ANALYSIS OF THE VARIATIONS IN THE STIFFNESS OF ASPHALT MIXTURE

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ABSTRACT

Recently the analyses of the performance of asphalt mixtures have come to the focus of attention also in Hungary, with key importance placed on international asphalt engineering practises as well as the understanding, validated adoption and application of such experiences.
The production of asphalt mixture shows a variation between the designed and produced asphalt composition even if all production requirements are complied with. This also affects the mechanical properties of the produced mixture. This article examines the impact of the above mentioned production variation in relation to asphalt stiffness, which is one of the most important mechanical properties of any asphalt mixture. To obtain the stiffness test results, both the IT-CY methodology and the Simple Performance Tester (SPT) machine were employed. The tested mixture was also checked against the Witczak Dynamic Modulus Prediction Model to be able to compare the seen production variation with the variation predicted by the model.

Keywords: asphalt production, dynamic modulus, Monte Carlo simulation

1. INTRODUCTION

In respect of asphalt designing, the Hungarian professional organizations have made their choice offered by the relevant material specifications and opted for the fundamental requirements instead of the empirical requirements. This decision not only allowed and accelerated the development of the profession at large, but also called for the reform of the existing Hungarian professional practice and approach. The analyses of the performance of asphalt mixtures have come to the focus of attention, with key importance placed on international asphalt engineering practices as well as the understanding, validated adoption and application of such experiences.

Due to the process engineering reasons, certain parameters of the asphalt production process such as grading, binder content, etc. necessarily and slightly deviate from the prescribed values to varying degrees. However, any variations even within the allowed thresholds may significantly affect the mechanical properties of the produced asphalt. Thus, all possible controls should be considered that can encourage the asphalt producer to reduce the degree of such variation.

In respect of the production of a newly emerging type of surface course, this article examines the variation of asphalt stiffness, which is one of the most important mechanical properties of any asphalt mixture. The tools to carry out the tests included the IT-CY methodology, which is widely used in Europe and the Simple Performance Tester (SPT) machine, which is mainly known in the USA. The tested mixture was also checked against the Witczak Dynamic Modulus Prediction Model to be able to compare the seen production variation with the variation predicted by the model.

2. TEST PROCEDURE

As is well-known, one of the most important mechanical properties of any asphalt mixture is its stiffness. The professionals in Hungary, however, have limited reliable experience concerning the stiffness of mixtures produced in Hungary. Having a reliable knowledge of our mixtures would be highly important for pavement design, quality assurance and many other considerations.

The tests were carried out for 25 production days at a Hungarian asphalt mixture plant to identify the variation of an asphalt mixture produced by the plant. The tested mixture was the then currently produced „SMA 8 surface course 45/80-60”. In terms of stiffness, this mixture is not the best choice, but stiffness variation can still be tested on it. Also, no tests have been carried out in Hungary for this mixture type before. We hope that with this test process we can contribute to a better understanding of the material behaviour of the asphalt mixture that is used in an increasing volume as a surface course for Hungarian motorways.

The planned input target composition of the mixture is summarized in Table 1.

Currently there are a few options for testing the stiffness of asphalt mixtures. One of them is the IT-CY method, which is the most frequently used technology in Hungary. The benefits of this test include its fast execution and the fact that Marshall or core specimen can be used as a test piece. However, its major disadvantage is that the indirect pulling applied for the test produces only a quasi modulus of resilience. Due to the static characteristic of the test, the viscous effect of the binder cannot be tested. Another less prevalent technology is to define stiffness by 2 or 4 points bending. The benefit of the method is that dynamic load is applied to provide a more comprehensive picture of the mixture’s behaviour, while the disadvantage stems from the fact that a large number of difficultly producible beam and trapezoid test pieces need to be used. In the laboratory of Budapest University of Technology and Economics, Department of Highway and Railway Engineering, a so called SPT machine (Simple Performance Tester) has been commissioned that can combine the benefits of the two techniques, while eliminating their negative effects. The tester’s major advantage is that easily producible cylindrical test pieces can be tested at different temperatures and varying frequency loads. The results can support a highly accurate description of the asphalt mixture’s stiffness, contrary to the type approval test, for example, where the stiffness value relates to a specific temperature and a static load that can often provide a misleading picture of the mixture’s real mechanical properties.

Table 1: The planned and the realized composition

Production day	Grading (Passing sieve % by mass) 0,063 mm	0,125 mm	0,25 mm	1 mm	2 mm	4 mm	5,6 mm	8 mm	11,2 mm	Binder content (%)	Air voids content (%)
	Input target composition										
	11,5	14	16	22	31	35	57	95	100	6,5	2,4
	Output target composition										
1	11,8	13	15	24	33	40	61	93	100	6,39	2,40
2	11,9	14	16	24	32	40	57	94	100	6,36	2,42
3	11,8	13	15	22	32	39	59	94	100	6,37	3,41
4	12,0	14	15	23	32	39	57	91	100	6,35	3,16
5	11,3	13	15	23	32	41	61	95	100	6,15	4,23
6	12,0	13	15	23	32	40	61	93	100	6,35	3,38
7	11,5	13	15	23	32	42	63	94	100	6,33	4,63
8	11,2	13	15	23	33	41	60	92	100	6,51	3,00
9	11,5	13	15	24	34	42	58	92	100	6,4	2,67
10	11,3	13	15	24	33	42	62	94	100	6,42	3,01
11	11,5	13	15	22	31	41	64	94	100	6,5	3,77
12	11,4	13	15	24	33	41	62	92	100	6,4	3,61
13	11,7	13	14	23	33	40	59	92	100	6,5	2,51
14	11,6	13	14	22	33	40	56	92	100	6,57	3,03
15	12,1	14	15	23	33	40	60	93	100	6,20	3,19
16	12,1	13	15	23	32	39	56	92	100	6,20	4,02
17	11,8	13	15	24	34	41	56	91	100	6,40	2,55
18	11,2	13	14	22	32	39	59	94	100	6,22	3,13
19	11,7	13	15	22	32	40	60	94	100	6,2	4,59
20	11,8	13	15	23	33	41	60	95	100	6,50	3,47
21	11,6	13	14	23	33	40	60	93	100	6,40	3,14
22	11,1	13	14	22	30	37	52	90	100	6,20	4,49
23	11,5	13	15	24	34	42	63	96	100	6,30	3,57
24	11,5	13	15	24	33	40	58	93	100	6,30	3,65
25	11,5	13	15	23	33	39	62	96	100	6,40	4,38

3. MEASUREMENT RESULTS

The SPT tests used 2 pairs of gyratory specimen from the daily production that were subsequently sawn to produce 4 cylindrical specimens from each pair for the IT-CY tests. The tests were carried out at 20 °C where 124 milliseconds was the build-up time for the IT-CY test and the SPT test was performed for 6 different loads. The load frequencies used were 0.1, 0.5, 1, 5, 10 and 25 Hz. Our first evaluation of the results showed that the measured stiffness value of the IT-CY test correlates closest to the dynamic modulus determined at 0.5 Hz. Figure 1 shows the tight nature and accuracy of the relation of the two methods.

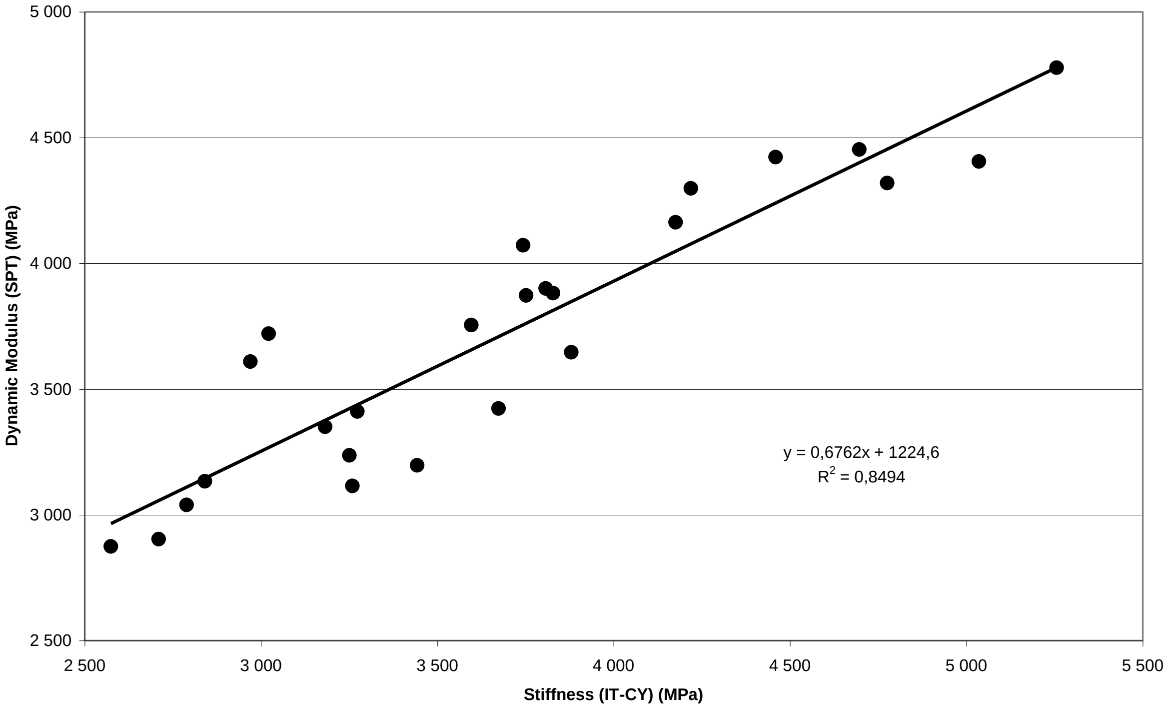

Figure 1: Relation of the IT-CY and SPT tests

Figure 2 depicts the stiffness values relative to the different production days, while Table 2 includes the main measurement results.

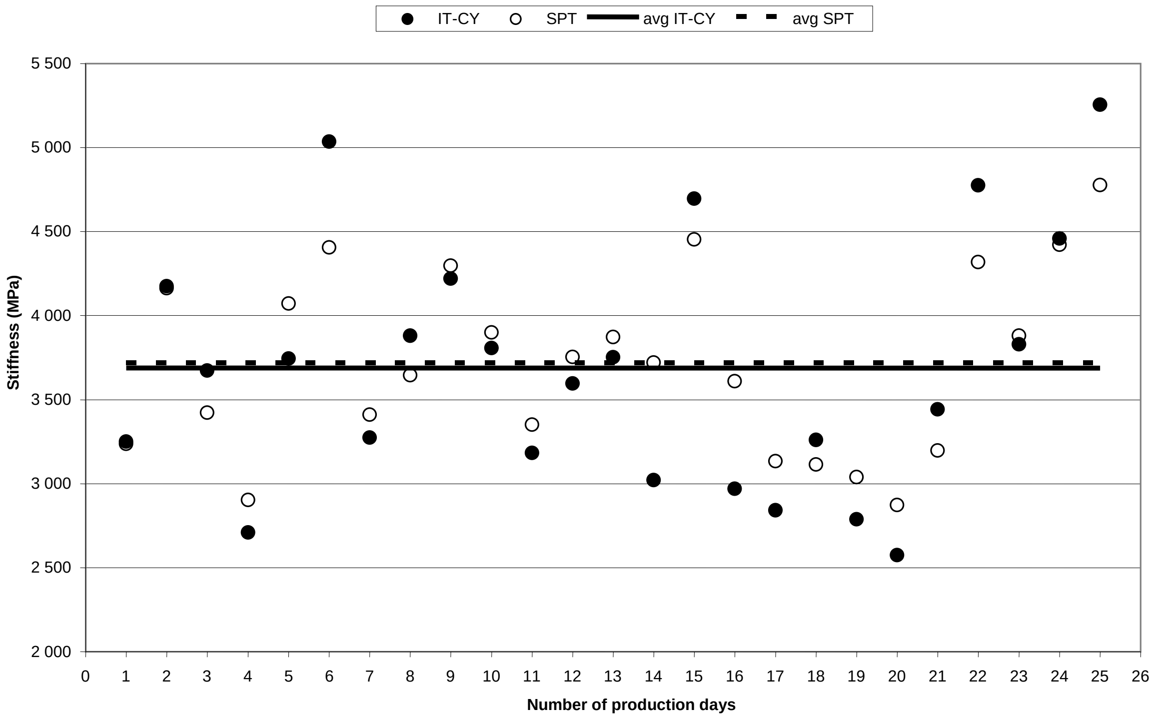

Figure 2: Stiffness values in the function of production days

The data of Figure 2 and Table 2 shows that the mean values and the variations are almost the same for both test processes, while the mean values of the SPT test are somewhat higher, but their variation is lower. This suggests that the SPT test provides more accurate results than the IT-CY test.

Table 2: Measured stiffness values

Production day	IT-CY	SPT (f=0.5 Hz)
	(MPa)	
1	3 251	3 236
2	4 176	4 163
3	3 674	3 423
4	2 710	2 903
5	3 744	4 072
6	5 036	4 405
7	3 274	3 411
8	3 880	3 646
9	4 219	4 298
10	3 807	3 900
11	3 182	3 350
12	3 596	3 754
13	3 752	3 872
14	3 022	3 720
15	4 697	4 452
16	2 970	3 610
17	2 841	3 134
18	3 260	3 114
19	2 789	3 040
20	2 575	2 874
21	3 443	3 196
22	4 776	4 319
23	3 828	3 881
24	4 460	4 422
25	5 256	4 778
Mean value	**3 689**	**3 719**
Standard deviation	**727**	**534**
Variation coefficient	**0,20**	**0,14**

In general, the measured values are relatively lower than those related to the traditional asphalt concrete mixture, but their absolute value cannot be assessed in this case, because no Hungarian historical data is available for this special mixture, and appropriate international data for comparison is not available either. The test results gain further importance considering that the laboratory tests of production verifying the proper use of design parameters (grading, binder content, etc.) did not find any non-compliance cases. The laboratory test results satisfied all of the relevant technical requirements. Therefore, the conclusion can be drawn that the experienced variation of the stiffness values emerged under appropriately controlled production.

4. STIFFNESS PREDICTION

The scarcity of Hungarian asphalt engineering tests restricts the possibility of examining mixture stiffness in every case. Having some stiffness estimates would also be beneficial in the mixture designing phase already. For this purpose, we have compared the measured values with the Witczak Model, which is frequently cited in the international literature. The well-known formula is as follows:

$$\log E = -0{,}261 + 0{,}008225 \cdot p_{200} - 0{,}00000101 \cdot (p_{200})^2 + 0{,}00196 \cdot p_4 - 0{,}03157 \cdot V_a -$$

$$- 0{,}415 \cdot \frac{V_{b,eff}}{(V_{b,eff} + V_a)} + \frac{1{,}87 + 0{,}002808 \cdot p_4 + 0{,}0000404 \cdot p_{38} - 0{,}0001786 \cdot (p_{38})^2 + 0{,}0164 \cdot p_{34}}{1 + e^{(-0{,}716 \cdot \log(f) - 0{,}7425 \cdot \log(\eta))}}$$

Where the variables represent:

E	Asphalt Mix Dynamic Modulus, in 10^5 psi
η	Bitumen viscosity in 10^6 poise (at any temperature, degree of aging)
f	Load frequency in Hz
V_a	% air voids in the mix, by volume
$V_{b,eff}$	% effective bitumen content, by volume
p_{34}	% retained on the ¾ inch sieve, by total aggregate (cumulative)
p_{38}	% retained on the 3/8 inch sieve, by total aggregate (cumulative)
p_4	% retained on the No. 4 sieve, by total aggregate (cumulative)
p_{200}	% passing on the No. 200 sieve, by total aggregate

Unfortunately, we did not find correlation after having made the estimation with the Witczak formula each production day concerning the stiffness of the mixtures and comparing them to the values measured each day. The reason for this, on the one hand, is that unfortunately, we did not have measurement results concerning the viscosity of the bitumen, these results were estimated with the Witczak-Mirza formula on the basis of the penetration results, on the other hand, the standard Hungarian sieve sizes differ from the ones used in the formula, in this case we counted applying the Hungarian sieve size closest to the Anglo-Saxon size.

We also made a modulus estimation composing an average from the results of the different production days and compared it to the average of the measured results. You can see the results of the dynamic modulus estimation concerning 20 °C comparing it to the average of the measured values of the SPT test performed on 6 different frequencies in Figure 3.

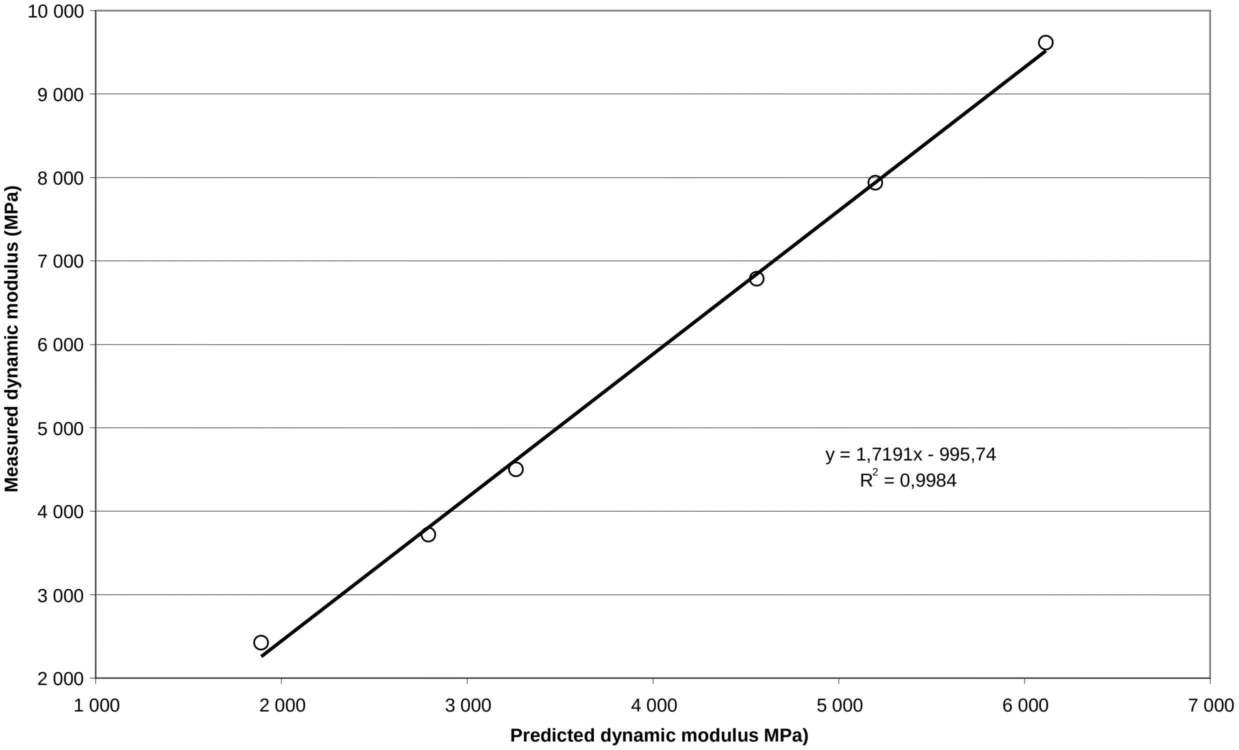

Figure 3: Comparison of dynamic modulus measured at 20 °C with the predicted dynamic modulus

It can be ascertained that although the Witczak model was not capable of giving notice the impact of the production oscillation on the stiffness – which may also happen due to the inexactness of the input data outlined before – the connection between the measured and the estimated average values is satisfyingly close.

Having examined the values, one can see that the model operates with a certain degree of underestimation. However, in addition to the above mentioned limitations of the model-based calculation, i.e. different sieve sizes and estimated binder viscosity, the underestimation is also due to the special gravel base used. No other model could provide better stiffness prediction for a mixture with discontinuous particle size distribution with particles maximum 8 mm in size.

On the basis of post-production composition test data, we have made an attempt to have a stochastic approach to the existing deterministic model. The simplest way of managing stochastic parameters is based on the so called Monte Carlo Simulation, and its objective is to determine the tested parameter's density function. This method relies on the principle that the input parameters are treated as random variables in addition to taking them into account with their expected or measured mean values. In essence, with this method we define the real distribution of all input data, from which we take random samples to select the necessary input data in order to identify the modulus of the asphalt mixture. Subsequent to a sufficiently large number of runs, a frequency histogram for the modulus of the asphalt mixture can be created, which helps estimate and analyse the distribution of the modulus. This principle is described in Figure 4.

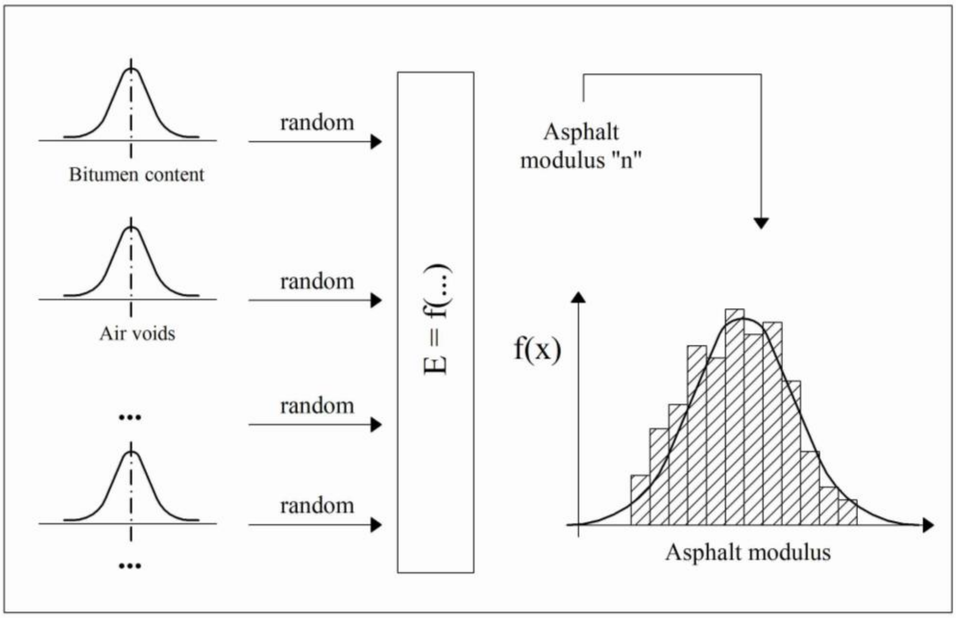

Figure 4: Schematic drawing for the Monte Carlo method

Our direct objective was to compare the values of the expected dynamic modulus and that of the variation to the statistical properties of the measured stiffness values.

For the model-based calculation the applied random variables included particle distribution, air-voids and binder content values. Their expected values and variations were calculated on the basis of daily laboratory test results. In addition to the load frequency, which was obviously treated as a discrete value, we were forced to consider a mean value also for the binder viscosity, because more accurate laboratory data was not available. We assumed a normal distribution of the random variables and presumed no correlation between these variables. Figure 5 shows the result of the Monte Carlo simulation including the density functions related to the data of the two test procedures.

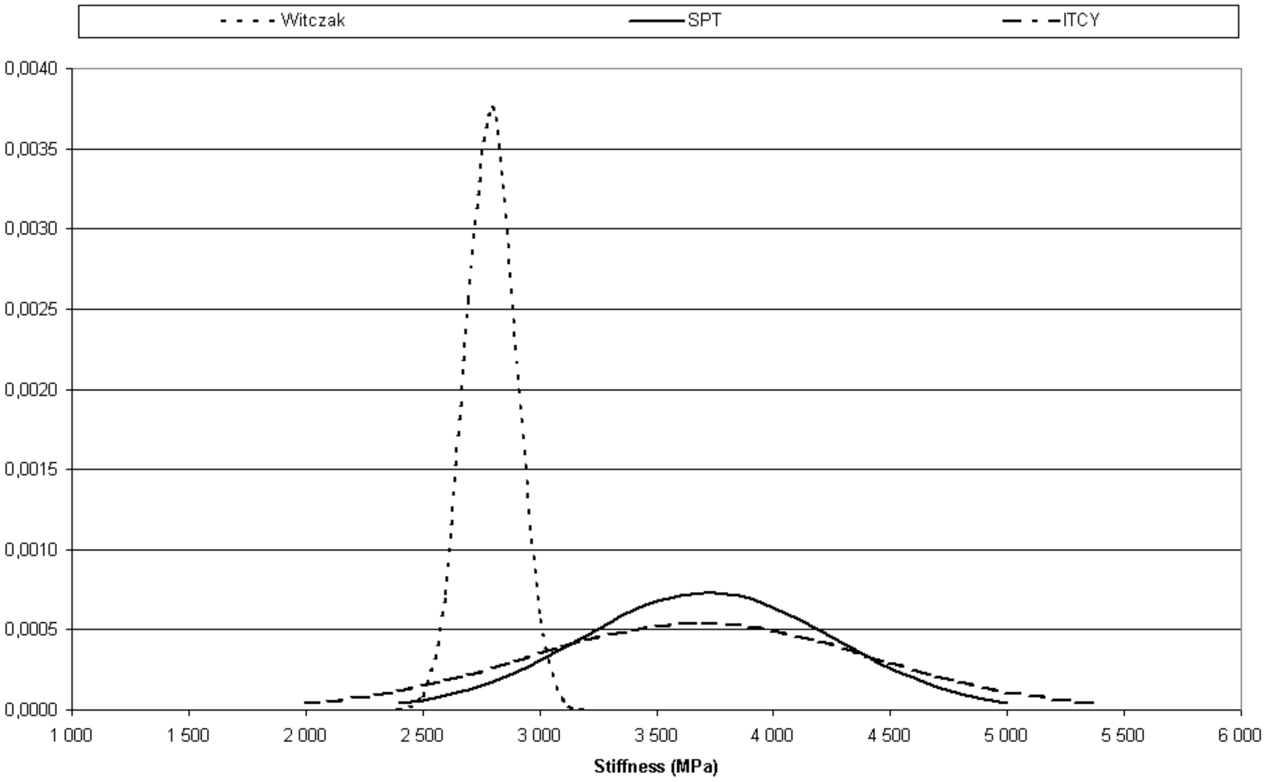

Figure 5: Measured and predicted stiffness distribution data

Compared with the accuracy of empiric models, the accuracy of these types of predictions is subject to the reliability of the input data. In addition to the underestimating nature of the model, as discussed earlier, it can be seen clearly that the variation of the predicted values is much lower than that of the measured values. This is obviously due to the stronger-than-expected impact of the cancellations used in the model calculation. To improve the accuracy of the model-based calculation, the correlation between the inputs must also be identified in addition to defining their expected values and variation. Going forward, the difficulty here stems from the fact that although probability trends may be established for these correlations, the deeper correlations will always be different for each asphalt mixture.

5. SUMMARY

The scarcity of available resources inevitably determines the need for the efficient use of public funds. Consequently, the public road authorities in the international professional practice intend to broaden the technical requirements in different ways. For example, pay adjustment can be made for the entrepreneurs subject to the quality of the implementation work. In Hungary, this approach has not yet become common in practice, but efforts are being made to introduce a pay adjustment factor based on differences between the expected and effective values of any specific quality parameter.

Our research efforts examined whether the stiffness value of an asphalt mixture could become a potential parameter for defining such a pay adjustment factor. The composition tests proved in each case that the composition of the tested mixture, i.e. particle-size distribution, binder content and air-voids complied with the relevant tolerance values. However, the stiffness values showed a large variation for both testing methods.

This confirms our expectation that stiffness in itself is a complex material property that represents the essence of many input parameters. Therefore, mixtures should not be described by a number of individual composition properties, but rather a single collective value of these properties should be used for this purpose. Moreover, the stiffness value is also very sensitive to any changes of these input parameters, which makes it difficult to link any stiffness specification to a specific reliability level. The test procedures described in this article are not capable either to confirm or, in our view, to reject whether such a pay adjustment factor could be defined in direct relation to the stiffness of asphalt mixtures that could encourage the production companies to reduce the quality fluctuations tied to the quality parameters of raw materials and whether a single measured parameter could be controlled by the stiffness value.

REFERENCES

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