Project Level Australian Methodology for Flexible Pavement Design

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Summary

This paper shows the principal aspects of the Australian Methodology for Flexible Pavement Design and Evaluation using principles from The Austroads *"Guide To Pavement Technology".* This guide was developed for Australia and New Zealand in order to standardize a procedure for pavement design and evaluation, considering national and international pavement experience.

The 2009 series of the Guide to Pavement Technology has been modified significantly from the previous 1992 guide. The latest series provides improvements to the methodology for pavement design and evaluation, not only for flexible pavements, but also for rigid based on continued research in Australia. This methodology considers a Mechanistic-Empirical analysis for pavement design, taking into account the fundamental material characteristics that comprise a pavement and their associated failure mechanisms.

The principal objective of this document is to show the new Austroads methodology for flexible pavement design and provide a comparison against the previous guide. In addition, this paper will show the additional material characteristic and design considerations, which have been incorporated in a modified approach by the technical team of Fugro-PMS based on research in the US and overseas aimed at improving the design process further.

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Project Level Australian Methodology for Flexible Pavement Design

1. Introduction

The Austroads *"Guide To Pavement Technology"*, was developed for Australia and New Zealand in order to standardise a procedure for pavement design and evaluation, considering national and international pavement experience. The 2009 series of the Guide to Pavement Technology reflects significant revisions made to the Guide for the design of flexible pavements in the 2004 and 2008 series. The Guide, initially published in 1987 by the National Association of Australian State Road Authorities (NAASRA) was subsequently re-issued by Austroads in 1992. The latest series considers a mechanistic-empirical analysis for pavement design, taking into account the fundamental material characteristics that comprise a pavement and their associated failure mechanisms.

"Mechanistic" refers to the application of the principles of engineering mechanics, which lead to a rational design process. This rational design process most take into consideration the theory used to predict the assumed failure or distresses parameter, the evaluation of the materials properties and the evaluation of these properties considering the level of performance of the pavement.

It is generally accepted that mechanistic theory involves three properties of the material behavior response. They are, the relationship between stress and strain (linear or non linear), the time dependency of the strain under a constant stress level (viscous or not viscous), and the degree to which the material can rebound or recover strain after stress removal (plastic or elastic).

These properties of the materials are strongly related to the level of traffic (Equivalent Standard Axle –ESA's-) and the environmental conditions (air temperature and level of moisture). Even though there have been substantial advances in mechanistic pavement design considering all the above variables, it is necessary for some simplification in order to undertake the design process.

The Austroads *"Guide To Pavement Technology"*, in its latest version has improved considerably on their previous procedures in order to achieve a method that takes into consideration the mechanical properties of the materials such as modulus, seasonal stress dependency and failure mechanisms, among others. In addition, the guide considers different failure mechanisms considering materials like, asphalt, cemented materials and unbound base/subbase or subgrade. These failure mechanisms are evaluated based on the stress and strain that a dual-wheeled single axle loaded with 80 kN will produce within the pavement.

The mechanistic-empirical design approach included in the guide, takes into account the asphalt pavement temperature as well as the level of moisture that affects unbound granular materials, these parameters are considered for three specific types of damage: a) fatigue of asphalt; b) rutting and permanent loss of surface shape, and c) fatigue of cemented materials.

Consideration for pavement design and evaluation can be applied at both network and project levels, however most of the mechanistic principles described above apply mainly to project level investigations. Under such circumstances, it is possible to undertake a detailed survey, which can provide material properties such as: dynamic modulus of the asphalt, resilient modulus of the unbound granular materials, stress and strain within the pavement structure, and the environmental conditions in a particular area, among others. Many agencies start with a network level survey considering general parameters like: level of traffic, roughness, deflections, soil capacity, etc., which allow them to detect specific deficiencies in a particular road or section. At this stage, a decision tree recognizes a project level investigation and a mechanistic analysis can be undertaken to address the pavement deficiencies. This paper contains a description of the mechanistic-empirical design procedure for a project level investigation included in the Austroads guide with some modifications based on.

It is important to point out that, the guide considers pavement design procedures for both flexible and rigid pavements. However, those pavements respond to load in such different ways that there are fundamental differences in the analysis theories applied. Considering that the scope of this paper is focused on flexible pavement, the methodology described in the following chapters is entirely focused on a flexible pavement design comprising of at least one asphalt layer.

2. AUSTROADS Mechanistic-Empirical Pavement Design Procedure

The Austrorads Guide provides two separate and distinct design procedures as follows: a) purely empirical design applicable to new flexible pavements consisting of a thin bituminous surfacing (sprayed seal or asphalt less than 40 mm thick) over granular material; b) mechanistic-empirical design applicable to new flexible pavements which contain one or more layers of bound material (asphalt or cemented material).

This investigation is focused on the mechanistic-empirical design for new flexible pavements that contain one or more bound materials.

2.1. Mechanistic-Empirical Pavement Design

The Austroads Mechanistic-Empirical procedure is based on the structural analysis of a multi-layered pavement, subject to normal road traffic loading. The pavement response model now considers a full standard axle in calculating the critical strains rather than a half axle as was the case in the previous Guides. This allows for the effect of the second set of tyres to be considered when modeling the critical strains, previously this second set of tyres was deemed to be insignificant and was not considered in the model. Substantial increases in traffic volumes and loads have meant that pavements are now being designed and constructed thicker and with materials of a higher stiffness than before, for example full depth asphalt pavements. The tyre pressures used in the standard model increased from 550kPa in 1992 to 750kPa in 1997 to reflect the higher tyre pressures of radial tyres. The critical locations of the strains within the pavement model and the idealised loading situation are shown in Figure 1, following.

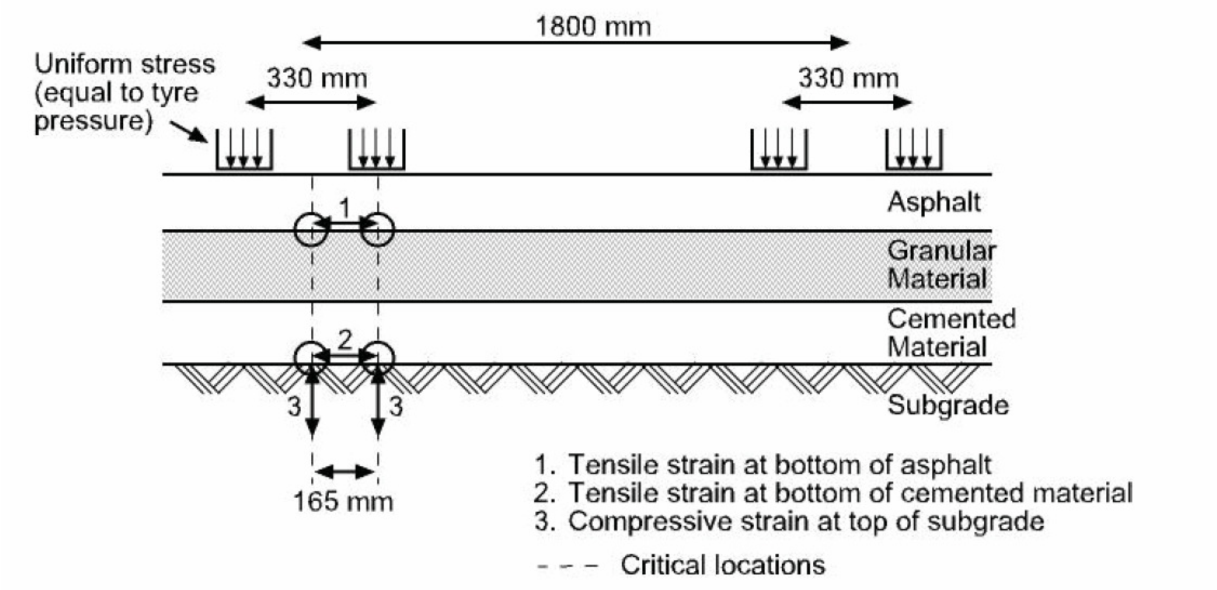


Figure 1 Pavement Response Model [2]

Significant features of the assumed model are as follows:

a. Pavement materials are considered to be homogeneous, elastic and isotropic (except for unbound granular materials and subgrade which are considered to be anisotropic.

b. Response to load is calculated using the linear elastic model.

c. The critical responses assessed for pavement and subgrade materials are:

   - Asphalt: horizontal tensile strain at the bottom of the layer.
   - Unbound granular: not considered in the model.
   - Cemented: horizontal tensile strain al the bottom of the layer.
   - Subgrade and selected subgrade material: vertical compressive strain at the top of the layer.

d. Standard Axle loading consists of a dual-wheeled single axle, applying a load of 80 kN. For flexible pavements, the critical responses within the pavement occur either along the vertical axis directly below the inner-most wheel of the dual wheel group or along the vertical axis located symmetrically between the pair of dual wheels.

e. Standard Axle loading is represented by four uniformly-loaded circular areas of equal area separated by centre-to-centre distances of 330mm, 1470mm, and 330mm respectively.

f. The contact stress is assumed to be uniform over the loaded area and, for the purpose of design, is taken to be 750 kPa. The contact stress is related to the tyre pressure which for highway traffic is assumed to be in the range of 500 to 1000 kPa.

In summary the procedure consists of:

- Evaluating the input parameters (materials, traffic, environment, etc.).
- Selecting a trial pavement.
- Analysing the trial pavement to determine the allowable traffic.
- Comparing the allowable traffic with the design traffic.
- Finally, accepting or rejecting the trial pavement.

In this procedure the design traffic plays a very important role in the mechanistic pavement design. Changes to the procedure for calculating the design traffic represents the most significant revision to the previous 1992 Guide. Following is a discussion about how the design traffic is considered in the mechanistic pavement design process.

3. Design Traffic for Flexible Pavement

The first requirement when undertaking a pavement design is to ensure the pavement will be adequate for the cumulative traffic loading anticipated in the design lane over the design period. Estimation of this loading firstly requires the calculation of the cumulative number of heavy vehicle axle groups (HVAG) over the design period. In the 1992 Guide limited load axle data was available and the presumptive SAR/ESA was adopted as 1.1 for asphalt fatigue and subgrade deformation and 20 for fatigue of cemented materials. Austroads have subsequently made the traffic calculations more consistent by including the number of HVAGs, including a procedure to estimate the damage per axle group, which multiplied by the HVAG, gives the total damage accumulated in the period of design, in other words, the standard axle repetitions (SAR) for design. It is important to note that this calculation requires the Traffic Load Distribution (TLD) for the project. TLDs may be determined by either Weigh in Motion (WIM) data or presumptive TLDs establishing for both Rural and Urban roads. This data in the case of presumptive TLDs is used in conjunction with vehicle classification traffic count data to determine the design SARs.

The general equation to derive the Design Traffic (N_{DT}), in cumulative heavy vehicle axle groups (HVAG), in the design lane during the specified period (N_{DT}) is:

$$N_{DT} = AADT \times \%HV/100 \times DF \times LDF \times 365 \times CGF \times N_{HVAG} \quad \text{(General equation)}$$

<u>Where:</u>

N_{DT}: Cumulative heavy vehicle axle groups (HVAG), in the design lane during the design period.

AADT: Annual Average Daily Traffic in vehicles per day in the first year.

%HV: Average percentage of heavy vehicles.

DF: Direction Factor is the proportion of the two-way AADT traveling in the direction of the design traffic.

LDF: Lane Distribution Factor, proportion of heavy vehicles in the design lane.

CGF: Cumulative Growth Factor.

N_{HVAG}: Average Number of Axle Groups per heavy vehicle.

There are some aspects to consider in the last equation:

a. AADT and %HV, must be considered in the intended date of opening of the road. It means that the traffic count must be actualized up to this date. In addition, those values together provide us the number of heavy vehicles in the intended date of opening.

b. DF and LDF, are factors to consider the number of heavy vehicles in the design lane, which in general is the most heavily trafficked lane.

c. Cumulative Growth Factor considers the repetitive standard load accumulated in the period of design. Following is the expression for the CGF.

$$CGF = ((1+GR)^n - 1) / GR)$$

Where:

GR: Traffic Growth Rate in the period of design.

n: Period of year for the Pavement Design.

In conclusion, the Design Traffic (N_{DT}) in the last equation represents the number of axles accumulated in the design lane during the period of pavement design. However, it does not consider the damage that the different axle groups with different loads cause to the pavement.

In the empirical design of granular pavements with thin bituminous surfacing, only one type of damage is considered, namely the overall damage of the pavement, reflecting increased levels of roughness and rutting. However, for pavements containing one or more bound layers up to three distinct types of damage are considered:

- Fatigue damage to asphalt.
- Rutting and permanent loss of surface shape.
- Fatigue damage to cemented material.

Design traffic loading in the 1992 Design Guide was described in terms of the number of Equivalent Standard Axles (ESA) and was assessed by means of the 4^{th} power law (exponent 4) for unbound materials, exponent 5 for asphalt, exponent 7.14 for subgrade and exponent 18 for cemented materials, later revised to 12 in 1997. In order to consider the damage produced by different axles groups with varying loads, a standard axle group load must be considered such that it causes the same damage as a standard axle, that being single axle with dual tyres carrying 80kN.

3.1. Design Traffic Standard Axle Repetitions

The loads carried on each axle group configuration that will cause the same damage as that of a standard axle are shown in Table 1 following.

Table 1 Standard Axle Loads

Axle group type	Load (kN)
Single axle with single tyres (SAST)	53
Single axle with dual tyres (SADT)	80
Tandem axle with single tyres (TADT)	90
Tandem axle with dual tyres (TADT)	135
Triaxle with dual tyres (TRDT)	181
Quad-axle with dual tyres (QADT)	221

The SAR of damage is determined proportionately for each load state within the TLD by dividing the load on each axle group but the axle group's standard load as follows:

$$SAR_{mij}=(L_{ij}/SL_i)^m$$

Where:

SAR_{mij}:	number of Standard Axle Repetitions (or passages of Standard Axle) which causes the same amount of damage as a single passage of axle group type "i" with load L_{ij} where the load damage exponent is "m".
SL_i:	Standard Load for axle group type "i" (see Table 1).
L_{ij}:	j^{th} load magnitude on the axle group type "i".
m:	load damage exponent for the damage type.

Considering a mechanistic pavement design, the Standard Axle Repetitions (SAR) are calculated for three values of the exponent "m". The load damage exponents used are derived from the fatigue relationships and the subgrade strain criterion of these materials

a) Exponent 5 – Fatigue of Asphalt;

b) Exponent 7 – Permanent Deformation or shape Loss

c) Exponent 12 – Fatigue of Cemented Materials

The design traffic requirement for flexible pavement design is, for each relevant damage type, the total number of Standard Axle Repetitions (SAR) during the design period which causes the same damage as the cumulative traffic.

To sum up, the SAR for the three types of damage considered in the mechanistic pavement design are calculated as follows:

a. Fatigue of Asphalt: $SAR5 = N_{DT} \times (L_{ij}/SL_i)^5$
b. Rutting and permanent loss of surface shape: $SAR7 = N_{DT} \times (L_{ij}/SL_i)^7$
c. Fatigue of Cemented Materials: $SAR12 = N_{DT} \times (L_{ij}/SL_i)^{12}$

The Austroads Guide includes TLDs for each of the different axle groups for both urban and rural roads which can be used if the WIM data is not available. In addition, the guide provides presumptive values for SAR5; SAR7 and SAR12, which are considered the same for urban and rural roads. In the case of asphalt fatigue these presumptive values have remained the same as those of the 1992 Guide at 1.1, but for rutting and shape loss they are instead now 1.6 and 12 for fatigue of cemented materials.

Once the design traffic is calculated in terms of SAR for the different types of damage, the candidate pavement is analysed to determine the allowable number of Standard Axle Repetitions (SAR) for the same damage types. These allowable SARs need to be equal to or exceed the design Standard Axle Repetitions (SAR) for the design to be considered adequate.

In order to determine the allowable number of SAR for the candidate pavement, three types of relationships must be addressed to control fatigue at the bottom of asphalt and cemented materials and permanent deformation at the top of the subgrade. Following is a description of these relationships.

4. Limiting Strain Criterion for Allowable Traffic

As we discussed in chapter 2, the mechanistic-empirical design considers three types of damage: a) fatigue of asphalt; b) rutting and loss of surface shape, and c) fatigue of cemented materials.

Each of these failure mechanisms have been considered so as to limit the strain within each material to a tolerable level throughout the life of the pavement. The strains have been limited by calculating the allowable number of SARs at this strain before an unacceptable level of the failure occurs.

Following is a description of each allowable number of SAR considering asphalt fatigue, permanent deformation in granular materials and fatigue of cemented materials.

4.1. Fatigue of Asphalt

The pavement design to prevent fatigue of the asphalt is designed to limited tensile strain at the bottom of the asphalt layer. The asphalt fatigue relationship used in the Austroads Guide is the laboratory fatigue relationship published by Shell (1978) adjusted to predict fatigue life in the pavement using a reliability factor according to the desired project reliability. Reliability factors have been incorporated in the calculation of the allowable SARs so as to allow the design engineer to determine the confidence with which they want the constructed pavement to perform beyond the design traffic.

For conventional bituminous binders used in asphalt placed on moderate-to-heavily trafficked pavements, the general relationship between the maximum tensile strain in asphalt produced by a specific load and the allowable number of repetitions of that load is:

$$N = \mathrm{RL}\left\{\frac{6918 \times (0.856 \times Vb + 1.08)}{S_{mix}^{0.36} \times \mu\varepsilon}\right\}^5$$

<u>Where:</u>

N: Allowable number of repetitions of the load (SAR).
$\mu\varepsilon$: Tensile strain produced by the load (in microstrain).
Vb: Percentage by volume of bitumen in the asphalt (%).
S_{mix}: Mix stiffness or modulus (MPa).
RL: Reliability factor for asphalt fatigue (see Table 2).

This equation is for standard asphalt mixes. For non standard mixes, i.e. Polymer Modified Binders, fatigue relationships should be obtained from the suppliers.

Table 2 Asphalt Fatigue Project Reliability Factors

Desired Project Reliability				
80%	85%	90%	95%	97.5%
2.5	2.0	1.5	1.0	0.67

4.1.2 Design Asphalt Modulus (S_{mix})

Typical asphalt is comprised of a mixture of bituminous binder and several, typically, single-sized aggregate fractions which are placed and compacted while hot, to form a pavement layer. Considering this mix between bituminous binder and aggregate, the asphalt has viscoelastic properties at normal operating temperatures and rates and magnitudes of loading which are applicable to a road pavement. Hence, the stiffness or modulus depends on both the temperature and loading rate (traffic speed).

The most important factor in determining the modulus of asphalt is the temperature. The modulus of the asphalt can vary significantly depending on the range of temperature applicable to the pavement. It means that at a low temperature the modulus of the asphalt is high and at high temperatures the modulus is low for a constant frequency of the load.

The other factor to consider for a modulus of the asphalt is the rate of loading, which in the field is related to the traffic speed, i.e the slower the rate of loading, the lower the modulus of the asphalt. This effect can vary significant, especially in pavement areas such as intersections and approaches, bus stops and parking areas. When determining the modulus for a given traffic speed, the loading time used will depend on the type of testing device and the shape of the load pulse as well the depth below the pavement surface at which the modulus is being sought.

The design asphalt modulus can be obtained from the following sources:

a) The resilient modulus measured directly from an asphalt sample using laboratory tests considering both the in-service temperature and the rate of loading. These laboratory tests include; The Standard Indirect Tensile Test (ITT) and Dynamic Modulus using a Universal Testing Machine (UTM).

b) Estimation from the bitumen properties and mix volumetrics by use of the Shell nomographs and the in-service temperature and rate of loading.

4.2. Subgrade Permanent Deformation

The subgrade permanent deformation is considered in the mechanistic-empirical design by limiting the vertical compressive strain at the top of the subgrade to a tolerable level throughout the life of the pavement. The strain induced is not fully recoverable and after many load applications, permanent deformation accumulates at the subgrade level, and also throughout all pavement layers. These permanent deformations typically manifest as rutting in the wheel paths.

The number of cycles to failure until an unacceptable level of permanent deformation of the subgrade is computed by the following equation, noting that Reliability Factors have not been incorporated as the relationship is expected to provide suitable reliability for SARs up to $1x10^8$.

$$N = \left(\frac{9{,}300}{\mu\varepsilon} \right)^7$$

Where:
N: Allowable number of repetitions of a Standard Axle at this strain before an unacceptable level of performance develops.

$\mu\varepsilon$: Vertical strain at the top of the subgrade (microstrain).

It is important to consider that the modulus of unbound materials is strongly influenced by the level of stress (vertical strain), which at the same time will limit the allowable number of repetitions. In other words, considering the stress dependency of the unbound materials, like a natural subgrade, it will carry a higher number of Standard Axle Repetitions if it has a high resilient modulus, which means high stiffness in the presence of a traffic load.

4.3. Cemented Material Fatigue

The Austroads Guide uses the following fatigue equation originally adopted by Queensland Main Roads as the stabilised pavement fatigue equation. Reliability factors have again been incorporated in the calculation of the allowable SARs.

$$N = RF\left[\frac{\left({113000}/{E^{0.804}} + 191\right)}{\mu\varepsilon}\right]^{12}$$

Where:

N: Allowable number of repetitions of the load.
$\mu\varepsilon$: Tensile strain produced by the load (microstrain).
E: Cemented material modulus (MPa).
RF: Reliability factor for cemented materials fatigue (see Table 3)

Table 3 Cemented Materials Project Reliability Factor

Desired Project Reliability				
80%	85%	90%	95%	97.5%
4.7	3.3	2.0	1.0	0.5

This fatigue criterion is valid for cemented materials with moduli within the range of 2000MPa to 10000 MPa.

5. Modified Mechanistic-Empirical Pavement Design Procedure

A modified mechanistic-empirical pavement design procedure based on that already discussed for the Austroads Guide 2009 but incorporating additional fundamental material characteristics, considering research in the US and overseas have been incorporated aimed at enhancing the design process further.

Following are some of the additional aspects that are considered in the modified Mechanistic-Empirical Pavement Design procedure:

a) Environmental factors impacting the stiffness of materials throughout the year which is highlighted in the Austroads Guide, namely temperature and rainfall are considered for multiple seasons across the year

b) Each design considers six seasons throughout the year incorporating the minimum and maximum air temperature and mean monthly rainfall at the project site, determined from Bureau of Meteorological (BOM) weather station data located nearest to the site.

c) Consideration for the distribution of SARs across the six seasons of the year to account for seasonal variations in traffic that may correspond with critical seasons of high rainfall or temperature.

d) Determination of the asphalt modulus in each period taking into consideration the thickness and temperature of each asphalt layer and location within the pavement structure.

e) Pavement surface temperature throughout the year is based on BOM data and the US Asphalt Institute relationship published in the Superpave Series No. 1 (SP-1), considering the latitude location of the project site.

f) Predicted asphalt pavement temperature at the depth coinciding with the mid point of each layer is determined based on the BELLS equations.

g) Modulus of new asphalt materials are based on asphalt bitumen properties and mix volumetrics using the SHELL nomographs, temperatures and loading frequency for each of the six seasons throughout the year.

h) Determination of non-standard unbound and modified material modulus values from internally developed relationships based on more than 10 years of structural and geotechnical data.

i) Sub-layering of unbound granular materials using either the Austroads or US Army Corp of Engineers (USACE) standard methods.

j) Configuration of non-standard tyre loads and spacings to accommodate specialised vehicle configurations.

5.1. Seasonal Traffic and Environmental Details

As previously discussed, the temperature of asphalt not only at the surface, but also within the pavement structure, will affect the stiffness or modulus of this material. Alternately the moisture conditions (rainfall) can affect the stiffness of granular and unbound materials. The design process for a new or rehabilitated pavement often only considers one season within the year representing the critical moisture condition of unbound materials or the Weighted Mean Annual Pavement Temperature (WMAPT) in predicting the average asphalt modulus throughout the year. This may be sufficient for thick

Taking into account these aspects, monthly maximum and minimum temperature of air, instead of WMAPT, have been considered and six different seasons within the year included for analysis. By calculating the seasonal surface asphalt temperature, the temperature at any depth and asphalt modulus for any load frequency can be predicted. The same has been considered and a seasonal granular reduction factor is determined based on monthly mean rainfall and temperature conditions to account for subsurface moisture conditions.

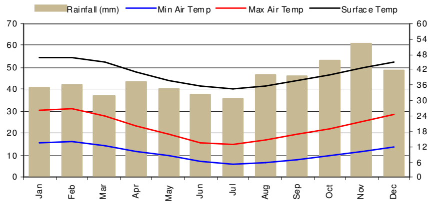
Asphalt having visco-elastic properties will vary in stiffness significantly between summer and winter, being more susceptible to fatigue in the winter months when at its stiffest. Conversely in summer when the stiffness is lowest the load carrying capacity of the pavement is diminished, however this may be offset somewhat by a stiffer unbound granular support which may occur in dryer months. The affect that these changes in environmental conditions have can be profound and are often overlooked when only considering the worst or average case when designing a pavement.

The impact that the range of material stiffness throughout the year can have may be further compounded by substantial seasonal fluctuations in traffic load which may be greatest in the hottest or wettest months of the year, further complicating the analysis. Being able to distribute the SARs for each damage mode across the same six seasons enables seasonal damage factors for each design to be determined. This ensures that the impact of fluctuations in seasonal traffic are assessed against the material properties in that season.

Figure 2 following illustrates the six seasons of the year for pavement analysis along with the seasonal traffic and environmental details.

Seasonal Traffic / Environmental Details

Site: Melbourne Airport 086282
Latitude: 37.67 ºSouth



Traffic (SARs)	Jan	Mar	May	Jul	Sep	Nov
Distribution	25.0%	10.0%	10.0%	25.0%	5.0%	25.0%
Fatigue of Asphalt	6.90E+05	2.76E+05	2.76E+05	6.90E+05	1.38E+05	6.90E+05
Rutting & Shape Loss	1.04E+06	4.14E+05	4.14E+05	1.04E+06	2.07E+05	1.04E+06
Fatigue of Cemented Materials	8.85E+06	3.54E+06	3.54E+06	8.85E+06	1.77E+06	8.85E+06

Environment	Jan	Mar	May	Jul	Sep	Nov
Rainfall (mm)	41.7	40.6	38.9	41.4	49.7	54.8
Min. Air Temp (°C)	13.9	11.4	7.3	5.6	7.7	11.2
Max. Air Temp (°C)	26.4	22.2	15.1	13.7	17.9	23.2
Surface Temperature (°C)	31.1	27.1	20.3	19.0	23.0	28.0
Granular Reduction Factor	0.92	0.98	1	0.96	0.88	0.83

Figure 2 Seasonal Traffic and Environmental Conditions

5.2. Damage in the Design Pavement Structure

Finally, a damage factor in each season is calculated, considering the relationship between the allowable traffic loading and the design traffic loading, if the allowable traffic loading exceeds the design traffic loading the trial pavement is structurally adequate. Otherwise, another trial pavement structure must be modeled.

Figure 3 following show a seasonal damage factor considering the three possible principal damages including the allowable SAR's and remaining life in terms of years. In this particular example the structure has been accepted with 1% of damage for permanent deformation and 90% of damage for asphalt fatigue.

Damage Permanent Deformation		**Reliability Factor**			**Damage Factor (%)**				
	Layer 4	1	1%	0%	0%	0%	0%	0%	5.8
								1%	**Accepted**
								3.43.E+08	**SAR's**
								20	**Years**
Damage Asphalt Fatigue		**Reliability Factor**			**Damage Factor (%)**				
	Layer 2	1.5	37%	8%	3%	8%	3%	30%	6.5.6
								90%	**Accepted**
								3.08.E+06	**SAR's**
								20	**Years**
Damage Cemented Materials Fatigue		**Reliability Factor**			**Damage Factor (%)**				
									N/A
								N/A	**SAR's**
								N/A	**Years**

Figure 3 Seasonal Damage Factor

5.3. Illustrative Comparison

To illustrate the potential optimisation of the design process that might be achieved by considering six seasons the modified procedure was compared with the Austroads procedure only considering one season for material stiffness. Both designs utilise the same inputs including traffic fluctuations throughout the year with the modified procedure considering the effect of moisture and temperature fluctuations affecting the stiffness of the asphalt and unbound granular materials. Figure 4 following provides an example of the Modified Austroads Design procedure considering all of the aspects discussed proceeding and Figure 5 shows the comparative Austroads Design procedure considering only one season for material stiffness.

As can be seen from the two design outputs, the damage factors vary across the six seasons; in the case of the Austroads Design the results would have otherwise been the same if not for the seasonal fluctuations in the traffic loading. On the other hand, the Modified Design procedure which estimates the seasonal asphalt and granular modulus, results in a 13mm saving in asphalt, noting that the thickness has been optimised to achieve as close as possible the same overall damage factor for asphalt fatigue. Whilst this example, results is an overall saving in pavement materials and cost of construction it may otherwise result in a thicker pavement under different environmental and loading conditions, despite this the confidence in the design output would be higher.

FUGRO PMS — Austroads Guide to Pavement Technology[1]

Mechanistic Design Report

Unit 7b 26 Powers Rd
Seven Hills, NSW, 2147

Report Date:	1-Aug-11	**Prepared By:**	Urbaez/Erskine
Project No.:	2011095	**Growth Rate:**	5%
Report No:	2011-01	**Design Period:**	20
Analysis Method:	PMS-QP4-002	**Project Reliability:**	90.0%
Location:	Example Road	**Treatment Description:**	Fugro PMS

Client: AAPA

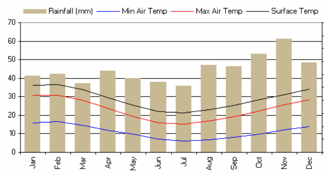
Loading

Total Gear Load:	8.00E+07	N
Tyre Pressure:	750	kPa
Gear Name:	Standard Axle	
No. Tyres:	4	
No. Repetitions:	2.76E+06	SAR5 (Fatigue of Asphalt)
	4.14E+06	SAR7 (Rutting & Shape Loss)
	3.54E+07	SAR12 (Fatigue of Cemented Materials)

Tyre Spacing: Tyre No	X	Y	Evaluation Points: Tyre No	X	Y
1	-165	0	1	0	0
2	165	0	2	165	0
3	1635	0	3	1635	0
4	1965	0	4	1800	0

Seasonal Traffic / Environmental Details

Site: Melbourne Airport 086282
Latitude: 37.67 °South



Traffic (SARs)	Jan	Mar	May	Jul	Sep	Nov
Distribution	20.0%	20.0%	15.0%	15.0%	20.0%	10.0%
Fatigue of Asphalt	5.52E+05	5.52E+05	4.14E+05	4.14E+05	5.52E+05	2.76E+05
Rutting & Shape Loss	8.28E+05	8.28E+05	6.21E+05	6.21E+05	8.28E+05	4.14E+05
Fatigue of Cemented Materials	7.08E+06	7.08E+06	5.31E+06	5.31E+06	7.08E+06	3.54E+06

Environment	Jan	Mar	May	Jul	Sep	Nov
Rainfall (mm)	41.7	40.6	38.9	41.4	49.7	54.8
Min. Air Temp (°C)	13.9	11.4	7.3	5.6	7.7	11.2
Max. Air Temp (°C)	26.4	22.2	15.1	13.7	17.9	23.2
Surface Temperature (°C)	31.1	27.1	20.3	19.0	23.0	28.0
Granular Reduction Factor	0.99	0.95	0.85	0.81	0.92	0.95

Pavement Materials

	Material	Description	Thickness (mm)	Modulus Calculation Method		Constants			
Layer 1	Asphalt	DG14	40	PMS-QF4-003					
Layer 2	Asphalt	DG20	50	PMS-QF4-003					
Layer 3	Granular(Sub Layered)	Crushed Gravel	150	Power	Austroads Gravel	k1	2.2973967	k2	1
Layer 4	Granular(Sub Layered)	Subbase Select	125	Power	Austroads Select	k1	1.7817974	k2	1
Layer 5	Granular(Sub Layered)	Subbase Select	125	Power	Austroads Select	k1	1.7817974	k2	1
Layer 6	Granular(Sub Layered)	Subbase Select	125	Power	Austroads Select	k1	1.7817974	k2	1
Layer 7	Subgrade	Silty Clay	0	Rainfall Adjustment		Dry Mod.*	37		

* Modulus or UCS in MPa

Pavement Structure

	AC	Cement	Deform	Degree of Anisotropy	Poisson's Ratio	Jan	Mar	May	Jul	Sep	Nov
						Modulus (MPa)					
Layer 1	☑	☐		1	0.40	1737	2600	4585	5075	3740	2384
Layer 2	☑	☐	☐	1	0.40	2566	3751	6378	7071	5340	3492
Layer 3	☐	☐	☐	2	0.35	476	457	409	389	442	457
Layer 4	☐	☐	☐	2	0.35	207	199	178	170	193	199
Layer 5	☐	☐	☐	2	0.35	116	112	100	95	108	112
Layer 6	☐	☐	☐	2	0.35	65	63	56	53	61	63
Layer 7	☐	☐	☑	2	0.45	37	35	31	30	34	35

Calculate

Vertical Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Top	Layer 2	40	113	61	22	17	33	69
Top	Layer 3	90	626	554	462	450	483	572
Top	Layer 4	240	436	418	404	410	395	425
Top	Layer 5	365	422	417	420	428	406	421
Top	Layer 6	490	438	434	444	455	426	438
Top	Layer 7	615	435	433	448	461	428	437

Horizontal Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Bottom	Layer 1	40	-41	-41	-36	-36	-38	-43
Bottom	Layer 2	90	220	204	179	176	184	209
Bottom	Layer 3	240	257	253	248	251	243	256
Bottom	Layer 4	365	254	252	254	259	246	254
Bottom	Layer 5	490	246	245	252	258	241	247
Bottom	Layer 6	615	233	232	241	248	230	234

Damage Permanent Deformation

	Reliability Factor	Damage Factor (%)						
Layer 7	1	0%	0%	0%	0%	0%	0%	5.8
							0%	Accepted
							1.88.E+09	SAR's
							20	Years

Damage Asphalt Fatigue

	Reliability Factor	Damage Factor (%)						
Layer 1	1.5	0%	0%	0%	0%	0%	0%	6.5.6
Layer 2	1.5	13%	17%	17%	19%	19%	8%	6.5.6
							94%	Accepted
							2.93.E+06	SAR's
							20	Years

Damage Cemented Materials Fatigue

	Reliability Factor	Damage Factor (%)	
			N/A
		N/A	SAR's
		N/A	Years

Figure 4 Modified Austroads Design Procedure

FUGRO PMS — Austroads Guide to Pavement Technology[1]

Mechanistic Design Report

Unit 7b 26 Powers Rd
Seven Hills, NSW, 2147

Report Date: 1-Aug-11	**Client:** AAPA	**Prepared By:** Urbaez/Erskine	
Project No.: 2011095		**Growth Rate:** 5%	
Report No: 2011-01		**Design Period:** 20	
Analysis Method: PMS-QP4-002		**Project Reliability:** 90.0%	
Location: Example Road		**Treatment Description:** Austroads	

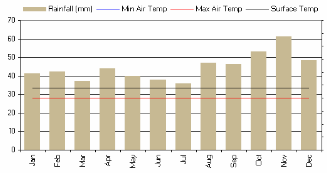
Loading

Total Gear Load: 8.00E+07 N
Tyre Pressure: 750 kPa
Gear Name: Standard Axle
No. Tyres: 4
No. Repetitions: 2.76E+06 SAR5 (Fatigue of Asphalt)
4.14E+06 SAR7 (Rutting & Shape Loss)
3.54E+07 SAR12 (Fatigue of Cemented Materials)

Tyre Spacing: Tyre No	X	Y	Evaluation Points: Tyre No	X	Y
1	-165	0	1	0	0
2	165	0	2	165	0
3	1635	0	3	1635	0
4	1965	0	4	1800	0

Seasonal Traffic / Environmental Details

Site: Melbourne Airport 086282
Latitude: 37.67 °South



Traffic (SARs)	Jan	Mar	May	Jul	Sep	Nov
Distribution	20.0%	20.0%	15.0%	15.0%	20.0%	10.0%
Fatigue of Asphalt	5.52E+05	5.52E+05	4.14E+05	4.14E+05	5.52E+05	2.76E+05
Rutting & Shape Loss	8.28E+05	8.28E+05	6.21E+05	6.21E+05	8.28E+05	4.14E+05
Fatigue of Cemented Materials	7.08E+06	7.08E+06	5.31E+06	5.31E+06	7.08E+06	3.54E+06

Environment	Jan	Mar	May	Jul	Sep	Nov
Rainfall (mm)	41.7	40.6	38.9	41.4	49.7	54.8
Min. Air Temp (°C)	24.0	24.0	24.0	24.0	24.0	24.0
Max. Air Temp (°C)	24.0	24.0	24.0	24.0	24.0	24.0
Surface Temperature (°C)	24.0	24.0	24.0	24.0	24.0	24.0
Granular Reduction Factor	1.00	1.00	1.00	1.00	1.00	1.00

Pavement Materials

	Material	Description	Thickness (mm)	Modulus Calculation Method		Constants			
Layer 1	Asphalt	DG14	40	PMS-QF4-003					
Layer 2	Asphalt	DG20	63	PMS-QF4-003					
Layer 3	Granular(Sub Layered)	Crushed Gravel	150	Power	Austroads Gravel	k1	2.2973967	k2	1
Layer 4	Granular(Sub Layered)	Subbase Select	125	Power	Austroads Select	k1	1.7817974	k2	1
Layer 5	Granular(Sub Layered)	Subbase Select	125	Power	Austroads Select	k1	1.7817974	k2	1
Layer 6	Granular(Sub Layered)	Subbase Select	125	Power	Austroads Select	k1	1.7817974	k2	1
Layer 7	Subgrade	Silty Clay	0	Rainfall Adjustment		Dry Mod.*	30		

* Modulus or UCS in MPa

Pavement Structure

	AC	Cement	Deform	Degree of Anisotropy	Poisson's Ratio	Jan	Mar	May	Jul	Sep	Nov
						Modulus (MPa)					
Layer 1	☑	☐		1	0.40	2611	2611	2611	2611	2611	2611
Layer 2	☑	☐	☐	1	0.40	3270	3270	3270	3270	3270	3270
Layer 3	☐	☐	☐	2	0.35	390	390	390	390	390	390
Layer 4	☐	☐	☐	2	0.35	170	170	170	170	170	170
Layer 5	☐	☐	☐	2	0.35	95	95	95	95	95	95
Layer 6	☐	☐	☐	2	0.35	53	53	53	53	53	53
Layer 7	☐	☐	☑	2	0.45	30	30	30	30	30	30

Calculate

Vertical Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Top	Layer 2	40	78	78	78	78	78	78
Top	Layer 3	103	540	540	540	540	540	540
Top	Layer 4	253	429	429	429	429	429	429
Top	Layer 5	378	442	442	442	442	442	442
Top	Layer 6	503	466	466	466	466	466	466
Top	Layer 7	628	469	469	469	469	469	469

Horizontal Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Bottom	Layer 1	40	-42	-42	-42	-42	-42	-42
Bottom	Layer 2	103	219	219	219	219	219	219
Bottom	Layer 3	253	266	266	266	266	266	266
Bottom	Layer 4	378	268	268	268	268	268	268
Bottom	Layer 5	503	264	264	264	264	264	264
Bottom	Layer 6	628	252	252	252	252	252	252

Damage Permanent Deformation

	Reliability Factor	Damage Factor (%)						
Layer 7	1	0%	0%	0%	0%	0%	0%	5.8
							0%	Accepted
							1.20.E+09	SAR's
							20	Years

Damage Asphalt Fatigue

	Reliability Factor	Damage Factor (%)						
Layer 1	1.5	0%	0%	0%	0%	0%	0%	6.5.6
Layer 2	1.5	19%	19%	14%	14%	19%	9%	6.5.6
							95%	Accepted
							2.91.E+06	SAR's
							20	Years

Damage Cemented Materials Fatigue

	Reliability Factor	Damage Factor (%)	
			N/A
		N/A	SAR's
		N/A	Years

Figure 5 Austroads Design Procedure

6. Conclusions

In summary, the key enhancements in the current Austroads Guide from that of the 1992 Guide, have been the incorporation of more detailed traffic load distributions for urban and rural roads based on the collection of substantial WIM data. This enables the pavement design engineer to establish the design traffic loading in terms of Standard Axle Repetitions based on the Heavy Vehicle Axle Groups that make up the traffic spectrum at the project site as measured by vehicle classification traffic counts.

With the introduction of radial tyres with higher tyre pressures and heavier vehicle loads, pavements have become thicker and stiffer to carry these higher loads and traffic volumes. This has led to a full single axle with dual tyres being used in the pavement response model as opposed to a half axle so as to model the impact on the critical strains deeper in the pavement.

The latest Guide also incorporates reliability factors into the fatigue relationships for asphalt and cemented materials that enable the pavement designer to determine the confidence with which they want the constructed pavement to perform beyond that of the design traffic.

The Modified Design procedure which estimates the seasonal asphalt and granular modulus, results in a 13mm saving in asphalt, noting that the thickness has been optimised to achieve as close as possible the same overall damage factor for asphalt fatigue. Whilst the example shown in this investigation, results is an overall saving in pavement materials and cost of construction it may otherwise result in a thicker pavement under different environmental and loading conditions, despite this the confidence in the design output would be higher.

7. References

1. Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, NCHRP, TRB and NRC, USA, March 2004.
2. Austroads Guide to Pavement Technology, Australia and New Zealand, 2009.
3. Flexible Pavement Design Procedure, FPMS-QP4-002, Fugro PMS, January 2010.