SEMI-FLEXIBLE PAVEMENT SYSTEMS FOR HEAVY DUTY PAVEMENT SECTIONS

Pavement Design Methodology

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Table of contents

1. Introduction

Pavement designs can be carried out using a number of alternative design methods. Based on the input details required the commonly used design methods can be categorised in the following levels:

- Design Catalogue
- Design Charts
- Analytical-Empirical Approach

Input to ‘Design Catalogue’ would typically be subgrade strength and traffic loading, both expressed as intervals. ‘Design Charts’ would typically be more flexible towards actual subgrade and actual number of load applications, whereas the materials would still be standard. In the ‘Analytical-Empirical Approach’ (sometimes referred to as ‘Mechanical-Empirical Approach’) all input would be variable, both in regard to the materials and the loads.

Going from ‘Design Catalogue’ to ‘Analytical-Empirical Approach’ will then imply a rise in demands of input parameters. As more input can be based on the actual condition on the site the more optimum the pavement design (and hence the layer thicknesses). Among the advantages in using the ‘Analytical-Empirical Approach’ can be mentioned; use of available non-standard materials (avoiding long hauling of standard quality materials), design to the actual and non-standard loads (type, odd-size and applications) and stage construction design.

Today’s computer capabilities are well advanced and numerous software has been developed, enabling the pavement design to designer and compare many structure in a relatively short time.

The ‘Analytical-Empirical Approach’ is well suited for semi-flexible pavement systems, taking into account the special material properties, and can be applied to pavement structures throughout the world.

The purpose of this design manual is to help collect the needed information to enable a proper design according to the ‘Analytical-Empirical Approach’. Each individual design input is shortly described below. In appendix A is given a summary of information needed. This can be filled out by the client and engineer/sale person and subsequently sent/faxed to Densit, enabling a quick reply on the pavement design.

Finally it should be noticed that any pavement selection should be base on technical performance, economical consequences (life-cycle-costs) and construction condition (such as timeframe, contractors etc.).

2. Analytical-Empirical Design Approach

The 'Analytical-Empirical Approach' encompasses two separate steps:

1. calculation of pavement responses under loading
2. calculation of pavement performance in reference to the responses

The calculation of pavement responses (stresses, strains, deflections) under traffic loads are carried out be applying theory of elasticity, while the pavement performance is evaluated by using empirical relationships (derived in situ or through laboratory tests) between response and rate of deterioration. Miner's law, [1], is then used to sum the damages caused by different combinations of loading and environmental conditions.

The two steps (actual responses and permissible responses) are illustrated in the figure below.

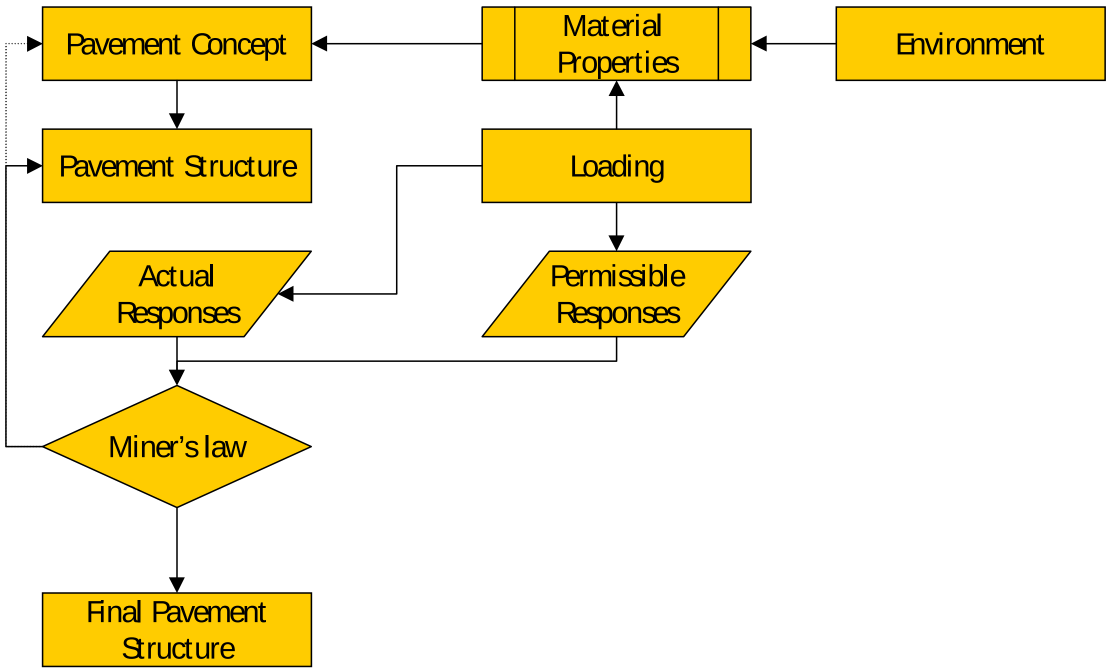

Figure 1 Illustration of the analytical-empirical design approach

The Analytical-Empirical is specially suited in situations where; loads are non-standard, materials are non-standard, and where there is a need for super optimisation of the pavement structure. The state-of-the-art software on the market makes it possible to analyse even rather complex multi-layer pavement systems.

3. Pavement System

The model of the pavement system is illustrated in the figure below.

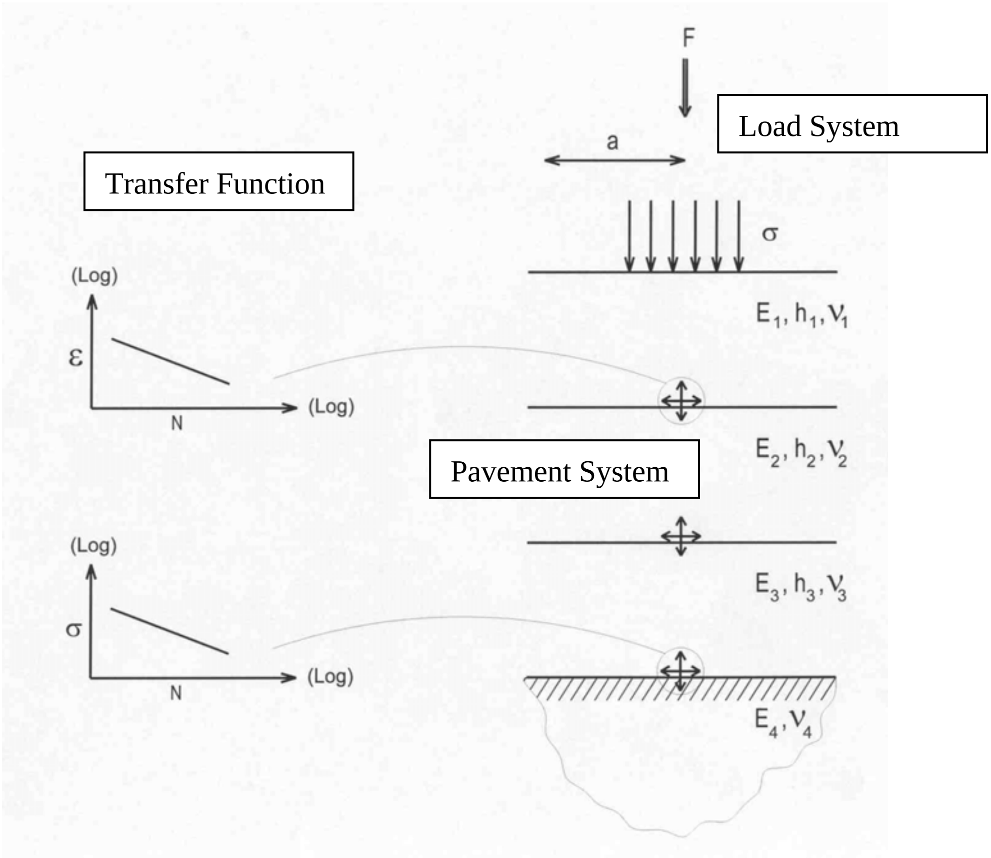

Figure 2 Pavement Model

As illustrated the system is described by; elasticity modulus (E), layer thickness (h) and Poisson's ratio (ν).

For design of a new pavement structure the layer thicknesses are determined, while in studies of bearing capacity the materials properties are computed. In maintenance and rehabilitation projects both the properties of the existing pavement structure and the thicknesses of need new layers are computed.

3.1 Material properties

As important input to the design care should be taken for the properties of the materials. The design is rather insensitive to the Poisson's ration (which would normally be described by values between 0.2 and 0.4), while it is rather sensitive to the elasticity modulus.

Depending on the material the properties would be dependent on factors such as temperature, load frequency and water content (season). For instance the properties of asphalt concrete, being a visco-elastic material is heavily dependent on the load frequency (velocity of the load), which is one of the reasons that asphalt (as wearing course or base course) is not suitable for pavement structures with static or quasi-static loads. Semi-flexible pavement materials, such as Densiphalt, show similar load frequency dependencies.

It is hence important to note whether the load is applied to the pavement at a normal frequency (assumed to be >50 km/h) or at a much lower speed (<5 km/h).

Further, for both flexible and semi-flexible pavement materials the properties are dependent on air temperature. This is normally handled through adoption of standard regional design temperatures.

Finally attention to the drainage structure should be provided, as the strength of for instance unbound base and subbase materials can vary with a factor 2-3 from dry to wet (spring to autumn, [2]). This also illustrates the importance of providing a suitable and effective drainage.

In the table below ranges of moduli of pavement materials typically used in designs are given.

Type	Material	Normal load frequency	Low load frequency
Bound	Densiphalt	8,000-9,000	4,000-4,500
	Cement Concrete	30,000-40,000	
	Asphalt Concrete	2,000-5,000	600-1,500
	High Modulus Asphalt	6.000-7,000	2,000-3,000
	Concrete blocks	1,500-2,500	
	Cemented base, intact	5,000-7,000	
	Cemented base, cracked	1,500-3,000	
Unbound	Macadam	700-1,000	
	Crushed Concrete	400-600	
	Gravel Base	200-400	
	Subbase (sand)	100-150	
Subgrade	Clayey	10-30	
	Sandy	40-70	

Table 1 Typical material properties, given in MPa (N/mm^2), 25°C

For unbound materials the strength is often expressed in CBR value (%). In countries which have adopted the principles of the AASHTO Design Guide the strength could also be expressed as layer coefficients (a-value). There is a vast of relationships in the literature (see for instance [1]) correlating CBR values and layer coefficients to material moduli. The pavement designer would make this conversion.

It should be noted that the material properties should represent the lower 10 or 25 percentile depending on the regional practise. Further the properties should represent an average for a one-year cycle. Alternatively an incremental-recursive design method need to be applied simultaneously. This adds significant complexity to the design, and is normally avoided.

The material properties for each particular design situation would normally be assessed by the pavement design engineer based on information from the client, such as:

- type/strength of subbase
- material available
- typical used materials in the region

4. Load System

To enable computation of the responses in the pavement system the load system needs to be defined (see figure 2; F, a and σ).

4.1 Description of loads

The loads are described by:

- Load types
- Number of load application (including growth)
- Load configuration (spacing between loads, a)
- Weight (per axle, per wheel, per gear, F)
- Contact Stress (tyre pressure, massive or air, σ)
- Wander (lateral distribution of loads)

The designer must obtain information on the total number of applications of each particular load. There is no need to convert the actual loads into some equivalent standard (as known for road designs). The number of application should not be the total number, but should be differentiate between the different pavement sections.

For each individual load is given the configuration, i.e. spacing between each load, the weight per load (axle, gear or wheel) and the contact/tyre pressure. In regard to the tyre pressure it is especially important to register whether the tyre is massive rubber or pumped with air.

Design tools applied today can model any load configuration. This is important as different loads, might not overlap due to their configurations.

4.2 Wander

It is important to recognise that the lateral distribution of all loads can be described by a normal distribution (given by its standard deviation). When the load is channelised the wander is set to or close to zero. For wide pavement sections, where loads are more distributed the wander can be as high as 1-2 m. The effect of wander is most predominant for the upper layers in the pavement structure. This is illustrated in the figure below.

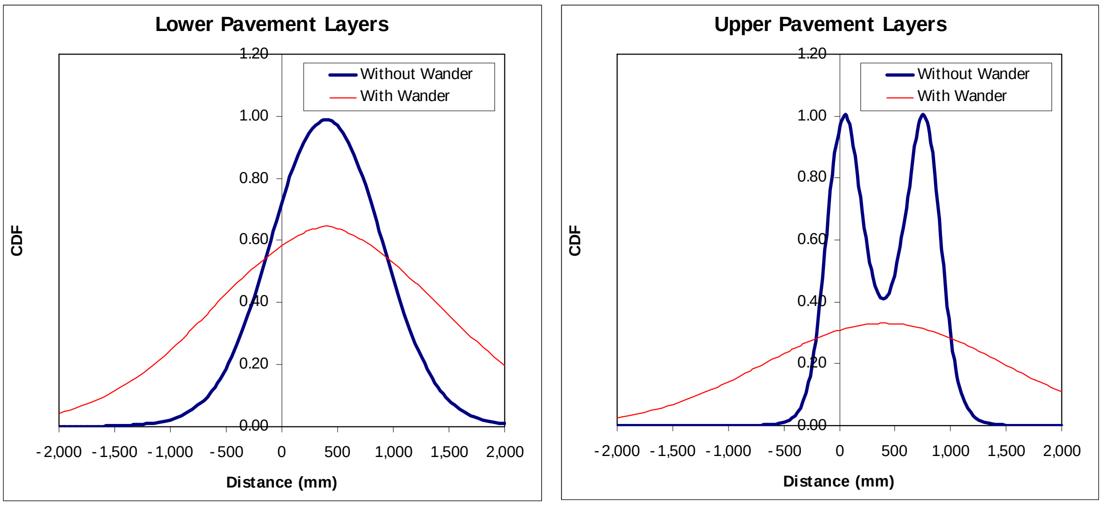

Figure 3 Effect of wander on damage in the structure

When wander is taken into consideration the damage effect on the upper layers can be reduced by a factor 2-3, while the effect on the lower layers would be much smaller. This means that the expensive upper bound layers can be reduced while compensating (increasing) in the less expensive lower unbound layers.

I some literature is used to term “wander zone”, defined as the width of the zone over which the centreline of the load is distributed 75% of the time. The “wander width” can be shown to be equal to 2.3 times the standard variation.

The wander used in the design would be assessed base on information on width of loaded area.

Base on the following information from the client the pavement designer would be able to model the pavement loadings:

- type/description of load
- wheel type
- axle, gear or pay load
- width of loaded area (such as carriageway width)
- vehicle/load speed

5. Transfer Functions

The computed responses from the load will be compared to the permissible responses based on the desired pavement performance (see figure 2). The performance is expressed in the relationship between response and number of load applications, to reach a defined terminal condition (such as percentage of cracking or rut depth).

If available local developed relationships should be used. Alternatively widely adopted international relationships can be applied (se table below).

Material	Developer	Terminal condition	Relationship
Asphalt	Shell, controlled strain, V_B=10%	-	$\varepsilon = -0.000340(E/3{,}000MPa)-^{0.4}(N/106)^{-0.2}$
	Asphalt Institute, V_B=10%, V_v=5%	20% cracking	$\varepsilon = -0.000240(E/3{,}000MPa)^{-0.25}(N/106)^{-0.304}$
Stabilised gravel	French Standard	-	$\varepsilon = DTS_{365} \cdot 0.77(N/106)^{0.067}$, where DTS = Direct Tensile Strength
Unbound	Shell, 85% reliability	-	$\varepsilon = -0.000664(N/106)^{-0.25}$
	TRL, 85% reliability	10 mm	$\varepsilon = -0.000453(N/106)^{-0.253}$
	Asphalt Institute	½ in	$\varepsilon = -0.000478(N/106)^{-0.223}$

Table 2 Transfer functions widely adopted

Please notice that changing transfer function would lead to significant changes in the permissible number of load applications, due to the linear log-log relationship. Caution should be taken by the pavement designer.

6. Literature

[1] Ullidtz, P. “Modelling Flexible Pavement Response and Performance”, Polyteknisk Forlag, 1998

[2] Linell, K.A. et al “Corps of Engineers’ Pavement Design in Areas of Seasonal Frost”, Highway Research Record 33, 1963

Appendix A – Input Sheet for Design of Densiphalt Pavement

Please fax to Densit A/S, + 45 9933 7788

Category	Information	
Pavement Materials	Type/strength of subbase (CBR, a or E)	
	Typical materials used in region	
If rehabilitation project please also indicate	Present pavement structure (materials and thickness)	
	Present pavement condition (surface distresses)	
Loads	Load Type (description)	
	Applications differentiate on pavement sections (per year, week or month)	
	Wheel type (massive or air)	
	Axle or pay load	
	Pavement width (to estimate wander)	
	Speed	

Note: Any other information, such as drawings, pictures etc. could with advantage be included in the fax.