Large stone asphalt mix design for heavy duty asphalt pavements

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LARGE STONE ASPHALT MIX DESIGN FOR HEAVY DUTY ASPHALT PAVEMENTS

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SYNOPSIS

The recent increase in traffic volumes and also axle loads on some of the major routes in South Africa has extended the traffic classes beyond the current highest design class. Additionally there is a strong lobby to increase the legal axle load to between 9 and 10 metric tonnes. There is also a tendency from overseas to use higher tyre pressures with new tyre types.

One of the main reasons why the top size stone in mixtures has been limited to 26,5 mm is because the conventional mix design procedures cannot handle aggregates larger than 26,5 mm. A design method to incorporate the benefits of large stone mixes is urgently needed.

Mix design, pavement design and pavement performance needs to be considered simultaneously and should not be independent functions as currently is so often the case. A mix design method must therefor be based on engineering properties, structural behaviour and long term performance.

The heavy duty asphalt pavements (HDAPs) project, sponsored by SABITA, is developing analytical large stone asphalt mix design procedures. This should provide guidance for the developing of a general analytical asphalt mix design method.

The first phase addresses compaction methods and engineering parameters. Initial results will be reported.

1. INTRODUCTION

The growth in traffic, both in terms of volume and in standard axle loads, on some of the major routes in South Africa, has resulted in traffic loading conditions on roads well beyond the highest current design class (E4 traffic as defined in the TRH4[1]). A higher traffic class (E5 - more than 50 x 10^6 equivalent standard axles in 20 years)[2] has already been discussed. In addition, there is currently a strong lobby from hauliers for an increase in the legal axle load from 8,2 to 9 or 10 metric tonnes. Furthermore, there is a tendency overseas to new tyre types with higher tyre pressures. Increases in tyre pressure have a significant effect on the performance of pavements, in particular the performance of the layers near the surface. The above situation could have a marked effect on the lives of existing pavements as well as maintenance and rehabilitation costs on these routes. Deregulation of the transport industry could aggrevate this situation. Although the road authorities have taken steps to control overloading it is believed that it will remain a problem for some time (and could in fact increase).

In relation to the design of asphalt mixes, the above scenario emphasises the fact that the asphaltic materials of the future will have to cope with more aggressive loading conditions. In future, these materials will not only have to cope with increased loading and tyre pressure conditions but also with increased demands on stability and durability.

Recent developments in asphalt mix design include investigations into modified binders as well as the use of large-stone aggregate gradings. This paper presents a brief status report on the Heavy Duty Asphalt Pavements study (HDAPs)[3] conducted by the Division of Roads and Transport Technology of the CSIR for the Southern African Bitumen and Tar Association (SABITA). In the initial stages the project concentrated on the use and performance of large-stone asphalt mixes. Some initial results and findings are presented. In addition, some aspects of the current asphalt mix design scenario and mix design procedures as well as a new system for asphalt mix design are discussed.

2. CHARACTERISTICS OF LARGE STONE MIXES

A literature survey[4] undertaken as part of the research project indicated that the use of large-stone gradings held considirable potential. Acott[5] stated: "Large stone asphalt mixes may hold potential for heavy duty pavements, designed to handle today's larger, heavier trucks and increasing tyre pressures."

Davis[6] reported his interest in the large stone pavements of the early 1900s because many gave excellent service for over fifty years. These pavements were characterised by large top size stones, high volume concentration of aggregate and low air voids (less than 3%). The recovered bitumen from some of these early pavements has hardened very little over the years and the pavements were generally in excellent condition.

The main benefits of increasing the maximum stone size are the following:

- The bearing capacity is improved as the maximum stone size increases.

- The thickness of the binder-film that can be accommodated increases as the maximum size of the aggregate increases and resulting in a slower ageing process of the binder.

- Resistance to indentation, abrasion and deformation is increased by increasing the maximum stone size.

- Possible reductions in the design binder content, may lead to more economic asphalt layers.

In the past the top size stone has been limited to 26,5 mm due to the fact that conventional mix design procedures (Marshall and Hveem) do not make provision for aggregates larger than 26,5 mm. This leads to a situation where the mix is designed to suit the test method and not the real field conditions.

A potential problem regarding the use of large-stone mixes lies in their constructability. Problems include wear and tear of equipment and plant, segregation of the mix and adjustments to the asphalt plants. However, views expressed by South African contractors were generally optimistic[7].

Large-stone mixes can be categorised in three groups with different attributes as discussed in the following subsections.

2.1 Uniform grading (see Figure 1)

This is simply a uniformly (continuously) graded, dense mix that primarily develops strength from aggregate interlock and the viscosity of the binder. The larger aggregate decreases the voids in mineral aggregate and improves its bearing capacity.

In addition to highway pavements, this type of mix has been used in sorting yards in the logging industries. In this specific example it showed sufficient bearing capacity to resist the high stresses induced by loaded log stackers (up to 1 100 kN on the front axle)[(5)]. So called Dense Bitumen Macadam (DBM) mixes, with stone sizes up to 37,5 mm, are being used very successfully in the United Kingdom.

2.2 Stone filled grading (see Figure 2)

This mix consists of a conventional small top size aggregate (continuously graded) combined with large single sized stones. The bridging effect of stone-on-stone makes the mix resistant to rutting and further densification under extreme heavy loading conditions.

In a joint project between the Minnesota Asphalt Association, NAPA and the Asphalt Institute, a stone filled mix was designed to be used in a container terminal carrying gross loads of 900 kN as well as punching loads resulted from the steel wheels of parked trailers[(5)]. After four years of service, the performance of this mix has been very encouraging.

2.3 Open grading (see Figure 3)

The mix consists of large, maximum sized stones (e.g. 63 mm) and voids in the 25% to 35% range. The mix develops strength from direct stone-on-stone contact which prevents both rutting and traffic densification.

Open graded mixes have been used in the Tennessee and Indiana projects built in 1967 and 1980, and no rutting or cracking was found in either of the mixes of these heavy duty pavements. Interesting aspects are the low binder content (typical 1,5%), very low rate of binder hardening and very thick binder films[(8)].

3. A CRITICAL OVERVIEW OF CURRENT MIX DESIGN METHODS

The Marshall method is currently used in South Africa for asphalt mix design and has been unchanged for more than twenty years. The Marshall and Hveem methods are empirically based and were developed for a conditions different to those currently experienced in South Africa. Asphalt mixes are now subjected to greater traffic volumes, higher axle loads and higher tyre pressures as mentioned above. Production and construction processes have changed (eg. the increased use of drum mixers) and there are also changes in construction processes eg. the use of new paving and compaction equipment. The situation is exacerbated by increasing use of a variety of additives and modifiers.

The aim of the traditional design methods is to produce laboratory samples with the empirical strength characteristics approximating those of an in-service mix after it has been used for a period of time. However, freshly compacted laboratory mixes do not accurately represent field conditions. Changes due to short term production ageing and the long term environmental ageing of the binder are totally disregarded.

Furthermore, in the conventional practice the pavement structural design and asphalt mix design proceed independently with the mix design normally being conducted after a structural design has been completed. Ideally these design procedures should be interactive. Currently advanced structural analysis procedures make use of estimated material input values due to the inadequacy of mix design parameters to describe fundamental engineering properties.

Therefore, the current empirical mix design parameters cannot provide a basis of evaluation for all the major forms of distress in asphalt mixes. An example is the relative inability of the Marshall method to indicate whether a mix will be susceptible to permanent deformation. Thus an asphalt mix can exhibit acceptable empirical properties but still perform inadeqately in the field.

As indicated earlier, the conventional asphalt mix design methods are limited to the use of 26,5 mm top size stone.

It is therefore clear that there is an urgent need to rationalize asphalt mix design to incorporate the use of large-stone mixes and modified binders and to overcome some of the problems mentioned above.

4. A SYSTEM FOR ASPHALT MIX DESIGN

An asphalt mix design system must simulate the behaviour of a mix in the field as shown in Figure 4. This includes inter alia the following aspects :

- The production process
- The construction process
- The process of traffic loading
- The effect of the environment (eg. ageing, moisture and low temperature cracking)

The following main framework for a general asphalt mix design system is proposed:

- Selection and proportioning of mix components
- Mix preparation and conditioning
- Sample preparation
- Sample conditioning
- Testing
- Prediction and evaluation of performance
- Establishing criteria for mix selection

The asphalt mix design method must optimize the selection, proportioning and the processing of aggregate and binder to produce mixes that are resistant to specific forms of distress depending on the application of the mix. The following aspects should receive attention:

- Maximum stone size and gradation of aggregate
- Type of aggregate (including type of filler and fine aggregate)
- Type (conventional or modified) and amount of bitumen
- Compaction effort and type
- Mixing and compaction temperature

To simulate the production process, the differences between laboratory and field mixes must be minimized through the conditioning of uncompacted material. The two most critical factors that should receive attention in this regard are:

- The ageing of the binder in the plant and during construction
- The absorption of the binder by the aggregate

The sample preparation or laboratory compaction is a critical aspect in the sense that it serves as a basis for the rest of the design system. For example variations in particle orientation resulting from different laboratory compaction methods, which may achieve the same density will yield different engineering properties[9]. A suitable laboratory compaction method simulating particle orientation achieved by compaction plant should therefore be aimed at and be for a specific type of mix, also assuming that suitable design criteria exist. Accordingly new design criteria will have to be developed.

Compacted samples must be conditioned and various energy levels should be used for compaction to simulate the effect of post-construction ageing and traffic. Variables to be investigated include:

- Long term ageing of the binder
- Possible moisture damage
- Traffic densification

Furthermore, the asphalt mix design method should measure engineering properties relevant to structural design eg. stiffness and elasto-plastic properties. The following criteria are important in the selection of test methods. The method should be:

- Sensitive to mix variables
- Able to simulate field conditions
- Usable in design/performance models
- User friendly
- Easy to implement
- Reliable
- Suitable for ageing and moisture conditioning

In addition to the normal volumetric properties (like voids, voids filled with bitumen and voids in mineral aggregate),it is proposed that the following engineering properties should be measured to evaluate the performance of the mix:

- Indirect tensile strength
- Strain at break and at maximum stress
- Stiffness
- Dynamic Creep

The method should also take cognisance of the probable distress mechanisms for the prevailing environmental conditions. The following modes of distress should be addressed (pertaining particularly to wearing courses are indicated by *):

- Fatigue cracking
- Permanent deformation
- Low temperature cracking
- Moisture damage
- ravelling*
- skid resistance*
- bleeding*
- stripping*

The above asphalt mix design objectives could form a framework for conducting further research. These objectives are in line with recent trends in asphalt research conducted in the AAMAS project in the Strategic Highway Research Program (SHRP)[10,11].

5. PRESENT STATUS OF THE HDAPs STUDY

The development of a reliable laboratory compaction method yielding repeatable results will form the basis of a new mix design procedure. Such a compaction method must simulate field compaction closely and has to allow for the use of larger aggregates.

After an investigation of selected compaction methods (including the Refusal method, Gyratory method and the Vibratory table compaction method), the project mainly focused on the Marshall and Hugo method due to the impractibility of some of the methods(12).

Both the Marshall and Hugo methods employ a falling weight for providing the necessary compaction energy. The difference lies in the face of the compaction hammer. The Marshall hammer face is flat whereas the hammer face of the Hugo method has indents. In addition to the above difference the face of the Hugo hammer is rotated 30° after each drop of the weight. The indents and the turning action of the Hugo hammer provides a kneading effect which results in a particle reorientation. This does not occur to any significant extent with the flat face of the Marshall hammer.

The Marshall and Hugo methods were modified to compact samples in 150 mm moulds. The mass of the hammer and number of blows were increased to ensure the same energy per volume as that used for the 100 mm samples compacted by the conventional Marshall method.

An extensive study was conducted to investigate the effect of the Marshall and Hugo methods on selected engineering properties (resilient modulus, indirect tensile strength and creep modulus)(13). Twenty one different combinations of variables such as mould size, stone size, lubrication, depth and type of indents, number of blows before turning, hammer mass and number of blows used, were built into the experiment. The analysis of these initial results led to a more specific repeatability study to investigate the effect of the dominant factors such as the method, mould size and the stone size(14).

The results are summarized in figures 5, 6, 7 and 8.

After evaluating all the results, the following initial conclusions can be made:

- The type of compaction method has a very significant influence on the engineering properties related to permanent deformation. Indications are that the creep modulus obtained when using the Hugo hammer may be more realistic than that obtained using the Marshall hammer[13].

- The effect of the compaction method is not as significant when the samples are tested for properties related to stiffness and tensile strength. When lower energy levels (simulation of construction density) are used, the type of compaction method may be important[9].

- The top stone size of a mix relative to the mould size has an important effect on the applicability of a specific compaction method. The difference in the properties of samples compacted by different methods is more significant when the top size stone is smaller relative to the mould size.

- The repeatability (coefficient of variance) of the Hugo method is higher (average of all the properties) than that of the Marshall method for the 150 mm diameter samples.

6. CONCLUSIONS AND PROPOSED STRATEGY FOR FUTURE RESEARCH

Over the past twenty years progress in the development of theoretically sound test methods yielding repeatable results suitable for the characterization of the engineering properties of asphalt mixes has not been satisfactory. Consequently current mix design methods are based on empirical testing of laboratory prepared specimens which are not realistic reproductions of field compacted mixes.

It is recommended that available analytical tests (such as the tests currently used in the HDAPs project) should be used to develop a new asphalt mix design method with performance based criteria. The SHRP project A-003A[15] involves inter alia an investigation into accelerated performance-related tests that can model construction and service conditions. Promising tests should be incorporated into the new asphalt mix design method.

It is essential that procedures be developed for producing realistic laboratory-prepared test specimens that respond to test methods in a manner comparable to the response of test specimens taken from field pavements at given stages of traffic and enviromental exposure.

Future research should address the following aspects:

- The production process: Procedures should be developed to condition laboratory prepared asphalt mixes to yield physical properties similar to that of mixes produced in a plant. Possible conditioning procedures include oven heating or extended mixing. The short term ageing is primarily due to the loss of volatiles from the binder.

- The construction process: The energy level of the laboratory compaction effort should be a variable in the new asphalt mix design method in order to set realistic target densities during the construction phase.

- Effect of traffic and environment: Samples should also be compacted to densities achieved at various stages of traffic loading. In addition, these samples must also be conditioned to simulated the long term ageing of binder due to oxidation and hardening. Promising methods include: oven ageing, pressure oxidation, actinic light treatment, and alternative ageing and moisture treatment. Moisture conditioning should also be incorporated into this phase.

The final result will be an entirely new approach in asphalt mix design which will be sensitive to all the aggregate and bitumen properties and which can be used to simulate the role of asphalt mixes under a wide range of in-service conditions.

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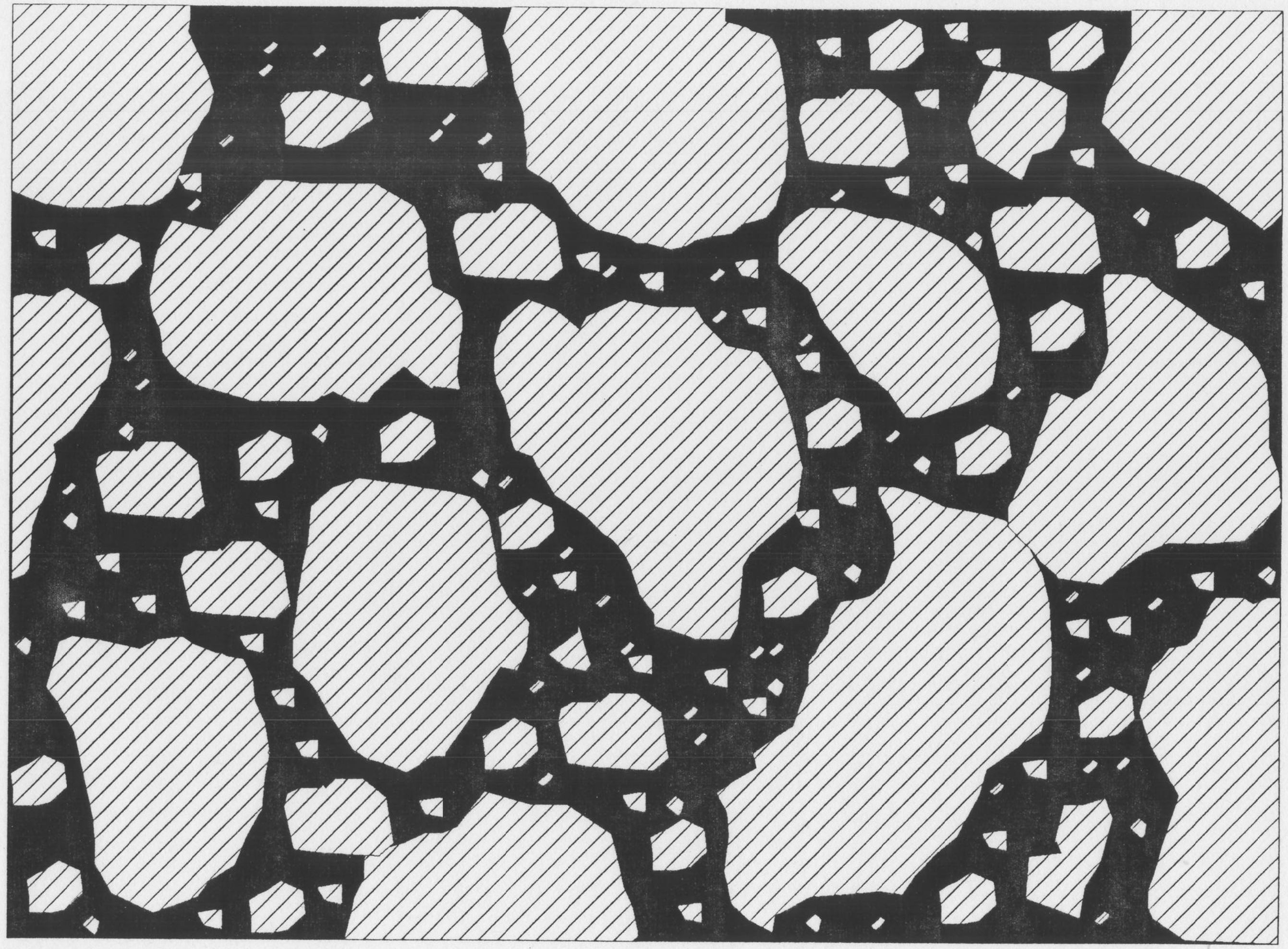

Figure 1 : Uniformly graded large stone mix

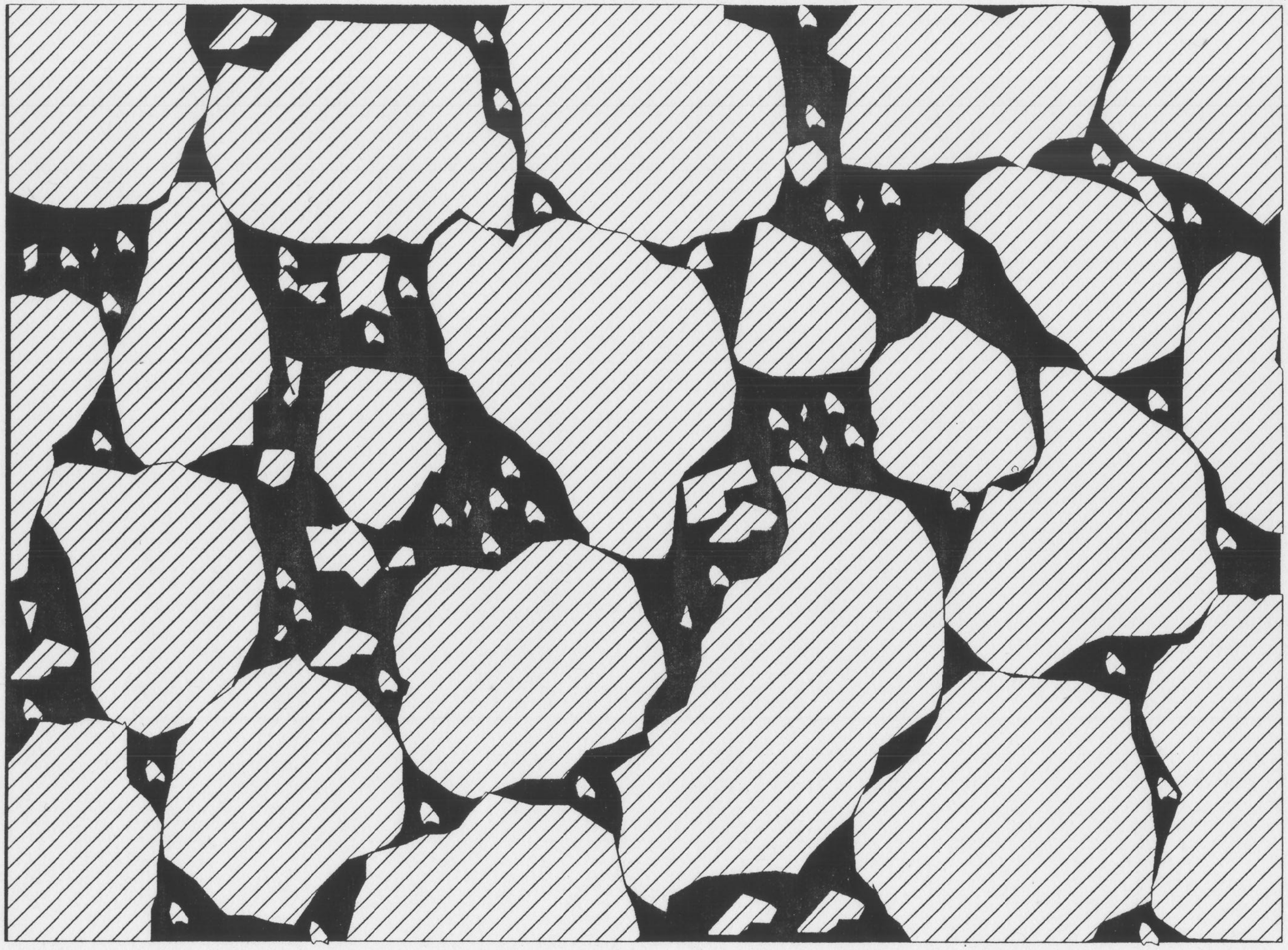

Figure 2 : Stone filled large stone mix

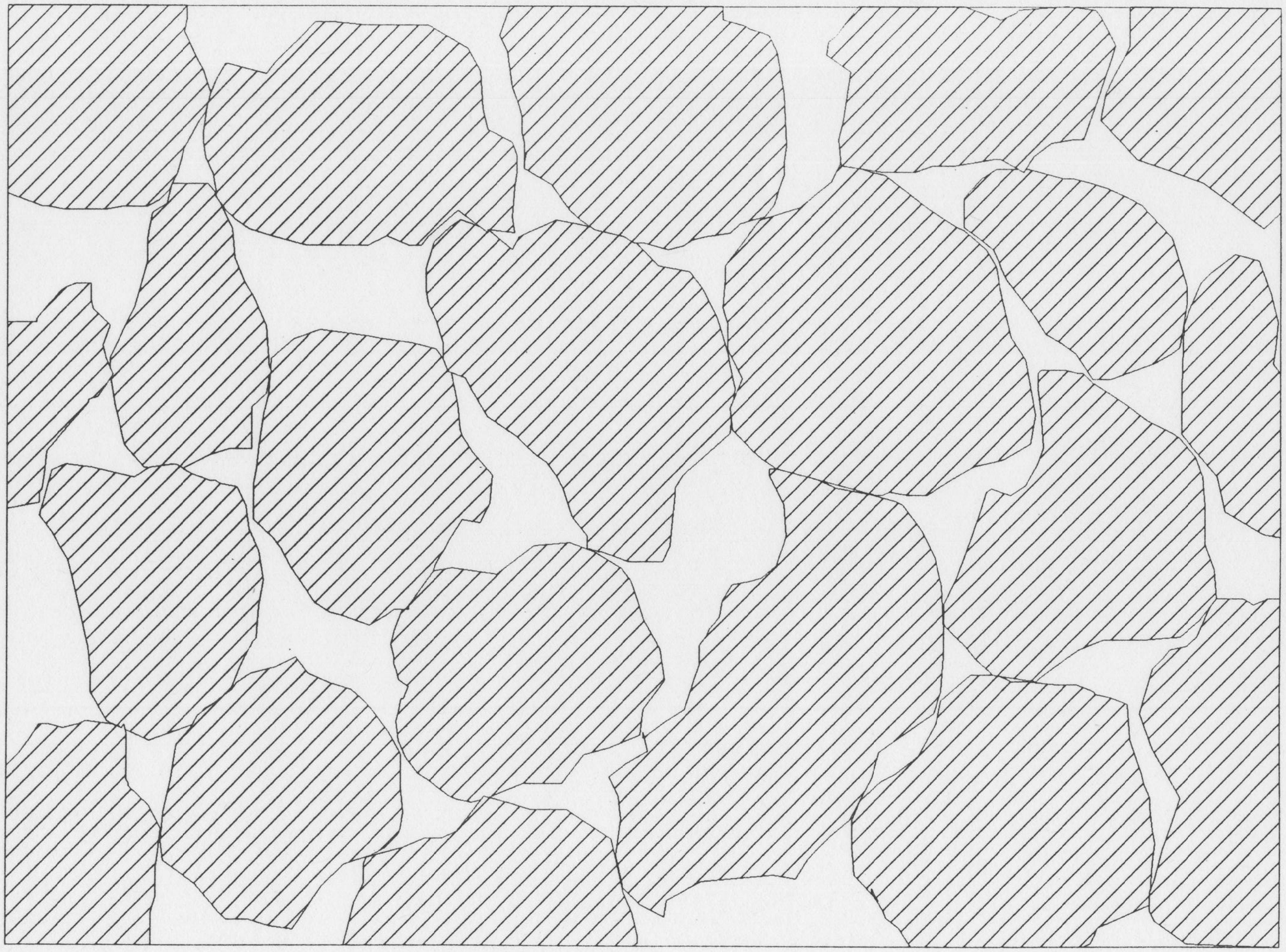

Figure 3 : Open graded large stone mix

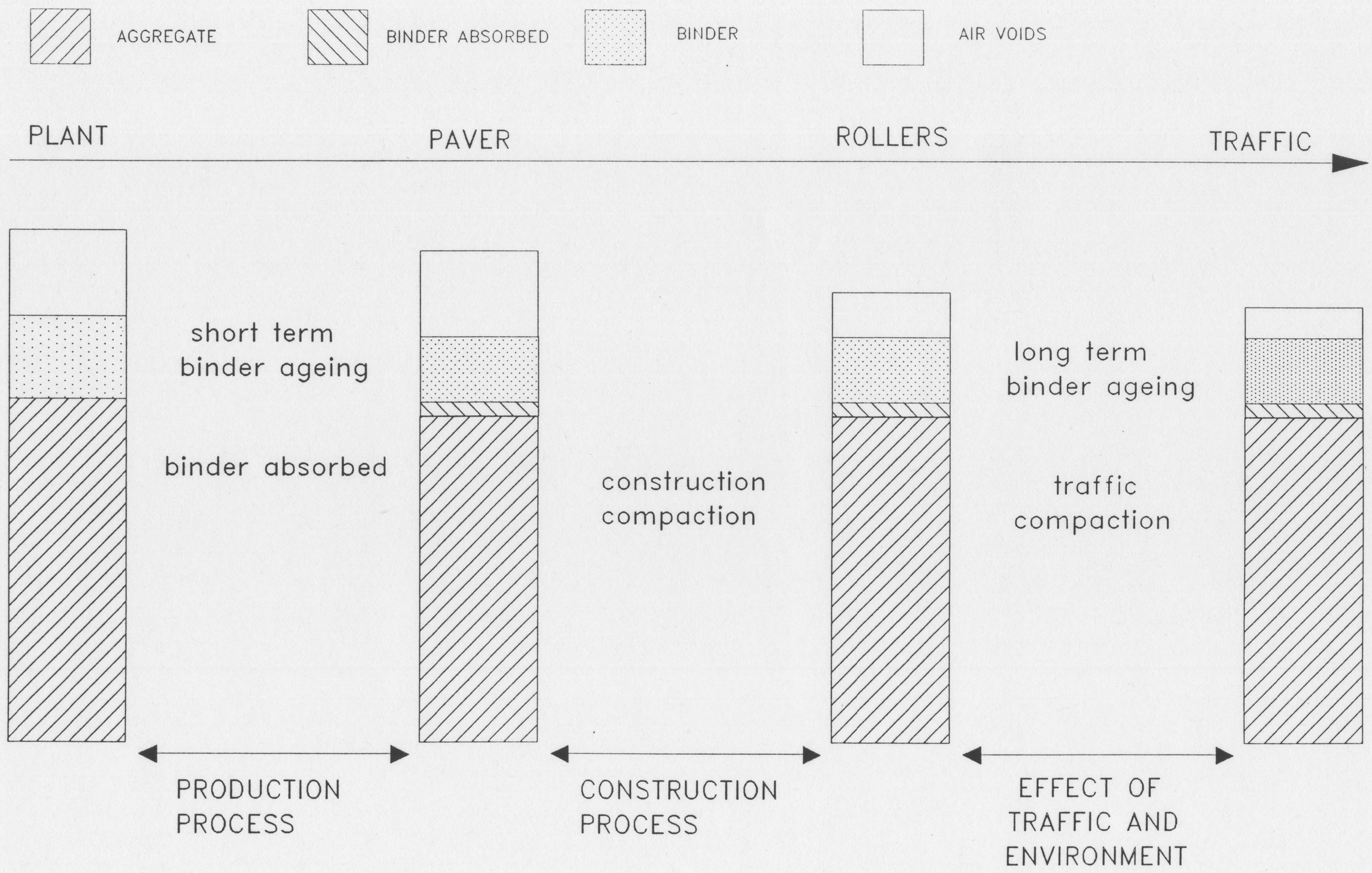

FIGURE 4 : DIFFERENT PROCESSES TO BE SIMULATED DURING MIX DESIGN

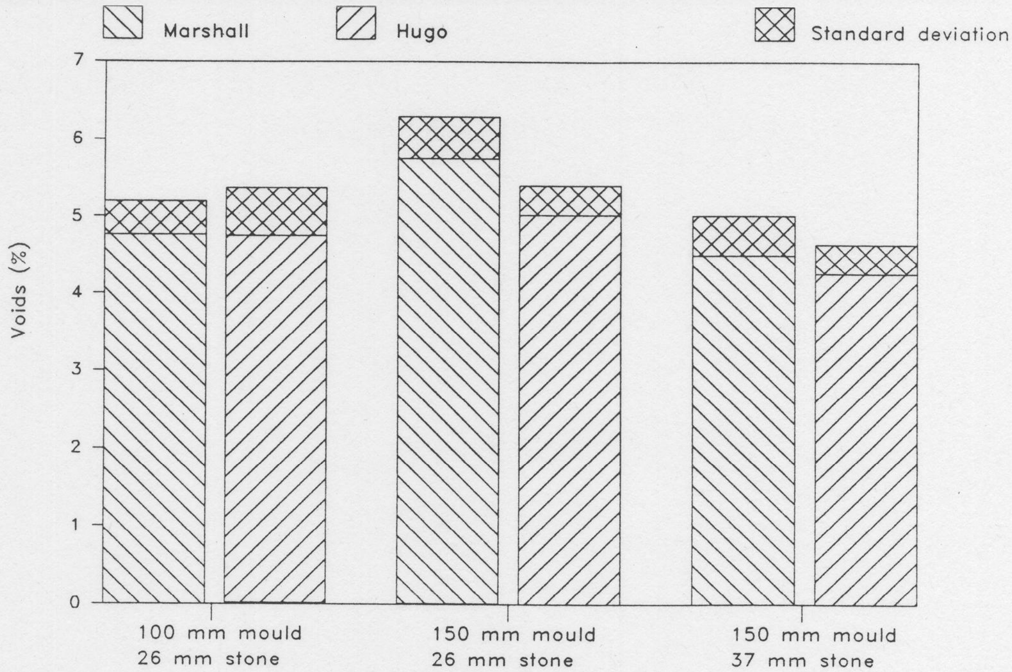

Figure 5 : Effect of variables on voids

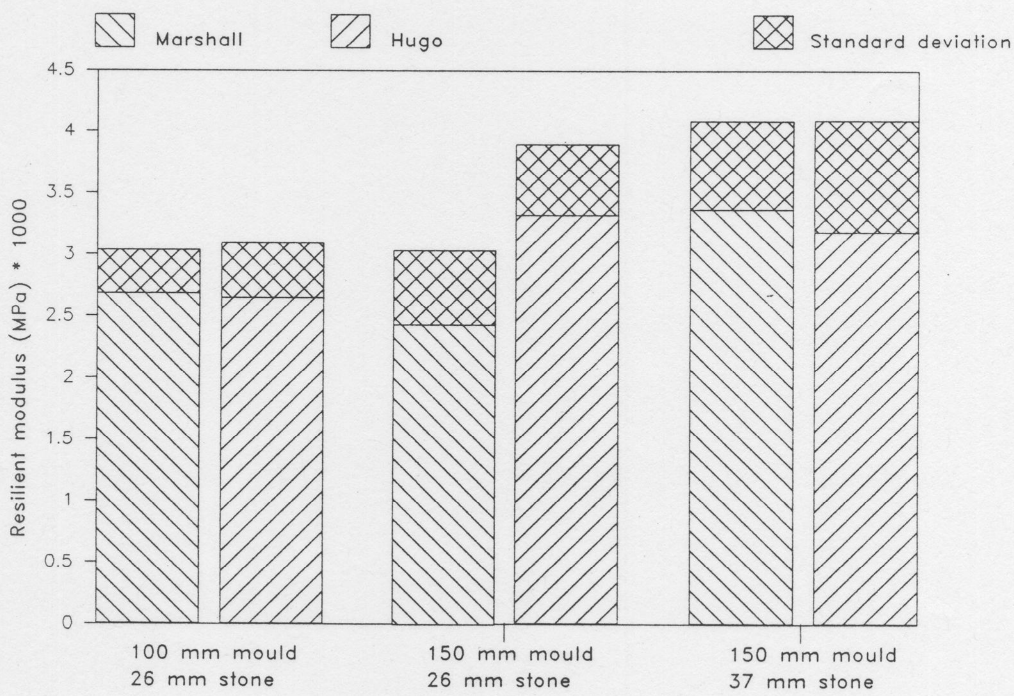

Figure 6 : Effect of variables on resilient modulus

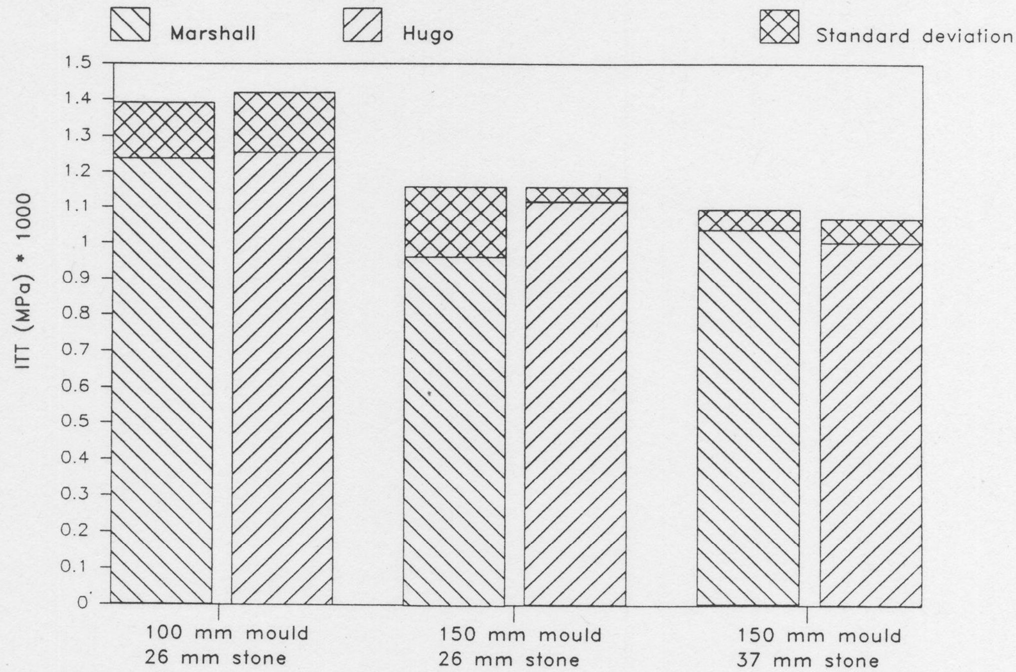

Figure 7 : Effect of variables on ITT.

Figure 8 : Effect of variables on creep modulus.