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THE BITUMEN BATCHING SYSTEM'S MODERNIZATION AND ITS EFFECTIVE ANALYSIS AT THE ASPHALT MIXING PLANT

Justas Bražiūnas¹, Henrikas Sivilevičius²

*Dept of Transport Technological Equipment, Vilnius Gediminas Technical University,
Plytinės g. 27, LT-10105 Vilnius, Lithuania*

E-mails: ¹justasbraziunas@gmail.com; ²henrikas.sivilevicius@vgtu.lt

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Abstract. Some particular aspects such as the improvement methods of technological parameters for hot bitumen storage in a pipeline transport system, transportation and dosed supply to batch asphalt mixing plant (AMP) are evaluated in this paper. Bitumen in asphalt concrete binds together the material of mineral particles into a strong conglomerate of a complicated structure, capable of withstanding the destructive effect of vehicles and the factors on the road pavements. The optimal amount of bitumen determined by calculation and laboratory testing should be maintained in mix batches of hot-mix asphalt (HMA) obtained from AMP mixer. In the periodic type of the asphalt concrete blender mass of the weighted matrix in the all merging batcher's tanks should correspond in percents equally in the HMA to the designed amount of the job-mix formula (JMF). The bitumen batcher does not always weigh bitumen portions precisely. Their mass deviations from the amount determined by JMF and its variation impair HMA composition and performance. In addition, an additive model for calculating the effect of factors causing the variance of bitumen content in the produced HMA mixture is presented in this current paper as well. The data on statistical evaluation of bitumen batcher's modernization performed at certain Lithuanian Enterprise are discussed. The differences in structures of reconstructed and not reconstructed bitumen batching systems (BBS) are analysed and methods of determining modernization effectiveness are presented. The effectiveness of BBS is analysed too, defining the deviations of bitumen content in subsamples, taken and extracted everyday for two seasons (before and after the batcher's modernization) of HMA mixture production from the value of JMF and comparing them to the values of tolerances. The analysis of column charts and histograms shows that the made modernization helped to increase the precision of supplying the required amount of bitumen to HMA mixture insignificantly. However, the control of BBS has been considerably increased.

Keywords: pipeline transport, bitumen pump, asphalt mixing plant (AMP), bitumen batching system (BBS), hot mix asphalt (HMA), mixture, job-mix formula (JMF), tolerance, accuracy, precision.

1. Introduction

Pipeline transport system integrated into asphalt mixing plant (AMP) must not pump hot bitumen from tank to mixer. This type of construction and technological parameters must prohibit bitumens ageing from oxydation, cooling down, overheating and also sediment formation in the coil. Technological transport system must ensure the compliance of bitumen dose weight to its projective amount in a hot mix asphalt (HMA), provided in a job mix formula (JMF). Continually, growing number of traffic flows, especially, heavy transport on Lithuanian and Ukrainian roads (Junevičius and Bogdevičius 2007, 2009; Sivilevičius and Šukevičius 2007; Beljatynskij *et al.* 2009) causes the appearance of more residual deformations on the asphalt road pavement, thereby impairing driving conditions (Vansauskas and Bogdevičius 2009).

Due to insufficient pavement strength, depending not only on the increased number of axles, running over a particular road section, but also on their heavier weight and the changing asphalt properties, ruts, waves, slips and pot holes which appear on the road surface. The unevenly distributed loads on vehicle's axles differently affect road pavement. Moreover, the roughness of road pavement causes higher disbalance of loading applied to the axles of a running vehicle (Sriramula *at al.* 2007).

Plastic deformations and premature failure of the road pavement are often caused by the insufficient or excessive amount of bitumen as well as by the use of the old or inappropriate grade bitumen in the newly mixed asphalt (Witczak and Foncesa 1996). Applying Marshall and Hweem methods (Mix design methods... 1993) or according to the absorption of the mineral aggregates in the HMA composition based on laboratory methods

(Королёв (Koroliiov) 1986) or by the calculating proportionally optimal amount of used mineral fillers in the bitumen and amount in HMA should be fixed and constant.

The deviations of bitumen content in HMA mixture if we take it from the amount specified by the JMF are inevitable, taking into account the HMA mixing technology errors, emerging on account of a particular AMP structure, the state of a used equipment, drawbacks of the control system, the operator's work, HMA segregation, as well as the errors made in taking HMA samples and their testing (Petkevičius and Sivilevičius 2008). Due to HMA segregation, the amount of bitumen in samples and asphalt pavement is unevenly distributed (Stroup-Gardiner and Brown 2000). The particles of mineral filler and fine aggregate absorb more bitumen than coarse aggregate particles (Brown *et al.* 1989; Wu and Romero 2005).

HMA making requires precise batching of mineral materials (hot fractions of mineral materials, reclaimed dust and imported filler), as well as bitumen, an organic binder. The composition and properties of any HMA grade are specified by the Lithuanian Technical Requirements 'TRA ASFALTAS 08' (2008). The amounts of the constituent HMA materials are defined in their design composition and JMF. Thus, batchers of mineral materials and bitumen are used at the AMP to ensure the design of HMA composition in industrial HMA production.

Batching is a technological operation of industrial HMA production aimed at measuring off the required amount of the material. Liquid bitumen may be measured either in mass or in volume. A batcher and the whole bitumen supply system (tanks, pumps, piping system, filters, valves, cocks, heaters, etc.) should satisfy the following requirements:

- to be able to measure off the amount of mass bitumen specified by the JMF, not exceeding the admissible batching error;
- to allow the amount of bitumen to vary in a wide range, maintaining high accuracy and precision of batching;
- to allow to change the mass of a bitumen dose, if required, quickly and accurately;
- to be able to pour out the weighed and measured (in volume) amount of bitumen from the bituminous material bucket into the mixer, i.e. to return it to a zero position (zero return bituminous material $\pm 0.1\%$ total batch weight of paving mix – ASTM D 995 – 95b);
- do not allow hot bitumen to cool in the system to the temperature lower than it is specified for its grade;
- do not allow hot bitumen to oxidize, age or change its chemical composition and properties due to overheating;
- to ensure fire, labour and environment protection.

If the actual amount of bitumen in the produced HMA mixture satisfies JMF requirements and does not exceed the tolerances, its performance may worsen be-

cause of the changes in its chemical composition due to the aging. Vaskovsky and Poradek (Васьковский и Порадек 2005), Poradek (Порадек 2007) showed by experiments that bitumen's properties begin to change when it is stored in tanks and when it is heated. Bitumen is aging not only in the processes of HMA manufacture, storage, transportation and placing, but also during the long-term use of a road pavement made of it (Said 2005). Destructive aging processes are continually taking place in bitumen binders and asphalt concrete layer (Radziszewski 2007). Aging was simulated in the laboratory by Huang *et al.* (1996). Some scientists claimed that viscoelastic properties of the aged and unaged bitumen binder differ considerably (Masad *et al.* 2008).

Scientific experiments conducted in Lithuania (Sivilevičius and Vislavičius 2008) and in other countries (Abdullah *et al.* 1998; Witczak and Fonseca 1996; Hunter 1994; Hurley and Prowell 2005) have shown that reliability and durability of asphalt road pavement depends on the number of HMA components determining the structure and properties of the mixture. Too large or too small amount of free bitumen impairs the structure of HMA mixture, physical and mechanical properties of asphalt pavement layer made of it. When the amount of bitumen is excessive, the plasticity of pavement and its roughness increases, while its resistance to rut formation and strength decreases, particularly in summer, when the temperature is high (Park 2007). However, when the amount of bitumen is insufficient, residual porosity of asphalt is increasing (Obaidat *et al.* 1998), while its resistance to frost and surface shelling is falling.

A micromechanical modelling method of steady-state deformation of bitumen was offered by Deshpande and Cebon (2004). The adhesion between bitumen and mineral materials was studied by Bhasin and Little (2009), El Hussein and El Halim (1993). Zolotariov *et al.* (Золотарев и др. 2007) stated that the higher the polymers content in bitumen, the higher its adhesion. Bonding, mixture and polymer differently affects the adhesion between bitumen and aggregates and asphalt resistance to the action of water. Bitumen binder modified by elastomers is less sensitive to average and high temperatures (Elseify *et al.* 2003).

Some studies were made to define the influential factors on the bitumen properties. Li *et al.* (2009) investigated the influence of the thickness of bitumen film around the particle of mineral material on HMA properties. Airey *et al.* (2008) studied the damaging effect of moisture on the asphalt mix, depending on the performance of mineral aggregates, mineral filler and bitumen. Essentially, the damage is caused by loss of adhesion between aggregate and bitumen and/or bitumen-filler mastic due to the presence of moisture in the asphalt mixture.

Lee *et al.* (2009a, 2009b), Mučinis *et al.* (2009), Doh *et al.* (2008) analysed the causes of the changes in bitumen performance and the extent of these changes in recycled asphalt pavement after short-term oven aging, using gel – permeation chromatography for investigating the structure and properties of bitumen film.

The higher the percentage of bitumen, mineral filler, coarse aggregate and fine aggregate in the produced HMA mixture deviates from the design (optimal) amount, the worse is its structure and properties (Sivilevičius *et al.* 2003; Petkevičius and Sivilevičius 2008). The content of bitumen in the produced in huge quantity of the HMA mixture always varies to some extent, therefore more precise batching of bitumen and mineral materials can improve the quality of the product.

A complex value indicating the quality of HMA mixture produced by an AMP largely depends on the deviations of the content of HMA mixture components due to the errors in materials batching (White and Brown 1977; Brown *et al.* 1989; Stroup-Gardiner and Brown 2000; Sivilevičius *et al.* 2008). The improvement of material batchers at the enterprises producing HMA mixture allows us not only to decrease the deviations of the amounts of HMA components from the values specified by JMF, but also to decrease bitumen oxidation and increase the reliability and durability of equipment, as well as simplifying its control, maintenance and repair (Brock 1986).

HMA mixture is produced by AMP of various structure and capacity which use various technological schemes. A batch – type AMP has become most popular (Sivilevičius and Šukevičius 2009; Brown *et al.* 1989).

The present paper aims to determine the modernization effectiveness of the elements of plant BBS, based on the statistical data on the deviations of bitumen content in the produced HMA mixture from that of JMF.

2. A Impact of the Bitumen Doses Mass on its Amount in HMA Mixture Models

All AMP operating in Lithuania roads transport companies are of batch type (Sivilevičius and Šuškevičius 2009; Sivilevičius *et al.* 2010). At this type of AMP HMA mixture components are obtained from three weighing batchers which weigh: additionally screened hot fractions of aggregates $A_3...A_7$, cold reclaimed dust A_2 and imported filler A_1 , whose mass, %, is denoted by $M_1...M_7$ (Fig. 1), as well as hot bitumen A_B .

The mass of a bitumen dose q_B (kg), ensuring the optimal amount of bitumen in percent x_{Bp} in a HMA mixture which is specified in JMF, also depends on the actual mass Q_{ma} , of HMA mineral aggregates and is calculated by the equation:

$$x_B = \frac{q_B}{Q_{ma}} \cdot 100 = x_{Bp} \quad (1)$$

Based on it, the required bitumen dose mass (kg) is obtained as follows:

$$q_B = \frac{x_{Bp} \cdot Q_{ma}}{100} = M_B \quad (2)$$

Mineral aggregate mass Q_{mai} of the i -th mix batch of HMA mixture makes the sum of dose masses of the cold batched imported filler q_{Ifi} , reclaimed dust q_{Rdi} and finally batched hot fractioned aggregates $q_{Fr1i}, \dots, q_{Fr5i}$:

$$q_{Ifi} + q_{Rdi} + q_{Fr1i} + \dots + q_{Fr5i} = Q_{mai} \quad (3)$$

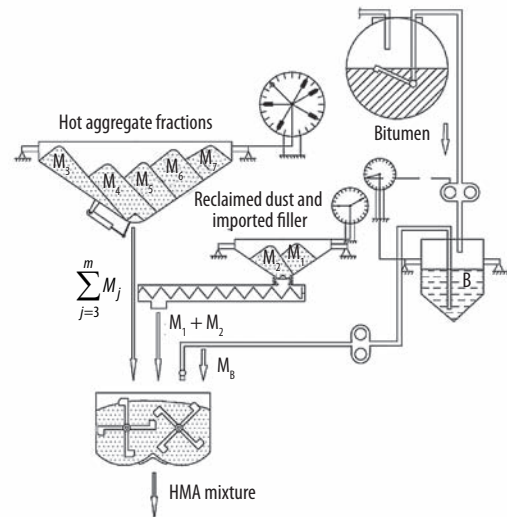


Fig. 1. A cross section of weighing batchers at AMP for bitumen and mineral aggregates

When the content of bitumen in HMA mixture is calculated over 100 percent of mineral aggregates Q_{mai} , their mass in per cent is calculated as follows:

$$M_1 + M_2 + M_3 + M_4 + M_5 + M_6 + M_7 = 100 \quad (4)$$

where: M_1 and M_2 denote mass %, of imported filler and reclaimed dust in HMA mixture, respectively; M_3, \dots, M_7 is mass, %, of the first, ..., fifth hot fraction in HMA mixture, respectively.

The mass of the i -th bitumen dose q_{Bi} (kg) should be such that its mass ratio to the i -th mix batch of HMA mineral aggregates mass Q_{mai} would be constant and equal to the design mass in per cent, q_{Bp} . Both these technological parameters (Q_{mai} and q_{Bi}) vary because of the inevitable random errors. When mass Q_{mai} is increased or decreased, mass q_{Bi} is not always increased or decreased proportionally. Usually, the bitumen dose mass q_{Bi} is not changed in accordance with the actual mineral aggregate mass Q_{mai} of HMA batch mix. Therefore, even if the bitumen is ideally batched, but the parameter Q_{mai} of the JMF has changed, the amount of bitumen, x_{Bi} in the produced HMA mixture deviates from the design value M_{Bp} , to equal x_{Bp} .

Batched bitumen of HMA mixture, enveloping its mineral particles of various sizes, should form unique films of (oriental and bulk) bitumen on their surface. The conversion of the bitumen batch, corresponding to its optimal amount, which is poured in mixer into bitumen films, takes place due to the intense interchanging of particles positions, when mineral materials are mixed, and due to their adhesion with bitumen (Королев 1986). When mixing bitumen binder, coarse aggregates, fine aggregates and mineral filler of HMA mixture, it is also sought that their particles of various size should evenly distribute in the mixer's body in the shortest possible mixing time (Asphalt Plant Manual 1979; The Asphalt Handbook 2007; Hunter 1994).

Technological parameters of HMA mixtures production should be such that the actual bitumen amount

determined in its sample x_B would match its design amount x_{Bp} , i.e. the difference between them Δx_B , should be smaller than the tolerance Δx_{Btol} depending on the number of samples (the number of test results) N and having the sign of either plus or minus:

$$\Delta x_B = x_B - x_{Bp} \tag{5}$$

The absolute value of the difference between actual x_B and design x_{Bp} bitumen amounts should be smaller than Δx_{Btol} the absolute value:

$$|x_B - x_{Bp}| < |\Delta x_{Btol}| \tag{6}$$

The tolerance Δx_{Btol} is higher, when the standard deviation of bitumen content in the lot σ_B is higher and the number of the samples tested N is smaller:

$$\Delta x_{Btol} = f(\sigma_B, N) \tag{7}$$

The tolerance of bitumen content in a particular subsample of HMA mixture (when $N = 1$) differs from that of JMF, given in specifications of various countries (Table 1). It has also changed the process of improving at the existing standards.

Table 1. Bitumen content weight, %, deviation from mixture tolerances provided in JMF of various countries transport systems

Literature or standard	Permissible deviation from JMF Δx_{Btol}
Asphalt Plant Manual (1979), USA	± 0.4
ASTM D3515-01 (2009), USA	± 0.5
PANK 4102 (Finnish Asphalt... 1995), Finland mixture class: A	± 0.3
mixture classes: B, C, D	± 0.4
BS 594-1 2005, UK	± 0.6
ČSN 73 6149, Czech Republic	+0.4; -0.3
ZTVT-StB 95, Germany	± 0.6
Statybos rekomendacijos R 35-01 (2001), Lithuania	± 0.5
ĮT ASFALTAS 08 (2008), Lithuania mixture type: AC P	± 0.6
mixture types: AC A, AC V, SMA, MA, PA, AC PD	± 0.5

The value of tolerance may be calculated based on the confidence interval's average value μ_B of HMA mixture's population (general set), when the variance σ_B^2 is known. The coordinated unbiased and effective estimator (in points) of parameter μ_B is the empirical average value \bar{x}_B . Its distribution is also normal. When the confidence level is probability $1 - \alpha$, the error ε of the estimator \bar{x}_B is calculated from the equation:

$$P(|\bar{x}_B - \mu_B| < \varepsilon) = 1 - \alpha, \tag{8}$$

for the equivalent equation:

$$P\left(\frac{|\bar{x}_B - \mu_B|}{\sigma_B} < \varepsilon \frac{\sqrt{N}}{\sigma_B}\right) = 1 - \alpha. \tag{9}$$

Denoting p -th quantile of standard deviation (the solution of the equation $\Phi(z_p) = p$) by z_p , we get:

$$\varepsilon = \frac{z_p \sigma_B}{\sqrt{N}} \tag{10}$$

Now:

$$1 - \alpha = P(|\bar{x}_B - \mu_B| < \varepsilon) = P\left(\bar{x}_B - \frac{z_p \sigma_B}{\sqrt{N}} < \mu_B < \bar{x}_B + \frac{z_p \sigma_B}{\sqrt{N}}\right), \tag{11}$$

and the confidence interval is as follows:

$$I = \left(\bar{x}_B - \frac{z_p \sigma_B}{\sqrt{N}}, \bar{x}_B + \frac{z_p \sigma_B}{\sqrt{N}}\right), p = 1 - \frac{\alpha}{2} \tag{12}$$

The values of quantile z_p are taken from the table of function $\Phi(x)$ values. For example, if confidence level is $1 - \alpha = 0.95$, then $p = 0.975$ and $z_{0.975} = \Phi^{-1}(0.975) = 1.96$.

The analysis (Sivilevičius and Vislavičius 2008; Sivilevičius *et al.* 2003; Mučinis *et al.* 2009) shows that the number of components in HMA mixture lot is distributed according to the normal Gaussian law. The variation of bitumen content may be determined by standard deviation of its population σ_B or variance σ_B^2 . When the variation is ascertained from data gained from experiments, than sample standard deviation s_B and variance s_B^2 are used.

The variation of bitumen amount in the produced HMA mixture depends on stochastic factors determined by using the parameters of mixture's production technology, a method of sampling and accidental or systematic errors of laboratory testing. When mass of the bitumen dose in HMA mixture's lot is not changed in the process of production (i.e. there are no systematic errors), the variance σ_B^2 of its content in the mixture's samples is made up of variances whose interrelation is shown in the model presented in Fig. 2.

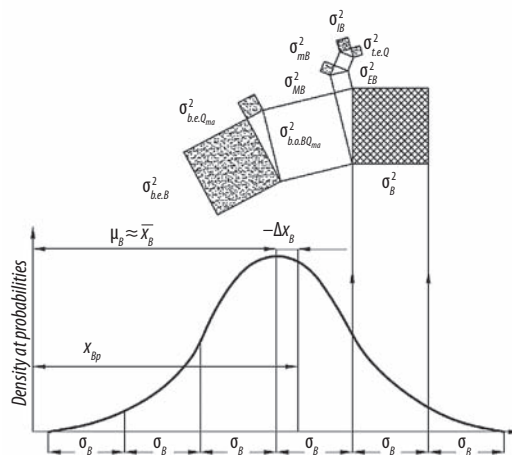


Fig. 2. The model of interrelation between variances constituting bitumen content variance σ_B^2 in HMA mixture lot

The variance of the bitumen content in HMA lot σ_B^2 , determined based on the data of its samples' extraction, is calculated by the equation:

$$\sigma_B^2 = \sigma_{IB}^2 + \sigma_{b.e.B}^2 + \sigma_{b.e.Q_{ma}}^2 + \sigma_{mB}^2 + \sigma_{t.e.B}^2, \quad (13)$$

where: σ_{IB}^2 is inherent bitumen content variance in HMA lot, depending on the highest possible uniformity of the particles and thickness of the enveloping films; $\sigma_{b.e.B}^2$ is variance caused by batching error of the bitumen mass; $\sigma_{b.e.Q_{ma}}^2$ is variance caused by the total batching error of mineral aggregates mass in HMA mix batches; σ_{mB}^2 is variance caused by the error in mixing the materials of HMA mix batch due to mixing drawbacks and mixer's defects; $\sigma_{t.e.B}^2$ is variance caused by HMA sample testing errors.

The sum of the inherent variance σ_{IB}^2 and variances due to testing errors of samples in the laboratory is the variance $\sigma_{t.e.B}^2$, of bitumen amount in HMA mixture lot caused by experimental error make bitumen content variance σ_{EB}^2 in HMA lot. Adding to it (σ_{EB}^2) the variance depending on the quality of mixing the materials in the mixer σ_{mB}^2 , we get bitumen content variance σ_{MB}^2 , showing the homogeneity of HMA mix batch according to this factor. The sum of the variance in bitumen content in HMA lot caused by random bitumen batching errors $\sigma_{b.e.B}^2$ and the variance, depending on the total variance of final batching of mineral materials' mass in a mix batch $\sigma_{b.e.Q_{ma}}^2$ shows the effect of preparatory operations, expressed by the variance $\sigma_{p.o.BQ_{ma}}^2$ (Fig. 2).

Decreasing the variances described by the model (13), the variance of bitumen content in HMA lot σ_B^2 , can be decreased, and more homogenous mixture of higher quality can be obtained.

Producing more homogenous HMA mixture (with respect to its bitumen content) with a lower σ_B value due to higher matching of bitumen dose mass to JMF allows us to reduce the deviation of x_{Bi} and \bar{x}_B from the design value x_{Bp} . Ensuring the required HMA mixture quality, determined by the economic potential of the state, the tolerance Δx_{Bek} , is added to the right side of equation (14), increasing the value of Δx_{Btol} :

$$|\Delta x_{Btol}| = \left| \frac{z_p \sigma_B}{\sqrt{N}} + \Delta x_{Bek} \right|, \quad (14)$$

where: μ_B is the population mean of bitumen content in HMA mixture lot.

By decreasing the value of tolerance Δx_{Bek} , AMP bitumen batcher and its system can be more effectively used, but the operator's work becomes more complicated as well and requires higher responsibility.

3. Structural changes in bitumen batching system (BBS) and their effect on HMA mixture composition

A batch-type BBS, operating at the discrete-type AMP of the Concrete Lithuanian Enterprise, was used in testing before and after its reconstruction. In 2007, the BBS of AMP *Amomatic VS 180 S* was reconstructed. Some structural elements (e.g. frequency converter of bitumen

pump's electric motor was installed) were replaced, and modern control systems and the elements, determining bitumen dose mass, were installed. Modernization was aimed at making HMA mixture production more precise, stable, simple and energy efficient, which would allow the production of higher quality HMA-mixture.

Other parts and devices of BBS such as cables for heating, a monitoring device of bitumen pump revolutions, bitumen tanks and the piping system were also improved. The devices were computer-controlled and automated (e.g. pneumatic valves were used).

The bitumen batcher operating in 2006 (Fig. 3) was unstable and difficult to control. The lack of bitumen made the production of HMA mixture with polymer-modified bitumen (PMB) a difficult process. The part of the system which was completely replaced is shown by a dotted line. Let us consider the sequence of technological operations of the system before reconstruction.

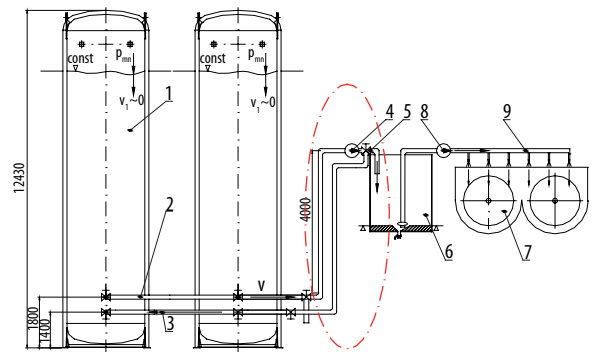


Fig. 3. The diagram of structural elements of the weighing discrete bitumen batcher in 2006 before system's reconstruction: 1 – bitumen tanks; 2 – pumping pipeline; 3 – recycling pipeline; 4 – bitumen pump; 5 – three-way valve; 6 – weigh bucket; 7 – mixer; 8 – the pump for pumping the weighed bitumen to mixer; 9 – the system of injecting bitumen into mixer

The operator's assistant opens a manually operated gate valve of a bitumen tank before starting the work (three tanks for various grade bitumen were used until 2007). When the bitumen pump 4 is turned on, hot binder is pumped at no-load: the binder flowing out from tank 1 is pumped through the pumping pipe 2 to three-way valve 5. Then, it returns to the tank via the return pipe 3. At the beginning of the weighing cycle, the three-way valve is switched over to another position. The flow of bitumen is reversed and it starts to flow into weigh bucket 6 at the same flow rate until the required bitumen dose is obtained, which is signalled by the weigher. After that, the signal is sent to three-way valve 5, which, changing its position, sends the bitumen back to the tank 2. The weighed bitumen (which is in the weigh bucket) is pumped out from the weigh bucket 6 by pumps 8 and sprayed via system 9 into HMA mixture's mixer 7 by high-pressure sprayers. Bitumen batcher, operating till the end of 2006, had quite a few defects, as well as being difficult to control and imprecise.

It was expected that bitumen batcher with some new structural elements (Fig. 4), which was introduced into operation in 2007, would allow to obtain higher quality HMA mixture and make the process of its production more easily controlled.

In the process of reconstruction, the additional fourth bitumen storage tank for separate storing of bitumen for the main four grades was installed. With the help of pneumatic storage tank valves, regulating bitumen flowing in and out, the operator, pushing the control buttons on the panel, can quickly change the grade of the pumped bitumen (i.e. to open the valves of one tank and to close the valves of another). Bitumen can be pumped from one storage tank to another through pumping line 2 and return line 3. New heating elements 11 and thermal insulation materials 10 of the equipment help to maintain the same bitumen temperature throughout the system. The most important device which was changed, was bitumen pump and the electric motor 4 rotating it.

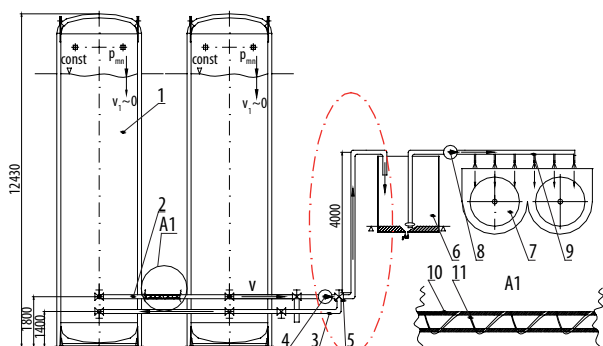


Fig. 4. A schematic view of major structural elements of bitumen batcher after the reconstruction of bitumen system equipment in 2007: 1 – bitumen storage tank; 2 – pumping line; 3 – return line; 4 – bitumen pump; 5 – three-way valve; 6 – weigh bucket; 7 – mixer; 8 – pump for pumping the weighed out bitumen into mixer; 9 – a system for bitumen injection into mixer; 10 – thermal insulation of pipeline; 11 – a heating element of the pipeline

The cyclograms of the pipelines transport system before (in 2006) and after (in 2007) reconstruction differ to some extent (Fig. 5). In 2006, a gear-wheel pump with the capacity of 600 l/min driven by an asynchronous three-phase electric motor was used. A portion of bitumen was pumped for about 20 sec, while the reverse pumping to a storage tank initiated by switching over a three-way valve was performed with the same capacity of 600 l/min.

In 2006, the pump and three-way valve of a batch-weigher were installed about in 3.5 m high over the weigh bucket to decrease the deviations of bitumen dose weight (when the distance between the three-way valve and weigh bucket was minimal). The improved pumping system allowed the bitumen pump unit and distributing valve to be placed lower, thereby shortening the path of the free bitumen flow by 8 meters. This improvement allowed the reduction of power consumption (because the pipeline shorter by 8 m than the previously used one should be heated).

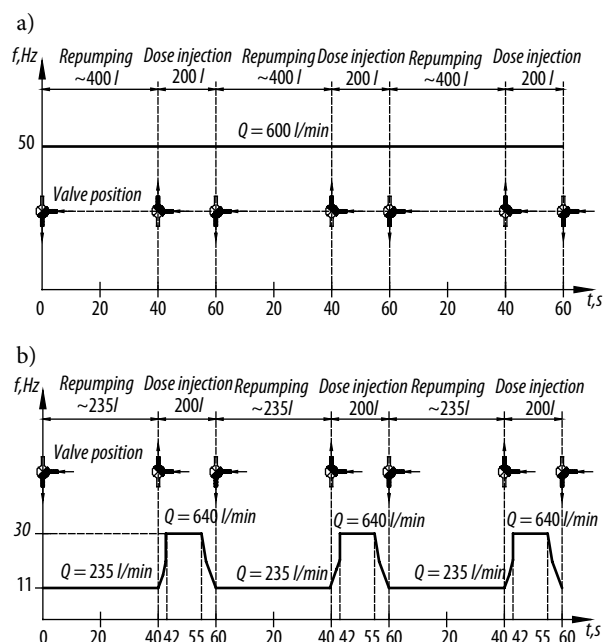


Fig. 5. Cyclograms of the pipelines transport system of a batch-type AMP BBS were used: a) in 2006; b) since 2007

In 2007, frequency converter, allows changing the engine rotation, was installed into the electric motor driving the pump. The frequency of the engine, pumping bitumen in the weigh bucket, is 30Hz ($Q = 640$ l/min). When weighting tank is filled with approximately 85% of the required mass dose of the bitumen, engine's frequency decreases gradually and when tank is filled by the 100% and shifted to the three-way valve, torque should be around 11Hz frequency.

The change of frequency takes about 2 sec after switching over to the batching mode, and about 3 sec are needed for slowing. The changing parameters of the engine mentioned above allows more accurate pouring of bitumen into a weigh bucket as well as reducing heat energy consumption for free bitumen flow.

4. Statistical analysis of the produced HMA mixture composition

Three direct and indirect methods are used to determine the actual batch which was weighed out and poured into the mixer which is based on:

- examining the data recorded by the computer control program about the masses of the bitumen doses or the indication of a dial indicator observed during HMA mixture's production;
- taking a representative sample of the produced mix poured out from the silo to the truck body as specified by LST EN 12697-27.

At present investigation, the data obtained from the third method, determining the compliance of the bitumen amount in HMA mixture with the JMF were used. A representative sample of the produced HMA mixture grade was taken in every working day during the whole production period (in 2006 and 2007). Then, bitumen was separated from it in the laboratory and its grading

was determined. The actual bitumen amount in the i -th sample x_{Bi} (percent by mass) was compared to its design quantity x_{Bp} and the difference (deviation) Δx_{Bi} was calculated by the equation:

$$\Delta x_{Bi} = x_{Bi} - x_{Bp}. \tag{15}$$

The modulus of this difference Δx_{Bi} should be smaller than tolerance Δx_{Btol} , specified for a subsample (Table 1), i.e. $|\Delta x_{Bi}| < |\Delta x_{Btol}|$.

During the work seasons of 2006 and 2007, HMA mixtures of various types and grades, with a range of optimally designed bitumen contents were produced (Fig. 6). It can hardly make sense to calculate the standard deviation σ_B of bitumen content x_{Bi} in HMA mixtures of various design compositions because it would be too large and would show not only bitumen content variation due to accidental actions. Therefore, the values Δx_{Bi} of bitumen content deviation from each project x_{Bp} in separate samples were chosen to analyse.

According to a new Lithuanian Technical Rules 'IT ASFALTAS 08' (2008), the content of liquid bitumen found in the subsample of HMA mixture after extraction should not differ from the design content by more than $\Delta x_{Btol} = \pm 0.5\%$. The closer the actual bitumen content x_{Bi} to its design amount x_{Bp} , in HMA mixture samples, the more precisely batched the bitumen is. The actual percentage of this organic binder x_{Bi} in the HMA mixture sample, taken and tested according to the respective LST EN standards, largely depends on the bitumen dose mass q_{Bi} weighed out by the batcher. The actual bitumen content x_{Bi} , %, also depends on the mass of the mineral part of HMA mix batch Q_{ma} (when Q_{ma} is increased, x_{Bi} is decreased) and on incomplete mixing of the components in the mixer (when small particles in the sample covered by bitumen membranes of larger area are taken, x_{Bi} is increased).

The effectiveness of bitumen batcher's improvement is assessed based on the deviations of the bitumen content x_{Bi} determined in separate HMA mixture subsamples after extraction from the design content x_{Bp} value Δx_{Bi} . The parameters, including the arithmetic mean of subsamples taken in the work season, $\Delta \bar{x}_B$, and variation of deviations, i.e. standard deviation $s_{\Delta x_B}$ of particular subsamples Δx_{Bi} , were calculated:

$$\Delta \bar{x}_B = \frac{\sum_{i=1}^n \Delta x_{Bi}}{n} \tag{16}$$

and

$$s_{\Delta x_B} = \sqrt{\frac{\sum_{i=1}^n (\Delta x_{Bi} - \Delta \bar{x}_B)^2}{n-1}}, \tag{17}$$

where: n is the number of HMA mixture subsamples taken and tested during the work season.

The statistical analysis of HMA mixture produced in 2006 and 2007 (Fig. 6) has shown that technological parameters of batch weigher's quality, $\Delta \bar{x}_B$ and $s_{\Delta x_B}$,

have not changed considerably. In 2006, the deviation of bitumen content Δx_B in only one subsample out of 209 exceeded the permissible value $\Delta x_{Btol} = \pm 0.5\%$ which made 0.48% of the total number of taken subsamples. In 2007, six HMA mixture subsamples, not satisfying the requirements, were found among 232 examined subsamples (which makes 2.5%).

Comparing the statistical parameters of the position and variation in two periods we can see that the values of the batched bitumen content deviations from the design arithmetic mean $\Delta \bar{x}_B$ and standard deviation $s_{\Delta x_B}$ have changed insignificantly, making $\Delta \bar{x}_B = 0.023\%$ and $s_{\Delta x_B} = 0.205\%$, in 2006, and $\Delta \bar{x}_B = 0.056\%$ and $s_{\Delta x_B} = 0.208\%$ in 2007, respectively. Standard deviation, based on the data obtained in the laboratory for all subsamples analysed, was actually of the same order and even slightly higher. However, a distribution histogram of bitumen content deviations Δx_{Bi} (Fig. 7) in the intervals (Table 2) allows us to state that there was a smaller amount of values, showing a considerable lack of bitumen, and a much smaller number of values, indicating the average shortage of bitumen in HMA mixture subsamples after reconstruction.

In 2006, 46.9% of HMA mix batches were made with insufficient amounts of bitumen, while 5.7% of mix batches lacked more than 0.30% of binder. In 2007, HMA mix batches with a low content of bitumen made 40.1%, while 5.2% of mix batches were made with the higher than 0.30% deviations from the specified amount. The improvement of a batch weigher resulted in the higher rate of production of HMA mix batches with excessive bitumen content, however, the amount of mixes with the highest permissible excess of the binder decreased from 9.6% to 8.6%. It was observed that in July 2-3, 2007, HMA mix batches with high and even inadmissible amount of bitumen were produced. However, this should be considered to be the operator's rather than batch weigher's error.

Table 2. The rate of deviation of bitumen content in the produced HMA mixture from the JMF in distributional intervals

Intervals of deviation of bitumen content in HMA mixture from JMF, %	In 2006, before reconstruction	In 2007, after reconstruction
	Rate of deviation in percent	
$\leq (-0.50)$	0.48	0.43
$(-0.50 - (-0.30])$	5.26	4.74
$(-0.30 - (-0.10])$	24.40	18.53
$(-0.10 - 0]$	16.75	16.38
$(0 - 0.10]$	21.05	16.81
$(0.10 - 0.30]$	22.49	32.32
$(0.30 - 0.50)$	9.57	8.62
≥ 0.50	0	2.15
Total	100	100

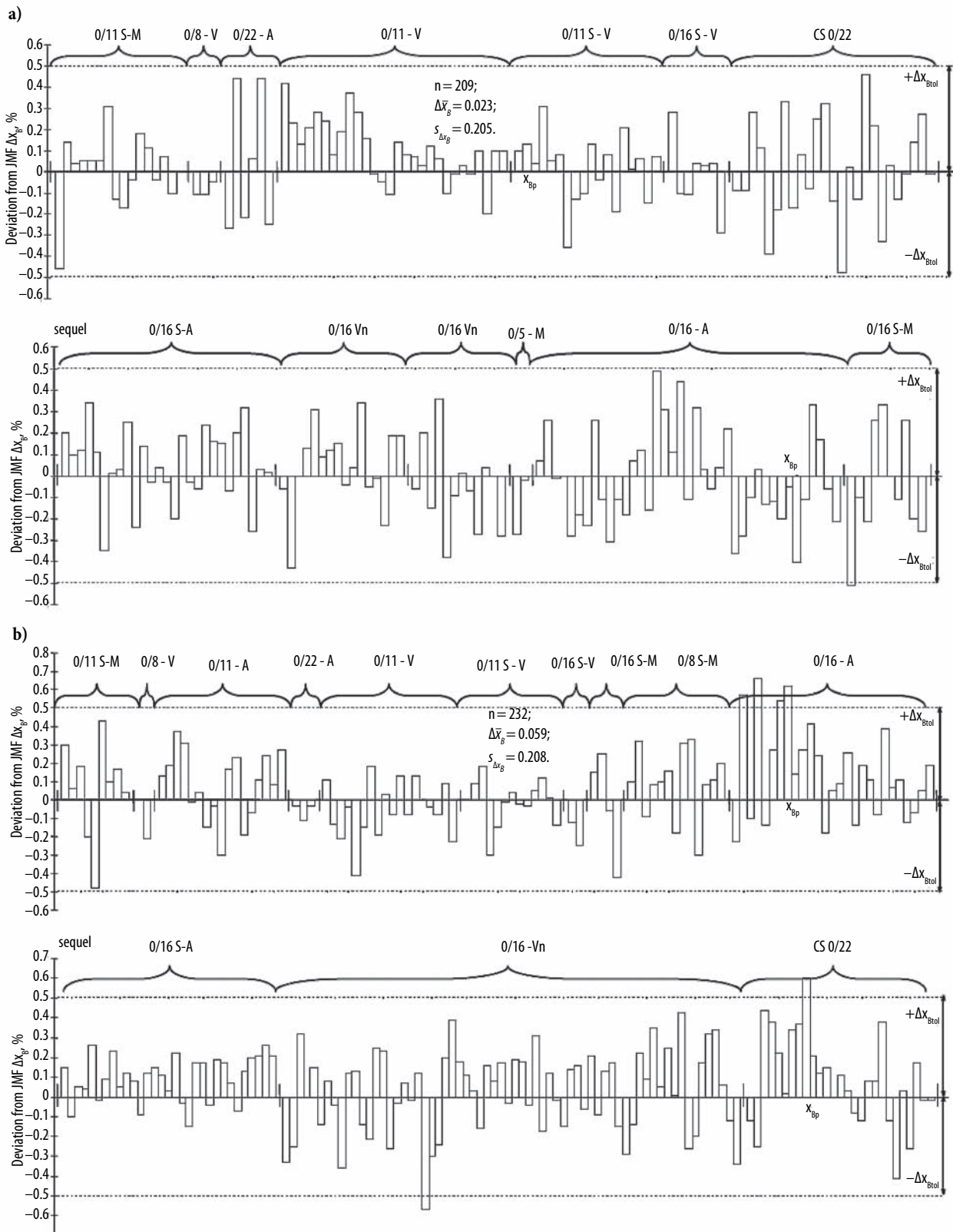


Fig. 6. Distribution of the determined liquid bitumen amount x_{B_i} deviations from JMF x_{Bp} values Δx_{B_i} in the subsamples of HMA mixture of various types and grades after extraction, which were made during the work season, and their compliance with tolerances $\pm \Delta x_{Btol}$: a – before bitumen batcher modernization in 2006; b – after batcher modernization in 2007

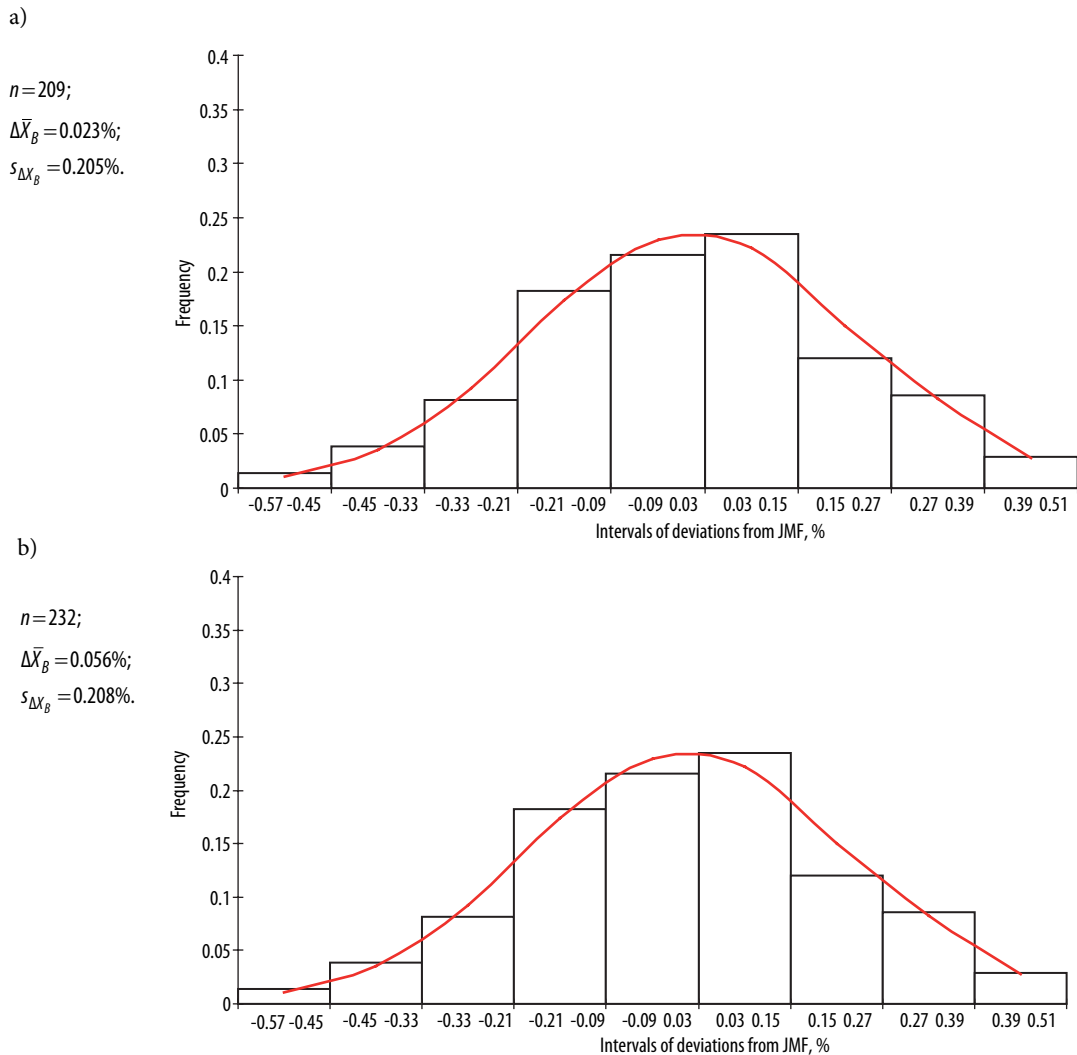


Fig. 7. A distribution histogram of bitumen deviations content Δx_{Bi} in HMA mixture subsamples taken from: a – not reconstructed BBS in 2006; b – reconstructed (improved) BBS in 2007

5. Conclusions

1. Calculation model of mixture lot dispersion of bitumen amount in hot-mix asphalt (HMA) provided allows determining the influence of some factors affecting its size. Dispersion of the bitumen amount in mixture lot in HMA mainly depending on technical parameters of batcher has been identified till now and only after taking and investigating several numbers of separate samples. Sample taking and investigating method is expensive and time consuming process.
2. Investigation of HMA mixture samples revealed that deviation of the amount of bitumen in mixture from JMF arithmetic average and standard deviation were similar. Before modernization they were 0.023% and 0.205% and after modernization 0.056% and 0.208% respectively. Standard deviation from deviation from JMF shows precision of batcher dosing and mainly depends on technical and technological parameters of bitumen system and operator’s action.
3. The results of testing HMA mixture subsamples have shown that the deviations of bitumen content from

the job-mix formula (JMF), i.e. standard deviation and arithmetic mean, actually remained in the same order. When all the deviations were divided into deviation intervals, it was found that, in 2006, 46.9% of all mix batches were made with the lower bitumen content than required, while 5.7% of the mix batches were lacking more than 0.30% of bitumen. In 2007, HMA mix batches with lower than specified bitumen content made 40.1%, while 5.2% of mix batches were lacking more than 0.30% of bitumen.

4. The reconstruction of a bitumen batching system (BBS) slightly improved the quality of HMA mixture. The process of its production became more easily to control. The use of the elements of automatic control helped to make the operation of system’s equipment more precise and effective.
5. When modernized BBS was put into operation the content of bitumen in HMA mix batches approached the optimal amount, and this is one of the most important tasks in HMA mixture production. An optimal bitumen content in HMA mixture means that asphalt pavement will be more durable and its resist-

ance to temperature changes will be increased. The pavement will also be stronger and have higher resistance to shear (rut formation) and corrosion (shelling caused by low frost resistance).

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