A DESIGN APPROACH FOR GRANULAR EMULSION MIXES (GEMS)

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Abstract

Granular Emulsion Mixes (GEMS) are used in a wide range or road applications, ranging from low volume roads in developing areas to freeways in developed urban areas. In this paper a dual design approach for granular emulsion mixes (GEMS) is presented. An "asphalt" approach is used in the design of stabilised GEMS with residual binder contents of more than 1,5%, using design methods such as the Marshall mix design method. A "gravel" approach is used in the design of modified GEMS with residual binder contents of less than 1,5%, using test methods such as the California Bearing Ratio test method. The mix and structural design procedures for both approaches are discussed. The research was done on behalf of the Southern African Bitumen and Tar Association.

1   INTRODUCTION

Granular emulsion mixes (GEMS) are used in a wide range of applications in road construction, ranging from emulsion treatment of substandard materials in remote or developing areas (e.g. for bus routes) to the treatment of good quality materials in developed urban areas (e.g. freeways).

This wide range of applications with various materials calls for a dual design approach, in which the expected traffic and the sources of aggregate are taken into consideration.

Stabilised GEMS consist of granular material which generally contains more than 1,5% of residual binder. In the stabilisation design approach, GEMS are evaluated in essentially the same manner as conventional asphalts, by means of applicable test methods such as the Marshall test and the Indirect Tensile Test (ITT). Stabilised GEMS are particularly suitable for application in remote areas (low to medium traffic volumes) where the availability of aggregate may be limited to recycled or in-situ materials.

Modified GEMS contain residual bitumen contents of less than 1,5%. In the modification design approach standard gravel design and test methods, such as the Mod AASHTO and California Bearing Ratio test, are used.

The behaviour of GEMS, particularly in the case of stabilised gravel, is more complex than that of asphalt. In addition to its visco-elastic nature, which is similar to that of asphalt, GEMS tend to increase in strength after construction during the curing process. This curing process, the type of emulsion treatment and aggregate quality can significantly affect the relevant engineering properties such as stiffness, resistance to permanent deformation and resistance to fatigue cracking. Although stabilised GEMS are very sensitive to permanent deformation in the immediate post-construction period, the ultimate mechanism of failure is generally fatigue cracking. With the possible exception of lime- or cement-treated GEMS, modified GEMS tend to fail in terms of permanent deformation. Mix and structural design procedures for both modified and stabilised GEMS, in which these behaviour and performance issues are taken into consideration, are discussed in this paper.

The work presented in this paper is based on a three-year research project on the design and performance of emulsion-treated bases (ETBs) conducted by the CSIR on behalf on the Southern African Bitumen and Tar Association (SABITA). It is supplemented by the views and experiences of representatives of the asphalt industry, consulting engineers and road authorities.

2   DEFINITION AND SCOPE OF GEMS

The term GEMS includes 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 cement- and lime-treated bases (in an equivalent granular state), and
- combinations of any of the above.

The term excludes cold-mixed asphalt. Cold-mixed asphalt is produced when large amounts of emulsion are used with high-quality aggregates blended to specific gradings (e.g. open or continuous). This results in a product which is very similar to conventional hot mix asphalt.

3   BACKGROUND

Bitumen emulsion may be defined as a liquid product in which bitumen particles are suspended in water by means of emulsifying agents. The sizes of these bitumen particles range from 1 to 10 μm. The total bitumen content is generally between 60 and 70 per cent.

The composition of emulsion enables it to be used at ambient temperatures with consequent savings in fuel consumption and in the equipment required for heating. In addition, emulsion adheres readily to damp aggregates, which, therefore do not have to be dried. These advantages of emulsions make them particularly suitable for wet, remote and/or developing areas.

In addition to energy savings, emulsion.is attractive from an environmental point of view as there is no possibility of the release of harmful solvents or of other substances into the atmosphere.

Because of these advantages, emulsions have found application in a wide range of road construction or maintenance operations: as dust palliatives, surface dressings and cold-mixed asphalt from the 1920s, in-situ treatment from the 1950s, in granular emulsion-treated mixes and slurries from the 1960s, in microsurfacings from the 1970s, and in cold recycling from the 1980s. The popularity of emulsions in southern Africa has grown significantly over the last two decades. The use of emulsions currently represents 40% of all locally produced bituminous road products.

As regards the use of GEMS, the international trend is to use relatively large quantities of emulsions (from 3% to 8%) in combination with a wide range of granular materials. The general approach, from a design point of view, is to treat GEMS in a similar manner as asphalt.

South Africa is unique in that many granular bases with residual binder contents as low as 0,7% have been constructed. GEMS used in this manner have performed very well. In these cases, the general design approach was to treat these GEMS in a similar manner to granular materials.

Despite the growing popularity and use of GEMS over the past three decades, there is no standard method for establishing their behavioural characteristics. This can be attributed mainly to the complex nature of GEMS. In addition to the wide range of possible GEMS combinations (low/high emulsion contents and good/poor materials), GEMS are multi-component systems consisting of aggregate, bitumen, water and in many cases, lime or cement. This results in GEMS being having visco-elastic properties like asphalts, as well as showing an increase in strength with time as a result of the curing process.

4   DESIGN APPROACH

The wide range of possible combinations of GEMS calls for a dual design approach i.e. either the stabilisation or the modification approach.

4.1   Stabilisation of GEMS

When GEMS have residual binder contents ranging from 1,5% to 5% by mass of mix, the resulting product is termed "stabilsed GEMS". Materials used may include "poor to "good" granular materials (normally classified as from substandard to G1/G2).

During the design process, stabilised GEMS are treated like asphalt mixes. Asphalt-related compaction and test methods, such as the Marshall compaction method, Marshall stability test and the indirect tensile test (ITT) are used.

This product is suitable for use in bases subjected to traffic in the lower to high traffic classes. It can easily be applied in developing and remote areas, particularly in cases where material availability may be a major constraint.

4.2   Modification of GEMS

GEMS may also consist of granular materials (which may be classified as G4/G5 to G2/G1 materials) in combination with emulsions, with a residual binder content of between 0,6 % and 1,5 %. The use of substandard materials is not neccesary excluded, but these must be be used with care. This product is termed "modified GEMS".

The design of modified GEMS is based on principles relating to conventional granular material. Granular-related compaction and test methods are used, including the Mod AASHTO compaction method, Califoria Bearing Ratio test (CBR) and Unconfined Compressive Strength test (UCS).

Conventional G1 bases have been used successfully in high traffic volume roads (e.g with E4 traffic). Therefore, the use of modified GEMS could significantly enhance the performance of these roads, by improving properties such as cohesion and resistance to moisture damage. Depending on the material quality, modified GEMS may in many cases be suited for meduim to low volume traffic situations.

4.3   Selection of the appropriate design approach

The design approach is directly related to the classification of the particular GEMS. The major differences between stabilised GEMS and modified GEMS are summarised in Table 1. The appropriate design approach is based primarily on the following factors:

*   design traffic class, and
*   material quality.

Table 1 : Characteristics of Stabilised and Modified GEMS

	Stabilised GEMS	Modified GEMS
Residual bitumen content	1,5% or more	1,5% or less
Aggregate	Substandard to G2/G1 materials	
Traffic volumes	Low to High	
Laboratory compaction	Marshall	Mod AASHTO
Laboratory testing	Marshall and ITT	CBR, UCS and ITT

Some broad guidelines on the selection of the appropriate design approach are given in Table 2. Selection of the design approach may be influenced by factors relating to the structural design and environment. Combinations other than those given in Table 2 are, therefore, not necessarily excluded.

Table 2: Selection of the appropriate design approach (modification or stabilisation)

Material quality	Traffic class			
	E1/E0	E2	E3	E4
High quality (G1 to G3)	not cost-effective	modification	modification	modification stabilisation
Acceptable quality (G4 to G6)	modification	modification	modification stabilisation	stabilisation
Substandard (G7 or lower)	modification	modification stabilisation	stabilisation	not suitable

5 BEHAVIOUR OF GEMS

During the construction process, the fines in the aggregate appear to attract the emulsion. Once the emulsion has broken, a plastic mortar is formed, thereby improving properties such as cohesion, impermeability and resistance to moisture damage. Resistance to internal friction is generally provided by the larger-sized aggregate fractions.

The curing process, during which the emulsion breaks and water evaporates, can result in significant increases in the strength of GEMS (as reflected by their stiffness) over a period of up to two years. This curing process and relevant engineering properties are further discussed below.

5.1 Curing of GEMS

Curing is an important characteristic of GEMS which should be considered during the design process. The length of the curing period is mainly a function of the composition of GEMS as well as the climatic region. Modified GEMS in dry areas may attain their full strength within a few weeks, whereas stabilised GEMS in wet areas may cure for up to two years before their full strength is attained. GEMS with small amounts of emulsion tend to cure more rapidly, whereas those with larger amounts, particularly where the granular material contains large quantities of fines (e.g. sub-standard material), take longer to cure and to attain their full strength.

Other factors influencing the length of the curing period or, more specifically, the rate of breaking of the emulsion, include:

- the water absorption characteristics of the aggregate;
- type, quality and, particularly, the grading of the aggregate;
- moisture content of the mix after construction;
- type and quality of emulsion;
- mineral composition of aggregate, and
- the presence of lime or cement.

The cement in a mix may act as a catalyst which can assist the breaking process of the emulsion. Whenever early curing is required, especially when stabilised GEMS are used in a thicker layer, the use of cement should be considered. The advantages of the use of cement in terms of early curing and other structural characteristics should always be weighed up against the financial implications.

5.2   Stiffness

The stiffness of GEMS has to be accurately determined if a sound structural design is to be achieved. GEMS with high stiffness values can contribute towards reducing subgrade rutting, or, alternatively, enable layer thicknesses to be reduced, resulting in more economical pavement designs.

A number of factors (particularly in the case of stabilised GEMS) influence the stiffness of GEMS and should be taken into consideration during the structural design process. These are:

*   amount of curing;
*   air temperature, and
*   rate of loading.

During the mix design process, the stiffness of stabilised GEMS should be characterised at both summer and winter temperatures. Stiffness is measured at both initial and final curing conditions during this process. Curing is then assessed during the structural analysis by means of various stiffness values (which are functions of the laboratory stiffnesses at initial and final curing conditions) at different time intervals.

As modified GEMS require less emulsion, the above factors are less significant. The structural design process is also simplified and only a single stiffness value is required.

5.3   Resistance to permanent deformation

Permanent deformation is the result of the accumulation of repeated plastic strains occurring in the GEMS due to traffic loading. This is caused by both consolidation and shear movement.

Stabilised GEMS are sensitive to permanent deformation during the early stages of curing, particularly during the first month.   Marshall stability is normally used as a design criterion for prevention of premature permanent deformation.

Once the curing process has been completed, permanent deformation is rarely the primary failure mechanism. However, if the GEMS return to an "equivalent granular" state after extensive cracking, permanent deformation will occur.

The primary mode of failure of modified GEMS is generally shear deformation. The design of these GEMS is therefore similar to that of conventional granular materials.

5.4 Resistance to fatigue cracking

The tensile strength of GEMS is progressively reduced by repeated stress applications, which can lead to fatigue cracking. This cracking is normally controlled by proper pavement and mix design.

During the structural design process, stabilised GEMS are designed to resist fatigue cracking. This resistance to fatigue cracking generally increases as the emulsion content increases. Another advantage of GEMS is that their fatigue resistance properties are not as sensitive to binder content as are those of asphalts. Small variations in binder content would not, therefore, affect the fatigue resistance of GEMS significantly.

When lime or cement is used in modified GEMS, their behaviour tend to be similar to that of lightly cemented materials: cracking is then be the dominant failure mechanism. In general, the use emulsion improves the flexibility of bases as opposed to the use of only lightly cemented materials.

5.5 Durability

A major advantage of emulsion treatment is that resistance to moisture susceptibility is improved, mainly because the fines in the mix are bound by the residual bitumen. Although the use of emulsion in quantities greater than the design emulsion content may not have significant structural benefits, it would greatly enhance the durability of the material.

Water can be an aggressive environmental factor whose effects should never be underestimated. It is good practice to assess the water susceptibility of GEMS in the following situations:

* when using water sensitive aggregates (e.g. ferricrete);
* when GEMS are used in wet regions, and
* when emulsion contents are low.

6 MATERIAL REQUIREMENTS

Proper control over the ingredients of GEMS is essential. In addition to the material requirements discussed below, careful attention should be paid to the storage and handling of emulsions during construction.

6.1 Emulsion

Stable-grade anionic (60% residual bitumen) is normally used for GEMS, although there is no reason to believe that cationic emulsion would not be equally or even more effective for certain types of aggregate.

The emulsion used should comply with the relevant SABS specifications for bitumen emulsions (SABS, 2 & 3). If there is no national standard for the emulsion to be used, the client's or manufacturer's in-house specifications should apply.

In theory, the type of aggregate in combination with the ionic nature of the emulsion affects the adhesion properties of the resulting product. Care should be taken when acid crystalline aggregates (e.g. quartzites and granites) are used with anionic emulsions. However, there have been no reports of problems arising out of the use of these aggregates in GEMS with anionic emulsions.

6.2   Aggregate

Some granular materials react well with emulsion, while there may be others which do not. The compatibility of an aggregate with emulsion should preferably be established before commencing a mix design. Types of materials which are known to react well with emulsions (without lime) include:

- non-plastic decomposed granites;
- non-plastic quartzite gravels;
- non-plastic dolomite/chert gravels;
- non-plastic sandstone gravels, and
- non-plastic crushed stone of various rock types.

Aggregates classified as G1 to G5 should comply with the recommendations given in TRH14 (CSRA, 4). Specifications for sub-standard material are contained in the SABITA manual on GEMS (SABITA, 1).

6.3   Lime and cement

If the Plasticity Index (PI) of the granular material to be used for either stabilised or modified GEMS exceeds the levels indicated in Table 3, the material should be treated with lime or cement to reduce the PI to an acceptable level.

Table 3 : Suggested limits for PIs before emulsion treatment.

Material type	Plasticity Index (PI)	
	Stabilisation	Modification
G1 to G2	-	3*
G3 to G5	7	6
Substandard materials	7	-

* The Department of Transport has assigned a value of three for slightly plastic materials.

The advantages of using granular materials with low PIs or even non-plastic materials cannot be overemphasized. PIs should be reduced to below 7 whenever it is economically possible to do so.

Not all types of granular materials react well with lime, while others do not necessarily react well with lime under all conditions. Tests such as the initial consumption of lime are required before emulsion treatment of such materials can be considered.

The following types of material are known to react well with lime:

*   weathered granite;
*   weathered dolerite, and
*   weathered norite.

Some materials which do not react well with lime are:

*   certain weathered diabases;
*   certain weathered andesites, and
*   certain pedogenic materials.

7   DESIGN OF STABILISED GEMS

The stabilisation approach, which is based on research initially conducted by Marais and Tait (5) is described in detail in the applicable SABITA manual (SABITA, 1). Some of the important elements of this approach are discussed below.

7.1   Sample preparation

The optimum fluid content of GEMS is determined according to the principles applicable to normal granular materials. There are, however, some differences. Firstly, a 50/50 blend of emulsion and water is used to determine the fluid content which yields the highest dry density. Secondly, the material is compacted according to the standard 75 blow Marshall procedure (at room temperature). As the material has to be compacted in a 100 mm diameter mould, particles larger than 19 mm should be crushed as described in Method A7 of TMH1 (CSRA, 6).

Samples are compacted at the same optimum fluid content according to the Marshall compaction method at various residual bitumen contents. Residual bitumen contents of 2%, 3%, 4% and 5% are suggested.

Samples are mixed at fluid contents above the optimum in order to allow for evaporation and aeration during mixing. The total fluid content (TFC) is defined as the optimum fluid content (OFC) plus the additional mixing water (e.g. 2%), which is allowed to evaporate prior to compaction.

7.2   Curing and testing

The relevant properties of GEMS are determined at two different curing conditions, namely after:

*   initial curing at 40°C for four hours, and
*   final curing at 60°C for 20 hours.

The Marshall stability and flow of the GEMS at 23°C and 40°C are determined after initial curing only. Stabilised GEMS may be sensitive to deformation during the period immediately after construction. It is therefore essential to characterise GEMS in terms of resistance to permanent deformation during this period by means of a simple

standard test such as the Marshall test. The appropriate design emulsion content is governed mainly by the required minimum Marshall stability.

Relevant engineering properties used during the structural design process are determined by the Indirect Tensile Test (see Figure 1). Both the resilient modulus (MR) and indirect tensile strength (ITS) are required at the initial as well as final cured states of the applicable samples. These tests are normally only conducted at the design emulsion content.

In addition to the standard test conditions (SABITA, 1), the MR and ITS are determined at both 23°C and 40°C so as to characterise the structural properties of GEMS in both winter and summer conditions.
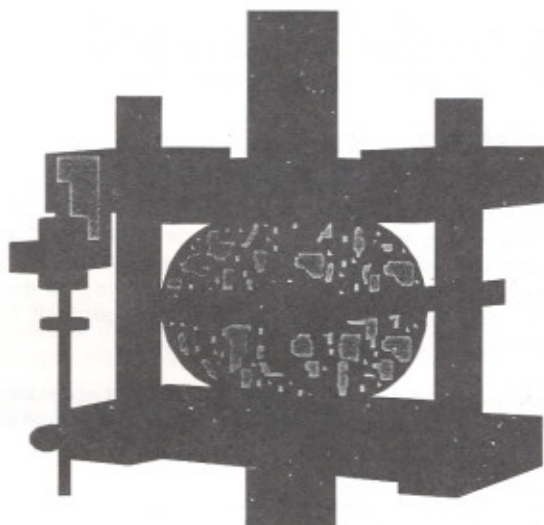

Figure 1 : The indirect tensile test (ITT)

If equipment for determining the stiffness of GEMS is not available, the following relationship may be used to determine the stiffness (E) from the indirect tensile strength (ITS):

$$E \ (MPa) = 2,2 \times ITS \ (kPa) + 168$$

Whenever required (e.g. in wet regions), the resistance of GEMS to water exposure should be determined. The capillary test is suggested for this purpose.

7.3   Mix design criteria

A modified Marshall method is used to determine the appropriate emulsion content. Although it would be preferable for the design emulsion content to correspond with the highest Marshall stability, lower contents may be used, provided that the mix design criteria (Marshall stability and stiffness) at both 23°C and 40°C as given in Table 4 are adhered to. The reason for this relaxation from the preferred situation, is that GEMS are not as sensitive to emulsion content as are asphalts.

A maximum void content of 15% is suggested so as to prevent ingress of water and consequent reduction in the cohesion properties of GEMS. GEMS need to be slightly permeable to allow the emulsion to break and the mix to cure, hence the minimum void content criterion of 5%.

Although the MR and ITS required for the structural design process are determined at various temperatures and under varying conditions of curing, mix design criteria at 23°C only are required at the final curing state. An ITS value of 50 kPA after the mix has been exposed to water (Capillary method) is suggested to control the durability of GEMS.

If the Marshall design criteria and the minimum indirect tensile strength and stiffness criteria are not met, or if the GEMS are very sensitive to water, the addition of 1,5 to 2% cement should increase the strength of the mixture.

7.4   Structural analysis

The structural design is based on a method proposed by Santucci (7) in which the analysis period is divided into smaller intervals. Santucci's method was simplified by using quarterly (three month) periods instead of monthly periods.

Table 4: Interim mix design criteria for GEM materials

Properties after initial curing	Traffic class	
	E0 to E2 (minimum)	E3 to E4 (minimum)
Marshall stability at 23 °C (kN) Marshall stability at 40 °C (kN)	2,2 1,0	4,0 2,0
Marshall stiffness at 23 °C (kN/mm) Marshall stiffness at 40 °C (kN/mm)	1,5 1,0	3,0 2,0
Percentage voids in mix	5 % to 15 %	
Properties after final curing	Water exposure	
	Before	After
Resilient modulus at 23 °C (MPa) Indirect tensile strength at 23 °C (kPa)	1 000 100	- 50

The E-value for each quarter is a function of:

- climatic region (wet, moderate or dry);
- amount of curing (e.g 6 months), and
- temperature (winter, spring, summer or autumn).

A method of determining the E-values at various quarters, using the resilient moduli of the mix as determined before and after final curing, is contained in the SABITA manual on GEMS (SABITA, 1).

As fatigue is generally the mechanism of failure of GEMS, the base layer is analysed accordingly. The maximum horizontal tensile strain at the bottom of the base should be determined using computer programs such as MECDE3 or ELSYM5.

Fatigue criteria published by Santucci (7) for GEMS (with and without cement-treatment) have been adopted. The fatigue curve for GEMS without cement treatment is provided in Figure 2.
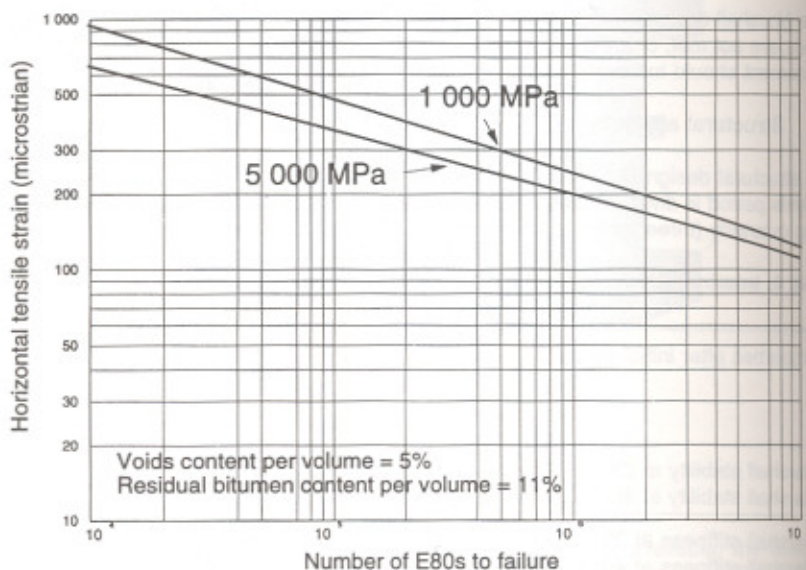

Figure 2 : Fatigue criteria for granular emulsion mixes (without cement)

When these fatigue curves are used, the void content and residual binder content of the mix are based on percentages of the total volume of the mix. Figure 2 applies to GEMS with a void content of 5% (by volume) and a residual binder content of 11% (by

volume). A method of determining the fatigue life of stabilised GEMS with different void and bitumen contents is given in the SABITA manual on GEMS (SABITA, 1).

8   DESIGN OF MODIFIED GEMS

The design of modified GEMS is considerably easier than that of stabilised GEMS. The design procedure of modified GEMS is discussed in detail in the SABITA manual on GEMS (SABITA, 1). Some elements of this approach are discussed below.

8.1   Sample preparation

The optimum moisture content (OMC) of modified GEMS is determined similarly to that of conventional granular materials using the standard Mod AASHTO described in Method A7 of TMH1 (CSRA, 6). In the case of modified GEMS the OMC is determined with water only.

After the OMC has been determined, samples are compacted according to the Mod AASHTO method at residual binder contents ranging from 0,6% to 1,5%. The total fluid content is generally 1% to 2% higher than OMC, and mixing should continue until the fluid content has reached the optimum fluid content for compaction.

8.2   Curing and Testing

The curing and testing process are simplified so that only final curing and one test temperature of 23°C are used. The final curing required for these mixes is 45 hours at 60°C.

After final curing modified GEMS is characterised in terms of:

- California Bearing Ratio (CBR);
- Unconfined Compressive Strength (UCS);
- Indirect Tensile Strength (ITS), and
- Resilient Modulus (MR).

Mix design criteria are usually based on CBR and UCS. However, as the ITS is a more fundamental property, it is suggested that this test should be carried out and the results recorded, so as to enable a database to be developed.

If equipment to determine the resilient modulus (23°C) is not available, the stiffness (E), required for the structural design, may be calculated from:

$$E(MPa) = k \times CBR\ (\%)$$

where
$\quad k = 5$ for G1 and G2 materials
$\quad k = 6$ for G3 and G4 materials
$\quad k = 7$ for G5 materials

8.3   Mix design criteria

The mix design criteria in terms of CBR and UCS for modified GEMS are given in Tables 5 and 6.

Table 5: Mix design criteria in terms of CBR

Traffic class	CBR (%)
E0	45 % at 95 % compaction
E1	60 % at 95 % compaction
E2	80 % at 98 % compaction
E3	100 % at 100 % compaction
E4	140 % at 100 % compaction

Table 6: Mix design criteria in terms of UCS

Material code	UCS (kPa) @ Mod AASHTO compaction
G1	1 500
G2	1 200
G3	1 000
G4	750
G5	500

The appropriate emulsion content is generally selected as the lowest emulsion content at which all the mix design criteria are met. It is suggested that samples be compacted at OMC in increments of 0,1% residual binder content.

If these criteria are not met, consideration should be given to adding lime or cement (preferably not more than 1 %).

8.4   Structural analysis

Modified GEMS are treated similarly to conventional granular materials. However, the emulsion in the mix tends to bind the fines, thereby increasing the cohesion of the material. The cohesion term used to calculate the safety factors is doubled during the structural design process of modified GEMS.

During the mechanistic analysis process, with computer programs such as MECDE3 or ELSYM5, the major and minor principal stresses in the middle of the base are calculated from only one E-value.

The safety factor for modified GEMS can be determined from the following conceptional model:

$$F_{GEM} = 2 \times c_g + \phi_g$$

where F_{GEM} = safety factor of modified GEM
         c_g = cohesion value of virgin material
         Φ_g = angle of internal friction of virgin material

More details on the calculation of safety factors for modified GEMS are given in the SABITA manual on GEMS (SABITA, 1). The number of E80s to failure of modified GEMS is then determined from Figure 3.
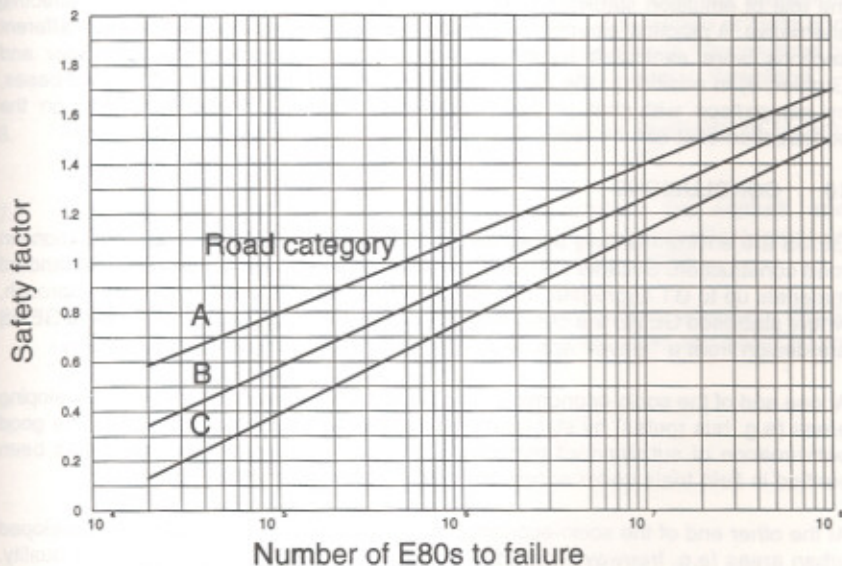

Figure 3 : Structural design criteria for granular emulsion mixes.

9   ECONOMIC CONSIDERATIONS

It is accepted that the additional cost of GEMS (e.g. modification approach) equates to less than 10 % of the total construction cost. However, if standard life cycle costs are included in the economic analysis, the additional cost of emulsion treatment, as a percentage of the Net Present Value (NPV), is significantly reduced.

In addition to the improvement in performance of GEMS, relative to that of conventional granular materials, the risk of unforeseen failures of these mixes is small. Such unforeseen failures are generally caused by moisture ingress, construction defects and overloading. Therefore, the use of GEMS should be considered when the amount of allowable risk is small (e.g. as in the case of category A roads).

When good quality aggregates have to be imported, haulage costs can be a substantial component of the overall construction cost. These costs are generally a function of the hauling distance. When the hauling distance exceeds a certain level, the use of emulsion stabilisation of substandard materials becomes a cost effective alternative. A practical example of this approach is the Heilbron trial, in which different sections were evaluated by the Heavy Vehicle Simulator (HVS) (de Beer and Grobler, 8) In addition to the excellent performance of these stabilised GEMS bases, by comparison with that of the G1 bases, meaningful financial savings on the construction cost can be realized.

10   CONCLUSIONS

GEMS are environmentally acceptable products with a wide range of applications in road construction. Suitable materials for emulsion treatment range from substandard materials up to G1 aggregate. This situation has resulted in a dual design approach, where stabilised GEMS are designed from an "asphalt" approach and modified GEMS are design from a "gravel" approach.

At one end of the socio-economic scale, GEMS can be used effectively in developing areas (e.g. bus routes) by stabilisation of in-situ material with emulsions. The good performance of substandard materials (using the stabilisation approach) has been verified in field trials under accelerated pavement testing (HVS).

At the other end of the socio-economic scale, GEMS are ideally suited for developed urban areas (e.g. freeways) provided that the aggregate is of an acceptable quality.

GEMS are economically justified in many instances. Economic advantages include improved performance, reduction in risk-related aspects and major savings in the haulage costs of good quality material.

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