A NEW HOT-MIX DESIGN METHOD FOR SOUTHERN AFRICA

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INTRODUCTION

Numerous changes have taken place in the realms of material properties and construction techniques over the past 20 years. Despite the fact that traffic loads, traffic volumes and tyre contact stresses have increased steadily, there have been relatively few changes in asphalt mix design in southern Africa over this period. The growing incidence of premature distress (rutting, ravelling, cracking and potholes) observed in recent years bears witness to the fact that the current approach to hot-mix asphalt (HMA) design has inherent deficiencies.

In southern Africa, practitioners, through committees such as the South African Bituminous Materials Liaison Committee (BMLC), have acknowledged that improvements in the design of hot-mix asphalt have become a necessity in order to ensure that the technology is geared to address current deficiencies and needs. To this end, a project was launched in early 1998 with the aim of developing a new HMA design method which incorporates state of the art knowledge of materials evaluation, mix design and performance assessment, and which takes cognisance of the climatic and pavement environments as well as aspects related to construction. The aim of this paper is to describe the background and structure of this project, to highlight some of the more salient features of the new design method, and to provide an overview of issues related to implementation.

BACKGROUND FOR A MODERN APPROACH

The hot mix asphalt design method described by the TRH8: 1987 manual (Technical Recommendations for Highways, No.8 Design and Use of Hot-Mix Asphalt in Pavements) has been used in southern Africa for over a decade. TRH8: 1987 is centred on the Marshall design method, but includes additional information and criteria for component evaluation. Although the approach and criteria described in TRH8: 1987 have been used with success on designs that involve high traffic volumes, unacceptable performance was reported on some projects. There is thus scope for improvement, as will be discussed next.

Challenges Posed by More Aggressive Design Situations

Over the past decade, HMA designers have been faced with increasingly challenging design situations. The most apparent of these - and perhaps also the most significant - has been the increase in legal single axle limit from 8.2 to 9 tonnes in South Africa. Such an increase in axle load is invariably coupled with higher tyre pressures and more aggressive tyre contact stresses which may induce stresses in the upper pavement structure which are more than 70 per cent greater than the contact pressure currently assumed in design (de Beer et al, 1997, Theyse et al, 1996).

Another change in the design situation is the increasing number of rehabilitation projects, in which newly constructed and unaged asphalt layers are immediately subjected to high numbers of truck traffic. In some instances, asphalt layers also have to be designed to function on old pavement structures that exhibit high deflections and have to operate under high traffic conditions.

Recent years have also witnessed the introduction of mix types such as Stone Mastic Asphalt (SMA) which had previously not been utilized on a large scale, and for which a documented and validated mix design method is lacking in southern Africa. New construction techniques have also been introduced, with both thicker bases and thinner surfacings being used increasingly. All of these elements may add up to design situations that pose a challenge to even the most experienced designers. To inexperienced designers, the challenge may well be insurmountable.

Deficiencies in the Existing Mix Design Method

As the TRH8: 1987 manual is essentially based on the Marshall design method, it relies on parameters such as the Marshall stability and Marshall flow. Although widely purported to be empirical design parameters, there is actually little evidence to link these indicators to HMA performance (Roberts et al, 1991). In fact, some studies of HMA field performance suggest that these parameters do not exhibit a strong correlation with rutting or fatigue in most instances (Huber and Heiman, 1987). Furthermore, the criteria used to evaluate these empirical design parameters were in many cases established more than twenty years ago, and cannot with any confidence be applied to current design situations.

Apart from the decreased confidence in empirical design parameters and criteria, several basic elements of the TRH8: 1987 and Marshall design methods have been seriously questioned in recent years. Some of these elements include:

- The validity of specimen compaction and conditioning procedures;
- Insufficient cognisance of the relationship between design traffic and compaction energy;
- The lack of including a workability index as part of the binder content selection process/criteria;
- Lack of modernized and fundamental evaluation of the mastic component;
- Not taking account of the finer fractions of a gradation on mix performance, and
- Not necessarily suitable to modified binders.

Influx of Overseas Information and Modern Equipment

The Strategic Highway Research Program (SHRP) initiated in the United States in 1987, has led to the adoption of new principles for component evaluation, volumetric design and performance testing (McGennis et al, 1994; Anderson and McGennis, 1994). Similar developments have taken place in Europe and Australia, which again have led to the development of new technologies and design principles (ARRB, 1997). Foremost amongst these is a fundamental understanding of packing concepts and spatial design of mixes as well as binder and mastic evaluation techniques.

These innovations, coupled with an increased understanding of the fundamental cause and effect mechanisms, which determine HMA performance, have enabled researchers to develop more rational indicators of performance which can be used both in the design process and in the prediction of mix performance. As a result, a new generation of testing equipment and design parameters have emerged, much of which has been adopted by the more innovative consulting and construction agencies in southern Africa. Although these new additions to the current design approach are to be applauded, the danger exists that haphazard additions to the mix design method can lead to a fragmented design approach. This poses significant problems for the development of unified and validated design criteria for all mix types.

Incorporation of these developments in a mix design method should therefore not be done in a disjointed manner, but requires a systematic revision of the design philosophy as well as of the more technical aspects such as component selection, grading selection and refinement as well as optimum binder content selection.

Lack of Scope and Insufficient Cognisance of Environmental Conditions

The TRH8: 1987 manual only provides guidelines for the design of dense graded mixes, and a need therefore exists for a unified design method. Such a method should implement an overriding approach that can be applied to all mix designs, but with specific procedures and test methods for mixes such as large aggregate mix bases (LAMBS), SMA’s and open graded mixes. Recent years have also witnessed increased use of modified binders and bitumen rubber. The new design method strives to put into place procedures that can consistently and rationally evaluate the performance of mixes with both conventional and modified binders.

A severe disadvantage of the TRH8 manual (and many other design methods) is the fact that the support conditions (i.e. the pavement environment) and the climatic environment are largely ignored in the process of mix selection and selection of design sophistication. The new design method strives to include a comprehensive evaluation of temperature, rainfall and support conditions, as well as other aspects related to geometry, site conditions etc. which may have an impact on mix type selection or level of design adopted.

PROJECT HISTORY AND STRUCTURE

Having recognized the need for an updated and expanded HMA design system, a project management group (PMG) consisting of CSIR Transportek, University of Pretoria and VKE Engineering was formed in March 1998 to plan and coordinate the activities, which are needed for developing a new HMA design method for southern Africa. Funder members who also serve on the PMG are drawn from the CSIR, the South African Bitumen Association (Sabita) and the South African National Roads Agency Ltd (SANRAL). A steering committee was also formed to guide the development process and create links with and between funders.

The ***vision*** of the HMA design project was formulated as follows:

> To develop a hot-mix asphalt design system, which is integrated with pavement design, takes cognisance of issues related to environment and construction and which allows a rational evaluation of expected performance to be made. The method should incorporate the best local and overseas practice and technologies and should yield improved and appropriate asphalt designs for all design situations.

The project team was structured in such a manner that a wide range of stakeholders (road users, road authorities, consulting engineers, contractors and product suppliers) would be drawn into the process of planning, research and implementation. Careful consideration of the mix design process, as well as problems identified by practitioners led to the grouping of design issues into five major mix design activities, which are called Technical Focus Areas (TFA's). Figure 1 shows the overall structure of the project management teams and the TFA activities.

A TFA leader, who interacts with TFA GROUP members, directs the activities of each TFA. TFA group members are all experts in the respective technical focus area, and are generally responsible for the execution of research projects as well as for the compilation and selection of methods and equipment.

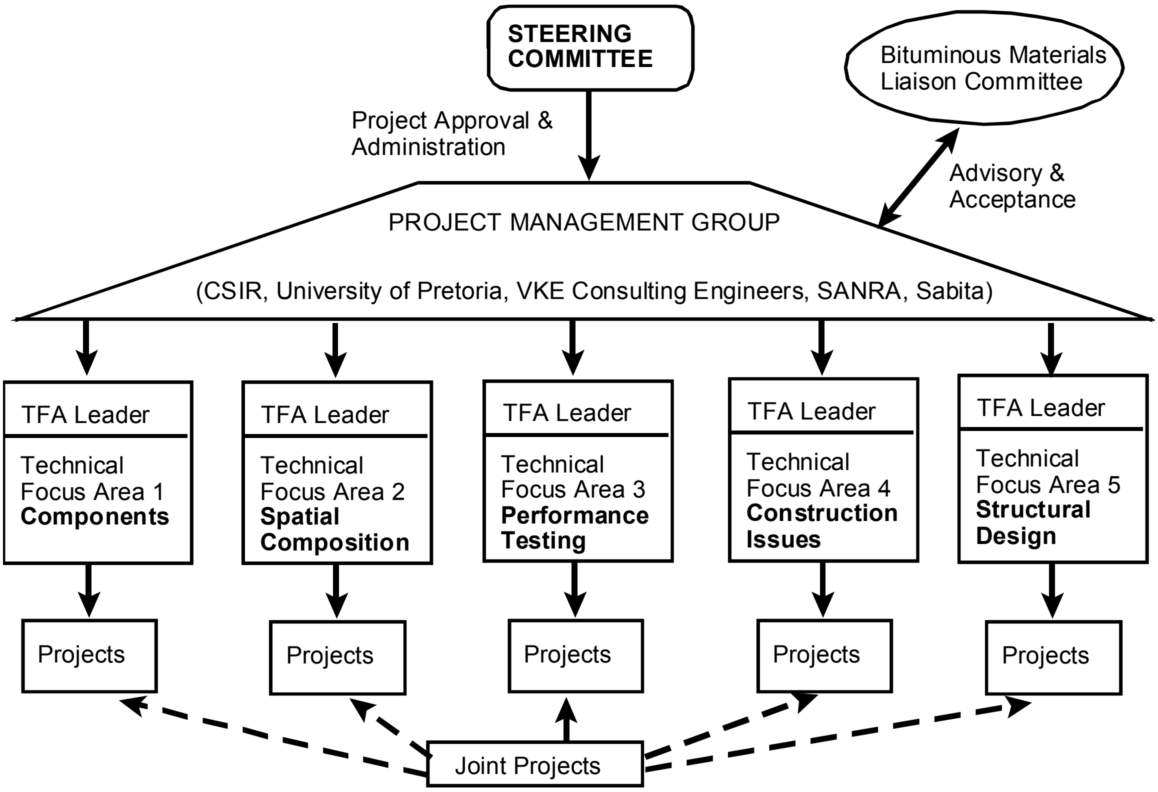

Figure 1 Management Structure of the SA HMA Project

The five TFA's are responsible for the following design elements:

TFA1: Components

The purpose of this TFA is to assess current specification for the materials used in asphalt mixes, to identify shortcomings and to make recommendations for test methods and evaluation criteria.

TFA2: Spatial Composition

This TFA is responsible for developing processes and procedures, which could be used to select, optimise and predict the performance of HMA based on spatial composition and volumetric principles.

TFA3: Performance Related Properties

This TFA is responsible for selecting or developing test methods, which can be used to evaluate and predict the performance of an asphalt mix during the design stage. The activities of this TFA form a major thrust of any HMA design system, and therefore this TFA needs to interact closely with all other TFA's.

TFA4: Construction issues

The purpose of this TFA is to identify construction issues which are or may become problematic, and which need to be taken into account during the mix design process. As such, the TFA focuses on issues related to cost, constructibility, specifications and quality control.

TFA5: Structural Design and Performance

The purpose of this TFA is to define requirements for linking the mix design method to the pavement structural design method, and also to link the HMA performance evaluation to the pavement structure. This TFA is also responsible for providing inputs to other TFA's on information required for structural design purposes.

The project was planned to proceed in four distinct phases: (i) basic formulation of design objectives, and most relevant technical elements; (ii) high gain phase in which existing knowledge and best practice are synthesized to form a draft design procedure; (iii) validation and further developments, and (iv) packaging. Phase (i) was completed in 1998, Phase (ii) in late 1999 and phase (iii) is currently in process (July, 2000).

ELEMENTS OF THE SYSTEM

The design method being proposed as a result of phases (i) and (ii) of the HMA project is similar to other modern design methods such as Superpave and the Australian mix design method (McGennis et al, 1994; Australian Road Research Board, 1997). The basic elements of the design process are illustrated in Figure 2, and essentially consist of three main tasks: (i) evaluation of the design situation; (ii) volumetric design, and (iii) performance testing.

Some specific elements marked (A) to (F) are described in more detail below. It is important to note that all of the elements (B) to (E) will be performed and evaluated on the basis of **mix specific guidelines**. Thus, although the process illustrated in Figure 2 is common to all mix types, the specific rules that apply for the selection of a compaction effort, evaluation of volumetric criteria etc. are mix type specific.

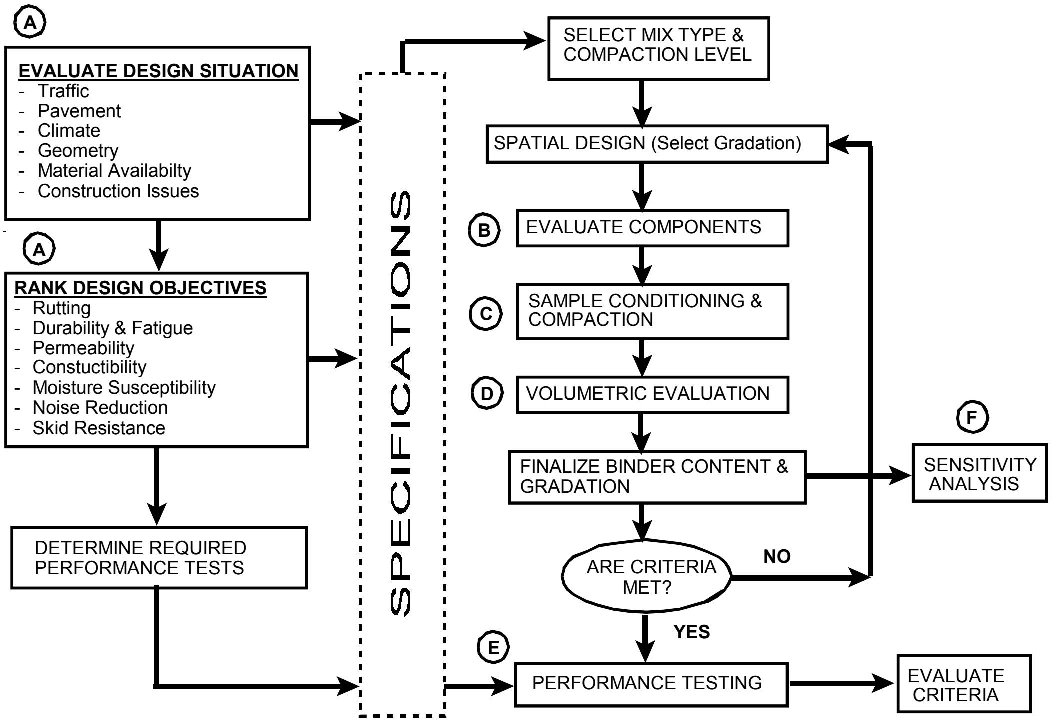

Figure 2 Mix Type Selection and Volumetric Design Process

A: Evaluation of Design Situation and Ranking of Design Objectives

In the new mix design manual, specific guidelines are be provided for the evaluation of items that relate to the selection of a mix type, level of compaction as well as types of performance tests required. These guidelines will enable designers to evaluate (and in some instances quantify) the importance of the different design objectives. Amongst other issues, these guidelines will take into account:

- Volume of heavy traffic;
- Temperature;
- Rainfall;
- Light and heavy vehicle speed;
- Geometry (slope, crossfall, presence of intersections, etc.);
- Material availability, and
- Issues related to constructibility (intersections, novel construction methods, quality control, etc.).

The design manual will contain a brief description of the influence of these issues on the selection of a mix type (including binder type), and will also enable designers to rank the different design objectives (such as rutting, fatigue, permeability, etc.). The new design method differs in this respect from other modern methods (such as Superpave) in that there are no fixed design levels coupled to traffic volumes. Rather, each design objective is rated separately based on a detailed evaluation of the design situation.

B: Component Evaluation

The evaluation of the different components relies in part on existing standard tests for aggregates and binders, but also includes several new developments that resulted from studies in the United States, Europe and Australia. In comparison with the procedures prescribed by the TRH8: 1987 manual, the new method places more emphasis on the filler as well as on the interaction between binder and filler. More attention is therefore being paid to the stiffness, adhesion and durability of the mastic portion of the mix. Testing proposed for inclusion in the new mix design method includes the Methylene Blue test and viscosity measurements of the mastic at 60°C and 135°C. Recent testing carried out has shown that aggregates with high Methylene Blue values coupled with high filler contents can cause compaction and durability problems.

C: Sample Conditioning and Compaction

The selection of a compaction method and compaction effort is a crucial element of any mix design method. Recent developments in the United States and Australia have led to the selection of the Gyratory compactor as the standard laboratory device for specimen preparation and evaluation of workability. Some methods, such as that prescribed by the Asphalt Institute in the MS2 manual, have retained the Marshall compactor as part of the mix design process. Other developments seem to favour the use of rolling wheel compactors. A difficult decision therefore had to be made, which was complicated by the lack of clear, scientific evidence in favour of one specific compaction device.

In view of the considerable investment in equipment, skill and knowledge that has gone into the Marshall design method in southern Africa, it was decided to retain the Marshall compaction device for volumetric design purposes, but with some modifications as described below.

For stone skeleton mixes (stone mastic asphalt and open graded asphalt), briquettes are compacted using 50 blows per side. For dense graded mixes (continuously graded, semi-gap graded and gap graded), a modified Marshall device is used, in which the height of the briquette is monitored with the number of blows. This provides a compaction curve that is evaluated to provide a suitable balance of design objectives such a compactibility, durability and stability. This is described in more detail in the next sub-section.

Although the new design method is principally centred on the Marshall device, additional guidelines are also provided for designers who prefer to use the gyratory compactor. Also, the rolling wheel compactor is used for the preparation of test specimens for some of the more advanced performance related tests such as fatigue and wheel tracking tests.

D: Evaluation of Volumetric Criteria

The volumetric design procedure to be used for open graded mixes is identical to the method published in SABITA Manual 17. The method for Stone Mastic Asphalt is based on the FHWA procedure developed by Brown et al. (Brown et al. 1998). Both these methods specify a fixed number of Marshall blows to be applied during laboratory preparation of specimens for volumetric design.

The process for the design of dense graded mixes is slightly more complex, and requires that the designer balance and evaluate several mix properties at the same time. The factors to be taken into account include:

- Traffic;
- Compactibility
- Initial voids after construction, and
- Final voids after trafficking.

In the past the specified maximum void content for dense graded mixes after construction was typically set at 97% of Rice's density minus the design voids determined in the Marshall Design Procedure. The design void content was generally set at 4% and hence the specified maximum construction void content was set at 7%. In many cases this resulted in excessively porous mixes on lightly trafficked roads, which did not compact any further due to the light traffic, and hence resulted in a mix that oxidised rapidly over time. On heavily trafficked roads severe deformation has occurred in places due to excessive densification under traffic resulting in inadequate ultimate voids and lack of deformation resistance.

In the new design method a range of initial as well as final void content criteria are proposed depending on the expected traffic volume. In the derivation of these criteria, variability was also taken into account to ensure that absolute minimum limits for void content are met at isolated points where the actual void content may differ from the design void content.

Table 1 shows the criteria for the selection of an optimum binder content for dense graded mixes. These criteria ensure that permeability and density requirements after construction are met, and at the same time ensure that stability requirements based on minimum void content are met after trafficking.

The criteria shown in Table 1 present a window through which the Marshall compaction curve should pass. For very heavy traffic, an additional assurance of stability is provided by the specification of a minimum void content after 300 gyrations with a Gyratory compactor, tested according to SHRP protocol. Figure 3 shows the voids criteria checkpoints for a high traffic application, after compaction and simulated trafficking, plotted together with Marshall compaction curves at three binder contents, for a medium continuously graded mix.

Table 1: Voids Criteria for Dense Graded Mixes

Traffic Level	Design Capacity*	Allowable Voids Range after 75 Marshall blows† (to simulate field compaction)		Allowable Voids Range after Additional compaction to simulate trafficking		
		Minimum	Maximum	Total No. of Blows	Minimum	Maximum
Light	<1	3.5%	5.5%	75 + 15	3.0%	4.5%
Medium	1 to 3	4.5%	6.5%	75 + 45	3.0%	5.0%
Heavy	3 to 10	5.5%	7.0%	75 + 75	4.0%	5.0%
Very Heavy	>10	5.5%	7.0%	75 + 75	4.0%	5.0%
		Min. voids content of 2% after 300 gyrations with Gyratory compactor, according to SHRP testing protocol				

* In millions of ESAL's;

† Here, 75 blows is the total number of blows, as applied in the Modified Marshall device, and not the number of blows per side;

The curves shown are the averages of three replicates compacted at each binder content. The optimum binder content should be selected such that the compaction curve at the optimum binder content passes between the checkpoints for compaction and simulated trafficking.

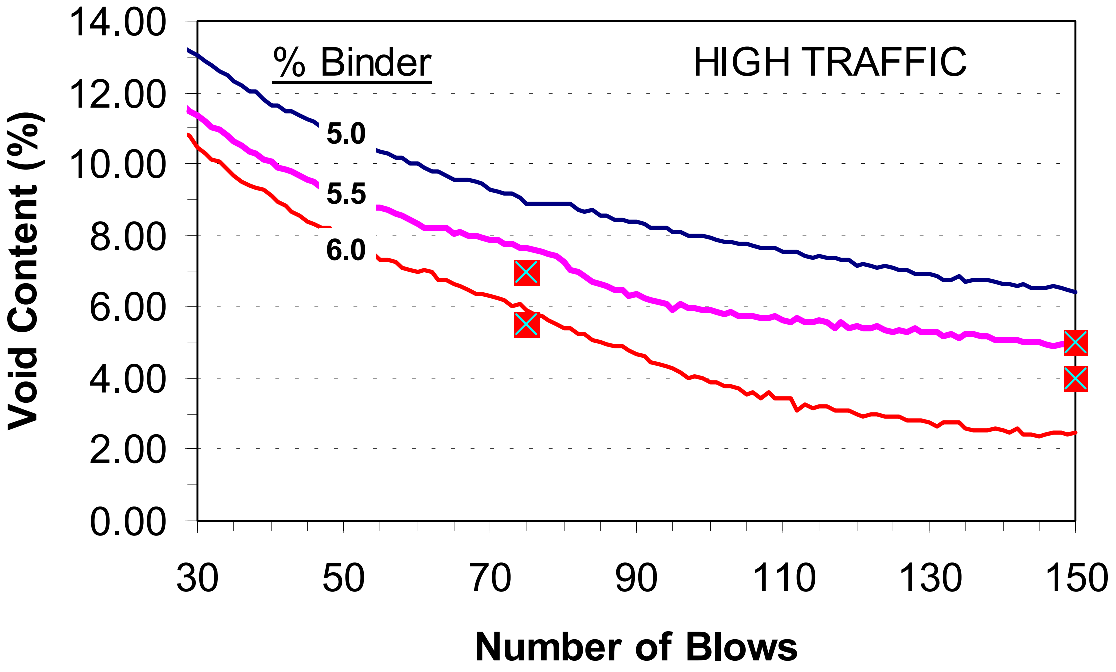

Figure 3 Compaction Curve and Voids Checkpoints for a High Traffic Design

E: Performance Related Testing

The number and types of performance tests required for a specific application are determined by the rating of each design objective. This rating is performed by considering (amongst other issues) the traffic volume, traffic speed, road geometry and climate. During the early phases of the project, it became apparent that clear qualitative relationships between laboratory tests and field performance have not been established with the required confidence. The evaluation of some performance tests is therefore based on recommended ranges of test values associated with different situations, rather than on a fixed criterion. Designers are therefore urged to be familiar with the typical ranges of test values obtained with the different types of performance tests. The performance tests recommended for different design situations are summarized in Table 2.

For most applications, rutting and fatigue evaluation is by far the most important consideration as far as performance testing is concerned. Feasible alternatives to the somewhat expensive bending beam fatigue test have not been found, and thus the evaluation of fatigue largely rests on the four-point bending beam fatigue test.

Table 2: Selected Performance Tests Recommended for Rated Design Objectives

Design Objective	Rating for Design Objective		
	1	2	3
Rutting	Expert system evaluation (dense graded mixes only)	Wheel tracking test	Wheel Tracking test **or** Axial loading slab test with associated probabilistic analysis
Durability and Moisture Susceptibility	Marshall Flow ITS Permeability Test	ITS Modified Lottman / Immersion Index Permeability Test	ITS / Resilient Modulus Modified Lottman / Immersion Index Permeability Test
Fatigue	ITS	ITS / Resilient Modulus	Bending Beam Test

Extensive efforts were made to address the rutting problem that has becoming more serious in recent years. No single, simplified solution has been found for the complex rutting phenomenon. Instead, the new HMA design method offers three approaches to the evaluation for rutting potential. Each method has different time and cost implications which allow designers to select the approach most suitable for a specific application. The three approaches are briefly described below.

Expert system evaluation

The system uses simple test parameters such as softening point, binder viscosity and voids filled with binder as input. A simple confined impact test parameter is also used as input to the system. These test values are evaluated using historically accepted threshold values for the different test parameters. The evaluation of test values is coupled with an evaluation of traffic intensity (traffic type and volume as well as vehicle speed) and climate to provide an overall estimate of rutting potential.

Wheel Tracking Tests

Two types of wheel tracking tests can be used. The Transportek wheel-tracking test uses a 400 mm diameter solid rubber wheel and can exert pressures in the range of 300 to 900 kPa. Slab thickness, support stiffness and wheel speed can be varied to suit specific site conditions. The Model Mobile Load Simulator (MMLS), operated and distributed by the University of Stellenbosch (Institute for Transport technology, 1998), is a mobile device that applies a high rate of loading (more than 10,000 simulated loads per hour can be applied) and can be used for the testing of full scale trial sections.

Axial Loading Slab Test

This test comprises a 320mm by 280 mm slab that can either be extracted from the field or compacted using a laboratory slab compactor. Deformation is measured while the slab is loaded by means of a dynamically applied axial load. Three slabs are tested at different load and temperature levels. The measured deformation curves are used to develop a function that relates rut increment to applied stress, temperature and number of load repetitions. This function is used in an analysis program that stochastically simulates traffic and temperature for the entire design period to provide an estimate of rut potential.

Both the wheel tracking and axial loading slab tests have associated software that incorporates a database in which historical test data can be recorded to facilitate comparison of mixes as well as faster evaluation of relative rutting performance.

F: Sensitivity Analysis

Once the gradation and binder content has been finalized, an analysis is performed to evaluate the sensitivity of the volumetric parameters to changes in the mix components. This information is used to identify elements that require stricter control during construction. The sensitivity model is based on an existing model for the prediction of volumetric properties, coupled with Monte Carlo simulation techniques.

CHALLENGES TO OVERCOME

The mix design process as outlined above describes the essential features of the design system, which can in concept be applied to dense graded mixes with several aggregate sizes (including LAMBS), SMA's, open graded mixes and fine gap graded mixes. Although the tests to be used for aggregate, binder and filler evaluation have been selected, and volumetric design criteria for the different mix types have been established, several key elements of the system require further research before the design procedure will be finalized. Some of these issues include:

- To assess whether the current proposals for mastic evaluation are adequate or whether further refinements need to be made;
- The procedure for the evaluation of mix durability needs to be formalized;
- A procedure for fast and reliable measurement of permeability needs to be developed;
- A workability index that can be measured using the standard Marshall device has to be devised. This development includes a process whereby the current proposal to monitor the change in sample height, and hence voids, as a function of the number of blows is validated in practice;
- The compatibility of the proposed tests need to be assessed and the predictions made by the various procedures (at different design levels) need to be harmonized.

As in any design system, a rational estimate of absolute performance using simplified tests remains a challenge. Efforts are being made to measure fatigue (using four point bending beam tests) and rutting (using wheel tracking tests) on several mix types to enable standard performance curves to be established. These curves will firstly be used in a relative manner to allow a fast and reliable evaluation of mix performance during the design stage. Such an evaluation will not provide an absolute evaluation of performance, but should alert designers of potential substandard mix performance.

The implementation of the new design method will be started in June 2000. An implementation programme has been formulated during which the new design method will be implemented in conjunction with the more established Marshall design procedure. During the implementation phase, the design method implementation will be monitored on several design projects. A task team has been appointed to oversee this implementation phase. Problems encountered with new approaches and test methods will be identified and addressed where possible. It is hoped that the finalized design procedure will be ready for routine implementation by August 2001.

CONCLUSIONS

In this paper, the structure and background of the proposed new HMA design method for southern Africa was described. The paper also highlighted some of the more prominent features of the proposed new method. The reasons for developing an updated, modern HMA design method include:

- More aggressive design situations, brought about by increased legal axle limits, higher tyre pressures, as well as an increasing number of rehabilitation projects with high traffic volumes being applied to freshly laid HMA.
- The existing southern African design method is described in the TRH8 manual. This manual is essentially based on the Marshal design method and has several deficiencies related to design parameters, sample conditioning and compaction etc.
- An influx of new technologies and equipment, which, although encouraging in some respects, may lead to a fragmented design approach.

- The existing TRH8 manual is insufficient in scope. This applies to mix types, binder types and the lack of taking sufficient cognisance of design situations (i.e. climate and pavement structure).

The project management is structured in a three-tier approach, with the management levels being a steering committee, a project management group and technical focus area leaders. Five technical focus areas were identified as being the essential elements of a sound design system: (i) component evaluation, (ii) spatial composition; (iii) performance testing; (iv) construction issues, and (v) pavement design issues.

The proposed design method is similar in many respects to modern design methods that were recently developed in the United States and Australia. Prominent elements of the system include:

- A complete and thorough evaluation of the design situation, including an evaluation of traffic, climate, construction issues and geometry. This information is used to assist in the selection of an appropriate mix type as well as for the ranking of design objectives.

- Sample compaction for purposes of volumetric design and binder content selection will utilize the Marshall compaction device, with additional guidelines for designers who use gyratory compactors.

- Mix evaluation centres around spatial design concepts and volumetric design parameters. Validation of the suitability of these design parameters is attained through performance testing.

- The system does not have fixed design levels for different traffic levels or environmental conditions. All designs start with an evaluation of volumetric design parameters. The types of performance tests required are selected on the basis of design objectives, which are ranked on the basis of the specific design situation.

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