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Research paper

Backcalculation of flexible pavement moduli including interlayer bonding conditions – numerical analysis

Paweł Tutka[1], Roman Nagórski[2], Magdalena Złotowska[3]

Abstract: One of the common defects of flexible road pavement is the loss of bonding between two layers of asphalt concrete: the base course and the binder course. The occurrence of this phenomenon has a major impact on the observed state of deflection and deformation of the pavement. This effect affects the results of non-destructive tests which are used to calculate material parameters and then are used in the diagnostics of the pavement condition or design of structural strengthening. This paper discusses the influence of the various level of bonding on the result of backcalculation and the obtained elastic moduli. For the obtained values of moduli, calculations of key deformations and pavement durability were performed. Improper assumptions about the interaction between the layers affects the observed results. Additionally paper discusses the effect of pavement displacement discontinuity on the observed deflection basin and compares the results with those for a model with continuity. Numerical calculations were carried out using Simulia Abaqus software, the computational model was verified using analytical solution.

Keywords: road pavement mechanics, flexible road pavement, interlayer bonding modelling, backcalculation, non-destructive testing, numerical modelling

[1]MSc., Warsaw University of Technology, Faculty of Civil Engineering, Al. Armii Ludowej 16, 00-637 Warsaw, Poland, e-mail: p.tutka@il.pw.edu.pl, ORCID: 0000-0003-0879-0310

[2]Prof., DSc., PhD., Eng., Warsaw University of Technology, Faculty of Civil Engineering, Al. Armii Ludowej 16, 00-637 Warsaw, Poland, e-mail: r.nagorski@il.pw.edu.pl, ORCID: 0000-0002-1039-1530

[3]MSc., Warsaw University of Technology, Faculty of Civil Engineering, Al. Armii Ludowej 16, 00-637 Warsaw, Poland, e-mail: m.zlotowska@il.pw.edu.pl, ORCID: 0000-0003-1654-1859

1. Introduction

The identification of the material parameters of an existing road pavement structure is widely used in the diagnosis of the pavement condition and in the design of the pavement structure. This process is most often carried out by measuring the deflections of the pavement under a known load, followed by backcalculation. It is an iterative process, consisting of taking the values of the material parameters of the analysed pavement model, calculating its deflections and comparing them with the known deflections of that pavement. If the results differ slightly (less than a threshold value) according to a certain adopted criterion, the material parameters of the pavement model are determined. The adoption of an appropriate mechanical pavement model is a key factor in obtaining the correct results. One of the factors that must be considered is the continuity of displacements between layers of the structure. The lack of continuity has a significant impact on the road deflection. Possible incorrect assumptions about the interaction between layers during backcalculation leads to misidentification of the material parameter values which are obtained for a specific mechanical model. This has a direct impact on the pavement design process, where the determination of the displacement and strain state of the structure is important. The maximum tensile deformation at the bottom of the asphalt layers and the extreme compressive deformation at the top of the subgrade under standard axle load are the key values for assessing the durability of a flexible road pavement using the mechanistic-empirical method [1]. Strains are determined using a mechanical model with backcalculated material parameters. In order to create a mechanical model, the interlayer bonding conditions must also be taken into account. Therefore, there is a direct need to identify whether the deflection measured during non-destructive testing indicates the possibility of a displacement discontinuity. There is an extensive literature describing a possible process to determine the interlayer continuity. The papers [2, 3], investigate the possibility of determining the level of interlayer bonding by analysing the deflection as a function of time during Falling Weight Deflectometer (FWD) test. The proposed approach does not guarantee the detection of discontinuities in every case analysed [2]. The durability of pavement for different values of interlayer bonding for the same material parameters is obtained in the papers [2, 4]. For the asphalt layers (thickness of 24 cm), decrease in the interlayer bonding from 100% to 70% causes reduction in fatigue life by 50%. Further decrease to 30% causes reduction in fatigue life by nearly 85% [4]. The paper [5] presents how bonding condition between asphalt pavement layers can be predicted by comparing pavement moduli obtained from measured deflection by FWD test and computed deflection from backcalculation. In some application the shear bond stiffness is treated as variable affecting deflection and backcalculated in a similar manner to a stiffness of layer [6]. In the paper [7] artificial neural network model was used to correct the backcalculated layer moduli based on interlayer bonding conditions. The developed model showed prediction accuracy of 95.1% in analysed case. Similarly, the paper [8] introduces a model based on neural networks to predict interlayer conditions and layer moduli of a multi-layered flexible pavement structure. In practice, many programs for computing backcalculation assume full boding [8].

The methods proposed in papers [5–8] characterized by higher computational complexity are not widely used. The aim of this paper is to estimate the consequences of adopting an incorrect mechanical model. The impact of the error on the results of backcalculation is determined, then the key deformation calculations and durability estimates are obtained.

An example of a method for determining material parameters is the Falling Weight Deflectometer (FWD) test [9], which is modelled in this study. In the FWD test, the force is applied at a specific point of the pavement, it has an impacting nature and the loading time is between 0.02 and 0.06 s. The maximum deflection of the pavement is measured. Simulations of this type of loading will be used as a basis for the analysis of the influence of discontinuities. An finite element (FE) computational model was created, using the Simulia Abaqus software [10]. Dynamic load distributed over the surface as in the FWD test was assumed. The dynamic effects associated with the inertia forces [11] were included in the computational model.

The most commonly used mechanical model for pavement is multilayer half-space [12]. it is composed of homogeneous and isotropic elastic layers, whose stiffness moduli are assumed as young's moduli of elasticity. the stiffness moduli and poisson's coefficients constitute the material parameters of the model. in this paper, in the modelling part of the fwd study, we assumed a three-layer model of the flexible pavement, whose top layer describes the asphalt layers, the middle layer – the aggregate base course, and the bottom layer (of infinite thickness) – the soil subgrade.

Adequate verification is extremely important in building numerical models. For this purpose, the results obtained using FEM were compared with the results from the VEROAD software [13] and with the results from the author's implementation of the solution of the layered elastic half-space using the Hankel transform.

2. Objectives

The main objective of this paper is to obtain error of assuming an incorrect mechanical model during backcalculation, due to the assumption of improper bonding condition between asphalt layers. The material parameter values are calculated from the same deflection basin in four cases, differing by bonding conditions. The obtained values of material parameter is used to obtain key deformations and pavement durability. The paper provides an estimate of the error in determining pavement durability based on FWD testing under the incorrect assumption of the bonding conditions in the mechanical model. The paper highlights the need to determine bonding conditions during FWD testing.

The main results of paper are presented in Section 6, where the results of backcalculation was visualized and described. In the Section 3 backcalculation scheme is described. Verification of numerical model implemented in Simulia Abaqus is included in Section 4. Section 5 presents deflection basin of pavement structure under load for various bonding conditions. The results for different bonding conditions and material parameters, for which the deflection basin is almost identical, are presented.

3. Backcalculation

The determination of the stiffness moduli of the road pavement layers on the basis of the measured deflections of the pavement requires the application of backcalculation. The first step is to take the initial values of the moduli of stiffness (seed moduli), for which the calculations of displacements of the pavement are performed. The measured deflections are then compared with the calculated deflections.

In the case of FWD testing, most often the maximum deflections in time are analysed at points with a specified distance from the load axis (measurement points). In this paper, backcalculations were performed for the so-called pavement deflection basin, defined by seven points located at distances of 0 m; 0.2 m; 0.3 m; 0.6 m; 0.9 m; 1.2 m; 1.5 m from the load axis respectively. The objective is to find a set of material parameters for which the calculated deflection values will be sufficiently close to the measured basin. The root square mean error (RSME) is taken as a measure of the similarity of the deflection basins. The calculation task is to find the minimum of the RSME function, where the minimum should be sufficiently close to the zero value – according to the assumed end of calculation condition. When, according to the assumed criterion, with specific values of stiffness moduli the differences of measured and calculated deflections exceed the assumed level, the values of material factors have to be modified. The procedure is repeated until the deflection calculation results are sufficiently close to the measured deflections. The calculation scheme is presented in the Fig. 1. A detailed procedure for backcalculation is described in the paper [14].

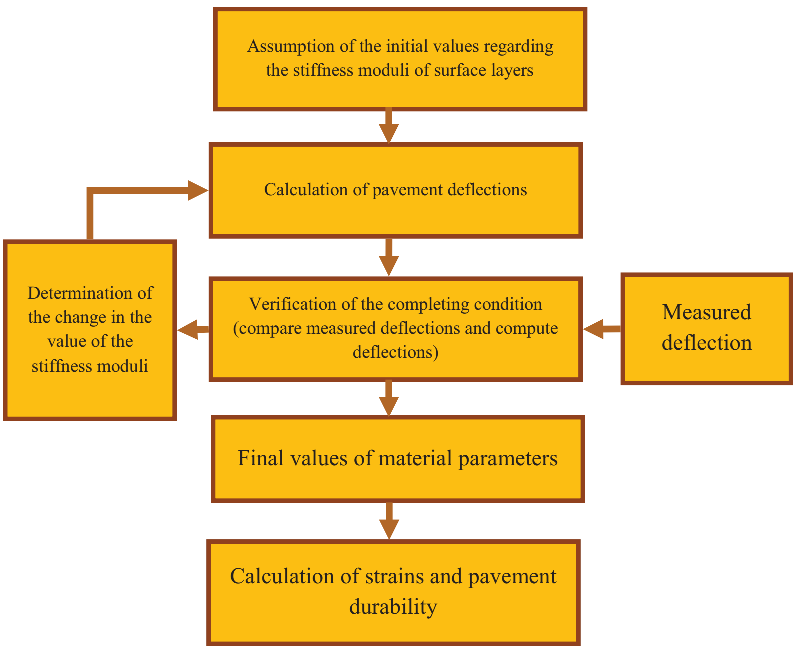

Fig. 1. Scheme of backcalculation process

The model of flexible pavement as three-layer half-space, with linear-elastic, homogeneous, isotropic layers was used (two upper layers of constant thickness and a lower one of infinite thickness). The top layer is a model of asphalt layer, the middle layer is a model of unbound aggregate base course, and the third one is a model of natural subgrade. The stiffness modulus is Young's modulus of elasticity of layers. The Poisson's coefficients and mass density of layers were assumed in the calculation process. Thicknesses of the layers were considered known. The asphalt layer discontinuity is considered. Four cases of bonding condition is taken under consideration.

4. Numerical model validation

The basic element of performing backcalculation is to determine the values of deflections of pavement with the assumed model of this pavement and its load. In order to present the method of backcalculation the pavement structure is modelled as a layered half-space [15]. To analyse the FWD test, a numerical model is necessary, which was created in the Simulia Abaqus software. The model was verified and the following comparisons were made:

- Comparison of results of static models with bonded layers developed in Simulia Abaqus, VEROAD [13] and the implementation of the Hankel transform calculation model.
- Comparison of results of static models with unbonded asphalt binder course and asphalt base course layers created in Simulia Abaqus and the author's implementation of a computational model using the Hankel transform.

The comparison is intended to check the correctness of the deflections obtained in Abaqus, in which pavement was modelled as the axisymmetric cylindrical domain. In each model, the pavement material layers were assumed to be linear-elastic. For the purpose of verification, six homogeneous, isotropic layers of constant thickness were assumed. The material data (Young's modulus E, Poisson's coefficients ν, mass densities ρ) and thicknesses of individual layers h of the structure are presented in Table 1. Verification

Table 1. Geometric and material parameters of the adopted road pavement structure with unbonded asphalt layers for numerical model verification

No.	Layer	h [cm]	E [MPa]	ρ [kg/m^3]	ν [m/m]
1.	Asphalt wearing course	4	9778	2565	0.3
2.	Asphalt binder course	6	14122	2615	0.3
3.	Asphalt base course	12	13307	2623	0.3
4.	Aggregate base course	20	400	2250	0.3
5.	Cement-treated subgrade	15	300	2050	0.3
6.	Natural soil subgrade	∞	100	1800	0.35

of the numerical model was performed by comparing the results of deflections for static Abaqus calculations with the calculations of the VEROAD software and with calculations using the implemented Hankel transform. The numerical model was then used for dynamic calculations simulating the FWD test.

The FEM calculations assumed an axisymmetric geometrical model of the pavement in the shape of a cylinder with dimensions: height $h = 12.07$ m and diameter $l = 4$ m for comparative static calculations, which allows to obtain the deflection values compatible with analytical solutions [16] (e.g. in the program VEROAD). The pavement model is shown in Fig. 2. The assumed boundary conditions of the cylindrical domain are shown in Fig. 3. Pavement was load uniformly on a circular surface with radius $r = 0.1368$ m, with resultant force $P = 50$ kN (half of the standard axle load of 100 kN) and intensity $p_0 = 850$ kPa. Finite elements with quadratic shape functions and CAX8R reduced integration [10] were used.

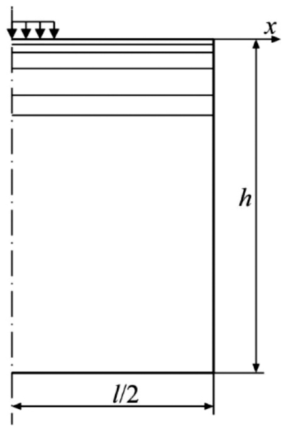

Fig. 2. Section of a axisymmetric cylindrical domain of a pavement modelled using FEM

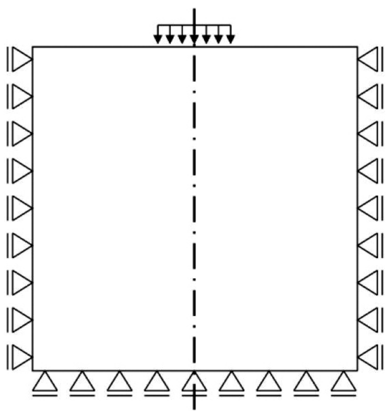

Fig. 3. Boundary conditions adopted in the FE model

The results from the numerical FEM calculations were compared with the solution of an axisymmetric task in tension using Love's function and Hankel transform [17, 18]. The solution has been implemented in the Wolfram Mathematica environment. The deflections on the surface of an asphalt pavement for bonded layers (for $z = 0$) calculated using VEROAD, FEM and an implementation of the Hankel transform solution are shown in Fig. 4. The calculations were carried out for the static load case. The maximum difference between the FEM results and the analytical results is about 0.4%.

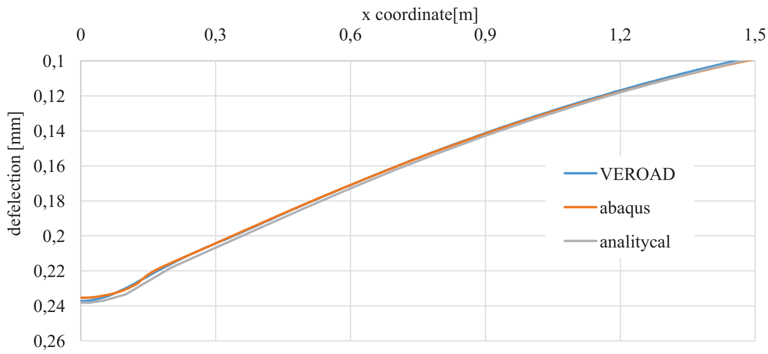

Fig. 4. Pavement deflections for models with bonded layers from FE calculations, VEROAD calculations and implementation of the Hankel transform solution

The results of deflections on the asphalt pavement surface for unbonded asphalt binder course and asphalt base course layers (for $z = 0$) calculated using FEM and the author's implementation of the Hankel transform solution are shown in Fig. 5. The maximum difference between the FEM results and the analytical results is approximately 0.9%.

The obtained results show the convergence of FEM results with the analytical method. In the following part of the paper, results obtained using the finite element method are presented. This method, including inertial forces, was used in the backcalculation.

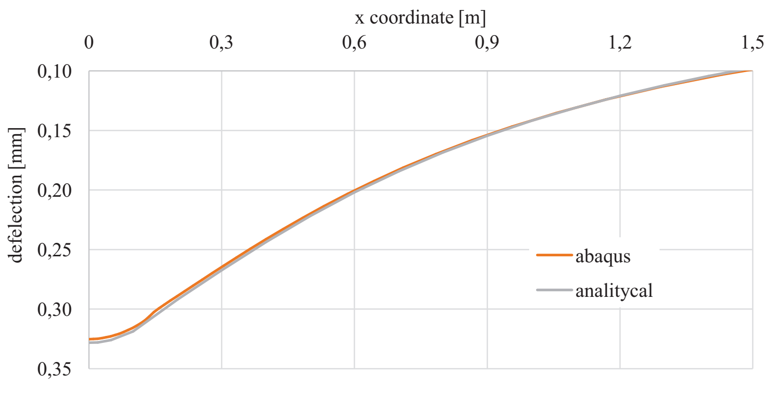

Fig. 5. Pavement deflections in the absence of adhesion between the binder course and the asphalt base course using, FEM and Hankel transform

5. Comparison of deflection values for the continuous and discontinuous model

This chapter compares the obtained deflection basins for pavement with various bonding condition. The deflections on the asphalt pavement surface in four design cases was analysed: for fully bonded pavement layers, unbonded pavement layers between the asphalt binder course and the asphalt base course (layers 2 and 3), and additionally for bonding level of 70% and bonding level of 30%. Interaction between asphalt layers was modelled in Simulia Abaqus as cohesive bonding. The value of stresses between layer interface is assumed as linearly dependent on the relative horizontal displacement at the interface. The stress dependence of the relative displacement is directly proportional to the modulus K_{ss} (shear modulus). Modulus for low bonding (around 30% bonding) was taken to be 3.846×103 MN/m^3 and for intermediate bonding (around 70% bonding) equal to 2.564×104 MN/m^3. The values were calculated from the standard spring shear compliance (AK) and reduced spring shear compliance (ALK). For 70% bonding, $ALK = 0.3$ m was assumed, and for 30%$ALK = 2$ m [2] – AK and K_{ss} was calculated as:

$$AK = ALK\frac{1+\nu}{E} \tag{5.1}$$

$$K_{ss} = \frac{1}{AK} \tag{5.2}$$

where:

E – Young modulus – assumed to be equal 10000 MPa,

ν – Poisson coefficient – assumed to be equal 0.3.

Experiments to describe testing asphalt mixture interlayer bonding (to determine shear modulus) are described in [2,19]. Additionally in [19] there is obtained correlation between the static and fatigue test results of the interlayer bonding of asphalt layers.

Fig. 6 presents obtained results. With the assumption of no bonding, the maximum displacement increases by approximately 38% comparing to the full bonding. The further away from the load axis the more similar the results were in all cases.

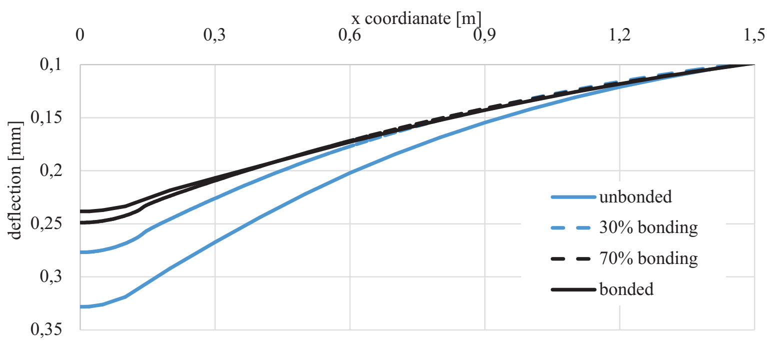

Fig. 6. Pavement deflections with various bonding condition

Fig. 7 presents the shape of the deflection basin – this is a plot of the proportion of deflections at each point to the maximum deflection. It can be seen that in the absence of continuity, deflections further from the axis represent a smaller percentage of the maximum deflection.

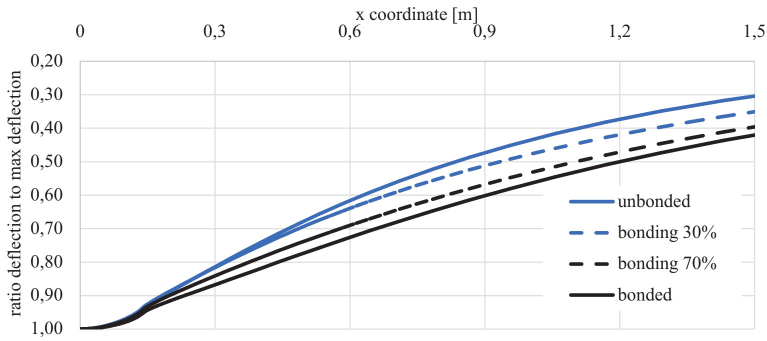

Fig. 7. Ratio of pavement deflections to maximum deflection with various bonding condition

An attempt was made to find a system of material parameters for which the deflection of the bonded layers was equal to the existing deflections for the unbonded layers. If converging deflection basin can be obtained, this creates a risk of error in the adoption of the mechanical model for the FWD backcalculations. For this purpose, the change in the shape of the deflection basin under the influence of changing material parameters was analysed (Fig. 8). Three cases were considered:

– weakening of asphalt layers by 1000 MPa,
– weakening of the aggregate base course and cement-treated subgrade by 100 MPa,
– weakening of the soil subgrade by 50 MPa.

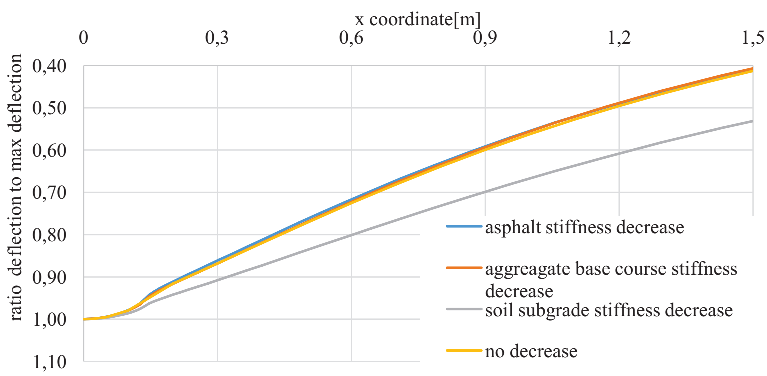

Fig. 8. Influence of the weakening of individual pavement layers on the shape of the deflection basin

Weakening of the asphalt layers and aggregate base course similarly changes the shape of the deflection basin. The weakening of the soil subgrade has a relatively greater effect on deflections further from the load axis – deflections in the load axis depend less on the elastic modulus of the soil subgrade.

Table 2 presents the values of material layer parameters for the model with fully bonded layers, for which deflections similar to the results for unbonded asphalt layers were obtained. The values of the soil parameters did not change, with more than 50% reduction in the elastic modulus of the asphalt layers. Fig. 9 shows that in spite of completely different bonding conditions and material parameters, it is possible to create mechanical model to obtain almost identical deflection basins.

Table 2. Geometric and material parameters of the adopted road pavement structure with fully bonded layers for numerical model verification

No.	Layer	h [cm]	E [MPa]	ρ [kg/m^3]	ν [m/m]
1.	Asphalt wearing course	4	4000	2565	0.3
2.	Asphalt binder course	6	5500	2615	0.3
3.	Asphalt base course	12	5300	2623	0.3
4.	Aggregate base course	20	250	2250	0.3
5.	Cement-treated subgrade	15	200	2050	0.3
6.	Natural soil subgrade	∞	100	1800	0.35

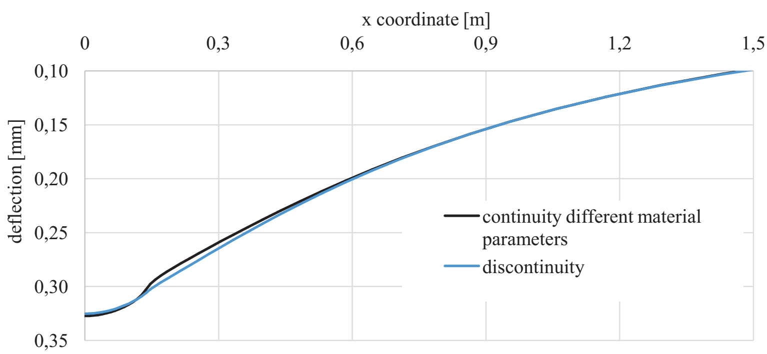

Fig. 9. Deflections of the road surface with and without bonding for different material parameters

6. Results of material parameter identification

For the analysed deflection basin (for deflection values of – 280 μm, 252 μm, 236 μm, 189 μm, 150 μm, 119 μm, 96 μm) 100 series of backcalculations were performed. Small perturbation of the measured deflection values was made in each calculation to test the sensitivity of the results to measurement errors. The error was set with a normal distribution of zero mean value and standard deviation $(2\ \mu\text{m} + 0,01 \cdot u_i)/3$, where ui is value of deflection. An important element of backcalculations is a function that determines the differences between measured displacements (or calculated but treated as measured in computer simulations) and those obtained from backcalculations. A value of RMS equal to 0.5 μm has been assumed as the condition for completing the calculations.

To perform calculations, the following (presented in Table 3) parameters of the pavement layers were established. The asphalt layer discontinuity between asphalt binder course and asphalt base course was considered (Table 3).

Table 3. Geometrical and material parameters of road structure used for backcalculation

No.	Layer	h [cm]	ρ [kg/m^3]	ν [m/m]
1a.	Asphalt layer wearing course and binder course	10	2610	0.3
1b.	Asphalt layer – base course	12	2610	0.3
2.	Aggregate base course	35	2250	0.3
3.	Subgrade	∞	1800	0.35

A load uniformly distributed on a circular surface with radius $r = 0.1368$ m, with resultant force $P = 50$ kN (half of the standard axle load of 100 kN) and intensity $p_0 = 850$ kPa (then $r = \sqrt{(P/\pi p_o)}$) was assumed. A time-varying load, described by the function $p(t) = po\sin(t/T)$, with a loading time of 0.03s ($T = 0.06$ s), which simulates the action of the FWD, was assumed for the FEM calculations using the Abaqus software. In addition (in calculations with FEM), an axisymmetric geometrical model of the pavement in the shape of a cylinder, of such a size that there is no reflection of the wave from the edge of the area in the case of dynamic calculations (height $h = 8$ m and diameter $l = 9$ m of this cylindrical area) was adopted. This led to deflection values consistent with analytical solutions [16] (e.g. in the program VEROAD). Finite elements with quadratic shape functions and CAX8R reduced integration [10] were used.

Fig. 10 shows the values of the modulus of elasticity of asphalt layers needed in the case of bonded and unbonded layers to achieve similar deflection. As expected, the lower bonding stiffness was assumed, the higher the value of stiffness moduli was obtained. For the case without bonding, relatively large modulus values are necessary to obtain the same deflections basin as in the case of full bonding. The sample median of the obtained value of the elasticity modulus in the case of the model with consideration of discontinuity is 14499 MPa with a sample standard deviation of 2826 MPa. The sample median for the model with full continuity of layers is 7261 MPa, with a sample standard deviation of 687 MPa. The required value of stiffness modulus to achieve the same deflection is about 100% higher for the model with discontinuity compared to the model with full continuity. Considering the case of intermediate bonding: for 30% interlayer bonding sample median is 8556 MPa and sample standard deviation is 1523 MPa, for 70% interlayer bonding sample median is 7436 MPa, and sample standard deviation is 428 MPa.

Fig. 11 shows the values of the moduli of elasticity of the aggregate base course needed in the case of full bonding and no bonding to achieve a similar deflection basin. The sample median value of the elasticity modulus for the unbonded model is 535 MPa and

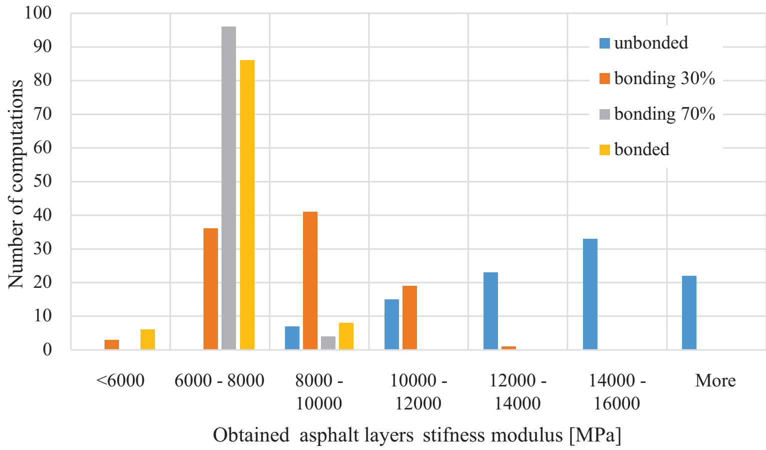

Fig. 10. Histogram of obtained elasticity modulus of asphalt layers

the sample standard deviation is 101 MPa, the sample average value of the modulus of elasticity for the fully bonded model is 232 MPa and the sample standard deviation is 72 MPa. For intermediate cases: sample median modulus in the case of 70% interlayer bonding is 208 MPa, sample median modulus in the case of 30% interlayer bonding is 532 MPa. Similarly to the determination of the stiffness modulus of asphalt, the lower the bonding level, the higher the stiffness from a backcalculation.

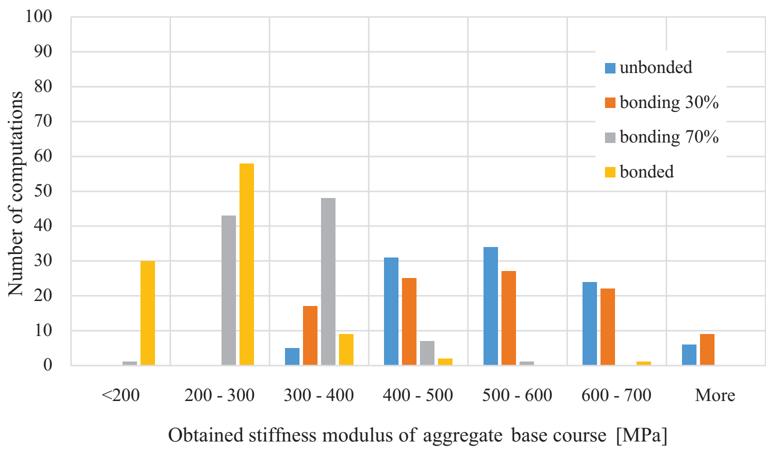

Fig. 11. Histogram of modulus of elasticity of aggregate base course

Fig. 12 shows the values of the soil subgrade modulus needed for the case of full bonding and no bonding to achieve similar deflection basin. The sample median of the modulus of elasticity for the unbonded model is 72 MPa with a sample standard deviation of 2.9 MPa. The sample median of the modulus of elasticity for the fully bonded model is

73 MPa with a sample standard deviation of 6 MPa. The sample median of soil modulus obtained is similar for the model without continuity compared to the model with full interlayer continuity. The slightly increase in the soil modulus value for bonded pavement is due to the fact that, in the case of discontinuity, the significant increase in the elastic modulus of aggregate base course must be offset by a decrease in the soil modulus in order to achieve similar deflection values at points distant from the load axis. Indeed, the lack of continuity itself has little effect on the deflections at these points (Fig. 5). Interestingly, when analysing the intermediate values of the bonding condition we notice that the dependence of the obtained modulus values for soil on the bonding condition is not the same as for the other moduli. This is due to the fact that the level of bonding has little influence on the deflections distant from the loading axis. These deflections are mainly influenced by the modulus of the aggregate base course and the soil. In the case where a relatively large aggregate base course modulus is obtained from backcalculation, this translates into lower modulus values for the soil.

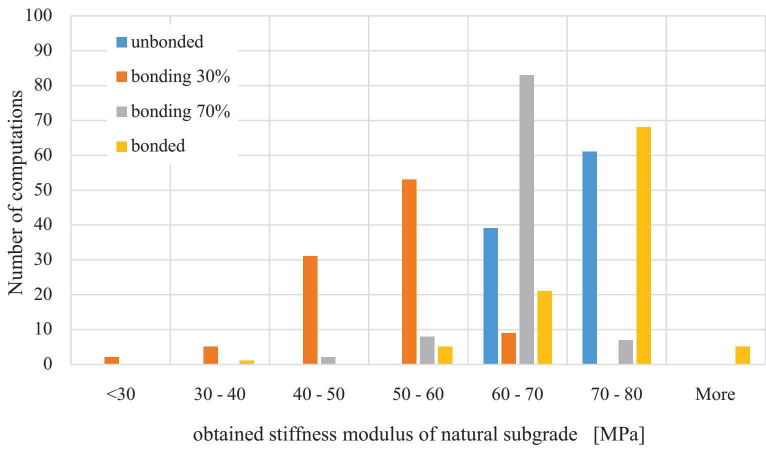

Fig. 12. Histogram of elastic modulus of natural soil subgrade

The obtained values of modulus of asphalt layers and aggregate base course in the case of various bonding condition are presented in Fig. 13. It can be seen that, depending on the adopted model of interlayer bonding, a different range of values of modulus was obtained. Influence of sensitivity on the obtained results is clearly seen in Fig. 13. Despite almost identical deflection basin for each calculation, different combinations of asphalt layer and aggregate base course moduli values were obtained even for the same bonding conditions. The values of obtained moduli are negatively correlated.

Fig. 14 shows the values of tensile strain at the bottom of the asphalt layer with various bonding condition for moduli obtained from backcalculations (strains calculated for the static model). The value of the sample median tensile strain for the model with full continuity is 28.4% higher than for the model without displacement continuity, 10.1% higher than for the model with 30% interlayer bonding, 4.9% higher than for the model with 70% interlayer bonding. For highest bonding value, maximum tensile strains is also

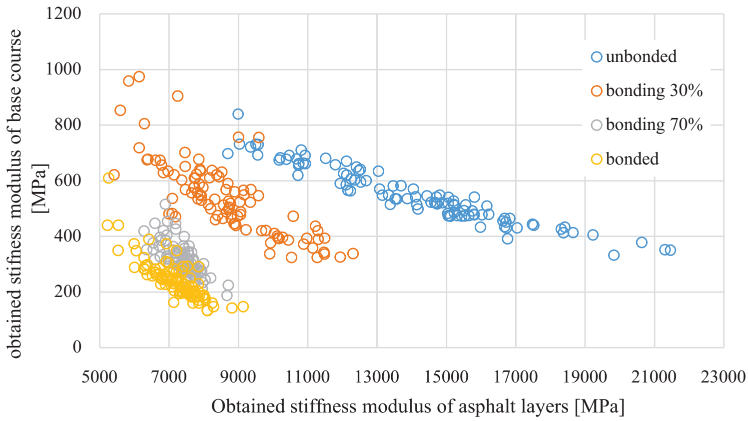

Fig. 13. Obtained values of moduli of asphalt layers and aggregate base course

higher, for the same deflection basin. This is followed by lower asphalt and aggregate base course moduli for bounded pavement structure. Presented results are caused by the fact that maximum strain is more sensitive to change of asphalt and aggregate base course moduli than to change of bonding condition, especially comparing with sensitivity of deflection basin. It is worth noting that for unbonded pavement, the maximum strains are obtained in the asphalt layer at the point of loss of adhesion.

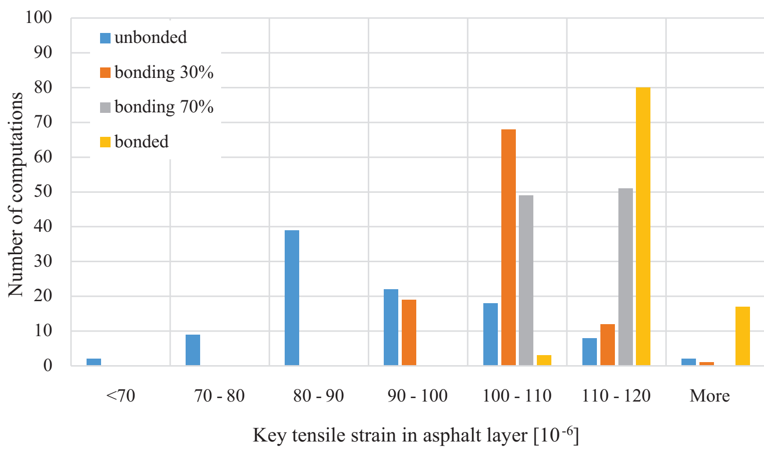

Fig. 14. Histogram of maximum tensile strains of the asphalt layer

Fig. 15 shows the values of compressive strain in the native soil with various bonding condition needed to achieve similar deflection basin. For the case without continuity sample median is equal to –293 μ strains, compared to a value of –246 μ strains for the case with full continuity.

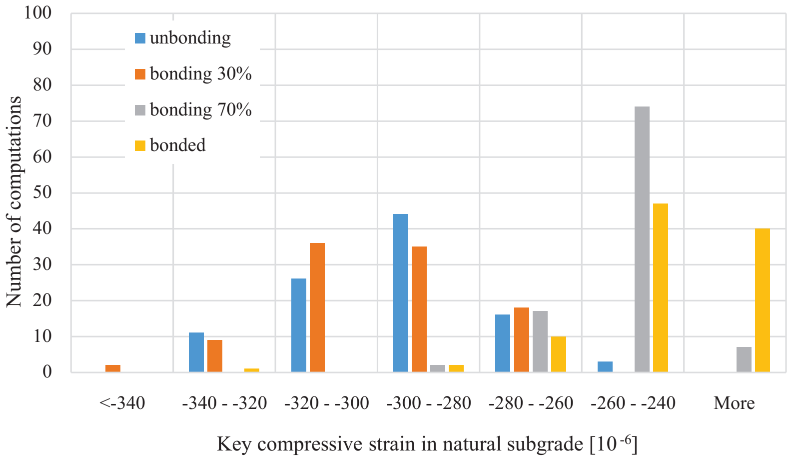

Fig. 15. Histogram of maximum compressive strains in the natural subgrade

When the model with continuity is adopted the design life of the structure is obtained, using the life criteria according to the Asphalt Institute [20] which was created based on measurement conduct in USA (assumed va – asphalt content by volume in the mixture (% v/v) in the layer where the cracks initiate–assumed to be 11.1%; vv – free space volume content of the mixture (% v/v) in the layer where the cracks initiate–assumed to be 4.6%). A histogram can be seen in Fig. 16 for the durability due to fatigue cracks at the bottom of the asphalt layers. Fig. 17 shows the results of the durability due to structural deformations of the soil. The median life for the case of discontinuity is 6.36 million standard 100 kN axles, for the case of full continuity it is 4.96 million standard 100 kN axles, for 30% bonding median life is equal to 6.06 million standard 100 kN axles, for 70% bonding

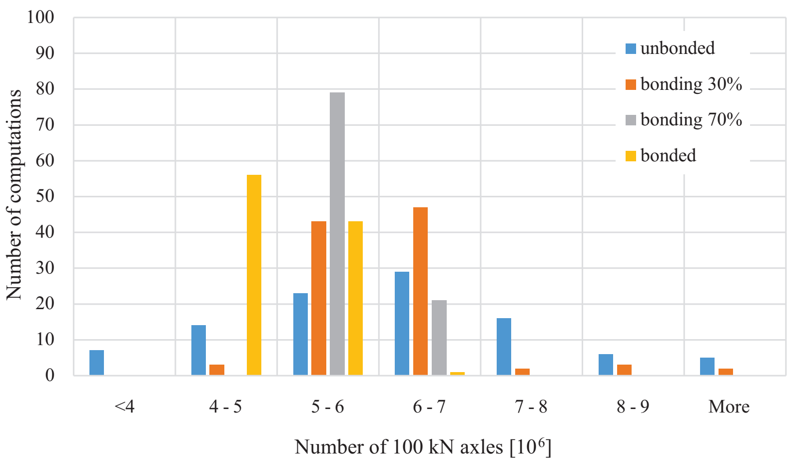

Fig. 16. Histogram of durability due to asphalt fatigue cracks

median life is equal to 5.78 million standard 100 kN axles. In every case, the design life based on tensile strains is lower than the life based on compressive strains. Asphalt fatigue cracks is critical in determining the design life. The fatigue life, according to the formula used, depends on two parameters that are variable in the cases studied: the tensile strain and the modulus of stiffness of the asphalt (for higher values of variables the fatigue life is lower). It should be noted that strain decreases for lower bonding, while modulus increases for lower bonding. This results in a non-obvious relationship of the obtained fatigue life in the different cases.

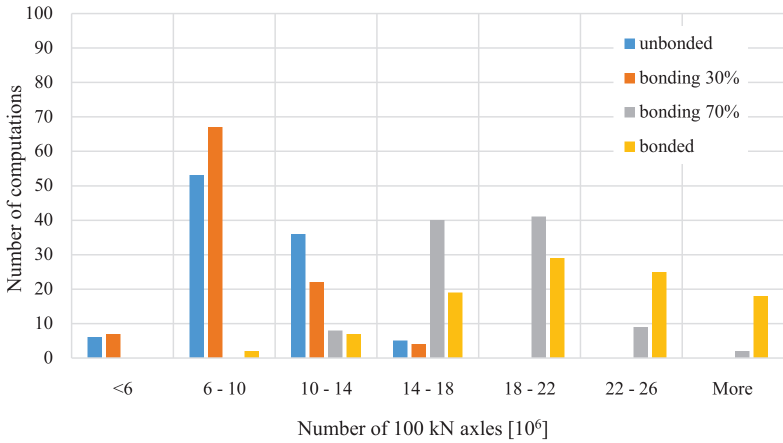

Fig. 17. Histogram of durability due to structural ruts

7. Recapitulation

The paper analyses the differences in deflection basins for pavements with various bonding condition between the asphalt binder course and the asphalt base course. There is a significant difference in the shape of the deflection basin – the pavement with no continuity shows much larger displacements near the load axis and similar far from the load axis. The maximum deflection difference at the load axis is approximately 38%.

It is possible to choose such combinations of the material parameters of the layers that the deflections with and without bonding are similar. The same deflection basin can be obtained for unbonded layers if the values of the elasticity moduli of the asphalt layers are adequately reduced. In analysed case, for an unbonded structure, the obtained deflection basin were similar to deflection for a bonded structure, when approximately 50% lower stiffness of the asphalt layer and stiffness of aggregate base course (respectively 50.0% and 56.7% lower) for bonded structure and similar values for the soil moduli (1.4% higher for bonded structure) was used. This raises the possibility of an error in the identification of material parameters by non-destructive tests, which is significant in the further determination of pavement durability.

In each case the proportion of deflections near the load axis and away from the axis must be analysed and, depending on the thickness of the package of asphalt layers, it must be decided whether this proportion indicates unbonded layers. If this is the case, additional tests are advisable depending on the reasons for the non-destructive test.

When using deflection basin from FWD test to obtain material parameters, a possible mistake in the identification of interlayer bonding results in an median error of 28.4% for maximum tensile strains in asphalt layers compering bonded structure to unbonded structure. The higher strains was obtained for bonded structure. Additionally maximum tensile strain for fully bonded structure is 10.1% higher than for the model with 30% interlayer bonding between asphalt binder and asphalt course layers, 4.9% higher than for the model with 70% interlayer bonding between asphalt binder and asphalt base course layers.

The value of the assessed fatigue life for the model with continuity is 22.0% lower than for the model with discontinuity, 18.1% lower than for the model with 30% interlayer bonding, 14.1% lower than for the model with 70% interlayer bonding. This shows that the assumption of incorrect bonding conditions in the model results in an life fatigue error of over 20% in the extreme case. These errors are important in road pavement design, so the bonding condition of the layers should be determined. The error in determining compressive deformation in the soil and durability due to structural deformation is much larger, but is not critical in analysed cases.

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Obliczenia półodwrotne modułów sztywności nawierzchni drogowej podatnej z uwzględnieniem sczepności warstw – analiza numeryczna

Słowa kluczowe: mechanika nawirzchni drogowej, nawierzchnia drogowa podatna, modelowanie sczepności międzywarstwowej, obliczenia półodwrotne, badania nieniszczące, obliczenia numeryczne

Streszczenie:

Jednym z częstych uszkodzeń nawierzchni drogowych podatnych jest utrata sczepności pomiędzy dwoma warstwami betonu asfaltowego: warstwą podbudowy i warstwą wiążącą. Wystąpienie tego zjawiska ma istotny wpływ na obserwowany stan ugięcia i odkształcenia nawierzchni. Wpływ ten jest niezwykle istotny, gdy badania nieniszczące są wykorzystywane do obliczania parametrów materiałowych, które następnie mają być wykorzystane w diagnostyce stanu nawierzchni lub projektowaniu wzmocnień konstrukcji. W artykule omówiono wpływ sczepności międzywarstwowej na wynik obliczeń półodwrotnych i uzyskane moduły sprężystości. Dla uzyskanych wartości modułów przeprowadzono obliczenia kluczowych odkształceń i trwałości nawierzchni. Niewłaściwe założenia dotyczące interakcji pomiędzy warstwami znacząco wpływają na obserwowane wyniki. Dodatkowo w artykule omówiono wpływ nieciągłości przemieszczeń nawierzchni na obserwowane wartości przemieszczeń nawierzchni drogowych i porównano to z wynikami dla modelu ciągłego. Obliczenia numeryczne przeprowadzono przy użyciu programu Simulia Abaqus, a model obliczeniowy zweryfikowano przy pomocy rozwiązania analitycznego.

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