LAMBS AND GEMS

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SYNOPSIS

The applications for Large Aggregate Mixes for Bases (LAMBS) are presented, together with a short look at the research behind it. The mix design procedure is discussed in detail, including the latest revisions following experiences on various contracts. The use of the gyratory compactor is discussed. The experience on construction is presented, including modifications to plant and equipment. Granular Emulsion Mixes (GEMS) are then presented, together with the research behind the project. The two mix design procedures: modification at low emulsion contents and stabilisation at high emulsion contents, are introduced. The application of GEMS through insitu deep milling is discussed.

1 INTRODUCTION

In South Africa, where the railway system for freight transport (excluding bulk transport) has been found to be less attractive than road transport, most goods are conveyed by road to and from main industrial centres rather than by rail. Road traffic volumes have increased steadily with time, but now, in the post-apartheid era of South Africa, are expected to grow as a faster rate. This, in addition to requests by haulers to increase the permissible axle load and tyre pressure limits, has necessitated a fresh look at pavement design in order to meet or to pre-empt the demand for pavement structures able to resist the effects of traffic loading over their structural design life.

In light of the above, the Southern African Bitumen and Tar Association (SABITA) in partnership with the road construction industry and the CSIR, launched a research and implementation project directed at the development of cost-effective heavy-duty asphalt pavement (HDAPs). The results of this project led to the implementation of Large-Aggregate Mixes for Bases (LAMBs)

Large-aggregate mixes for bases or LAMBs are defined as asphalt mixes which obtain their strength and resistance to deformation from aggregate interlock. This is readily achieved by using large top size aggregate in the order of 37,5 mm and 53 mm. LAMBs do not presuppose a specific grading - rather, the approach optimises the properties of available resources in terms of raw material and plant.

LAMBs technology was developed following a detailed laboratory study, complemented by various field trials to validate their perceived benefits and the design methodology. The Heavy Vehicle Simulator (HVS) was used to establish criteria for LAMBs and to assess the performance of the asphalt by means of accelerated testing.

Transfer of technology was accentuated during the development of the technology in order to verify its soundness, to facilitate its acceptance by the industry and to accelerate its implementation. This took the format of technical presentations (South Africa, United States and United Kingdom), demonstrated projects (Cape Town, Dundee and Heidelberg road trials), technology transfer to authorities and consultants (at project level) and seminars in the main centres of South Africa.

The technology has now been widely accepted, as reflected by the number of projects where LAMBs has been or will be implemented. Except for the technology itself, the approach which had been followed led to a number of additional positive developments, amongst which are:

- greater awareness in the industry of volumetric and performance-related material properties and the significance of these
- the development of performance-related field testing devices
- the establishment of partnerships in the industry between authorities, civil consultants, contractors and research organisations (elimination of adversarial relationships) for the purpose of design and decision taking (greater focus on quality of end product), and
- greater emphasis on training ion all construction activities in order to improve the workability and homogeneity of the end product.

2 LARGE AGGREGATE MIXES FOR BASES (LAMBS)

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The advantages of LAMBs include the improvement in the structural capacity of the pavement at reduced cost resulting from:

- the increase in bearing capacity as aggregate size increases relative to layer thickness
- the increase in binder film thickness for a given binder content (by mass) as maximum size of aggregate increases, resulting in greater durability
- the increased resistance to indentation, abrasion and deformation as maximum stone size increases
- the decrease in material cost because of the savings in binder content on account of the smaller aggregate surface area which needs to be covered as aggregate size increases

2.1 Design of LAMBs

The design of LAMBs is based on a three-level rejection analysis of mixes manufactured with a grading selected based on available aggregate fractions and containing at least three different binder contents and two filler contents. The proposed tests to be conducted in each of the phases are summarised below. The design criteria of LAMBs are given in Table 1.

- Phase I : determination of bulk relative density, maximum theoretical bulk density, void content, voids in mineral aggregate and voids filled with binder
- Phase II: determination of indirect tensile properties, including resilient modulus and indirect tensile strength
- Phase III : determination of resistance to permanent deformation by means of the dynamic creep test

TABLE I : Design criteria of LAMBs

Property	Criterion
Density	Aim for maximum
Void content	Minimum 3%, maximum 6%
Voids in mineral aggregate (VMA)	Dry side of minimum VMA vs binder content, minimum 12%
Voids filled with binder	Minimum 72%, maximum 80%
Resilient modulus @ 25°C/10Hz	Minimum 2000 MPa (stiff layer) 1000 - 2500 MPa (flexible layer)
Indirect tensile strength (25°C)	Minimum 800 kPa
Dynamic creep modulus (40°C)	Minimum 10 MPa

The pavement structure influences the structural response and performance of LAMBs as the response of underlying layers to loading influences the stresses and strains in the upper asphalt layers. During the design phase it is important to ensure that the structural behaviour of the pavement subjected to loading is incorporated in the mix design of LAMBs. Pavement design and mix design should, therefore, form an interactive process. If LAMBs are to overlay a flexible structure, the emphasis of the mix design should be on the provision of LAMBs of low stiffness, unless the thickness of the LAMBs layer is such that it can protect the underlying layers effectively. In the latter case, LAMBs should be designed to have a great stiffness which can be achieved by selecting mixes with relatively high filler contents and low binder contents. If LAMBs are intended for use on a stiff supporting structure, such as on a cement treated layer, a mix of high stiffness should also be selected.

2.2 Constructibility of LAMBs

The constructibility of LAMBs is important as it influences the engineering properties of the pavement layer. Segregation in large stone mixes is a common problem, especially in mixes with discontinuous gradings (semi-gap or semi-open). Although LAMBs are not linked to a particular grading, the selection of a continuous grading would reduce the risk of segregation. The risk of segregation can be further reduced by proper control exercised at the mixing plant or by increasing both the binder and filler contents. As the latter would, however, result in an increase in cost, the process should be controlled during the mix design phase, where a balance between economic considerations and constructibility should be achieved.

2.3 Expected performance of heavy duty asphalt pavements containing LAMBs

In order to evaluate the performance of pavements containing LAMBs, three trial sections were constructed in the Province of KwaZula - Natal and evaluated by means of accelerated testing by the Heavy Vehicle Simulator (HVS). Based on the results obtained from HVS testing on continuously-graded LAMBs, indications are that these mixes should be able to carry traffic well in excess of 50 million standard 80kN axles without failure in terms of deformation within the base.

The successful implementation of LAMBs in South Africa could only have been achieved through the adoption of a partnership approach during the development, refinement and implementation of the technology. Although SABITA was the main financial contributor to the project, several other organisations contributed as the value of the end product became apparent.
An asphalt supplier based in the Western Cape Province (Much Asphalt) sponsored the construction of the Cape Town trial sections (also referred to as the Much Asphalt trials), while the Department of Transport and the Provincial Administration of KwaZulu - Natal sponsored

the constructed and HVS evaluation of the Dundee trial sections.

However, it has been the willingness of road authorities to test the technology in practise on large scale, and the commitment of civil consultants, contractors and producers to make it work which ensured the successful implementation of LAMBs. As Dr Horak, one of the pioneers into the implementation of LAMBs, said "The research project can be viewed as a model of focused and successful research and development. The need was clearly client driven and from the onset the project was directed towards the attainment of a practical and useful output. Specific and well planned management and funding were also committed to technology transfer, a phase which has often been neglected .... The technology transfer of LAMBs had already commenced when it was decided to use LAMBs as part of the rehabilitation on the M2 Motorway in Johannesburg. This decision significantly accelerated the transfer of knowledge and expertise to the road industry at large".

Even now, when the technology is being applied throughout South Africa, partnerships are still being formed to ensure that the best possible product is being delivered to the road users. One such an example is the KwaZulu - Natal LAMBs Liaison Committee, on which two road authorities (Department of Transport and KwaZulu - Natal Provincial Administration), three civil consultants, five contractors, two asphalt sub-contractors, SABITA and CSIR Transportek are represented, in order to conduct the planning, review the design, deal with constructibility issues and the means of controlling the quality of the product on the road.

2.4 Technology transfer

2.4.1 Industry awareness plan

As development of the LAMBs technology proceeded, continuous feedback on the progress of the technology was presented to the industry in order to create better awareness of the technology at the various stages of its development and to test the market for its acceptability. This was achieved by means of technical presentations and local research papers on the following occasions:

- Meetings of the Bituminous Materials Liaison Committee (BMLC) and of the
- Annual Transportation Convention (ATC)

The objectives of the BMLC, consisting of approximately 400 members involved in the uses of bituminous products, are to keep its members fully informed of activities and progress in the field of bituminous materials and to provide a forum for the discussion of problems of mutual interest. Feedback on the project received at BMLC meetings has given strong impetus to the project and assisted in focusing its objectives to meet the needs of the industry at large.

In addition to the above, the soundness of the technology was also verified by the publication of papers at two international conferences:

- 7th International Conference on Asphalt Pavements (SAP, 1992), and
- 6th Conference on Asphalt Pavements for Southern Africa (CAPSA, 1994)

In 1993, a SABITA Manual on the design and use of LAMBs was compiled by CSIR Transportek through a process involving the participation of representatives from:

- the South African Association of Consulting Engineers (SAACE)
- the Committee of Urban Transportation Authorities (CUTA)
- the Committee of State Road Authorities (CSRA)
- the asphalt industry (through SABITA), and
- CSIR Transportek

On completion of the manual seminars on the design and construction of LAMBs were held at three major venues in South Africa: Cape Town, Johannesburg and Durban. These seminars were attended by delegates with a wide range of competencies, ranging from major decision makers to technicians at grass-root level. Follow-up seminars were also held for focus groups, each addressing specific needs experienced during the planning, design or execution of contracts.

2.4.2 Technology transfer: implementation of technology

As was discussed previously, verification of the technology was initiated shortly after the commencement of the project (Much Asphalt trials) and LAMBs specifications were established, based on the results obtained from the Dundee trials where three types of LAMBs were subjected to accelerated testing by means of the Heavy Vehicle Simulator. The early involvement of asphalt producers and of road authorities during the construction and consequent evaluation of the mixes facilitated the implementation of full scale LAMBs projects.

Since completion of the development stage, the following projects have been or will be undertaken:

- MR7, Queensburgh, KwaZulu - Natal (1000 tonnes)
- N3, Athlone, KwaZulu - Natal (4000 tonnes)
- Jan Smuts Airport, Gauteng (5100 tonnes)
- Mitchell's Pass, Western Cape (27000 tonnes)
- M2 - Motorway, Gauteng (8900 tonnes)
- Outenique Pass, Western Cape (33000 tonnes)
- Durban, KwaZulu - Natal (15000 tonnes)

Planned LAMBs projects:

- N10, Olifantkop, Eastern Cape (35000 tonnes)
- Johannesburg, Gauteng (50000 tonnes)
- N2, Mtunzini, Project 1, KwaZulu - Natal (57600 tonnes)
- N2, Mtunzini, Project 2, KwaZulu - Natal (57600 tonnes)
- N2, Mtunzini, Project 3, KwaZulu - Natal (57600 tonnes)
- N2, Mtunzini, Project 4, KwaZulu - Natal (57600 tonnes)

The value of the projects where LAMBs technology has been or is to be used in the near future has exceeded all expectations and the technology is very likely to become an integral part of the roads industry. In some of the projects listed, LAMBs were selected in preference to competing granular or cementitious materials. Typical cases are the M2 -Motorway in Johannesburg and Mtunzini projects in the Province of KwaZulu - Natal. This is indicative of the willingness of the roads industry to implement the research findings obtained from the LAMBs project.

2.5 Impact of research, development and implementation

2.5.1 Direct benefits to the asphalt industry

The total investment by the asphalt industry in the development of LAMBs was approximately R1,0 million over a five year period. In addition, the Department of Transport and the Kwazulu - Natal Provincial Administration invested R5000000 into Heavy Vehicle Simulator testing of trial sections. The current direct returns to the industry in terms of turnover are R47 million, which justifies the research investment.

In order to assess the return on the investment in a simplistic way, it was assumed that only 50 per cent of this amount would accrue to the industry from additional asphalt work, and that normal industry profit margins would be achieved. Figure ? shows the resulting cash flow to the industry (taking into account investment by the industry as well as investment by the Department of Transport into HVS testing). With these assumptions, the research investment would be recovered within three years of completion of the main project. As the use of LAMBs becomes entrenched in the market place and the product cycle matures, this rate of return on the original investment is expected to increase.

2.5.2 Technology impact

Apart from the tangible benefits, the development of LAMBs technology has also resulted in a number of intangible benefits to the industry. The necessary new approach to mix design as a consequence of using larger aggregate sizes (conventional Marshall mix design approach being no longer applicable), led to the development of a performance-related mix design procedure which also found application in the design of and specifications for conventional asphalt mixes. The Standard Specifications for Road and Bridge Works, recently revised by the Committee of Land Transport Officials (COLTO), now includes specification for total air void contents, voids in mineral aggregate (VMA), indirect tensile strengths, dynamic creep moduli and other acceptance criteria applicable to the various types of asphalt wearing courses.

Also prior to the introduction of these new specifications, several parallel developments took place in order to validate as well as to facilitate the introduction of these specifications, such as:

- conditioning of laboratory mixes to simulate the processes taking place in the asphalt plant
- identification and implementation of compaction devices which better simulate field compaction
- introduction of field apparatus to determine the dynamic properties of laboratory specimens and cores (without these, the introduction of performance-related mix design criteria would have been a futile exercise), and
- establishment of databases to record the long-term performance of mixes designed according to the revised procedures

The use of Heavy vehicle Simulator (HVS) to validate the laboratory studies on LAMBs, to determine suitable design criteria and to prove the viability of the product, boosted the marketing potential of the technology in South Africa and elsewhere in Africa. The soundness of this approach resulted in the HVS-characterisation of a number of other innovative products to demonstrate their viability, such as:

- Granular Emulsion Mixes (GEMs) for use in bases
- porous asphalt wearing courses
- alternative types of surfacings for low-volume roads

Problems with the construction of LAMBs on certain projects necessitated a review of construction practices and of quality assurance methodologies in contractor organisations. This, in addition to trends elsewhere in the world to move towards total quality management and to the certification and performance guaranteeing of products, resulted in greater emphasis on training, technology acquisition and quality (possibly an ISO 9000 approach). These drives will lead to the improvement of asphalt technology and, more importantly, to the improvement of the road construction industry at large. Greater awareness has been created in the roads industry better to meet the challenges imposed by a changing environment. Furthermore, by the implementation of new technologies, such as LAMBs, the industry is being seen as a provider of quality products and of cost-effective technologies.

2.6 Guidelines on constructibility

It has been shown in the construction of the trial sections and in several large contracts that large-aggregate mixes can be constructed with relative ease. Problems related to constructibility can be avoided if appropriate measures are taken. Some recommendations regarding the manufacture and construction of LAMBs are given below, based on experience gained by industry and on the results of trial sections and implementation projects.

2.6.1 Stockpiling

Attention should be given to the stockpiling of the aggregate. This is the first phase in the manufacturing process and, if even limited segregation occurs in the stockpile, the effects of this could be exacerbated during the other phases.

2.6.2 The coldfeed system

The coldfeed system need not be modified for LAMBs. However, if 53 mm stones are used, some modifications to the gates of the 53 mm cold storage may be required. Because of the large grading spectrum, there should be sufficient coldfeed bins, especially in the case of drum plants.

2.6.3 Screen house

Modifications to the screen sizes may be required to accommodate the large-sized aggregate. In many cases all that is necessary is the removal of the top screen - provided that the quality of the large-aggregate stockpile is carefully monitored. The landing deck may require strengthening and the screen tensions should be checked.

2.6.4 Pugmill mixing process

The flights in the dryer and drum mixers may have to be reinforced to minimise increased wear and tear. In the case of a batch plant, the clearance between the paddle tips and liners in the pugmill may have to be increased.

The capacity of the pugmill is important and the motors must have adequate power. It is advisable to install a belt-driven device in case overloading occurs. A longer mixing time may be necessary to allow the larger aggregate to be coated.

2.6.5 Drum mixes

With respect to wear and tear, drum mixers are preferred to batch plants for the production of LAMBs, mainly because they do not have elevators, a screen house or a pugmill. However, it may be more difficult to control the grading in drum mixes. The following procedures are suggested to improve mixing in a drum mixer:

- devoting special attention to the lifters/flights in the drum
- extension of the mixing time by changing the angle of the drum
- shortening or lengthening of the bitumen injection pipe to achieve the required coating
- the use of an after mixer is preferable but not essential
- the installation of a secondary discharge chute at the exit of the drum is recommended. This will create storage for a reasonable amount of asphalt and reduce the vertical drop of the asphalt

2.6.6 Loading onto trucks

Segregation may occur when the asphalt is dumped onto a truck. This can largely be prevented by loading the front of the truck first, then the rear and finally the centre.

2.6.7 Silos

Silos should preferably be cylindrical. Segregation may occur if the asphalt is dropped a significant height in tall silos. To reduce this effect, a secondary stage within the silo is suggested. The silo should not be continually emptied and a fair volume of material should remain to reduce the height of the drop.

2.6.9 Paving

Handwork should be limited to the absolute minimum during the paving process and backspreading should be avoided. The thickness of the lift being paved should be at least 1,5 times the nominal maximum aggregate size. The flow control gates and slat feeders should be set so as to ensure that the required amount of material is fed to the augers and that a uniform height of asphalt is maintained at the front of the screed. The paving speed should be as uniform as possible. A lower paving speed co-ordinated with the asphalt plant production is preferred to a faster paving speed with a stop/start process.

An auger of sufficient length should be fitted to ensure movement across the full width of the paver. Efficient tampers are essential to push the mix under the screed. The wings of the receiving hopper should be left open as segregation may occur if they are opened and closed. Any surplus material should be discarded at the end of the day. The placement of buffer plates in the hopper may assist in reducing segregation. Finally, the hopper of the paver should be kept full in order to provide a continuous flow of asphalt.

2.6.10 Compaction

Compaction is generally regarded as the single most important factor affecting the durability and resistance to permanent deformation and fatigue cracking of the asphalt. Adequate compaction is one of the most cost-effective methods of ensuring the quality of the layer.

The advantage of LAMBs over conventional asphalt is that they retain their temperature longer which can assist the compaction process. LAMBs have proved to be easier to compact than some thin asphalt layers.

It is recommended that a static steel-wheel roller be used for breakdown compaction. A 22 to 27 tonne pneumatic-tyred roller should be used for the intermediate compaction phase, and a static steel-wheel roller again for the finishing. Vibratory rollers should be used with care.

2.6.11 Trial sections

Trial sections for final assessment of the mix and for honing the contractor's operation are recommended. Trial sections should be of sufficient length. Nuclear gauges can be used to evaluate the densities achieved and can be calibrated during the trials.

3 GEMS

3.1 INTRODUCTION

The development of a specialised design methodology for Granular Emulsion Mixes (GEMs) was defined as a need by the Southern African Bitumen and Tar Association (SABITA) in 1989. To this end it subsequently funded a technology development project conducted by the Division of Roads and Transport Technology (Transportek) of the CSIR. The initial research was validated through Heavy Vehicle Simulator (HVS) testing of three trial sections constructed near Heilbron in the Free State. The HVS work indicated that GEMS bases could carry up to E3 traffic under specific conditions. A cost analysis indicated that GEMS bases were indeed a cost effective alternative in areas where crushed aggregate has to be imported.

The success of the above work led to a further project to implement GEMS technology and to transfer the technology to industry. The work was conducted in the Britstown to Brak River road in conjunction with the Provisional Administration of the Western Cape and the appointed consulting engineering firm.

Various mix design methods were evaluated. A number of mix design variables were incorporated in the process, such as the addition of cement and the type of curing.

The investigation was limited to the design, evaluation and construction of the GEMS bases and did not include aspects such as pavement structural design.

3.2 DEFINITION OF GEMS

In the Gems manual [1] the following definition is given for GEMS:

The term "GEMS" includes emulsion modification or stabilisation of the following granular materials:

- ***substandard materials (normally those with high PI values)***
- ***other granular materials of better quality (up to G1/G2 materials)***
- ***recycled granular bases (may include surfacing)***
- ***recycled cement and lime-treated bases (in an equivalent granular state)***
- ***combinations of any of the above***

3.3 CONSTRUCTION

The construction techniques used on the Britstown-Brak River GEMS and Heilbron GEMS projects were relatively similar. These are briefly summarised below [3].

- ripping of existing surfacing and base
- provision of additional base material when required by importing from borrow pits
- grid rolling and removal of oversize material
- spreading and moistening of material
- spreading and mixing of cement
- spraying of 90 per cent of the total emulsion required (previously diluted to give a residual binder content of 30 per cent)
- mixing and compaction
- scarification of the top 30 mm of the base
- application of the remaining 10 per cent of the emulsion for enrichment
- mixing and compaction
- light mudrolling with water
- after two days fines swept off
- light sprinkling with emulsion (diluted to about 8%), and
- application of seal after 7 to 10 days.

Several problems were encountered during construction. These are discussed below [3].

Although as much oversize material as possible was removed, some inevitably remained, particularly on the shoulders and in the subbase. Where oversized material was present, the situation was improved by infilling with enriched material and by application of a final light mudroll.

The enriched mudrolled surface was not able to withstand heavy traffic and tended to ravel, despite the basecourse having been kept closed to traffic for over a week. Traffic was, therefore, kept off the basecourse until it had been surfaced.

The material used differed slightly from that used in the original design (the material used on the road was very variable). The graduation of the material used in the laboratory investigations is given in Table 1. The Optimum Fluid Content (OFC), determined in accordance with the

SABITA manual was satisfactory and agreed with that determined according to the method developed by Marais and Tait [2]. Although this was lower than that used in the actual project, the difference may be ascribed to the variability of the material. It is noteworthy that the contractor remarked on the high moisture content of the project material. The Resident Engineer subsequently authorised a reduction in the fluid content.

As part of this investigation two methods of determining the OFC were used and evaluated the standard Marshall mix design method and the Mod. AASHTO method. In the case of the Marshall method the mix was evaluated in terms of ITS, stability and resilient modulus. In the case of the Mod. AASHTO method the mix was evaluated in terms of CBR and ITS. In order to determine the effects of differences in treatment of oversized material, two different methods of eliminating oversize material were used; (1) the >37,5 mm material was scalped off and (ii) the oversize material was broken down to >19 mm material. The effects of the addition of cement were also evaluated, as were the effects of different types of curing. The results of theses test are given in Figures 1 to 3.

It can be seen that the addition of cement had a significant effect on the ITS and on Marshall stability as had variations in the curing period. There was, however, no apparent correlation between resilient modules and any of the other parameters. It was also found that breaking down the oversize aggregate to <19 mm results in a more workable mix and gives more reliable results.

3.4 CONCLUSIONS

The design of the GEMS, as regards optimum emulsion content, was well executed. It correlated well with the techniques prevailing at the time and with the provisions of the SABITA manual. The conclusions arising from the rehabilitation project and from the subsequent laboratory investigation may be summarised as follows:

- A GEMS base was successfully constructed on the Britstown-Brak River road.
- The variability of the base material used significantly affected the engineering properties of the emulsion-treated base.
- Dynamic Cone Penetrometer (DCP) measurements provided a reliable method of assessing the strength of the base. This is particularly useful since it is frequently difficult, if not impossible, to recover cores from the completed base for laboratory testing.
- The construction techniques appeared to be satisfactory.
- The engineering properties of the insitu material, the tests used and the results of these tests correlated closely with those recommended by SABITA [1].
- Although the strength of the base was inadequate for E3 traffic, indications are that, with time, the base will develop sufficient strength to carry this type of traffic.
- The quality control of GEMS during construction appears to be an issue which needs further investigation. Sampling of material for laboratory evaluation is not always feasible due to the breaking process of the emulsions. Coring of GEMS in the field, in particular when cement is used, is often difficult if not impossible.

4 REFERENCES

1 SABITA. GEMS-The design and use of granular emulsion mixes. Manual 14, SABITA, Cape Town, 1993

2 Marais C P, Tait M I. Pavements with bitumen emulsion treated bases: Proposed material specifications, mix design criteria and structural design procedures for Southern African conditions. Proceedings of the 5th Conference on Asphalt Pavements for Southern Africa, Swaziland, 1989.