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# STATISTICAL ANALYSIS OF COMPONENT CONTENT DEVIATION FROM JOB-MIX FORMULA IN HOT MIX ASPHALT

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**Abstract.** Dose masses of bitumen and finite dosing mineral materials (imported fillers, reclaimed dust and hot fractions) weighed by the dosing systems (batchers) of batch tipe asphalt mixing plant (AMP) shall guarantee that the percentage component ((bitumen (B), mineral fillers (MF), fine aggregate (FA) and coarse aggregate (CA)) content in all mixes of the hot mix asphalt (HMA) mixture batch meets the design content established in the job mix formula (JMF). Batchers do not always weigh the doses of HMA mixture materials accurately and succinctly. Factual deviations of component content from JMF and variation worsen HMA composition and properties. Statistical characteristics suitable to evaluate the quality of HMA mixture are presented. Parameters showing the quality of HMA mixtures produced in AMP in Lithuania are analyzed. The results of laboratory testing obtained from taking and analyzing representative HMA mixture subsamples during the whole production period are presented. The analysis of column diagrams and histograms showed that deviations of component content from JMF in hot mix asphalt produced in modern AMP are frequently smaller than statistical deviations. It shows that broad intervals established in the standards do not encourage to explore all structural and technological capabilities of AMP.

**Keywords:**. Hot mix asphalt (HMA) mixture, bitumen, mineral components, statistical analysis, representative subsample, permitted deviation, factual deviation, tolerances, job mix formula (JMF), asphalt mixing plant (AMP).

## 1. Introduction

Asphalt mixture is composite material consisting of different content asphalt binder, aggregates, filler, air voids, and, in some cases, additives. Its constitutive mechanical performance is significantly influenced by these constituents at different scales and their contents in the mixture (Wang and Hao 2011).

When producing hot mix asphalt (HMA) mixture it is important to dose mineral materials and an organic binder, i.e. bitumen, accurately and evenly. The composition and efficiency of the produced HMA mixture varies and is produced in various technological asphalt mixing plants, the most popular of which are periodical AMP (Sivilevičius and Šukevičius 2009; Brown *et al.* 1989). It has been proved that the component content in HMA mixture influences on its structure and properties, which, in turn, impact on the dependability and durability of the road pavement (Witczak and Fonseca 1996; Witczak 2005; Abdullah *et al.* 1998; Petkevičius and Sivilevičius 2008; Chollar *et al.* 1989). Deterministic and stochastic methods of designing optimal composition were developed and upgraded by Ceylan *et al.* 2009; Huang *et al.* 1996; Sivilevičius and Vislavičius 2008; Sivilevičius *et al.* 2011. When HMA mixture is produced in AMP, the component content always deviates from JMF due to inevitable systematic and random errors. The larger the deviations of the component content in the produced HMA mixture are, the worse the quality of it is. To reduce the deviations of the component content as much as possible, statistical tolerances are normalized.

The dependence of bitumen and mineral materials‘ properties from temperature variations was analyzed by Yi-qiu *et al.* in 2010. Bitumen adhesion with mineral materials was investigated by Bhasin and Little 2009; El Hussein and Abd El Halim 1993. The impact of the thickness of bitumen films coating particles of mineral materials on the properties of HMA mixture was investigated by Li *et al.* 2009. Airey *et al.* 2008; Xiao and Amirkhanian 2009; Kassem *et al.* 2009 studied the impact of mineral aggregate, mineral fillers and bitumen on the damage of moisture in HMA mixture. Mučinis *et al.* 2009; Lee *et al.* 2009 investigated the change of bitumen properties and the factors influencing on the scope of changes in the reclaimed asphalt pavement. Said 2005 investigated the aging process of bitumen mixtures and its impact on their mechanical properties. The value of AMP quality complex indicator mostly depends on the deviations of component content in the produced HMA, which are influenced by materials‘ dosing errors (Brown *et al.* 1989; Sivilevičius *et al.* 2008). In the course of time, materials‘ batchers, which enable not only to reduce the deviations of component content from JMF but also to reduce bitumen oxidation and to increase the dependability and durability of the equipment, are upgraded in HMA mixture production companies (Bražiūnas and Sivilevičius 2010).

The aim of the study is to analyze and evaluate statistically the values of HMA mixture component content deviations from JMF in separate subsamples and to compare them with the tolerances which enable to determine their conformity with technical and technological capabilities of the operating AMP.

## 2. Statistical evaluation of materials‘ dosing process

In various countries, HMA mixture component content deviations from JMF vary (Table 1). Factual component content deviations may be estimated only by taking representative subsamples from the produced mixture and testing them in a laboratory. The obtained laboratory testing data are compared with each component‘s content statistical intervals $\Delta x_{tol}$. Separate subsamples in which component content deviations from JMF are smaller than statistical intervals are considered of good quality and show that mixture production technological process parameters do not deviate from the required ones.

In the study, the factual bitumen content $x_{Bi}$ in subsample *i* (mass %) was compared with its design content $x_{Bp}$. The difference showing bitumen content deviation $\Delta x_{Bi}$ from JMF, which mostly depends on the bitumen dose mass, was calculated. Having extracted liquid bitumen from the subsample and sieved HMA mixture mineral aggregate, the grading of the mixture was estimated. Mineral aggregate is divided into three components: mineral filler - MF, fine aggregate - FA and coarse aggregate - CA. The factual content $x_{MFi}$ of mineral filler in subsample *i* (mass %) was compared with the design content $x_{MFp}$ written in the HMA mixture formula. The difference (deviation) $\Delta x_{MFi}$ was calculated. Factual quantities of fine and coarse aggregates ($x_{FAi}$ and $x_{CAi}$) were compared with the design content of these components ($x_{FAp}$ and $x_{CAp}$) and deviations from JMF ($\Delta x_{FAi}$ and $\Delta x_{CAi}$) were calculated.

**Table 1.** Bitumen and aggregate permitted content weight deviation % from JMF in HMA mixture, tolerances of standards in various countries

| Guidelines or standard | Components of the HMA mixture | | | |
|---|---|---|---|---|
| | Bitumen $\Delta x_{Btol}$ | Mineral filler $\Delta x_{MFtol}$ | Fine aggregate $\Delta x_{FAtol}$ | Coarse aggregate $\Delta x_{CAtol}$ |
| ASTM Standard D 3515-01 (USA) | ±0.5 | ±3.0 | ±7.0 | ±7.0 |
| PANK 4102 (Finland) mixtures class: A | ±0.3 | ±2.0 | ±4.0 | ±4.0 |
| B, C, D | ±0.4 | ±2.0 | ±5.0 | ±5.0 |
| ČSN 73 6149 (Czech Republic) | +0.4; -0.3 | ±2.0 | ±5.0 | ±5.0 |
| ZTVT – StB 95 (Germany) | ±0.6 | +7.0<br>-3.0 | ±9.0 | ±9.0 |
| Construction recommendations R 35 – 01, 2001 (Lithuania) | ±0.5 | ±3.0 | ±8.0 | ±8.0 |
| ĮT ASFALTAS 08, 2008 (Lithuania) mixture types: AC P | ±0.6 | +7.0<br>-3.0 | ±8.0 | ±9.0 |
| MA | ±0.5 | ±4.5 | ±8.0 | ±8.0 |
| PA | ±0.5 | ±2.0 | ±2.5 | ±6.0 |
| AC A, AC V, SMA, AC PD | ±0.5 | ±3.0 | ±8.0 | ±8.0 |

Bitumen and mineral component content in HMA mixture from JMF is calculated by the following equations:

$$\Delta x_{Bi} = x_{Bi} - x_{Bp}, \quad (1)$$

$$\Delta x_{MFi} = x_{MFi} - x_{MFp}, \quad (2)$$

$$\Delta x_{FAi} = x_{FAi} - x_{FAp}, \quad (3)$$

$$\Delta x_{CAi} = x_{CAi} - x_{CAp}. \quad (4)$$

Modules of all components‘ factual deviations from JMF $\Delta x_{Bi}, \Delta x_{MFi}, \Delta x_{FAi}, \Delta x_{CAi}$ shall be smaller than the tolerances for separate components established in the ĮT ASFALTAS 08 ($x_{Bp}, x_{MFp}, x_{FAp}, x_{CAp}$):

$$|\Delta x_{Bi}| < |\Delta x_{Btol}|; \quad (5)$$

$$|\Delta x_{MFi}| < |\Delta x_{MFtol}|; \quad (6)$$

$$|\Delta x_{FAi}| < |\Delta x_{FAtol}|; \quad (7)$$

$$|\Delta x_{CAi}| < |\Delta x_{CAtol}|. \quad (8)$$

Arithmetic means $\overline{\Delta x_B}$, $\overline{\Delta x_{MF}}$, $\overline{\Delta x_{FA}}$, $\overline{\Delta x_{CA}}$ of component content deviations from JMF calculated in all tested subsamples during the works' season with bitumen, mineral filler, fine or coarse aggregates are calculated by the following formula (9).

$$\overline{\Delta x} = \frac{\sum_{i=1}^{n} \Delta x_i}{n}. \quad (9)$$

The deviations of each component from JMF in separate subsamples are shown by standard deviation, which is calculated by the following formula (10):

$$s_{\Delta x} = \sqrt{\frac{\sum_{i=1}^{n}\left(\Delta x_i - \overline{\Delta x}\right)^2}{n-1}}, \quad (10)$$

here $n$ – the number of HMA mixture subsamples tested during the works' season; $\Delta x_i$ - deviation from JMF of the component content in HMA mixture subsample $i$, %.

Position ($\bar{x}$) and dispersion (variation) ($s_x$) parameters of any component content in HMA mixture are calculated by the following formula (11) and (12).

Arithmetic mean

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}, \quad (11)$$

and standard deviation

$$s_x = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}}, \quad (12)$$

here $x_i$ - component content in an HMA mixture subsample $i$, mass %.

Component position and dispersion parameters (arithmetic mean $\overline{\Delta x}$ and standard deviation $s_{\Delta x}$) used in the study were obtained from the subsamples taken and tested in a laboratory by extracting bitumen. We state that random size $x$ of separate values $x_i$ deviations (difference) $\Delta x_i$ from any constant number, for example, design value $x_p$, standard deviation $s_{\Delta x}$ equals standard deviation $s_x$ of separate values $x_i$.

According to the theory of mathematical statistics, if constant quantity $x_p$ is substracted from all property values (in our case $x_i$), dispersion will not change. Therefore, the square mean of deviations may be calculated not only from the values of the investigated property, but from their deviations from some constant quantity (in our case from JMF). Graphically shown positions of surplus (Fig 1 a) and deficit (Fig 1 b) of the component content $x_i$ deviation from JMF prove that arithmetic means $\bar{x}$ and $\overline{\Delta x}$ of absolute values $x_i$ and $\Delta x_i$ differ, and standard deviations $s_x$ and $s_{\Delta x}$ are the same.

When dispersion parameters are calculated through the use of absolute values of component content, their dispersion is:

$$s_x^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2. \quad (13)$$

If the same quantity $x_p$ is substracted from each quantity in the brackets of formula 13, the following dispersion of deviations is obtained:

$$s_{\Delta x}^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left[\left(x_i - x_p\right) - \left(\bar{x} - x_p\right)\right]^2. \quad (14)$$

Whereas $x_i - x_p = \Delta x_i$ and $\bar{x} - x_p = \Delta x$, we obtain the following:

$$s_{\Delta x}^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - x_p - \bar{x} + x_p)^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 = \quad (15)$$

$$= s_x^2, \text{ i. e. } s_{\Delta x}^2 = s_x^2.$$

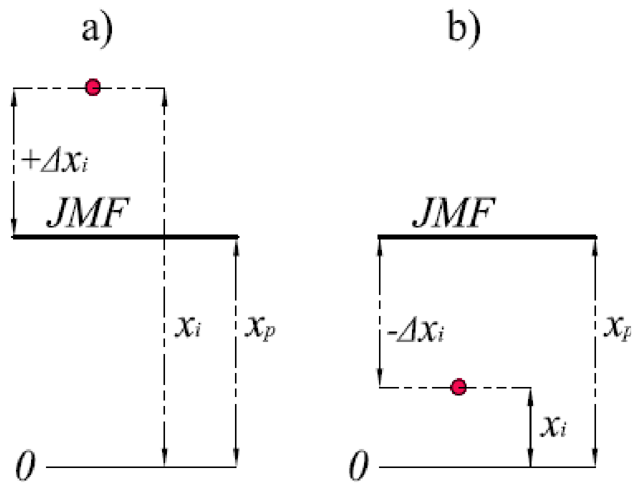


**Fig 1.** *i* component content deviation from JMF in HMA mixture : a – positive deviation (surplus), b – negative deviation (deficit)

This property of standard deviation and dispersion enables to calculate component content dispersion parameters provided only project value $x_p$ and component content in HMA mixture subsamples deviations $\Delta x_i$, not absolute values $x_i$, which depend on a concrete design, are available. It is known that during the works' season HMA mixture of various types and marks with different project $x_p$ of each component is produced in AMP.

When studying AMP capabilities to meet the requirements of statistical tolerances, deviations $\Delta x_i$ may be used instead of absolute values $x_i$ when calculating standard deviation $s_x$ or dispersion $s_x^2$. It enables to investigate HMA mixtures of all design compositions as a whole by determining the stability of any component content in an HMA mixture (dispersion, variation).

## 3. Factual deviations of component content in the produced HMA mixture

Self-control of bitumen (B) and mineral component (MF, FA, CA) content in HMA mixtures is carried out by observing the technological process. The company carrying out state control continually controls road construction projects. The data on the production technological process, materials' quality and their amounts obtained in laboratories are submitted to the operator who, in turn, changes the parameters of the production process. The company tests the laid asphalt concrete pavement. The change of the composition and properties of the produced HMA mixture after transporting and laying asphalt concrete pavement is studied.

The actual quantity of dosed bitumen and mineral materials charged into the mixing drum may be estimated in the following three direct and indirect ways:

- by taking data written in the computerized handling programme or from the clock-face indicators, observed during the HMA mixture production process;
- by taking a representative subsample of the produced HMA mixture's tested batch and having extracted it, by calculating bitumen and other mineral component content;
- by taking a representative subsample of the produced HMA mixture discharged from the cumulative bin silo into the truck cabin, as indicated in LST EN 12697-27.

This study uses the data obtained through the application of the third method of estimating the component content in an HMA mixture. During one works' season mixtures of various marks were produced. In one year, 209 representative subsamples were taken. Liquid bitumen was extracted and grading was estimated according to the procedures set in the standards. At present, the normative document ĮT ASFALTAS 08 valid in Lithuania defines the requirements set to the composition of mixtures. The regulations define the permitted deviations from JMF of bitumen and mineral component content (Table 1).

The carried out statistical analysis proved that technological parameters $\overline{\Delta x_B}$, $\overline{\Delta x_{MF}}$, $\overline{\Delta x_{FA}}$, $\overline{\Delta x_{CA}}$ and $s_{\Delta x_B}$, $s_{\Delta x_{MF}}$, $s_{\Delta x_{FA}}$, $s_{\Delta x_{CA}}$, which show the quality of the material dosing and handling system, operator's actions, material sieving process and other factors, in essence complied with the requirements set in regulations ĮT ASFALTAS 08(Fig 2). Out of 209 tested subsamples, the factual bitumen content in only one of them exceeded tolerance limits $\Delta x_{Btol} = \pm 0.5\%$. Bitumen dose position and dispersion statistical parameters completely complied with the requirements: $\overline{\Delta x_B}$ =0.023% and $s_{\Delta x_B}$ =0.205%.

Statistical parameters of mineral components complied with the requirements as well.

Arithmetic mean of mineral filler content deviations from JMF was $\overline{\Delta x_{MF}}$ =0.458%, standard deviation - $s_{\Delta x_{MF}}$ =0.801%. According to the regulations ĮT ASFALTAS 08, mineral filler (i.e. particles <0.063mm) mass content in a separate subsample shall not differ from the design content by more than $\Delta x_{MFtol} = \pm 3.0\%$. Suppose probability is 99.73%, the highest mineral filler deviation from JMF may be $x_p \pm 3 s_{\Delta x_{MF}} = x_p \pm 3 \cdot 0.8 = 2.4\%$. The calculated mean of deviations from JMF of fine aggregate (particles 0.063-2mm) and coarse aggregate (particles >2mm) is as follows: $\overline{\Delta x_{FA}}$ =-0.975% and $\overline{\Delta x_{CA}}$ =0.516%, and standard deviations of deviations are $s_{\Delta x_{FA}}$ =2.430% and $s_{\Delta x_{CA}}$ =2.606%, respectively. The application of the same 99.73% probability showed that statistical tolerance of fine aggregate may be $x_p \pm 3 \cdot 2.43 = x_p \pm 7.29\%$, and that of coarse aggregate $x_p \pm 3 \cdot 2.61 = x_p \pm 7.83\%$, i. e. in both cases less than $\pm 8.0\%$. $\Delta x_{FAtol} = \Delta x_{CAtol} = \pm 8.0\%$.

Distribution histograms of component content deviations from JMF contained in the HMA mixture (Fig 3) show that most of separate values have less dispersion (variation) than those set in statistical tolerances.

Suppose component content deviations from tolerances were not 0.27% of all data, but 5% (probability of 95%) of data, which is sufficient in the production, tolerances may be reduced by 1/3. Bitumen content would be $x_p \pm 0.41\%$, mineral filler - $x_p \pm 1.6\%$, fine aggregate $x_p \pm 4.85\%$, and that of coarse aggregate $x_p \pm 5.2\%$.

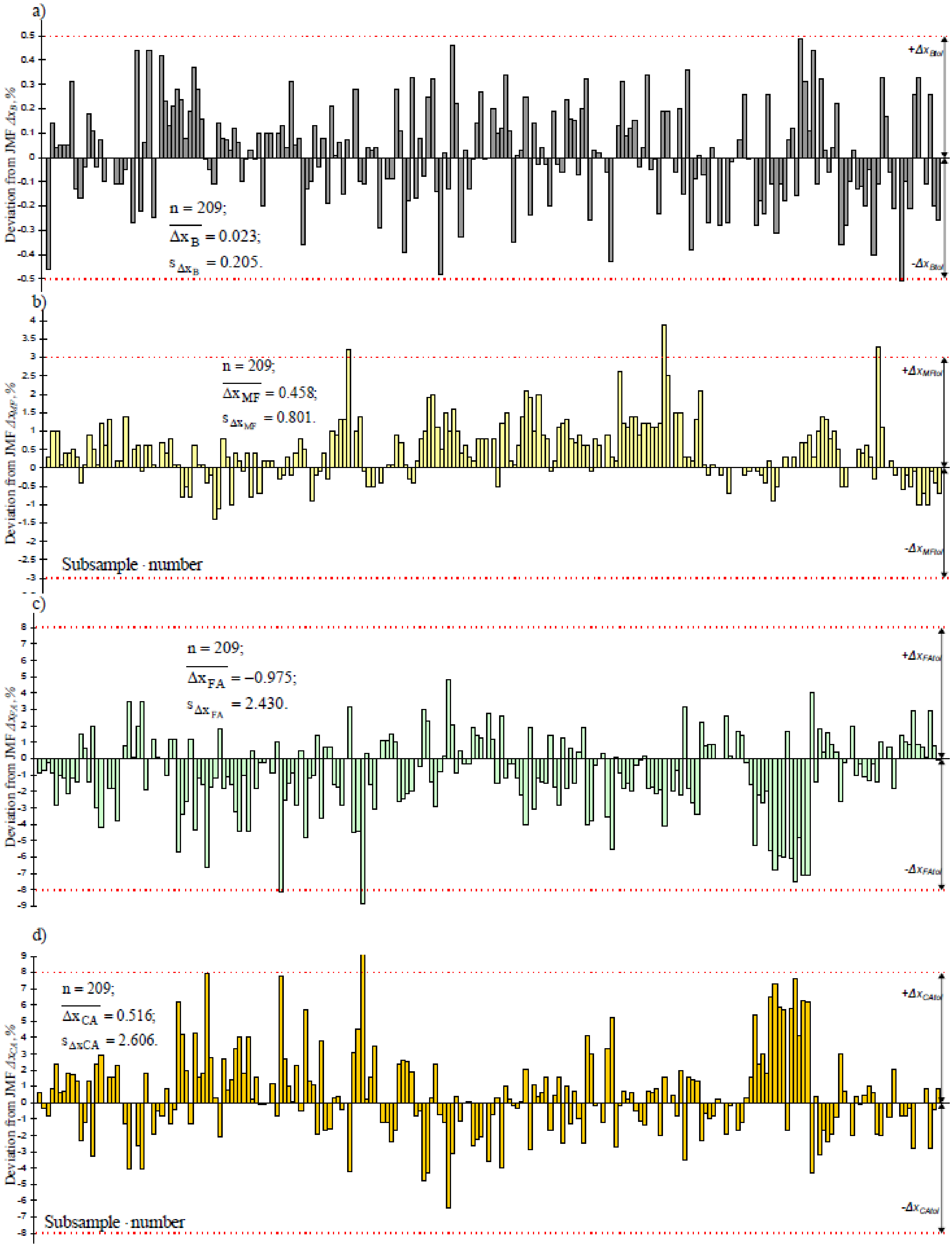


**Fig 2.** Distribution of the estimated liquid bitumen (a), mineral filler (b), fine aggregate (c) and coarse aggregate (d) content $x_i$ deviations from JMF $x_p$ values $\Delta x_i$ in the subsamples of HMA mixture of various types and grades after extraction, which were made during one works' season, and their compliance with tolerances $\pm\Delta x_{tol}$

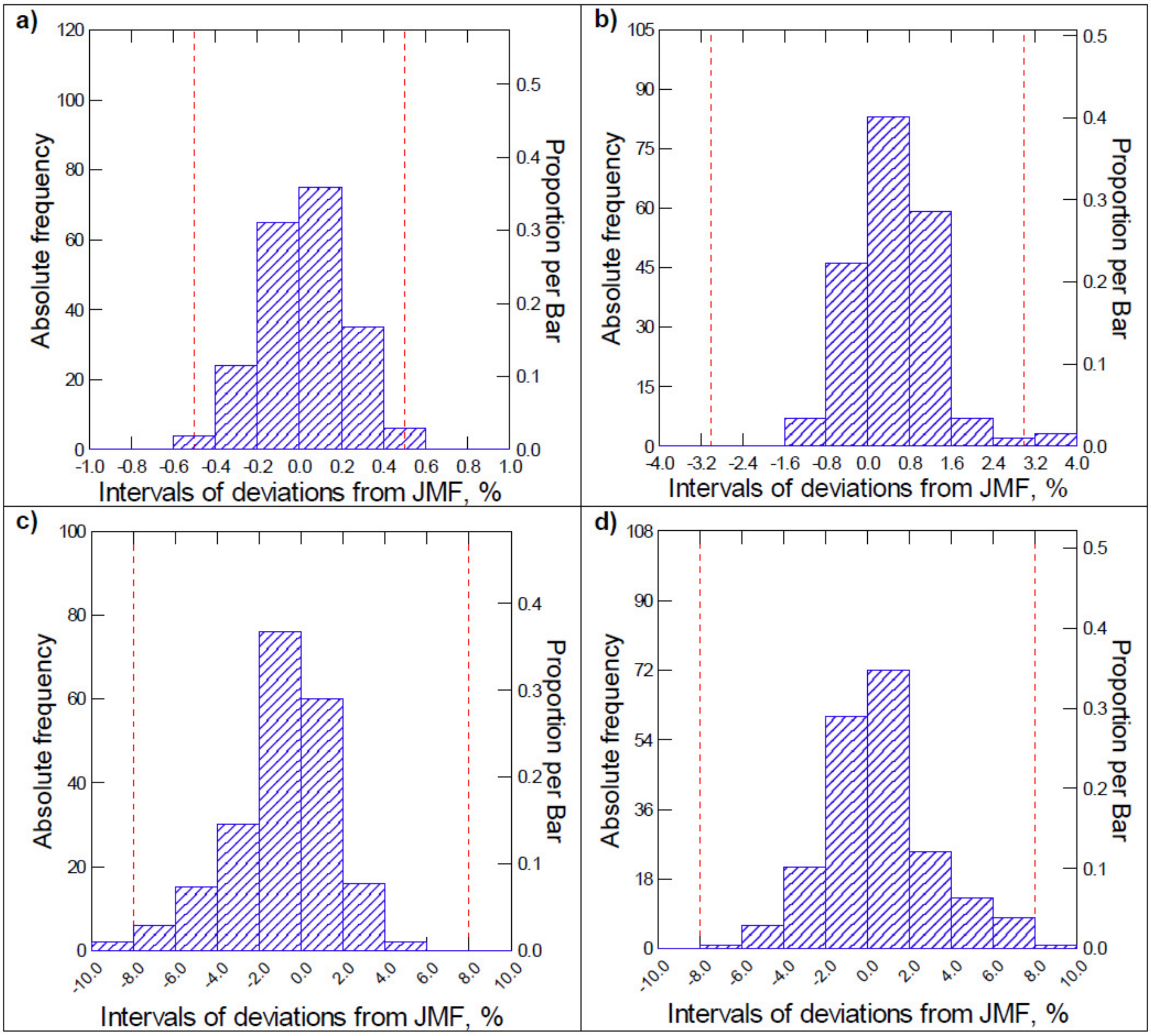


**Fig 3.** Distribution histograms of bitumen (a), mineral filler (b), fine aggregate (c) and coarse aggregate (d) content deviations $\overline{\Delta x_B}$, $\overline{\Delta x_{MF}}$, $\overline{\Delta x_{FA}}$ and $\overline{\Delta x_{CA}}$ in HMA mixture subsamples

## 4. Conclusions

1. HMA mixture component amounts and their deviations from JMF estimated from a large number of representative subsamples ($n$ = 209) as well as their standard deviations are dependable. Dispersion (variation) of bitumen, mineral filler, fine aggregate and coarse aggregate content in the produced HMA mixture was evaluated by standard deviations of deviations from JMF, but not by standard deviation of absolute values. This enabled to investigate mixtures of different designs as one mixture produced during one works‘ season.

2. Modern AMP are capable of producing an HMA mixture of much higher quality than it is established in the standards. Component amounts, which depend on the dosing and other technological process operations‘ errors, materials‘ homogeneity and operator‘s actions, frequently deviate from JMF less than the permitted tolerances. Technical and technological parameters of AMP enable to state that statistical tolerances set in the standards may be tightened through a better use of AMP capabilities. It would enable to use the achievements of technological progress through the implementation of the developed and upgraded AMP.

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