AUSTRIAN PAVEMENT DESIGN METHOD

A CRITICAL REVIEW

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PAVEMENT DESIGN METHOD

AUSTRIAN PAVEMENT DESIGN CATALOGUE (RVS 08.03.63)

• 1986 Standardized pavement structures for bituminous and concrete pavements (1st version)
• 1998 Modification of underlying analytical design procedure & extension by load classes for highest level of traffic (completely revised version published March 1998)
• 2005 New lower load class & addition of block pavements and slabs, updating according to new material standards (completely revised version published in May 2005)
• 2008 Updating according to new EN material standards for stabilized and asphalt layers, small revisions in respect to requirements to slab pavements (revised version of edition 2005 published in April 2008)
PAVEMENT DESIGN METHOD

OUTLINE OF THE DESIGN CATALOGUE (RVS 3.63)

- Calculation of design traffic load & attribution to load classes (olad class S – highest to VI – lowest)
- Standardized construction types
  - 4 bituminous construction types
  - 2 concrete construction types
  - 2 block pavement construction types
- Standardized minimum bearing capacity at formation level \((E_v \geq 35 \text{ MN/m}^2)\)
- Background: Analytical design calculations

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Generally the relevant traffic load - expressed in Design ESAL's (= DESAL's) - is determined by means of the following formula:

\[
\text{DESAL} = \text{ESAL}_{\text{day}} \cdot R \cdot V \cdot S \cdot 365 \cdot n \cdot z
\]

- \( \text{ESAL}_{\text{day}} \) average daily standard load applications (passages of the 100 kN standard axle load) across the entire cross-section at the time the road is opened to traffic.
- \( R \) factor for considering traffic direction (\( R = 0.5 \) if traffic is equally distributed on the two directions).
- \( V \) factor according to number of lanes per direction (\( V = 1.0 \) for 1 or 2 lanes per direction; \( V = 0.9 \) if lanes per direction \( \geq 3 \)).
- \( S \) factor for distribution of wheel tracking in one lane.
TRAFFIC LOAD CALCULATION

Average daily standard load applications ESAL\text{day}

- either if the annual average daily traffic AADT\text{cv,i} of vehicle type i across the entire cross-section is known at the time the road is opened to traffic:

\[ ESAL_{\text{day}} = \sum_i \left( AADT_{\text{cv,i}} \cdot ACV_{i} \right) \]

where \( ACV_i \) is the mean equivalency factor of vehicle category \( i \)

<table>
<thead>
<tr>
<th>representative heavy vehicle category ( i )</th>
<th>( ACV_i ) Vehicle equivalency factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>truck</td>
<td>0.70</td>
</tr>
<tr>
<td>truck with trailer, semi-trailer</td>
<td>1.20</td>
</tr>
<tr>
<td>bus</td>
<td>0.60</td>
</tr>
<tr>
<td>low-floor bus, in urban public transport</td>
<td>0.80</td>
</tr>
<tr>
<td>articulated bus, in urban public transport</td>
<td>1.40</td>
</tr>
</tbody>
</table>

- or if data from traffic counts do not differentiate between vehicles of different vehicle categories:

\[ ESAL_{\text{day}} = AADT_{cv} \cdot ACV \]

where AADT\text{cv} is the annual average daily traffic of commercial vehicles (trucks, etc. and busses within a 24-hour period, all days) across the entire cross-section at the time the road is opened to traffic

<table>
<thead>
<tr>
<th>road category</th>
<th>( ACV ) equivalency factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td>1.0</td>
</tr>
<tr>
<td>Other roads</td>
<td>0.9</td>
</tr>
</tbody>
</table>
TRAFFIC LOAD CALCULATION

Shift factor $S$
Taking into account the distribution of vehicle tracks across a lane

<table>
<thead>
<tr>
<th>width of lane [m]</th>
<th>3.00</th>
<th>3.25</th>
<th>3.50</th>
<th>3.75</th>
<th>≥ 4.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>reduction factor $S$</td>
<td>0.90</td>
<td>0.85</td>
<td>0.80</td>
<td>0.75</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Design period $n$
Design period in years is generally assumed
- 30 years for concrete pavements
- 20 year for all other pavement types

Growth factor $z$
Is generally derived from the results of traffic counts or traffic forecasts.
If no counts or forecasts are available, a mean annual growth rate $p$ of
- $p = 3\%$ is assumed for motorways
- $p = 1\%$ for other roads.

MATERIAL CHARACTERISTICS – NEW CONSTRUCTIONS

DESIGN CALCULATION METHODOLOGY
MATERIAL CHARACTERISTICS – NEW CONSTRUCTIONS

DESIGN CALCULATION METHODOLOGY
Flexible and semi-rigid pavement types
• Linear elastic multi-layer theory
• Sub-grade model taking into account seasonal variation of bearing capacity (4 seasons of different bearing capacity)
• Stiffness of unbound sub-base and unbound base layers determined with respect to the material type and thickness, and to the stiffness of the underlying layer
• Stiffness of cement stabilized layer is considered to be constant during the life time
• Stiffness of asphalt is dependent on representative seasonal temperature distribution in the bituminous bound layer (6 climatic periods / day & night)
• Number of permissible load applications to fatigue damage is calculated for each individual period from the respective material fatigue law
• Summation over the whole year is based on Miner’s law and results in the consumption of life-time per year
• Minimum design life of 20 years

FORMATION LEVEL:
• For computation purposes, the static deformation modulus ($E_{st} = 35$ N/mm$^2$) was transformed into a dynamic modulus of elasticity ($E_{dy} = 2 - 4. E_{st}$).
• Seasonal variations in subgrade strength were taken into account by dividing the year into four different periods with a decrease in the $E_{dy}$ value by 50% during the spring thaw period.

Unbound bases and subbases:
• Depending on the thickness of each layer and the material used (gravel, crushed material, etc.), its dynamic elasticity modulus was stated as a multiple of the modulus of the unbound supporting layer (factor 1.5 to 2.5).
MATERIAL CHARACTERISTICS – NEW CONSTRUCTIONS

LAYER CHARACTERISTICS

Unbound bases and subbases (cont.):
• beside origin materials the following proportions of reclaimed asphalt concrete RAC (crushed or milled granulated asphalt) may be used:
  ➢ subbase up to 100 % RAC
  ➢ base course ≤ 5 % RAC for load classes S - II
    ≤ 50 % RAC for load classes III - VI only
    up to 100 % RAC for construction type 3,
    suitable only for load classes III - VI

Cement-treated base course:
• acc. to of back-calculations, the modulus of elasticity of these layers was stated as a constant 5,000 N/mm² under operating conditions, e.g. in the presence of micro cracks.
• the permissible load repetitions to fatigue damage were calculated by means of a fatigue law derived from backcalculations and comparisons with existing pavement structures.

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MATERIAL CHARACTERISTICS – NEW CONSTRUCTIONS

Hot Mix Asphalt (HMA) STIFFNESS

Bituminous layers:

Stiffness (dynamic modulus \(E_{\text{dyn}}\)) of the bituminous layers was derived from a diagram in the Shell Design Manual for a standard asphalt ("model asphalt") at a given temperature.

\[
\begin{array}{|c|c|c|c|c|}
\hline
T [{^\circ}C] & -20 & 0 & +20 & +40 & +60 \\
\hline
E_{\text{dy}} [{\text{MN/m}^2}] & \times 10^2 & \times 10^3 & \times 10^4 & \times 10^5 \\
\hline
\end{array}
\]

[HELL, 1978]

no representative values were available from laboratory tests at the time the standard was established.
Temperature profile in bituminous layers:

- twelve representative temperature profiles (6 periods per year, day & night) in the bituminous layer are taken into account for Austria
- two climatic regions are considered (inner alpine region – zone I, outer alpine region – zone II)
- Stiffness (dynamic modulus) of the model asphalt is derived for each layer from the temperature profile and used for the design calculations

**Material Characteristics – New Constructions**

### Temperature

- bituminous layer temperature [°C]
- depth [cm]

**Design Calculation**

- Pavement Model
- Strength Hypothesis
- HMA Fatigue
- Effective Strain
- Stress/Strain calculation under standard axle (100 kN)

**Allowable Load Repetitions** $N_{allowable}$
MATERIAL CHARACTERISTICS – NEW CONSTRUCTIONS

STRENGTH HYPOTHESIS

- Different fatigue mechanism:
  3D stress/strain field $\leftrightarrow$ 2D stress in lab (fatigue test)

- Concept of effective stress $\sigma_{eff}$/strain $\varepsilon_{eff}$:
  modified shear stress hypothesis acc. to [LEON, 1934] and
  [HAGEMANN, 1980]: LEON'sche Parable

$$\sigma_{eff} = f(\sigma_1, \sigma_3, c(T))$$

$$c = \frac{\sigma_1}{\sigma_2} \left( \frac{72.7749 - T}{32.8565} \right)^{1.583}$$

HMA FATIGUE LAW

- Adapted fatigue law acc. to [KENIS et al., 1982]

$$N_{allowable} = k_1 \left( \frac{1}{\varepsilon_{v}} \right)^{k_2}$$

$$k_1(T) = k_1(70) \cdot 10^{(0.0899(T-70)-0.0025817(T-70)^2)}$$

$$k_2(T) = k_2(70) - 0.01349 \cdot (T - 70) + 0.0004624 \cdot (T - 70)^2$$
For a correct application of the specified standardised pavements, however, the following additional conditions must also be considered:

- The thicknesses specified for the different pavement types (flexible, semi-rigid and rigid) apply only in the case of (completely) new construction, not in the case of stage by stage construction. In the latter case, material fatigue occurring during the first loading phase must be taken into account in designing the second construction stage.
- The fundamental conditions regarding the required minimum bearing capacity of the subgrade and the unbound courses must be strictly complied with.
- Special attention must be paid to ensuring full bonding of bituminous pavement courses in bituminous structures as calculations are based on the assumption of one fully bound asphalt package.
- On sections exposed to slow-moving heavy traffic, e.g. before intersections, on uphill sections, the material of the asphalt courses must conform to special requirements (deformation resistance).
AUSTRIAN STANDARD FOR OVERLAY DESIGN
RVS 03.08.63 (1992)

Three different methods applicable:

- Determination of the effective layer thickness (empirical method)
- Deflection method (semi-empirical method)
- Backcalculation on basis of FWD measurements (analytical method)
MATERIAL CHARACTERISTICS – RECONSTRUCTION

EFFECTIVE LAYER THICKNESS

Austrian method utilizes The Asphalt Institute condition information from visual inspections to compute the effective thickness of the in situ pavement using the equation:

\[
D_{\text{eff}} = \sum d_i c_i
\]

where:

- \( D_{\text{eff}} \) = total effective HMA thickness of existing pavement
- \( d_i \) = thickness of pavement layer \( i \)
- \( c_i \) = HMA conversion factor for pavement layer \( i \)

The required overly thickness \( D_{\text{overlay}} \) can be calculated from

\[
D_{\text{required}} = D_{\text{eff}} + D_{\text{overlay}}
\]

\[
D_{\text{overlay}} = D_{\text{required}} - D_{\text{eff}}
\]

\( D_{\text{required}} \) = required HMA thickness according to RVS 03.08.63 (Austrian Design Catalog) for the remaining design period

HMA conversion factor \( c_i \) for pavement layer \( i \) according to the Austrian overlay design method:

<table>
<thead>
<tr>
<th>HMA condition</th>
<th>HMA conversion factor ( c_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>asphalt surfaces and bases that show extensive cracking, considerable raveling or aggregate degradation and lack of stability</td>
<td>0.3 to 0.5</td>
</tr>
<tr>
<td>Asphalt concrete surface that exhibit appreciable cracking and crack patterns</td>
<td>0.5 to 0.7</td>
</tr>
<tr>
<td>Asphalt concrete surface that exhibit some fine cracking, have small intermittent cracking patterns in the wheel paths but remain stable</td>
<td>0.7 to 0.9</td>
</tr>
<tr>
<td>Asphalt concrete surface generally uncracked</td>
<td>0.9 to 1.0</td>
</tr>
</tbody>
</table>
MATERIAL CHARACTERISTICS - RECONSTRUCTIONS

DEFLECTION METHOD

Factor influencing actual surface deflection

- Traffic load
- Temperature
- Water content in un-bound layers and ground
- Fatigue
- Cracking
- Aging
- Layer type & thickness
- Compaction
- Layer bounding

Road Bearing Capacity

Road condition

Road structure

- Measurement point
- Loading
- y_c = 34 cm
- Unloading

Static deflection measurement – Benkelman beam
**MATERIAL CHARACTERISTICS – RECONSTRUCTIONS**

**DEFLECTION METHOD**

Calculation of effective deflection

\[
d_m = c \cdot (\bar{d} + k \cdot s)
\]

- \(\bar{d}\): mean value of measured deflections
- \(s\): standard deviation of measured deflections
- \(d_m\): effective deflection
- \(c\): correction factor for measurements outside the frost and thaw period between 1.3 and 2.0
- \(k\): correction factor to consider the statistical distribution of the deflection measurements (confidence interval)

<table>
<thead>
<tr>
<th>Load class</th>
<th>I, II</th>
<th>III</th>
<th>IV, V</th>
</tr>
</thead>
<tbody>
<tr>
<td>(k)</td>
<td>2.0</td>
<td>1.6</td>
<td>1.3</td>
</tr>
</tbody>
</table>

**RECONSTRUCTION - OVERLAY DESIGN**

**DEFLECTION METHOD**

Calculation of required overlay

\[
d_m \text{ [1/100mm]}
\]

- min. overlay 4 cm
- no overlay

DESAL [-]
Falling Weight Deflector FWD MEASUREMENTS

dynamic deflection measurement

backcalculation of pavement layer stiffness

E-Modul [MPa]

Stationierung [km]
RECONSTRUCTION - OVERLAY DESIGN

ANALYTICAL OVERLAY DESIGN

Long term test

Material fatigue

Material stiffness

Pavement model

FWD backcalculation

PAVEMENT LIFE

PROBLEMS/POSSIBLE IMPROVEMENTS OF PAVEMENT DESIGN

Critical Review & Improvements
Critical Review of current Austrian Pavement design method

- Design traffic load is not based on modern Weight-In-Motion (WIM) technology allowing to take into account specific axle and gross weight data of HGV's.
- Vehicle equivalency factors the ESAL concept are not state of the art anymore since advanced computing capacities and computing speed facilitate the consideration of different vehicle classes and axle load distributions to assess stresses and strains in pavement layers.
- Due to the consideration of just one representative HMA material behaviour ("model asphalt") in the design calculations neither modified HMA nor innovative HMA concepts are taken into account.
- Modern performance based bitumen and HMA test methods to assess stiffness and material fatigue are disregarded.

- The method permits the calculation of a "theoretical structural" life time and therefore is capable to assess different pavement structures in this respect. A link to the "real" life time is missing.
- Only the classical failure criteria "bottom down fatigue cracking" is facilitated. However, different failure modes such as top down cracking or rutting also effect the practical pavement life time.
- No Life Cycle Cost Analysis (LCCA) is included in the given design concept and different pavement types are only evaluated on the basis of their ESAL bearing capacity.
- The Effective Thickness concept for overlay design is rather imprecise and should be strictly restricted to low volume roads.
- The static deflection method (Benkelman beam) uses very empirical correction factors for the measured deflections with a broad variation of possible values.
PROBLEMS/ POSSIBLE IMPROVEMENTS OF PAVEMENT DESIGN

Some of this topics are subject of the on-going revision of Austrian pavement design method

Thank you for your attention!