THE PAVERS SYSTEM; A NOVEL APPROACH TO THE DESIGN AND ASSESSMENT OF ROAD, AIRFIELD AND INDUSTRIAL PAVEMENT

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SYNOPSIS

Rigid pavement thickness design is either still based on the classical Westergaard solutions or is based on a more comprehensive finite element rigid pavement model to resolve the shortcomings of the layered elastic Burmister model. The latter gives a principally better representation of the slab edges and joints. However, because of the ability to quickly compute edge stresses, the attractiveness of Westergaard's solutions have never diminished. The classical discrepancy between the Westergaard-Winkler (joints) model and the Burmister model (no joints) can be overcome with a Westergaard-Pasternak model. The Pasternak foundation is a more realistic representation and encompasses the disadvantages of the Westergaard-Winkler or Burmister multi-layer model, while the great advantages of Westergaard's model (edge and corner loading) are maintained. By using closed formed solutions, it is possible to calculate the effect of multiple loads at located at random positions on a slab. For practical use, the pavement models have been implemented a software tool called ‘PAVERS.’ This tool can be used for design and reversed-design purposes for road, airfield and industrial pavement. The reverse-design can be based on FWD surveys. The tool can be used for flexible pavements (with cemented bases) too. However, this paper mainly focuses on rigid pavement design and evaluation.

1. INTRODUCTION

Over the last decades, a lot of progress has been made in the implementing pavement design in a computer environment. The giant leap in computer power has led to the development of comprehensive computer models often developed as a three-dimensional finite element model (3D-FEM). The latter appears to be elaborate, but is too time consuming for use in pavement assessment projects. The need of a practical and parametric design and FWD based assessment tool led to the development of the software tool PAVERS, which is an acronym for PAVement Evaluation and Reporting Strength.

PAVERS is a complete software package for the analytical design and assessment of rigid and flexible pavements. It comprises of (re)design procedures for in-situ FWD testing, laboratory testing, modelling the pavement structure e.g. assessing mechanical pavement properties, residual pavement life and bearing strength assessment. It allows the pavement engineer to define or use calibrated failure criteria for all pavement materials. The effect of different pavement materials, strengths, load or complex load mixes can quickly be explored.

2. PAVEMENT MODELLING

2.1. Design concepts

The basis of any mechanistic pavement design method is the structural pavement models employed. The rigid pavement is modelled as a slab on-grade system. The Pasternak two-parameter foundation was chosen as an attractive alternative for the classical Winkler (k) foundation [1]. The introduction of a horizontal linkage, Pasternak's shear constant (G), in Winkler's model is a remedy for the discrepancies between Westergaard's theory and the multilayer theory, while the great advantages of Westergaard's model (edge and corner loading) are maintained (for G=0, one obtains a classical Winkler foundation). Multiple loads can be placed anywhere on the slab. This model allows (back-)calculation not only at the interior position, but also on the slab's edge position. The closed form mathematical solving technique allows the use of n-number of loads, overcoming the ESWL concept which can be considered as one of the major drawbacks of the Westergaard model. The model allows for load transfer at the slab edge [2].

The Westergaard model is often used for cemented bases too. This conflicts with Westergaards solution which is based on the theory of thin plates: thin against other dimensions means a two-layered structures (slab on an infinite subgrade).
McCouloch’s transformation by computing an equivalent k-modulus is often used, but is only valid when the modulus of the layered materials is far smaller than the Young’s modulus of the concrete. This is obviously not always the case when using cemented bases. A multi-layered slab model should be used instead. Van Cauwelaert’s multi-slab model is based in equivalency of elasticity and allows partial friction at the interfaces of adjacent layers. Thermal gradients also introduce stresses into a slab. Eisenmann’s model seems not to be applicable on layered structures due to the postulation of constant contact of the layers (friction is possible, but full adhesion is a necessity). The theory of the determination of thermal stresses in a single or a multi-layered structure on a Pasternak foundation has been developed by Lemlin et al. [3]. The radii of curvature of the different layers can be different (variable gradient with depth, different thermal dilatations).

The flexible multi-layer model in PAVERS is a classical linear elastic Burmister multi-layered structure. The layers are isotropic except for the bottom layer where anisotropy is addressed by different moduli in the horizontal and vertical direction. The interface between two adjacent layers can be varied between full friction to full slip using the BISAR or WESLAY definition.

No matter how good the pavement and load models might be, mechanistic-empirical data is still required to tie the life of a pavement to the computed stress or strain response. It is important to carefully calibrate the function so that the predicted distress can match with field applications. Mechanistic-empirical calibration can be done by using calibrated transfer functions which relate critical stresses and strains in a multi-layered pavement structure to an allowable number or load repetitions.

2.2. Pavement design

The philosophy of the analytical approach to pavement design is that the structure should be treated in the same way as other civil engineering structures, the procedure for which may be summarised as follows:

1. Specify the loading.
2. Estimate the size of components.
3. Consider the materials available.
4. Carry out a structure analysis using theoretical principles.
5. Compare critical stresses, strains or deflections with allowable values.
6. Make adjustments to material or geometry until a satisfactory design is achieved.

7. Consider the economic feasibility of the result.

This contrasts with the traditional method of designing pavements which is based on experience and the use of a test (the CBR) on the subgrade. Application of such empirical methods is restricted to the conditions under which the experience was obtained. It is because of the complexities of structural behaviour and material properties that empirical procedures have endured for so long in pavement engineering. However, with the knowledge now available from research, a procedure similar to that outlined above can be applied to asphalt and rigid pavements. Conversely, for a pavement of known thickness constructed on a subgrade of identifiable characteristics, it is possible to determine the loads that the pavement can safely carry. This method of evaluating the load-bearing capacity is known as the ‘reverse-design method’. This method is used for the evaluation of pavements.

Implementation of calibrated design criteria into modern software tools allows the pavement designer to access the full advantages of the layered elastic design method, including treatment of wander, and quickly produce designs for complex load mixes and layered structures that are consistent with the original design concept.

Following the load input into the model, the stresses and strains are calculated at the design positions. For flexible pavements these are at the bottom of the bituminous layer (fatigue cracking), the top of the subgrade (rutting) and in a cement bound base at the bottom of this layer (reflective cracking).

For concrete pavements the edge-loading position is critical. Stresses and strains are calculated at the edge position using Westergaard incorporating temperature induced stresses and the measured load transfer. By means of fatigue relationships the (residual) allowable number of standard axles and thus the residual pavement lives are calculated. The assessment process also corrects the results for seasonal variations (e.g. flexible material/concrete temperature, subgrade variations etc).

For the calculation of a pavement’s structural life, it is necessary to have details on the traffic which will or has used the pavement in the past and also to forecast the use of the pavement in the future. Wander effects are addressed with a normalised beta-distribution. The complex frequency distribution and different gear loads are analytically transferred into a fatigue damage distribution of the pavement along different tracks and positions on the slab or flexible pavement.
Accumulation of the effects of the number of load repetitions is made on the basis of Miner's damage hypothesis for all pavement materials, i.e. concrete, flexible layers, foundation sub-base layers and subgrade.

3. STATEMENT OF CAPABILITIES

PAVERS is a joint development of dr. Frans Van Cauwelaert, Bert Thewessen and Marc Stet teaming up in Aperio NL. Listed below are a number of novelties. This list is by no means comprehensive; it concentrates on the highlights of the software tool:

- Windows oriented help files clarifying the models and usage of the program,
- Microsoft in- and output: deflection basin and construction data can be read directly from Excel files,
- It is important that all pavement materials of the distinct layers are evaluated in a design process. PAVERS allows to set design criteria to all pavement layers and subgrade. The user can define his criteria or select the appropriate criteria from a database for cement concrete, asphalt concrete, bound base materials or subgrade type,
- Automated back-calculation routine for bulk processing of flexible pavement data. The back-calculation part is compatible with Dynatest, Carlbro (formerly Phönix), JILS and Komatsu deflectometer devices, which operate with a pulse duration of about 25 milliseconds. For KUAB deflectometers, with a pulse duration of approx. 60 ms a conversion for pavements on a weak subgrade is necessary. Coefficients to convert KUAB deflections into deflections with smaller pulse duration for specific geophone locations are given.
- A versatile routine to fix input parameters (e.g. percentage of slip, thickness, Young’s moduli) in the back-calculation process,
- Database with ‘known’ fatigue relations for asphalt, cement concrete, cemented base materials, subbases and subgrade. The user can either select one of the many predefined relationships or input the constants of the transfer function using a tool to determine the constants of the asphalt fatigue relationships,
- A database containing over 200 aircraft with details on gear geometry, load and ACN data and a routine to accommodate LCN/LCG and PCN assessment,
- The lateral wander concept is employed in asphalt pavements to determine the heaviest trafficked pavement strip and to determine the most critical joint in a rigid pavement. The different tracking paths of aircraft types relative to pavement centreline are taken into account. Any degree of wander can be specified and the effect of wander is rigorously treated, eliminating the need of the pass-to-cover-ratio concept,
- Statistical tools for the required number of H/FWD measurements and the Bootstrap,
- Several helpful tools: a/o tools to determine plate foundation parameters, a tool to assess fatigue transfer functions and graphs to present results etc.

3.1. Back-calculating pavement

The back-calculation suite has an automatic back-calculation routine. Deflection basis and construction data can be read from Excel files. The program allows for back-calculating flexible and rigid pavement. For rigid pavement, the user can either back-calculate deflections at the slab interior or at the slab’s joint. For the latter, the deflection transfer across the joint is required as an additional input value. The friction between two layers and the layer thickness can either be fixed or set variable in the back-calculation routine. Furthermore, the user can also set his own seed moduli and boundary values.

For illustration purposes, figure 3 reports the results of back-calculate a deflection bowl measured at the slab’s edge.
3.2. Design and Assessment

Once the structural pavement parameters are assessed, the life (or bearing capacity) can be determined. For the calculation of the (residual) life, it is necessary to have details on the traffic (which has used the pavement in the past and also) to forecast the use of the pavement in the future.

The user may compose his own load mix for evaluation out of a database with the load characteristics of PAVERS. Own loads can be entered into this database. The accumulated pavement damage is assessed by adding the damage of the load, taking into account the position of the loads on the pavement. PAVERS calculates the most heavily loaded strip of the pavement due to a specific load mix.

3.3. Load-carrying capacity of Airport Pavement

PAVERS enables the determination of a technical Load Classification Number (LCN) and the Pavement Classification Number (PCN). The former method is used by NATO. A universal system for civil airport pavements for determining the weight limitation of aircraft operating on airport pavements involves comparison of an airport’s Pavement Classification Number (PCN) with an Airplane Classification Number (ACN).

According to this world-wide ICAO standard, aircraft can safely operate on a pavement if their ACN is less than or equal to the pavement load bearing capacity or PCN. An aircraft having an ACN equal to or less than the PCN can operate without weight restrictions on a pavement.

The PCN is formally published in an Aeronautical Information Publication (AIP).

3.4. Statistical concept

Due to a natural deviation in material strength and constructed layer thickness, pavements do not fail suddenly but gradually. Results based on an FWD survey enables the possibility to determine the pavement’s strength with a certain statistical precision. Statistics are often applied to determine the quality of a population based on a limited number of random samples e.g. test results. The Bootstrap method should be used in cases where the shape of the distribution is not known. In general terms, the Bootstrap method is a generic simulation method to assess the precision of a statistic without knowing the distribution of the statistic. PAVERS has a suite to accommodate the Bootstrap assessment.

4. SHARING KNOWLEDGE

PAVERS was created to give pavement specialists the definite tool for the structural design and evaluation of road, airport and industrial rigid and flexible pavement. The conviction to transfer and share knowledge with other people and companies working in the field of pavement design and FWD evaluation, forms the basis for the ongoing development of the program. Those who buy a license are registered and invited to join the User’s Group. As a user group member, you can help decide what the next improvement to the program will be. License fees are essential to improve the program. Registered users get periodic updates of the program at handling costs. New developments not funded by the Users Group is made available at reasonable costs.
5. REFERENCES


