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THERMAL CONDITIONS OF ROAD PAVEMENTS AND THEIR INFLUENCE ON MOTOR TRAFFIC

Alfredas Laurinavičius[1], Donatas Čygas[2]

Dept of Roads, Vilnius Gediminas Technical University,
Saulėtekio al. 11, LT-2040 Vilnius, Lithuania

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Abstract. The article presents the analysis of climatic conditions in the Republic of Lithuania and describes their influence on road asphalt concrete pavement. Dependence of the main properties of asphalt concrete mixtures on temperature is described with the help of carried out experiments. Research findings show that the probability of plastic deformations (rutting and corrugation) in asphalt concrete pavement is higher when the pavement temperature is 20-40 °C. Practical application of the presented conclusions and recommendations will enable to reduce the occurrence of undesirable deformations in asphalt concrete pavements and to improve traffic conditions on the roads.

Keywords: thermal conditions; road pavement; temperature; plastic deformations.

1. Introduction

The state road network of the Lithuanian Republic is completely developed and makes up 21,315 kilometers, 1,724 km of which are main roads, 4,864 km national roads, and 14,727 km regional roads.

Out of the total network, 9,226 km are gravel roads and almost all of these roads are district roads. In 2002 the total length of local roads is 34,800 km in Lithuania. Most of them are gravel roads.

Road pavement is one of the most important road elements. Static and dynamic transport loads and environmental factors continuously affect it. The properties of asphalt concrete pavements vary depending on temperature, level and frequency of loading and the composition of asphalt concrete mixtures.

At low temperatures, low load levels, and high frequencies asphalt concrete materials are linearly viscous elastic with hereditary characteristics. However, at high temperatures slow loading rates and high loads, the behavior of the material tend to be nonlinear elastic viscous plastic [1, 2].

These relatively weak pavements are considerably influenced by climatic factors, which significantly vary in Lithuania.

The climate of Lithuania, as a certain geographical region, forms under the influence of global and local climatic factors.

The most common climatic features of Lithuania are influenced by the geographical location of its territory. Lithuania is located in the northern part of the middle climatic zone. The distance of the territory from the Equator (6,100 km) as well as the North Pole (3,900 km) influence on the total radiation of the sun: on average, Lithuania receives 3,600 MJ/m^2 per year, and the areas of the Equator receive 6,000–8,000 MJ/m^2. The second global factor is the prevailing western air masses transfer on middle latitudes. This transfer occurs due to temperature and pressure contrasts between high and low latitudes [3].

The local geographical latitude, sun radiation, atmospheric circulation, and the interaction of these factors with the surface of the Earth cause uneven distribution of air temperature in time and space. Fluctuations of air temperature due to the geographical latitude and sun radiation are not great in Lithuania since its territory is located between 53°34' and 56°27' of the northern latitude and 20°56' and 26°51' of the eastern longitude.

Due to the warming influence of the sea winter is much warmer, spring is cooler, fall is longer and warmer. The influence of the Atlantic Ocean is felt not only on the seaside area, but also on the territory of the whole Lithuania, the climate of which is much warmer than the climate of continental regions on the same latitudes. The average monthly temperature in January is almost ten degrees higher than the average temperature of Central Russia of our geographical latitude, and summer temperature fluctuations are inconsiderable. The main cause of the Lithuanian air temperature deviations from the climatic norm is atmospheric circulation, i.e. how far warm and humid air penetrates into the continent.

The Lithuanian climate is described as medium cold with snowy winter. The amount of precipitation is quite high throughout the whole year, especially higher in the

[1]E-mail: alfla@ap.vtu.lt
[2]E-mail: dcyg@ap.vtu.lt

warm period. The average temperature of the coldest month is lower than –3°C, and it does not exceed +22°C during the warmest month. The average temperature of not less than 4 months is higher than 10°C. Such climate is typical of the central part of Eastern Europe. The climate of the western region of Lithuania is described as medium warm since the average temperature of the coldest month is higher than – 3°C. This type of climate prevails in Western Europe [4].

2. The Main Climatic Factors

2. 1. Thermal Conditions of Road Pavements in Lithuania

Air temperature depends on the season of the year and the region.

In autumn and winter the temperature in Western Lithuania is 2–3°C higher than in the Eastern Lithuania. The warming influence of the Baltic Sea is extremely strong on the seaside area up to the Zemaiciai highland. The meridional distribution of temperature testifies that the Atlantic and Baltic thermal advection has the greatest impact on the formation of thermal regime during this time of the year [4].

In March the meridional distribution of temperature remains only on the seaside area since it is more influenced by the increase of the sun insulation, and the contrast in temperature between the land and the sea disappears. In April the sea area of water becomes cooler than on the land on the latitude of Lithuania. However, the cooling influence of the Baltic Sea is not great in April. The average temperature is not higher than 5°C in 24 hours in April (the earliest in south-west is at the end of the first decade, and in north-west and east: at the end of the second decade). At the end of spring and the beginning of summer the thermal contrast between the sea and the land starts increasing again, but it is not as high as in winter. In summer when cyclic activities weaken the relief has the most influence on the temperature distribution on the territory of Lithuania since vertical temperature gradients are the highest at this time of the year. In summer two important factors, which influence on temperature (the distance from the sea and the altitude of the location) compensate each other. Due to the increasing altitude of the location in Eastern Lithuania the air temperature is even 0.2–0.3°C lower in July than in the lowlands of Central Lithuania. Therefore, due to the distance from the sea the relief and the sun radiation, a specific climatic zone of summer air temperature forms: territorial fluctuations make up only 1.3–1.4°C in July; the lowest temperature is in north-west, Zemaiciai highland as well as north-east, and warm slopes of the middle reaches of the rivers Nevezis and Nemunas, where air temperature reaches up to 17.0–17.5°C in July (Table 1).

Table 1. Peculiarities of Lithuanian Regions and Sub districts

Regions	Seaside			Zemaiciai		Central Lowland		North-east Highlands		
Sub districts	Corronian Spit	Sea Shores	Seaside Low-lands	Zemaiciai Highlands	The Middle Venta Low-lands	Musa, Nevezis	The Lower Nemunas	Suduva	Dzukai	Aukstaiciai
Average annual temperature (°C)	7.2	6.3–7.0	6.3–6.8	5.7–5.9	6.0	5.9–6.2	6.3–6.7	6.4	6.1–6.5	5.4–5.8
The warmest month and its average temperature (°C)	July 17.2	July 16.0–16.6	July 16.3–16.7	July 16.1–16.4	July 16.5	July 16.6–17.1	July 16.0–17.5	July 16.6	July 16.9–17.5	July 16.7–17.1
The coldest month and its average temperature (°C)	February –3.2	February –3.2	January –(4.2–3.8)	January –(5.3–4.7)	January –4.6	January –(5.7–5.4)	January –(5.0–4.4)	January –5.0	January –(5.8–5.2)	January –(6.8–5.9)
Precipitation per year (mm)	~700	~740	750–800	800–900	650–750	520–620	650–750	550–650	600–700	600–700
The duration of the period with snow layer (in days)	75–80	70–75	75–80	90–100	80–90	85–100	75–90	80–85	85–100	100–110
The most important processes influencing climatic peculiarities	1. Transfer of marine weather to the continent. 2. Breeze circulation on the seashore.			1. Rise of wet air masses on the slopes of highlands. 2. The impact of local altitude.		1. Adiabatic weather moving down from adjacent altitudes. 2. Poor conditions of flowing on the flat surface. Reirrigation of soil.		1. Increase of turbulentic air circulation and thermal convection on the uneven location. 2. Impact of local altitude.		

An average air temperature is the same in July and August on the seaside area (16.7–17.0°C), and the warmest period is in the third decade of July and the first decade of August (17.5°C).

The coldest month of the year is January almost in the whole territory of Lithuania (except seaside); on average, the temperature drops to –5.3–-6.9°C in the third decade. The coldest month is February in the seaside area (–3.2°C), especially its second decade (–3.8°C).

Due to the delay of temperature extremes on the territory of Lithuania, an average air temperature in August is higher than in June. This difference is the highest on the seaside area: ca 2.4°C, and it drops to 0.3–0.4°C in the direction of east.

The change of air temperature in 24 hours is an important climatic indicator. The main factor, which influences the change of air temperature in 24 hours, is the development of the radiation balance and its addends in 24 hours [4].

2.2. Soil Temperature and the Depth of Frost

Soil temperature depends not only on the factors influencing the temperature, but also on the type of soil and its mechanical composition, humidity, flora and a snow layer. If compared with air temperature, on average, the surface of soil is 3–6 °C warmer in summer and colder in winter.

Temperature fluctuations of soil surface, the heat conductivity of which is high, cause the same fluctuations in the bottom layers of soil. Due to this heated thick soil layer will accumulate more heat and will partially compensate cooling at night [5]. The circulation of heat in dry friable soils (heat conductivity of which is very poor) occurs in a much thinner surface layer; therefore, higher temperature amplitudes per 24 hours are typical of them. For example, the surface of sandy soils heats up to 38 °C in the daytime, and up to 11–12 °C at night in the south-east of Lithuania in July. The temperature amplitude per 24 hours on the soil surface is 4–5 °C less on Zemaiciai highlands where more humid clayey soils prevail. In summer, the amplitude of temperature per 24 hours reaches 4–5 °C in clayey soils, and it does not exceed 3 °C at the depth of 0.2 metres in loams.

Instantaneous temperature of soil at the positive radiation balance reduces deeper (in the daytime), and when the radiation balance is negative, it increases at night [5]. During the warm period the highest soil temperature is at 17.00-18.00 at the depth of 5 cm, and at 20.00–21.00 at the depth of 20 cm. Temperature fluctuations in 24 hours occur at the depth of 0.7–0.8 m in most soils.

If ground water does not lie deep, capillary humidity easily reaches soil and flora. Due to this ground water, which does not lie deep, cools soil in summer. In winter, vice versa, it warms and checks freezing of deeper layers of soil.

The least depth of frozen ground occurs in Zemaiciai highlands since the thickest snow layer forms there (25–30 cm). The greatest depth of frozen ground has been observed in Southern Lithuania, where dry sandy soils prevail; ground waters lie deep and the thickness of the snow layer is 5 cm less than in Zemaiciai highlands. The thickness of the layer of snow does not exceed 20–25 cm. Due to this soil freezes comparatively deep basically influencing the depth of frozen ground. The greatest depth of frozen ground is at the end of winter (February–December). The depth of frozen ground varies depending on meteorological conditions in winter. During extremely cold winters soil freezes up to 1–1.5 m. During warm winters without snow the ground cannot freeze at all or it can be not deep (10–20 cm) and unstable. Temperature of soil under the snow layer is relatively stable and rarely drops lower than – 10 °C. In spring the frozen ground starts melting during the first decade in April (on average).

2.3. Precipitation

On average, precipitation is 675 mm per year in Lithuania (44 km3 of water). According to the amount of precipitation Lithuania is in the zone of excessive irrigation since not all of it can evaporate.

According to the composition in phases liquid precipitation prevails in Lithuania (72–77% of the total amount of precipitation). The second type is mixed precipitation (13–19%), and lastly, hard precipitation (snow and ice) (6–9%). The least amount of precipitation is in January–March (in February–April on the seaside area), and the greatest amount is in June–August.

The maximum amount of precipitation is at the beginning of summer in the east and South East of Lithuania (70–80 mm precipitation in June–July). August is the rainiest month in the west and north- west of Lithuania (90–100 mm on Zemaiciai highland and 70–85 mm during other months). The greatest amount of precipitation (80–90 mm) on the seaside area is in September. Rain makes up 30–40% of the total amount of precipitation on the seaside area in winter and 5–15% in Eastern Lithuania. In summer liquid precipitation makes up 98–99%; the rest 1–2% (1–3 mm) is mixed precipitation (which is mostly hail with rain). The hard precipitation falls from October until April; however, part of the total amount of precipitation does not exceed 40–50% (36% on the seaside area) even in January–February. The amount of precipitation is almost the most varying climatic element in various years.

A very important indicator of precipitation amount variation per year is the sum of precipitation during the warm (April–October) and cold (November–March) periods. In Lithuania, 64–72% of annual amount of precipitation falls during the warm period. This is a transitional type of annual development of middle latitude precipitation from marine to continental.

On average the total duration of precipitation is 1,300–1,000 hours/ per year in Lithuania. The duration of precipitation is less during the warm period than during the cold period even if the amount of precipitation is bigger. Precipitation lasts not longer than 3–4 hours in 24 hours in summer and 8–10 hours in 24 hours in winter (ca 90% cases).

Dry periods when there is no precipitation for 5–9 days in turn mostly occur in May (9–12 times in 10 years) and rarely in December (7 times in 10 years on average).

The dates when the first snow falls are close to the average dates when air temperature falls below zero. The earliest dates of the first snow in the east and the north of Lithuania are on approximately the 15th November, and the latest on the Pajurys lowland on the 25th November. However, permanent snow layer forms much later (after 3–4 weeks) due to frequent thaws. A permanent snow layer is a layer which stays for not less than one month with not longer than three–day breaks. The dates of permanent snow layer formation vary each year depending on the type of weather and atmospheric circulation.

3. The Influence of Air Temperature on Plastic Deformations in Asphalt Concrete Pavements

Scientists from various countries investigate the specificity of climatic conditions, their variety as well as the influence on the performance of road pavement construction. A lot of attention is being paid to the study of thermal conditions and the influence of temperature on the main characteristics of asphalt concrete pavement as well as the analysis of undesirable plastic deformations' occurrence [6, 7].

Road pavement directly influenced by vehicle wheels and climatic factors constantly changes its properties when pavement surface wears: wearing asphalt concrete course becomes thinner and sharp edges of particles on the pavement surface are polished; therefore, pavement strength, roughness and traffic safety on the road decrease [8]. Climatic factors and their impact on the pavement are not the same as well. At the beginning of winter snow is usually ploughed from the carriageway to shoulders and slopes of the embankment; therefore a thermal insulation layer of certain thickness is laid and the road pavement cools sooner [8–10].

Since traffic volumes, the number of heavy vehicles as well as axle loads of these vehicles have increased on the Lithuanian roads and streets recently, plastic deformations such as rutting and corrugation form on road and street pavements [11]. The occurrence of such deformations is increasing considerably during the hot period when air temperature rises up to 25–30 °C, and asphalt concrete pavement heats up to 40–50 °C.

The Road Research Laboratory of the Department of Roads systematized the average air and pavement temperature measurement data obtained on the motor roads of the Vilnius region in July 2001. Data were received from the RWIS (Road Weather Information System) database.

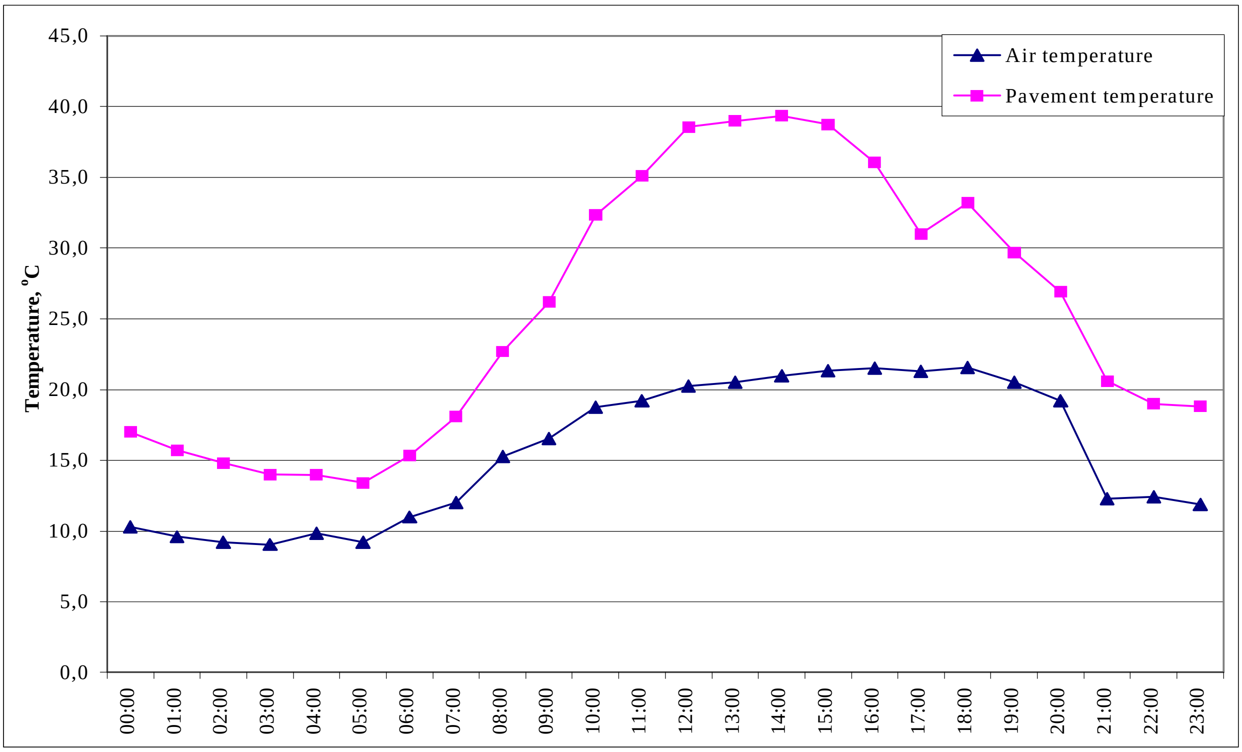

Fig 1. Variation of air and road pavement temperature in 24 hours (maximum air temperature is 20–25 °C)

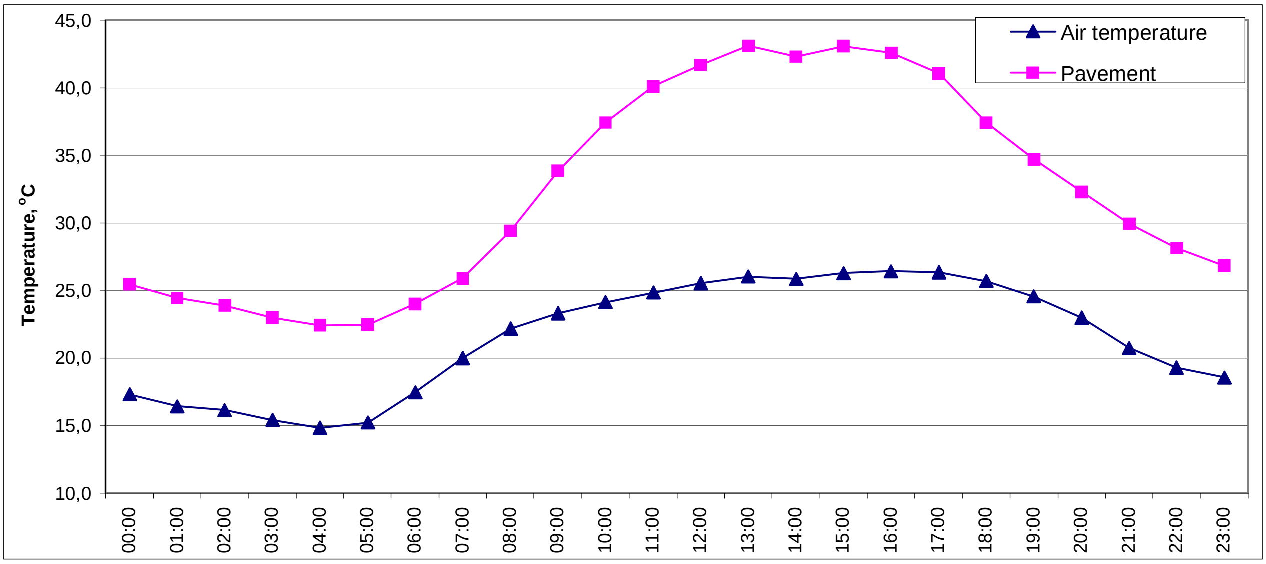

Fig 2. Variation of air and road pavement temperature in 24 hours (maximum air temperature is 25–30 °C)

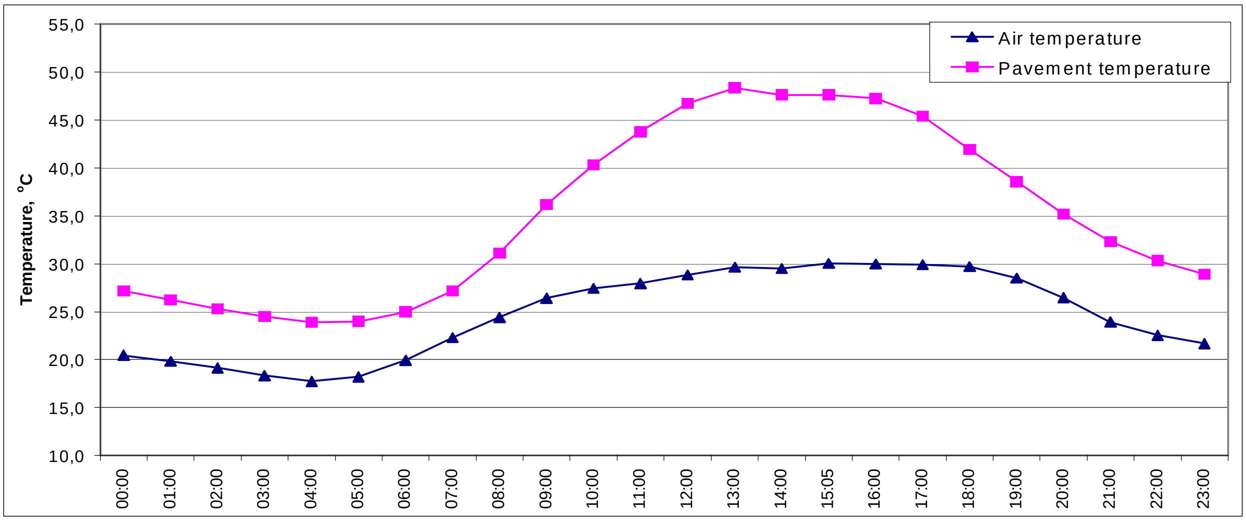

Fig 3. Variation of air and road pavement temperature in 24 hours (maximum air temperature is >30 °C)

Measurements show that the temperature of pavement can reach even 48 °C in summer when the air temperature is 30 °C (Figs 1–3).

When the road pavement temperature increases, viscosity of bitumen in an asphalt concrete mixture decreases. The adhesion of mineral materials weakens as well and which decreases asphalt concrete strength.

When the temperature decreases a reverse process occurs: viscosity of bitumen increases and the strength of asphalt concrete increases. When strength changes, deformation properties of asphalt concrete pavement change as well. Working conditions of asphalt concrete pavement require asphalt concrete mixtures used in laying road and street pavement to have structural as well mechanical properties at a wide range of temperatures, be thermally stable at high temperatures, maintain its deformation and plasticity properties at the low air temperatures, be resistant to the occurrence of plastic deformations under the influence of various climatic factors and motor vehicle traffic [12–14].

The resistance to the occurrence of plastic deformations is closely connected with the strength of asphalt concrete. The higher the asphalt concrete strength is during the hot period, the more stable the whole road pavement is [15]. To resist the formation of plastic deformations asphalt concrete shall comply with the following condition:

$$R_{sk} = \frac{2\sigma h\lambda}{Dtg(\frac{\pi}{4}+\frac{\varphi}{2})}, \quad (1)$$

σ – calculated tensions influencing on the road pavement, MPa; h – thickness of asphalt concrete layer, cm; λ – coefficient of vertical as well as horizontal tensions; D – diameter of a wheel track, cm; φ – angle of internal friction of asphalt concrete.

Following this formula, the thicker the asphalt concrete layer is, the more resistant to plastic deformations the pavement is. However, this tendency is characteristic only for a certain thickness of the pavement layer (10–12 cm).

4. Carried out Experiments and Analysis of Findings

To identify the influence of air temperature on the deformation properties of asphalt concrete mixtures experiments studies have been carried out in the Automobile Road Research Laboratory of the Department of Roads.

Granite crushed stone as well as its siftings produced by company "Granitinė skalda", mineral powder produced by company "Kalcitas", and bitumen B 70/100 produced by company "Mažeikių nafta" were used producing asphalt concrete mixtures.

Asphalt concrete mixtures 0/11V and 0/16S–V containing different amount of bitumen were produced and studied. The grading of all mixtures complied with the mean of the curves of dense mixtures. The temperature of the investigated asphalt concrete mixtures was changed from 20 °C up to 80 °C, at the interval of 10 °C. The findings of asphalt concrete mixtures Marshall stability and flow are presented in Table 2 and Figs 4–7.

The findings of carried out experiments show that Marshall stability of asphalt concrete mixtures 0/11 and 0/16S–V decreases considerably when the temperature increases. This tendency is evident when the temperature of asphalt concrete increases from 20 °C to 40 °C. The greater the contents of bitumen in asphalt concrete mixture is, the less stable it is when the testing temperature is increased. The influence of bitumen contents on the variation of Marshall stability of asphalt concrete mixture is greater for asphalt concrete mixture 0/11V when the testing temperature is increased (Fig 4).

Marshall flow of asphalt concrete mixtures increases considerably when the testing temperature varies at the interval of 20–40 °C. Marshall flow does not increase considerably at the interval of 40 °C to 80 °C when the testing temperature is increased.

Table 2. Dependence of of asphalt concrete mixture Marshall stability and flow on temperature and bitumen content

Bitumen content	Testing temperature						
	20 °C	30 °C	40 °C	50 °C	60 °C	70 °C	80 °C
Asphalt concrete Marshall stability, KN							
Mixture 0/11V							
5,3	48,60	38,17	27,74	22,46	17,17	13,31	9,46
5,6	48,57	36,79	25,02	20,93	16,84	13,13	9,41
5,9	48,53	35,41	22,29	18,48	15,39	12,26	9,38
6,2	48,53	34,64	20,74	16,78	12,82	10,60	8,37
6,5	48,41	33,38	18,36	14,64	10,91	9,32	7,72
6,8	48,29	32,13	15,98	13,20	10,42	8,75	7,07
Mixture 0/16S-V							
4,6	48,92	37,59	26,26	20,75	15,23	12,74	10,24
4,9	48,80	37,42	26,03	19,83	13,62	11,67	9,71
5,2	48,68	37,24	25,80	19,03	12,30	10,68	9,07
5,5	48,64	36,52	24,39	17,64	10,88	9,67	8,46
5,8	48,60	36,21	23,82	17,32	10,88	9,31	7,80
9,1	48,56	35,90	23,24	16,95	10,66	8,90	7,14
Asphalt concrete Marshall flow, mm							
Mixture 0/11V							
5,3	1,43	2,48	3,53	3,57	3,60	3,57	3,54
5,6	1,58	2,74	3,91	3,97	4,03	3,99	3,95
5,9	1,73	3,01	4,29	4,26	4,35	4,36	4,37
6,2	1,83	3,25	4,66	4,63	4,59	4,64	4,69
6,5	3,39	4,35	5,31	5,32	5,32	5,46	5,60
6,8	4,95	5,46	5,96	5,98	6,00	6,26	6,52
Mixture 0/16S-V							
4,6	1,52	2,37	3,22	3,08	2,94	3,09	3,26
4,9	1,62	2,59	3,56	3,49	3,43	3,25	3,91
5,2	1,73	2,82	3,90	3,91	3,90	3,92	3,94
5,5	1,80	3,31	4,81	4,83	4,84	4,85	4,86
5,8	1,84	3,40	4,96	4,95	4,93	4,86	5,06
9,1	1,88	3,49	5,10	5,19	5,29	5,29	5,26

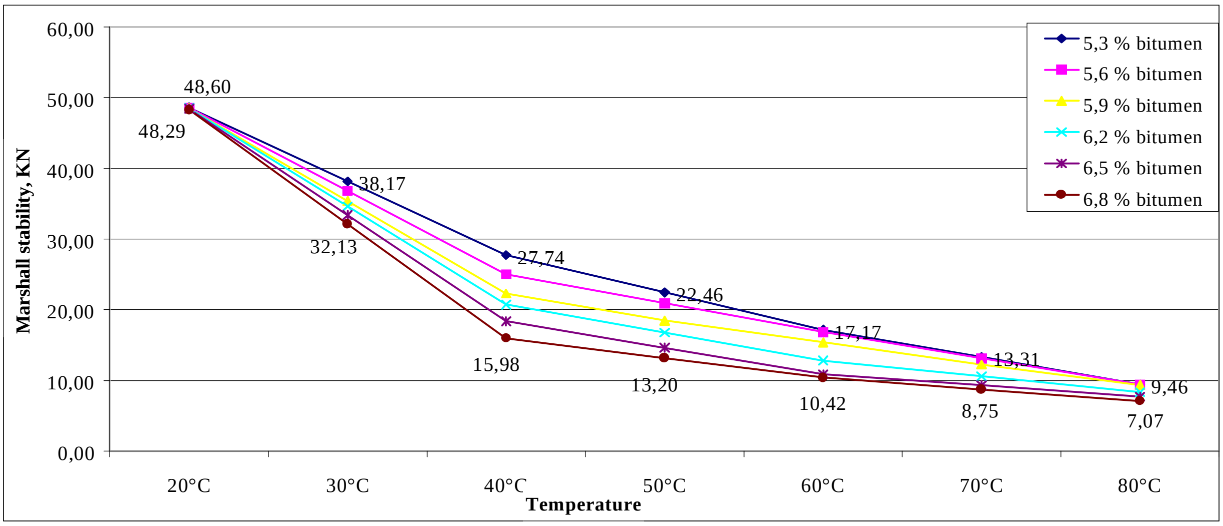

Fig 4. Dependence of asphalt concrete mixture 0/11V Marshall stability on temperature and bitumen content

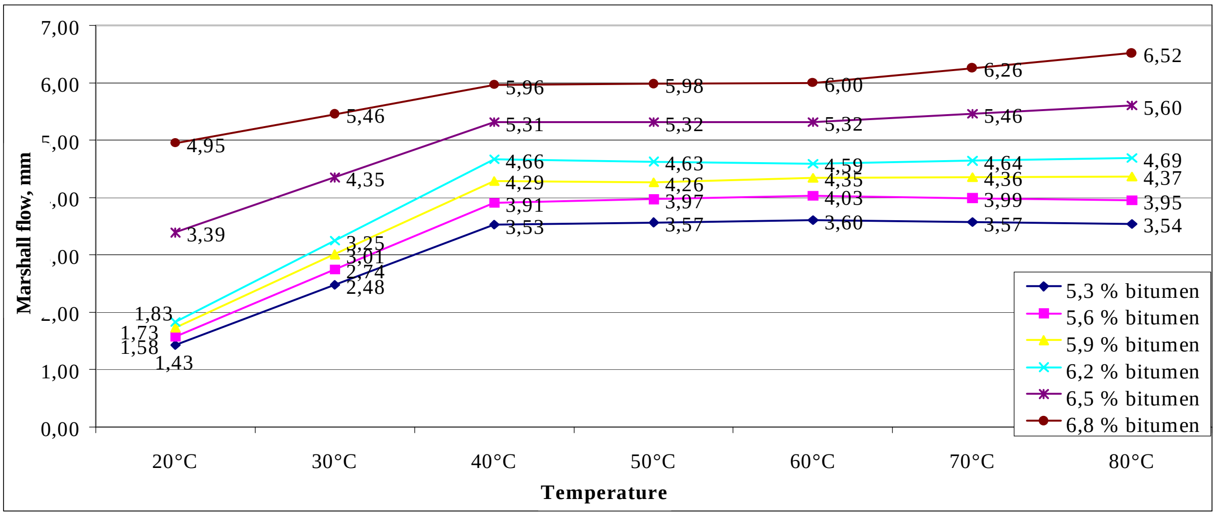

Fig 5. Dependence of asphalt concrete mixture 0/11V flow according to Marshall on temperature and bitumen content

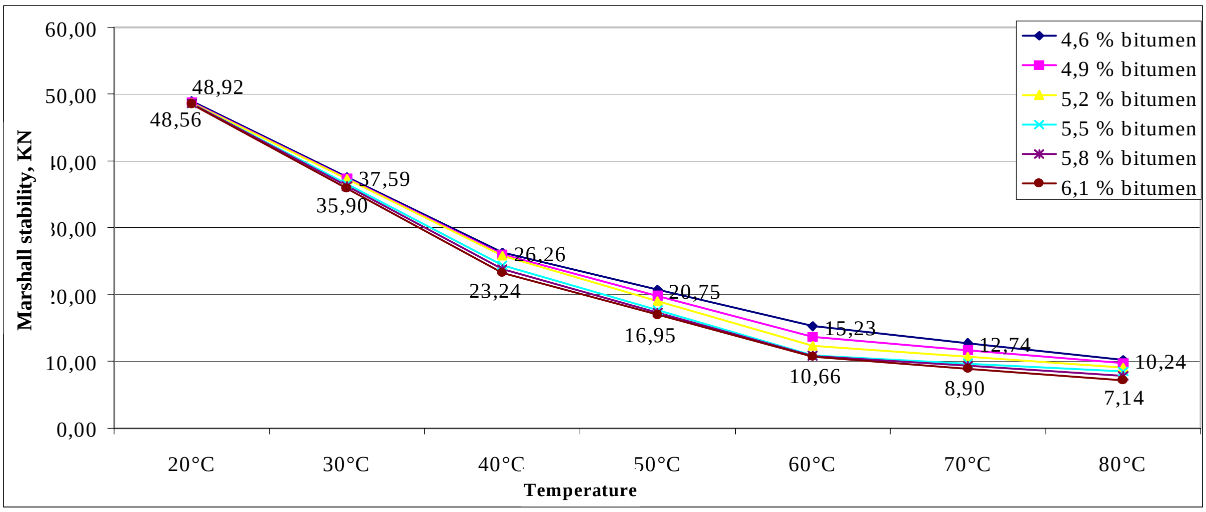

Fig 6. Dependence of asphalt concrete mixture 0/16S-V Marshall stability on temperature and bitumen content

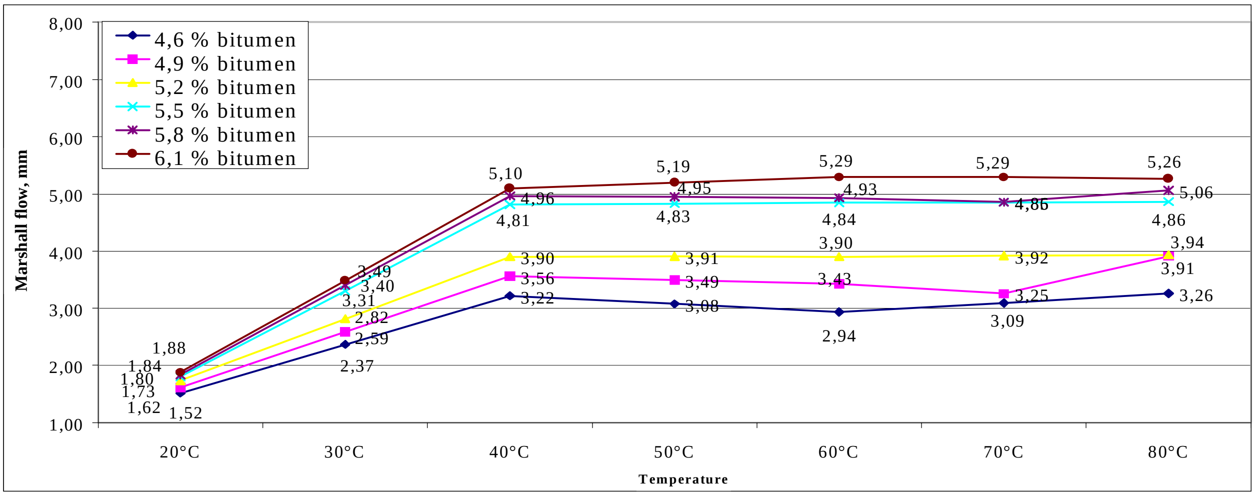

Fig 7. Dependence of asphalt concrete mixture 0/16S-V Marshall flow on temperature and bitumen content

The obtained research findings correlate with the researches carried out by scientists from other countries. Researchers from other countries study the change of plastic characteristics of asphalt concrete mixtures depending on temperature. Depending on the types of used asphalt concrete mixtures, characteristics of binder and its content in mixtures, the interval of temperatures at which plastic properties of asphalt concrete change most is tried to be identified. Having identified the interval, the aim is to avoid the load of heavy vehicles during the hot period by restricting traffic volumes of heavy vehicles. In some countries the recommended interval of heavy traffic restriction differs and depends on the concrete climate of the country. Specific Lithuanian climatic conditions and characteristics of road construction materials used in our country were taken into account as well.

5. Conclusions

1. The main climatic factors of the Lithuanian Republic (air temperature, depth of frozen ground, the wind, the sun radiation, precipitation) have great influence on the design, construction, and maintenance conditions of roads and streets.

2. The formation of plastic deformations (rutting and corrugation) in asphalt concrete pavement in summer depends not only on the used type of asphalt concrete mixture, the quality of materials, size of vehicles axle load, driving regime, but on the air temperature as well.

3. Measurements of air and asphalt concrete pavement surface temperatures showed that when the air temperature changes from 20 °C to 30 °C, pavement heats up to 40–50 °C.

4. The findings of experiments carried out in the laboratory show that the most dangerous interval of temperatures on plastic deformations in asphalt concrete mixtures is from 20 °C to 40 °C.

5. To avoid the occurrence of plastic deformations, (rutting and corrugation) on roads and streets, traffic of heavy vehicles shall be restricted on hot summer days from 10.00 a.m. until 7.00 p.m. when the temperature of pavement rises up to 30–50 °C. Firstly, it shall be implemented on our roads, where the index of heavy transport is higher than 3,200.

6. In summer, when air temperature is higher than 20 °C, the permitted loading and axle load of heavy vehicles shall be kept under strict control and heavy fines shall be levied on those exceeding them. It shall enable to decrease the occurrence of undesirable deformations on motor road pavement.

References

1. Garba, R.; Horvly, J. Prediction of rutting resistance of asphalt mixtures. *Bearing Capacity of Roads, Railways and Airfields,* Vol 2, A. A. Balkema Publishers, Tokyo, 2002, p. 839–848.
2. Bogren, J.; Gusstavson, T.; Lindqvist S. A description of a local climatological model used to predict temperature variations along stretches of road. *Meteor. Magaz.*, 1992, 121, p. 157–164.
3. Bukaitis, A. Lithuanian Climate (Lietuvos klimatas). HMV, Vilnius, 1994. 105 p. (in Lithuanian).
4. Reference of Lithuanian Climate. Air Temperature (Lietuvos klimato žinynas. Oro temperatūra). HMV, Vilnius, 1992. 203 p. (in Lithuanian).
5. Gusstavson, T.; Bogren, J. Infrared thermography in applied road climatologically studies. *Int. J. Remote Sensing,* 1991, 12, p. 1811–1828.
6. Mostafa, A. Development of pavement temperature predic-

tion model for asphalt concrete pavements. *Bearing Capacity of Roads, Railways and Airfields*, Vol 1, A. A. Balkema Publishers, Tokyo, 2002, p. 285–294.

7. Wahhab, H.; Fatani, M.; Noureldin, A.; Bubshait, A.; Dubabe, I. National study of asphalt pavement rutting in Saudi Arabia. *Transportation Research Record,* No 1473, National Academy Press Washington, D. C. 1995, p. 34–42.
8. Sivilevičius, H.; Petkevičius, K. Regularities of defect development in the asphalt concrete road pavements. *Journal of Civil Engineering and Management*, Vol VIII, No 3, 2002, p. 206–213.
9. Earl, H.; Inge, J.; Kim I. Prediction of effective asphalt layer temperature. *Transportation Research Record*, No 1473, National Academy Press Washington, D. C. 1995, p. 93–100.
10. Jacobs, W.; Raatz, W. E. Forecasting road-surface temperatures for different site characteristics. *Meteorol. Appl.,* 1996, 3, p. 243–256.
11. Čygas, D.; Laurinavičius, A. The main problems of using asphalt concrete mixtures for pavements of automobile roads and town streets. *Urban development and roads. Civil Engineering (Statyba)*, 2000, p. 20–26 (in Lithuanian).
12. Thornes, J. E.; Shao, J. Spectral analysis and sensitivity tests for a numerical road surface temperature prediction model. *Meteor. Magaz*., 1991, p. 117–124.
13. Was, S. Benefits of weather services for highway authorities? In: WMO, Economic and social benefits of meteorological and hydrological services, Geneva, WMO, 1990, p. 453–457.
14. Heavy-duty surfaces. The arguments for SMA. EAPA, The Netherlands, 1998. 40 p.
15. Croney, D.; Croney, P. Design and Performance of Road Pavement. NY: Mc Graw-Hill, 1997. 509 p.