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DEVELOPMENT OF A DESIGN CATALOG FOR BONDED CONCRETE OVERLAYS IN THE REGIONAL ROAD NETWORK

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Abstract

This paper describes the development of a design catalog for the design of bonded concrete overlays (whitetopping) for existing asphalt roads in the regional road network of Austria. For the underlying calculations of stresses and strains due to traffic loads, different finite-element models with multiple layers were used. Thereby, a large variety of important input parameters were taken into account, such as the condition of the existing pavement, described by its residual bearing capacity. The influence of different climatic conditions over the course of a year to the material properties of the pavement-layers (Young's moduli) and the bonding properties between the existing asphalt and the new concrete layer were also considered. The calculation of stresses due to temperatur loads (curling stresses) were estimated by using the revised Eisenmann's model [1]. Based on the determined stresses in the concrete layer due to traffic and temperature loads, a new performance-based design method was used for the implementation of a proper failure criterion and the calculation of the technical service life of the modelled whitetopping pavements. In a further step, the required layer thicknesses of the concrete overlay were determined, depending on the length and the width of the concrete slabs as well as the residual bearing capacity and the remaining thickness of the existing asphalt layers. This allowed the development of different proposed designs for whitetopping-pavements, each with defined layer thicknesses, which were finally summarized into a design catalog. The development of this design catalog and the usage of the proposed pavements will enable a simple but realistic design of whitetopping-overlays on existing asphalt pavements.

Keywords: bonded concrete overlays, whitetopping, design catalog

1 Introduction

The existing Austrian provincial and municipal road network was built as hot mix asphalt (HMA) pavements almost without exception. The usual rehabilitation measure of these HMA roads comprises partial milling of the existing asphalt layers and the subsequent replacement with new HMA layers. However existing, distressed asphalt pavements can also be overlaid with a new concrete layer. This economical rehabilitating measure is called whitetopping. The existing pavement is used as a foundation for the new concrete layer, whereby the existing and distressed asphalt layer is usually milled off to a defined milling depth, which depends on the detected crack depth in the existing HMA layer. Whitetopping slabs are usually constructed with smaller layer thicknesses than conventional concrete slabs. Due to this, higher traffic load stresses occur and therefore smaller joint spacings have to be considered. Whitetopping overlays can also be classified into bonded and unbonded constructions. While unbonded whitetopping overlays act on its own, the bonded whitetopping-over-

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lays use the residual bearing capacity of the HMA layer. In Austria, pavement standards from design catalogs are used for the dimensioning of road pavements, which are summarized in tabular form in the directive RVS 03.08.63 [2]. Depending on the pavement type (e.g. flexible or rigid pavements), the layer structure, the layer properties and the expected traffic load (by classification into different load classes), suitable standard construction types with defined layer thicknesses are proposed in these design catalogs. For the design of whitetopping pavements, however, no design catalogs or dimensioning guidelines have existed so far. So, the goal of this work was to develop a design catalog for standardized bonded whitetopping pavements for rehabilitating low-ranked HMA roads.

The design calculations as a basis for the definition of standardized whitetopping pavements as well as their summary in a design catalog were realized by applying a new performance-based design method for bonded whitetopping overlays [3]. In addition to various structural parameters (residual load-bearing capacity of the existing pavement, concrete slab dimensions, remaining asphalt layer thickness, etc.), the stresses in the concrete layer due to traffic load and due to temperature impact (curling stresses) are the most important input parameters into this new design method. The calculation of these types of stresses is described in sections 3.1 and 3.2. The derivation of design diagrams from the results of the design calculations is described in section 3.3. The use of these design diagrams for the determination of required concrete layer thicknesses and for the definition of pavement standards for whitetopping overlays as well as their summary in a design catalog is shown in section 3.4.

2 Consideration of traffic loads

2.1 Determination of the decisive traffic load

The knowledge of the decisive traffic load is one of the central aspects for the design of road pavements. In Austria, the traffic load is calculated according to the guideline RVS 03.08.63 [2] as the expected number of load cycles N_{imp} occurring during the design life. N_{imp} describes the equivalent number of transitions of a standard axle load of 100 kN and is determined by Eqn. (1):

$$N_{imp} = N_{daily} \cdot R \cdot V \cdot S \cdot 365 \cdot n \cdot z \tag{1}$$

Where:

N_{daily} - Number of average daily standard load cycles [-],

R - Factor related to the distribution of heavy traffic vehicles to different driving directions

V - Factor related to the distribution of heavy traffic vehicles tracks to several lanes [-],

S - Factor considering the loading distribution of vehicle tracks within one lane [-],

n - Design life [a],

z - growth factor [-].

2.2 Allocation to load classes

Depending on the determined N_{imp} value, an allocation to a dedicated load class is subsequently made. The different load classes are defined in the guideline RVS 03.08.63 [2]. Each load class (LC) describes a category of technically equivalent pavements that can resist a defined number of traffic loads (expressed as equivalent number of transitions of a standard axle load of 100 kN) until structural fatigue theoretically occurs. A standard pavement with a load class of LC10 is designated to resist approx. 10 million standard load cycles, a pavement with a load class of LC4 can resist approx. 4 million standard load cycles. In the course of the development of a design catalog for whitetopping pavements, the load classes LC10, LC4, LC1.3 and LC0.4 were considered. These are load classes of HMA pavements that are common in Austria's low-ranking provincial and municipal road network.

3 Development of pavement standards

3.1 Determination of traffic load stresses

The traffic load stresses occurring in the concrete layer were determined by calculations with three-dimensional finite element models of whitetopping pavements. Thereby road pavements were modelled, which consisted of whitetopping concrete slabs, an HMA layer, an unbound base course and the subgrade. The individual layers of the modelled whitetopping pavements were characterised in the FE models with associated values for the stiffness (Young's modulus), density and Poisson's ratio.

3.1.1 Modelling of the concrete layer

Since concrete exhibits elastic behavior, the concrete properties were characterised just by the Young's modulus and the Poisson's ratio. The respective values for the mechanical properties were taken from a material database for different types of concrete that are often used in Austrian road constructions [4].
The modelled concrete slab dimensions are derived from two-lane cross section widths with sealed carriage ways of 6.0 m, 7.0 m and 8.0 m of the regional road-network. In order to avoid longitudinal joints directly in the area of usual wheel tracks, the slab width B was chosen to be half the width or quarter the width of the sealed carriage way. The slab lengths L of the respective concrete slabs were recalculated from the respective slab widths B by applying an L/B ratio of 1.0 and 1.5. In the case of a rectangular slab geometry, the longer dimensions were always applied in the driving direction. A list of the modelled slab dimensions L and B can be seen in Table 1. Each of these concrete slab geometries was simulated with slab thicknesses of 8 cm, 12 cm, 16 cm and 20 cm.

Table 1 Overview of slab lengths L and slab widths B of the modelled concrete slabs

		Slab lenght L [m]										
		1,5	1,75	2,0	2,25	2,625	3,0	3,5	4,0	4,5	5,25	6,0
Slab width B [m]	1,5	x			x							
	1,75		x			x						
	2,0			x			x					
	3,0						x			x		
	3,5							x			x	
	4,0								x			x

3.1.2 Modelling of the asphalt layer, the unbound base course and the subgrade

Due to the thermo-viscoelastic material properties of asphalt, the Young's modulus of the HMA layer was varied depending on four different seasonal climate periods. To consider the seasonally variation in stiffnesses of the underlying layers, the Young's moduli of the unbound base course and the subgrade were also varied.

During the modelling procedure, whitetopping pavements with varying HMA layer thicknesses were generated. Each concrete slab geometry from Section 3.1.1 was modelled with a thickness of the underlying remaining HMA layer of t = 5 cm, 10 cm and 15 cm. In difference to the variation of HMA and concrete layer thicknesses, the thickness of the unbound layers (t = 50 cm) and the subgrade (t = 150 cm) remained unchanged in each of the modelled whitetopping pavements.

The impact of the residual bearing capacity of the existing pavement to the technical service life of the modelled whitetopping pavements was taken into account by applying three different values for the residual bearing capacity (50 %, 70 % and 100 % of the original bearing capacity). These three percentage values were implemented in the modelling procedure by an additional variation of the Young's modulus of the HMA layer, the unbound layer and the subgrade.

3.1.3 Modelling the bonding conditions between concrete and HMA layer

The use of the new performance-based design method for bonded whitetopping overlays allowed the consideration of temperature-dependent bonding conditions between the new concrete and the existing HMA layer within the design calculations [5]. The consideration of these bonding properties was done within the FE modelling of whitetopping pavements by using the cohesive-zone-model (CZM) [3]. The model parameters of the CZM were also varied depending on the four seasonal climate periods mentioned above.

3.1.4 Modelling of the traffic load

The traffic load simulated in the FE models was applied as a load in the form of a single axle with a standard axle load of 100kN. The load transfer of this axle load was modelled by two equally loaded, circular contact areas located at the central edge of a slab, each with a surface pressure of 0.7 N/mm².

3.2 Determination of curling stresses

The determination of the resulting curling stresses due to unequally heating of the top and the bottom of the concrete slabs was carried out using Eisenmann's theory, revised by Houben [1, 6]. In order to consider the variating temperature gradients in the slab over the course of the year, the year was divided into six characteristic periods with approximately uniform climatic conditions. For each of these six periods characteristic values for the temperature gradients, which were developed in [7], were applied.

3.3 Design calculations

Based on the determined traffic load stresses and curling stresses, design calculations were done by applying the new design method to determine the maximum number of transmissible load cycles N_{res} until structural fatigue theoretically appears. Thereby, the concrete fatigue behaviour is described by Smith's fatigue criterion [1].

The results of these design calculations were summarised in design diagrams. Using regression analyses, the curve of the maximum transferable number of load cycles was determined and illustrated as a function of the concrete slab thickness, the HMA layer thickness and the residual load-bearing capacity of the existing pavement. Figure 1 shows an example of a design diagram for whitetopping concrete slabs with a slab length of 2.0 m and a slab width of 2.0 m.

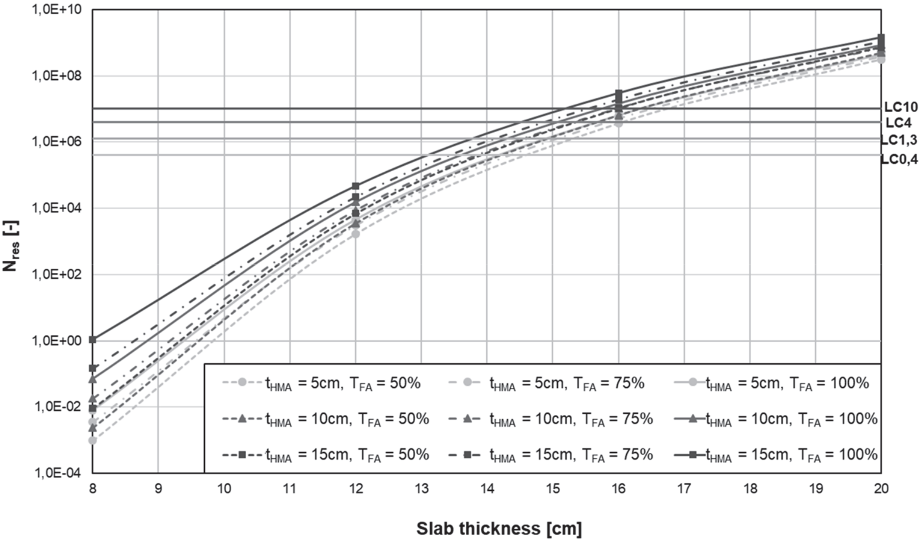

Figure 1 Design diagram with dependency between estimated design life, slab thickness, HMA thickness (t_{HMA} = 5 cm, 10 cm and 15 cm) and the residual bearing capacity (T_{FA} = 50 %, 70 % and 100 %) for a slab length and width of 2.0 m

3.4 Development of a design catalog

By applying the design diagrams from Section 3.3, the required whitetopping concrete layer thicknesses were determined. From this, appropriate whitetopping standard pavements for typical load classes (see Section 2.2) and sealed carriageway widths (6.0, 7.0 and 8.0 m) were defined and summarized in a design catalog.

Within the FE simulations and the design calculations, a large number of possible combinations with varying amounts of design-relevant structural parameters, such as different concrete slab dimensions, HMA layer thicknesses and residual bearing capacities, were investigated. As part of the definition of standard pavements and their summary in a design catalog, a limitation was made to a few, fixed basic values of these parameters. The standard whitetopping pavements proposed in the design catalog respectively the required concrete layer thickness, assume a residual bearing capacity of ≥ 70 %, an HMA layer thickness of 5 cm and concrete slab widths of either 3.0, 3.5 or 4.0 m. Furthermore, the ratio of concrete slab length L to concrete slab width B must be between 1.0 and 1.5 (see Figure 2).

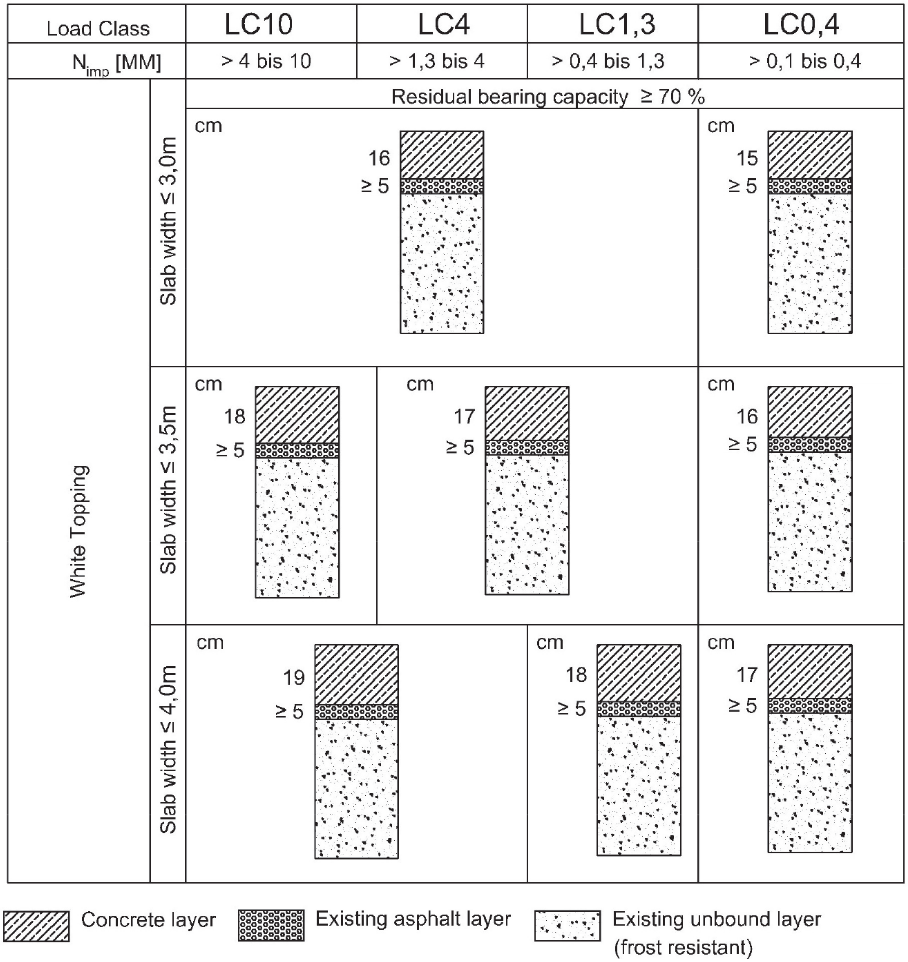

Figure 2 Developed Design catalog for bonded whitetopping pavements

3.5 Adjustment of the required concrete layer thickness due to deviating structural parameters

If structural parameters occur that deviate from the specified basic parameters from Section 3.4 or Figure 2, the required concrete layer thickness of the standard structures from the design catalog must be adjusted according to the following Table 2.

Table 2 Adjustment of slab thickness due to deviating structural parameters

	Increased / reduced thickness of the concrete layer [cm]	**Changes applicable for load class**
	Joint spacing	
Slab width 1,5 m (sealed carriage way 6 m)	-1.0	LC0.4, LC1.3, LC4, LC10
Slab width 1,75 m (sealed carriage way 7 m)	-1.0	
Slab width 2,0 m (sealed carriage way 8 m)	-2.0	
	Remaining thickness of the existing HMA layer	
< 5 cm	Not permissible	LC0.4, LC1.3, LC4
5 cm - 15 cm	0	
≥ 15 cm	-1.0	
	Residual bearing capacity	
< 50 %	Not permissible	LC0.4, LC1.3, LC4, LC10
50 % - 69 %	+1.0	
70 % - 100 %	0	

4 Conclusion

Based on finite-element models of whitetopping pavements, performance-based design calculations were done for a variety of different concrete slab geometries and varying structural parameters (HMA layer thickness, residual bearing capacity of the existing pavement, temperature-dependent concrete-asphalt bonding properties, etc.) and design diagrams were derived. By evaluating these design diagrams for typical load classes used in Austria's regional road network, it was possible to define standard pavements for bonded whitetopping overlays and to summarize them in the form of an easy-to-use design catalog.
This allows to select the required concrete layer thickness depending on the load class, the thickness of the remaining HMA layer, the residual bearing capacity of the existing pavement and the projected width of the concrete slabs.
If the properties of the existing pavement deviate from those in the design catalog, the required concrete layer thickness can be adapted.

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