FOAM

Duurzame funderingen door in situ recycling met schuimbitumentechnologie

PART IV:

Structural design of pavements with BSM

EMIB
Energy & Materials in Infrastructure & Buildings
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Summary

Belgium, like many other countries, is looking for cost-effective, sustainable and environmentally friendly solutions for pavement rehabilitation. Cold recycling of deteriorated pavements using bitumen stabilization, such as foamed bitumen or bitumen emulsion, appears to be a priority solution for the sustainable future of the road paving industry. However, this technology is still not entirely accepted in the Belgian road industry. The FOAM project was recently launched in Flanders to demonstrate the feasibility of using bitumen stabilization for the base layer of asphalt pavement in terms of technical, economic and environmental aspects.

This report documents the technical basis of the structural design of asphalt pavements incorporating bitumen stabilized material BSM base layer. Moreover, this Flemish guide provides a wide range of standard BSM pavement structures. These standard structures would be a good reference for all stakeholders (such as contractors, consultant engineers, local governments…..etc) who will deal with BSM technology in the Flemish market. In this guideline, two types of standard BSM pavement structures are available :

- Type A : (AC wearing layer 4cm + AC underlayer + BSM base + Subbase).
- Type B : (AC wearing layer 4cm + BSM base + Subbase), Where BSM will be utilized as double use in the pavement system. It won't be only a pavement foundation but also to compensate the AC underlayer.

This report provides 90 standard BSM pavement structures of type A were designed, in addition to 50 standard BSM pavement structures of type B.

The pavement design was implemented using a Flemish mechanistic pavement design approach and then verified using the South African mechanistic pavement design approach. In general, a good correlation between design methods was observed during the design process. It was noticed that the seasonal AC stiffness approach, that followed in Flanders, resulted in safer standard pavement designs. While the South African pavement design approach resulted in longer service life or thinner structures.

However, the cold recycling technology seeks the upper horizon of the pavement system, the existing pavement foundation, subbase and subgrade shall be fully investigated. For each uniform road section, a single uniform design section shall be designed. So that, for rehabilitation design situations, it is presumed that the designer will have detailed information on the existing pavement layer properties for each uniform section. Consequently, it should be recognized that each uniform section may require a different BSM mix design and therefore different shear parameters and consequently a different BSM layer thickness (recycling depth) to achieve the required structural capacity. More cost-effective structures could be designed based on the current condition of the road, the construction history and the deflection patterns.

Furthermore, the Flemish standards SB250 v4.11 should be always consulted to check if the minimum acceptable criteria are fulfilled or not. If not, then it is recommended to consult a professional pavement expert who has good experience with cold recycling technology.

By observation in the design trails, it was discovered that an increase in one or more of the following 'qualitative' parameters leads to an extension in the service life of a pavement incorporating BSM, according to the Stellenbosch BSM transfer function:

- BSM cohesion,
- BSM friction angle,
- BSM thickness,
- BSM stiffness,
- Subgrade elastic modulus/stiffness.

Abbreviations

AASHTO	American Association of Highway and Transportation Officials
BSM	Bitumen Stabilised Materials
C	Cohesion
CBR	California Bearing Ratio
CIPR	Cold In-Place Recycling
DSR	Deviator stress ratio
HMA	Hot-Mix Asphalt
ITSDRY	Indirect Tensile Strength test
ITSWET	Indirect Tensile Strength test, soaked specimens.
LTPP	Long-Term Pavement Performance
MDD	Maximum dry density
ME	Mechanistic-Empirical
MESAL	Million equivalent standard axles, 100 kN axles – (super single)
OMC	Optimum moisture content
PN	Pavement number design method
RAP	Reclaimed Asphalt Pavement
SB250	Flemish standard manual (standardbestek) for infrastrucutre.
SAMDM	South African Mechanistic (pavement) Design Method
TG2	Technical Guideline No. 2, published by the Asphalt Academy (2002)
σ1, σ2, σ3	Major, intermediate and minor principal stress
Ø	Fricition angle

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1 Introduction

1.1 Project Description

The Tetra project HBC.2020.2094 "Sustainable base layers through in-situ recycling with foamed bitumen technology" - referred to as the "FOAM project"- has the overall objective of technically, economically and ecologically testing and evaluating foamed bitumen technology for base layers, leading to a more sustainable base. The results are disseminated for further implementation. The project started on November 1st, 2020 and was finalised on 31 October 2022. The project was carried out by the University of Antwerp, the Belgian Road and Research Centre, and Odisee University College. The project was funded by VLAIO.

To obtain sustainable road structures, attention should not only be paid to the asphalt pavement, the base layer also plays a decisive role. Bitumen Stabilised Material "BSM" is a material in which the granulates - in this project 100 % reclaimed asphalt - are held together by 3 % foamed bitumen or bitumen emulsion. The FOAM project tested the use of BSM as a base material, investigating its structural, ecological and economic impact. The project resulted in a method for mixture design and structural road design with BSM and was demonstrated through the construction of pilot sections. These trial sections are further followed up by a monitoring campaign.

The report of the FOAM project consists of 6 reports.

- PART I: Management report FOAM project
- PART II: Market Potential for BSM in Flanders
- PART III: Mix design of BSM
- **PART IV: Structural design of pavements with BSM**
- PART V: Sustainability Assessment of pavements with BSM
- PART VI: Synthesis report of test sections

This report covers **Part IV** which seeks to find a sets of standard pavement structures incorporating with BSM's foundation, which would be beneficial for any stakeholders (Flemish governmental agencies, Flemish municipalities & contractors). By this way, a new type of pavement foundation material (i.e. BSM) could be inserted in the AWV manual, similar to other foundation materials in (MOW/AWV/2010/2).

As a first Flemish experience, a Foam project (2020-2022) aims to clarify BSM's properties in the laboratory and to investigate the mix design perfectly, in addition to demonstrate structural design practices. Hopefully, this initiative will assist in showcasing this technology to the in general market or to potential customers.

The objective of the pavement structural design is to ensure that the pavement system provides an adequate level of service while sustaining the traffic loading for the design period in the prevailing climate. The pavement lifespan will be expressed as "the number of standard axle loads that can be transferred by the pavement to subgrade before one of the layers of the structure fails".

A pavement design can be done in different methods, either empirical or mechanistic, depending on the materials and the accuracy with which the design has to be carried out. Rather than empirical pavement design approach, The mechanistic-empirical ME design approach gives more clarification/justifications over the pavement performance depending on the mechanical properties of pavement materials. Therefore, The mechanistic-empirical ME design approach will be applied in this guideline to design the standard structures of pavements incorporating BSM's materials. Thus, the mechanical properties of the pavement materials and subgrade are used to calculate the stresses, strains and displacements within the pavement under vehicular axle loading. These stresses and strains are subsequently 'translated' into maximum allowed number of loading repetitions until failure using transfer functions /models (e.g. fatigue laws or stress laws…etc.). These models have been developed through pavement performance information supplemented by several specific full scale pavement studies (i.e. Long Term Performance Prediction LTPP). Lastly, the final design will be checked through empirical design method: Pavement Number method for confidence and verification purposes.

Therefore, the material properties and changes caused by loading and the environment are required to predict the characteristics and performance of the pavement. The primary characteristics (mechanical properties) used to evaluate the performance of pavement materials under various loading and environmental conditions are the resilient modulus (E) and Poisson's ratio (ν) of the materials.

Predicted loading shall be preassigned for road design. The traffic composition, intensity, axle configuration and speed are all required. Moreover, the predominated climate conditions in the project region are also very important and shall be taken into account; especially the temperature switches from very low in winter to a high degree in summer.

A good structural design will ensure that the load distribution is optimal from top to bottom through a good choice of pavement and successive layers (base layer, subbase) and their thickness , (See Figure 1).

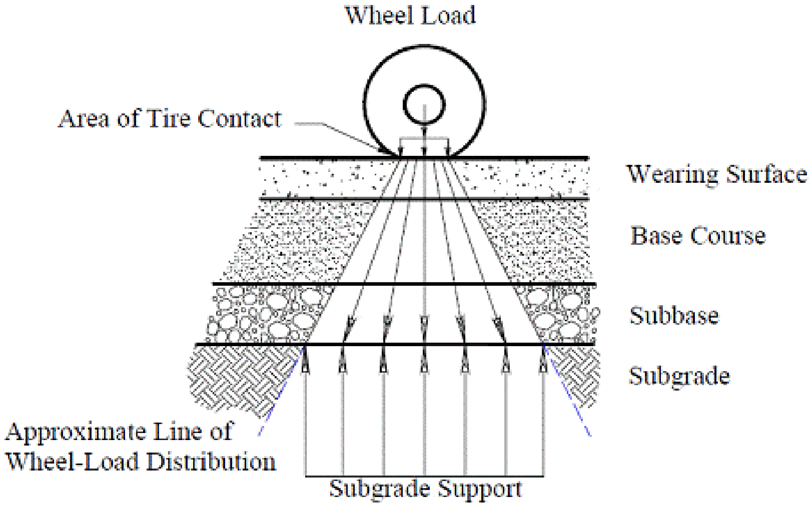


Figure 1 : Load distribution pattern from top to subgrade

The pavement structural design is therefore an iterative process, where suitable materials with their mechanical properties and their respective thicknesses are tested against failure criteria. The iterative process can go both ways:

- Adjusting the pavement structure through re-dimensioning "thicker or thinner".
- Changing the materials, e.g "stiffer or softer", other fatigue property, "bound or semi-bound or unbound".

The design life is analyzed via a multilayer elastic analysis model (MLEA) and then is evaluated by :

- The fatigue cracking of bound materials such as asphalt (horizontal deformation at the bottom of each asphalt layer) and the vertical deformation of the sub-foundation/subsoil
- The permanent deformation of semi-bound/unbound material such as bitumen stabilized material by foam or emulsion.

To start the pavement structural design, the traffic study is considered as the first step. Where traffic loads and spectrum can be measured by performing traffic counts and/or axle counts with Weight In Motion WIM campaign. Hereafter the various traffic loads are arithmetically calculated cumulatively for the desired design life and then converted to equivalent standard axle loads of ESAL-100kN using the guideline of the Flemish Road & Traffic Agency (AWV Manual MOW/AWV/2010/2).

Moreover, in AWV Manual (MOW/AWV/2010/2), there are a set of a designed standard structures for each road class (B1,B2, ….B10) using different foundation materials such as: (granular base, treated base, cemented stabilized material and lean concrete).

Today's trend is to incorporate more recovered asphalt (RA) in bitumen stabilized materials (BSMs). In the upcoming years, the importance of BSM technology, including RA as a more sustainable and environmentally friendly construction technology, is expected to rise.

1.2 Sustainable Pavement Base of Bitumen stabilized material BSM by In-Situ Recycling

Pavement recycling is a series of pavement rehabilitation techniques that can be used to rehabilitate a deteriorated asphalt pavement effectively while reducing costs and environmental impacts and improving performance. One of these promising recycling technologies which has currently a global noticeable increase is the Cold Recycling (In-Situ or In-Plant) using the technology of foamed-bitumen and emulsion-bitumen stabilized materials (BSMs) to increase the bearing capacity of the pavement system. It has therefore become imperative that BSMs are used optimally. In order to achieve this, practitioners need to understand the mechanisms that influence durability and long-term performance.

Foamed-bitumen: To produce a BSM-foam, the bitumen is foamed in expansion chambers that are fitted to machines on site that instantly mixes it with aggregate while still in its foamed state. The greater the volume of the foam, the thinner the film of bitumen surrounding the steam and the better the resulting dispersion of bitumen amongst the aggregate particles.

During the mixing process, the bitumen bubbles burst, producing tiny bitumen splinters that disperse throughout the aggregate by adhering only to the finer particles (fine sand and smaller). Where the aggregate include reclaimed asphalt (RA), the bitumen splinters are able to attach themselves as spots to the aged bitumen on coarser particles.

The temperature and moisture content of the material prior to the addition of foamed bitumen play an important role in dispersing the bitumen. On compaction, the individual bitumen splinters are physically pressed against the aggregate particles, resulting in localized non-continuous bonds (“spot welding”).

Emulsion-bitumen: When mixed with aggregate at ambient temperatures, the relatively low viscosity of the emulsion allows wetting of all the particles. The moisture and type of aggregate being mixed play an important role in dispersing the bitumen emulsion and preventing a premature “break” (flocculation and coalescence of the bitumen droplets, resulting in separation of the bitumen from the water) during mixing.

Once mixed, the bitumen emulsion needs to break to allow the bitumen to act as a “glue” (binding agent). However, since the bitumen emulsion also acts as a lubricating agent, the break should occur only after the material has been fully compacted. The treated material will have a “speckled” appearance due to the concentration of bitumen on the finer particles.

The repair of asphalt pavements can be done in two different ways, depending on two causes:

- Functional repair: due to rutting in the top layer where the bearing capacity is guaranteed. In the case of functional repair, only the top layer is replaced.
- Structural repair: due to structural failure (fatigue cracks from bottom to top or permanent deformation) requiring replacement of the top layer and the bottom layer. BSM technology is classified under this category of pavement repairs. According to Technical Guideline (TG2 - 3rd edition South

Africa,2020), BSM as a base layer could be covered by either a thin asphalt layer or by a thick asphalt layer, depending on loading.

The changes in the behaviour and the failure mechanisms of BSM mixtures are long-term phenomena, just like ordinary asphalt roads. This implies that the study of the mechanical properties of the mixtures is vital. Modeling the behaviour of these mixtures is complicated by the variety of foamed mixtures and the range of mixing variables: (binder content, active filler content, parent aggregates type, aggregates gradation, plasticity, moisture content, etc.). A unified approach to mix design with these materials, taking all of these variables into account, is challenging.

1.3 BSM's Advantages

The technology of stabilizing pavement foundations using Foam-BSM or Emulsion-BSM, has many advantages, as follow:

1. It is a novel, promising, and ecologically beneficial technology that seeks to recycle/stabilize up to100% of reclaimed asphalt particles RAP. It is good to mentioned that there is around a 2.5Millionton of reclaimed asphalt aggregates "RAP" distributed over the three regional Belgian governments (Flanders, Wallonia and Brussels-Capital). A small part of this huge amount is reused in asphalt mixtures. Therefore, the investigations/researches are still looking for a good application to reuse more RAP as possible in Belgium. Since these amounts are in stockpiles, BSM could be produced using in-situ cold recycling ISCR, which is performed by a portable stabilizer unit that is set up a few hundred meters from the construction site, then product BSM will be supplied to the paver/finisher to be paved and hereafter compacted by rollers before transport it to the site to be laid by a finisher, and then compacting by rollers. On the other hand, thousands kilometers of damaged asphalt pavement could be recycled directly using in-place cold recycling IPCR, this is executed by a recycler which will do: (milling + foaming/stabilizing) and then compacting by rollers.
2. New roads can be constructed using BSM produced by in plant cold recycling of stockpiled material, which can then be transported to site, placed and compacted in the new road. Additionally, new roads can be constructed using BSM produced using in situ cold recycling of imported graded crushed stone or reclaimed asphalt material.
3. Existing roads can be recycled in plant by either removing and stabilising the existing material, or replacing the material with stockpiled BSM. By rehabilitating existing roads using cold in situ recycling, the existing road materials can be utilised at high production rates without hauling of material. In both approaches: ISCR or IPCR, the road treated with foamed bitumen can be used immediately by traffic, once the BSM base has been compacted thoroughly. Because foamed-BSM achieves a significant increase in cohesive strength as soon as it is compacted. This provides the new layer with sufficient structural strength to withstand traffic loads immediately after construction, although protection from the ravelling action of tires is required.
4. Bitumen stabilization improves the shear strength of a material and significantly reduces moisture susceptibility (i.e better durability). Therefore, BSMs are best suited to top pavement layers because strength & durability as benefits are costly, where stresses from applied loads are highest and moisture infiltration owing to surfacing cracks is most likely to occur. Consequently, a BSM can replace other high-quality materials on the top pavement. For instance, replacing an asphalt base with a high quality foamed-BSM can result in significant cost savings.
5. Furthermore, at low road classes, BSM's could be designed to be laid on a subgrade directly without subbase layer, in case of a new construction project.

1.4 BSM's Challenges

The BSM's technology in Flanders will face some concerns/limitations as follow:

1. If an existing road needs to be rehabilitated, adding materials (foamed bitumen + active filler or emulsion bitumen) during the stabilization process will increase the volume of the mixture and, as a result, raise the elevation of the finalized road surface. As a result, it is expected that there will be drainage issues and access issues to private residences. Pre-milling a few centimeters (4cm-6cm) might easily fix this issue. This might not be a problem, however, if the elevation is uncontrolled on a rural existing road. Furthermore, the height isn't a concern with new roads.
2. Existing of manholes are often seen to be one of the biggest obstacles facing the in-situ cold recycling by recycler. This issue is less common in the rural roads.
3. Temperature challenge is one of the key factors that influence the BSM production process. Foamed bitumen will not disperse if the temperature of the material RAP is too low <15°C. In general, foamed bitumen is not recommended when the temperature of the material being treated is below 15°C. In Belgium, the desired temperature >15 °C could be only achieved in the summer season (June-September). Therefore, the weather forecast in foaming/recycling day(s) should be checked beforehand.
4. Each project using cold recycling and BSM's is individual. No two projects are same because each existing road has different paved materials/layers; and therefore different mechanical properties for all layers (subgrade, subbase, foundation, AC base, AC wearing). So, each project shall have a unique mix design to find out the job mix formula (optimum amounts/grading ..etc). Moreover, shear properties of BSM's shall be measured laboratory because they are key inputs in the pavement structural design of BSM pavement. Consequently, a professional engineers who had a good experience should be consulted.
5. The moisture content of the material prior to the addition of foamed bitumen plays an important role in dispersing the bitumen. This is especially important when using bitumen emulsion as treatment of dry material will result in premature break. However, if the in situ moisture content is too high, adding bitumen emulsion will increase the moisture content above the optimum required for compaction, preventing the compaction to the required target density. Ideally, the moisture content should be between 65% and 75% of the optimum moisture content to achieve the optimal mix. Water can usually be added with either in situ or in plant recyclers, but when the moisture content is too dry, material should be dried before stabilising.
6. Professional operators is needed to achieve the target grading in case of ISCR approach by recycler. The drum speed of recycler plays a main role in finding the desired grading.

2 Pavement Design Approaches

The most common pavement design approaches are :

- The Mechanistic-Empirical (ME) method : This design approach is well-known and commonly used in the Flemish region. Recently, a new structural design transfer function has been developed for BSM materials in the South African Technical Guideline (TG2 - 3rd edition South Africa,2020) which is considered as one of the most common guidelines in BSM pavement design.
- The Intelligent Pavement Number (PN) method: It was developed using a Long-Term Pavement Performance (LTPP) based on AASHTO; which is also in the South African Technical Guideline (TG2 - 3rd edition South Africa,2020).
- Structural Number (SN) method: which is developed by AASHTO.

It would be more confident if the designer do the pavement design with ME method and then do a verification using another design such as: SN or PN method.

2.1 Mechanistic - Empirical Design Method

2.1.1 Conceptual of Mechanistic-Empirical (ME) Design Method

The main headlines for the structural design using the ME method are the following steps, see (Figure 2):

a) Prepare design inputs and formulate design assumptions (assume layers thicknesses).
b) Computer Model: Calculate responses (stresses and strains) in each layer at the critical position via a multi-layer elastic analysis program, see (Figure 3). If the critical position is not known, then it could be more confident to analyze the whole depth; for example every 1mm. Mostly, for bound materials, this will be at the bottom of the layer.
c) Extract critical responses and the corresponding position.
d) Transfer function: Estimate repetitions to failure for each layer by translating the responses to maximum allowed number of loading cycles, using the corresponding transfer function/model (e.g. fatigue laws or stress laws…etc.).
e) Determine critical layer or weakest layer that will bear lowest number of axle loading cycles.
f) Estimate the structural capacity for pavement.
g) Repeat the whole process if needed.

Figure 2 : Predicting the service life for each layer in the pavement system

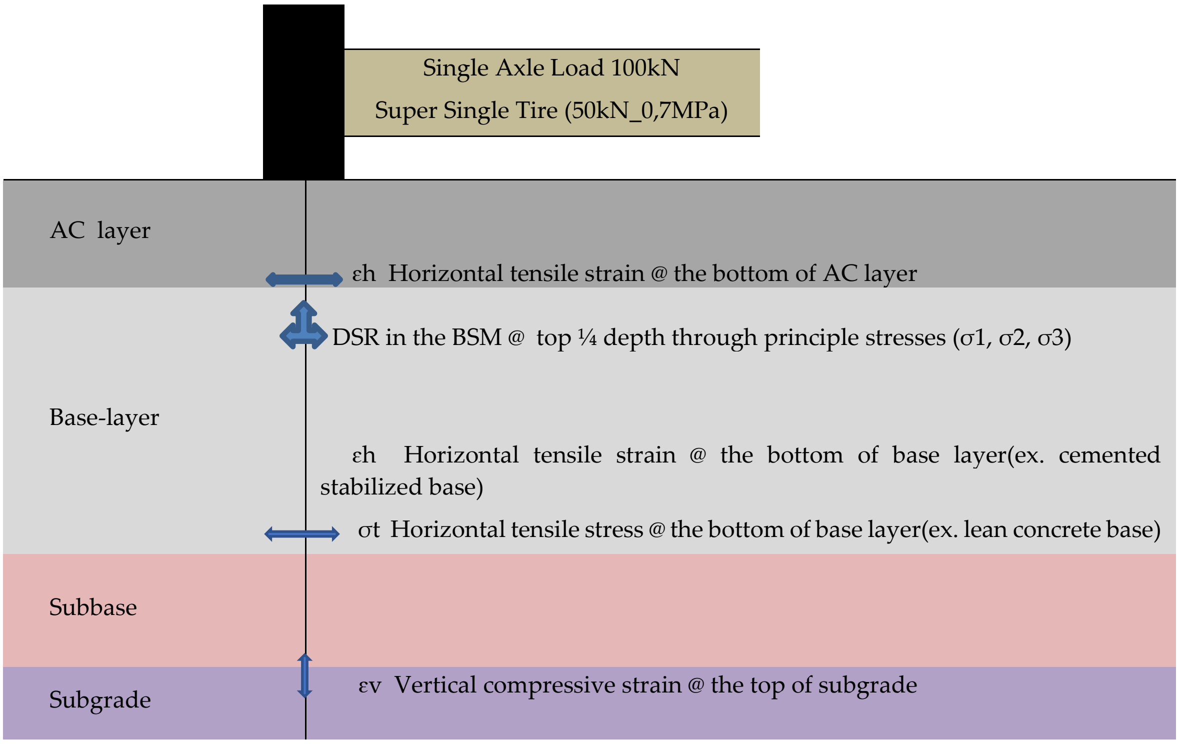


Figure 3 : Critical analysis positions in the pavement structure

2.1.2 Failure Mechanisms of Pavement Materials

The failure mechanism in pavement system could be either : fatigue cracking or permanent deformation, and that depends on the material (bonded/or unbonded/semi-bonded). The following (Figure 4) shows the difference:

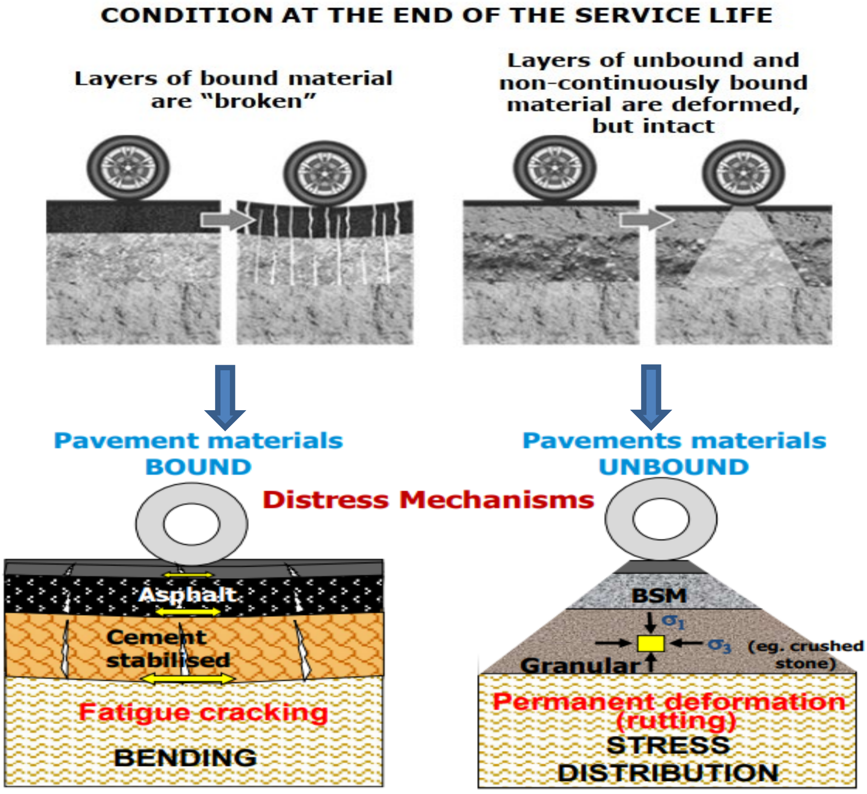


Figure 4 : Failure mechanisms of the pavement materials (Loudon international, 2020)

In the BSM mixture, the individual bitumen particles are not connected and the coarser aggregates remain uncoated. Consequently, BSM keeps the granular characteristics of the parent material. Some researchers believe it is closer to that of granular materials, which is stress-dependent, but with higher cohesion. Therefore, the BSM failure mode is strongly figured due to a permanent shear deformation as a critical performance parameter. That is to say, it is not susceptible to fatigue cracking.

2.1.3 Factors Influence Structural Pavement Behaviour

There are some factors that often influence the structural pavement behavior :

- Layer thickness : The layer's thickness has a 3rd power effect because the thickness is cubic in the bending formula. See (Figure 5) below :

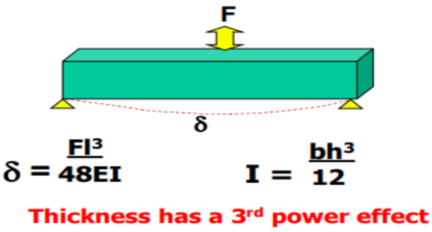


Figure 5 : 3rd power effect of layer thickness

- Mechanical properties of paving materials: especially stiffness in term of dynamic modulus. For instance, stiffer bound material reduces the fatigue cracking. In addition, the bearing capacity of the subgrade are important for the design.

Normally in Belgium, the stiffness value of the paving material can be measured by:

1. Lab measurements for mixtures (ideal way); see (Figure 6).
2. On-site measurements for the existing pavement using Falling Weight Deflectometer FWD.
3. Via Pradoweb-OCW software during designing the mixture.
4. Via Qualidim analysis model.

Figure 6 : Resilient Modulus Test

While the bearing capacity of subgrade (existing soil) could be measured in Belgium by the following method:

1. Static plate load test
2. Dynamic plate load test
3. Dynamic cone pentrometer DCP
4. Ground Penreating Radar GPR georadar.

2.1.4 Summary of Distress Models for Common Paving Materials

In order to estimate the lifespan of the pavement structure, the fatigue laws or other transfer functions could be used. These functions calculate the maximum allowed number of loading repetitions for each layer/or material. The following (Table 1) summarized transfer functions for some materials:

Table 1 : Summary of distress models/ transfer functions of common paving materials

Layer	Material	Design parameter	Response position	Failure mode (Terminal condition)	Transfer function N= the maximum allowed number of loading repetitions
AC layers	Bitumen mix	Horizontal tensile strain ε_h "m/m"	Bottom	fatigue cracking @ %20 lane area cracked	$N = \left(\frac{0{,}0016}{\varepsilon_h}\right)^{4{,}76}$
	Bitumen mix with high stiffness AVS	Horizontal tensile strain εh "m/m"	Bottom	fatigue cracking @ %20 lane area cracked	$N = \left(\frac{0{,}00081}{\varepsilon_h}\right)^{7.39}$
Base layer	Cement stabilised material	Horizontal tensile strain εh "m/m"	Bottom	fatigue cracking @ %20 lane area cracked	$\log N = 12 - 80.000 * \varepsilon_h$
	Lean concrete (gravel)	Horizontal tensile stress σh "MPa"	Bottom	fatigue cracking @ %20 lane area cracked	$\log N = 14 * \left(1 - \frac{\sigma h}{1.20}\right)$
	Lean concrete (gravel-bitumen)	Horizontal Tensile strain εh "m/m"	Bottom	fatigue cracking @ %20 lane area cracked	$N_f = \left(\frac{0{,}00111}{\varepsilon h}\right)^5$
	Foam-BSM / Emulsion-BSM Stabilized material	Deviator Stress Ratio DSR	Roughly at top ¼ depth in BSM	shear permanent deformation @ 10mm rut-depth with Reliability 90%	Stellenbosch BSM Design Function $\log N = A - 57.286(DSR)^3 + 0.0009159(P_{MMD}.RetC)$
Subgrade	Sand/clay …	Compressive vertical strain εv "m/m"	Top	permanent deformation @ 12.5mm rut-depth	$\frac{1}{N} = \left(\frac{\varepsilon_v}{0{,}011}\right)^{1/0{,}23}$

2.1.5 Stellenbosch BSM Transfer Function

Based on the BSM is stress-dependent, as stated previously, the principal stresses at various points in the BSM layer are measured, then used to calculate the deviator stress ratio "DSR" which considered as a design parameter in defining the rate of permanent shear deformation of a BSM material. The Deviator Stress Ratio "DSR" is defined as the ratio of the actual (applied) deviator stress to the maximal (failure) deviator stress and expressed as a percentage. Subsequently, the magnitude of the critical DSR "= maximal DSR" for design purposes is estimated using a multilayer elastic analysis model. According to Ebels L.J., 2008, the critical DSR is strongly believed to occur at such a depth in the BSM layer, just before the point where the minor principal stress σ3 is being shifted from compression to tension; which is often at top ¼ depth in BSM layer. However it is recommended to investigate the principle stresses at many positions until the maximal DSR is found.

The following equations are used to compute DSR; according to TG2 3rd edition, 2020:

$$Deviator\ Stress\ Ratio\ DSR = \frac{\sigma_d}{\sigma_{d,f}} = \frac{\sigma_1 - \sigma_3}{\sigma_{1,f} - \sigma_3} \qquad \text{(eq.1)}$$

$$\sigma_{1,f} = \frac{(1+\sin\emptyset).\sigma_3 + 2.C.\cos\emptyset}{(1-\sin\emptyset)} \qquad \text{(eq.2)}$$

Where,

DSR	Deviator Stress Ratio
σ_1	Major principle stress in the layer (KPa)
σ_3	Minor principle stress in the layer (KPa)
$\sigma_{1,f}$	Major principle stress at failure from a triaxial test (KPa)
C	Cohesion value of BSM from project mix design (KPa)
Ø	Friction Angle of BSM from project mix design

The DSR is highly influenced by both of these factors:

- Subgrade stiffness: stiffer subgrade reduces the DSR which means longer service life for the pavement.
- BSM thickness: Thicker BSM reduces the DSR which means longer service life for the pavement.
- BSM properties: DSR depends slightly on BSM stiffness (*resilient modulus*), but it depends mainly on BSM shear parameters: (*cohesion + angle of friction*) which shall be obtained by Triaxial test. Those parameters shall be measured for each project since each project has different material. For preliminary structural designs, the default input values of Cohesion (C) and Friction Angle (Ø) can be used for DSR input based on below (Table 2) (Ref. TG2, 2020). should be always measured in the lab for the mix since each project is unique

Table 2 : Default Values for the BSM Shear Parameters in Preliminary ME Design (Ref. TG2, 2020)

Material Class	**% RAP**	**ITS (KPa)**		**Triaxial**		
		ITS DRY	**ITS WET**	**Cohesion (KPa)**	**Friction angle (◦)**	**Retained Cohesion %**
BSM 1	< 50%	225	125	250-300 (250)[1]	40-50 (40)	70-85 (75)
	50% - 100%	225	125	265-350 (265)	38-45 (38)	75-90 (75)
BSM 2	< 50%	175	100	200-250 (225)	38-40 (39)	65-75 (70)
	50% - 100%	175	100	225-250 (238)	35-40 (37)	70-85 (75)

(1) Ranges of input values are provided, with recommended default values in parentheses

Similar the resilient modulus should be always measured in the lab for the mix since each project is unique in this technology, because many studies don't show a good correlation between each other in the BSM resilient modulus. Following Table 3 : Summary of test methods for determination of 'Modulus' of BSM**Fout! Verwijzingsbron niet gevonden.** summarized those values:

Table 3 : Summary of test methods for determination of 'Modulus' of BSM

Test protocol	investigator	Sample size	Modulus	Loading mode	Frequency/Loading time	Test temperature (°C)	Post-processing
Indirect tension resilient modulus	Muthen	100mm diameter X 65mm height	1500MPa(soaked); 6000MPa(dry)	Indirect tension	50 ms loading	25°C	Elasticity based Indirect tension resilient modulus
	Nataatmadja	150mm diameter	200MPa	Indirect tension	0.1 s loading	Not reported	
	Marquis et al.	Not reported	1400–3500 MPa	Indirect tension	5 s loading	25°C	
Beam stiffness modulus	Fu et al.	450X150X80mm	250 MPa(soaked); 1700 MPa(unsoaked)	Tension	Constant displacement rate of 25 mm/min	20°C	Tangent modulus
Triaxial resilient modulus	Fu et al.	152 X 305 mm	850–1500 MPa	Compression	0.05,0.1,0.2,0.4 s loading	20°C	Ratio of peak stress and recoverable strain and Granular material based Uzan's model
	Jenkins et al.	150 X 300 and 300 X 600 mm	275 MPa	Compression	2–5 Hz	25°C	Ratio of peak stress and recoverable strain and Granular material
	Wirtgen	100 X 200 mm	800–1600 MPa	Compression	0.1 s loading	25°C	Ratio of peak stress and recoverable strain and Granular material
AASHTO: TP-62	Kim et al.	100 X 150 mm	10.000 MPa(4.4°C) 2500 MPa (37.8°C)	Compression	25,10,5,1,0.5,0.1 Hz	4.4,21.1, 37.8°C	Ratio of peak stress and recoverable strain and Granular material
	Khosravifar et al.	101 X 115 mm	3700–5000MPa(25°C)	Compression	20,10,5,1,2.5,0.1 Hz	5, 15, 25, 35 °C	Ratio of peak stress and recoverable strain and Granular material

To find the service life of the BSM layer, A Stellenbosch BSM transfer function (see the formula below) has been applied. This model was recently developed by Stellenbosch University in South Africa based on Mechanistic-Empirical Approach (Ref. TG2, 2020). The maximal DSR refers to “critical DSR” which means lowest allowed number of loadings repetitions.

$$\log N = A - 57.286(DSR)^3 + 0.0009159(P_{MMD}.RetC) \qquad \text{(eq.3)}$$

Where;

- N = Maximum allowed number of standard axle load repetitions to reach a set rut depth
- DSR = Deviator Stress Ratio, expressed as fraction.
- P_{MMD} = Maximum Dry Density of BSM, expressed as %
- RetC = Retained Cohesion %
- A = Reliability Coefficient linked to Road Category , see (Table 4)

Table 4 : coefficient A

Reliability	Road Category	Coefficient A	Rut limit (mm)
95%	A	1.71113	10
90%	B	1.79873	15
80%	C	1.88733	20
50%	D	2.00443	25

2.1.6 Standard Axle Load for Design Purpose

The standard axle load is determined per country (or region). As a result, pavement structures can differ per road type from country to country. This depends on the total weight of the truck and loading distribution (axle configuration + tire configuration + tire inflation pressure). For example, in South Africa, the ESAL= 80kN with dual tires configuration “20kN/tire” with tire pressure 750KPa. While in Germany, ESAL= 130kN with single tire “65kN/tire” with tire pressure 700KPa. In Flanders, The ESAL= 100kN with single tire “50kN/tire“ with tire pressure 700KPa according to the AWV agency (see Figure 7). This does not mean that higher axle loads do not occur in daily practice. By combining several axles into an axle set, the payload of a truck (combination) can be increased. Therefore, ESAL-100kN will be applied in this preliminary BSM design , and ESAL-130kN will be applied in further investigations since the Stellenbosch function can accept the DSR yielded from the actual stress whatever the axle load (Reference Prof.Kim Jenkins).

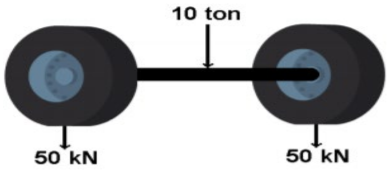


Figure 7 : Flemish standard axle load 100kN

In Flanders, the maximum gross vehicle weight is 44 ton. Rather than road engineering, road safety plays a role in determining that weight. At a speed of 90 km/h, bringing a mass of (more than) 44 ton to a standstill is difficult.

Every vehicle has a certain load distribution on the road: the weight is distributed over the axles, and each axle has one or more tires on each side. The distance of the axles, as well as the tire configuration, are essential factor in yielding of stresses and strains in the pavement. Moreover, the multi-axles are frequently placed one behind the other to spread the load on a wide area over the pavement surface. For instance, a tandem axle set consists of two axles, whereas a tridem axle set consists of three axles. A single ordinary tire, a dual tires, or a "super single/ wide tire" can be installed on the axle’s edge. In the last years, It is observed that the combination of two tires mounted side by side is sometimes replaced by a super single ”wide tire”. The super single is a trend nowadays.

Predefining the percentage of the super single trucks is a very important design parameter to get an efficient pavement design, since the super single can lead to higher damage than dual tires. However the super single tire has a negative effect on the pavement structure, it is still having a set of advantages :

- Super single tires eliminate the effects of uneven pressure between tires on one side of an axle by switching to a single tire.
- Super single tires have a more substantial contact patch than standard dual tires, which increases a fleet’s load capacity.
- Super single tires can improve vehicle performance and reduce fuel consumption and maintenance costs.
- Overall tire weight is reduced which could allow for extra freight.

Note: By experience in Flanders, if ESAL 100KN is used for analyzing lean concrete as base layer, then the strains will be too low with very high -illogical- N repetitions as result. In order to avoid this error, next Table 5 shows the recommended standard axle loads for each materials and the applied corresponding conversion factor to equal ‘damage’ with ESAL 100kN :

Table 5 : Conversion factors (calculated based on the fourth power law 4th power law)

Material	ESAL	Single tire	conversion factor
Unbound gravel or crushed base layer	100kN	50KN	1
Unbound gravel or crushed + additives	100kN	50KN	1
Cement stabilized base layer	130kN	65KN	2.8561
Lean Concrete	160kN	80KN	6.5536

For example: A pavement structure that has a AC layer on lean concrete foundation, then

a. analyze/design with 100kN/axle for asphalt and substrate
b. analyze/design with 160KN/axle for lean concrete foundation and multiply by 6.5536

Moreover, the healing factor of 7.11 can be applied to take into account healing in asphalt mixtures. Healing can ensure that cracks disappear; especially in summer at higher temperatures. This factor can be applied whatever the standard axle loads 100 or 130 or 160 according to some experts in Flanders.

Finally, the weakest layer is determined as the most critical layer with lowest number of axle loads during the desired design life.

2.1.7 Multilayer Elastic Analysis Models

In Flanders/Belgium, Qualidim software is commonly used as a multilayer elastic analysis (MLEA) model. But it would be good to use other MLEA models. Mechanistic design method was developed to analyze the major and minor principal stresses and strains for each layer in the pavement structure. For this purpose two different linear-elastic multi-layer programs were can be used:

- ALIZE-LCPC Pavement software : ALIZE-LCPC is the professional software. It’s a multi-layer elastic linear model for the mechanical analysis and pavement design. First-line of ALIZE-LCPC is designed to integrate a rational method. The software does not calculate the structure a given service life but rather estimate the evolution over time in terms of cumulative probability of failure. This design method is used in France for many years and is widely spread in Europe and Africa. As ALIZE-LCPC integrates a rich database of materials (rubber, treated, concrete…), it allows the analysis of a wide range of pavements.

- Rubicon Stress-Strain Calculator: This module uses a computer solution of classical Layered Elastic Theory (LET) for a layered homogeneous, non-linear, isotropic pavement system. The module used in the Rubicon Online Tools was developed by Rubicon Solutions provide excellent agreement to more traditional programs such as WESLEA, ELSYM5 and BISAR.

It was observed that both software's were resulted in similar response values (stress, strain, deflections). However, Rubicon tool seems easier, faster and more flexible Alize and other software's. Thus, the pavement design in this study will be done using Rubicon stress/strain analyzer.

2.1.8 Flemish Analysis Approach Based on Seasonal Stiffness Change

It is well known that the resilient modulus of the bituminous materials such as asphalt are temperature dependent. A high temperature in summer will lead to softer material. Actually, uniform stiffness approach may result in conservative design. That's why, the Flemish Road & Traffic Agency recommends to calculate the pavement service life based on a seasonal stiffness (see Table 6). The pavement design would be more realistic. The following equation is recognized in Flanders to find the allowed number of loading repetitions N:

$$\frac{1}{N} = \frac{0.25}{N_{summer}} + \frac{0.5}{N_{spring}} + \frac{0.25}{N_{winter}} \qquad \text{(eq.4)}$$

Where;

N_{summer} = the allowed number of loading repetitions during summer.

N_{spring} = the allowed number of loading repetitions during Spring + Autumn.

N_{winter} = the allowed number of loading repetitions during winter.

Table 6 : Typical stiffness values per material per season according to the Flemish AWV Agency

Layer	season	E (MPa)	Poisson ratio υ
AC wearing (APT or SMA)	Summer (30 °C, 10 Hz)	4000	0.35
	Spring + Autumn (15 °C, 10 Hz)	8000	0.35
	Winter (0 °C, 10 Hz)	16000	0.35
AC underlayer (APO)	Summer (30 °C, 10 Hz)	5000	0.35
	Spring + Autumn (15 °C, 10 Hz)	10000	0.35
	Winter (0 °C, 10 Hz)	20000	0.35
AC underlayer with high stiffness AVS	Summer (30 °C, 10 Hz)	6000	0.35
	Spring + Autumn (15 °C, 10 Hz)	12000	0.35
	Winter (0 °C, 10 Hz)	24000	0.35
Unbound gravel or crushed base layer		500	0.5
Unbound gravel or crushed + additives		800	0.5
Cement stabilized base layer		4000	0.3
Lean Concrete		8000	0.3
Subbase		250	0.5

Subgrade		50	0.5

2.2 Intelligent Pavement Number PN Design Method

2.2.1 Overview PN

The Intelligent Pavement Number (PN) design method is a simplified pavement design method based on sound engineering principles. The method has been calibrated and validated using structures from Long Term Pavement Performance (LTPP) and the TRH4 and SATCC design catalogues. The first version of the PN was released in South Africa 2009, and the updated version in 2020. As thick asphalt layers are not common practice in South Africa, the PN method does not allow thick asphalt layers as an input. To overcome this shortfall, the asphalt was split between the surfacing and the Bitumen Treated Base (BTB) layers. This was only applicable when analysis the standard pavement structures.

Before the calculation of the pavement number is started, the designer should check to ensure that the design method is applicable to the pavement situation. To ensure that the method is not used inappropriately, the designer should always check to ensure that none of the following situations apply:

i. **Design traffic greater than 40 MESAL**: The PN-based method was calibrated using a knowledge base which was limited to pavements that have accommodated less than 40 MESAL.
ii. **Presence of thin, weak lenses:** If thin, weak lenses of material exist below the surfacing, or between stabilized layers, then zones of high slip and shear will develop, and routine design calculations will not apply. In such instances, the structural capacity assessment of the PN method, or of the traditional ME design method will not be appropriate, and special treatment of the affected weak lens must be undertaken. The PN-based design method cannot be applied to situations where such lenses still exist within the pavement structure, especially where such lenses are located within the upper 400 mm of the pavement structure.
iii. **Subgrade CBR less than 3 percent:** The knowledge based on which the PN method was calibrated did not include any pavements in which the subgrade CBR was less than 3 percent. The PN method should therefore not be used in cases where the subgrade CBR is less than 3 percent at a depth below 600 mm.

For more details on the knowledge base and methodology used to develop the design method, the Technical Guideline (TG2 - 3rd edition South Africa) can be consulted.

2.2.2 PN Design Procedures

- **Step 1.** Check to ensure that the design method is applicable for the above-mentioned design situations.
- **Step 2.** Determine the thicknesses of the layers, and available material properties for each layer. Determine the design equivalent material class (DEMAC) using the guidelines in (Table C.3 - Appendix C). To prevent the use of unrealistic layer thicknesses, and to limit the pavement thicknesses to those for which the method has been calibrated, maximum and minimum limits are given. BSM layers can only have a thickness between 100 mm and 300 mm.
- **Step 3.** If needed, Combine layers with similar properties to obtain a five layer pavement system, including the subgrade (four layers plus the subgrade)
- **Step 4.** Determine the basic stiffness of the subgrade by means of the given values (Table C1 - Appendix C). Adjust the stiffness for the climatic region (Table C1 - Appendix C) and depth of subgrade cover (Figure C3 - Appendix C).

- **Step 5.** For each layer above the subgrade, determine the Modular Ratio limit and maximum allowed stiffness using (Table C3 - Appendix C).
- **Step 6.** Use the Modular Ratio limit and maximum allowed stiffness to determine the ELTS for each layer by working up from the subgrade.
- **Step 7.** For the base layer, determine the Base Confidence Factor (BCF).
- **Step 8.** For asphalt, cement stabilized and BSM layers, determine the thickness adjustment factors using (figures C4,C5,C6,C7 - Appendix C)
- **Step 9.** For each layer, calculate the layer contribution using the ELTS and layer thickness, and BCF and thickness adjustment factors where applicable.
  Note : Remark that E is an equivalent for stiffness, but not actual stiffness value.
- **Step 10.** Add the layer contributions for each layer to get the PN.
- **Step 11.** Determine the minimum expected structural capacity in standard axles of the pavement for the applicable Road Category (A and B) from the frontier curve (Table C4 - Appendix C).
- **Step 12.** Evaluate.

2.3 AASHTO 1986 Design

2.3.1 Overview SN Method

The AASHTO 1986 Design tool allows to evaluate the structural capacity of a pavement using the empirical AASHTO 1986 design method. This design method is now quite outdated but can still serve as a useful extra check to compare pavement structure to accepted standards.

2.3.2 Key inputs

2.3.2.1 Initial Serviceability:

The initial serviceability is an indication of the initial smoothness of the pavement. A pavement with a high initial smoothness would naturally take longer to deteriorate to an unacceptable level of service than one which is already rough at the start of the design period. The serviceability is quantified by the present serviceability index (PSI). This value ranges from 0 to 5, with 0 being the lowest serviceability (i.e. the roughest road) and 5 the highest serviceability. Typical values for initial serviceability range from 4.2 to 4.5.

2.3.2.2 Terminal Serviceability:

The terminal serviceability is the lowest acceptable level of service. It quantifies the roughness of the road at the stage where resurfacing or reconstruction is needed. For major highways, a terminal serviceability index of 2.5 to 3.0 is typically used. For minor highways, a terminal serviceability of 1.5 to 2.0 may be used.

2.3.2.3 Standard Deviation:

The selection of an appropriate standard deviation is important for the correct assessment of the design reliability. For the case where variance of the projected traffic is considered with the other variances in the design model, AASHTO recommends a standard deviation of 0.34 and 0.44 for rigid and flexible pavements, respectively. For the case where variance of the projected traffic is NOT considered with the other variances in the design model, AASHTO recommends a standard deviation of 0.39 and 0.49 for rigid and flexible pavements, respectively. The overall ranges of standard deviations recommended by AASHTO are 0.40 to 0.50 for flexible pavements.

2.3.2.4 Design Reliability:

According to AASHTO, the selection of the reliability level depends primarily on the projected level of road usage and the risk and consequences associated with early failure. On highly trafficked roads, the consequences of failure and repair are significantly greater than on minor roads, and hence an increased reliability level needs to be selected.

2.3.2.5 Pavement Layer Properties:

For each pavement layer, the material type, stiffness modulus, thickness and drainage factor needs to be provided. The drainage factor is typically applied to granular bases and subbases, and allows for an adjustment to be made to the layer's contribution to the pavement's Structural Number. A drainage coefficient of less than 1.0 means that the layer's contribution (or coefficient) is reduced because of less than ideal drainage conditions, and vis versa. The default drainage coefficient is 1.0, which means that no adjustment to the layer contribution is made.

3 Defining Road Class

In a full example, this chapter shows how one can define the road class and the anticipated traffic load during the desired design life. The Flemish Road Agency AWV Guidelines (SB250 + Annex MOW/AWV/2010/2 + MOW/AWV/2017/4) should be consulted to do that.

3.1 Road classification " Flemish Road Agency AWV"

3.1.1 Road Classes

In Flanders, the road is classified according to the number of ESAL loading cycles that will travel on that road during its design life, see below (**Fout! Verwijzingsbron niet gevonden.Fout! Verwijzingsbron niet gevonden.Fout! Verwijzingsbron niet gevonden.**). For example, B2 is the road class, located between 32 and 64 MESAL-100kN. In Flanders, no roads have yet been defined with a higher number than B1.

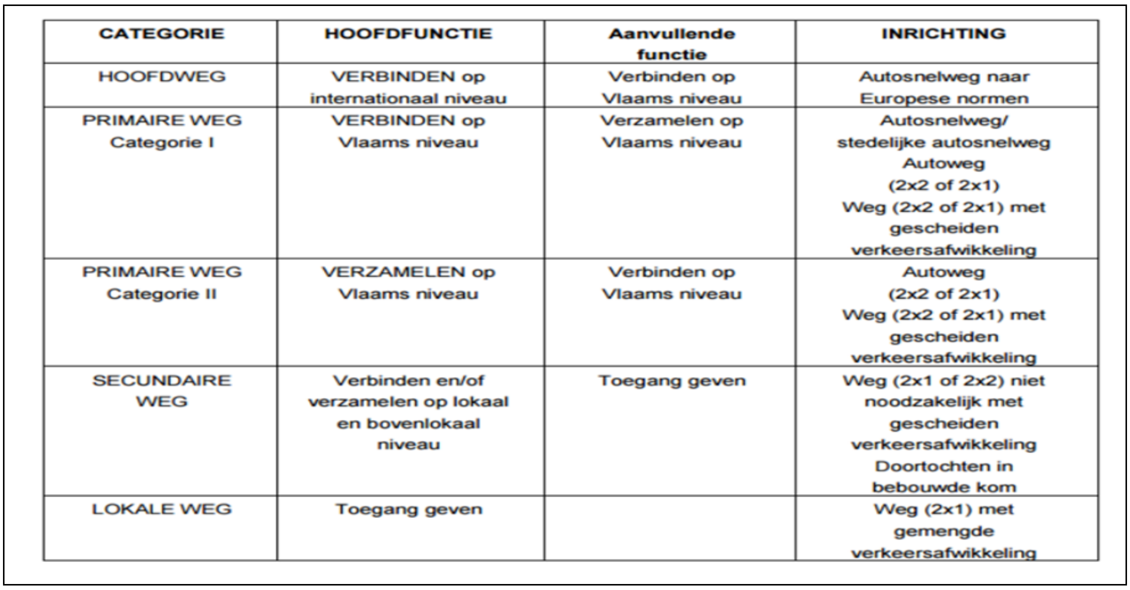
Table 7 : Maximum allowed number of loading repetitions in Millions according to the Flemish AWV Agency

Road Class	ESAL-80kN	ESAL-100kN	ESAL-130kN
B1	<312	<128	<44,8
B2	<156	<64	<22,4
B3	<78	<32	<11,2
B4	<39	<16	<5,6
B5	<19,5	<8	<2,8
B6	<10	<4	<1,4
B7	<5	<2	<0,7
B8	<2,5	<1	<0,35
B9	<1,2	<0,5	<0,18
B10	<0,6	<0,25	<0,09
BF	-	-	-

3.1.2 Road functional classification in Flanders

In Flanders, the road can be classified according to its function as the following **Fout! Verwijzingsbron niet gevonden.** shows :

Table 8 : Road functional classification according to the Flemish AWV Agency



CATEGORIE	HOOFDFUNCTIE	Aanvullende functie	INRICHTING
HOOFDWEG	VERBINDEN op internationaal niveau	Verbinden op Vlaams niveau	Autosnelweg naar Europese normen
PRIMAIRE WEG Categorie I	VERBINDEN op Vlaams niveau	Verzamelen op Vlaams niveau	Autosnelweg/ stedelijke autosnelweg Autoweg (2x2 of 2x1) Weg (2x2 of 2x1) met gescheiden verkeersafwikkeling
PRIMAIRE WEG Categorie II	VERZAMELEN op Vlaams niveau	Verbinden op Vlaams niveau	Autoweg (2x2 of 2x1) Weg (2x2 of 2x1) met gescheiden verkeersafwikkeling
SECUNDAIRE WEG	Verbinden en/of verzamelen op lokaal en bovenlokaal niveau	Toegang geven	Weg (2x1 of 2x2) niet noodzakelijk met gescheiden verkeersafwikkeling Doortochten in bebouwde kom
LOKALE WEG	Toegang geven		Weg (2x1) met gemengde verkeersafwikkeling

3.1.3 Design Life

The design life is the structural life of the entire pavement structure. This does not mean that no maintenance or repair will be required during this period. It is possible that the pavement must be repaired earlier because of, for example, excessive rutting which need a functional repair "not structural repair". Rutting does not necessarily affect the bearing capacity of the structure, as mentioned above in section 1.2. This is the difference between functional and structural repair, respectively replacing a top layer because of fraying and replacing the top layer and bottom layer because of cracks. However, the carrying capacity must always be guaranteed.

The recommended design life to be selected based on the type of pavement's surface is given in (**Fout! Verwijzingsbron niet gevonden.**). Because the pavement's surface is bituminous the design life is set to 20 years.

Table 9 : Recommended road design life according to the Flemish AWV Agency

Pavement type	*Design life "desired service life"*
Bituminous pavement "flexible pavement"	*20 year*
Bituminous pavement with high stiffness mixture AVS	*30 year*
Cementious pavement "concrete rigid pavement"	*30 year*

3.1.4 Traffic Data

The composition of the frequent traffic is a fundamental input in pavement design. A detailed example with assumed inputs would be easier and helpful to show the users of this guideline how to calculate the anticipated traffic is expected during the design life. The following parameters are assumed:

- An existing damaged road with 2 directions; 1 lane per direction; lane width 4m.
- The expected annual average daily traffic AADT= 475 vehicle/working day per direction.
- The speed limit is 50Km/h.
- A secondary road "internal road" will be loaded daily by 100% of trucks (small trucks, large trucks, and towed trucks).
- The expected percentage of trucks with wide-tires (super single tire) is 50%.
- The average number of axles per truck is between 4 axle/truck.
- 280 working days per year.
- The main function of this road is secondary road , see (Table 8)

- Growth Rate (i):

  The traffic growth rate is represented by the value i. If the growth rate is unknown, a reference value (i=1 % per year) can be taken from (Table 10Table 10) via (MOW/AWV/2010/2).

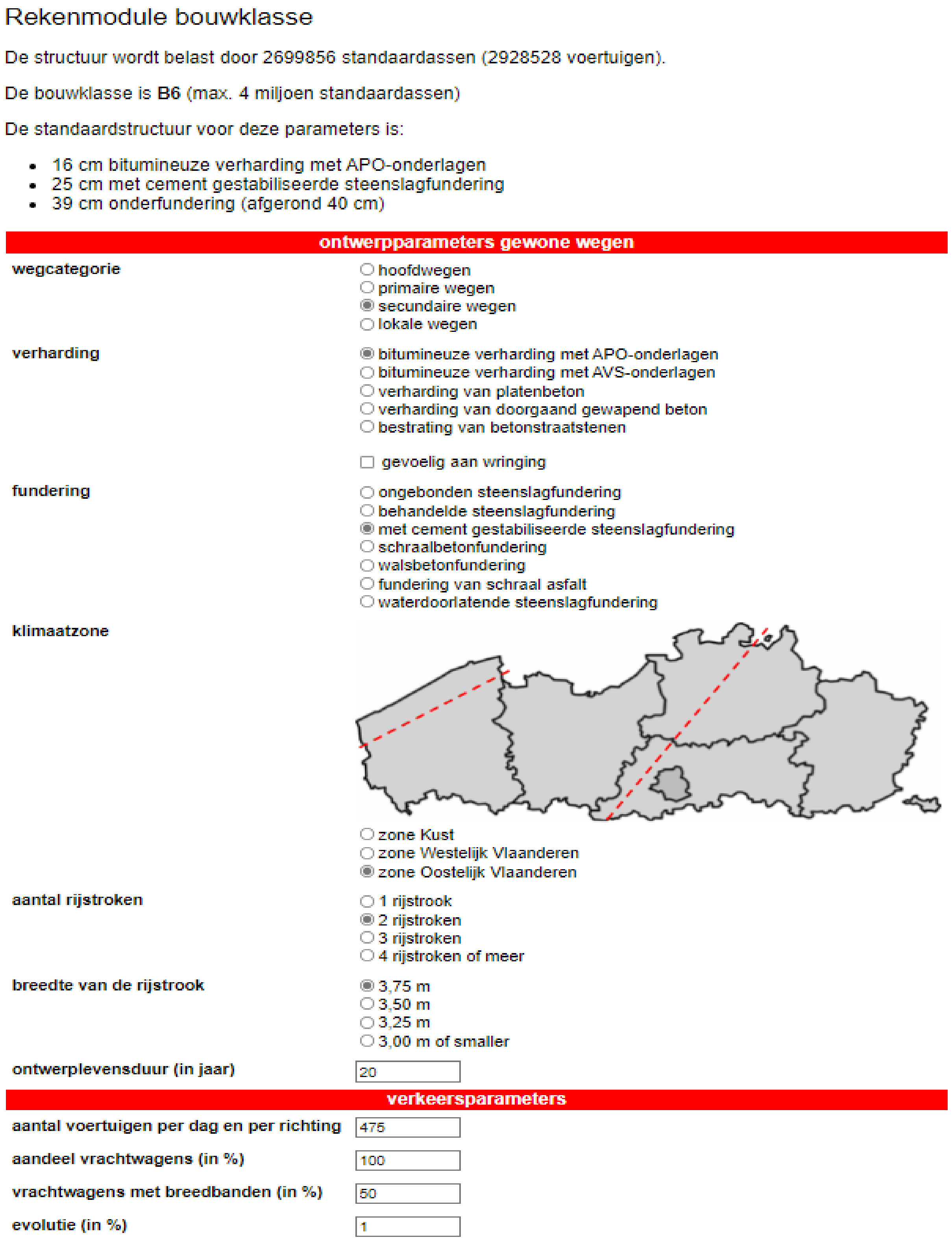
Table 10 : Recommended traffic growth rate according to the Flemish AWV Agency

Road category	Growth rate i%
Main roads “hoofdwegen”	2%
Primary roads “primaire wegen”	1,5%
Secondary roads “swcundaire wegen”	1%
Local roads “lokale wegen”	0,5%

- Design Speed: The speed on this road is 50 km/h “assumed”
- Trucks Percentage: All vehicles that will use this road are lorry (trucks). So the proportion of trucks is 100% “assumed”.
- Trucks with wide tires “super single”: The expected percentage of trucks with broad tires is presented as 50% “assumed”.

3.1.5 Online Calculator

Because all data is now available, the calculation can be made via the online calculation module of the AWV (Rekenmodule Bouwklasse (wegenenverkeer.be).Figure 8: Example of road classification and standard structure for assumed road (via AWV online module) Figure 8 shows the data used for the design according to the calculation module. The structure can be loaded by 2.699.856 standard axles (ESAL-100kN) at maximum. This means that according to the calculation module, the road class is **B6 (up to 4 MESAL-100kN).**



Rekenmodule bouwklasse

De structuur wordt belast door 2699856 standaardassen (2928528 voertuigen).

De bouwklasse is **B6** (max. 4 miljoen standaardassen)

De standaardstructuur voor deze parameters is:

- 16 cm bitumineuze verharding met APO-onderlagen
- 25 cm met cement gestabiliseerde steenslagfundering
- 39 cm onderfundering (afgerond 40 cm)

ontwerpparameters gewone wegen

wegcategorie	○ hoofdwegen ○ primaire wegen ● secundaire wegen ○ lokale wegen
verharding	● bitumineuze verharding met APO-onderlagen ○ bitumineuze verharding met AVS-onderlagen ○ verharding van platenbeton ○ verharding van doorgaand gewapend beton ○ bestrating van betonstraatstenen ☐ gevoelig aan wringing
fundering	○ ongebonden steenslagfundering ○ behandelde steenslagfundering ● met cement gestabiliseerde steenslagfundering ○ schraalbetonfundering ○ walsbetonfundering ○ fundering van schraal asfalt ○ waterdoorlatende steenslagfundering
klimaatzone	○ zone Kust ○ zone Westelijk Vlaanderen ● zone Oostelijk Vlaanderen
aantal rijstroken	○ 1 rijstrook ● 2 rijstroken ○ 3 rijstroken ○ 4 rijstroken of meer
breedte van de rijstrook	● 3,75 m ○ 3,50 m ○ 3,25 m ○ 3,00 m of smaller
ontwerplevensduur (in jaar)	20

verkeersparameters

aantal voertuigen per dag en per richting	475
aandeel vrachtwagens (in %)	100
vrachtwagens met breedbanden (in %)	50
evolutie (in %)	1

Figure 8: Example of road classification and standard structure for assumed road (via AWV online module)

3.1.6 How does online calculation module calculate road class?

This can be done using the following equations and tables (Annex MOW/AWV/2010/2):

$$N_{100kN} = SPEC * N_{as} * C_b * C_{sn} * C_{bb} * (C_r * N_{vv1} + N_{vv2}) \qquad \text{(eq.5)}$$

In this formula applies:

- SPEC: is the axles-spectrum value in Flanders since (1998), which is equal to **0,2597 ESAL/axle**. This value is lower than the old value from 1990, as more trucks have been equipped with super singles since the 1998 spectrum, which reduces the axle load.

- N_{as}: is the average number of axles per truck and it depends on the road category. Since this assumed road is a secondary road, AWV table below shows the average Nas =of 3.0 axles/truck (Table 11).

Table 11 : Recommended average number of axles per truck according to the Flemish AWV Agency

Road category	$\mathbf{N_{as}}$
Main roads "hoofdwegen"	**4,0**
Primary roads "primaire wegen"	**3,5**
Secondary roads "swcundaire wegen"	**3,0**
Local roads "lokale wegen"	**2,5**

- C_{sn}: is a correction factor for the average speed of vehicles. It depends on the design speed and the type of pavement's surface. Table 12 shows that the correction factor **C_{sn} = 1,17 since** the assumed design speed is 50km/h and pavement type is asphalt pavement.

Table 12: C_{sn} correction factor for speed according to the Flemish AWV Agency

Design speed	Correction factor for the average speed of vehicles $\mathbf{C_{sn}}$	
	Bituminous flexible pavement	*Cementious rigid pavement*
10 km/h	1,55	1,00
30 km/h	1,35	1,00
50 km/h	1,17	1,00
70 km/h	1,07	1,00
90 km/h	1,00	1,00

- C_{bb}: is a correction factor for trucks with wide tires (super single tires). The greater the number of trucks with super single, the greater the correction factor C_{bb} . As mentioned above, the assumed percentage of trucks with super single tires will be 50% , therefore the correction factor **C_{bb} = 1,45**. (Table 13) below:

Table 13: C_{bb} correction factor for super single trucks according to the Flemish AWV Agency

Trucks percent with super single tires	Correction factor for trucks with super single tires $\mathbf{C_{bb}}$
0 %	1,00
10 %	1,09
20 %	1,18
30 %	1,27
40 %	1,36
50 %	1,45
60 %	1,54

- Cb: is a correction factor for the width of the lanes. For example, it is argued here that a wider lane will ensure a better loading distribution and therefore lowest correction factor. This road has a lane width of 4m "max 3,75m", so a correction factor **C_b =0,75** (Table 14 14)

Table 14: C_b correction factor for lane width according to the Flemish AWV Agency

Lane width	Correction factor for the width of the lanes $\mathbf{C_b}$
3,75m	0,75

3,50m	0,85
3,25m	0,95
3,00m of minder	1,00

- Total traffic (NVV1 and NVV2) : To avoid any expected traffic saturation, The traffic (NVV1 and NVV2) has to be split into two steps as follow: First, the growing traffic is checking the saturation of the full direction of travel and checking the saturation of the most congested lane.

A. *Checking the saturation in the entire driving direction*

To prevent saturation of the entire direction of travel, the following condition must be met:

$$V_{0-24} * \left(1+\frac{VV_{wd}}{100}\right) * \left(1+\frac{i}{100}\right)^{L} \le CAP * N_r \qquad \text{(eq.6)}$$

Where,

- V_{0-24} = 475 truck per working day per direction
- V_{wd} = 100 % truck
- i = 1 % (According to AWV, annual growth is 1.0% for the secondary road)
- L = 20 years (According to AWV the design life is 20 years for bituminous pavement)
- CAP = 10.000 (Because the design speed is 50Km/h)
- Nr = 1 lane per direction >>> Cr = 1

It is important to check whether the traffic increase will increase or not during the entire life of the pavement. The maximum lane capacity is expressed in equivalent passenger car (p.e.) per hour and it is also a function of the design speed. From (Table 15Table 15) **CAP = 10.000.**

Table 15 : Maximum lane capacity according to the Flemish AWV Agency

Design speed	Maximum lane capacity per day, CAP
10 km/h	5000 p.e.
30 km/h	7000 p.e.
50 km/h	10000 p.e.
70 km/h	14000 p.e.
90 km/h	20000 p.e.

By calculating the data in the formula, a capacity equal to 1160 passenger car equivalent is obtained. This calculated value is lower than the maximum value, which is 20,000 p.e. This means that saturation of the entire direction of travel will not occur.

$$475 \times (1+\frac{100}{100}) \times \left(1+\frac{1.0}{100}\right)^{20} = 1160$$

1160< 10.000 (1*10.000) (OK , No saturation in the entire direction)

B. *Checking the saturation in the most congested lane*

To guarantee that there is no saturation in the most congested lane, the following condition must be met:

$$2 \times V_{0-24} \times \frac{V_{wd}}{100} \times C_r \times \left(1+\frac{i_{tot}}{100}\right)^{L} < CAP \qquad \text{(eq.7)}$$

$$2 \text{ x } 475 \times (1+\frac{100}{100}) \times \left(1+\frac{1.0}{100}\right)^{20}) = \mathbf{2320}$$

This shows that the calculated capacity of 2320 equivalent passenger car (p.e.) will not exceed the maximum capacity of the road (10,000 p.e.). It can therefore be concluded that there will be no saturation of the most heavily loaded lane, as well.

2320 <10.000 (OK , no saturation in the most congested lane)

It can be concluded from both checks that the road will not be saturated. It follows that NVV2 is equal to 0. NVV1 gives of the number of vehicles during the design life of this assumed road. NVV1 = 2.928.528 vehicles; calculated using the following equation:

$$N_{VV1} = V_{0-24} \times \frac{V_{wd}}{100} \times WD_j \times \left[\frac{(1+i)^L - 1}{i} \right] \qquad \text{(eq.8)}$$

$N_{VV1} = 475 \times \frac{100}{100} \times 280 \times \left[\frac{(1+1.0/100)^{20}-1}{1.0/100}\right] = \mathbf{2.928.528}$ “As expected, same value was collected as AWV module , see Figure 8.

Now all values are known for the calculation of the number of standard axles N100kN of the road during the design life:

SPEC= 0,2597

$N_{as} = 3$

$C_b = 0{,}75$

$C_{sn} = 1{,}17$

$C_{bb} = 1{,}45$

$C_r = 1$

$N_{VV1} = 2.928.528$

$N_{VV2} = 0$

$N_{100kN} = SPEC \text{ x } N_{as} \text{ x } C_b \text{ x } C_{sn} \text{ x } C_{bb} \text{ x } (C_r \text{ x } N_{VV1} + N_{VV2})$

= 0,2597*3*0,75*1,17*1,45*(1*2.928.528+ 0.0)

= 2.903.071 standard axle of ESAL-100kN

This number is in range (2 MESAL100kN - 4 MESAL100kN), therefore the road class will be B6 (see Fout! Verwijzingsbron niet gevonden. **above)**

The road class produced by the AWV equation was similar to the road class produced by the online AWV module.

3.2 Defining The Standard Structure Using AWV Manual (MOW/AWV//2017/4)

A standard structure is a vertical road structure that is sufficient to bear the loads during the predetermined lifespan. Next, a decision should be made to define which material per layer? and what is the thickness per layer (pavement design)?. For more illustration, the design will be done based on the results of the example in section 3.1 above.

3.2.1 Defining The Standard Pavement Materials/Mixtures

Mainly, pavement structures can be one of the following three types:

- Flexible structures: substrate, sand bed, crushed stone foundation and bituminous layers
- Semi-rigid structures: substrate, sand bed, lean concrete and bituminous layers
- Rigid structures: substrate, sand bed, lean concrete and cement concrete

As mentioned in the above example, it is an existing damaged road. Therefore, a structural repair is needed and in-situ cold recycling would be good rehabilitation option. Therefore, a flexible pavement structure will be applied for that road of B6 class. Two different sections will be constructed , but both shall have similar service life since it is same road:

- Structure A "AC wearing layer 4cm + AC underlayer +BSM base + Subbase",
- Structure B "AC wearing layer 4cm + BSM base + Subbase",

3.2.1.1 AC layers

An asphalt or bituminous pavement consists of:

- AC top wearing layer
- AC underlayer
- (optional) a profiling layer

Using Table 16 (Annex MOW/AWV/2017/4) , the proper asphalt mixture can be selected based on both: road class and road location. Therefore, **APT-C "Asfaltbeton met Prestatie eisen voor Toplaag" is** recommended as the top layer, which is ideal for a road class B6 outside residential zone (**Buiten bebouwde kom**).

Table 16 : Asphalt mixtures for top wearing layers (toplagen) for secondary and local roads according to the Flemish AWV Agency (MOW/AWV/2017/4)

Recommended asphalt mixtures for top HMA wearing layer for main roads or primary roads "hoofdwegen en primaire wegen"				
Road class	Main roads = hoofdwegen		Primary roads = primaire wegen	
	Standard	Alternative	Standard	Alternative
B1-B3	SMA-D	SMA-C , ZOA-B , AGT	SMA-D	SMA-C , ZOA-B , AGT
B4-B5	-	-	SMA-D	SMA-C , AGT
B6-B10	-	-	-	-
Recommended asphalt mixtures for top HMA wearing layer for secondary roads or local roads				
Road class	Outside residential area "buiten bebouwde kom"		Inside residential area "binnen bebouwde kom"	
	Standard	Alternative	Standard	Alternative
B1-B2	-	-	-	-
B3	SMA-D	SMA-C , AGT	-	-
B4-B5	SMA-D	SMA-C , AGT	-	-
B6-B8	APT-C , APT-D	-	APT-C , APT-D	-
B9-B10	AB-4C , AB-4D	-	AB-4C , AB-4D	-
BF	AB-4D	-	AB-4D	AB-4C , GA

Concerning the AC underlayer is selected according to (SB250- Annex MOW/AWV/2017/4) (see Table 17). Based on the road category, **APO-A mixture could be a good choice as AC underlayer**. If needed, the same mixture type can be applied for any extra profile layers.

Table 17 : Asphalt mixtures for AC underlayers according to the Flemish AWV Agency (MOW/AWV/2017/4)

Road class	Main roads & Primary roads		Secondary roads & Local roads	
	Standard	Alternative	Standard	Alternative

B1-B2	AVS-B	APO-A , APO-B	-	-
B3	AVS-B	APO-A , APO-B	APO-A , APO-B	AVS-B
B4-B5	APO-A , APO-B	AVS-B	APO-A , APO-B	-
B6-B10,BF	APO-A , APO-B	-	APO-A , APO-B	-

3.2.1.2 Base Layer

Four types of materials may be selected as base layer/foundation, according to the AWV standards, see (Table 18) below:

Table 18 : Types of pavement foundations in Flemish standard structures

Crushed aggregates base “steenslagfundering”	○ crushed aggregates base with continuous gradation without additives; ○ crushed aggregates base with non-continuous gradation.
Treated crushed aggregates base “behandelde steenslagfundering”	○ additive-treated crushed aggregates base with continuous gradation, type IB & IIB; ○ base of fly ash-lime mixtures.
Stabilized crushed aggregates base “gestabiliseerde steenslagfundering”	○ additive-treated aggregates base with continuous gradation, type IA and type IIA; ○ crushed aggregates base with tar; ○ sand cement base; ○ base of fly ash-cement mixtures; ○ base by stabilizing the existing pavement with cement; ○ bitumen stabilized material or Foam-BSM OR Emulsion-BSM (1)
Lean concrete base “schaarlbetonfundering”	○ lean concrete base; ○ base of draining lean concrete
(1) BSM’s materials as foundation is new in the Belgian market.	

Normally, excessive permanent shear deformation (or rutting) is a distress mode age phenomenon with unbound foundations/materials such as gravel or crushed stone, or subgrade. While cemented materials such as CSM or Lean concrete will be damaged due to fatigue cracking. Each base material has typical mechanical properties in Table 6 above.

For this existing damaged road, which assumed above, in-situ cold recycling will be applied to recycle/stabilize a 100% RAP using a Foam technology. The produced foamed bitumen stabilized material BSM would be used as a base layer in section A, while in section B, the BSM won’t be used as base layer only but also as an alternative for all AC underlayers (HMA asphalt base). The following Table 19 illustrates the minimum requirements of shear parameters of BSM that produced by RAP (50%-100%). These are special/additional design parameters for Stellenbosch BSM transfer function:

Table 19 : Minimum requirements of shear parameters of BSM made by RAP (50%-100%)

Parameters	Value	Recommended by
Cohesion C KPa	265	TG2 when RAP BSM made by RAP (50%-100%), see Table 2 above.
Friction Angle ø	38	
Retained Cohesion RetC %	75	
BSM dry density PMDD %	100	
BSM resilient modulus MPa	800 (1),(2)	Wirtgen study (800-1600MPa)

(1) By consulting TG2 authors, the BSM layer can have a stiffness up to 3 times the stiffness modulus of the underlying layer. For instance, if the subbase has a stiffness of 250 MPa, then the BSM layer will have stiffness modulus = 3 * $E_{subbase}$ 250MPa= 750 MPa. The justification behind this: is that BSM stiffness modulus which can be generated practically in-situ, won't be more than 3 times "at maximal" the stiffness modulus of the underlying layer, according to their observations. However, the laboratory testing program may lead to higher stiffness modulus for BSM, see Table 3 above.

(2) The BSM will be assumed a temperature independent. In other words, BSM stiffness modulus will be constant all seasons. However, the effect of seasonal stiffness in AC layers will affect the BSM performance, that's why the service life of BSM will be predicted in the three seasons.

Applying these typical "default values" mechanical properties directly in the design process without measuring it laboratory, will surely lead to a less confident pavement design.

Due to compaction considerations, it is recommends to lay the BSM in multilayers within range 10cm-30cm. How thinner separate layers, how better compaction rate. For more safety, a BSM thickness of 12cm as lower limit is recommended to avoid any technical issue in-situ.

3.2.1.3 Subbase

There are three different types of subbase materials, according to the AWV standards:

- Subbase (type 1) of sand; with elastic modulus range of E (50 MPa-250MPa)
- Subbase (type 2) of coarse materials:
  - Natural gravel; with elastic modulus range of E (250 MPa-400MPa)
  - Coarse aggregates with fines or crushed stone (Steenslag); with elastic modulus range of E (400 MPa-600MPa)
- Subbase of stabilized subsoil by cement or lime; with elastic modulus range of E (250 MPa-600MPa)

If an existing road would be rehabilitated, then the subbase as support of BSM layer shall be evaluated using a suitable test such as : DCP test, dynamic plate loading test, static plate loading test and/or GPR georadar.

According to SB250 v4.0, the compressibility of subbase M1 value obtained by plate loading test must be greater than M1 >=35MPa which could calibrated to Elastic modulus of 250MPa "as worst-case scenario".

Assume that a subbase was evaluated as crush stone with fines (0/40) and stiffness modulus is 250 MPa and it is thickness = 35cm.

3.2.1.4 Subgrade "existing soil"

The subgrade shall have sufficient bearing capacity to resist the permanent deformation. Thus it shall support all the traffic loads that are delivered by the upper pavement body during the desired road lifespan. Therefore, the mechanical properties of the subgrade are key parameters in the design process to estimate the fatigue life. For design purposes, the load-bearing capacity of subgrade is characterized by elastic modulus which can be correlated from the CBR value (E MPa=10xCBR%). Similar to subbase, subgrade modulus E can be thus evaluated using a suitable test such:

- Static plate loading test CBR,
- Dynamic plate loading test ,
- DCP test
- GPR georadar

According to SB250 v4.0, the compressibility of subgrade M1 value obtained by plate loading test must be greater than M1>=17MPa which could calibrated to Elastic modulus of 50MPa "as worst-case scenario". If the CBR value of the substrate is not known, typical CBR values can be hired from the following Table 20:

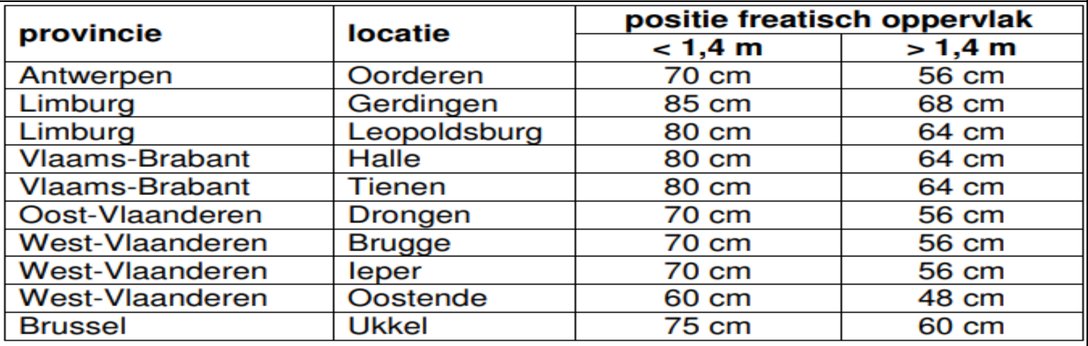
Table 20 : Typical values of bearing capacity of subgrade (WVDB, wegenbouwbook,2018)

Material of subgrade	Bearing capacity CBR value	Modulus of elasticity (MPa) E=10XCBR	Improvement of subgrade bearing capacity
Clay (Klei)	2%-3%	20MPa - 30MPa	If the required bearing capacity is not met, it can be increased and improved by : o Compaction; o Hydraulic treatment by cement or lime; o Reinforced by geogrids; o Soil replacement (not recommended– highest cost).
Loam (Leem)	3%-5%	30MPa - 50MPa	
Loam-sand (Leemhoudend zand)	5%-8%	50MPa - 80MPa	
sand-clay mixture (zand-klei mengsel)	7%-15%	70MPa - 150MPa	
Sand (Zand)	7%-20%	70MPa - 200MPa	

3.2.2 Defining frost-free depth

The thickness of the subbase primarily depends on the frost-free depth. Table 21 shows the minimum pavement thickness to guarantee a frost-free structure according to the Flemish AWV Agency, as a function of the position of the phreatic surface level "*positive freatisch oppervlak*". Some drilling tests will help in evaluate the a phreatic surface level. If the structure is thinner than the frost-free thickness, then the thickness of the subbase should be increased until the total pavement thickness fulfills the minimum thickness to achieve frost-free depth. In other words, the thickness of AC layer plus base layer is subtracted from the frost-free structure, the remaining thickness of the sub-foundation is obtained.

Table 21: Minimum pavement thickness to achieve a frost-free depth according to the Flemish AWV Agency (MOW/AWV/2017/4)

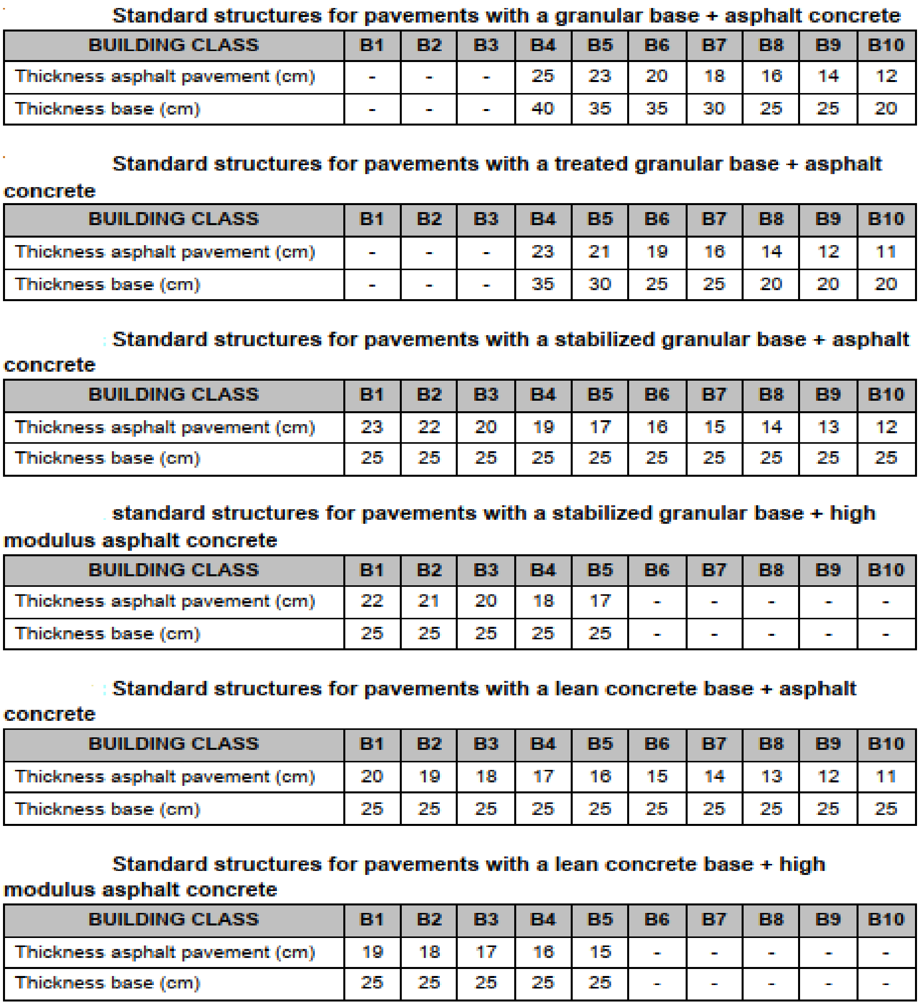


provincie	locatie	positie freatisch oppervlak	
		< 1,4 m	> 1,4 m
Antwerpen	Oorderen	70 cm	56 cm
Limburg	Gerdingen	85 cm	68 cm
Limburg	Leopoldsburg	80 cm	64 cm
Vlaams-Brabant	Halle	80 cm	64 cm
Vlaams-Brabant	Tienen	80 cm	64 cm
Oost-Vlaanderen	Drongen	70 cm	56 cm
West-Vlaanderen	Brugge	70 cm	56 cm
West-Vlaanderen	Ieper	70 cm	56 cm
West-Vlaanderen	Oostende	60 cm	48 cm
Brussel	Ukkel	75 cm	60 cm

3.2.3 Defining thicknesses per each layer

Table 22 shows the recommended standard structures in Flanders.

Table 22 : Recommended standard structures based on AWV Standards according to the Flemish AWV Agency (MOW/AWV/2017/4)



Standard structures for pavements with a granular base + asphalt concrete

BUILDING CLASS	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Thickness asphalt pavement (cm)	-	-	-	25	23	20	18	16	14	12
Thickness base (cm)	-	-	-	40	35	35	30	25	25	20

Standard structures for pavements with a treated granular base + asphalt concrete

BUILDING CLASS	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Thickness asphalt pavement (cm)	-	-	-	23	21	19	16	14	12	11
Thickness base (cm)	-	-	-	35	30	25	25	20	20	20

Standard structures for pavements with a stabilized granular base + asphalt concrete

BUILDING CLASS	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Thickness asphalt pavement (cm)	23	22	20	19	17	16	15	14	13	12
Thickness base (cm)	25	25	25	25	25	25	25	25	25	25

standard structures for pavements with a stabilized granular base + high modulus asphalt concrete

BUILDING CLASS	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Thickness asphalt pavement (cm)	22	21	20	18	17	-	-	-	-	-
Thickness base (cm)	25	25	25	25	25	-	-	-	-	-

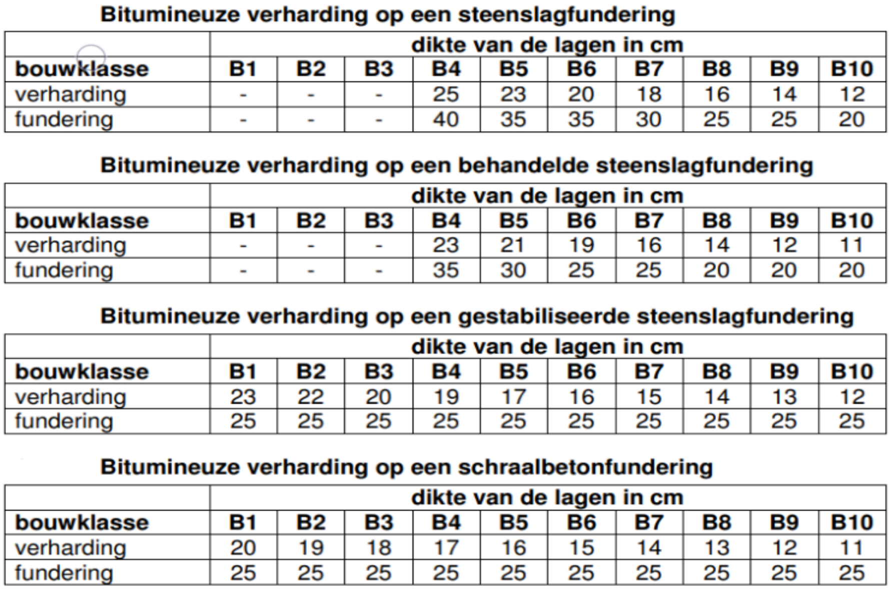
Standard structures for pavements with a lean concrete base + asphalt concrete

BUILDING CLASS	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Thickness asphalt pavement (cm)	20	19	18	17	16	15	14	13	12	11
Thickness base (cm)	25	25	25	25	25	25	25	25	25	25

Standard structures for pavements with a lean concrete base + high modulus asphalt concrete

BUILDING CLASS	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Thickness asphalt pavement (cm)	19	18	17	16	15	-	-	-	-	-
Thickness base (cm)	25	25	25	25	25	-	-	-	-	-

In Dutch :



Bitumineuze verharding op een steenslagfundering

	dikte van de lagen in cm									
bouwklasse	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**
verharding	-	-	-	25	23	20	18	16	14	12
fundering	-	-	-	40	35	35	30	25	25	20

Bitumineuze verharding op een behandelde steenslagfundering

	dikte van de lagen in cm									
bouwklasse	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**
verharding	-	-	-	23	21	19	16	14	12	11
fundering	-	-	-	35	30	25	25	20	20	20

Bitumineuze verharding op een gestabiliseerde steenslagfundering

	dikte van de lagen in cm									
bouwklasse	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**
verharding	23	22	20	19	17	16	15	14	13	12
fundering	25	25	25	25	25	25	25	25	25	25

Bitumineuze verharding op een schraalbetonfundering

	dikte van de lagen in cm									
bouwklasse	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**
verharding	20	19	18	17	16	15	14	13	12	11
fundering	25	25	25	25	25	25	25	25	25	25

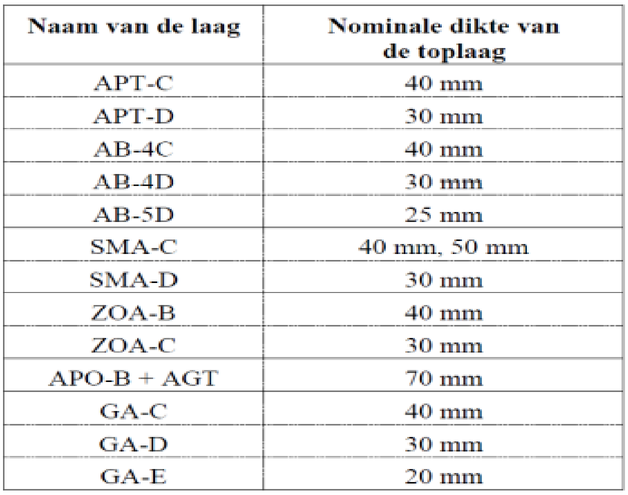
As result, the standard structure for B6 road can be defined as follow (Table 23):

Table 23 : Standard structure (thickness per layer) for a bituminous pavement with a stabilized material; determined according to AWV standard

Layers	Thickness
AC Asphalt surface layer = APT-C AC underlayer = APO-A AC extra profile underlayer = APO-A	**16 cm** Check Road Class B6 in Table 22
Base layer of bitumen stabilized material BSM	**--- cm** BSM is undefined in Table 22
Subbase (*Always min 20 cm according to AWV for frost-free structure purposes)*	**35 cm**

Hereafter, for more detailed AC layer, the SB250 v4.0 (AWV standard) gives more details about the top layer, the AC underlayer and the profiling AC layer. Both Table 24 & Table 25 can help in defining the thickness of each AC layer, keeping in mind that the sum of the thicknesses of the AC layers must equal 16cm. Since the thickness of an **APT-C is nominally 4 cm** (see Table 24), the pavement must be further divided into an underlayer and a possible profile layer. The remaining thickness of the pavement is still 12 cm corresponding to the total AC thickness of 16 cm.

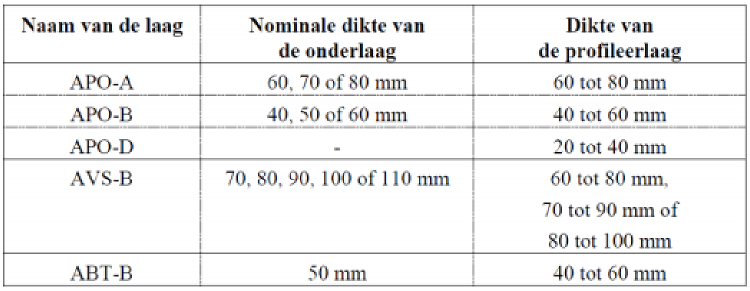
Table 24 : Nominal thickness of wearing AC layer - AWV SB250 v4.0



Naam van de laag	Nominale dikte van de toplaag
APT-C	40 mm
APT-D	30 mm
AB-4C	40 mm
AB-4D	30 mm
AB-5D	25 mm
SMA-C	40 mm, 50 mm
SMA-D	30 mm
ZOA-B	40 mm
ZOA-C	30 mm
APO-B + AGT	70 mm
GA-C	40 mm
GA-D	30 mm
GA-E	20 mm

A 6 cm thickness of APO-A can be used as AC underlayer according to Table 25. The remaining 6 cm (16 cm - 4cm -6cm = **6cm for AC profile layer**) can be assigned as a profile additional underlayer of the same type.

Table 25 : Nominal thickness of AC underlayer/AC profile layer - AWV SB250



Naam van de laag	Nominale dikte van de onderlaag	Dikte van de profileerlaag
APO-A	60, 70 of 80 mm	60 tot 80 mm
APO-B	40, 50 of 60 mm	40 tot 60 mm
APO-D	-	20 tot 40 mm
AVS-B	70, 80, 90, 100 of 110 mm	60 tot 80 mm, 70 tot 90 mm of 80 tot 100 mm
ABT-B	50 mm	40 tot 60 mm

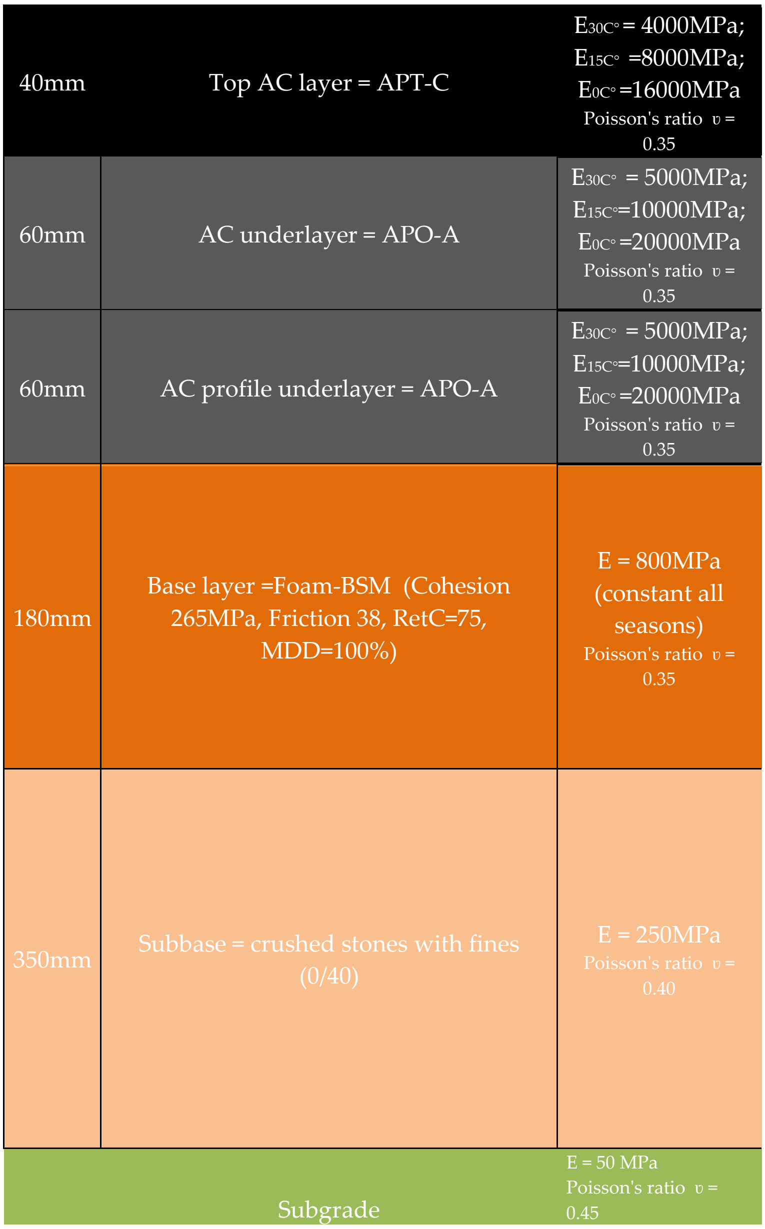
4 Pavement design with a Foam-BSM : Structure A

Firstly, the pavement structure was analyzed and hereafter was designed using the Flemish Mechanistic Empirical ME design approach, then a verification will be done using The South African Pavement Engineering Manual (SAPEM) , while all thicknesses and mechanical properties will be kept similar for both methods. The designer will test if the South African ME design approach will result in similar structural capacity as the Flemish ME design approach when exactly identical thicknesses were selected. This methodology will be applied for designing all standard structures of type A for road classes.

4.1 Structure "A" Design Using ME - Flemish Design Method

4.1.1 Preparing Input Parameters

The mechanical properties and the thickness of the standard structure A (AC wearing layer 4cm + AC underlayer + BSM base + Subbase) that was predefined in section 3.2 above; can be summarized in the following Figure 9:



40mm	Top AC layer = APT-C	E_{30C° = 4000MPa; E_{15C° =8000MPa; E_{0C° =16000MPa Poisson's ratio υ = 0.35
60mm	AC underlayer = APO-A	E_{30C° = 5000MPa; E_{15C°=10000MPa; E_{0C° =20000MPa Poisson's ratio υ = 0.35
60mm	AC profile underlayer = APO-A	E_{30C° = 5000MPa; E_{15C°=10000MPa; E_{0C° =20000MPa Poisson's ratio υ = 0.35
180mm	Base layer =Foam-BSM (Cohesion 265MPa, Friction 38, RetC=75, MDD=100%)	E = 800MPa (constant all seasons) Poisson's ratio υ = 0.35
350mm	Subbase = crushed stones with fines (0/40)	E = 250MPa Poisson's ratio υ = 0.40
	Subgrade	E = 50 MPa Poisson's ratio υ = 0.45

Figure 9: Best design option for Structure A (AC wearing layer 4cm + AC underlayer + BSM base + Subbase)

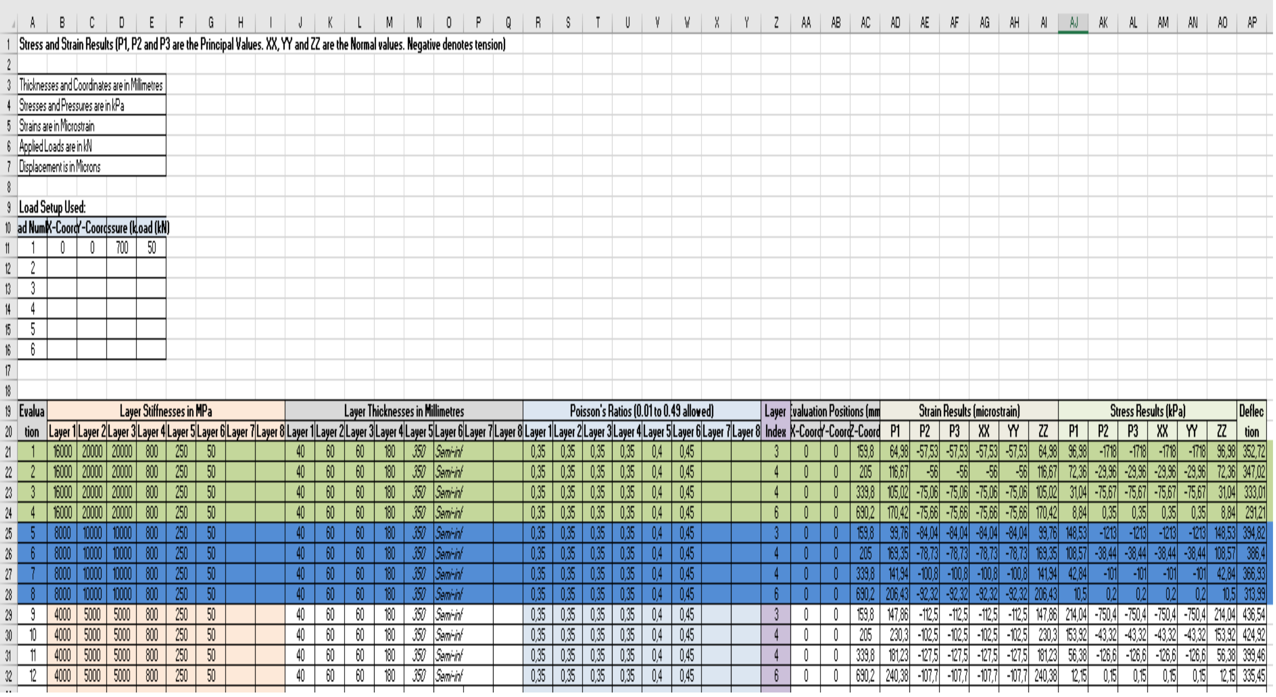
4.1.2 Measuring Pavement Responses Using Rubicon Stress/Strain Calculator

The design parameters were filled in Rubicon stress/strain model, then the model generated the responses strains/stresses. These responses were then applied in the corresponding transfer functions. Concerning the BSM layer, the actual responses were then applied in the Stellenbosch BSM transfer functions.

During full depth analysis , it was observed that the critical DSR position, which equals to the highest value, isn't always at ¼ depth. So, it is recommended to perform a full depth analysis to find out exactly the maximal DSR since the service life can be changed with millions when applying the effective DSR_{max}.

Depending on the pavement system and materials properties as an integrated system, the maximal DSR moves up and down around top ¼ depth in BSM. As mentioned above in chapter 2, the maximal DSR will occur before the shifting point of minor principle stress from compression to tension. Moreover, it was noticed that when the top AC layers become stiffer at low temperatures, the critical DSR position in BSM layer moves up to higher position, See Table 26 below :

Table 26 : Pavement responses for structure A using Rubicon stress/strain analyzer



Stress and Strain Results (P1, P2 and P3 are the Principal Values. XX, YY and ZZ are the Normal values. Negative denotes tension)

Thicknesses and Coordinates are in Millimetres
Stresses and Pressures are in kPa
Strains are in Microstrain
Applied Loads are in kN
Displacement is in Microns

Load Setup Used:

ad Num	X-Coord	Y-Coord	ssure (k	Load (kN)
1	0	0	700	50
2				
3				
4				
5				
6				

Evalua	Layer Stiffnesses in MPa								Layer Thicknesses in Millimetres							
tion	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8
1	16000	20000	20000	800	250	50			40	60	60	180	*350*	*Semi-inf*		
2	16000	20000	20000	800	250	50			40	60	60	180	*350*	*Semi-inf*		
3	16000	20000	20000	800	250	50			40	60	60	180	*350*	*Semi-inf*		
4	16000	20000	20000	800	250	50			40	60	60	180	*350*	*Semi-inf*		
5	8000	10000	10000	800	250	50			40	60	60	180	*350*	*Semi-inf*		
6	8000	10000	10000	800	250	50			40	60	60	180	*350*	*Semi-inf*		
7	8000	10000	10000	800	250	50			40	60	60	180	*350*	*Semi-inf*		
8	8000	10000	10000	800	250	50			40	60	60	180	*350*	*Semi-inf*		
9	4000	5000	5000	800	250	50			40	60	60	180	*350*	*Semi-inf*		
10	4000	5000	5000	800	250	50			40	60	60	180	*350*	*Semi-inf*		
11	4000	5000	5000	800	250	50			40	60	60	180	*350*	*Semi-inf*		
12	4000	5000	5000	800	250	50			40	60	60	180	*350*	*Semi-inf*		

Evalua	Poisson's Ratios (0.01 to 0.49 allowed)								Layer	valuation Positions (mm		
tion	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8	Index	X-Coord	Y-Coord	Z-Coord
1	0,35	0,35	0,35	0,35	0,4	0,45			3	0	0	159,8
2	0,35	0,35	0,35	0,35	0,4	0,45			4	0	0	205
3	0,35	0,35	0,35	0,35	0,4	0,45			4	0	0	339,8
4	0,35	0,35	0,35	0,35	0,4	0,45			6	0	0	690,2
5	0,35	0,35	0,35	0,35	0,4	0,45			3	0	0	159,8
6	0,35	0,35	0,35	0,35	0,4	0,45			4	0	0	205
7	0,35	0,35	0,35	0,35	0,4	0,45			4	0	0	339,8
8	0,35	0,35	0,35	0,35	0,4	0,45			6	0	0	690,2
9	0,35	0,35	0,35	0,35	0,4	0,45			3	0	0	159,8
10	0,35	0,35	0,35	0,35	0,4	0,45			4	0	0	205
11	0,35	0,35	0,35	0,35	0,4	0,45			4	0	0	339,8
12	0,35	0,35	0,35	0,35	0,4	0,45			6	0	0	690,2

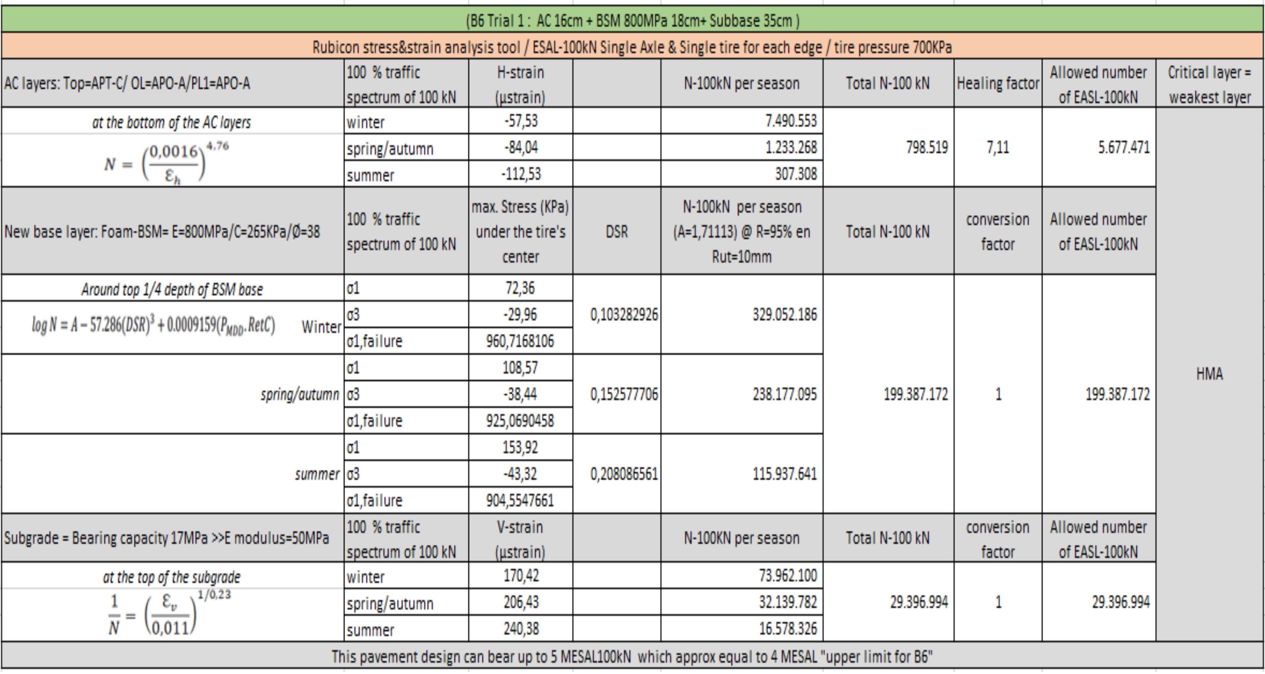
Evalua	Strain Results (microstrain)						Stress Results (kPa)						Deflec
tion	P1	P2	P3	XX	YY	ZZ	P1	P2	P3	XX	YY	ZZ	tion
1	64,98	-57,53	-57,53	-57,53	-57,53	64,98	96,98	-1718	-1718	-1718	-1718	96,98	352,72
2	116,67	-56	-56	-56	-56	116,67	72,36	-29,96	-29,96	-29,96	-29,96	72,36	347,02
3	105,02	-75,06	-75,06	-75,06	-75,06	105,02	31,04	-75,67	-75,67	-75,67	-75,67	31,04	333,01
4	170,42	-75,66	-75,66	-75,66	-75,66	170,42	8,84	0,35	0,35	0,35	0,35	8,84	291,21
5	99,76	-84,04	-84,04	-84,04	-84,04	99,76	148,53	-1213	-1213	-1213	-1213	148,53	394,82
6	169,35	-78,73	-78,73	-78,73	-78,73	169,35	108,57	-38,44	-38,44	-38,44	-38,44	108,57	386,4
7	141,94	-100,8	-100,8	-100,8	-100,8	141,94	42,84	-101	-101	-101	-101	42,84	366,93
8	206,43	-92,32	-92,32	-92,32	-92,32	206,43	10,5	0,2	0,2	0,2	0,2	10,5	313,99
9	147,86	-112,5	-112,5	-112,5	-112,5	147,86	214,04	-750,4	-750,4	-750,4	-750,4	214,04	436,54
10	230,3	-102,5	-102,5	-102,5	-102,5	230,3	153,92	-43,32	-43,32	-43,32	-43,32	153,92	424,92
11	181,23	-127,5	-127,5	-127,5	-127,5	181,23	56,38	-126,6	-126,6	-126,6	-126,6	56,38	399,46
12	240,38	-107,7	-107,7	-107,7	-107,7	240,38	12,15	0,15	0,15	0,15	0,15	12,15	335,45

Similar response values (stresses & strains) were obtained using Alize multi-layer analyzer software, see Appendix B in section 10.2 that presents analysis results for the above structure in Figure 9.

4.1.3 Service Life Calculation of Structure A using ME - Flemish Design Method

The following Table 27 shows the calculations of the maximum allowed number of loading repetitions.

Table 27 : Service life calculation of structure A using ME - Flemish Design Method



(B6 Trial 1 : AC 16cm + BSM 800MPa 18cm+ Subbase 35cm)								
Rubicon stress&strain analysis tool / ESAL-100kN Single Axle & Single tire for each edge / tire pressure 700KPa								
AC layers: Top=APT-C/ OL=APO-A/PL1=APO-A	100 % traffic spectrum of 100 kN	H-strain (µstrain)		N-100kN per season	Total N-100 kN	Healing factor	Allowed number of EASL-100kN	Critical layer = weakest layer
at the bottom of the AC layers	winter	-57,53		7.490.553	798.519	7,11	5.677.471	HMA
$N = \left(\frac{0,0016}{\varepsilon_h}\right)^{4.76}$	spring/autumn	-84,04		1.233.268				
	summer	-112,53		307.308				
New base layer: Foam-BSM= E=800MPa/C=265KPa/Ø=38	100 % traffic spectrum of 100 kN	max. Stress (KPa) under the tire's center	DSR	N-100kN per season (A=1,71113) @ R=95% en Rut=10mm	Total N-100 kN	conversion factor	Allowed number of EASL-100kN	
Around top 1/4 depth of BSM base	σ1	72,36	0,103282926	329.052.186	199.387.172	1	199.387.172	
$\log N = A - 57.286(DSR)^3 + 0.0009159(P_{MDD}.RetC)$ Winter	σ3	-29,96						
	σ1,failure	960,7168106						
spring/autumn	σ1	108,57	0,152577706	238.177.095				
	σ3	-38,44						
	σ1,failure	925,0690458						
summer	σ1	153,92	0,208086561	115.937.641				
	σ3	-43,32						
	σ1,failure	904,5547661						
Subgrade = Bearing capacity 17MPa >>E modulus=50MPa	100 % traffic spectrum of 100 kN	V-strain (µstrain)		N-100KN per season	Total N-100 kN	conversion factor	Allowed number of EASL-100kN	
at the top of the subgrade	winter	170,42		73.962.100	29.396.994	1	29.396.994	
$\frac{1}{N} = \left(\frac{\varepsilon_v}{0,011}\right)^{1/0,23}$	spring/autumn	206,43		32.139.782				
	summer	240,38		16.578.326				
This pavement design can bear up to 5 MESAL100kN which approx equal to 4 MESAL "upper limit for B6"								

So in the above example, the AC layer indicate the lowest structural capacity in the whole pavement system, so the critical layer is AC layer with 5,6 MESAL100kN.

Next, step by step calculating the service life of BSM at winter in the above Table 30 "as an example":

$$\sigma_{1,f} = \frac{(1+\ \sin\emptyset).\sigma_3 +\ 2.C.\cos\emptyset}{(1-\ \sin\emptyset)} = \frac{(1+\ \sin 38).-29{,}96\ \ +\ 2.265.\cos 38}{(1-\ \sin 38)} = 960{,}71\ KPa$$

$$Deviator\ Stress\ Ratio\ DSR = \frac{\sigma_d}{\sigma_{d,f}} = \frac{\sigma_1 - \sigma_3}{\sigma_{1,f} - \sigma_3} = \frac{72{,}36-(-29{,}96)}{960{,}71-(-29{,}96)} = 0{,}1032$$

$$\log N =\ 1{,}71113 - 57.286(0{,}1032\ )^3 + 0.0009159(100\ X\ 75)$$

$$N_{winter} = 329\ \text{MESAL-100kN}$$

$$N_{spring} = 238\ \text{MESAL-100kN}$$

$$N_{summer} = 115\ \text{MESAL-100kN}$$

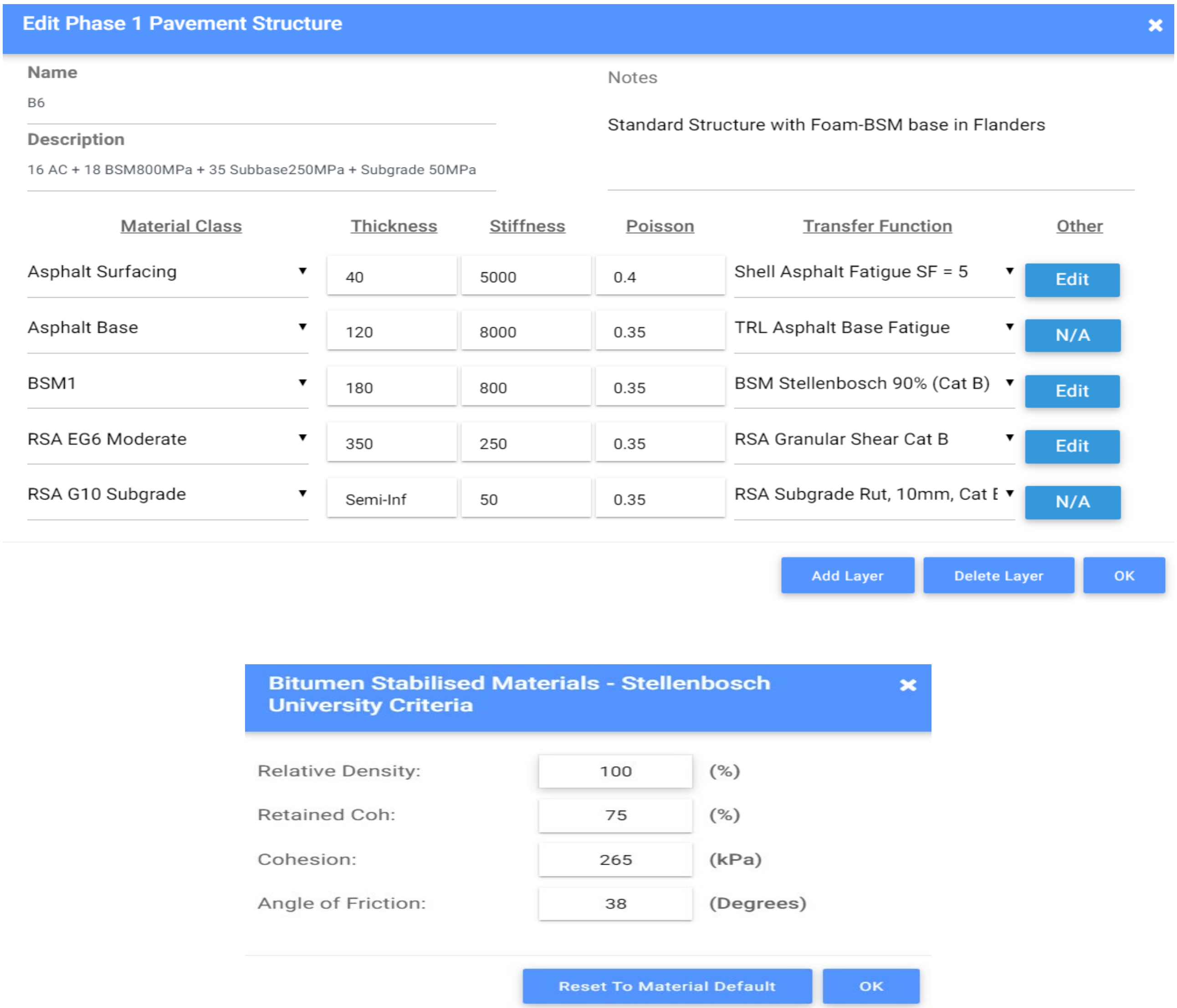
$$\frac{1}{N} = \frac{0.25}{N_{summer}} + \frac{0.5}{N_{spring}} + \frac{0.25}{N_{winter}} = \frac{0.25}{115} + \frac{0.5}{238} + \frac{0.25}{329}$$

$$\mathbf{N_{Total} = 199\ Million\ ESAL\text{-}100kN}$$

The Mechanistic Design of BSM layer has a much higher calculated service life which is related to that BSM in structure A is protected with a very thick asphalt layer.

4.2 Structure "A" Design Using ME-SAPEM 2014 – South African Guideline

Extra verification for the pavement design of the structure A using ME-SAPEM 2014 – South African Guideline was done. The design can be done using the Rubicon Standard Axle Design Tool. This tool was developed based on the Layered Elastic Theory (LET). It is a quick and easy assessment of the stress and strain in a pavement under a selected axle configuration. The South African ME design approach uses fatigue laws/transfer functions assigned per material. Thus ME-SAPEM will lead for sure to different results comparing with ME – Flanders. Figure 10 below shows the design inputs (thicknesses & mechanical properties) that can be defined by (SAPEM,2014) manual. Unlike Flemish ME design approach, the South African ME design approach applies other default values for the mechanical properties of the paving materials (see Table C.5 in Appendix C), while the Flemish ME design approach applies the seasonal stiffness approach. With respect thicknesses, the designer will test if the South African ME design approach will result in similar structural capacity as the Flemish ME design approach when exactly identical thicknesses were selected. This methodology will be applied for designing all standard structures of type A for road classes.



Edit Phase 1 Pavement Structure

Name: B6

Description: 16 AC + 18 BSM800MPa + 35 Subbase250MPa + Subgrade 50MPa

Notes: Standard Structure with Foam-BSM base in Flanders

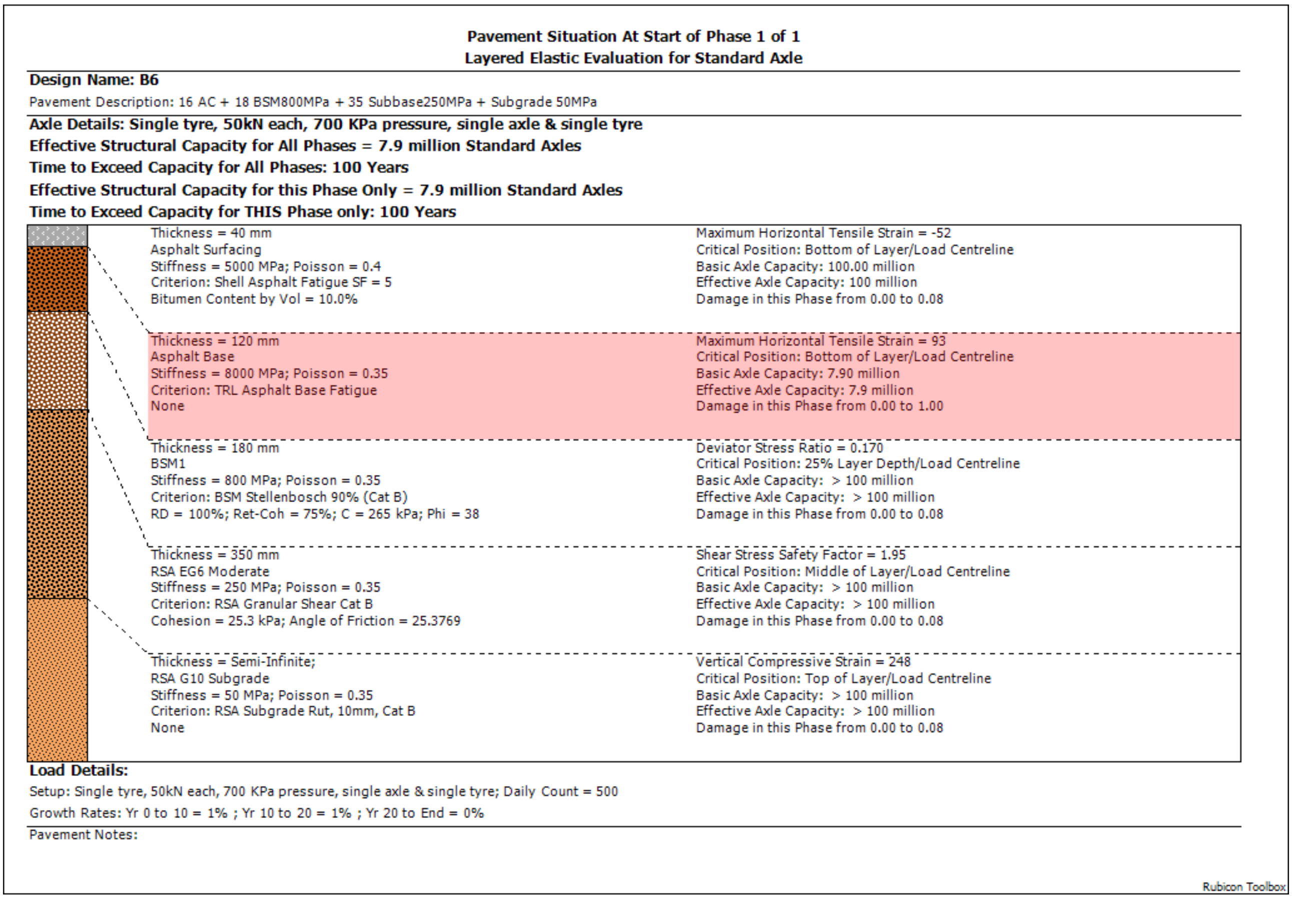
Material Class	Thickness	Stiffness	Poisson	Transfer Function	Other
Asphalt Surfacing	40	5000	0.4	Shell Asphalt Fatigue SF = 5	Edit
Asphalt Base	120	8000	0.35	TRL Asphalt Base Fatigue	N/A
BSM1	180	800	0.35	BSM Stellenbosch 90% (Cat B)	Edit
RSA EG6 Moderate	350	250	0.35	RSA Granular Shear Cat B	Edit
RSA G10 Subgrade	Semi-Inf	50	0.35	RSA Subgrade Rut, 10mm, Cat E	N/A

Bitumen Stabilised Materials - Stellenbosch University Criteria

Relative Density:	100	(%)
Retained Coh:	75	(%)
Cohesion:	265	(kPa)
Angle of Friction:	38	(Degrees)

Figure 10 : Structure A - Design inputs at Rubicon Standard Axle Design Tool

The results from the software will be presented in Figure 11.



Pavement Situation At Start of Phase 1 of 1
Layered Elastic Evaluation for Standard Axle

Design Name: B6
Pavement Description: 16 AC + 18 BSM800MPa + 35 Subbase250MPa + Subgrade 50MPa

Axle Details: Single tyre, 50kN each, 700 KPa pressure, single axle & single tyre
Effective Structural Capacity for All Phases = 7.9 million Standard Axles
Time to Exceed Capacity for All Phases: 100 Years
Effective Structural Capacity for this Phase Only = 7.9 million Standard Axles
Time to Exceed Capacity for THIS Phase only: 100 Years

Thickness = 40 mm
Asphalt Surfacing
Stiffness = 5000 MPa; Poisson = 0.4
Criterion: Shell Asphalt Fatigue SF = 5
Bitumen Content by Vol = 10.0%

Maximum Horizontal Tensile Strain = -52
Critical Position: Bottom of Layer/Load Centreline
Basic Axle Capacity: 100.00 million
Effective Axle Capacity: 100 million
Damage in this Phase from 0.00 to 0.08

Thickness = 120 mm
Asphalt Base
Stiffness = 8000 MPa; Poisson = 0.35
Criterion: TRL Asphalt Base Fatigue
None

Maximum Horizontal Tensile Strain = 93
Critical Position: Bottom of Layer/Load Centreline
Basic Axle Capacity: 7.90 million
Effective Axle Capacity: 7.9 million
Damage in this Phase from 0.00 to 1.00

Thickness = 180 mm
BSM1
Stiffness = 800 MPa; Poisson = 0.35
Criterion: BSM Stellenbosch 90% (Cat B)
RD = 100%; Ret-Coh = 75%; C = 265 kPa; Phi = 38

Deviator Stress Ratio = 0.170
Critical Position: 25% Layer Depth/Load Centreline
Basic Axle Capacity: > 100 million
Effective Axle Capacity: > 100 million
Damage in this Phase from 0.00 to 0.08

Thickness = 350 mm
RSA EG6 Moderate
Stiffness = 250 MPa; Poisson = 0.35
Criterion: RSA Granular Shear Cat B
Cohesion = 25.3 kPa; Angle of Friction = 25.3769

Shear Stress Safety Factor = 1.95
Critical Position: Middle of Layer/Load Centreline
Basic Axle Capacity: > 100 million
Effective Axle Capacity: > 100 million
Damage in this Phase from 0.00 to 0.08

Thickness = Semi-Infinite;
RSA G10 Subgrade
Stiffness = 50 MPa; Poisson = 0.35
Criterion: RSA Subgrade Rut, 10mm, Cat B
None

Vertical Compressive Strain = 248
Critical Position: Top of Layer/Load Centreline
Basic Axle Capacity: > 100 million
Effective Axle Capacity: > 100 million
Damage in this Phase from 0.00 to 0.08

Load Details:
Setup: Single tyre, 50kN each, 700 KPa pressure, single axle & single tyre; Daily Count = 500
Growth Rates: Yr 0 to 10 = 1% ; Yr 10 to 20 = 1% ; Yr 20 to End = 0%
Pavement Notes:

Rubicon Toolbox

Figure 11 : Structure A design using ME - SAPEM Design Method at subgrade stiffness 50MPa

The South African design guideline (SAPEM,2014) shows that AC layer will be the critical layer with **7,9 MESAL100kN** in the pavement structure, similar to the Flemish approach above that shows also AC layer is critical.

4.3 Comparison Structure "A" Design Using Flemish vs South African approach

It was observed that both design approaches resulted in similar critical layer (AC layer) see Table 28. However, Flemish approach resulted in lower allowed loading repetitions (i.e. shorter lifespan). So, it could conclude that Flemish design approach lead to safer design than South African design approach, which could related to :

- Using effective transfer functions (performance relationships);
- Applying seasonal stiffness concept

Table 28 : Summary of service lives for structure A using ME - SAPEM Design Method at various scenarios for subgrade stiffness

Structure A		Service life in MESAL 100kN	
Applied 100kN axle	Thickness cm	Flemish ME design approach	South African ME design approach
AC	16	**5,6**	**7,9**
BSM	18	199	>100
Subbase	35	-	>100
Subgrade	∞	29	>100
Total cover	69		

5 Pavement design with a Foam-BSM : Structure B

Firstly, the pavement structure was analyzed and hereafter was designed using the Flemish Mechanistic Empirical ME design approach, then a verification will be done using The South African Pavement Engineering Manual (SAPEM,2014) , while only mechanical properties will be kept similar for both methods. With respect to thicknesses, the designer will will try thicker or thinner BSM thickness until getting an identical structural capacity, as possible. This methodology will be applied for designing all standard structures of type B for road classes.

5.1 Structure “B” Design Using ME - Flemish Design Method

5.1.1 Preparing Input Parameters

In this structure B, no AC base was used. While **BSM won’t be used only as base layer but also as an alternative for all AC underlayers (HMA asphalt base).** The mechanical properties and the thickness of the standard structure B (AC wearing layer 4cm + BSM base + Subbase) will be kept similar as structure A, except the thickness of BSM that will be increased. Thus the following Figure 12 summarizes all design parameters for structure B for road class B6:

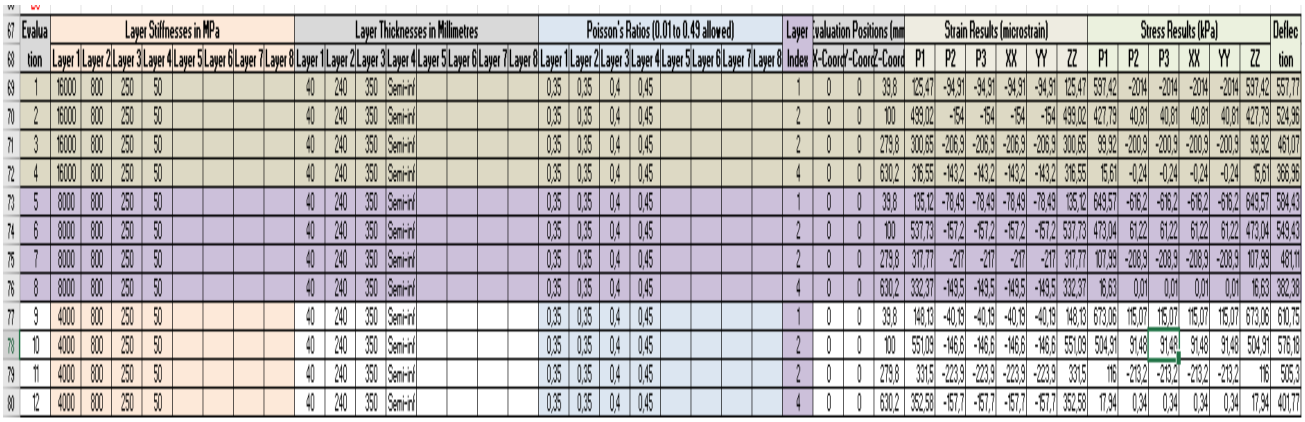
40mm	Top AC layer = APT-C	E_{30C° = 4000MPa; E_{15C° =8000MPa; E_{0C° =16000MPa Poisson's ratio υ = 0.35
240mm	Base layer =Foam-BSM (Cohesion 265MPa, Friction 38, RetC=75, MDD=100%)	E = 800MPa (constant all seasons) Poisson's ratio υ = 0.35
350mm	Subbase = crushed stones with fines (0/40)	E = 250MPa Poisson's ratio υ = 0.40
	Subgrade	E = 50 MPa Poisson's ratio υ = 0.45

Figure 12 : Best design option for Structure B - (AC wearing layer 4cm + BSM base + Subbase)

5.1.2 Measuring Pavement Responses Using Rubicon Stress/Strain Calculator

Table 29 below show the pavement response using Rubicon stress/strain analyzer

Table 29 : Pavement responses for structure B using Rubicon stress/strain analyzer

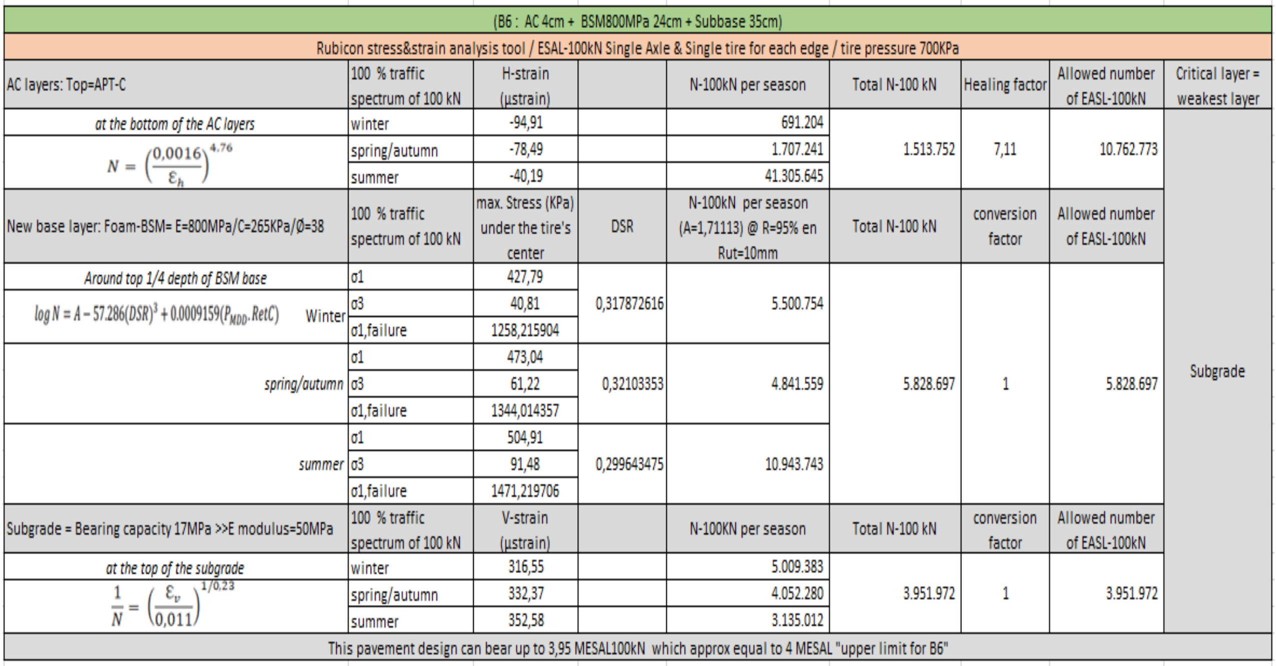


67	Evalua	Layer Stiffnesses in MPa								Layer Thicknesses in Millimetres								Poisson's Ratios (0.01 to 0.49 allowed)								Layer	valuation Positions (mm			Strain Results (microstrain)						Stress Results (kPa)						Deflec
68	tion	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8	Index	X-Coord	Y-Coord	Z-Coord	P1	P2	P3	XX	YY	ZZ	P1	P2	P3	XX	YY	ZZ	tion
69	1	16000	800	250	50					40	240	350	Semi-inf					0,35	0,35	0,4	0,45					1	0	0	39,8	125,47	-94,91	-94,91	-94,91	-94,91	125,47	597,42	-2014	-2014	-2014	-2014	597,42	557,77
70	2	16000	800	250	50					40	240	350	Semi-inf					0,35	0,35	0,4	0,45					2	0	0	100	499,02	-154	-154	-154	-154	499,02	427,79	40,81	40,81	40,81	40,81	427,79	524,96
71	3	16000	800	250	50					40	240	350	Semi-inf					0,35	0,35	0,4	0,45					2	0	0	279,8	300,65	-206,9	-206,9	-206,9	-206,9	300,65	99,92	-200,9	-200,9	-200,9	-200,9	99,92	461,07
72	4	16000	800	250	50					40	240	350	Semi-inf					0,35	0,35	0,4	0,45					4	0	0	630,2	316,55	-143,2	-143,2	-143,2	-143,2	316,55	15,61	-0,24	-0,24	-0,24	-0,24	15,61	366,96
73	5	8000	800	250	50					40	240	350	Semi-inf					0,35	0,35	0,4	0,45					1	0	0	39,8	135,12	-78,49	-78,49	-78,49	-78,49	135,12	649,57	-616,2	-616,2	-616,2	-616,2	649,57	584,43
74	6	8000	800	250	50					40	240	350	Semi-inf					0,35	0,35	0,4	0,45					2	0	0	100	537,73	-157,2	-157,2	-157,2	-157,2	537,73	473,04	61,22	61,22	61,22	61,22	473,04	549,43
75	7	8000	800	250	50					40	240	350	Semi-inf					0,35	0,35	0,4	0,45					2	0	0	279,8	317,77	-217	-217	-217	-217	317,77	107,99	-208,9	-208,9	-208,9	-208,9	107,99	481,11
76	8	8000	800	250	50					40	240	350	Semi-inf					0,35	0,35	0,4	0,45					4	0	0	630,2	332,37	-149,5	-149,5	-149,5	-149,5	332,37	16,63	0,01	0,01	0,01	0,01	16,63	382,38
77	9	4000	800	250	50					40	240	350	Semi-inf					0,35	0,35	0,4	0,45					1	0	0	39,8	148,13	-40,19	-40,19	-40,19	-40,19	148,13	673,06	115,07	115,07	115,07	115,07	673,06	610,75
78	10	4000	800	250	50					40	240	350	Semi-inf					0,35	0,35	0,4	0,45					2	0	0	100	551,09	-146,6	-146,6	-146,6	-146,6	551,09	504,91	91,48	91,48	91,48	91,48	504,91	576,18
79	11	4000	800	250	50					40	240	350	Semi-inf					0,35	0,35	0,4	0,45					2	0	0	279,8	331,5	-223,9	-223,9	-223,9	-223,9	331,5	116	-213,2	-213,2	-213,2	-213,2	116	505,3
80	12	4000	800	250	50					40	240	350	Semi-inf					0,35	0,35	0,4	0,45					4	0	0	630,2	352,58	-157,7	-157,7	-157,7	-157,7	352,58	17,94	0,34	0,34	0,34	0,34	17,94	401,77

5.1.3 Service Life Calculation of Structure "B" Using ME - Flemish Design Method

The following Table 30 shows the calculations of the maximum allowed number of loading repetitions for structure B using ME - Flemish Design Method.

Table 30 : Service life calculation of structure B using ME - Flemish Design Method

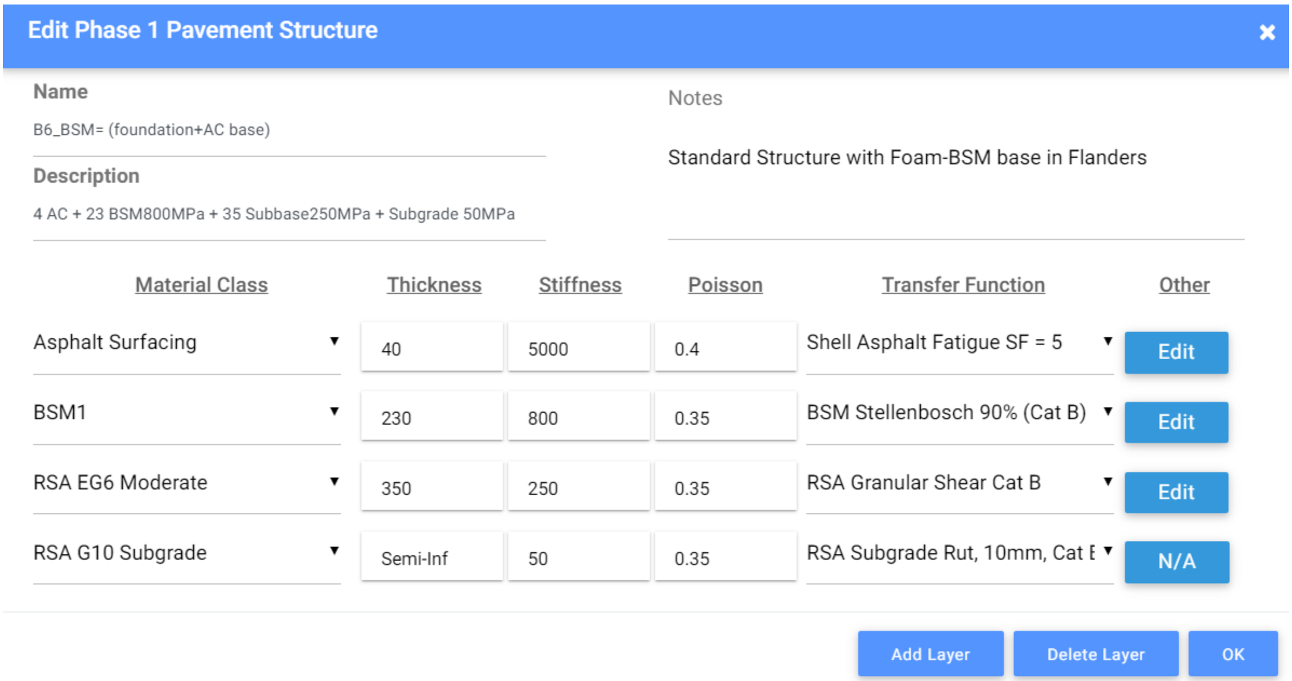


(B6 : AC 4cm + BSM800MPa 24cm + Subbase 35cm)								
Rubicon stress&strain analysis tool / ESAL-100kN Single Axle & Single tire for each edge / tire pressure 700KPa								
AC layers: Top=APT-C	100 % traffic spectrum of 100 kN	H-strain (µstrain)		N-100kN per season	Total N-100 kN	Healing factor	Allowed number of EASL-100kN	Critical layer = weakest layer
at the bottom of the AC layers	winter	-94,91		691.204	1.513.752	7,11	10.762.773	Subgrade
$N = \left(\frac{0,0016}{\varepsilon_h}\right)^{4.76}$	spring/autumn	-78,49		1.707.241				
	summer	-40,19		41.305.645				
New base layer: Foam-BSM= E=800MPa/C=265KPa/Ø=38	100 % traffic spectrum of 100 kN	max. Stress (KPa) under the tire's center	DSR	N-100kN per season (A=1,71113) @ R=95% en Rut=10mm	Total N-100 kN	conversion factor	Allowed number of EASL-100kN	
Around top 1/4 depth of BSM base	σ1	427,79	0,317872616	5.500.754	5.828.697	1	5.828.697	
$\log N = A - 57.286(DSR)^3 + 0.0009159(P_{MDD} \cdot RetC)$ Winter	σ3	40,81						
	σ1,failure	1258,215904						
spring/autumn	σ1	473,04	0,32103353	4.841.559				
	σ3	61,22						
	σ1,failure	1344,014357						
summer	σ1	504,91	0,299643475	10.943.743				
	σ3	91,48						
	σ1,failure	1471,219706						
Subgrade = Bearing capacity 17MPa >>E modulus=50MPa	100 % traffic spectrum of 100 kN	V-strain (µstrain)		N-100KN per season	Total N-100 kN	conversion factor	Allowed number of EASL-100kN	
at the top of the subgrade	winter	316,55		5.009.383	3.951.972	1	3.951.972	
$\frac{1}{N} = \left(\frac{\varepsilon_v}{0,011}\right)^{1/0,23}$	spring/autumn	332,37		4.052.280				
	summer	352,58		3.135.012				
This pavement design can bear up to 3,95 MESAL100kN which approx equal to 4 MESAL "upper limit for B6"								

The results show that subgrade is the critical layer with lowest structural capacity of 3,95 MESAL-100kN. By comparing the structural capacity for structure A & B using ME - Flemish Design Method, it was noted that both have roughly similar structural capacity : Structure A=5,8 MESAL ; Structure B=3,95 MESAL. However, AC layer will fail first in structure A and subgrade will fail first in structure B.

5.2 Structure "B" Design Using ME-SAPEM 2014 – South African Guideline

Extra verification for the pavement design of the structure B using South African ME design approach (SAPEM,2014) was done. The design can be done using the Rubicon Standard Axle Design Tool. Figure 13 below shows the design inputs (thicknesses & mechanical properties) that can be defined by (SAPEM,2014) manual. Unlike Flemish ME design approach, the South African ME design approach applies other default values for the mechanical properties of the paving materials (see Table C.5 in Appendix C), while the Flemish ME design approach applies the seasonal stiffness approach. Another methodology will be followed to design the structure, where the designer will try thicker or thinner BSM thickness until getting an identical structural capacity as possible. This methodology will be applied for designing all standard structures for road classes.



Name
B6_BSM= (foundation+AC base)

Description
4 AC + 23 BSM800MPa + 35 Subbase250MPa + Subgrade 50MPa

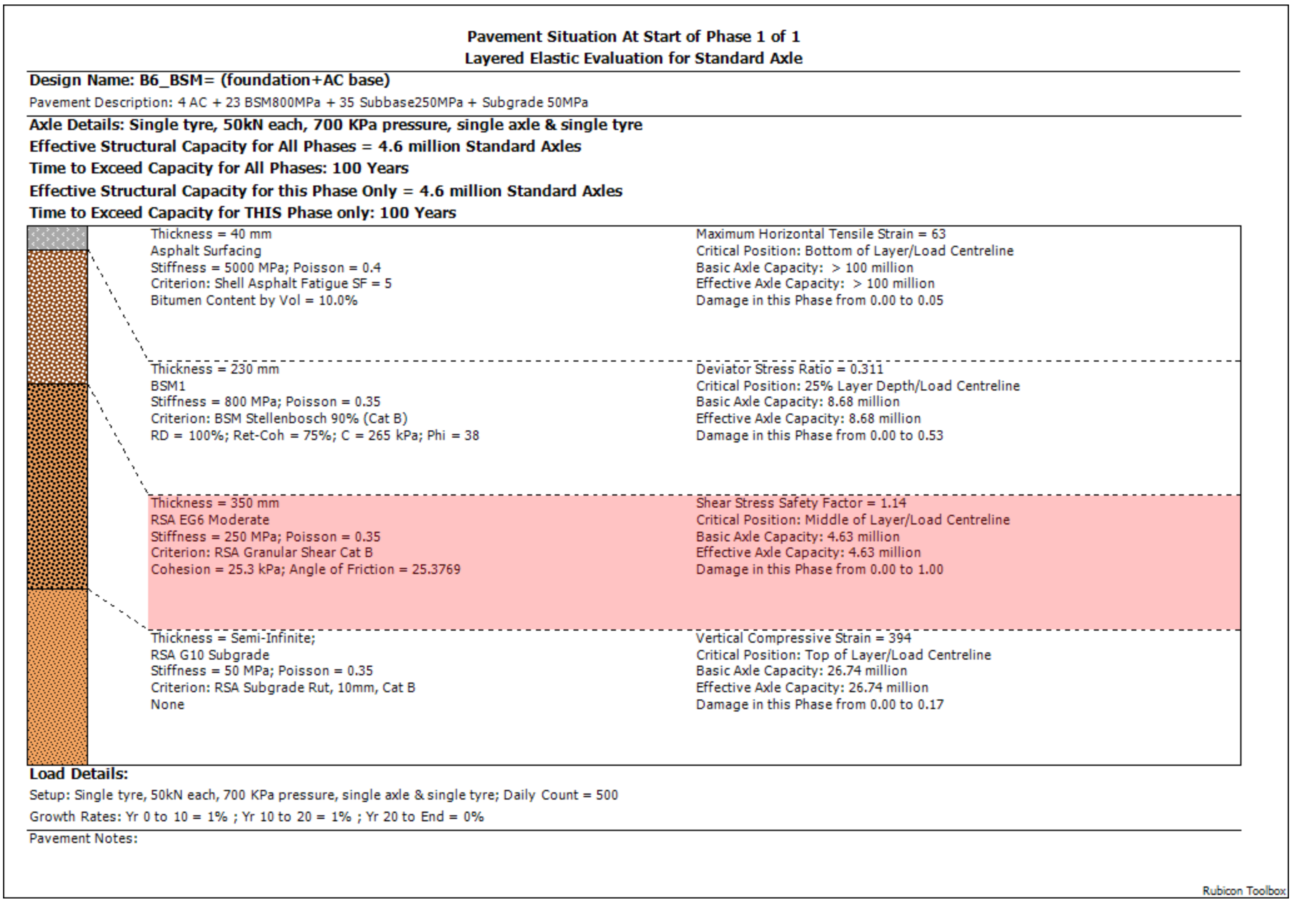
Notes
Standard Structure with Foam-BSM base in Flanders

Material Class	Thickness	Stiffness	Poisson	Transfer Function	Other
Asphalt Surfacing ▼	40	5000	0.4	Shell Asphalt Fatigue SF = 5 ▼	Edit
BSM1 ▼	230	800	0.35	BSM Stellenbosch 90% (Cat B) ▼	Edit
RSA EG6 Moderate ▼	350	250	0.35	RSA Granular Shear Cat B ▼	Edit
RSA G10 Subgrade ▼	Semi-Inf	50	0.35	RSA Subgrade Rut, 10mm, Cat E ▼	N/A

Relative Density: 100 (%)
Retained Coh: 75 (%)
Cohesion: 265 (kPa)
Angle of Friction: 38 (Degrees)

Figure 13 : Structure B - Design inputs at Rubicon Standard Axle Design Tool

The results from the software will be presented in Figure 14 .



Pavement Situation At Start of Phase 1 of 1
Layered Elastic Evaluation for Standard Axle

Design Name: B6_BSM= (foundation+AC base)
Pavement Description: 4 AC + 23 BSM800MPa + 35 Subbase250MPa + Subgrade 50MPa

Axle Details: Single tyre, 50kN each, 700 KPa pressure, single axle & single tyre
Effective Structural Capacity for All Phases = 4.6 million Standard Axles
Time to Exceed Capacity for All Phases: 100 Years
Effective Structural Capacity for this Phase Only = 4.6 million Standard Axles
Time to Exceed Capacity for THIS Phase only: 100 Years

Thickness = 40 mm
Asphalt Surfacing
Stiffness = 5000 MPa; Poisson = 0.4
Criterion: Shell Asphalt Fatigue SF = 5
Bitumen Content by Vol = 10.0%

Maximum Horizontal Tensile Strain = 63
Critical Position: Bottom of Layer/Load Centreline
Basic Axle Capacity: > 100 million
Effective Axle Capacity: > 100 million
Damage in this Phase from 0.00 to 0.05

Thickness = 230 mm
BSM1
Stiffness = 800 MPa; Poisson = 0.35
Criterion: BSM Stellenbosch 90% (Cat B)
RD = 100%; Ret-Coh = 75%; C = 265 kPa; Phi = 38

Deviator Stress Ratio = 0.311
Critical Position: 25% Layer Depth/Load Centreline
Basic Axle Capacity: 8.68 million
Effective Axle Capacity: 8.68 million
Damage in this Phase from 0.00 to 0.53

Thickness = 350 mm
RSA EG6 Moderate
Stiffness = 250 MPa; Poisson = 0.35
Criterion: RSA Granular Shear Cat B
Cohesion = 25.3 kPa; Angle of Friction = 25.3769

Shear Stress Safety Factor = 1.14
Critical Position: Middle of Layer/Load Centreline
Basic Axle Capacity: 4.63 million
Effective Axle Capacity: 4.63 million
Damage in this Phase from 0.00 to 1.00

Thickness = Semi-Infinite;
RSA G10 Subgrade
Stiffness = 50 MPa; Poisson = 0.35
Criterion: RSA Subgrade Rut, 10mm, Cat B
None

Vertical Compressive Strain = 394
Critical Position: Top of Layer/Load Centreline
Basic Axle Capacity: 26.74 million
Effective Axle Capacity: 26.74 million
Damage in this Phase from 0.00 to 0.17

Load Details:
Setup: Single tyre, 50kN each, 700 KPa pressure, single axle & single tyre; Daily Count = 500
Growth Rates: Yr 0 to 10 = 1% ; Yr 10 to 20 = 1% ; Yr 20 to End = 0%

Pavement Notes:

Rubicon Toolbox

Figure 14 : Structure B design using ME - SAPEM Design Method at subgrade stiffness 50MPa

The South African design guideline (SAPEM,2014) shows that subbase layer will be the critical layer with **4,63 MESAL100kN** in the pavement structure, unlike to the Flemish approach above that shows subgrade/soil is critical.

5.3 Comparison Structure "B" Design Using Flemish vs South African approach

It was observed that both design approaches resulted approximately in similar structural capacity; where Flemish ME=3,95MESAL and South African ME=4,63MESAL. However, the critical layer is different between both methods, **subgrade** will fail first according to the Flemish ME approach while **subbase** will fail first according to the South African ME approach, see Table 31. Moreover, it was observed that BSM layer will bear less loading cycles when applying Flemish ME design approach, however, similar Stellenbosch BSM function was applied. That could be justified by using the seasonal stiffness concept for AC layer above. So it could conclude that Flemish design approach lead to safer design than South African design approach.

Table 31 : Summary of service lives for structure B using ME - SAPEM Design Method at various scenarios for subgrade stiffness

Structure B	Service life in MESAL 100kN			
Applied 100kN axle	Flemish ME design approach		South African ME design approach	
	Thickness cm	N_{20yrs}	Thickness cm	N_{20yrs}
AC wearing layer	4	-	4	-
BSM	24	5,83	23	8,68
Subbase	35	-	35	4,63
Subgrade	∞	3,95	∞	26,74
Total cover	63 cm		62 cm	

6 Standard Structures with Foam-BSM Material – Structure Type A

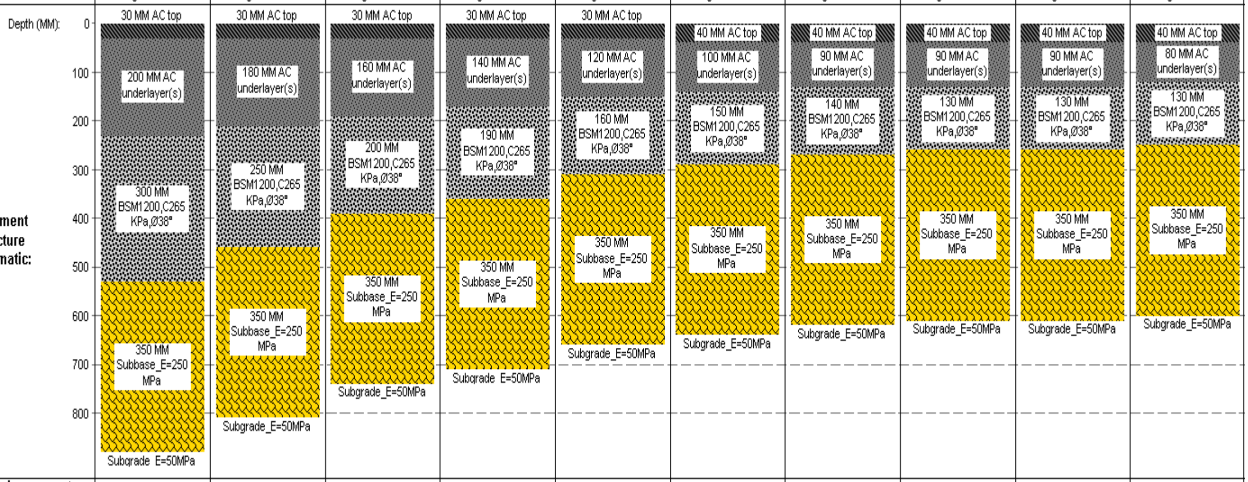
In this chapter, different design scenarios were done for structure type A (AC wearing layer 4cm + AC underlayer +BSM base + Subbase).The pavements designs for each road class will be done same as the example in chapter 4 above. The matrix of design cases was developed via three different BSM stiffness values (800, 1000, 1200MPa) and three different subgrade/soil modulus values E (50, 150, 250MPa) as follow:

Table 32: Matrix of design cases - type A

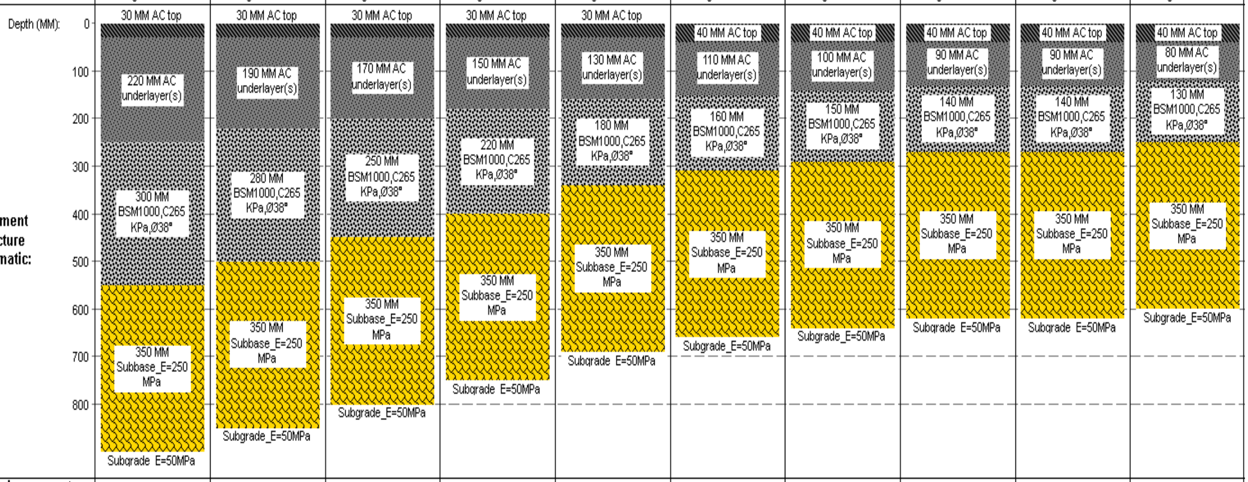
B1	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B2	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B3	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B4	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B5	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B6	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B7	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B8	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B9	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B10	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250

By this methodology, a wide range of option would be available for the market. A 90 pavement structure with BSM will be designed for structure A from B1 till B10.

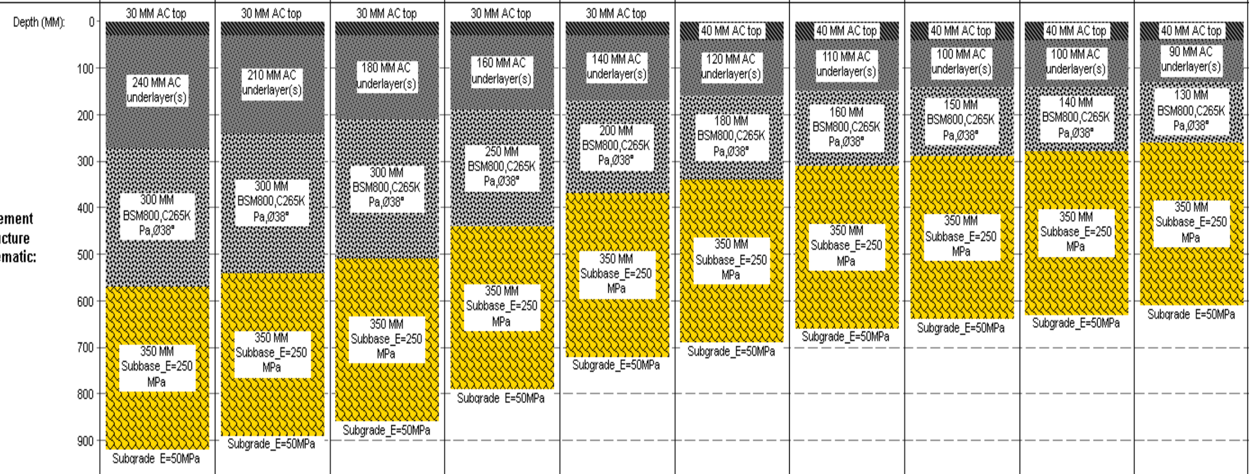
6.1 Standard Structures B1-B10 / type "A"/ BSM 1200MPa/Subgrade 50MPa

Pavement Name	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Description	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa
Pavement Structure Schematic: 	30 MM AC top 200 MM AC underlayer(s) 300 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	30 MM AC top 180 MM AC underlayer(s) 250 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	30 MM AC top 160 MM AC underlayer(s) 200 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	30 MM AC top 140 MM AC underlayer(s) 190 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	30 MM AC top 120 MM AC underlayer(s) 160 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 100 MM AC underlayer(s) 150 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 90 MM AC underlayer(s) 140 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 90 MM AC underlayer(s) 130 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 90 MM AC underlayer(s) 130 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 80 MM AC underlayer(s) 130 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa
Total pavement thickness "cover" mm	880	810	740	710	660	640	620	610	610	600
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 126 MESAL-100kN (AC layer)	N = 66 MESAL-100kN (AC layer)	N = 33 MESAL-100kN (AC layer)	N = 20 MESAL-100kN (AC layer)	N = 10 MESAL-100kN (AC layer)	N = 7 MESAL-100kN (AC layer)	N = 2,6 MESAL-100kN (BSM layer)	N = 0,83 MESAL-100kN (BSM layer)	N = 0,83 MESAL-100kN (BSM layer)	N = 0,3 MESAL-100kN (BSM layer)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	N > 100 MESAL-100kN (AC layer)	N = 66 MESAL-100kN (AC layer)	N = 35 MESAL-100kN (AC layer)	N = 22 MESAL-100kN (AC layer)	N = 12 MESAL-100kN (AC layer)	N = 9 MESAL-100kN (AC layer)	N = 7,3 MESAL-100kN (AC layer)	N = 3,8 MESAL-100kN (BSM layer)	N = 3,8 MESAL-100kN (AC layer)	N = 1,4 MESAL-100kN (AC layer)
NOTES										

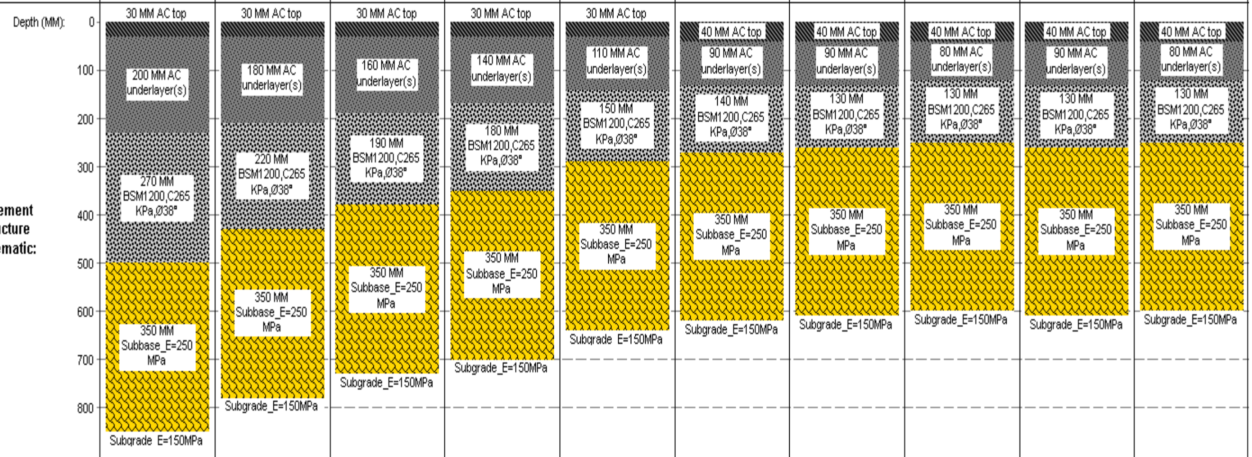
6.2 Standard Structures B1-B10 / type "A"/ BSM 1000MPa/Subgrade 50MPa

Pavement Name	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Description	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa
Pavement Structure Schematic: 	30 MM AC top 220 MM AC underlayer(s) 300 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	30 MM AC top 190 MM AC underlayer(s) 280 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	30 MM AC top 170 MM AC underlayer(s) 250 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	30 MM AC top 150 MM AC underlayer(s) 220 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	30 MM AC top 130 MM AC underlayer(s) 180 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 110 MM AC underlayer(s) 160 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 100 MM AC underlayer(s) 150 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 90 MM AC underlayer(s) 140 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 90 MM AC underlayer(s) 140 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 80 MM AC underlayer(s) 130 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa
Total pavement thickness "cover" mm	900	850	800	750	690	660	640	620	620	600
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 125 MESAL-100kN (AC layer)	N = 60 MESAL-100kN (AC layer)	N = 33,8 MESAL-100kN (AC layer)	N = 18,7 MESAL-100kN (AC layer)	N = 9,4 MESAL-100kN (AC layer)	N = 6,5 MESAL-100kN (AC layer)	N = 4,9 MESAL-100kN (AC layer)	N = 3,6 MESAL-100kN (AC layer)	N = 3,6 MESAL-100kN (AC layer)	N = 2,8 MESAL-100kN (AC layer)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	N > 100 MESAL-100kN (AC layer)	N = 64 MESAL-100kN (AC layer)	N = 38,2 MESAL-100kN (AC layer)	N = 22,2 MESAL-100kN (AC layer)	N = 11,9 MESAL-100kN (AC layer)	N = 8,4 MESAL-100kN (AC layer)	N = 6,4 MESAL-100kN (AC layer)	N = 4,9 MESAL-100kN (AC layer)	N = 4,9 MESAL-100kN (AC layer)	N = 3,8 MESAL-100kN (AC layer)
NOTES										

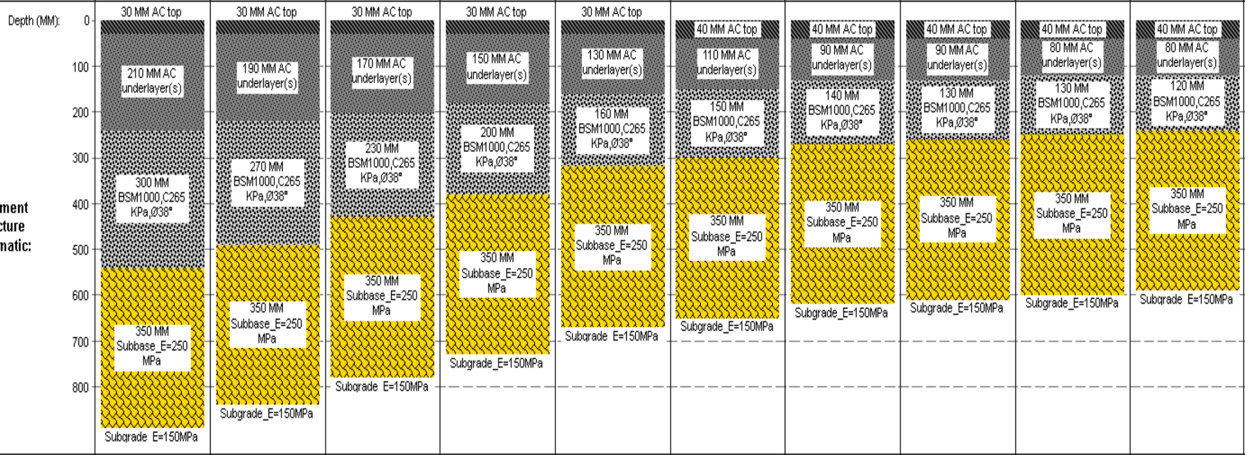
6.3 Standard Structures B1-B10 / type "A"/ BSM 800MPa/Subgrade 50MPa

Pavement Name	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Description	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa
Pavement Structure Schematic: Depth (MM): 0 100 200 300 400 500 600 700 800 900	 30 MM AC top 240 MM AC underlayer(s) 300 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade E=50MPa	30 MM AC top 210 MM AC underlayer(s) 300 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	30 MM AC top 180 MM AC underlayer(s) 300 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	30 MM AC top 160 MM AC underlayer(s) 250 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade E=50MPa	30 MM AC top 140 MM AC underlayer(s) 200 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 120 MM AC underlayer(s) 180 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 110 MM AC underlayer(s) 160 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 100 MM AC underlayer(s) 150 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 100 MM AC underlayer(s) 140 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=50MPa	40 MM AC top 90 MM AC underlayer(s) 130 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade E=50MPa
Total pavement thickness "cover" mm	920	890	860	790	720	690	660	640	630	610
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 122 MESAL-100kN (AC layer)	N = 62,4 MESAL-100kN (AC layer)	N = 30,8 MESAL-100kN (AC layer)	N = 16 MESAL-100kN (AC layer)	N = 8 MESAL-100kN (AC layer)	N = 5,6 MESAL-100kN (AC layer)	N = 3,9 MESAL-100kN (AC layer)	N = 2,9 MESAL-100kN (AC layer)	N = 2,7 MESAL-100kN (AC layer)	N = 1,9 MESAL-100kN (BSM layer)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	N > 100 MESAL-100kN (AC layer)	N = 71 MESAL-100kN (AC layer)	N = 37,2 MESAL-100kN (AC layer)	N = 20,7 MESAL-100kN (AC layer)	N = 10,9 MESAL-100kN (AC layer)	N = 7,9 MESAL-100kN (AC layer)	N = 5,6 MESAL-100kN (AC layer)	N = 4,2 MESAL-100kN (AC layer)	N = 4,0 MESAL-100kN (AC layer)	N = 3,0 MESAL-100kN (AC layer)
NOTES										

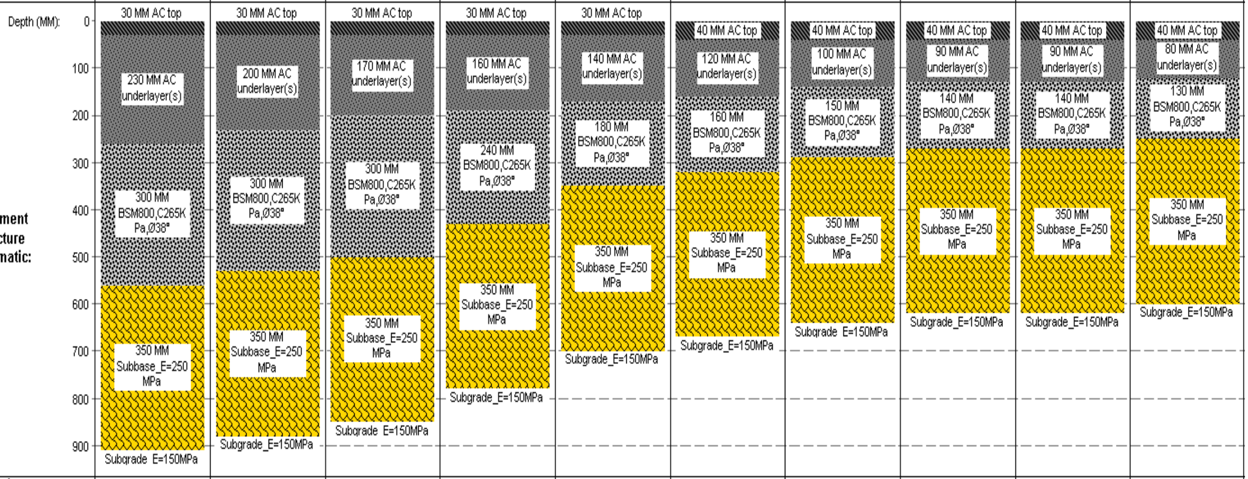
6.4 Standard Structures B1-B10 / type "A"/ BSM 1200MPa/Subgrade 150MPa

Pavement Name	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Description	E-BSM=1200MPa ; E-subgrade=150MPa	E-BSM=1200MPa ; E-subgrade=150MPa	E-BSM=1200MPa ; E-subgrade=150MPa	E-BSM=1200MPa ; E-subgrade=150MPa	E-BSM=1200MPa ; E-subgrade=150MPa	E-BSM=1200MPa ; E-subgrade=150MPa	E-BSM=1200MPa ; E-subgrade=150MPa	E-BSM=1200MPa ; E-subgrade=150MPa	E-BSM=1200MPa ; E-subgrade=150MPa	E-BSM=1200MPa ; E-subgrade=150MPa
Pavement Structure Schematic: Depth (MM): 0 100 200 300 400 500 600 700 800	 30 MM AC top 200 MM AC underlayer(s) 270 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade E=150MPa	30 MM AC top 180 MM AC underlayer(s) 220 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	30 MM AC top 160 MM AC underlayer(s) 190 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	30 MM AC top 140 MM AC underlayer(s) 180 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	30 MM AC top 110 MM AC underlayer(s) 150 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade E=150MPa	40 MM AC top 90 MM AC underlayer(s) 140 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 90 MM AC underlayer(s) 130 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 80 MM AC underlayer(s) 130 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 90 MM AC underlayer(s) 130 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 80 MM AC underlayer(s) 130 MM BSM1200,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa
Total pavement thickness "cover" mm	850	780	730	700	640	620	610	600	610	600
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 127 MESAL-100kN (AC layer)	N = 66 MESAL-100kN (AC layer)	N = 35 MESAL-100kN (AC layer)	N = 21,1 MESAL-100kN (AC layer)	N = 8,8 MESAL-100kN (AC layer)	N = 6,5 MESAL-100kN (BSM layer)	N = 2,7 MESAL-100kN (BSM layer)	N = 1,0 MESAL-100kN (BSM layer)	N = 1,0 MESAL-100kN (BSM layer)	N = 0,26 MESAL-100kN (BSM layer)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	N > 100 MESAL-100kN (AC layer)	N = 68 MESAL-100kN (AC layer)	N = 39 MESAL-100kN (AC layer)	N = 24 MESAL-100kN (AC layer)	N = 10,7 MESAL-100kN (AC layer)	N = 8,2 MESAL-100kN (AC layer)	N = 7,4 MESAL-100kN (AC layer)	N = 4,4 MESAL-100kN (BSM layer)	N = 4,4 MESAL-100kN (BSM layer)	N = 2,0 MESAL-100kN (BSM layer)
NOTES										

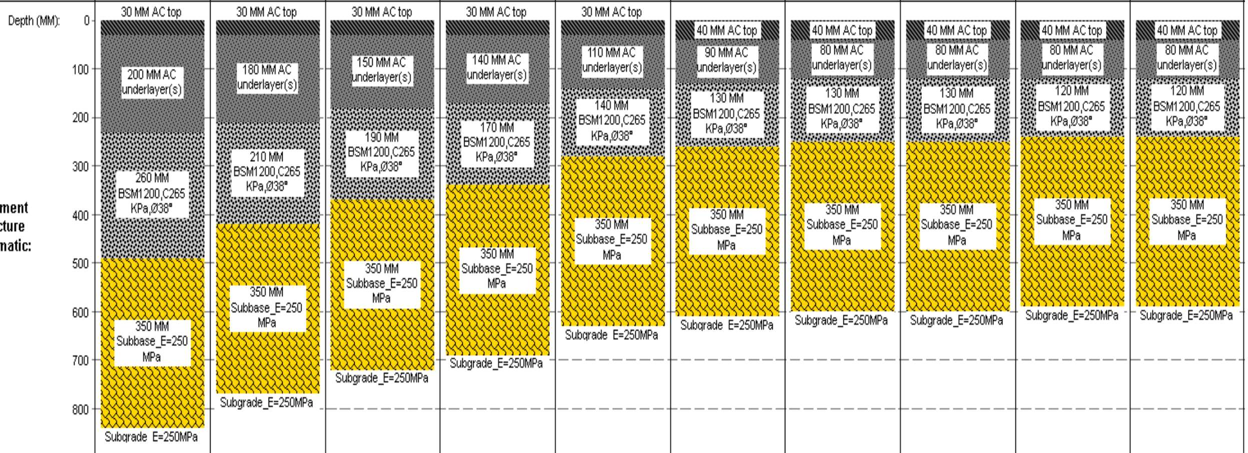
6.5 Standard Structures B1-B10 / type "A"/ BSM 1000MPa/Subgrade 150MPa

Pavement Name	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Description	E-BSM=1000MPa ; E-subgrade=150MPa	E-BSM=1000MPa ; E-subgrade=150MPa	E-BSM=1000MPa ; E-subgrade=150MPa	E-BSM=1000MPa ; E-subgrade=150MPa	E-BSM=1000MPa ; E-subgrade=150MPa	E-BSM=1000MPa ; E-subgrade=150MPa	E-BSM=1000MPa ; E-subgrade=150MPa	E-BSM=1000MPa ; E-subgrade=150MPa	E-BSM=1000MPa ; E-subgrade=150MPa	E-BSM=1000MPa ; E-subgrade=150MPa
Pavement Structure Schematic: 	30 MM AC top 210 MM AC underlayer(s) 300 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade E=150MPa	30 MM AC top 190 MM AC underlayer(s) 270 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	30 MM AC top 170 MM AC underlayer(s) 230 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade E=150MPa	30 MM AC top 150 MM AC underlayer(s) 200 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	30 MM AC top 130 MM AC underlayer(s) 160 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade E=150MPa	40 MM AC top 110 MM AC underlayer(s) 150 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 90 MM AC underlayer(s) 140 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 90 MM AC underlayer(s) 130 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 80 MM AC underlayer(s) 130 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 80 MM AC underlayer(s) 120 MM BSM1000,C265 KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade E=150MPa
Total pavement thickness "cover" mm	890	840	780	730	670	650	620	610	600	590
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 115 MESAL-100kN (AC layer)	N = 65 MESAL-100kN (AC layer)	N = 35 MESAL-100kN (AC layer)	N = 19 MESAL-100kN (AC layer)	N = 9,4 MESAL-100kN (AC layer)	N = 6,9 MESAL-100kN (AC layer)	N = 4,1 MESAL-100kN (AC layer)	N = 3,7 MESAL-100kN (AC layer)	N = 3, MESAL-100kN (AC layer)	N = 2,75 MESAL-100kN (AC layer)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	N > 100 MESAL-100kN (AC layer)	N = 72 MESAL-100kN (AC layer)	N = 41 MESAL-100kN (AC layer)	N = 23 MESAL-100kN (AC layer)	N = 12,2 MESAL-100kN (AC layer)	N = 9,1 MESAL-100kN (AC layer)	N = 5,5 MESAL-100kN (AC layer)	N = 5,1 MESAL-100kN (AC layer)	N = 4,2 MESAL-100kN (AC layer)	N = 3,8 MESAL-100kN (AC layer)
NOTES										

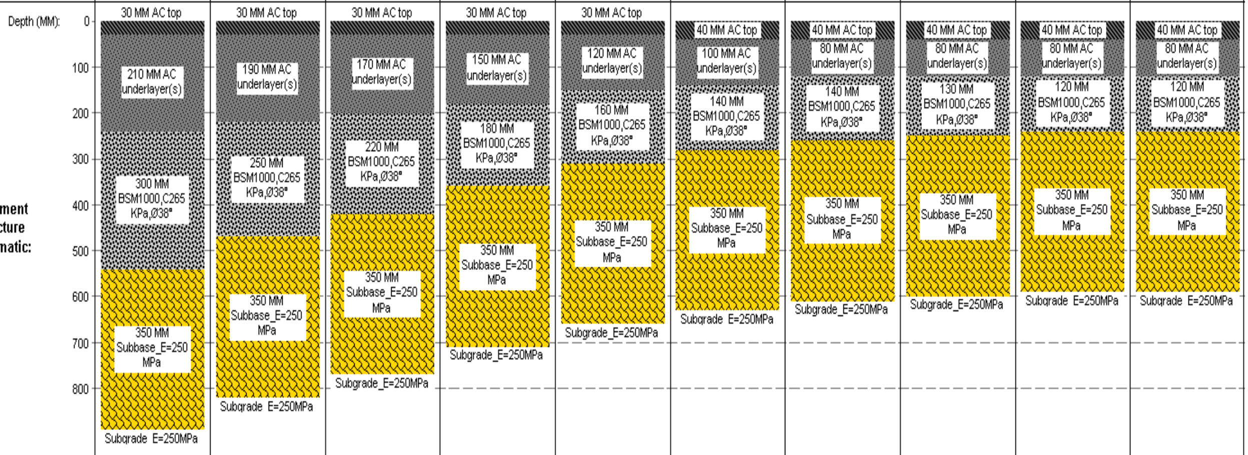
6.6 Standard Structures B1-B10 / type "A"/ BSM 800MPa/Subgrade 150MPa

Pavement Name	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Description	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP
Pavement Structure Schematic: 	30 MM AC top 230 MM AC underlayer(s) 300 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade E=150MPa	30 MM AC top 200 MM AC underlayer(s) 300 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	30 MM AC top 170 MM AC underlayer(s) 300 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade E=150MPa	30 MM AC top 160 MM AC underlayer(s) 240 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	30 MM AC top 140 MM AC underlayer(s) 180 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 120 MM AC underlayer(s) 160 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 100 MM AC underlayer(s) 150 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade E=150MPa	40 MM AC top 90 MM AC underlayer(s) 140 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 90 MM AC underlayer(s) 140 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 80 MM AC underlayer(s) 130 MM BSM800,C265K Pa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa
Total pavement thickness "cover" mm	910	880	850	780	700	670	640	620	620	600
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 116 MESAL-100kN (AC layer)	N = 56 MESAL-100kN (AC layer)	N = 26,5 MESAL-100kN (AC layer)	N = 17,6 MESAL-100kN (AC layer)	N = 8,4 MESAL-100kN (AC layer)	N = 5,8 MESAL-100kN (AC layer)	N = 3,3 MESAL-100kN (AC layer)	N = 2,4 MESAL-100kN (AC layer)	N = 2,2 MESAL-100kN (AC layer)	N = 1,7 MESAL-100kN (BSM layer)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	N > 100 MESAL-100kN (AC layer)	N = 66 MESAL-100kN (AC layer)	N = 33,4MESAL-100kN (AC layer)	N = 23,1 MESAL-100kN (AC layer)	N = 11,8 MESAL-100kN (AC layer)	N = 8,3 MESAL-100kN (AC layer)	N = 4,9 MESAL-100kN (AC layer)	N = 3,6 MESAL-100kN (AC layer)	N = 3,4 MESAL-100kN (AC layer)	N = 2,7 MESAL-100kN (AC layer)
NOTES										

6.7 Standard Structures B1-B10 / type “A”/ BSM 1200MPa/Subgrade 250MPa

Pavement Name	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Description	E-BSM=1200MPa ; E-subgrade=250MPa	E-BSM=1200MPa ; E-subgrade=250MPa	E-BSM=1200MPa ; E-subgrade=250MPa	E-BSM=1200MPa ; E-subgrade=250MPa	E-BSM=1200MPa ; E-subgrade=250MPa	E-BSM=1200MPa ; E-subgrade=250MPa	E-BSM=1200MPa ; E-subgrade=250MPa	E-BSM=1200MPa ; E-subgrade=250MPa	E-BSM=1200MPa ; E-subgrade=250MPa	E-BSM=1200MPa ; E-subgrade=250MPa
Pavement Structure Schematic:										
Total pavement thickness "cover" mm	840	770	720	690	630	610	600	600	590	590
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 130 MESAL-100kN (AC layer)	N = 67 MESAL-100kN (AC layer)	N = 29,9 MESAL-100kN (AC layer)	N = 21,0 MESAL-100kN (AC layer)	N = 10 MESAL-100kN (AC layer)	N = 4,1 MESAL-100kN (BSM layer)	N = 1,6 MESAL-100kN (BSM layer)	N = 0,45 MESAL-100kN (BSM layer)	N = 0,45 MESAL-100kN (BSM layer)	N = 0,45 MESAL-100kN (BSM layer)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	N > 100 MESAL-100kN (AC layer)	N = 70 MESAL-100kN (AC layer)	N = 33,4 MESAL-100kN (AC layer)	N = 24,2 MESAL-100kN (AC layer)	N = 10,4 MESAL-100kN (AC layer)	N = 7,8 MESAL-100kN (AC layer)	N = 6,3 MESAL-100kN (AC layer)	N = 3,1 MESAL-100kN (BSM layer)	N = 3,1 MESAL-100kN (BSM layer)	N = 3,1 MESAL-100kN (BSM layer)
NOTES										

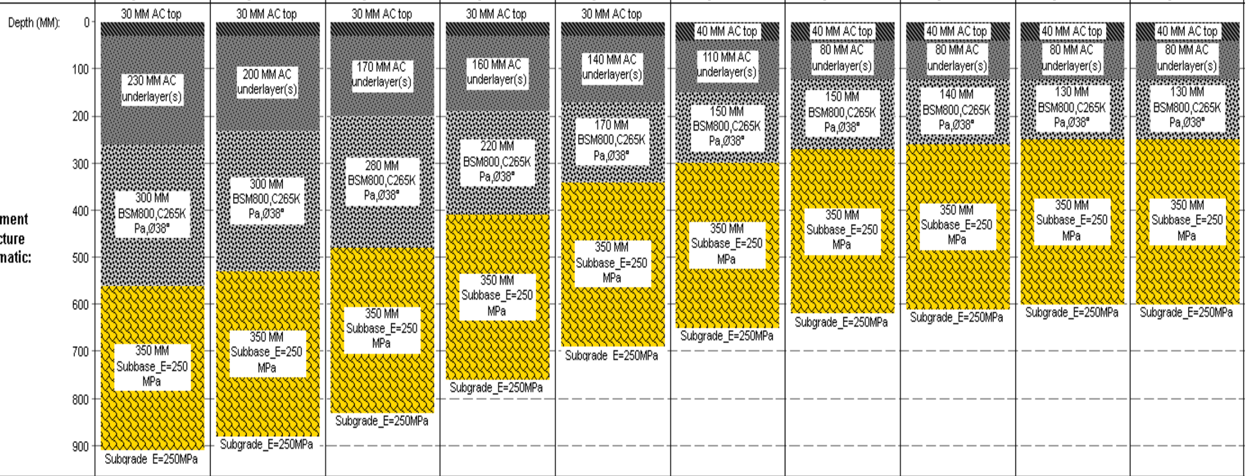
6.8 Standard Structures B1-B10 / type “A”/ BSM 1000MPa/Subgrade 250MPa

Pavement Name	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Description	E-BSM=1000MPa ; E-subgrade=250MPa	E-BSM=1000MPa ; E-subgrade=250MPa	E-BSM=1000MPa ; E-subgrade=250MPa	E-BSM=1000MPa ; E-subgrade=250MPa	E-BSM=1000MPa ; E-subgrade=250MPa	E-BSM=1000MPa ; E-subgrade=250MPa	E-BSM=1000MPa ; E-subgrade=250MPa	E-BSM=1000MPa ; E-subgrade=250MPa	E-BSM=1000MPa ; E-subgrade=250MPa	E-BSM=1000MPa ; E-subgrade=250MPa
Pavement Structure Schematic:										
Total pavement thickness "cover" mm	890	820	770	710	660	630	610	600	590	590
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 121 MESAL-100kN (AC layer)	N = 65 MESAL-100kN (AC layer)	N = 36 MESAL-100kN (AC layer)	N = 18 MESAL-100kN (AC layer)	N = 7,9 MESAL-100kN (AC layer)	N = 5,4 MESAL-100kN (AC layer)	N = 3,5 MESAL-100kN (AC layer)	N = 3,2 MESAL-100kN (AC layer)	N = 2,8 MESAL-100kN (AC layer)	N = 2,8 MESAL-100kN (AC layer)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	N > 100 MESAL-100kN (AC layer)	N = 72 MESAL-100kN (AC layer)	N = 42 MESAL-100kN (AC layer)	N = 23 MESAL-100kN (AC layer)	N = 10,3 MESAL-100kN (AC layer)	N = 7,2 MESAL-100kN (AC layer)	N = 4,7 MESAL-100kN (AC layer)	N = 4,4 MESAL-100kN (AC layer)	N = 4,0 MESAL-100kN (AC layer)	N = 4,0 MESAL-100kN (AC layer)
NOTES										

6.9 Standard Structures B1-B10 / type "A"/ BSM 800MPa/Subgrade 250MPa

Pavement Name	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Description	E-BSM=800MPa ; E-subgrade=250MP	E-BSM=800MPa ; E-subgrade=250MP	E-BSM=800MPa ; E-subgrade=250MP	E-BSM=800MPa ; E-subgrade=250MP	E-BSM=800MPa ; E-subgrade=250MP	E-BSM=800MPa ; E-subgrade=250MP	E-BSM=800MPa ; E-subgrade=250MP	E-BSM=800MPa ; E-subgrade=250MP	E-BSM=800MPa ; E-subgrade=250MP	E-BSM=800MPa ; E-subgrade=250MP

Pavement Structure Schematic:



Pavement Name	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Total pavement thickness "cover" mm	910	880	830	760	690	650	620	610	600	600
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 125 MESAL-100kN (AC layer)	N = 59 MESAL-100kN (AC layer)	N = 26,5 MESAL-100kN (AC layer)	N = 17,5 MESAL-100kN (AC layer)	N = 8,4 MESAL-100kN (AC layer)	N = 4,5 MESAL-100kN (AC layer)	N = 2,2 MESAL-100kN (AC layer)	N = 2,4 MESAL-100kN (AC layer)	N = 1,8 MESAL-100kN (AC layer)	N = 1,8 MESAL-100kN (AC layer)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	N > 100 MESAL-100kN (AC layer)	N = 70 MESAL-100kN (AC layer)	N = 33,7 MESAL-100kN (AC layer)	N = 23,2 MESAL-100kN (AC layer)	N = 12,1 MESAL-100kN (AC layer)	N = 6,6 MESAL-100kN (AC layer)	N = 3,2 MESAL-100kN (AC layer)	N = 3,6 MESAL-100kN (AC layer)	N = 2,8 MESAL-100kN (AC layer)	N = 2,8 MESAL-100kN (AC layer)
NOTES										

7 Standard Structures with Foam-BSM Material– Structure Type B

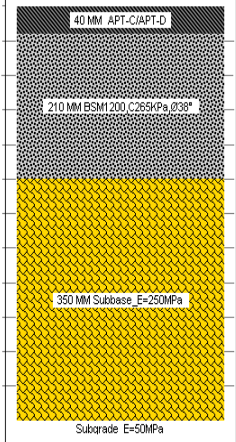
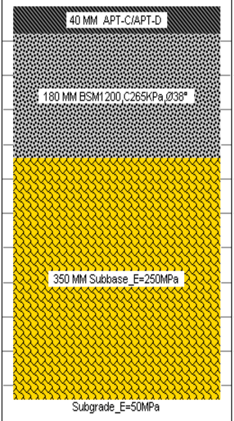
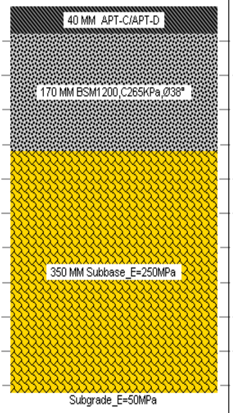
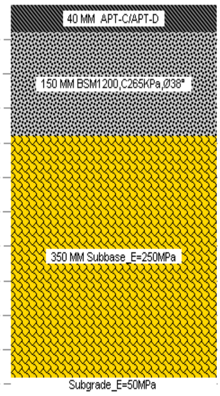
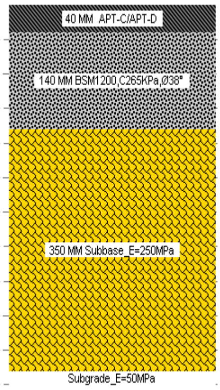
In this chapter, different design scenarios were done for structure type B (AC wearing layer 4cm + BSM base + Subbase). The pavements designs for each road class will be done same as the example in chapter 5 above. A design matrix was developed via three different BSM stiffness values (800, 1000, 1200MPa) and three different subgrade/soil modulus values E (50, 150, 250MPa) as follow:

Table 33: Matrix of design cases - type B

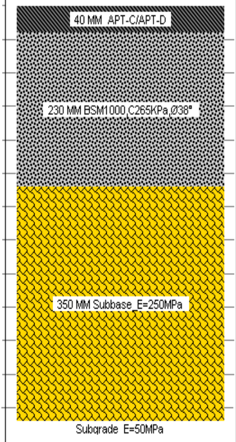
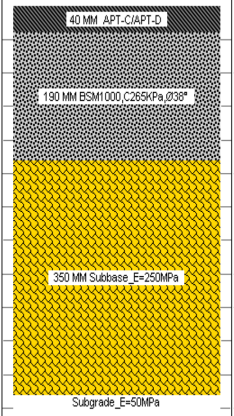
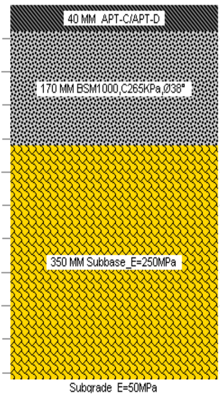
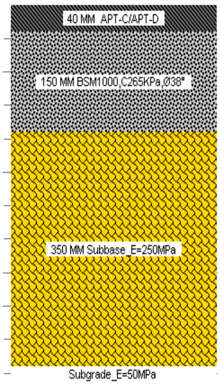
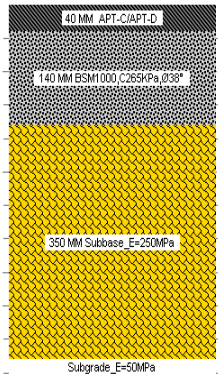
B6	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B7	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B8	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B9	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250
B10	BSM1200/Subgrade50	BSM1000/Subgrade50	BSM800/Subgrade50
	BSM1200/Subgrade150	BSM1000/Subgrade150	BSM800/Subgrade150
	BSM1200/Subgrade250	BSM1000/Subgrade250	BSM800/Subgrade250

By this methodology, a wide range of option would be available for the market. A 50 pavement structure with BSM will be will be designed for structure B from B6 till B10. Structure B with only a thin wearing AC layer might not be acceptable at that early stage neither by the Flemish road agency nor by private sector. However, the calculations shows that BSM could bear a large piece of the loads. While in advance stages, after having enough Flemish experience with BSM, it might be acceptable to use structures (type B) in the Flemish market for a high road classes such as B5 till B1. More investigation are still needed in this frame, which could enrich this guideline in the future.

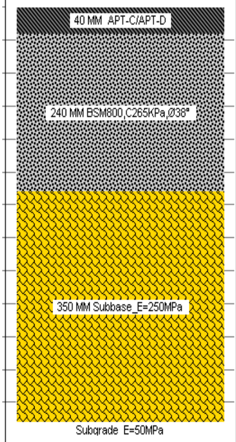
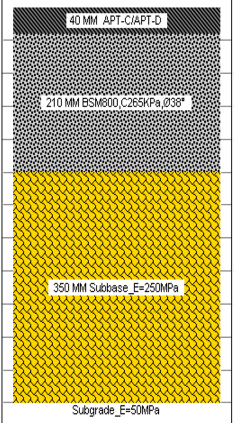
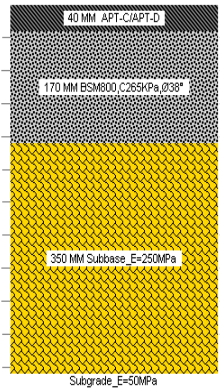
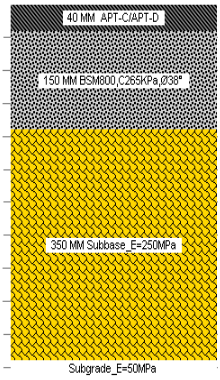
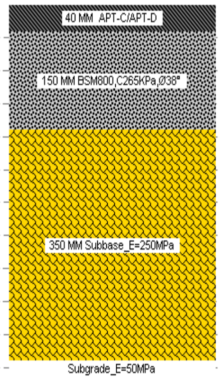
7.1 Standard Structures B6-B10 / type "B"/ BSM 1200MPa/Subgrade 50MPa

Pavement Name	B6	B7	B8	B9	B10
Description	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa
Pavement Structure Schematic: Depth (MM): 0 50 100 150 200 250 300 350 400 450 500 550					
Total pavement thickness "cover" mm	600	570	560	540	530
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 3,9 MESAL-100kN (Subgrade)	N = 2,27 MESAL-100kN (Subgrade)	N = 1,87 MESAL-100kN (Subgrade)	N = 0,70 MESAL-100kN (Subgrade)	N = 0,38 MESAL-100kN (BSM)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	BSM 21CM _Critical layer is Subbase (6,3 MESAL)	BSM 18CM _Critical layer is Subbase (2,58 MESAL)	BSM 17CM _Critical layer is Subbase (1,94 MESAL)	BSM 14CM _Critical layer is Subbase (0,85 MESAL)	BSM 12CM _Critical layer is Subbase (0,51 MESAL)
NOTES					

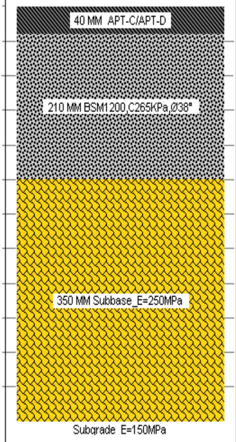
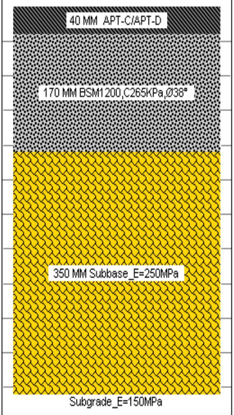
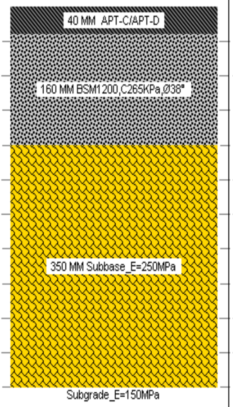
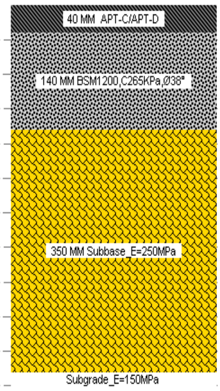
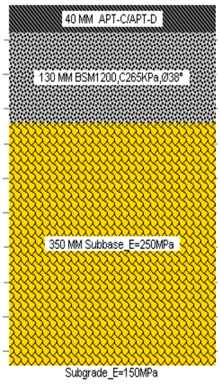
7.2 Standard Structures B6-B10 / type "B"/ BSM 1000MPa/Subgrade 50MPa

Pavement Name	B6	B7	B8	B9	B10
Description	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=50MPa
Pavement Structure Schematic: Depth (MM): 0 50 100 150 200 250 300 350 400 450 500 550 600					
Total pavement thickness "cover" mm	620	580	560	540	530
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 4,4 MESAL-100kN (Subgrade)	N = 2,24 MESAL-100kN (Subgrade)	N = 1,55 MESAL-100kN (Subgrade)	N = 1 MESAL-100kN (Subgrade)	N = 0,87 MESAL-100kN (Subgrade)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	BSM 22CM _Critical layer is Subbase (5,6 MESAL)	BSM 19CM _Critical layer is Subbase (2,45 MESAL)	BSM 18CM _Critical layer is Subbase (1,87 MESAL)	BSM 15CM _Critical layer is Subbase (0,86 MESAL)	BSM 13CM _Critical layer is Subbase (0,53 MESAL)
NOTES					

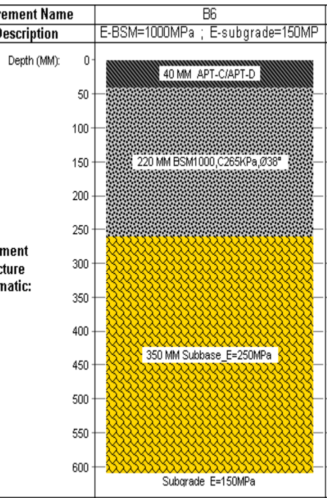
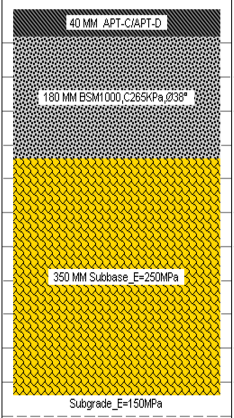
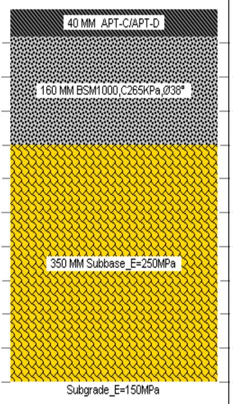
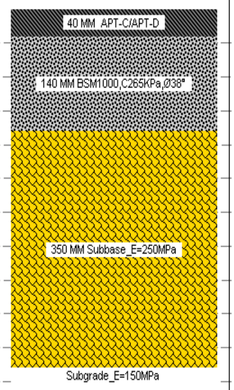
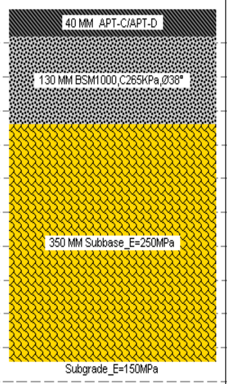
7.3 Standard Structures B6-B10 / type “B”/ BSM 800MPa/Subgrade 50MPa

Pavement Name	B6	B7	B8	B9	B10
Description	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=50MPa
Pavement Structure Schematic:					
Total pavement thickness "cover" mm	630	600	560	540	540
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 3,95 MESAL-100kN (Subgrade)	N = 2,46 MESAL-100kN (Subgrade)	N = 1,24 MESAL-100kN (Subgrade)	N = 0,86 MESAL-100kN (Subgrade)	N = 0,86 MESAL-100kN (Subgrade)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	BSM 23CM _Critical layer is Subbase (4,6 MESAL)	BSM 21CM _Critical layer is Subbase (2,7 MESAL)	BSM 19CM _Critical layer is Subbase (1,6 MESAL)	BSM 16CM _Critical layer is Subbase (0,82 MESAL)	BSM 14CM _Critical layer is Subbase (0,52 MESAL)
NOTES					

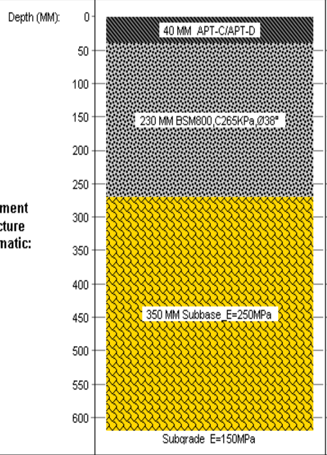
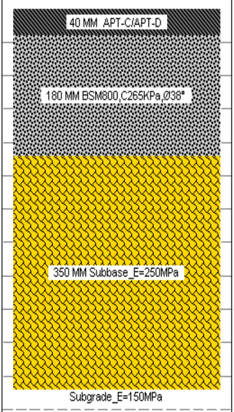
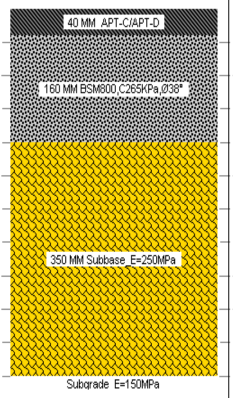
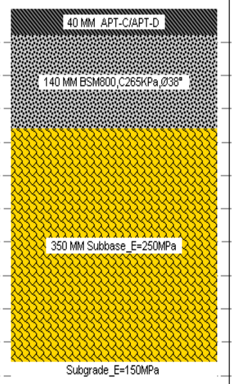
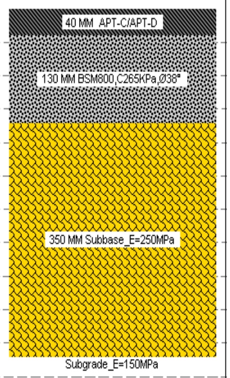
7.4 Standard Structures B6-B10 / type “B”/ BSM 1200MPa/Subgrade 150MPa

Pavement Name	B6	B7	B8	B9	B10
Description	E-BSM=1200MPa ; E-subgrade=150MP	E-BSM=1200MPa ; E-subgrade=150MP	E-BSM=1200MPa ; E-subgrade=150MP	E-BSM=1200MPa ; E-subgrade=150MP	E-BSM=1200MPa ; E-subgrade=150MP
Pavement Structure Schematic:					
Total pavement thickness "cover" mm	600	560	550	530	520
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 3,9 MESAL-100kN (BSM)	N = 2,0 MESAL-100kN (BSM)	N = 1,50 MESAL-100kN (BSM)	N = 0,52 MESAL-100kN (BSM)	N = 0,22 MESAL-100kN (BSM)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	BSM 20CM _Critical layer is Subbase (5,6 MESAL)	BSM 17CM _Critical layer is Subbase (2,30 MESAL)	BSM 16CM _Critical layer is Subbase (1,70 MESAL)	BSM 13CM _Critical layer is Subbase (0,72 MESAL)	BSM 11CM _Critical layer is Subbase (0,42 MESAL)
NOTES					

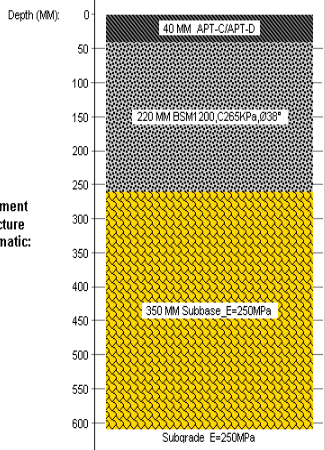
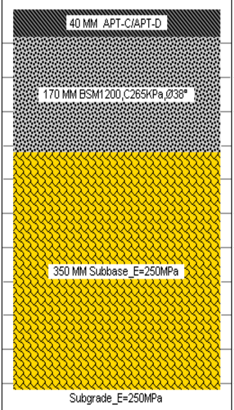
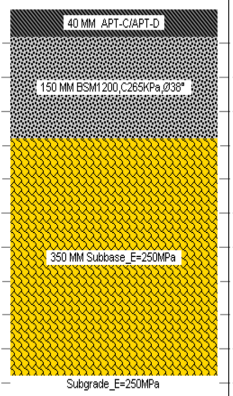
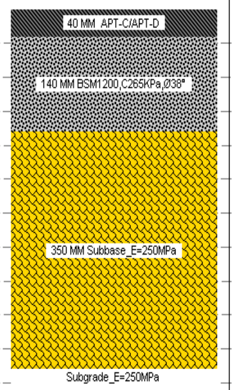
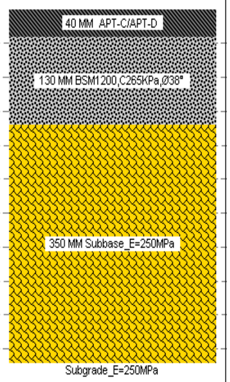
7.5 Standard Structures B6-B10 / type "B"/ BSM 1000MPa/Subgrade 150MPa

Pavement Name	B6	B7	B8	B9	B10
Description	E-BSM=1000MPa ; E-subgrade=150MP	E-BSM=1000MPa ; E-subgrade=150MP	E-BSM=1000MPa ; E-subgrade=150MP	E-BSM=1000MPa ; E-subgrade=150MP	E-BSM=1000MPa ; E-subgrade=150MP
Pavement Structure Schematic:					
Total pavement thickness "cover" mm	610	570	550	530	520
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N =4,28 MESAL-100kN (BSM)	N = 2,99 MESAL-100kN (BSM)	N = 2,0 MESAL-100kN (BSM)	N = 0,99 MESAL-100kN (BSM)	N = 0,57 MESAL-100kN (BSM)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	BSM 21CM _Critical layer is Subbase (5,27 MESAL)	BSM 18CM _Critical layer is Subbase (2,19 MESAL)	BSM 17CM _Critical layer is Subbase (1,65 MESAL)	BSM 14CM _Critical layer is Subbase (0,74 MESAL)	BSM 12CM _Critical layer is Subbase (0,45 MESAL)
NOTES					

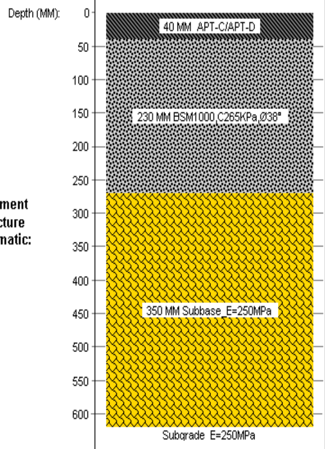
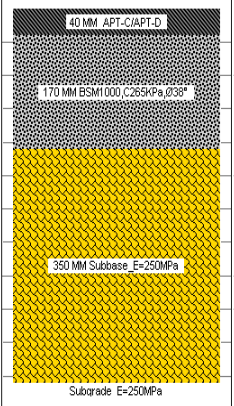
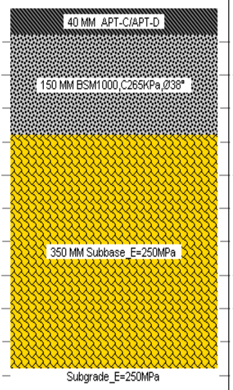
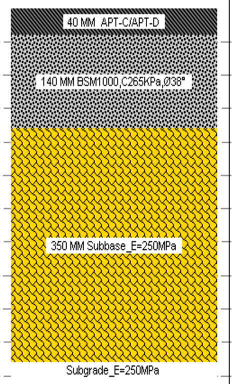
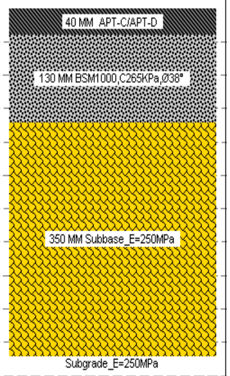
7.6 Standard Structures B6-B10 / type "B"/ BSM 800MPa/Subgrade 150MPa

Pavement Name	B6	B7	B8	B9	B10
Description	E-BSM=800MPa ; E-subgrade=150MPa	E-BSM=800MPa ; E-subgrade=150MPa	E-BSM=800MPa ; E-subgrade=150MPa	E-BSM=800MPa ; E-subgrade=150MPa	E-BSM=800MPa ; E-subgrade=150MPa
Pavement Structure Schematic:					
Total pavement thickness "cover" mm	620	570	550	530	520
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N =5,20 MESAL-100kN (BSM)	N = 3,6 MESAL-100kN (BSM)	N = 2,9 MESAL-100kN (BSM)	N = 1,9 MESAL-100kN (BSM)	N = 1,3 MESAL-100kN (BSM)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	BSM 22CM _Critical layer is Subbase (4,31 MESAL)	BSM 20CM _Critical layer is Subbase (2,5 MESAL)	BSM 18CM _Critical layer is Subbase (1,48 MESAL)	BSM 15CM _Critical layer is Subbase (0,71 MESAL)	BSM 13CM _Critical layer is Subbase (0,44 MESAL)
NOTES					

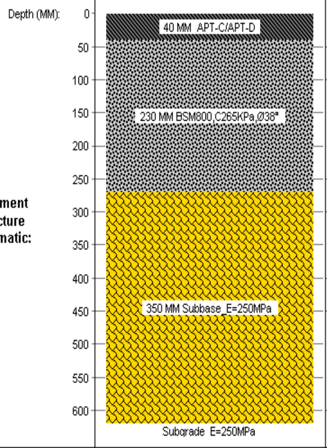
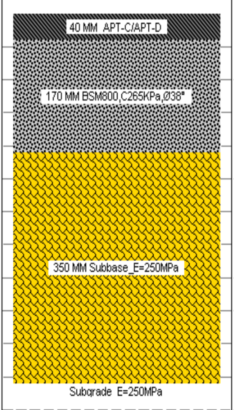
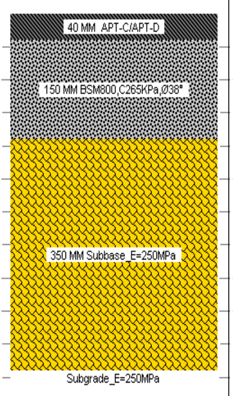
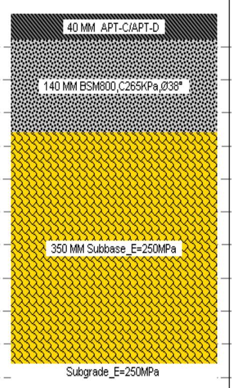
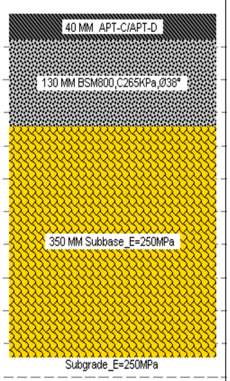
7.7 Standard Structures B6-B10 / type "B"/ BSM 1200MPa/Subgrade 250MPa

Pavement Name	B6	B7	B8	B9	B10
Description	E-BSM=1200MPa ; E-subgrade=250MP	E-BSM=1200MPa ; E-subgrade=250MP	E-BSM=1200MPa ; E-subgrade=250MP	E-BSM=1200MPa ; E-subgrade=250MP	E-BSM=1200MPa ; E-subgrade=250MP
Pavement Structure Schematic:					
Total pavement thickness "cover" mm	610	560	540	530	520
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 3,9 MESAL-100kN (BSM)	N = 2,0 MESAL-100kN (BSM)	N = 1,0 MESAL-100kN (BSM)	N = 0,56 MESAL-100kN (BSM)	N = 0,25 MESAL-100kN (BSM)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	BSM 20CM _Critical layer is Subbase (5,4 MESAL)	BSM 17CM _Critical layer is Subbase (2,14 MESAL)	BSM 15CM _Critical layer is Subbase (1,19 MESAL)	BSM 12CM _Critical layer is Subbase (0,52 MESAL)	BSM 10CM _Critical layer is Subbase (0,31 MESAL)
NOTES					

7.8 Standard Structures B6-B10 / type "B"/ BSM 1000MPa/Subgrade 250MPa

Pavement Name	B6	B7	B8	B9	B10
Description	E-BSM=1000MPa ; E-subgrade=250MP	E-BSM=1000MPa ; E-subgrade=250MP	E-BSM=1000MPa ; E-subgrade=250MP	E-BSM=1000MPa ; E-subgrade=250MP	E-BSM=1000MPa ; E-subgrade=250MP
Pavement Structure Schematic:					
Total pavement thickness "cover" mm	620	560	540	530	520
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N =4,0 MESAL-100kN (BSM)	N = 2,4 MESAL-100kN (BSM)	N = 1,46 MESAL-100kN (BSM)	N = 1,0 MESAL-100kN (BSM)	N = 0,58 MESAL-100kN (BSM)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	BSM 21CM _Critical layer is Subbase (4,88 MESAL)	BSM 18CM _Critical layer is Subbase (2,04 MESAL)	BSM 16CM _Critical layer is Subbase (1,17	BSM 13CM _Critical layer is Subbase (0,54 MESAL)	BSM 11CM _Critical layer is Subbase (0,33 MESAL)
NOTES					

7.9 Standard Structures B6-B10 / type "B"/ BSM 800MPa/Subgrade 250MPa

Pavement Name	B6	B7	B8	B9	B10
Description	E-BSM=800MPa ; E-subgrade=250MPa	E-BSM=800MPa ; E-subgrade=250MPa	E-BSM=800MPa ; E-subgrade=250MPa	E-BSM=800MPa ; E-subgrade=250MPa	E-BSM=800MPa ; E-subgrade=250MPa
Pavement Structure Schematic:					
Total pavement thickness "cover" mm	620	560	540	530	520
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N =4,39 MESAL-100kN (BSM)	N = 3,0 MESAL-100kN (BSM)	N = 2,29 MESAL-100kN (BSM)	N = 1,8 MESAL-100kN (BSM)	N =1,3 MESAL-100kN (BSM)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	BSM 21CM _Critical layer is Subbase (3,99 MESAL)	BSM 20CM _Critical layer is Subbase (2,32 MESAL)	BSM 17CM _Critical layer is Subbase (1,07	BSM 14CM _Critical layer is Subbase (0,52 MESAL)	BSM 12CM _Critical layer is Subbase (0,33 MESAL)
NOTES					

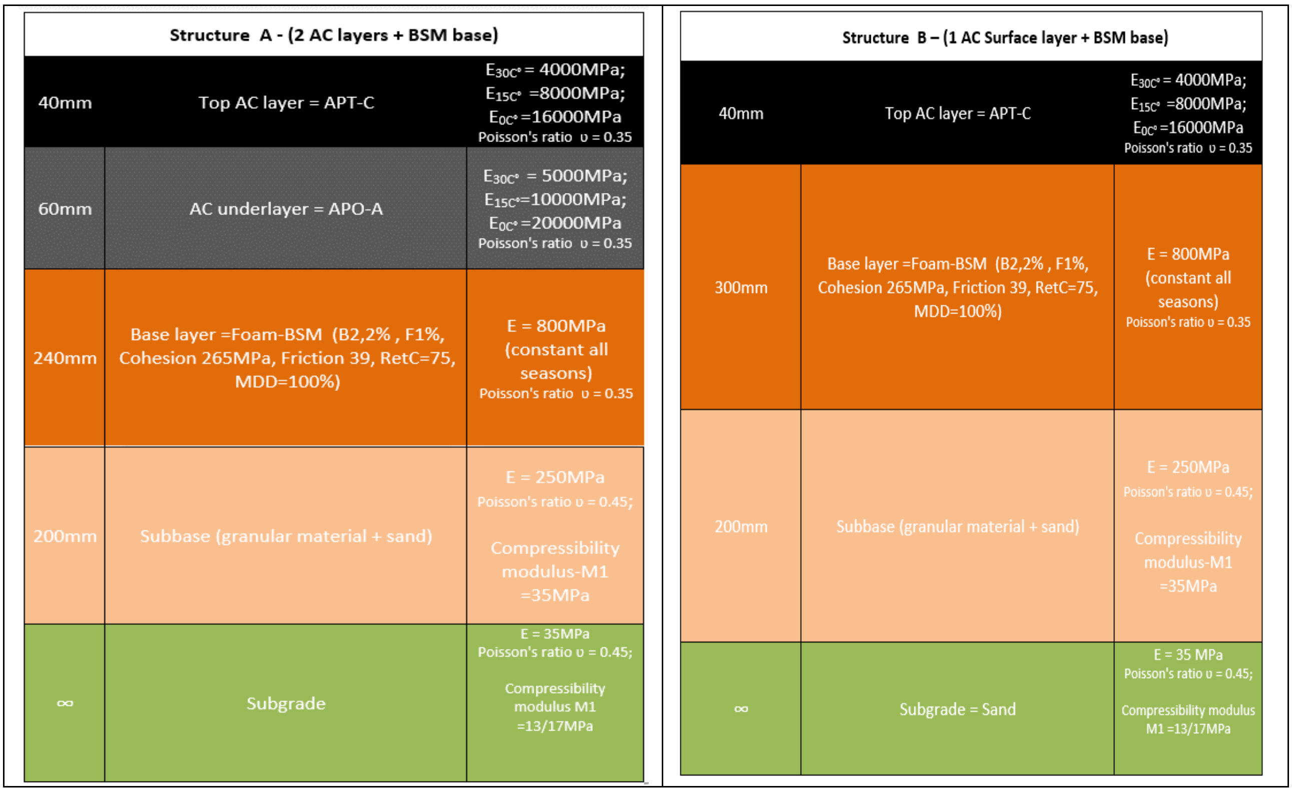
8 Case studies of pavement design with BSM base

8.1 Trial section in Neder-Over-Heembeek- Brussels city

The trial section in Neder-Over-Heembeek- Brussels was constructed in two different pavement structure with BSM base as follow:

- Type A : (AC wearing layer 4cm + AC underlayer + BSM base + Subbase).
- Type B : (AC wearing layer 4cm + BSM base + Subbase), Where BSM will be utilized as double use in the pavement system. It won't be only a pavement foundation but also to compensate the AC underlayer.

Both structures A & B shall have a similar service life or similar structural capacity. The expected traffic refers to that this road will be classified as : (**Road class B7 which could bear up to 2.0 MESAL-100kN)**. The following figures show the final structural design for both types A & B. (Note: figures without scale)



Structure A - (2 AC layers + BSM base)

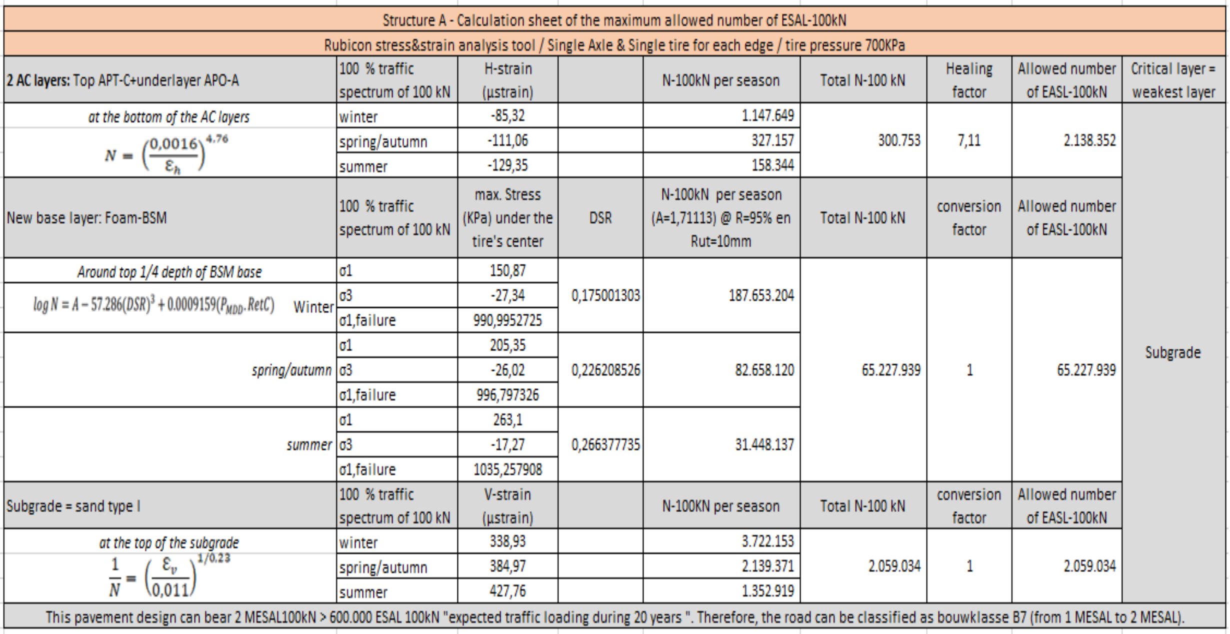
40mm	Top AC layer = APT-C	E_{30C° = 4000MPa; E_{15C° =8000MPa; E_{0C° =16000MPa Poisson's ratio υ = 0.35
60mm	AC underlayer = APO-A	E_{30C° = 5000MPa; E_{15C°=10000MPa; E_{0C° =20000MPa Poisson's ratio υ = 0.35
240mm	Base layer =Foam-BSM (B2,2% , F1%, Cohesion 265MPa, Friction 39, RetC=75, MDD=100%)	E = 800MPa (constant all seasons) Poisson's ratio υ = 0.35
200mm	Subbase (granular material + sand)	E = 250MPa Poisson's ratio υ = 0.45; Compressibility modulus-M1 =35MPa
∞	Subgrade	E = 35MPa Poisson's ratio υ = 0.45; Compressibility modulus M1 =13/17MPa

Structure B – (1 AC Surface layer + BSM base)

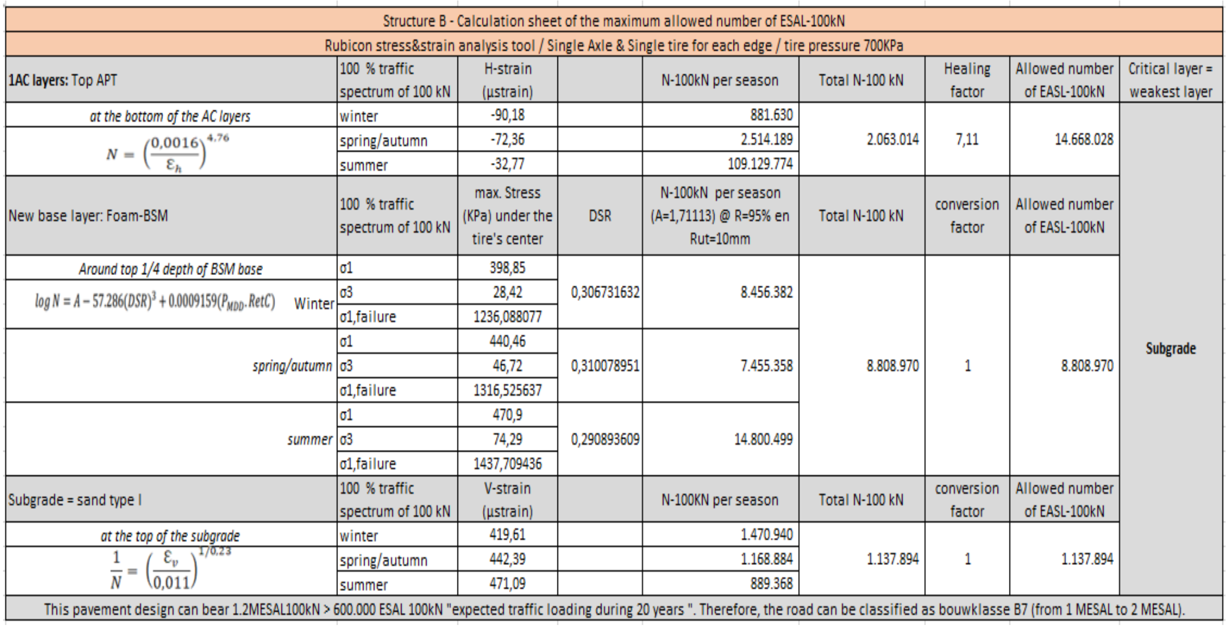
40mm	Top AC layer = APT-C	E_{30C° = 4000MPa; E_{15C° =8000MPa; E_{0C° =16000MPa Poisson's ratio υ = 0.35
300mm	Base layer =Foam-BSM (B2,2% , F1%, Cohesion 265MPa, Friction 39, RetC=75, MDD=100%)	E = 800MPa (constant all seasons) Poisson's ratio υ = 0.35
200mm	Subbase (granular material + sand)	E = 250MPa Poisson's ratio υ = 0.45; Compressibility modulus-M1 =35MPa
∞	Subgrade = Sand	E = 35 MPa Poisson's ratio υ = 0.45; Compressibility modulus M1 =13/17MPa

BSM Input parameters	
Cohesion C KPa - volgens 100%RAP	265
Friction Angle ø	39
Retained Cohesion RetC %	75
BSM dry density PMDD %	100
Reliability	95%

The analysis is done using the above-mentioned input parameters together with the assumed thicknesses. Hereafter the calculation was performed as follow:



Structure A - Calculation sheet of the maximum allowed number of ESAL-100kN								
Rubicon stress&strain analysis tool / Single Axle & Single tire for each edge / tire pressure 700KPa								
2 AC layers: Top APT-C+underlayer APO-A	100 % traffic spectrum of 100 kN	H-strain (µstrain)		N-100kN per season	Total N-100 kN	Healing factor	Allowed number of EASL-100kN	Critical layer = weakest layer
at the bottom of the AC layers	winter	-85,32		1.147.649	300.753	7,11	2.138.352	Subgrade
$N = \left(\frac{0,0016}{\varepsilon_h}\right)^{4.76}$	spring/autumn	-111,06		327.157				
	summer	-129,35		158.344				
New base layer: Foam-BSM	100 % traffic spectrum of 100 kN	max. Stress (KPa) under the tire's center	DSR	N-100kN per season (A=1,71113) @ R=95% en Rut=10mm	Total N-100 kN	conversion factor	Allowed number of EASL-100kN	
Around top 1/4 depth of BSM base	σ1	150,87	0,175001303	187.653.204	65.227.939	1	65.227.939	
$\log N = A - 57.286(DSR)^3 + 0.0009159(P_{MDD}.RetC)$ Winter	σ3	-27,34						
	σ1,failure	990,9952725						
spring/autumn	σ1	205,35	0,226208526	82.658.120				
	σ3	-26,02						
	σ1,failure	996,797326						
summer	σ1	263,1	0,266377735	31.448.137				
	σ3	-17,27						
	σ1,failure	1035,257908						
Subgrade = sand type I	100 % traffic spectrum of 100 kN	V-strain (µstrain)		N-100KN per season	Total N-100 kN	conversion factor	Allowed number of EASL-100kN	
at the top of the subgrade	winter	338,93		3.722.153	2.059.034	1	2.059.034	
$\frac{1}{N} = \left(\frac{\varepsilon_v}{0,011}\right)^{1/0.23}$	spring/autumn	384,97		2.139.371				
	summer	427,76		1.352.919				
This pavement design can bear 2 MESAL100kN > 600.000 ESAL 100kN "expected traffic loading during 20 years ". Therefore, the road can be classified as bouwklasse B7 (from 1 MESAL to 2 MESAL).								



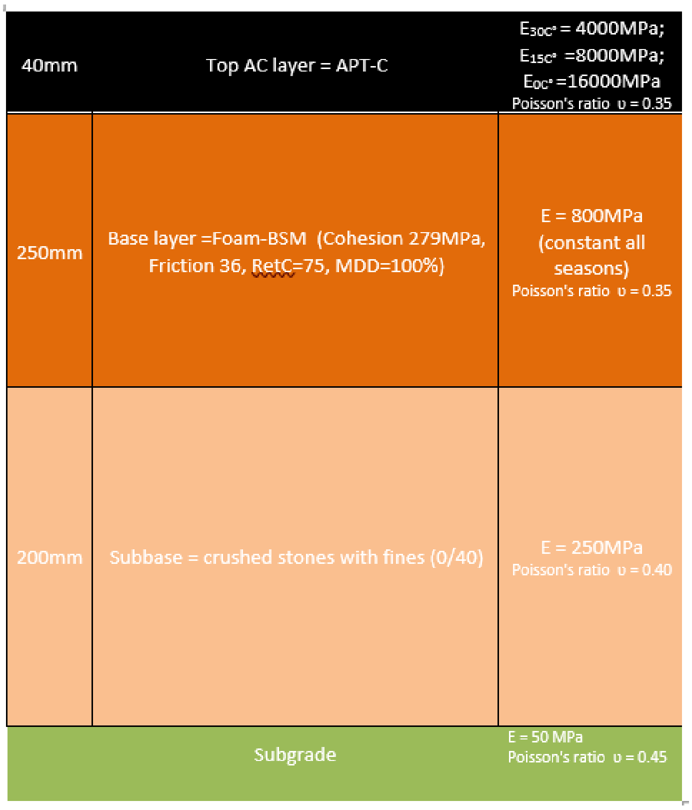
Structure B - Calculation sheet of the maximum allowed number of ESAL-100kN								
Rubicon stress&strain analysis tool / Single Axle & Single tire for each edge / tire pressure 700KPa								
1AC layers: Top APT	100 % traffic spectrum of 100 kN	H-strain (µstrain)		N-100kN per season	Total N-100 kN	Healing factor	Allowed number of EASL-100kN	Critical layer = weakest layer
at the bottom of the AC layers	winter	-90,18		881.630	2.063.014	7,11	14.668.028	**Subgrade**
$N = \left(\frac{0,0016}{\varepsilon_h}\right)^{4.76}$	spring/autumn	-72,36		2.514.189				
	summer	-32,77		109.129.774				
New base layer: Foam-BSM	100 % traffic spectrum of 100 kN	max. Stress (KPa) under the tire's center	DSR	N-100kN per season (A=1,71113) @ R=95% en Rut=10mm	Total N-100 kN	conversion factor	Allowed number of EASL-100kN	
Around top 1/4 depth of BSM base	σ1	398,85	0,306731632	8.456.382	8.808.970	1	8.808.970	
$\log N = A - 57.286(DSR)^3 + 0.0009159(P_{MDD}.RetC)$ Winter	σ3	28,42						
	σ1,failure	1236,088077						
spring/autumn	σ1	440,46	0,310078951	7.455.358				
	σ3	46,72						
	σ1,failure	1316,525637						
summer	σ1	470,9	0,290893609	14.800.499				
	σ3	74,29						
	σ1,failure	1437,709436						
Subgrade = sand type I	100 % traffic spectrum of 100 kN	V-strain (µstrain)		N-100KN per season	Total N-100 kN	conversion factor	Allowed number of EASL-100kN	
at the top of the subgrade	winter	419,61		1.470.940	1.137.894	1	1.137.894	
$\frac{1}{N} = \left(\frac{\varepsilon_v}{0,011}\right)^{1/0.23}$	spring/autumn	442,39		1.168.884				
	summer	471,09		889.368				
This pavement design can bear 1.2MESAL100kN > 600.000 ESAL 100kN "expected traffic loading during 20 years ". Therefore, the road can be classified as bouwklasse B7 (from 1 MESAL to 2 MESAL).								

So in the above tables, the actual critical layer for both structures A & B was the subgrade with 2,06 MESAL100kN and 1,2 MESAL100kN respectively.

8.2 Trial section in Bornem city

The trial section in Bornem was constructed using Type B : (AC wearing layer 4cm + BSM base + Subbase), Where BSM will be utilized as double use in the pavement system. It won't be only a pavement foundation but also to compensate the AC underlayer.

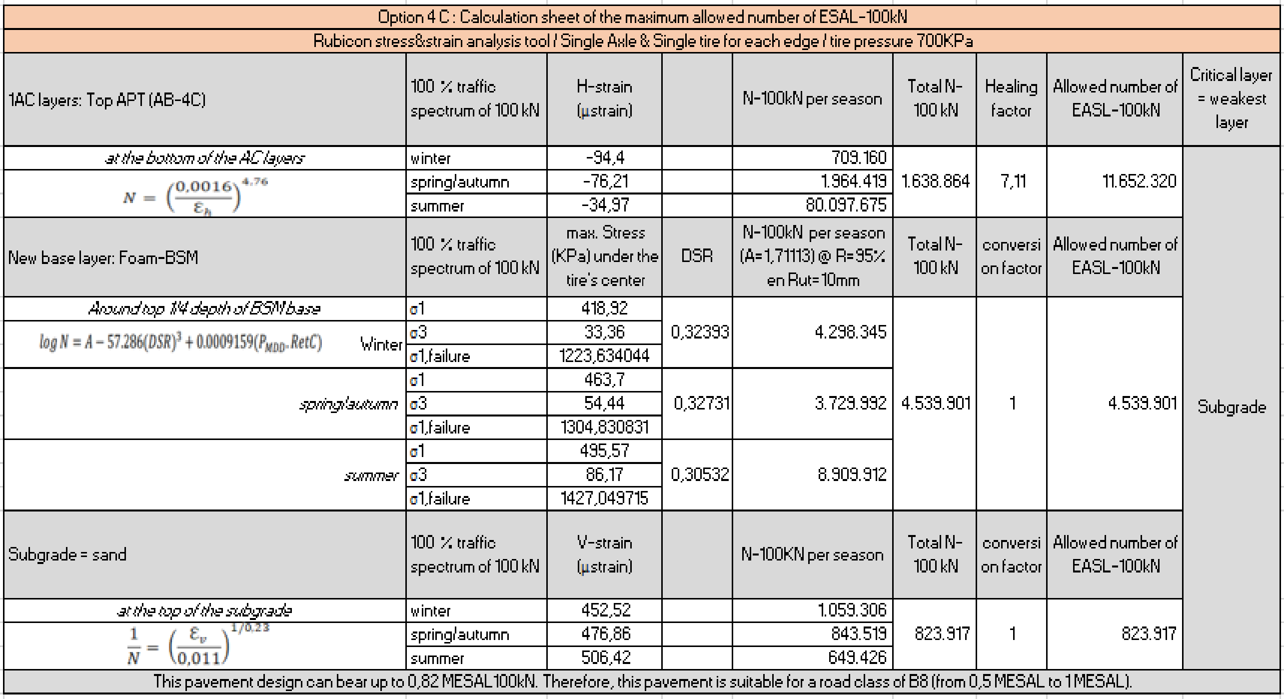
The expected traffic refers to that this road will be classified as : (**Road class B8 which could bear up to 1.0 MESAL-100kN)**. The following figure shows the final structural design for both types A & B. (Note: figure without scale)



40mm	Top AC layer = APT-C	E_{30C° = 4000MPa; E_{15C° =8000MPa; E_{0C° =16000MPa Poisson's ratio υ = 0.35
250mm	Base layer =Foam-BSM (Cohesion 279MPa, Friction 36, RetC=75, MDD=100%)	E = 800MPa (constant all seasons) Poisson's ratio υ = 0.35
200mm	Subbase = crushed stones with fines (0/40)	E = 250MPa Poisson's ratio υ = 0.40
	Subgrade	E = 50 MPa Poisson's ratio υ = 0.45

BSM Input parameters	
Cohesion C KPa - volgens 100%RAP	279
Friction Angle ø	36
Retained Cohesion RetC %	75
BSM dry density PMDD %	100
Reliability	95%

The analysis is done using the above-mentioned input parameters together with the assumed thicknesses. Hereafter, the pavement design was implemented using a Flemish mechanistic pavement design approach and then verified using the South African mechanistic pavement design approach. The following table illustrates calculation:



Option 4 C : Calculation sheet of the maximum allowed number of ESAL-100kN								
Rubicon stress&strain analysis tool / Single Axle & Single tire for each edge / tire pressure 700KPa								
1AC layers: Top APT (AB-4C)	100 % traffic spectrum of 100 kN	H-strain (µstrain)		N-100kN per season	Total N-100 kN	Healing factor	Allowed number of EASL-100kN	Critical layer = weakest layer
at the bottom of the AC layers	winter	-94,4		709.160	1.638.864	7,11	11.652.320	Subgrade
$N = \left(\frac{0,0016}{\varepsilon_h}\right)^{4.76}$	spring/autumn	-76,21		1.964.419				
	summer	-34,97		80.097.675				
New base layer: Foam-BSM	100 % traffic spectrum of 100 kN	max. Stress (KPa) under the tire's center	DSR	N-100kN per season (A=1,71113) @ R=95% en Rut=10mm	Total N-100 kN	conversion factor	Allowed number of EASL-100kN	
Around top 1/4 depth of BSM base	σ1	418,92	0,32393	4.298.345	4.539.901	1	4.539.901	
$\log N = A - 57.286(DSR)^3 + 0.0009159(P_{MDD}\text{-}RetC)$ Winter	σ3	33,36						
	σ1,failure	1223,634044						
	σ1	463,7	0,32731	3.729.992				
spring/autumn	σ3	54,44						
	σ1,failure	1304,830831						
	σ1	495,57	0,30532	8.909.912				
summer	σ3	86,17						
	σ1,failure	1427,049715						
Subgrade = sand	100 % traffic spectrum of 100 kN	V-strain (µstrain)		N-100KN per season	Total N-100 kN	conversion factor	Allowed number of EASL-100kN	
at the top of the subgrade	winter	452,52		1.059.306	823.917	1	823.917	
$\frac{1}{N} = \left(\frac{\varepsilon_v}{0,011}\right)^{1/0.23}$	spring/autumn	476,86		843.519				
	summer	506,42		649.426				
This pavement design can bear up to 0,82 MESAL100kN. Therefore, this pavement is suitable for a road class of B8 (from 0,5 MESAL to 1 MESAL).								

So in the above table, the actual critical layer was the subgrade with 0,82 MESAL100kN.

Step by step calculating the service life of BSM at **winter** in the above table:

$$\sigma_{1,f} = \frac{(1+\sin\emptyset).\sigma_3 + 2.C.\cos\emptyset}{(1-\sin\emptyset)} = \frac{(1+\sin 36).33,36 \;+\; 2.279.\cos 36}{(1-\sin 36)} = 1223,6\;KPa$$

$$Deviator\ Stress\ Ratio\ DSR = \frac{\sigma_d}{\sigma_{d,f}} = \frac{\sigma_1 - \sigma_3}{\sigma_{1,f} - \sigma_3} = \frac{418,92-(33,36)}{1223,6-(33,36)} = 0,3239$$

$$\log N = 1,71113 - 57.286(0,3239)^3 + 0.0009159(100\ X\ 75)$$

N_{winter} = 4,29 MESAL-100kN

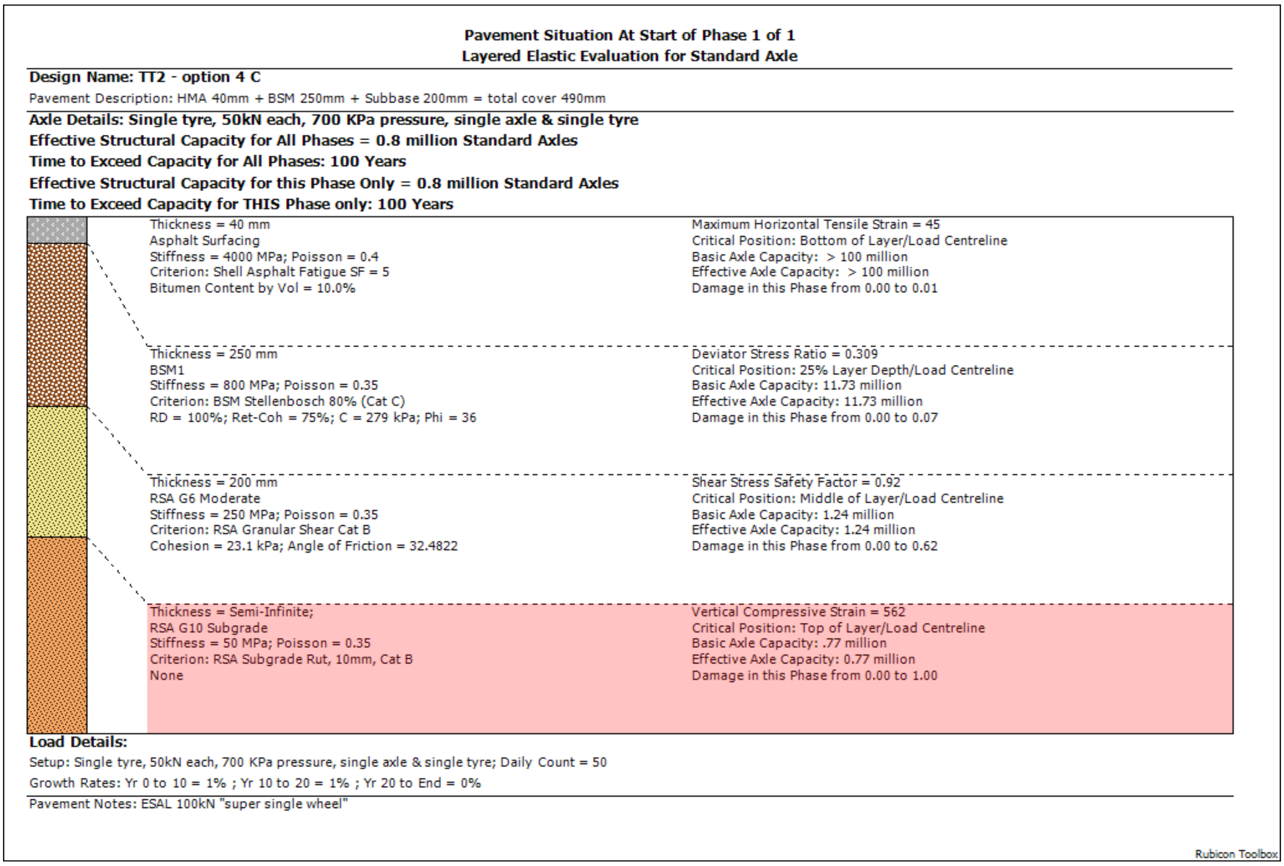
N_{spring} = 3,72 MESAL-100kN

N_{summer} = 8,9 MESAL-100kN

$$\frac{1}{N} = \frac{0.25}{N_{summer}} + \frac{0.5}{N_{spring}} + \frac{0.25}{N_{winter}} = \frac{0.25}{8,9} + \frac{0.5}{3,72} + \frac{0.25}{4,29}$$

N $_{\text{Total}}$ = 4,5 Million ESAL-100kN

A verfication was also performed using South African ME design approach using similar design paramters:



Pavement Situation At Start of Phase 1 of 1
Layered Elastic Evaluation for Standard Axle

Design Name: TT2 - option 4 C
Pavement Description: HMA 40mm + BSM 250mm + Subbase 200mm = total cover 490mm

Axle Details: Single tyre, 50kN each, 700 KPa pressure, single axle & single tyre
Effective Structural Capacity for All Phases = 0.8 million Standard Axles
Time to Exceed Capacity for All Phases: 100 Years
Effective Structural Capacity for this Phase Only = 0.8 million Standard Axles
Time to Exceed Capacity for THIS Phase only: 100 Years

Thickness = 40 mm
Asphalt Surfacing
Stiffness = 4000 MPa; Poisson = 0.4
Criterion: Shell Asphalt Fatigue SF = 5
Bitumen Content by Vol = 10.0%

Maximum Horizontal Tensile Strain = 45
Critical Position: Bottom of Layer/Load Centreline
Basic Axle Capacity: > 100 million
Effective Axle Capacity: > 100 million
Damage in this Phase from 0.00 to 0.01

Thickness = 250 mm
BSM1
Stiffness = 800 MPa; Poisson = 0.35
Criterion: BSM Stellenbosch 80% (Cat C)
RD = 100%; Ret-Coh = 75%; C = 279 kPa; Phi = 36

Deviator Stress Ratio = 0.309
Critical Position: 25% Layer Depth/Load Centreline
Basic Axle Capacity: 11.73 million
Effective Axle Capacity: 11.73 million
Damage in this Phase from 0.00 to 0.07

Thickness = 200 mm
RSA G6 Moderate
Stiffness = 250 MPa; Poisson = 0.35
Criterion: RSA Granular Shear Cat B
Cohesion = 23.1 kPa; Angle of Friction = 32.4822

Shear Stress Safety Factor = 0.92
Critical Position: Middle of Layer/Load Centreline
Basic Axle Capacity: 1.24 million
Effective Axle Capacity: 1.24 million
Damage in this Phase from 0.00 to 0.62

Thickness = Semi-Infinite;
RSA G10 Subgrade
Stiffness = 50 MPa; Poisson = 0.35
Criterion: RSA Subgrade Rut, 10mm, Cat B
None

Vertical Compressive Strain = 562
Critical Position: Top of Layer/Load Centreline
Basic Axle Capacity: .77 million
Effective Axle Capacity: 0.77 million
Damage in this Phase from 0.00 to 1.00

Load Details:
Setup: Single tyre, 50kN each, 700 KPa pressure, single axle & single tyre; Daily Count = 50
Growth Rates: Yr 0 to 10 = 1% ; Yr 10 to 20 = 1% ; Yr 20 to End = 0%
Pavement Notes: ESAL 100kN "super single wheel"

Rubicon Toolbox

In general, a good correlation between design methods (Flemish & South African) was observed during the design process. Both were resulted that subgrade will be the critical layer with 0,8MESAL.

Regarding BSM layer, it was noticed that the seasonal AC stiffness approach, that followed in Flanders, resulted in safer pavement designs or shorter service life of 4,5MESAL-100kN, while the South African pavement design approach resulted in longer service life with 11,7 MESAL-100kN.

9 Conclusion and Recommendations

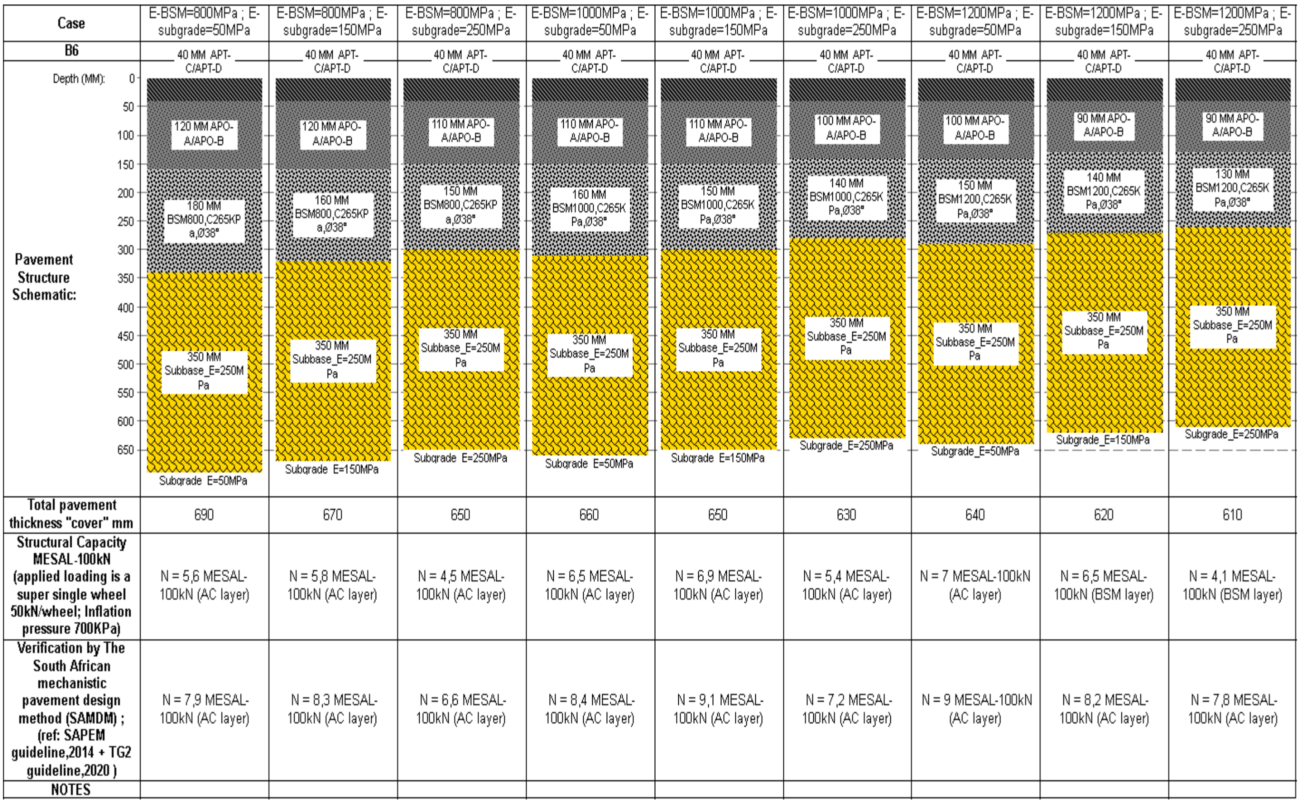
- The standard structures, that were designed above, would be a good reference for all stakeholders such as contractors who will deal with BSM technology in the Flemish market. In this guideline, a wide range of BSM pavement structures will be available. This report documents 90 standard BSM pavement structures of type A, in addition to 50 standard BSM pavement structures of type B. However, more cost-effective structures could be designed based on the current condition of the road, the construction history and the deflection patterns. For each uniform road section, a single uniform design section shall be designed. So that, for rehabilitation design situations, it is presumed that the designer will have detailed information on the existing pavement layer properties for each uniform section. Consequently, it should be recognized that each uniform section may require a different BSM mix design and therefore different shear parameters and consequently a different BSM layer thickness (recycling depth) to achieve the required structural capacity.

- Some of common/default design parameters are kept constant as follow:
  - *The BSM mix has a cohesion C=265 KPa,*
  - *And/or the BSM mix has lower friction angle Ø=38,*
  - *And/or the subbase =35cm,*
  - *And/or the subbase E modulus=250MPa.*

  Therefore, it is recommended to consult a professional pavement designer if any of the above parameters has lower/worser values. An alternative solution should be decided in this case. For instance, guess that the subbase thickness has 25cm which is lower than 35cm that presumed for all standard structures, then the designer can compensate that with a bit thicker BSM. This issue might be common concern in the future since the subbase is a deep layer in the underneath horizon, however the cold recycling technology seeks the upper horizon of the pavement system.

- It would be very important to perform a full investigation for the existing pavement and existing soil. As result, a pavement design will be high confident. Anyhow, the Flemish standards SB250 mentioned that the lowest allowed subgrade elastic modulus of E=50MPa (which is equivalent to M1=17MPa from plate loading test “by experience”). So, this value was assumed as a worst-case scenario for subgrade. And similar to subbase, where the Flemish standards SB250 mentioned that the lowest allowed subbase modulus of E=250MPa (which is equivalent to M1=35MPa from plate loading test “by experience”). And therefore, this value was assumed as a worst-case scenario for the subbase. If the plate loading test of subgrade results in M1<17MPa “E<50MPa”, then the recycling approach should be adapted to include treating the subgrade “existing soil”, for instance using compaction, stabilization by cement,…..etc. Similarly, if the plate loading test of subbase results in M1<35MPa “E<250MPa”, then the recycling approach should be adapted to include treating the subbase, for instance using compaction, stabilization by cement,…..etc. Contrary, if the subbase shows a higher bearing capacity using plate loading test M1>35MPa “E>250MPa”, then the standard structure in this guideline will be safer since it designed based on E=250MPa only. However, a specific pavement design could be done to avoid expected overdesign/overdimensioning structures because a strong subbase shall result in a thinner structure than those in this guideline.

- On the other hand, if the BSM mix shows higher cohesion, then the pavement structure will bear for sure a higher loads. Similarly, if the friction angle is higher, then structure will have a longer service life. For instance, each additional 1 KPa difference in cohesion or additional 1 degree difference in friction angle would affect the structural capacity of the pavement in 2-3 Million ESAL. Furthermore, it was discovered that paving a stiffer BSM could compensate the weaker/softer subgrade to achieve the target/desired structural capacity. For instance, the below diagram shows that road class B6 will have a similar thickness 65cm in the following cases :
    - *BSM modulus 800MPa & subgrade modulus 250MPa*
    - *BSM modulus 1000MPa & subgrade modulus 150MPa*
    - *BSM modulus 1200MPa & subgrade modulus 50MPa*



Case	E-BSM=800MPa ; E-subgrade=50MPa	E-BSM=800MPa ; E-subgrade=150MPa	E-BSM=800MPa ; E-subgrade=250MPa	E-BSM=1000MPa ; E-subgrade=50MPa	E-BSM=1000MPa ; E-subgrade=150MPa	E-BSM=1000MPa ; E-subgrade=250MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=150MPa	E-BSM=1200MPa ; E-subgrade=250MPa
B6	40 MM APT-C/APT-D	40 MM APT-C/APT-D	40 MM APT-C/APT-D	40 MM APT-C/APT-D	40 MM APT-C/APT-D	40 MM APT-C/APT-D	40 MM APT-C/APT-D	40 MM APT-C/APT-D	40 MM APT-C/APT-D
Pavement Structure Schematic: Depth (MM): 0, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650	120 MM APO-A/APO-B 180 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=50MPa	120 MM APO-A/APO-B 160 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=150MPa	110 MM APO-A/APO-B 150 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=250MPa	110 MM APO-A/APO-B 160 MM BSM1000,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=50MPa	110 MM APO-A/APO-B 150 MM BSM1000,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=150MPa	100 MM APO-A/APO-B 140 MM BSM1000,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=250MPa	100 MM APO-A/APO-B 150 MM BSM1200,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=50MPa	90 MM APO-A/APO-B 140 MM BSM1200,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=150MPa	90 MM APO-A/APO-B 130 MM BSM1200,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=250MPa
Total pavement thickness "cover" mm	690	670	650	660	650	630	640	620	610
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 5,6 MESAL-100kN (AC layer)	N = 5,8 MESAL-100kN (AC layer)	N = 4,5 MESAL-100kN (AC layer)	N = 6,5 MESAL-100kN (AC layer)	N = 6,9 MESAL-100kN (AC layer)	N = 5,4 MESAL-100kN (AC layer)	N = 7 MESAL-100kN (AC layer)	N = 6,5 MESAL-100kN (BSM layer)	N = 4,1 MESAL-100kN (BSM layer)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	N = 7,9 MESAL-100kN (AC layer)	N = 8,3 MESAL-100kN (AC layer)	N = 6,6 MESAL-100kN (AC layer)	N = 8,4 MESAL-100kN (AC layer)	N = 9,1 MESAL-100kN (AC layer)	N = 7,2 MESAL-100kN (AC layer)	N = 9 MESAL-100kN (AC layer)	N = 8,2 MESAL-100kN (AC layer)	N = 7,8 MESAL-100kN (AC layer)
NOTES									

- By observation in the design trails, it was discovered that an increase in one or more of the following ‘qualitative’ parameters leads to a significantly extension in the service life of a pavement incorporating BSM, according to Stellenbosch BSM function:
    - BSM cohesion,
    - BSM friction angle,
    - BSM thickness,
    - BSM stiffness,
    - Subgrade elastic modulus/stiffness.

- The pavement design was implemented using a Flemish mechanistic pavement design approach and then verified using the South African mechanistic pavement design approach. In general, a good correlation between design methods is observed during design process. It was noticed that the seasonal AC stiffness approach, that followed in Flanders, resulted in safer standard pavement designs. While the south Africa design approach resulted in longer service life or thinner structures.

- In these standard structures, the BSM was assumed as a temperature independent, however, the opposite is more realistic when the BSM's layer is covered only with a thin AC layer of 4cm, then it is strongly believed that the temperature effect on BSM's behaviour and on BSM's stiffness modulus will be high. Therefore, a further study is recommended to investigate that in the lab and/or in-situ via a smart pavement monitoring system. By this way, a more effective design would be generated when the seasonal BSM stiffness approach is applied same as a seasonal AC stiffness approach.

- Due time restrictions in this project, the design using "BSM sublayer approach" couldn't be performed. However, it would be realistic to design the BSM layer in two separate layers. Observations around the worldwide noticed that the BSM layer can have a stiffness up to 3 times the stiffness modulus of the underlying layer. For instance, if the subbase has a stiffness of 250 MPa, then the BSM layer will have stiffness modulus = 3 * $E_{subbase}$ 250MPa= 750 MPa. The justification behind this concept that: the maximal BSM stiffness modulus which can be generated practically in-situ, won't be more than 3 times "at maximal" the stiffness modulus of the underlying layer, according to these observations. However, the laboratory testing program may result a higher stiffness modulus for BSM.

- Further deeper study shall investigate the BSM performance under effect of heavier axle loads such as 130kN, especially if the recycled zone is located in heavy loaded area such as commercial zones, ports, airports ….etc.

10 APPENDICES :

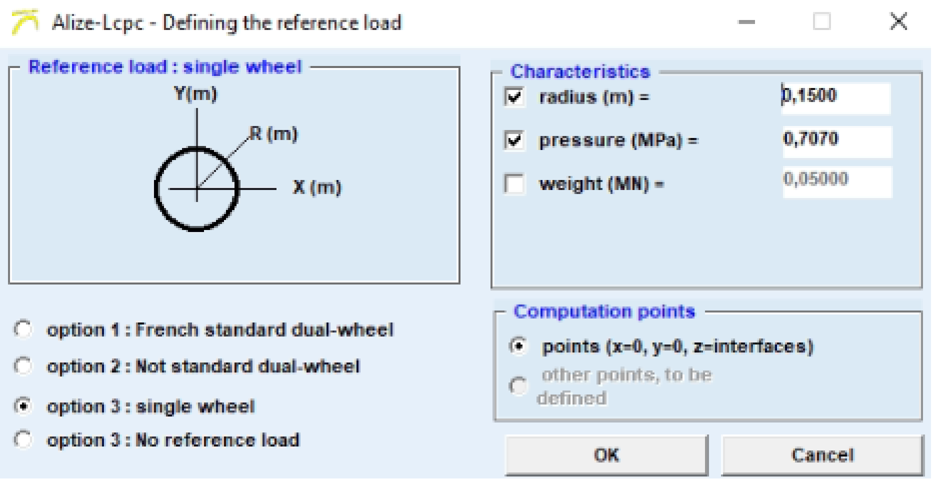
10.1 Appendix A : Subgrade “Existing soil” investigation

- Dynamic Cone Penetration Test

- Dynamic plate load test

- Static Plate Load Test

10.2 Appendix B : Alize analysis software



Alize-Lcpc - Defining the reference load

Reference load : single wheel

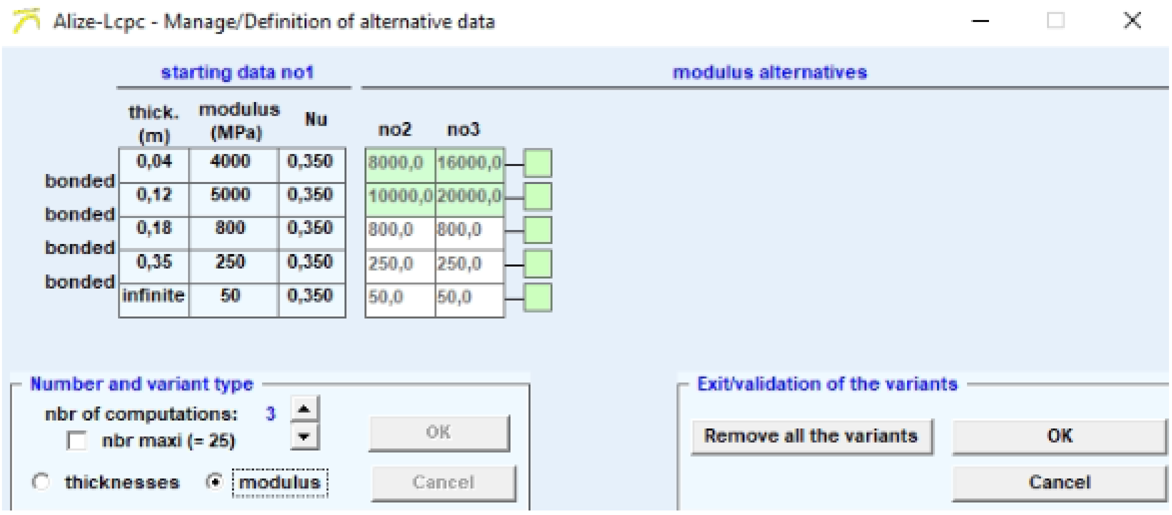
Characteristics

- ☑ radius (m) = 0,1500
- ☑ pressure (MPa) = 0,7070
- ☐ weight (MN) = 0,05000

- ○ option 1 : French standard dual-wheel
- ○ option 2 : Not standard dual-wheel
- ● option 3 : single wheel
- ○ option 3 : No reference load

Computation points

- ● points (x=0, y=0, z=interfaces)
- ○ other points, to be defined



Alize-Lcpc - Manage/Definition of alternative data

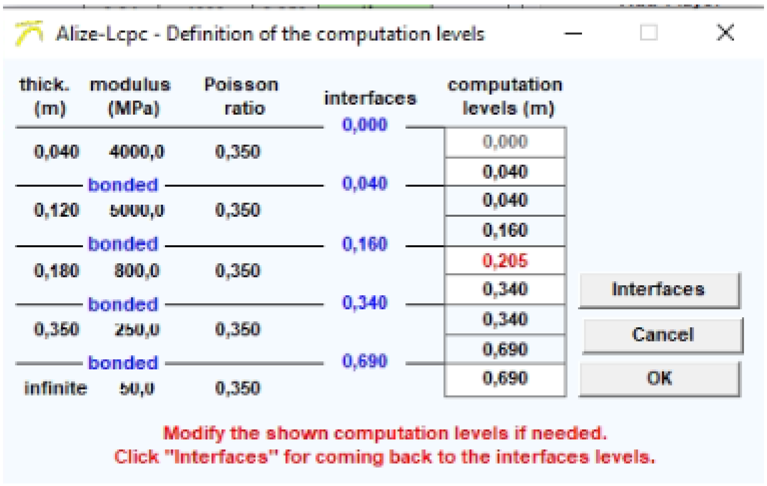
	starting data no1			modulus alternatives		
	thick. (m)	modulus (MPa)	Nu	no2	no3	
	0,04	4000	0,350	8000,0	16000,0	🟩
bonded	0,12	5000	0,350	10000,0	20000,0	🟩
bonded	0,18	800	0,350	800,0	800,0	🟩
bonded	0,35	250	0,350	250,0	250,0	🟩
bonded	infinite	50	0,350	50,0	50,0	🟩

Number and variant type

nbr of computations: 3

☐ nbr maxi (= 25)

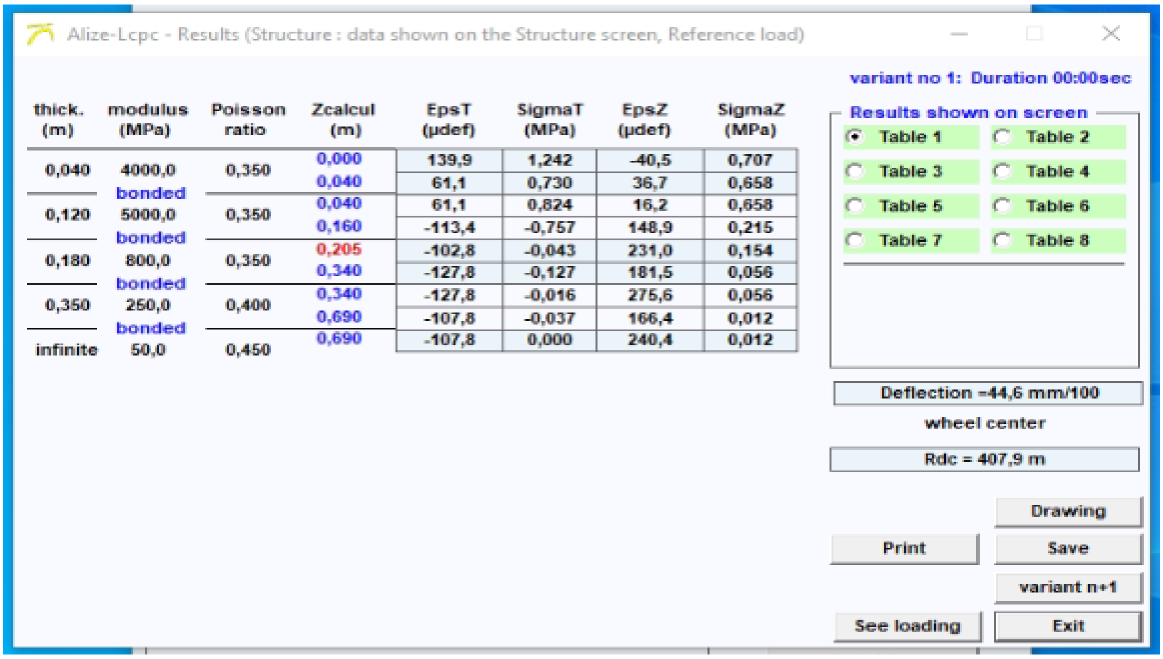
○ thicknesses ● modulus



Alize-Lcpc - Definition of the computation levels

thick. (m)	modulus (MPa)	Poisson ratio	interfaces	computation levels (m)
			0,000	0,000
0,040	4000,0	0,350		0,040
bonded			0,040	0,040
0,120	5000,0	0,350		0,160
bonded			0,160	0,205
0,180	800,0	0,350		0,340
bonded			0,340	0,340
0,350	250,0	0,350		0,690
bonded			0,690	0,690
infinite	50,0	0,350		

Modify the shown computation levels if needed.
Click "Interfaces" for coming back to the interfaces levels.

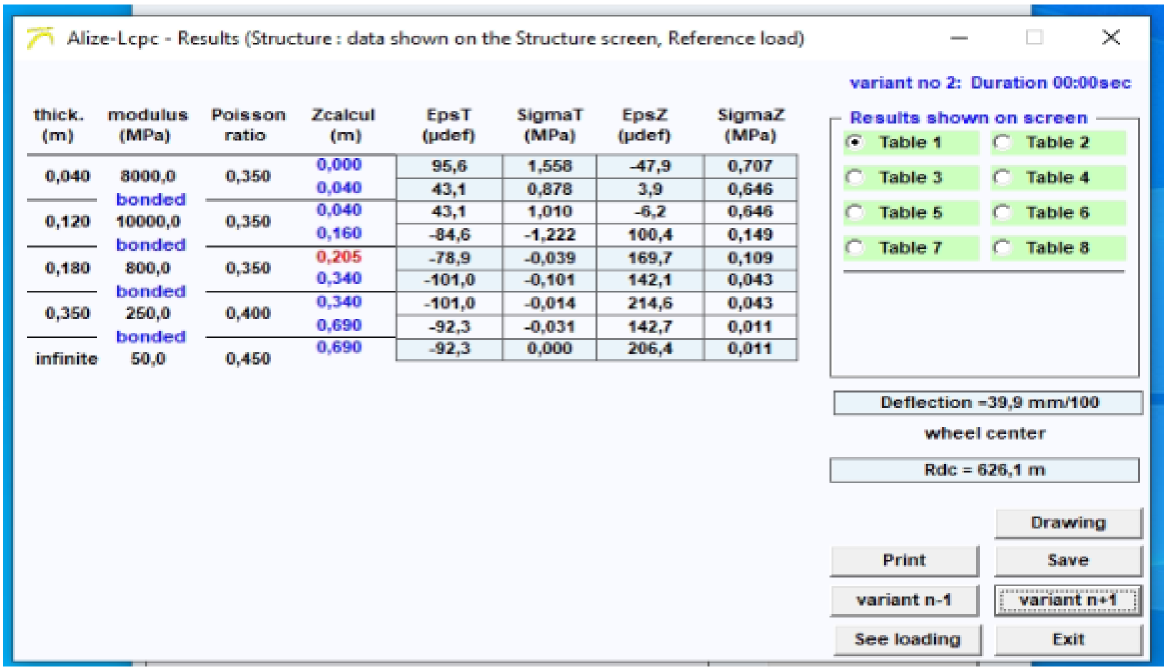


variant no 1: Duration 00:00sec

thick. (m)	modulus (MPa)	Poisson ratio	Zcalcul (m)	EpsT (µdef)	SigmaT (MPa)	EpsZ (µdef)	SigmaZ (MPa)
0,040	4000,0	0,350	0,000	139,9	1,242	-40,5	0,707
	bonded		0,040	61,1	0,730	36,7	0,658
0,120	5000,0	0,350	0,040	61,1	0,824	16,2	0,658
	bonded		0,160	-113,4	-0,757	148,9	0,215
0,180	800,0	0,350	0,205	-102,8	-0,043	231,0	0,154
	bonded		0,340	-127,8	-0,127	181,5	0,056
0,350	250,0	0,400	0,340	-127,8	-0,016	275,6	0,056
	bonded		0,690	-107,8	-0,037	166,4	0,012
infinite	50,0	0,450	0,690	-107,8	0,000	240,4	0,012

Results shown on screen
● Table 1 ○ Table 2
○ Table 3 ○ Table 4
○ Table 5 ○ Table 6
○ Table 7 ○ Table 8

Deflection =44,6 mm/100
wheel center
Rdc = 407,9 m

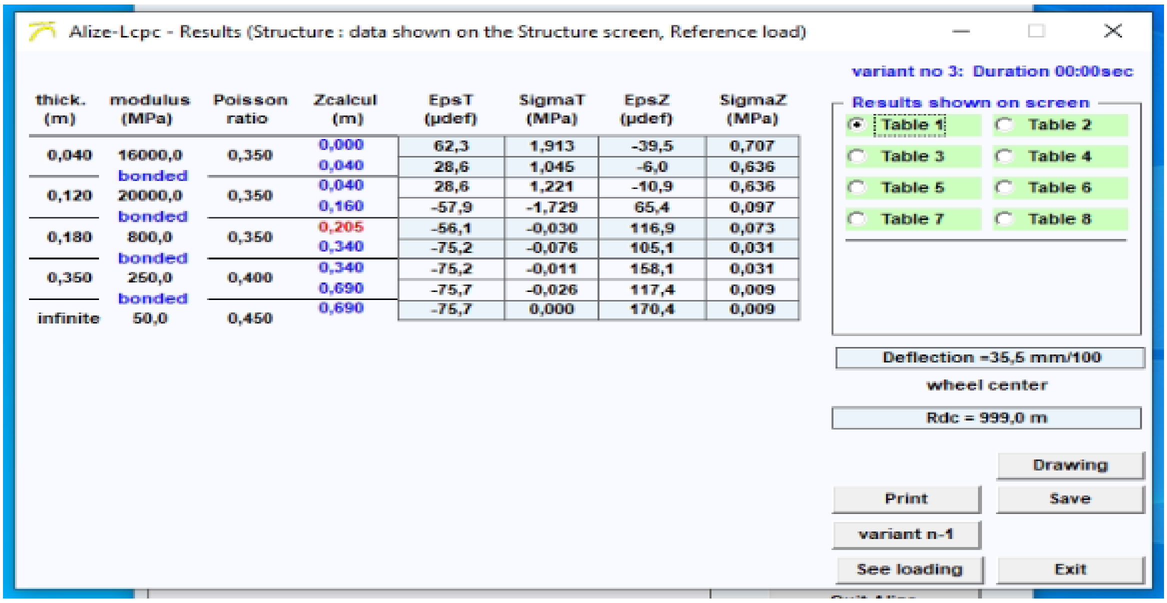


variant no 2: Duration 00:00sec

thick. (m)	modulus (MPa)	Poisson ratio	Zcalcul (m)	EpsT (µdef)	SigmaT (MPa)	EpsZ (µdef)	SigmaZ (MPa)
0,040	8000,0	0,350	0,000	95,6	1,558	-47,9	0,707
	bonded		0,040	43,1	0,878	3,9	0,646
0,120	10000,0	0,350	0,040	43,1	1,010	-6,2	0,646
	bonded		0,160	-84,6	-1,222	100,4	0,149
0,180	800,0	0,350	0,205	-78,9	-0,039	169,7	0,109
	bonded		0,340	-101,0	-0,101	142,1	0,043
0,350	250,0	0,400	0,340	-101,0	-0,014	214,6	0,043
	bonded		0,690	-92,3	-0,031	142,7	0,011
infinite	50,0	0,450	0,690	-92,3	0,000	206,4	0,011

Results shown on screen
● Table 1 ○ Table 2
○ Table 3 ○ Table 4
○ Table 5 ○ Table 6
○ Table 7 ○ Table 8

Deflection =39,9 mm/100
wheel center
Rdc = 626,1 m



variant no 3: Duration 00:00sec

thick. (m)	modulus (MPa)	Poisson ratio	Zcalcul (m)	EpsT (µdef)	SigmaT (MPa)	EpsZ (µdef)	SigmaZ (MPa)
0,040	16000,0	0,350	0,000	62,3	1,913	-39,5	0,707
	bonded		0,040	28,6	1,045	-6,0	0,636
0,120	20000,0	0,350	0,040	28,6	1,221	-10,9	0,636
	bonded		0,160	-57,9	-1,729	65,4	0,097
0,180	800,0	0,350	0,205	-56,1	-0,030	116,9	0,073
	bonded		0,340	-75,2	-0,076	105,1	0,031
0,350	250,0	0,400	0,340	-75,2	-0,011	158,1	0,031
	bonded		0,690	-75,7	-0,026	117,4	0,009
infinite	50,0	0,450	0,690	-75,7	0,000	170,4	0,009

Results shown on screen
● Table 1 ○ Table 2
○ Table 3 ○ Table 4
○ Table 5 ○ Table 6
○ Table 7 ○ Table 8

Deflection =35,5 mm/100
wheel center
Rdc = 999,0 m

10.3 Appendix C : PN Design Tables and Diagrams

Table C.1 Stiffness Determination for the Subgrade

Design Equivalent Material Class for Subgrade	Stiffness Value (MPa)
G6 or better	250
G7	140
G8	100
G9	90
G10	70

Note: Subgrade stiffness value should be adjusted for climate (Table C.2) and cover depth (Figure C.3).

Table C.2 Climate Adjustment Factors

Climate	Weinert (N)	Thornthwaite (Im)	Climate Adjustment Factor
Wet	Weinert N < 2	Humid (20 – 100) Perhumid (> 100)	0.6
Moderate	Weinert N = 2 to 5	Dry sub-humid (-20 to 0) Moist sub-humid (0 to 20)	0.9
Dry	Weinert N > 5	Arid (< -40) Semi-arid (-40 to -20)	1.0

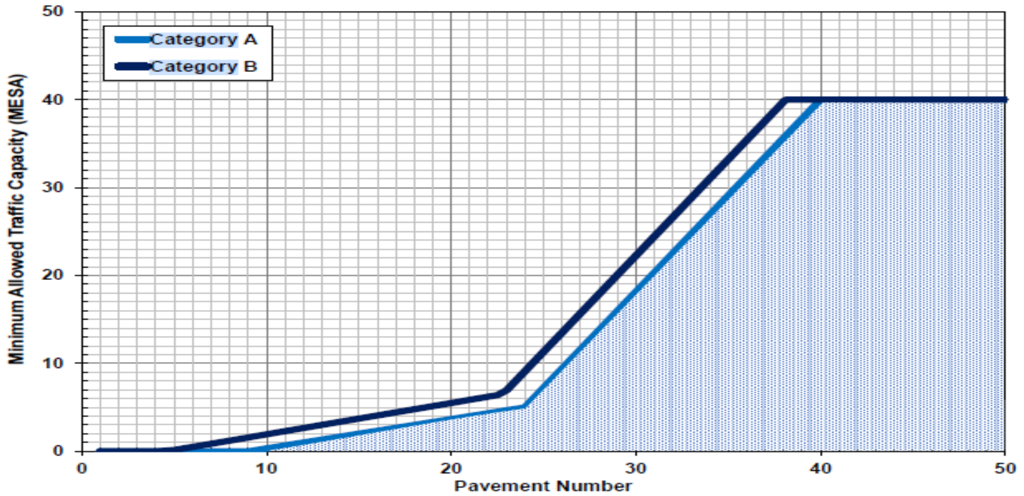
Table C.3 Modular Ratio, Maximum Allowed Stiffness and Thickness Limits for Pavement Layers

General Material Description	Material Class[1]	Thickness Limits (mm)	Modular Ratio Limit	Maximum Allowed Stiffness (Emax)(MPa)	Base Confidence Factor (BCF)
Surface seals	S1, S2, S3, S4, S5, S6	10	2	1000	N/A
Asphalt surfacings	AG, AC, AS, AO	20 – 100	4	2000	1.0
Asphalt bases	BC, BS, BTB	20 – 200	4	1500	1.0
Bitumen Stabilised Material (BSM)	BSM1[2]	100 – 300	3	700	1.0
	BSM2[3]	100 – 300	2.5	600	0.7
Crushed stone material	G1	100 – 150	3	600	1.0
	G2	100 – 200	2	450	0.8
	G3	100 – 200	1.8	400	0.7
Natural Gravel	G4	100 – 300	1.8	375	0.2
	G5	100 – 300	1.8	350	0.1
	G6	100 – 300	1.8	250	-2.0
Gravel-soil blend	G7	100 – 350	1.7	140	-2.5
	G8	100 – 350	1.6	100	-3.0
	G9	100 – 350	1.4	90	-4.0
	G10	100 – 350	1.2	70	-5.0
Cement stabilised natural gravel	C3	100 – 350	4	500	0.6
	C4	100 – 350	3	400	0.4
Equivalent granular (previously cement stabilised)	EG4	100 – 350	2	400	0.4
	EG5	100 – 350	1.8	300	0.2

Notes:

1. *Design equivalent material class (DEMAC) for rehabilitation projects.*
2. *BSM1 parent material is normally using crushed stone or reclaimed asphalt (RA) source material.*
3. *BSM2 parent material is normally using natural gravel or RA source material.*

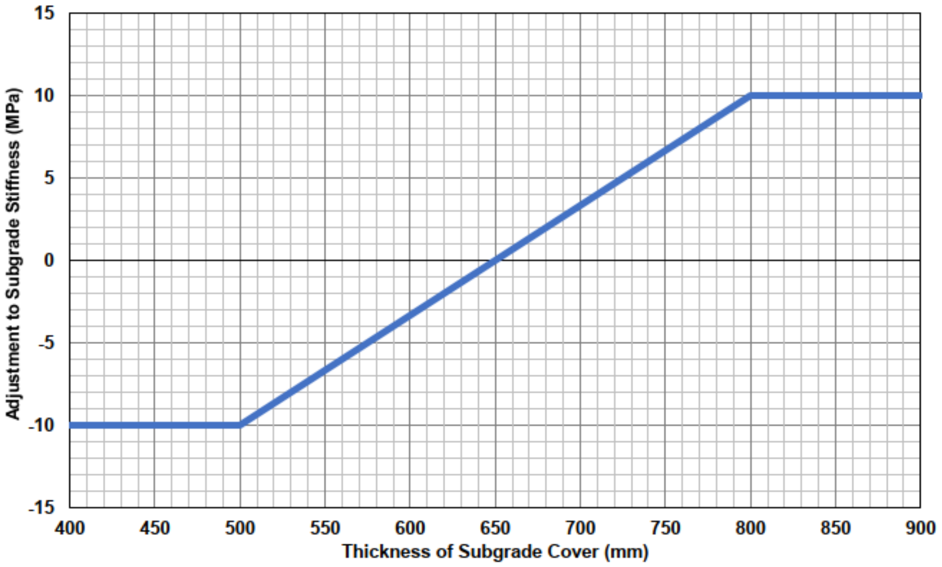
Table C.4 Pavement Capacity Calculation for Pavement Number



$$N_{allow} = N_1 + PN * Slope$$

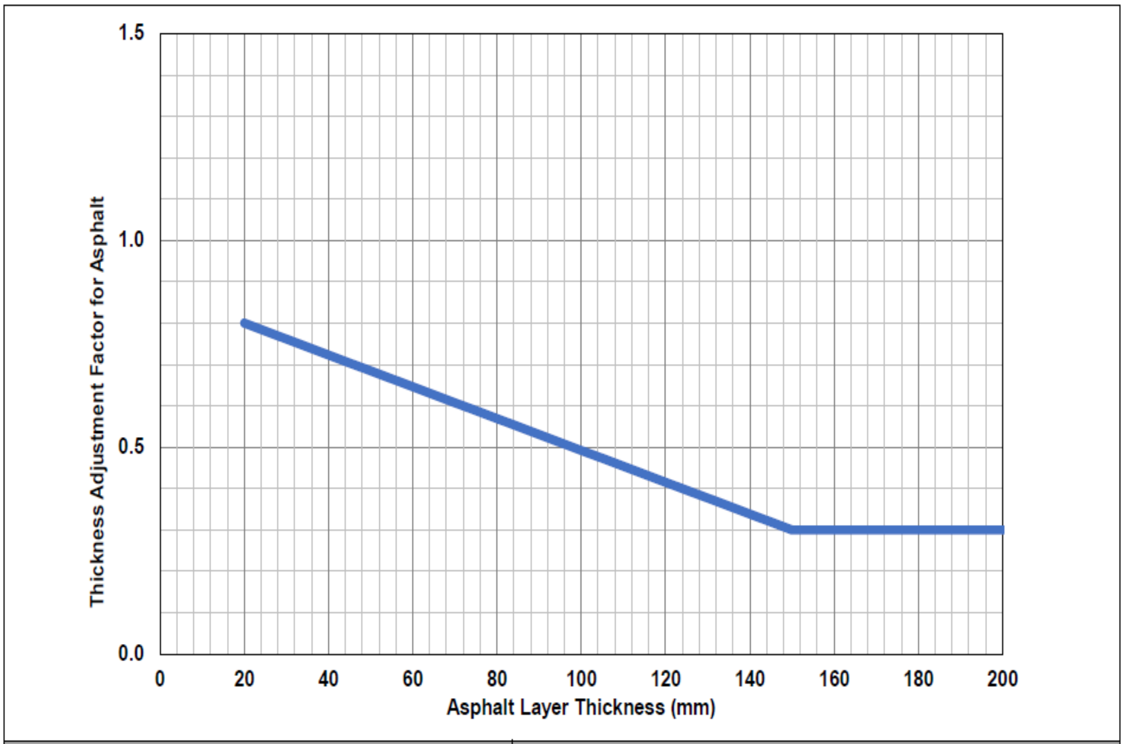
Where: N_{allow} = Minimum Allowed Pavement Capacity (million equivalent standard axles, MESA)
N_1 = Intercept for line segment, from constants below
PN = Calculated Pavement Number
Slope = Slope for the line segment, from constants below

	Pavement Number	N_1	Slope
Category A	< 9	Not suitable	
	9 to 24	-3.0	1/3
	24 to 40	-47.5	2.1875
	> 40	40	0
	Pavement Number	N_1	Slope
Category B	< 4.6	Not suitable	
	4.6 to 22.8	-1.6429	0.3571
	22.8 to 38.1	-43.4216	2.1895
	> 38.1	40	0



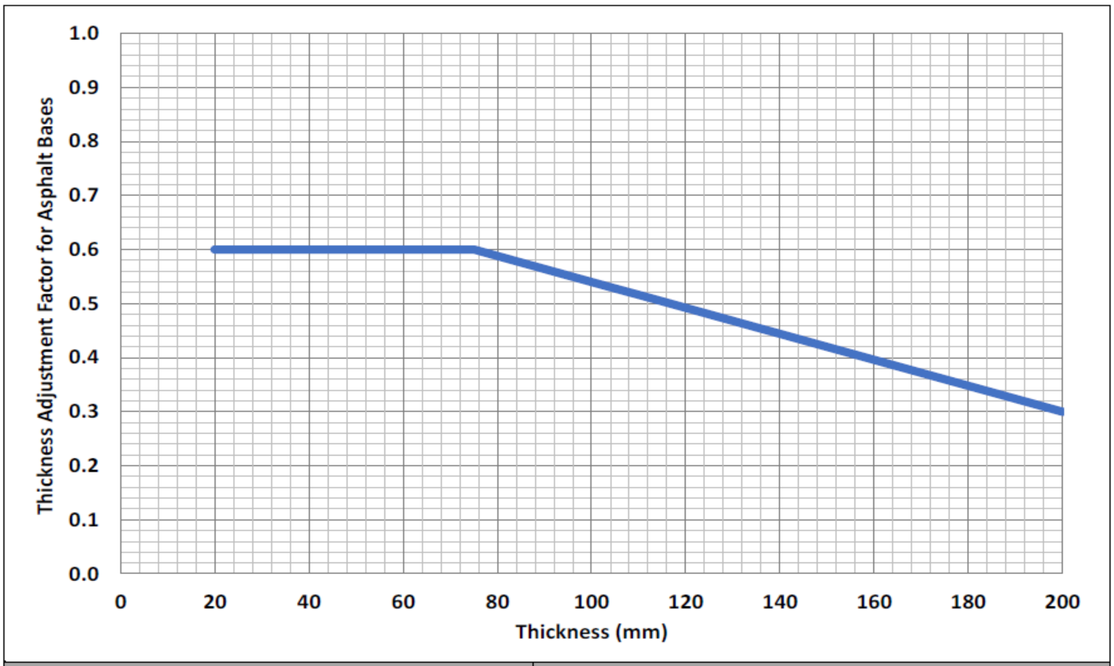
Thickness of Subgrade Cover	Adjustment to Subgrade Stiffness
< 500 mm	- 10 MPa
500 to 800 mm	-10 + [(Cover – 500)/300] * 20 MPa
> 800 mm	+ 10 MPa

Figure C.3 Adjustment of Subgrade Stiffness Based on Cover Thickness



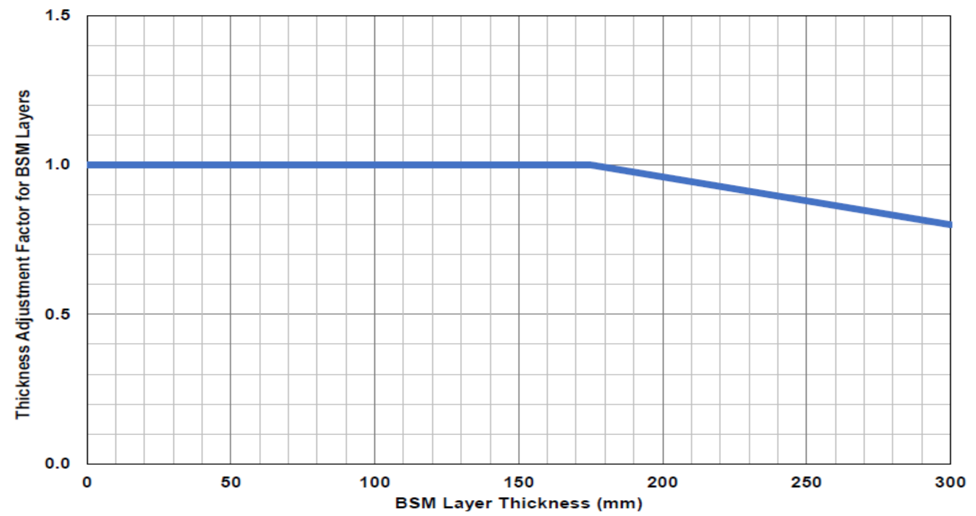
Thickness of Asphalt Surfacing	Thickness Adjustment Factor
20 – 100 mm	= -(1/260) * thickness + (11.4/13)

Figure C.4 Thickness Adjustment Factor for Hot-Mix Asphalt Surfacing Layers



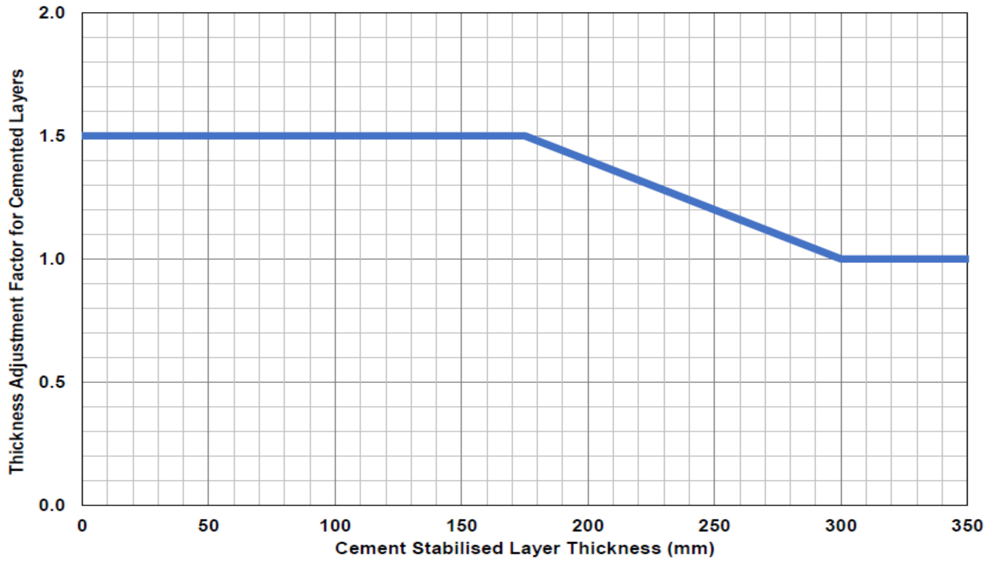
Thickness of Asphalt Base Layer	Thickness Adjustment Factor
20 – 75 mm	0.6
75 – 200 mm	= -0.0024 * thickness + 0.78

Figure C.5 Thickness Adjustment Factor for Hot Mix Asphalt Base Layers



Thickness of BSM Layer	Thickness Adjustment Factor
20 – 175 mm	1.0
175 – 300 mm	= - (0.0016 * thickness) + 1.28

Figure C.6 Thickness Adjustment Factor for BSM Layers



Thickness of Cement Stabilised Layer	Thickness Adjustment Factor
< 175 mm	1.5
175 – 300 mm	= - 0.004 * thickness + 2.2
300 – 350 mm	1.0

Figure C.7 Thickness Adjustment Factor for Cement Stabilised Layers

Table C.5 Default Stiffness Values per Paving Material according to South African Standard

Class	Description	Key properties	Modular ratio	Max modulus	
				PN	ME **
AC	HMA surfacing	All seals	4	2000	3000
S1	Surfacing seal	Thickness <75mm	2	1000	N/A
G1	Graded crushed stone	Grading / ACV	3	600	300 – 900
G2	Graded crushed stone	Grading / ACV	2	450	250 – 800
G3	Graded crushed stone	CBR > 100 (100%)	1.8	400	200 – 750
G4	Gravel	CBR > 80 (@98%)	1.8	375	100 – 600
G5	Gravel	CBR > 45 (@95%)	1.8	350	50 – 400
G6	Gravel	CBR > 25 (@95%)	1.8	250	30 – 250
G7	Soil	CBR > 15 (@93%)	1.7	140	20 – 200
G8	Soil	CBR > 10 (@93%)	1.6	100	20 – 180
G9	Soil	CBR > 7 (@93%)	1,4	90	20 – 140
G10	Soil	CBR > 3 (@93%)	1.2	70	20 – 90
C3	Cement stabilised	1.5 < UCS < 3.0	4	500	2000 – 3000
EG4	Previously C3	G5+ treated	4	400	300 – 600
C4	Cement stabilised	0.75 < UCS < 1.5	3	400	1500 – 2500
EG5	Previously C4	G6+ treated	2	300	200 – 400
BSM-1 RA	RA > 75%	C >250 / ϕ >40°	3	700	900 – 1500
BSM-1	RA < 75%	C >250 / ϕ >40°			
BSM-2	RA < 50%	C >225 / ϕ >35	2.5	600	750 – 900

** Modulus influenced by climate and support conditions (i.e. natural material or stabilised)