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The effect of stiffness and duration parameters to the service life of the asphalt pavement structure

PhD. thesis

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1. Introduction, research aims

The big size of the traffic on the road pavements and its increase causes the necessity of building economically and technologically suitable pavements.

The asphalt and the concrete are two principal building materials of pavements, but the asphalt pavement structures are most prevalent. Designing of pavements meets with difficulties, because of the diversity of the traffic load and the extreme meteorological effects. The mechanical characteristics of the earthwork and the asphalt mixture can be difficult to be defined exactly and have inhomogenity.

As a result of the different weighting of the above problems the design method of asphalt pavements can be different by countries. Before the 1960's the design methods were based on an experimental basis. From the 1960's the so called AASHO tests were performed and formed the basis of the conscious pavement design methods. Many field and laboratory examinations were performed in order to recognise the mechanical properties of the asphalt mixtures. All countries processed his own design methods based on these examinations. The design methods applied in the practice contains simplifications in order to use them easily in the planning practice. One of the practical forms of it is the system of type constructions (catalogue method). The Hungarian standard is also based on this method.

The aim of present paper is to determine the effect of various material parameters to the fatigue life of the pavement structures and the necessary pavement thicknesses. Laboratory examinations have been made to determine these material parameters. The examination of it is considerable, because the simplifications of present Hungarian pavement design method does not take into account of the favourable characteristics of the new asphalt mixtures, so the increasing of fatigue life of these pavements can not be handled.

In the course of the research work stiffness modulus and fatigue tests were performed on diverse asphalt mixtures (on a binder and surface courses' usual mixtures). The final result of these tests are the two principal data of the pavement design.

I manifest it in the paper, how the fatigue life of the asphalt pavements can be varied depending on the real mechanical parameters of the asphalt mixtures. For example in the course of the development of the asphalt and bitumen technology worked out asphalts made of polymer modified bitumen; these mixtures have better stiffness and fatigue parameters, and because of this the pavement thicknesses could be less. The fatigue is just one failure method of the pavements – in this paper only this were examined. The optimisation of the thickness of pavement structures depends on many other aspect.

2. Research results

2.1. Performing IT-CY test (Indirect Tensile Test On Cylindrical Specimen) on many types of asphalt mixtures shows that the 'Verstraeten formula' can be applied on the asphalt mixtures currently being produced. This formula can be used to the preliminary planning [17].

The difference between measured and calculated stiffness moduli can be seen on Table 1. Verifiable, that asphalt mixtures made of polymer modified bitumen have great difference between the calculated and measured stiffness moduli.

Table 1.

Mixture identification	Number of various mixtures	Difference between measured and calculated stiffnesses eltérésének átlaga (%)
AB-11/F	11	-18 %
AB-12/F	46	-18 %
AB-16/F	8	-1 %
K-20/F	29	+12 %
K-22/F	14	+3 %
mAB-11/F, mAB-12/F	18	-51 %
mK-20/F, mK-22/F	10	- 9%
mZMA-11, mZMA-12	21	-61 %
All mixtures	**157**	

2.2.1. The result of the four-point bending test on asphalt specimens is not only the cycle number belonging to the 50% of the initial stiffness. The result can be the linear regression line of the cycle number vs. stiffness modulus function. [2]

In the course of running the flexing-beam fatigue test the testing equipment will, at given number of load cycles, register the cycle number [n], and the value of the complex stiffness modulus [S_{mix}, MPa] belonging to it. If the registered data were set to graphic figure, a diagram similar to that in *Figure 1* might be the result.

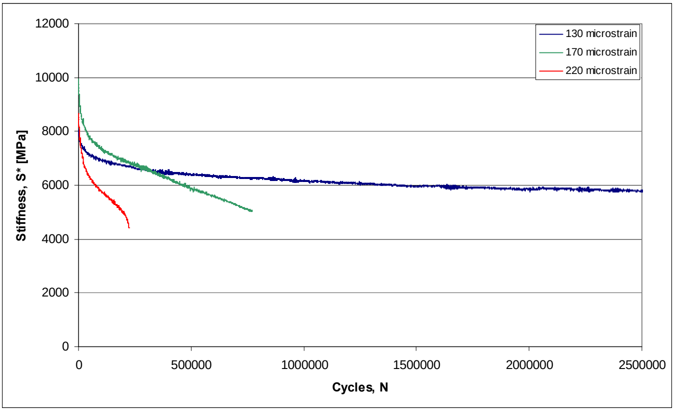

Figure 1.

2.2.2. It can be stated that the cycle number vs. stiffness modulus function can be divided into two well separable sections: first, strongly concave section and a further, nearly linear section. The border of two sections is at the 80% of the initial stiffness of the specimen. The linear section has a correlation (R^2) above 0,90. [2]

The practical range of the linear section can be calculated to the adequately high correlation value of the regression line (Figure 2.).

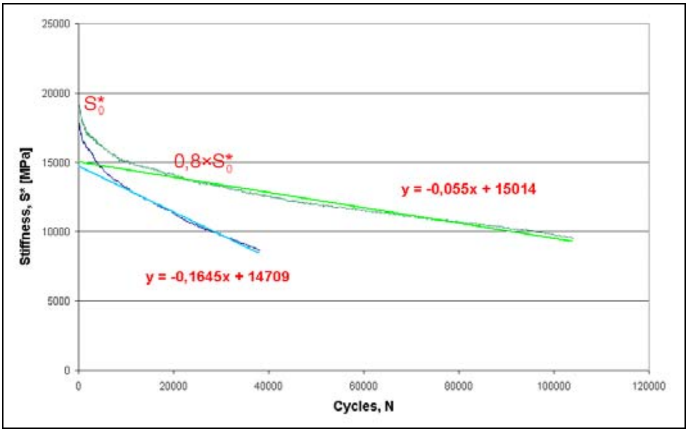

Figure 2.

2.2.3. Performing the four-point bending fatigue test, the result of the test (cycles to failure, $N_{50\%}$) can be estimated if the test were performed to the 60% of the initial stiffness ($N_{60\%}$). In these case some laboratory examination time (ca. 0,5-1 week), – the 25% of the complete time – can be saved. [2]

Four types of asphalt mixtures were analysed to calculate the difference between the real and the estimated cycles to failure. In different cases the test were performed to the 50%, 60% and 70% of the initial stiffness on the specimens **(See Table 2.)**. Then the regression line and the estimated cycles to failure were calculated. Plotting the failure results of the different specimens on a Wöhler-curve can represent the microstrain level belonging to the $N=10^6$ cycles. In the case of performing the test to the 60% of the initial stiffness agrees the result of the test performed according to the Standard.

Table 2.

Mixture identification	**Fatigue test end level (percent of the initial stiffness)**		
	50%	**60%**	**70%**
	[microstrain]		
H61 GB	166	166	159
56B-BD	91	100	105
56B-DD	79	76	104
FB6-B	109	109	108

2.3.1. The domestic pavement structure patterns' surface courses has important tensile strain at the lowest level if no friction exists between the asphalt layers. That may appear in the practice in extreme cases only. [1]

I determined the strains at the lowest level of asphalt layers in the pavement structures based on the present domestic pavement design method (technical specifications called ÚT 2-1.202:2005). The stiffness moduli of the layers were changed in a practical range. The variations of the structures are :

- lower base course with 5 types (M56,. FZKA, CTB-150 mm, CTB-200 mm, concrete)
- subgrade, five different values of modulus (40, 50,60,70,80 MN/m^2)
- three surface course stiffness modulus value (mixture type AB-11/F; minimum, average, and maximum values of laboratory measurements);
- three binder course stiffness modulus value (mixture type K-22/F; minimum, average, and maximum values of laboratory measurements);
- slip between layers, five different values;
- four traffic load classes (based on technical specifications)

I defined 1125different pavement structure types.

It can be stated that the strain at lowest level of the surface course reach a dangerous value if there is no friction between the asphalt layers. In all another cases the total surface course is in the compression zone. In the cases of 50% friction between layers, the strain levels are insignificant (See **Table 3.**).

Table 3. Strain range at the lowest level of the surface course in the case of 50% friction between layers [microstrain]

Lower base course type	**Traffic load case**			
	C	**D**	**E**	**K**
M56 (200mm)	-12 ÷ +5	-22 ÷ -35	-13 ÷ -19	-3 ÷ -9
FZKA (200mm)	-7 ÷ -20	-23 ÷ -36	-20 ÷ -30	-10 ÷ -17
CTB (150mm)	-16 ÷ 32	-21 ÷ -32	-20 ÷ -30	-17 ÷ -25
CTB (200mm)	-2 ÷ -14	-9 ÷ +1	-7 ÷ -18	-8 ÷ -16
concrete (150mm)	4 ÷ 11	-7 ÷ -2	-8 ÷ -2	0 ÷ -3

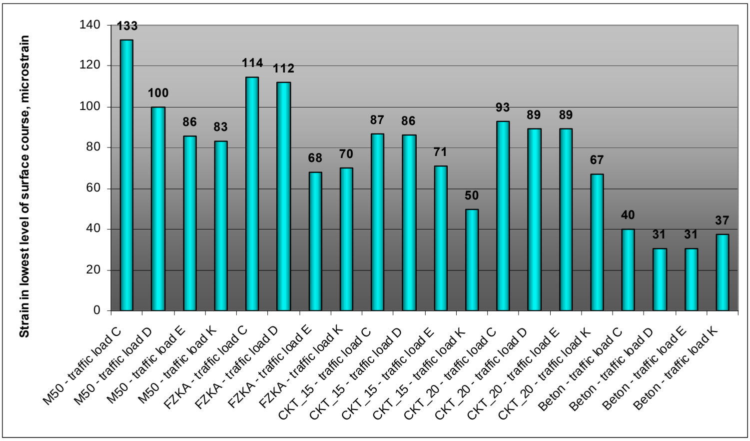

Figure 3.: Strain at the lowest level of the surface course in the case of full slip between layers

2.3.2. In the pavement structures the strain at the lowest level of the lowest asphalt layer strongly depends on the stiffness of the binder courses, and less dependent from the stiffness of the surface course. The strain at the lowest level of the lowest asphalt layer can be stated in the function of the binder courses' stiffness modulus with a good correlation coefficient (R^2 >0,99). The function decreases according to a power function. [1]

The forces arising in the lowest levels of the asphalt layer are one of the main reasons of the fatigue failure of the pavement structures, this means, the forces, strains are the highest here. In this case it has to be determined that the change of which parameter of the pavement structure causes significant change in the strain. Based on the experience of calculations, the lowest level strain is less dependent from the stiffness modulus of the surface course **(Figure 4.)**. The stiffness of binder layers has a stronger effect on the performance of pavement structures **(Figure 5.)**, so I made additional calculations with this issue.

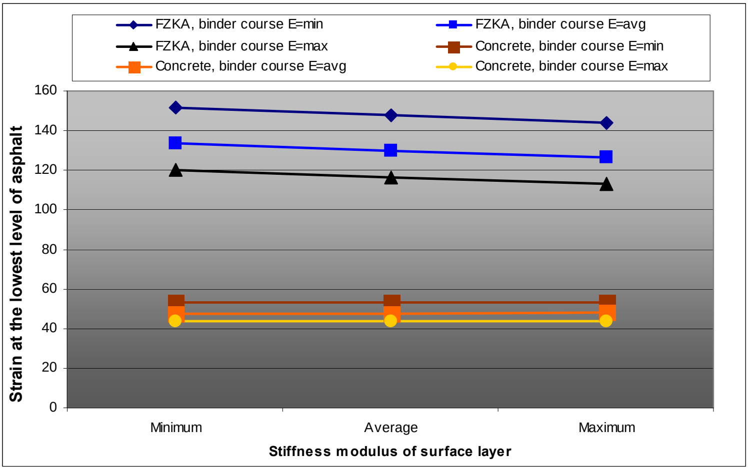

Figure 4. Strain at the lowest level of asphalt in the function of the stiffness modulus of the surface course

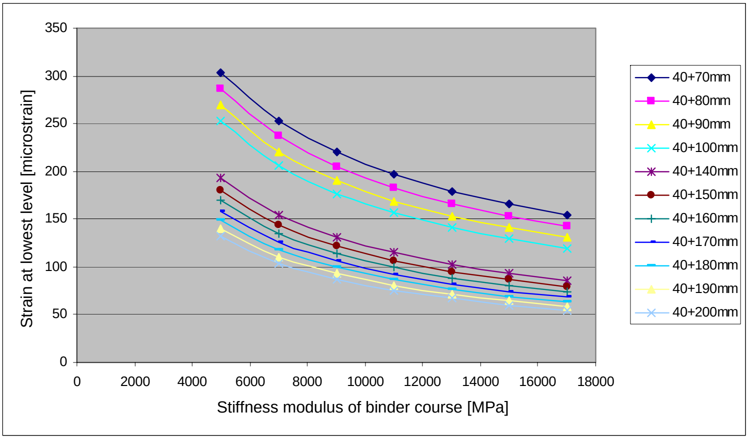

Figure 5. Strain at the lowest level of asphalt in the function of the stiffness modulus of the binder course (base course: CTB-150 mm)

The pavement structures are constructed considering the following principles:

- Surface course (stiffness modulus 10000 MPa, thickness 40 mm)
- Binder course (varied stiffness modulus and 70, 75….200 mm thicknesses)

As seen on the graph, a power function can be calculated depending on the thickness and the stiffness modulus of the binder course, showing the strain at the lowest level of the lowest asphalt layer.

2.3.3. A fourth-degree parabola function can be fitted onto the slip between asphalt layers vs. the strain at the lowest level of asphalt function, with a good correlation coefficient (R^2 >0,99). The slip between the layers above 50% strains arising in the lowest level of asphalt asphalt, so the fatigue life of the pavement structure decreases significantly. According to the calculations the case of the full slip causes 70-80% increase, the case of the half slip cauess 55-65% increase in the strain at the lowest level of asphalt. The slip between the layers changed between the asphalt layers only in the calculation, under the lower asphalt layer a full slip were considered. [1]

According to the curves (See **Figure 6.**) at the pavement structure construction the contractor has to pay attention to the friction between asphalt layers, since above its 50% slip raises the strain at the lowest level of asphalt and rapidly reduces the lifetime.

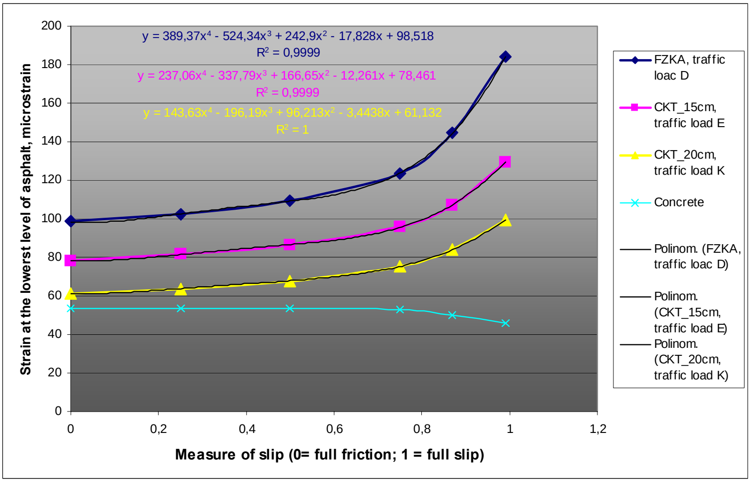

Figure 6. Strain at the lowest level of asphalt in the function of the slip between asphalt layers (examples)

2.4. The stiffness modulus and the Wöhler curve of asphalt mixtures used in the lower asphalt layers affects the fatigue life of the pavement structure largely. The increase of the initial stiffness takes an advantage to the pavement thickness definition at smaller cycle numbers, the slope of the Wöhler curve takes it at bigger cycle numbers. [7]

I presented the fatigue design of the pavement structures if real mixtures – defined with real mechanical parameters – were applied. The calculations were made with two conventional mixtures and two asphalts made of polymer modified bitumen **(Figure 7.),** on which the necessary layer thickness in the different traffic load categories were calculated.

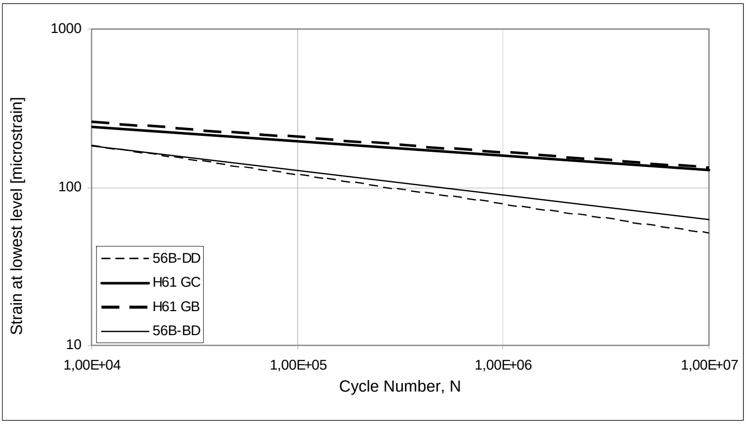

Figure 7. Wöhler curves of applied mixtures in the calculation

2.5. There are exponential connection between the thicknesses of the pavement structures (v) and the load cycle number (TF) if the other parameters are constant. The exponential contact descriptor is the $\mathrm{TF} = \mathrm{a} \cdot \mathrm{e}^{\mathrm{b}\times\mathrm{v}}$ **curve. In the case of knowing the *a, b* parameters the surface and the binder course thickness can be stated [7].**

I calculated the strains at the lowest level of asphalt in the function of the stiffness modulus on all of the pavement structures contained 70, 75…200 mm binder course. After this calculation the fatigue life of the pavement structure (based on the Wöhler-curve of examined asphalt mixtures) could be determined.

The single example of the connection between the asphalt layer's thickness and the cycle number to fatigue can be seen **on Figure 8.** The contact between the two quantities is exponential, for which the constant parameters can be determined onto a given asphalt mixture.

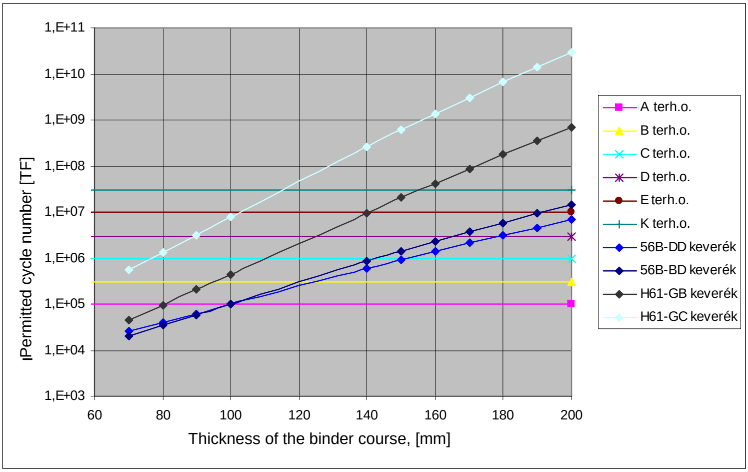

Figure 8. Applicable asphalt layer thicknesses (Base course: CTB-150 mm)

2.6 The decrease of stiffness occurring in the pavement structures – because of the load cycles – has effect to the strains appearing in the asphalt layers. The calculated lifetime of the pavement structure is generated from the momentary stiffness values, counted according to the Miner hypothesis. Knowing the slope of the Wöhler-curve can determine the fatigue-reducing effect of this phenomenon: [7]

$$N = \left(\frac{\varepsilon}{a}\right)^{1/b} \cdot (-1{,}8417b + 0{,}08144)$$

The stiffness of the asphalt layers is decreasing with the fatigue of the pavement structure. This decrease causes changes in the pavement structures: less stiffness produces higher strains at the lowest level of asphalt layers. The higher strain level causes more intensive stiffness decrease, and so on. Because of this the fatigue is going more rapidly, comparing to the original fatigue method. **Figure 9.** shows an example to the decrease of the lifetime.

This effect is increasing when the Wöhler curve has a greater slope, because the pavement system is more sensitive to the strain at the lower level of asphalt (because of the meaning of the Wöhler-curve).**Figure 10.** shows the correlation between the slope of the Wöhler-curve and the fatigue life; the correlation coefficient tends to 1,00.

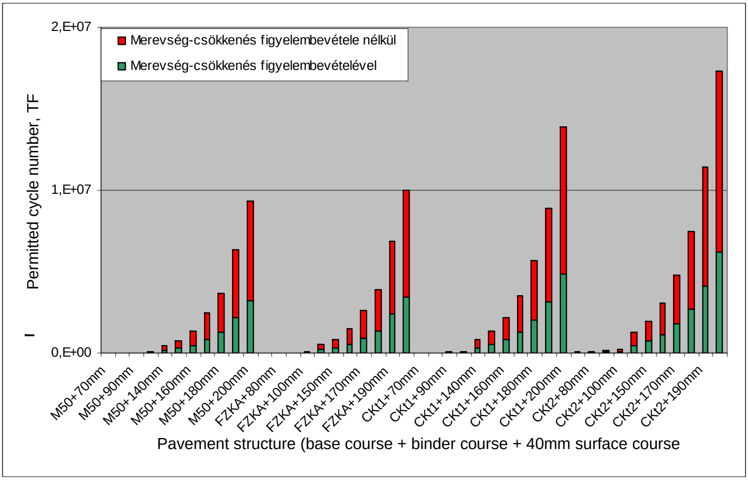

Figure 9. Permitted load cycles to failure, binder course id. 56B-BD (type K-20/F)

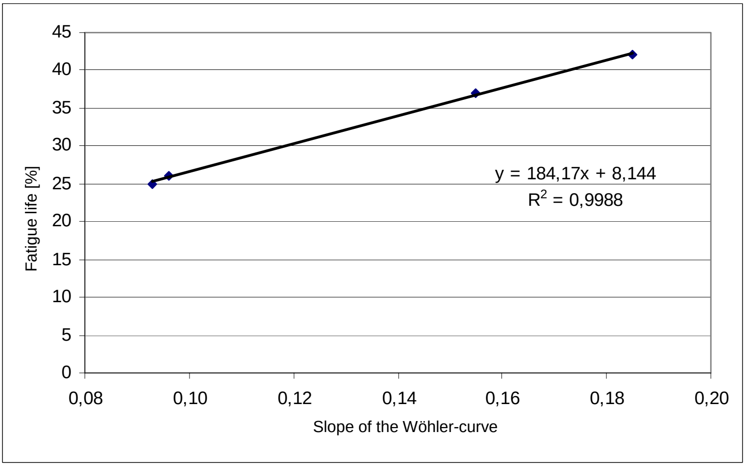

Figure 10. Correlation between the slope of the Wöhler-curve and the fatigue life

3. Using the results of dissertation in the practice

The design solutions analised in the dissertation bring the laboratory examination results of the asphalt mixtures closer to the theoretical design methods. We may choose the asphalt layers' mechanics characteristics according to his place occupied in the pavement. Here to be noticed, that e.g. ‘JU‘ (base course mixture) mixtures were built into base course of pavement for a long time, its fatigue properties are not so good. This dissertation showed that the lower asphalt layer plays the largest role in the fatigue characteristics of pavement structure.

Respecting other effects (e.g. plastic deformation) longer lifetime pavement structures can be built, possibly without raising the thicknesses of the asphalt layers written in the technical specifications.

4. Additional research topics

I used the four-point flexing beam bending fatigue test in my dissertation. Another current method to determine the fatigue characteristic of asphalt mixture is the two-point bendig test on trapezoidal specimens. In this test the applied frequency is higher. The results of the two methods and the fatigue life calculations of the pavement structure written in the dissertation can be compared. This is important because the two measuring methods give different results of mechanical parameters, so the effect of choosing different test methods on asphalt mixtures can be calculated.

In Hungary the other important building demand is the reconstruction of the old road property. The question is that how the old asphalt layers can fulfil their task after the reconstruction. The extension of the methods mentioned in the dissertation may be an additional research topic onto the reconstruction of existing pavement structures.

5. 4. Publications ont he subject of the new results

1.) International journal papers

1. Bocz, P., 2009, „*The Effect of Stiffness and Duration Parameters to the Service Life of the Pavement Structure*”, Periodica Polytechnica Ser. Civil Engineering 53/1. pp. 35-41.
2. Bocz, P., 2009, „*Pre-Assumption of Final Results of the Asphalt Four-Point Flexing-Beam Fatigue Test*”, Acta Technica Jaurinensis, 2009/2. *(approved 2009.04.15)*

2.) Hungarian Journal papers

3. Almássy, K.– dr. Ambrus, K., Bocz, P., Fi, I.: *„Aszfalthálók útépítési alkalmazásai”.* Közúti és Mélyépítési Szemle, 2005/4. *pp 30-36*
4. Bocz, P. – Devecseri, G. – Fi, I.– Joó, A. – Kovács, D. –Pethő, L.: „*Útpályaszerkezetek szélesítésének technológiai szabályozása*” Közúti és Mélyépítési szemle, 2008/12, *pp 6-11.*
5. Bocz, P. – Devecseri, G. – Fi, I.– Joó, A. – Kovács, D. –Pethő, L: *„Aszfaltrácsok szerepe megerősített és szélesített útpályaszerkezetekben”* Közúti és Mélyépítési Szemle 2009/2. *pp 1-14.*
6. Bocz, P. – Devecseri, G. – Fi, I.– Pethő, L.: *„Meglévő pályaszerkezetek megerősítésének analitikus számítása”* (Közlekedésépítési Szemle 58. évf. 2009/5. *pp. 8-22*
7. Bocz, P.– Pethő, L.: *„Pályaszerkezetek fáradási élettartamának meghatározása aszfaltanyagok laboratóriumi vizsgálata alapján”* Közlekedésépítési Szemle, 2009/8
8. Almássy, K., Bocz, P., Fi, I., Tompai, Z., 2005., "*A kátyúzásról*", Mélyépítő Tükörkép Magazin, 2005/6. *pp. 15-18.*
9. Almássy, K., Bocz, P., Fi, I., Tompai, Z., 2006., "*A 2005. évi fővárosi útfelújítások kivitelezési munkáinak minőségvizsgálatai*", Városi Közlekedés, 2006/3., *pp. 137-138.*
10. Bocz, P, 2007., „*Aszfaltkeverékek vizsgálati módszerei – Próbatesteken végzett négypontos vizsgálatok eredményei*”, Mélyépítő Tükörkép Magazin 2006/5.
11. Bocz, P. – Devecseri, G.: *„A 2004 és 2006 között felújított budapesti utak minőségellenőrző vizsgálatainak eredménye*”, Városi Közlekedés, 2007/5. *pp. 287-291.*
12. Bocz, P. – Pethő L..: *„Aszfalt próbatestek merevségi modulusának meghatározása”* Mélyépítő Tükörkép Magazin 2009/3.