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MECHANISTIC ASPHALT OVERLAY DESIGN METHOD FOR HEAVY DUTY PAVEMENTS

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Abstract

The current Hungarian overlay design manual was developed in the 1990s and no major review has been conducted since then. Therefore the technological and material advances e.g. modified binders and mixes, high modulus mixes, use of reclaimed asphalt pavements, asphalt grids and nets, compromises with local resources, changes in traffic loading and volume, cannot be incorporated in the calculations and the design method is considered outdated in many ways. The current methodology enables two options for the asphalt overlay design, the deflection and the pavement condition criteria. There are cases when the overlay is necessary primarily due to the condition of the asphalt layer(s), and not due to the lack of structural capacity. In such cases, i.e. when a thick existing asphalt layer is to be strengthened – primarily at highways and heavily trafficked roads – the difference between the two methods may be considerable, implying there is an error in either method, or the special circumstances require special considerations.

In this paper a researcher group at the Budapest University of Technology and Economics presents a new, mechanistic approach for overlay design. The proposed method is based on statistical analysis of Falling Weight Deflectograph (FWD) measurements, followed by the determination of the analytical input parameters either by laboratory tests or back-calculation of FWD data. Then the strains at the bottom of the asphalt layers are calculated using Odemark's transformation and the method of equivalent thicknesses. The required asphalt overlay thickness is calculated based on the allowable strains and the strains calculated for varying thicknesses.

The proposed method is presented using FWD measurements, core test results and traffic loads of a motorway in service. The method, followed by field calibration, may be an answer to the problems presented, as analytically incorporating the parameters of each material, and taking into account the remaining life of the existing pavement.

Keywords: deflections, strains, overlay, method of equivalent thicknesses

1 Introduction

The current Hungarian pavement and overlay design methods date back to a professionally advanced period of the Hungarian pavement engineering. Despite the former world-class state of the Hungarian practice, besides some minor updates the design guides have not been further developed since the 1990s. As there were intensive developments regarding the primary road network in the past decades in Hungary, in the near future the nearly completed network is expected to face a dramatically growing need for rehabilitation on a significant length of the network.

The road construction industry, facing a constant lack of funds, finds itself in an environment where both new and strengthened roads must face increasing traffic and climatic loads and the need for a proper, mechanically based design method which enables the efficient utilization of financial and material resources is inevitable. The design method of new pavements and overlays should be able to incorporate innovative technologies and new materials developed since the development of the guide. These new technologies, though they are readily available, cannot be taken into consideration at the design stage. There have been attempts to renew the current design methods ([1-4]); however, the pavement design guides have not been revised yet.

In this paper the authors present a mechanistic approach of the overlay design, being under development at the Budapest University of Technology and Economics, as an alternative to the current guide. The method proposed has been previously tested on actual pavement design tasks and is constantly being refined to achieve a thorough design procedure.

2 Critical review of the current overlay design method

2.1 Overlay design based on deflections

The Hungarian standard e-UT 06.03.13 (2005) imposes overlay design primarily based on static deflections measured on the existing pavement surface. The deflections should be corrected according to the pavement temperature and a seasonal factor which considers the probable moisture content of subbases for various soil types. Dynamic deflectographs may be used; hovewer, in this case the “d” dynamic deflections should be converted to “s” static deflections according to the rather simple Eq (1). Unfortunately only deflections measued at the loading point are considered instead of the whole deflection bowl.

$$s\ [\mathrm{mm}] = 1{,}2 \cdot d - 0{,}08 \tag{1}$$

Issues regarding the accuracy of the various correctional factors, and the method of conversion to static deflections are not discussed in this paper. Based on deflections the analysed road section is divided into homogenous segments using the cumulative sum method [5]. Such segments are assumed to have statistically similar in terms of load bearing capacity and thus the calculated overlay thickness and technology will be constant within a segment. Design deflection “s_m” is calculated for each homogenous section considering reliability factors. Design traffic is calculated in 100 kN ESALs for a design life of 10 (low volume roads) to 20 years (highways). Based on fatigue curves determined for extremely flexible, flexible and semi-rigid pavements the allowed deflections may be determined. The required (minimal) overlay thickness is determined using graphs based on the measured and the allowed deflections.

2.2 The comparative method

There are cases where the measured deflections are so low that the method discussed in Section 2.1 gives uniterpretable results. In these cases, provided the design traffic exceeds 1 million ESALs, the comparative method may be applied. The method considers a “v” reduction factor between 0,40-1,00 (based on the visual assessment of the pavement surface) for the “h_{ap}” thickness of the existing pavement as well as the thickness of milling “h_{ae}”. In this case the “Δh_a” overlay thickness is calcualted according to Eq.(2):

$$\Delta h_a\ [\mathrm{mm}] = h_{au} - h_{ae} + h_{ap} \cdot v \tag{2}$$

In Eq. (2) the method uses the ashalt thickness from the pavement design catlogue for new pavements according to the design traffic calculated for the required design life of the overlay.

The pavement catalogue and the deflection curves presented in the standard were developed in the 1990's and are practically the same today apart form minor updates. As seen the current methods are quite conservative with respect to the technological and modelling power available today.

The methods assume that the bond between the old and the new asphalt layers will weaken shortly after construction thus the critical strains that determine fatigue life of the strengthened pavement will occur at the bottom of the overlay. In this case the existing structure will only marginally lower strains as compared to a full friction between the old and the new layers. Such loss of bond is not obvious, especially when analysing pavements with thick asphalt layers and good load bearing capacity. In addition, the pavement catalogue and the deflection curves are statically provided, meaning there is no possibility to assess the effect of modern asphalt mixes and special technologies, nor material parameters of special asphalt mixes made with various additives that are however commonly used.

3 Background and outlines of the proposed method

3.1 Mechanical model

The proposed mechanical model is based on the Odemark-Ullidtz method of equivalent thicknesses (MET) [6]. A rather important assumption of the authors counter to the current theory is that the bond between the overlay and the existing structure will be adequate for the layers to interact. This is likely in cases where a thick existing asphalt layer is available and the bearing capacity of the existing structure is relatively high (e.g. typically the primary road network). Accordingly, the presented method itself is proposed for such cases. According to the assumption the critical strains that cause fatigue failure will occur at the bottom of the existing asphalt layer (Figure 1 C), and will be significantly reduced as compared to the modelling applied in the current standard (Figure 1 A).

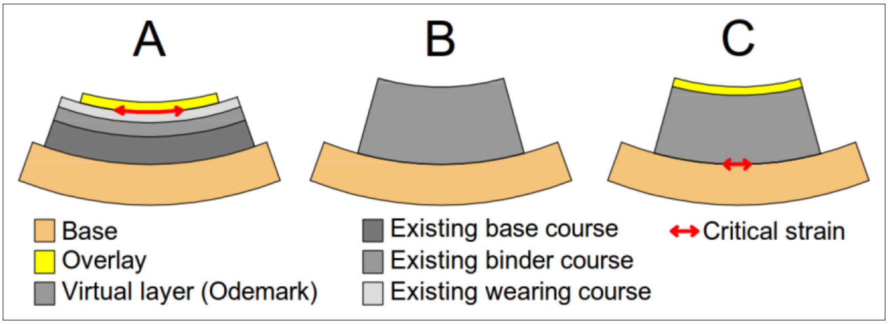


Figure 1 Position of critical strains: (A) Current standard method (B) Odemark transformation (C) Proposed method

The model consists of 3 layers, namely the asphalt layers, the subbase and the subgrade . The required material parameters are the stiffness moduli, the Poisson's ratio and the thickness of each layer (the subgrade is of infinite thickness). The existing asphalt layers and the overlay are cumulated using Odemark's transformation [7] based on the equality of the E*J flexural momentum of the layers (Figure 1 B). The calculation of the virtual thickness “$h_{e,n}$” of a given layer having an actual thickness “h_i” and moduli “E_i”, to a virtual moduli of “E_n” is according to Eq. (3).

$$h_{e,n} = f \cdot \sqrt[3]{\sum_{i=1}^{n-1} h_i^3 \cdot \left(\frac{E_i}{E_n}\right)} \tag{3}$$

3.2 Critical strains

Applying MET, strains occuring at the bottom of the asphalt layers can be calculated for a range of asphalt thicknesses which consist of the existing layers and a varied overlay thickness, cumulated using Odemark's transformation. As a result the thickness-strain curves based on actual material properties are determined. Stains occuring at a given “z” depth in a given asphalt layer are calculated according to Eq. (4), based on the stiffness moduli “E” and the Poisson number “ν” of the layer, the radius of the loadin plate “a”:

$$\varepsilon_z = \frac{(1+\nu)\cdot\sigma_0}{E}\cdot\left[\frac{\frac{z}{a}}{\left(\sqrt{1+\left(\frac{z}{a}\right)^2}\right)^3}\cdot(1-2\nu)\cdot\left(\frac{\frac{z}{a}}{\sqrt{\left(1+\frac{z}{a}\right)^2}}\right)\right] \tag{4}$$

In terms of critical strains to cause fatigue failure, paramter “z” is equal to the thickness of the asphalt layers.

3.3 Allowed strains

Allowed strains for a given design traffic (the number of 100 kN ESALs) can be calculated based on laboratory fatigue tests for a given asphalt mix, or according to known prediction formulas, e.g. the SHELL fatigue equations [8]. Previous research [9] at the Department involving fatigue tests of core samples showed that the SHELL equations slightly underestimate the real fatigue performance of old asphalt layers. Due to its approximation to the benefit of reliability, the SHELL formula, based on the “V_b” binder volume, the “E_e” stiffness of the mix and “N” design traffic in ESALs is used according to Eq. 5.

$$\varepsilon_t = (0{,}856 \cdot V_b + 1{,}08) \cdot E_e^{-0{,}36} \cdot N^{-0{,}2} \tag{5}$$

The required binder volume and stiffness values are determined via laboratory tests. As a result the allowed strains or each homogenous segment may be calculated in microstrains.

4 Calculations

The proposed mechanical overlay design method is presented below step-by-step for a highway section in Hungary based on actual measurements.

4.1 Evaluation of FWD data

For the proposed method, unlike the standardised method, the whole deflection bowl will be assessed. The deflection bowl obtained using KUAB FWD measurements consists of an overall 7 points. Measurements were taken in both directions in the most heavily trafficked slow lane every 50 meters. As there are some disputes about the current seasonal and temperature corrections of dynamic deflections used in Hungary [10], the data is corrected using factors developed by Wagberg [11]. Both directions are divided into homogenous segments using the same method as in the standard. Figure 2 shows the cumulative sum values for both directions.

Homogenous segments are determined via calculation, according to the changes in the trends of the CUSUM curves. As shown three segments can be determined for each directions.

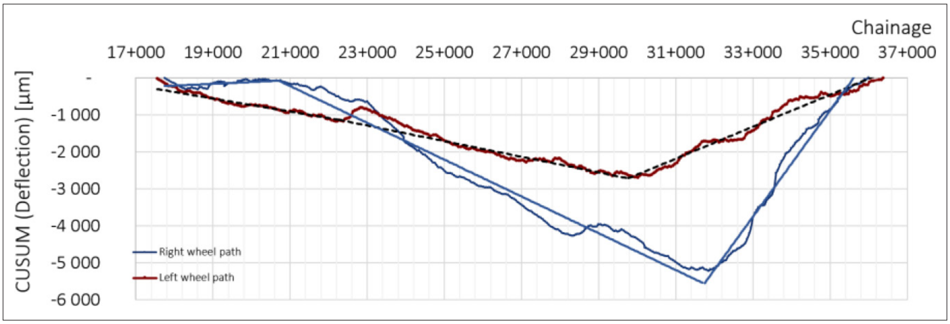


Figure 2 Cumulative sum values for both directions

4.2 Characterisation of a section

Within each homogenous segment the significantly weak sections, based on deflections, are identified using the area parameter developed by Adorjányi [12]. The parameter is calculated using the deflection bowl, and the higher its value, the higher the ratio of the pavement is involved in carrying the loading. The calculation of the area parameter “TP”, using deflections measured at given “d_i” sensors placed at “i” distances from the loading plate, is according to Eq. (4).

$$TP = \frac{1}{12} \cdot \left[d_0 + 1{,}25 \cdot d_{300} + 2{,}25 \cdot d_{600} + 1{,}5 \cdot \left(d_{200} + d_{450} + 2 \cdot d_{900} + d_{1200} \right) \right] \tag{4}$$

The area parameter is calculated for every beflection bowl. The representatively weakest section within a homogenous segment is assumed to have the 95% frequency of occurence of the highest area parameter. Using this method it is possible to detect a section being weak in a general sense, as compared to the central deflections, which primarily indicate the condition of the asphalt layers.

4.3 Core samples and material parameters

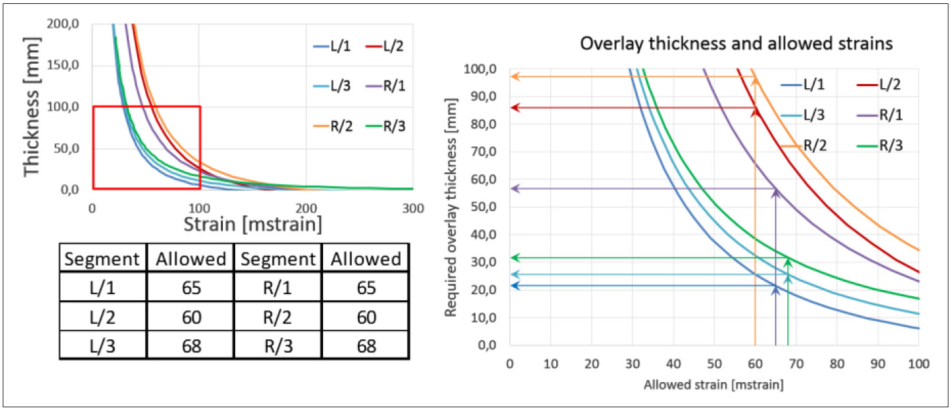
Core samples were taken at the representative cross-section determined for each homogenous segment. The samples provided actual thickness data and optionally material parameters may be determined via laboratory tests. Required material parameters for the mechanistic model may be also determined using back-calculation of FWD data as presented in [13]. In this paper the material properties of the asphalt layers were determined using indirect tensile strength test (IT-CY) according to EN 12697-26 (method C), the moduli of the subbase and the subgrade were determined by back-calculation of the deflection data using EVERCALC software. Layer thicknesses and properties are shown in Table 1.
According to previously discussed boundary conditions of the proposed method in this case the wearing course is assumed to be milled out and is not considered in the modelling. Based on Odemark’s transformation the binder and base asphalt layers are transformed into a virtual layer with the moduli of the base course. The model of the existing structure consists of the three highlighted layers shown in Table 1.

Table 1 Thicknesses and material properties of existing layers

	Left track			Right track		
Homogenous segment	**L/1**	**L/2**	**L/3**	**R/1**	**R/2**	**R/3**
Representative section	21+000	27+174	31+750	18+750	28+600	33+550
Wearing course	32 mm	41 mm	38 mm	59 mm	43 mm	50 mm
Binder course	77 mm	84 mm	70 mm	80 mm	82 mm	82 mm
	3563 MPa	3631 MPa	3104 MPa	4341 MPa	4209 MPa	3265 MPa
Base course	125 mm	109 mm	118 mm	110 mm	78 mm	96 mm
	4214 MPa	6561 MPa	3881 MPa	5145 MPa	6806 MPa	3170 MPa
Asphalt layers (Odemark; binder and base course)	198 mm	178 mm	183 mm	186 mm	148 mm	179 mm
	4214 MPa	6561 MPa	3881 MPa	5145 MPa	6806 MPa	3170 MPa
Subbase	250 mm	250 mm	250 mm	250 mm	250 mm	250 mm
	1996 MPa	1117 MPa	1115 MPa	856 MPa	1173 MPa	265 MPa
Subgrade	178 MPa	166 MPa	159 MPa	179 MPa	209 MPa	155 MPa

5 Results and discussion

Using the calculated thickness-strain curves for each homogenous segment and the allowed strains based on the calculated design traffic the required overlay thickness can be easily determined, as shown on Figure 3. The design was conducted according to the current standards for comparison, however, as the measured deflections are low, the method based on deflections resulted in uninterpretable results.



Segment	Allowed	Segment	Allowed
L/1	65	R/1	65
L/2	60	R/2	60
L/3	68	R/3	68

Figure 3 Determination of required overlay thickness

The required overlay thicknesses for each homogenous segment, assuming AC11 50/70 wearing course with a moduli of approximately 4500 MPa, and using the model described, are shown in Table 2. As expected, calculations based on the actual parameters of the existing structure and the overlaying asphalt mix result in a significantly lower overlay thickness in all cases.

The proposed method is under fine tuning and has been tested on various pavement types based on actual measurements and laboratory tests. Further calibration of the method is however required, such as the corrections of the measured deflections especially in light of the changing climatic factors [14], or the correct calculation of the design traffic and integration of WIM data into the parameters used. The method itself has shown in previous and this actual research that due to its simplicity it is a viable alternative to the currently used methods. Further research will be conducted to establish the limitations of the system and to develop a framework for an eventual transition period between the current and the proposed method.

Table 2 Overlay thicknesses calculated for each homogenous segment

	Left track			**Right track**		
Homogenous segment	**L/1**	**L/2**	**L/3**	**R/1**	**R/2**	**R/3**
Representative section	21+000	27+174	31+750	18+750	28+600	33+550
Design traffic [100 kN ESALs]	18 306 566	25 881 098	14 108 131	18 306 566	25 881 098	14 108 131
Allowed strain (SHELL formula)	65 mstrain	60 mstrain	68 mstrain	65 mstrain	60 mstrain	68 mstrain
Overlay (mechanistic)	21 mm	86 mm	26 mm	57 mm	97 mm	32 mm
Overlay (comparative)	95 mm	139 mm	93 mm	116 mm	144 mm	93 mm

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