system with sensors for long-term monitoring of temperature and moisture. It has been established that the daily and seasonal changes and distributions of temperature (in warm and hot periods temperature varied from 24 °C to 60 °C and higher) and moisture (it varied from 6% to 23%) can cause the occurrence and progression of plastic strains in the soil base and fatigue destruction in the asphalt concrete layers of road pavements. Recommendations are given for their prevention.

KEYWORDS: Experimental road sections, pavements, soil bases, temperature, moisture.

1 INTRODUCTION

The main structural elements of highways - road pavement and subgrade - function in difficult conditions. Highways are designed to ensure uninterrupted passage of vehicles. Therefore, they must first of all be resistant to mechanical effects from the wheels of passing vehicles. Highways are strongly affected by natural (geological, hydrological), weather and climatic (rain, snow, fog, solar radiation, temperature, moisture) factors. The physical and mechanical characteristics of asphalt concrete and bitumen-containing materials are highly dependent on temperature (Huang, 2004; Papagiannakis, 2008). The properties of clay and swollen soils are highly dependent on moisture content (SN RK 3-03-03-2014; SP RK 3.03-104-2014*). As is known, the processes of moisture and heat transfer are interrelated (Bergman et al. 2017). In addition, at negative temperatures, especially in cold regions, phase transitions occur in wet base soils, causing some of the moisture to transition from a liquid state (water) to a solid state (ice), while other moisture remains in an unfrozen state (Teltayev et al. 2015; Teltayev & Suppes 2019). The deformation and strength characteristics of clay soils in these physical states vary significantly.

The above shows how important it is to have information about temperature and moisture conditions in road pavement structures and subgrade in order to correctly determine strains and stresses in them (Teltayev & Aitbayev 2015; Teltayev et al. 2018).

The works of Teltayev and others (Teltayev et al. 2020; Teltayev et al. 2022; Teltayev & Suppes 2017) are known, in which the features of temperature and moisture change and distribution in road pavement structures and subgrade located in several regions of Kazakhstan are experimentally studied.

This article experimentally studies the changes and distribution of temperature and moisture in road pavement

structures and base soil in the cities of Almaty and Shymkent, located in southern Kazakhstan.

2 EXPERIMENTAL ROAD SECTIONS

2.1 *Experimental Road Section on Abay Avenue (Almaty)*

To conduct long-term monitoring of temperature and moisture in the layers of road pavement and soil base in the city of Almaty, a section of the road on Abay Avenue (in line with a building located at 64 Bereke Street) was selected. The road pavement structure on the section consists of the following layers:

Layer 1: Stone mastic asphalt concrete 20, thickness $h_1 = 5$ cm;

Layer 2: Coarse-grained asphalt concrete, $h_2 = 10$ cm;

Layer 3: Coarse-grained asphalt concrete, $h_3 = 13$ cm;

Layer 4: Mixture of gravel and sand, $h_4 = 20$ cm;

Base soil: Mixture of crushed stone, gravel and sand, $h_5 = 65$ cm.

2.2 *Experimental Road Section on A-2 Highway (Shymkent)*

A section of the A-2 highway in the city of Shymkent was selected. The road pavement structure on the section consists of the following layers:

Layer 1: Stone-mastic asphalt concrete (SMA-20), $h_1 = 5$ cm;

Layer 2: Coarse-grained porous asphalt concrete, $h_2 = 7$ cm;

Layer 3: Crushed stone treated with bitumen, $h_3 = 5$ cm;

Layer 4: Sand and gravel mixture, $h_4 = 80$ cm;

Base soil: loam.

3 MONITORING SYSTEM FOR TEMPERATURE AND MOISTURE

In order to carry out long-term monitoring of temperature and moisture on the selected road sections, a special measuring

systems (Fig. 1a) with temperature and moisture sensors (Fig. 1b) was installed. The sensors were installed in the layers of the road pavements and in the points of the soil bases at different depths from the pavements surfaces. The monitoring systems are powered by solar panels. The values of temperature and moisture are measured hourly in the specified locations and the measurement results are saved.

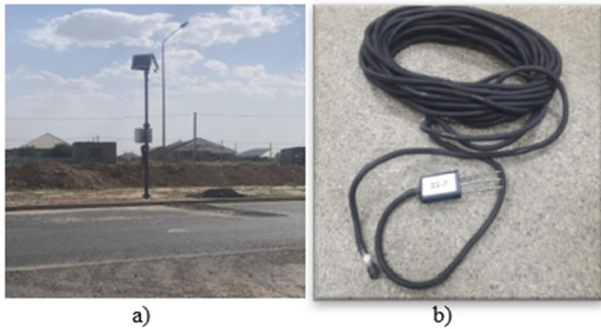


Figure 1. Monitoring system for temperature and moisture: a) Above-ground part of the system; b) - Temperature and moisture sensors

4 RESULTS AND DISCUSSION

4.1 Temperature

The air temperature values, as well as the values of temperature in the road pavements layers and the points of the soil bases in the cities of Almaty and Shymkent, were obtained using the temperature and moisture monitoring systems.

Figures 2-5 show the daily temperature changes in the air, in the layers of the road pavement, and in the points of the soil base in the city of Almaty during the autumn (October), winter (December and February), and spring (March) periods. As can be seen, the pavement surface temperature of the road rises to 27 °C in October. Daily temperature fluctuations penetrate up to a depth of 40 cm. In December, the maximum temperature is around 5 °C. The depth of daily temperature changes also decreases to 20-25 cm. In February, the pavement surface temperature can reach 9 °C. The daily temperature effect can be observed up to 35-40 cm. In March, there is already active warming: the surface temperature of the asphalt concrete pavement increases to 37 °C, and the depth of daily temperature fluctuations reaches 60 cm.

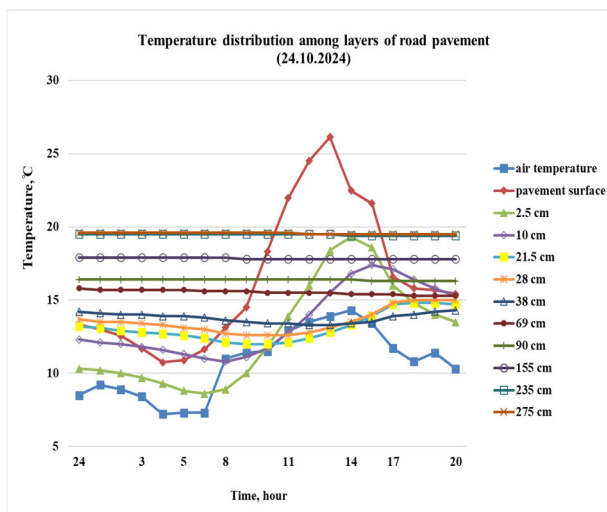


Figure 2. Daily change in temperature of air, in pavement layers and soil base points in Almaty in October, 2024

Thus, as the transition from winter to spring increases, both the amplitude and the depth of daily temperature fluctuations in the road pavement structures increase. During the winter period, the temperature gradient in the layers of the road pavement structure is not significant, while it increases in the spring, especially in the upper layers.

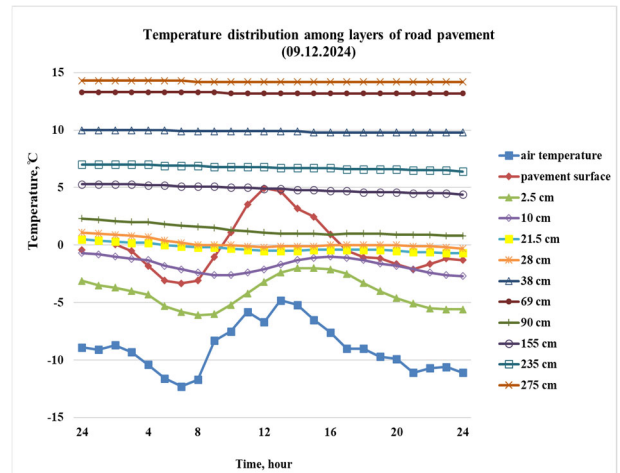


Figure 3. Daily change in temperature of air, in pavement layers and soil base points in Almaty in December, 2024

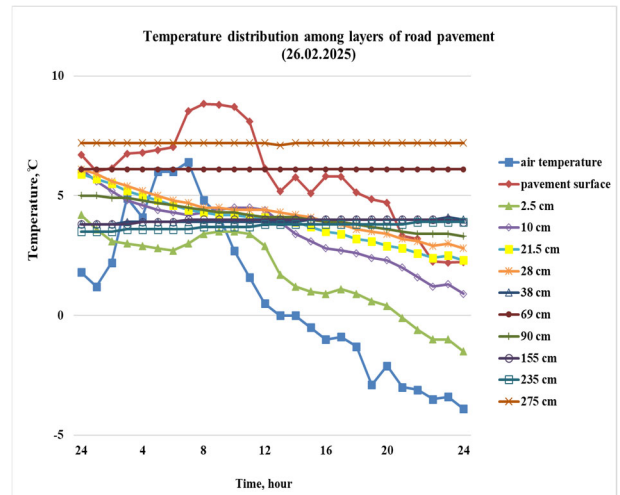


Figure 4. Daily change in temperature of air, in pavement layers and soil base points in Almaty in February, 2025

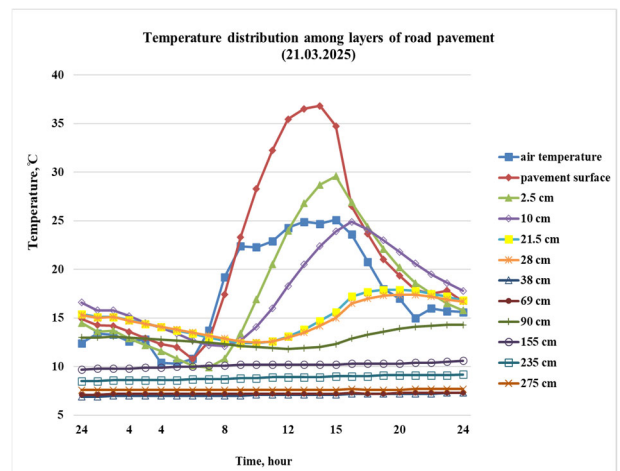


Figure 5. Daily change in temperature of air, in pavement layers and soil base points in Almaty in March, 2025

Figures 6-9 show graphs of daily changes in air temperature, in layers of the road pavement, and in points of the soil base in the city of Shymkent during different periods of the year.

As can be seen, in August (one of the hottest months), the surface temperature of the asphalt concrete pavement reaches 60 °C, which is due to the high solar radiation. The daily temperature fluctuations penetrate up to 60-80 cm. In the autumn period (October), the maximum temperature is around 25 °C, and the depth of the daily influence decreases slightly (40-50 cm). In the early winter period (December), the pavement surface temperature does not exceed 15 °C, and the daily temperature change is observed only up to a depth of 20-25 cm. In the late winter season (February), the maximum pavement surface temperature can be around 12 °C, and the depth of daily temperature fluctuations gradually increases (up to 30-35 cm).

Thus, in the summer in Shymkent, the surface temperature of the asphalt concrete pavement can reach high values (up to 60 °C and higher). The depth of daily temperature fluctuations extends up to 80 cm.

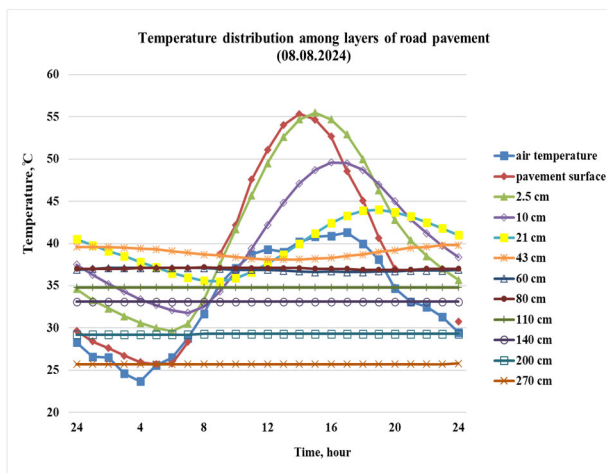


Figure 6. Daily change in temperature of air, in pavement layers and soil base points in Shymkent in August, 2024

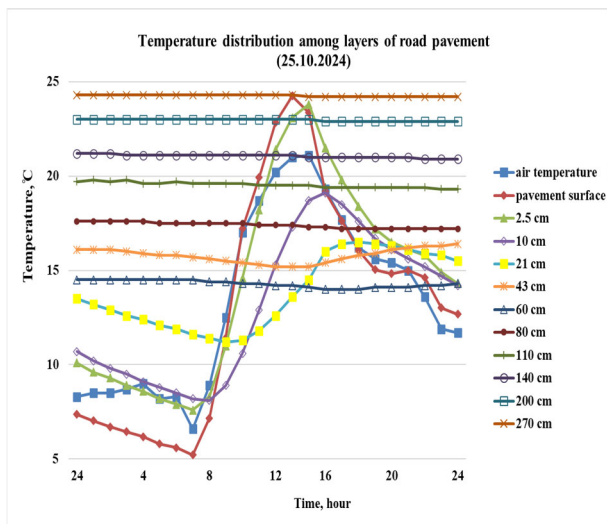


Figure 7. Daily change in temperature of air, in pavement layers and soil base points in Shymkent in October, 2024

4.2 Moisture

Figure 10 shows the depth-distribution graphs of moisture content in the layers of the road pavement base and in the points of the soil base on the experimental road section in the city of

Almaty in different seasons of the year. It can be seen that at a depth of more than 270 cm, the moisture content remains unchanged (about 5%) throughout the entire period under consideration (October 2024 - March 2025). In the direction from bottom to top, the moisture content in the points of the road pavement and soil base changes in different months (seasons) of the year. At the same time, the value of the seasonal change in moisture is greater in the layers of the road pavement base and the upper part of the soil base (28-155 cm); at these depths, the moisture content varies from 7.5-8% to 14%. These results show that the groundwater is located deep (more than 3 m) and has almost no effect on the moisture regime in the road pavement and the soil base. The seasonal changes in moisture in this road section are caused by seeping (infiltrating) surface water (rain and melted snow). To ensure the stability (unchangeability) of the moisture regime in the road pavement and soil base, it is recommended to exclude the entry of surface water in such road sections during an annual cycle.

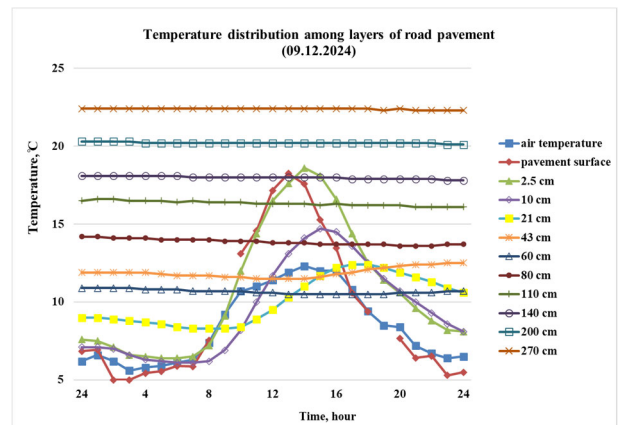


Figure 8. Daily change in temperature of air, in pavement layers and soil base points in Shymkent in December, 2024

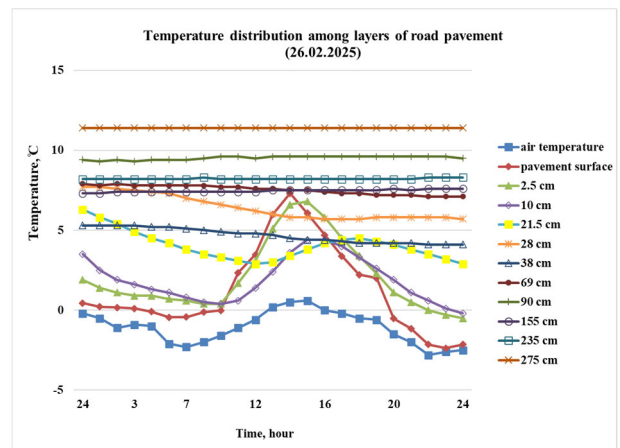


Figure 9. Daily change in temperature of air, in pavement layers and soil base points in Shymkent in February, 2025

Similar graphs of seasonal moisture distribution on the road section in the city of Shymkent are provided in Figure 11. This figure clearly shows that the moisture content varies significantly with depth (from 1-1.5% at a depth of 21 cm to 23% at a depth of 140 cm), but remains relatively constant in the road pavement and soil base during the summer, autumn, and winter seasons (August-December 2024). In other words, the moisture regime on this road section is stable. However, this moisture regime poses a serious danger: at depths of 80 and 140 cm, the soil base contains 18-23% moisture. Given that the strength characteristics of loam are significantly reduced at

such moisture levels, and the total thickness of the "rigid protective" layers (the two asphalt concrete layers and the layer of bitumen treated with a crushed stone) is only 17 cm, and their rigidity (protective capacity) is significantly reduced during the hot summer months, there is a reason to believe that plastic (irreversible) strains may occur and progress more rapidly in such road sections (Teltayev et al. 2024; Teltayev et al. 2025). A decrease in the rigidity (strength) of the soil base, in turn, will accelerate the occurrence and progression of fatigue destructions in the asphalt concrete layers of the road pavement (Iskakbayev et al. 2017; Teltayev, 2015). The above-mentioned destructive processes can lead to a significant loss of strength and durability of the road.

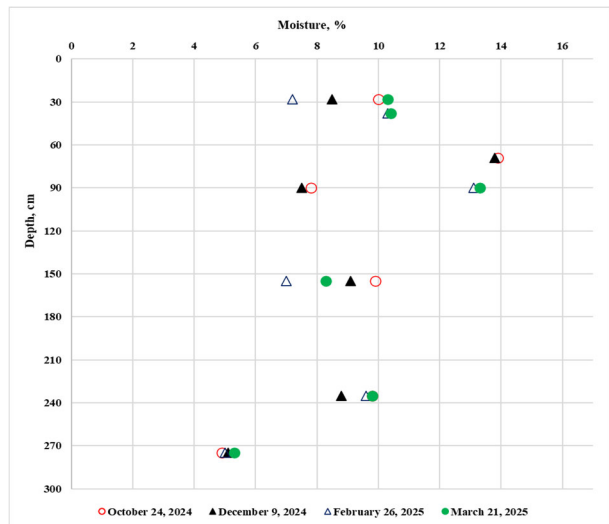


Figure 10. Seasonal distribution of moisture at different depths of pavement and soil base in Almaty (October, 2024 – March, 2025)

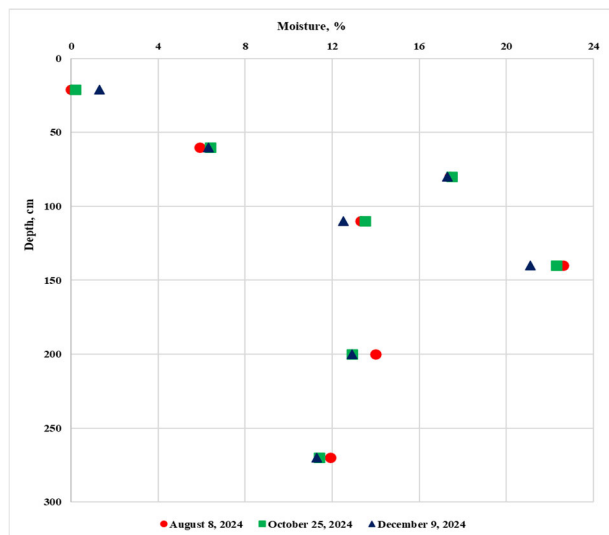


Figure 11. Seasonal distribution of moisture at different depths of pavement and soil base in Shymkent (August, 2024 – December, 2024)

5 CONCLUSIONS

1. The upper part of the road pavement structures is exposed to daily and seasonal changes of temperature. The maximum temperature of the asphalt concrete pavement surface in the city of Almaty in spring (in March) reaches 37°C, and in the city of Shymkent in summer (in August) - 60°C. The greatest depth of daily temperature change takes place in the summer period and it reaches 60-80 cm.

2. In the experimental section in the city of Almaty there is a significant seasonal change in moisture (6-14%) at depths of 60-90 cm; to stabilize the moisture regime it is recommended to exclude the infiltration of surface water (rain and melted snow).

3. In the experimental section in the city of Shymkent the moisture content of loam at depths of 80 and 140 cm is 18% and 23%, respectively, which can cause the occurrence and rapid progression of plastic strains in the soil base and fatigue damage in the asphalt concrete layers of the road pavement. These negative processes can be prevented by regulating the moisture regime in the soil base.

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