BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
FACULTY OF CIVIL ENGINEERING
DEPARTMENT OF HIGHWAY AND RAILWAY ENGINEERING

Thesis booklet

Mechanical overlay design method for asphalt pavements and the analyses of the required parameters

Ph.D. dissertation

Author:
Soós Zoltán,
MSc. in Civil Engineering

Supervisor:
Dr. Tóth Csaba PhD, MBA, associate professor

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1. Introduction

Road structures, similarly to other civil engineering structures must be properly designed considering the effects throughout their design life, to ensure that the new, or overlaid structure – assuming proper maintenance – will be able to fulfil functional, structural and economical requirements for the desired time [1]. This complex optimization task, the design meant the examination of the geometrical properties of the structures earlier, mostly based on construction experience, doing approximate calculations at most.

With scientifical developments this approach was later gradually replaced by analytical methods, enabling the even finer calculations and comparison of the effects and load bearing capacity of the structures. The development of testing and modelling methods, together with the development of the mathematical probability theories lead to several probability and semi-probability based methods in the 1990's, as shown on Fig. 1.

These methods were based on the recognition of the fact that – as stated by Kármán – when designing structures only the sufficient security can be the goal, not the absolute. After lengthy debates, initial rejection, these methods lead to a better use of compromises between the structures and materials, and the expectations regarding the structures.

The allowable, or expected rate of risk, or safety as shown on Fig. 1 are the basis of the design, and are determined based on the function attributed to a given structure. As seen, the essence of design remains the comparison of loads and load bearing capacity, however the determination of their quantities have changed, mostly variables are used, thus the various values are considered according to a probability of occurrence [2].

During calculations the variables are considered by using their characteristic values, which are determined based on density functions and using safety factors, mostly at both the effects and resistance side of the structures [3].

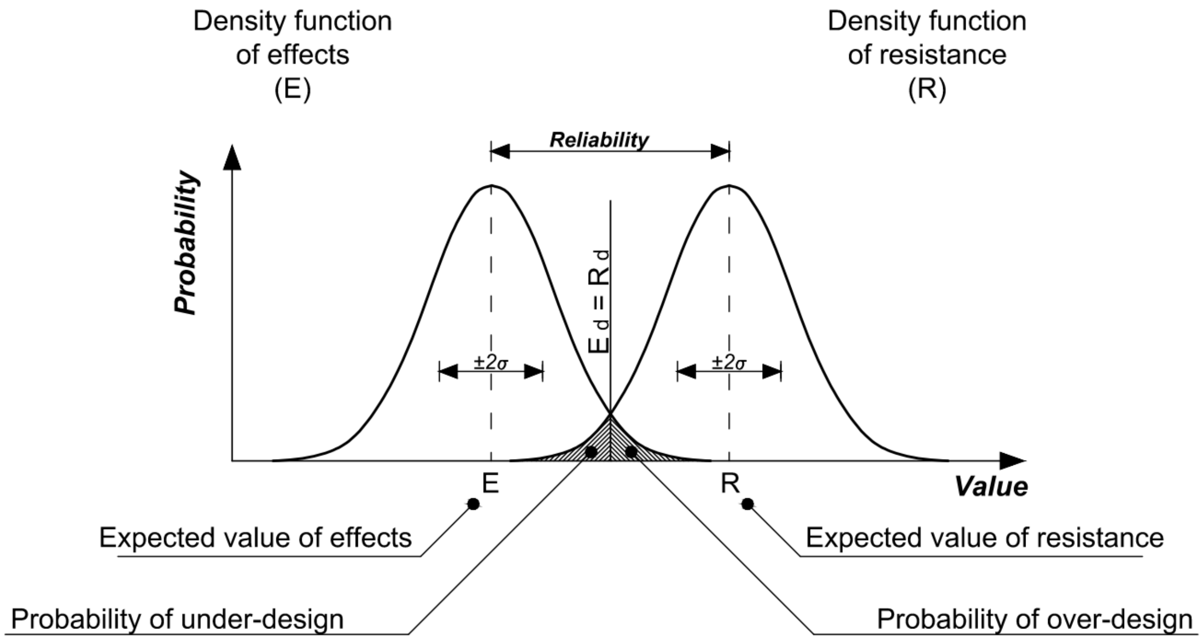


Fig. 1. Basis of the stochastic design

The compliance of the structure, in a general sense, is defined by Eq. (1) as used in the field of structural design.

$$E_d \leq R_d \tag{1}$$

where:

E_d : design value of loads (*Effect of Action*),
R_d : design value of load bearing capacity (*Resistance*).

Although pavements are considered structures, their design methods differ from those of classical civil engineering structures, as the uncertainty is high bot at the determination of loads and the resistance, furthermore there may be a high difference in accuracy, even of the order of magnitude [1].

Regarding loads, in case of road structures mostly the traffic loads occurring under the design life are considered. In the model for assessing the traffic loads the determination of the number of heavy vehicles, their properties, the damage done by such vehicles, there is an inevitable uncertainty, not only at the generalization of the data, but at the estimation of its change during the design life.

However the models for the determination of stresses and strains in arbitrary points of a pavement structure are available, and the most known ones are computable since the 1970's – a good example is shown by the work of Nemesdy regarding the development of the Hungarian pavement catalogue [4] – there must be significant simplifications done at the modelling of the structure, being multi-layer in reality, and at the consideration of the properties of the materials, as seen at the case of traffic loads.

This leads to further uncertainties at the design of a road structure. Uncertainties have been variously considered which lead to the development of more or less different methods for the design of new pavements and overlays in countries – some of these are referred to in this research as well – however due to regularities and similar experience many similarities are also found.

The design of asphalt pavements in Hungary, similar to most countries, is based on the foundings of the AASHO road experiments. The Design Guide of Flexible Pavements (HUMU [5]), published in 1971, was in place, with modifications, until 1994, when the pavement catalogue system took over its place, as a result of the work of Nemesdy [6], in the form of the ÚT 2-1.202 standard. This standard and the original system is still in place, however some modifications have been done.

Recognition of the obsolescence of the – once world-class – design guide lead to the initiation of development of a new design method for new pavements by the government recently [7], however the official work on a design guide for overlays for existing structures is yet to come, although it must be stated that detailed but not integrated research is available.

The upkeep of the primary road network in Hungary, having a length about 9000 kilometres in 2015, assuming a design life of about 15-20 years, requires the renewal of about 450 kilometres each year, which itself means tens of billions annual expenditure, not mentioning the expenses related to new road network elements.

This underlines the importance of a modern, analytical overlay design method and the requirement of reliable input data.

Goal and structure of the dissertation

Based on the introduction the research is based on the assessment of the loads and the load bearing capacity of road structures, and discusses the overlay design for asphalt pavements, as seen on Fig. 2

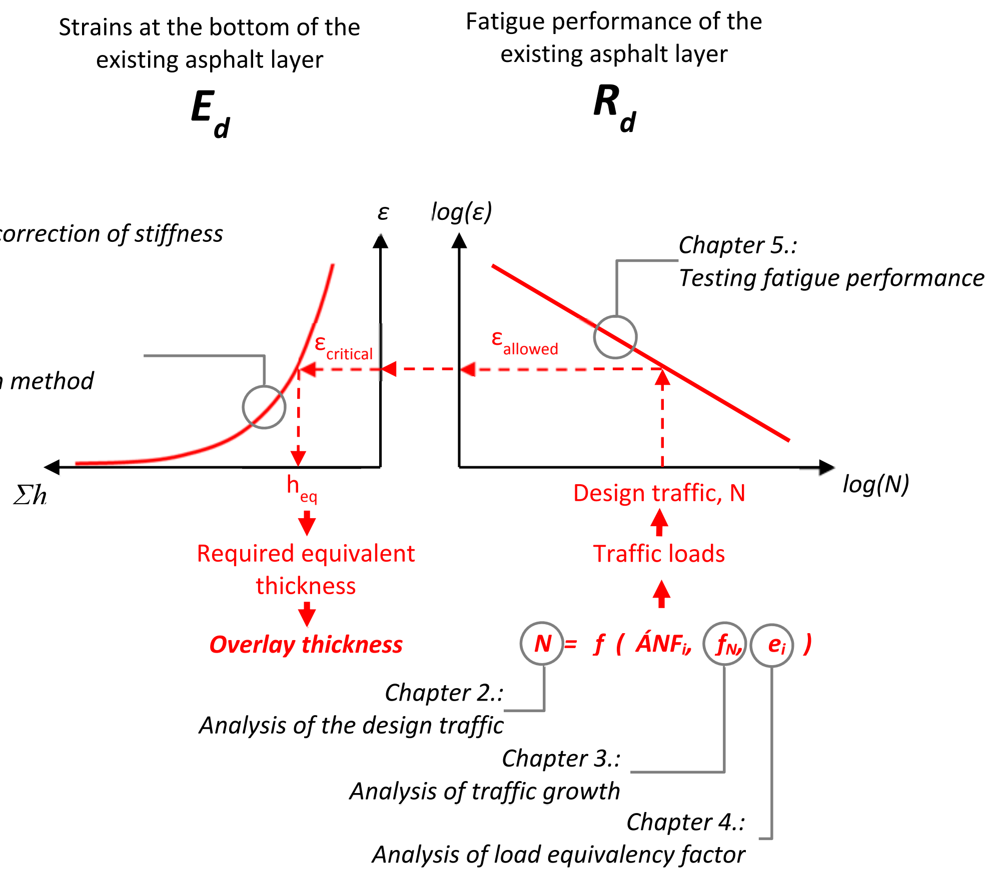


Fig. 2. Structure of the dissertation

Some elements of the developed design method – having in mind the available resources, available Hungarian data, and the "importance" of a given element – have been selected for further analysis within this thesis.

The first part of the research – Chapters 2., 3., 4. – deal with the most important input parameters at the design of road structures, the determination and the possibilities to refine design traffic, in a matter that enables the use of the findings in the current design method regardless of the proposed design method.

The second part of the dissertation – Chapters 5., 6., 7. – present the developed method for the overlay design of asphalt pavements, primarily suited for the primary road network. The method is built based on the current Hungarian pavement diagnostics and material test methods, but in contrast to the current standard method, considers the actual mechanical parameters of a given road segment, resulting in objectively comparable rehabilitation alternatives.

The logical build of the chapters, and the self-standingness of the individual chapters was an important goal at the compilation of the dissertation.

Due to the length limits if the dissertation, some important background and supplementary materials, and data enabling the follow-up, even supervision of the calculations, moreover the further use of the data and the results have been placed in the Annex of the thesis, in order of appearance.

The literature assessed during the research is found in a designated reference chapter, in order of appearance. The introduction of the used professional literature is found at the beginning of the relevant chapters, except if intelligibility required otherwise.

The dissertation contains 14 chapters based on 6 main chapters.

Chapter 2 introduces analyses made regarding the method to determine the design traffic. To point out the opportunities to refine the calculation of design traffic, and to identify the "importance" of given input parameters with regard to reliability of the result, sensitivity analyses have been conducted.

Input parameters and their variability for the analysis have been determined based on available official data and literature. Based on the results it can be numerically stated that to further refine the determination of design traffic the proper determination of traffic growth rate is most important, followed by the use of correct load equivalency factors.

Chapter 3, accordingly, presents the analyses regarding the determination of the traffic growth rate factors. The values and the mode of the calculation is also assessed, as well as the problems found in this field, and suggestions are made to make corrections.

Chapter 4. presents a proposed method to determine load equivalency factors based on Weigh-In-Motion measurements. The chapter presents the possibility to fit a function as a combination of three normal distributions to use the whole axle load spectra for further analyses. Using this approach to determine load equivalency factors enables the assessment of not only the overweight vehicles, but vehicles with legally increased axle loads according to the European laws, during pavement design.

Chapter 5. presents analyses of one of the most important feature of asphalt mixes, the temperature dependency of the stiffness, and presents the model chosen for application in the developed design method. The model is used for the temperature correction of the stiffness of the layers in the analytical model.

Chapter 6. presents a similarly important parameter for overlay design of existing pavements, the testing of fatigue performance. The goal of the chapter is to assess the possibility to introduce the indirect tensile fatigue test mode in the Hungarian practice, previously used only for research in Hungary, but frequently used in the international practice.

Chapter 7. presents the developed overlay design method for asphalt pavement structures, based on elements currently available in Hungary regarding diagnostics and testing capacity. The method is primarily designed for structures with good load bearing capacity, with relatively thick asphalt layers – i.e. mostly roads of the primary road network – having significant remaining fatigue life, in which cases the current Hungarian standard often leads to an otherwise evitable over-design.

A further advantage of the method is that in contrast to the current Hungarian standards, it is capable to consider actual mechanical and technological parameters as well.

The thesis is closed with a brief summary in Chapter 8., followed by Chapter 9., presenting new scientifical results, and Chapter 10. presenting the list of publications done within this research.

2. Research methodology

In this research both sides of the design are assessed, i.e. analyses have been conducted both regarding the determination of loads and the determination of the load bearing capacity of the structure. The research methodology is different for the two sides.

Analysis of the determination of the design traffic

The design traffic is determined as shown by Eq. (2) [8].

$$TF = z \cdot 1{,}25 \cdot 365 \cdot t \cdot r \cdot s \cdot f_N \cdot (ÁNF_a \cdot e_a + ÁNF_n \cdot e_n + ÁNF_p \cdot e_p + ÁNF_{ny} \cdot e_{ny}) \quad (2)$$

where:

- TF : design traffic, F100, equivalent single axle (ESAL) passes [no],
- $ÁNET$: daily number of ESAL passes in one lane in one direction [ESAL/day],
- z : factor to consider the excess damaging effect of the single 115 kN, the dual 180 kN and the 190 kN road friendly axles, until load equivalency factors assessing such vehicles are determined,
- $1{,}25$: safety factor,
- t : design life [years],
- r : factor to consider the directional distribution of the heavy traffic,
- s : factor to consider the number of lanes in a given direction,
- f_N : factor to consider traffic growth rate of the merged vehicle classes used for pavement design according to the e-UT 02.01.31 [ÚT 2-1.118:2005] Hungarian standard,
- $ÁNF_a$: number of single and articulated buses [vehicle/day],
- e_a : load equivalency factors for single and articulated buses,
- $ÁNF_n$: number of single heavy vehicles [vehicle/day],
- e_n : load equivalency factors for single heavy vehicles,
- $ÁNF_p$: number of trucks with trailer [vehicle/day],
- e_p : load equivalency factors for trucks with trailer,
- $ÁNF_{ny}$: number of trucks with articulated trailers [vehicle/day],
- e_{ny} : load equivalency factors for trucks with articulated trailers.

The sensitivity analysis enabled the numerical demonstration of the traffic growth rate being the most definitive component of the uncertainty in the method to determine the value of design traffic. Although as the determination of the value of this parameter is a question rather of economic geography and traffic policy, only general conclusions have been drawn in the current research. The other important and distinguishable part of the uncertainty is related to the availability of statistically reliable data regarding the properties of heavy traffic and heavy vehicles. Factors as axle load, features to the tires, the suspension, tire pressure, and others obviously influence the damaging effect of heavy vehicles on the pavement structure, although the reliable availability of such data would require large number of regular measurements. At this moment there is no such data available in Hungary besides the measurements of weighing stations at the border crossings. The data has been provided for this research by the Hungarian Roads Agency, allowing the processing of several million vehicle weighing, and the continue of previous research [9] [10].

The mechanical overlay design method

I developed a mechanically based method for the overlay design of asphalt pavement structures. The basis of this method are already existing elements, as the dynamic deflection measurements, the method to determine homogenous segments, the area parameter and asphalt mechanical tests. The design method requires the build of three models as shown by Fig. 3.

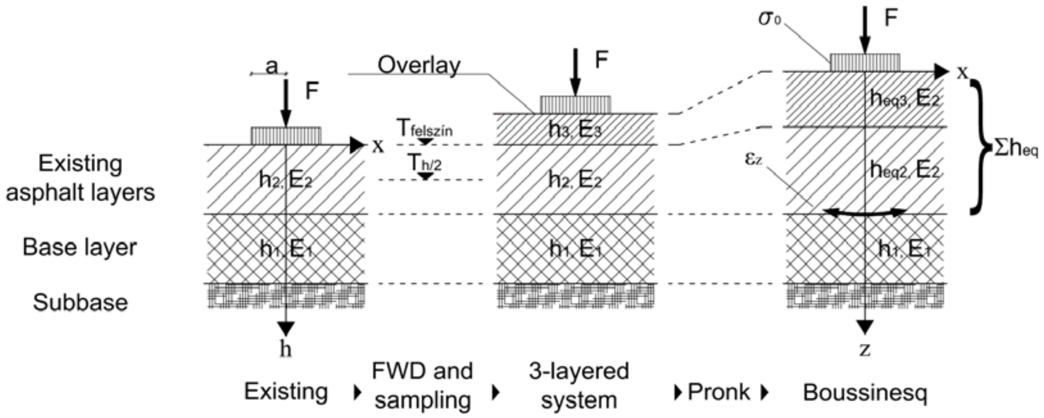


Fig. 3. Models used in the design method

In the model, the subbase is represented by an infinite half-space, the further layers above it are represented by their moduli, Poisson's number and thickness. The assumption that the layers are homogenous, isotropic and linear elastic is an essential one, although required for the solution of the model, i.e. for the Boussinesy-equations to be valid and applicable for the determination of stresses and strains in arbitraty points in the structure.

Three models are built in the design method. The first model represents the existing structure, containing the moduli of the layers obtained with the back-calculation of FWD data. The second model represents the overlaid structure, which considers the optionally removed and the newly built layers as well.

To solve the multilayer model the third model is required, in which the asphalt layers are merged, and the stresses and strains at the bottom line of the asphalt layers are calculated using the Boussinesq equations.

3. New scientific results

Thesis 1.

Using sensitivity analyses I proved that, amongst the input parameters of design traffic, the determination of the correct value of the traffic growth factor is the most important, followed by the correct determination of load equivalency factors of buses in the case of main roads, and the load equivalency factors of semitrailers in the case of highways.

Publication related to Thesis 1: (2)

Thesis 2.

I suggest the revision of the cubic functions used to estimate the growth of traffic in the case of primary roads and highways – in the latter case using a special resolution as well – and using the revised functions I suggest the yearly calculation and summation of design traffic, in contrast to the method according to the current standard.

Based on the analysis of national traffic counting data, I have shown that at the calculation of design traffic the estimation of the cubic form of traffic growth according to the current standard is correct, but the parameters of the functions are incorrect, leading to a possible over-design in the case of the analysed main roads and an under-design in the case of highways. With regard to the use of the growth factor I have shown that its calculation for the "t/2"-th year, only for the sake of simplifying the calculations, leads to an unnecessary further inaccuracy.

Publication related to Thesis 2: (2), (4)

Thesis 3.

I developed a method to determine load equivalency factors based on dynamic axle load measurements, using the description of the axle load spectra with a continuous function and methods based on random number generation.

Thesis 3.1.

The dynamic load spectra of a given axle can be defined using the linear combination of three normal distributions with adequate precision in a statistical sense, using the form shown by Eq. (3).

$$p(x) = \sum_{k=1}^{3} \pi_k f(x|\mu_k, \sigma_k^2) \quad (3)$$

where:

$p(x)$	:	function constructed using “k” normal distributions,
$k=0...3$	:	number of normal distributions,
$\pi_k = 0 \dots k$	:	weigh of the “k”th normal distribution, $\sum_{k=0}^{N} \pi_k = 1$
$f(x\|\mu_k, \sigma_k^2)$	:	“k”th normal distribution,
μ_k	:	expected value of the “k”th normal distribution,
σ_k^2	:	value of standard deviation of the “k”th normal distribution.

Thesis 3.2.

I suggest the integration of a new detailed vehicle class – marked in this research with “Dx” – which consists of a lorry with two or three axles and a trailer with a single or a tandem axle, into the relevant Hungarian standard and connected parts. Using the proposed methodology I determined the load equivalency factors, as shown below, which may be used in the current Hungarian pavement design method as well.

Detailed vehicle classes		Merged vehicle classes	
C1	0,30	C	0,34
C2	1,51		
D1	1,70	D	2,07
D2	2,20		
Dx	2,14		
E1	0,79	E	1,81
E2	1,94		
E3	1,92		
E4	1,49		

Suggested load equivalency factors

Thesis 3.3.

In case of the presented load equivalency factors, determined based on weigh-in-motion measurements, the “z” factor used according to the current Hungarian standards in no longer required at the determination of design traffic.

Publication related to Thesis 3: (5), (6)

Thesis 4.

The assumption that the remaining fatigue life of the existing pavement is negligible during overlay design, and the design criteria is to the horizontal strain at the bottom of the overlay, leads to a significant overdesign in cases when the existing structure consists of thick asphalt layers that work together. I have shown that the fatigue performance of the in-service layers can be determined using indirect tensile fatigue tests, and the results can be used at the design of the overlay.

Publication related to Thesis 4: (9)

Thesis 5.

For the proposed overlay design method, based on the analyses of a high number of laboratory test results, I suggest the model used in the AASHTO design guide for the temperature correction of asphalt mixes having a nominal aggregate size of about 20-22 mms.

The model is shown by the following equation:

$$f_{ref} = \frac{10^{0,000164671\cdot\left[T\cdot\frac{9}{5}+32\right]^{1,92544}}}{10^{0,000164671\cdot\left[T_{ref}\cdot\frac{9}{5}+32\right]^{1,92544}}}$$

where:

T : actual measurement temperature [°C],

T_{ref} : reference temperature, 20 °C.

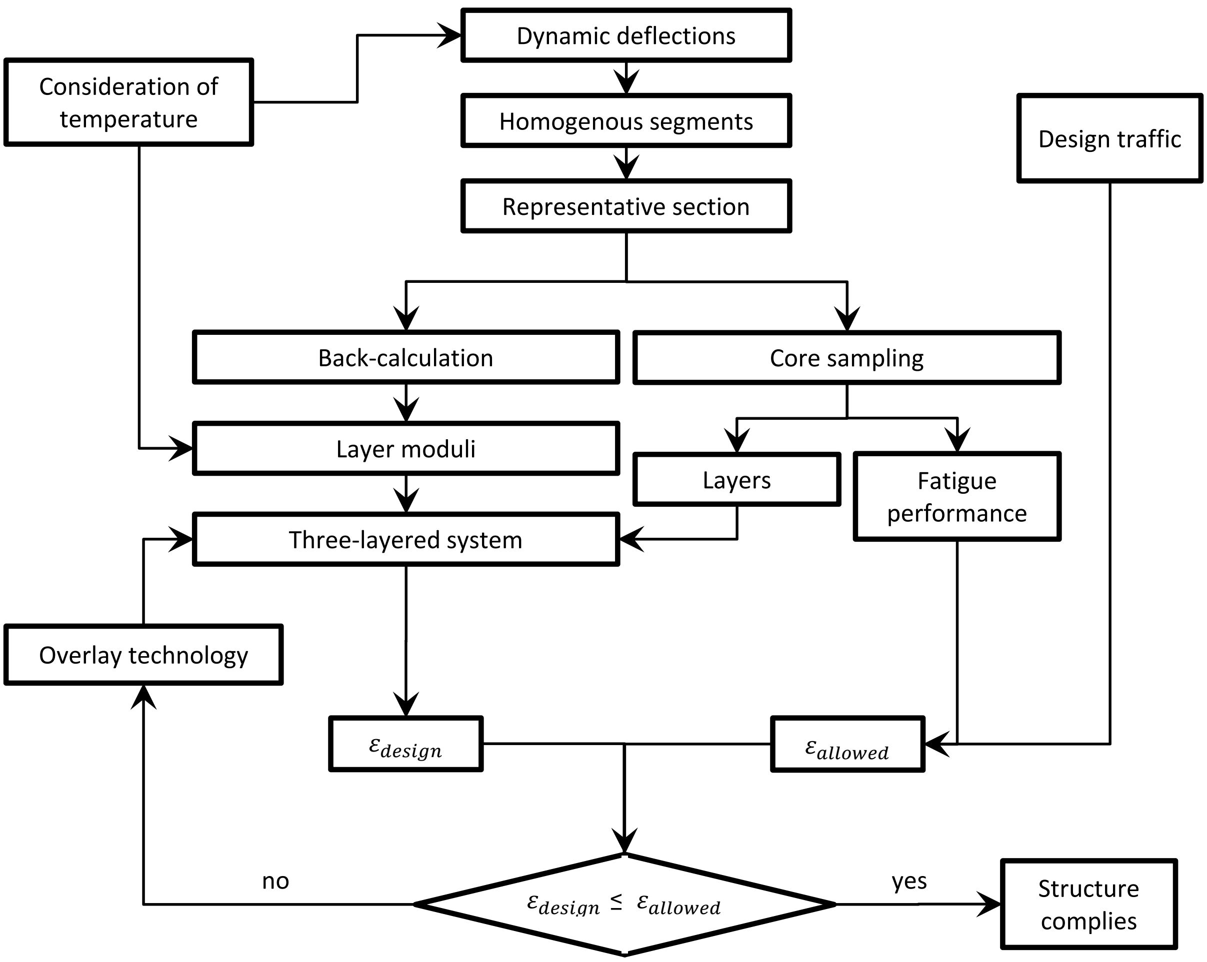
Publication related to Thesis 5: (8)

Thesis 6.

I developed a new method for the mechanistic design of overlays, which considers the actual mechanical properties of the existing and the overlaid structure, as well as the numerical value of the design traffic.

The method is primarily applicable for the overlay design of structures having a good load bearing subbase, and asphalt layers having a considerable remaining fatigue life.

The method is summarised by the following graph.



Algorithm of the design method

<u>Publication related to Thesis 4: (1), (3), (7)</u>

4. Summary

4.1. General conclusions

The main goal of the research was to develop the outlines of a mechanically based overlay design method. During the research, design was assessed as a process, meaning that the determination of the loads and the load bearing capacity was analysed as well. The analyses of the determination of the load of the structure was based on the current Hungarian standards. Although the method itself is relatively simple, the basis of this part of the research was the sensitivity analysis of the equation, leading to a quantitative evaluation of the factors most essential in order to improve reliability of the results. This was followed by the analysis of the given input values.

Although most important with regard to reliability, the determination of a correct value of the traffic growth rate is difficult. Having in mind the length limits of this thesis the factor was not analysed in detail, however some general conclusions have been made.

In case of the load equivalency factor of heavy vehicles an approach is introduced, utilizing the Weigh-In-Motion (WIM) data acquired at border crossings. The current network is expected to be significantly developed with inland stations, giving the opportunity to regularly check the factors, which is uttermost suggested. Using the factors determined based on the introduced method, the "z" factor used in the current design method is no longer required.

The overlay design of asphalt pavements is a more and more important international field. Shifting the design to a mechanical basis, to be able to consider the various materials and technologies available today is an obvious criteria to avoid the over- or under design of pavements and overlays. The proposed method was developed with the aim to utilize current pavement diagnostics possibilities in Hungary, and to consider the mechanical parameters of the structure and the overlay, e.g. the fatigue performance and stiffness of the existing layers and the material parameters available by using various technologies, in an analytical manner.

Within the current research, two important issues regarding the design method have been analysed, namely the temperature dependency of the stiffness of asphalt mixes and a method suggested for the determination of the fatigue strength of in-service layers. In the lack of statistically sufficient data, there was no possibility to develop a new model for the temperature correction of stiffness, thus based on previous and own results existing models have been validated.

The applicability of the indirect tensile fatigue test (ITFT) was analysed on statistically low sample size, but the introduction of this test in Hungary is highly recommended. Primarily, mostly because for the test core samples can be used, the method is highly suitable to determine the fatigue performance of in-service layers as compared to other methods. Second, based on experiences supplemented by literature review, a high reliability is found for the test. Also, several practical features also emphasize the test method, as the reduced material need, the simple specimen production, and the simple test conditions.

I hope the analyses concerning the determination of design traffic underlined the importance of monitoring the features of heavy traffic with regard to pavement design, and contributed to the more accurate and sound determination of the most important input data of pavement design. With the development of the outlines for a new overlay design method, by introducing theoretical considerations and relevant professional literature I hope to have contributed to possibilities to efficiently use national resources in the work at hand regarding the rehabilitation and strengthening of the main road network.

4.2. Utilization of the results

During the development of theses regarding the design traffic – Thesis 1., 2., 3. – and at the choosing of the research methods it was a goal for the research to be repeatable in the future and to be applicable in practice regardless of accepting the developed design method, in the current Hungarian standards.

The sensitivity analysis showed the importance of the regular revision of heavy traffic characteristics. The regular revision of the factors that consider traffic growth, and the load equivalency factors is essential to avoid the under- or overdesign of pavement structures and overlays.

The presented load equivalency factors can be easily integrated into the current design guide as well. Besides, the currently used “z” factor is not needed as the suggested load equivalency factors include these vehicles as well, having it deleted from the design method helps avoid the overdesign of roads in which these heavy vehicle types are negligible, such as most of the urban roads.

The practical utilization of the results regarding the overlay design of asphalt pavements – Thesis 4., 5., 6. – is self-evident.

The indirect tensile fatigue test presented in Thesis 4., regardless of its use in overlay design, is suitable for use in Hungary besides the other test methods, due to its numerous practical advantages.

The application of state of the art in evaluation of fatigue test results to the everyday practice is yet to come in Hungary and most international practices as well. This field requires many further research and practical experience as well.

4.3. *Further research*

Based on the presented sensitivity analysis it was shown that to determine the correct value of design traffic the revision of the traffic growth rate factors is of upmost importance, this however needs proper research. To determine correct factors an analysis of economic-geographical aspects and the traffic policy of the neighbouring countries is also needed, which exceeded the scope of the current research.

Regarding the development of load equivalency factors the further research of reliability of the data is highly recommended. Despite the huge professional literature available, it is recommended to analyse the reliability and data quality considering the endowments of the Hungarian measuring network – e.g. speed and vehicle characters – in detail. The exact effect of some specifics, as tire size and type, tire pressure, overlap of tandem and tridem axles on the damaging effect of vehicles is yet an open question. Besides the obvious importance of this question regarding the load equivalency factors, if the effects are considerable, there is more research to be done in order to generalise the data for a whole traffic stream, while minimising the uncertainty at the same time.

All elements of the proposed design method are open research fields that are independently analysable, regardless of the design method. E.g. the correctional factors of dynamic deflections have not been revised since the work of Dr. Tibor Boromissza, and there is a decade’s professional demand for the revision of the factors that consider the actual state of the subbase.

The current regulations are ignorant regarding the better use of the deflection bowl, as well as in case of the use of design software. These fields undeniably need attention in the near future.

The suggested model for temperature correction of asphalt stiffness is based on a high number of measurements. However, the development of a new model based on Hungarian data can be considered.

To introduce the indirect tensile fatigue test a statistically convincing number of tests have to be done, to determine the requirements of new mixes, and naturally further tests are to be done regarding the remaining fatigue life of in-service layers as well.

There is a very rich professional literature available regarding the design and overlay design of asphalt pavements, and generally, of pavements.

There are more robust and more fine methods than the proposed one. As they aim to simplify reality, all models – similar to the presented one – have inevitably a degree of inaccuracy and uncertainty, and the acceptable level of these of a question of wide professional compromise.

5. *Publications of the author*

5.1. Publications related to the theses

(1) **Soós Z., Tóth Cs., Szentpéteri I., Pethő L. (2015)** *„Advanced pavement overlay design using the general mechanistic method"*, Proc. Second International Conference on Infrastructure Management, Assessment and Rehabilitation Techniques, Sharjah, United Arab Emirates. Paper A-2-3 7p.

(2) **Soós Z. (2016a)** *„A tervezési forgalom meghatározásának vizsgálata sztochasztikus módszerekkel"* (Stochastic analysis of the method to determine design traffic), Az Aszfalt: a Magyar Aszfaltipari Egyesülés (HAPA) Hivatalos Szakmai Lapja 20:(1) pp. 15-23. (in Hungarian)

(3) **Soós Z., Igazvölgyi Zs., Tóth Cs., Pethő, L. (2016)** *„Mechanistic Asphalt Overlay Design Method for Heavy Duty Pavements",* Road and Rail Infrastructure IV, Proceedings of the Conference CETRA 2016, Sibenik, Croatia. pp. 173-179.

(4) **Soós Z. (2016b)** *„A forgalomfejlődés becslésének módszertana a valós forgalom tükrében"* (Analysis of the method to estimate of traffic growth with regard to realised traffic), Közlekedéstudományi Szemle 66:(5) pp. 28-40. (in Hungarian)

(5) **Soós Z., Bóka D., Tóth Cs. (2016)** *„Determination of Load Equivalency Factors by Statistical Analysis of Weigh-In-Motion Data"*, The Baltic Journal of Road and Bridge Engineering 11:(4) pp. 266-273. DOI: doi:10.3846/bjrbe.2016.31

(6) **Soós Z. (2016c)** *„A nehézgépjármű-forgalom jellemzőinek elemzése az aszfaltburkolatú útpályaszerkezetek méretezéséhez történő felhasználásra"* (Analysis of the properties of heavy traffic for use in pavement design), Útügyi Lapok: A Közlekedésépítési Szakterület Mérnöki és Tudományos Folyóirata 8, Paper 6. (in Hungarian)

(7) **Soós Z., Tóth Cs. (megj. alatt)** *„Simple overlay design method for thick asphalt pavements based on the method of equivalent thicknesses",* Periodica Polytechnica Civil Engineering, Online First (2017) paper 9721. DOI: 10.3311/PPci.9721

(8) **Soós Z. (megj. alatt)** *„Consideration of Temperature at the Moduli of Asphalt Layers for a Suggested Mechanistic Overlay Design Method"*, Pollack Periodica: An International Journal for Engineering and Information Sciences. (Accepted.)

(9) **Soós, Z. (megj. alatt)** *„Aszfaltkeverékek hasító-húzó fárasztási vizsgálata és az eredmények feldolgozásának lehetőségei"* (The indirect tensile fatigue test of asphalt mixes and the possibilities to interpret the results), Az Aszfalt: a Magyar Aszfaltipari Egyesülés (HAPA) Hivatalos Szakmai Lapja (Accepted manuscript.) (in Hungarian)

5.2. Other publications in the field of the research

(10) **Tóth C, Pethő L, Geiger A, Soós Z. (2016) „***Performance Assessment of hot mix asphalt with chemically stabilized rubber bitumen"*. In: Karel Suchý, Jan Valentin, Mike Southern, Carsten Karcher, Helene Odelius, Jean-Paul Michaut, Frederique Cointe (szerk.) Proceedings of the 6th Eurasphalt & Eurobitume Congress. Konferencia helye, ideje: Prága, Csehország, 2016.06.01-2016.06.03. Praha: Czech Technical University in Prague ISBN:978-80-01-05962-3

(11) **Tóth C, Soós Z. (2016)** *„A "fenntartható" útpályaszerkezetek: Környezettudatosan tervezett útburkolatok és közutak*" ("Sustainable" pavements: sustainably designed pavements and roads). Innotéka Mélyépítés 2:(2) pp. 4-7 (in Hungarian)

(12) **Igazvölgyi Z, Soós Z. (2015)** *„Aszfaltkeverékek vízáteresztő képességének laboratóriumi vizsgálata"* (Laboratory analysis of asphalt mix permeability). Az Aszfalt: a Magyar Aszfaltipari Egyesülés (HAPA) Hivatalos Szakmai Lapja XX:(2) pp. 72-77. (in Hungarian)

(13) **Igazvölgyi Z, Soós Z. Tóth C. (2015)** *„Víz az útpályaszerkezetben"* (Water in pavements). Útügyi Lapok: a Közlekedésépítési Szakterület Mérnöki és Tudományos Folyóirata 2, Paper 7. (in Hungarian)

(14) **Soós Z, Parrag F. (2015)** *„Teljesítményelvű útügyi beruházási szerződések II. rész: a német példa"* (Performance based road contracts part II: the German example). Útügyi Lapok: a Közlekedésépítési Szakterület Mérnöki és Tudományos Folyóirata 2015:(5) pp. 1-15 (in Hungarian)

(15) **Soós Z. (2015)** *„Cellulózrost alapú modifikáció hatása az aszfaltkeverék teljesítményére"* (The effect of cellulose based modification on the performance of asphalt mixes). Az Aszfalt: a Magyar Aszfaltipari Egyesülés (HAPA) Hivatalos Szakmai Lapja XX:(2) pp. 55-59. (in Hungarian)

(16) **Tóth C, Soós Z. (2015)** *„The effect of VIATOP® plus FEP on the stiffness and low temperature behaviour of hot mix asphalts"*. Építőanyag 67:(4) pp. 126-131.

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