NACOE
NATIONAL
ASSET CENTRE
OF EXCELLENCE

ANNUAL SUMMARY REPORT

Project Title: P69: Selection and Use of Unbound Granular Pavements with Thin Asphalt Surfacing (2017/18)

ARRB Project No: PRP17041

Author/s: Lory Noya and Joe Coomer

Client: Queensland Department of Transport and Main Roads

Date: December 2020

AN INITIATIVE BY:

arrb Queensland Government

SUMMARY

This is the first year of a project which was aimed at giving the Department of Transport and Main Roads (TMR) a better understanding of performance and behaviour of thin asphalt surfacing on an unbound granular pavement (TAS-UB).

Two main project tasks conducted this year include:

- A literature review of design practices of TAS-UB domestically and internationally with the aim to identify the latest approach that can be adopted by TMR. A preliminary boundary condition was developed as a basis to review TMR practice.
- Selection of the performing TAS-UB sections utilising TMR's ARMIS and Chartview data. Four sections of performing TAS-UB pavement within the greater Brisbane region and two more from Logan City Council (LoCC) were selected and inspected.

It is expected that the outcome of Year 1 tasks will provide background for the team to determine the direction of the project from Year 2 onwards.

From the literature review, selection and field investigation, the following tasks are recommended for the project to be carried out from Year 2 onwards:

- Expand the selected sections further to include performing and non-performing sections, variety of asphalt mix types and those located in different climatic zones.
- In addition, the project team would like to include relatively new TAS-UB pavement sections. Those which have been completed in the last, say three years. These sections should have more accessible and complete design and material test information available that are useful to the project.
- Provide TMR with an understanding of the current use of TAS-UB pavements on their network by providing a state-wide view of where they are located utilising the ARMIS data. This should include a review of:
  - The relevancy of the current limit to use TAS-UB between 100 – 1000 daily ESA (in year of opening) against the actual performing sections to see if this range is adequate or adjustment is needed.
  - Likelihood of getting good quality granular material for the identified area.
  - Maintenance cost where cracking exists. This may be treated as a building block to a separate project to investigate the life-cycle cost of TAS.
  - Potential adoption of deflection and curvature limit when considering TAS application by various traffic band.
- Establish limited number of sections for further geotechnical testing by coring to confirm the make-up material and the back-calculated unbound layer strength. The number of selected sites is dependent on the available project fund.
- Follow up on the condition monitoring of the 17 previously monitored sites by TMR focusing on relatively successful use of SMA mix.

- To supplement the full-scale testing with APT, the project should consider including validation with finite element (FE) analysis following the methods adopted in WA study. As it involves determining the unbound material moduli from lab testing to be used later in FE analysis, the project team and TMR should consider the above and plan the lab test to accommodate.
- Continue to get the LGA involvement – the team have been working with Logan City Council and now looking to get involvement from Brisbane City Council (BCC). BCC has been contacted and shared some anecdotal comments on the use of TAS-UB in the last 20 years.

The ultimate practical objective of the project is to eventually update the current provision in the TMR's pavement design supplement for TAS-UB. A draft matrix of the guide was developed by TMR pavement engineers in June 2018 based on their anecdotal experiences. The draft matrix, included in Appendix B, was intended to be a starting point for a more rigorous investigation. The limits and boundary conditions used will be confirmed and investigated as part of this project.

This page is intentionally left blank

CONTENTS

TABLES

FIGURES

1 INTRODUCTION

1.1 Background

Unbound granular pavements with thin asphalt surfacing (TAS-UB) are an economical pavement type for low to moderately trafficked roads in urban environments, or rural environments where sprayed seal surfacing does not meet the serviceability requirement.

There is some anecdotal evidence that the fatigue life of TAS-UB is longer than predicted by the Austroads procedures. However, the actual life is unknown and has not been analysed.

Some designers are reluctant to select this economical pavement type because of the very low asphalt fatigue lives predicted using the current Austroads pavement design procedure. To meet the current Austroads asphalt fatigue requirement, this often requires designers to select pavement solutions with significantly thicker asphalt layers. On the other hand, the thin asphalt surfacing option is sometimes selected because the asphalt fatigue life is ignored in the design process.

1.2 Project Objective

The project will consider:

- actual performance of TAS-UB pavements and compare the field performance with the Austroads predictions
- measures to improve performance, such as the need to select appropriate material properties for the asphalt surfacing and the supporting granular base layers.

The aim of this project is to have a better understanding of the actual life of such pavements and provide guidance to designers which will lead to more appropriate selection of this pavement type.

The 2017-18 financial year is the first year of this project with two primary tasks. Firstly, conducting a literature review of practices in using TAS-UB pavement internationally and from other state and local road authorities within Australia. Secondly, identifying reliable in-service performance of sections with TAS-UB utilising the Department of Transport and Main Roads (TMR) ARMIS database and previous site investigation records.

To be able to meet the project objective, it will also be necessary to define the expected or acceptable minimum life of thin asphalt surfacings. For the initial analyses in this report, minimum acceptable lives of 12 years for dense graded asphalt and 15 years for stone mastic asphalt were adopted. However, these lives may be reviewed during this project.

1.3 Definitions and Scope

For the purpose of this study a thin asphalt surfacing (TAS) on unbound granular pavement is defined as:

- The application of asphalt layer with a total thickness of between 40 to 60 mm.
- With unbound granular base and/or sub-base. Application of TAS on the upside-down pavement is also considered during the literature review.
- The study is limited to the design of thin asphalt on granular unbound material for greenfield application. The design for thin-overlay is out of scope.

1.4 Structure of the Report

Following this section, the report is structured as:

Section 2 – is the literature review of practices for designing TAS-UB pavement from within Australia and internationally. Some studies on the areas related to gaining more accurate prediction of the responses of the granular material is also included.

Section 3 – provides the summary of the in-service performance investigation done under this project and previously undertaken by TMR. Under this project, four performing sites were selected based on the performance data from ARMIS. TMR have previously conducted a similar exercise on 17 sites.

Section 4 – highlights the key lessons from the literature review and the in-service performance investigation which can help define the scope of next year of the project. The section includes recommendations of the follow up tasks to be undertaken in year 2 of the project.

The report also includes the following appendices:

- Appendix A, Field inspection record.
- Appendix B, Example format of the guide to TAS-UB composition.

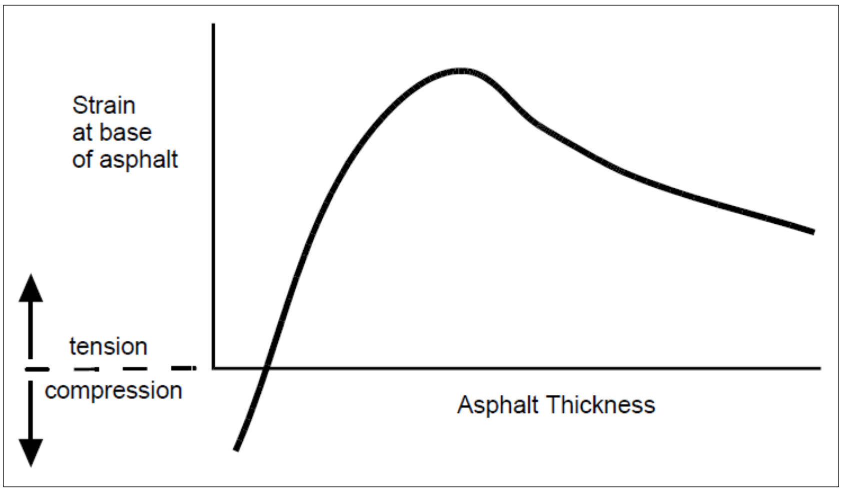
2 LITERATURE REVIEW

This section scans the design method adopted by various road authorities in Australia and overseas regarding TAS-UB application and design. A review of other the relevant studies is also included to provide summary by key research areas to help determine the next steps of the project.

2.1 Austroads

Figure 2.1 as extracted from the Austroads Pavement Design guide, AGPT02 (Austroads 2017), illustrates the relationship between the increase in asphalt layer thicknesses and the horizontal strain at the bottom of the asphalt layer.

Figure 2.1: Asphalt thickness and Fatigue Life relationship



To design a pavement for fatigue means that a designer will have to ensure that the fatigue life corresponding to the calculated critical tensile strain at the bottom of the asphalt layer (bottom-up cracking) exceeds the design life. For a highway traffic loading, a peak occurs between 40mm to 80mm thick range. As the Austroads mechanistic procedure considers only horizontal tensile strain in the fatigue relationship (Equation 25, AGPT02-17), the uncertainty exists for thickness less than 40mm as it transitioned from tension to compression with decreasing thickness.

The above also means that below certain thickness cracking will instigate from the top of the asphalt layer because of the compression induced from the edge of the tyre. The model however, does not adequately represent the behaviour of thinner asphalt under tyre loading. Other assumptions that may impact the thin asphalt surfacing but not as much on thicker asphalt layer are; interface bond, the omission of horizontal loads due to breaking, turning or climbing, assumed moisture levels of the granular base, construction variability and the omission of environmental effects.

Designers are therefore cautioned when using the mechanistic-empirical procedure when designing granular pavement having asphalt surface less than 40 mm thick. As an alternative, two empirical design charts are provided for either bituminous seal or asphalt with thickness of less than 40 mm. One for lightly-trafficked granular pavement for design traffic (DESA) range from 10^3 to 10^5 reproduced in Figure 2.3, the other for a moderate DESA range of between 10^5 to 10^8 in Figure 2.2.

Figure 2.2: Reproduction of AGPT-02 Figure 8.4

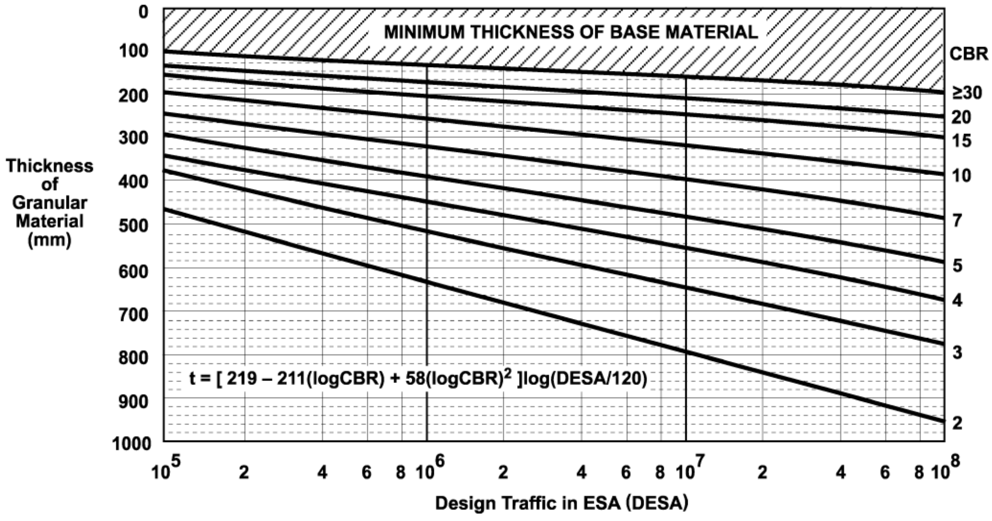
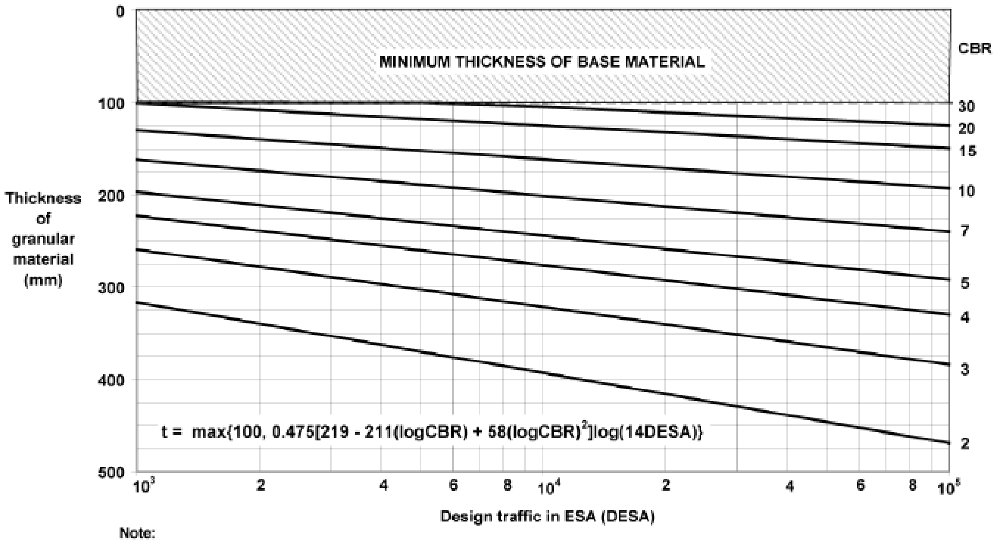


Figure 8.4: Design chart for granular pavements with thin bituminous surfacing

Figure 2.3: Reproduction of AGPT-02 Figure 12.2



Note:
1. Appropriate local conditions, environmental and drainage issues must be considered in using these design curves.
2. Thin asphalt surfacings may be included in total granular thickness. However, the minimum thickness of the granular base is 100 mm.

Figure 12.2: Example design chart for lightly-trafficked granular pavements with thin bituminous surfacings

The AGPT02 recommends the application of thin asphalt for low-level traffic roads where fatigue cracking is assumed to be uncommon and thus not considered.

To avoid premature fatigue cracking, the asphalt mix will need to be customised to be more flexible, more durable and less permeable than those carrying heavier traffic loading. It will also need to be modified to ensure compaction, which is harder to achieve during construction in colder months. The mix will need to have a higher binder content, use a modified aggregate grading from continuous to gap grading and use a softer binder. Other factors such as bonding between the asphalt and underlying layers will need to be ensured.

When designing a lightly-trafficked pavement (i.e. 10^3 to 10^5 ESA), the unbound base needs to be a higher quality material (with CBR 80% or better) to be located near the top 100mm of the pavement. The AGPT02 noted that a lower quality base material with CBR > 60% maybe used in lightly traffic roads in dry environments.

For a medium to heavy trafficked roads (10^5 to 10^8 ESA), the minimum thickness of granular base is a function of the design traffic as shown in Figure 2.2.

While Figure 2.2 includes pavement thicknesses for traffic loadings up to 1 x 10^8 ESA, a pavement comprising < 40 mm asphalt over unbound granular material would not commonly be used at such high traffic loadings due to performance concerns. For most TMR projects, a minimum of 50 mm dense graded or stone mastic asphalt would be used, which then leads to the need for an asphalt fatigue analysis according to AGPT02.

Some typical asphalt fatigue lives were calculated using AGPT02 procedures, assuming 50 mm asphalt over 1000 mm unbound granular material. This thickness of unbound material is much greater than would typically be used for unbound pavements but was adopted to maximise the calculated asphalt fatigue lives. Other inputs include a load speed of 50 km/h and WMAPT of 32 ˚C (for determination of asphalt moduli) and subgrade design CBR of 5% (results are relatively insensitive to this input due to the thickness of unbound material). A growth rate of 4% per annum was used to deduce the allowable ESA/day (at opening) to achieve a 12 year surface life for dense graded asphalt and 15 year surface life for stone mastic asphalt (that is, when the cumulative 12 or 15 year traffic equals the calculated fatigue life). The results are presented in Table 2.1.

Table 2.1: Typical theoretical fatigue lives

Surfacing option (all 50 mm)	Calculated fatigue life (MESA)	Acceptable fatigue life (years)	Allowable ESA per day (at opening) to achieve acceptable fatigue life
Dense graded asphalt with C320 bitumen	0.4	12	67
Dense graded asphalt with A15E binder	0.7	12	129
Stone mastic asphalt with A15E binder	2.1	15	287

The results will be used for future comparison with actual field performance data.

2.2 The Department of Transport and Main Roads

Compared to the AGPT02, the TMR pavement design supplement provides a more explicit selection guideline on when to use or not to use thin asphalt surfacing for practitioner in Queensland (TMR 2018).

TMR considers the suitability of thin asphalt application for urban environments given that the average daily ESA's in design lane in the year of opening is no more than 100. It may also be considered suitable for up to 1000 average daily ESA's in urban and rural environments provided the asphalt fatigue life is acceptable. However, as detailed in Section 2.1, a check of the fatigue life restricts the applicability of this pavement type, generally to loadings well below 1000 ESA per day.

When designing granular pavement with asphalt surfacings less than 40 mm thick, TMR refers to the two AGPT02 empirical charts to provide minimum granular base and minimum subgrade cover thicknesses. For completeness, the extract from TMR pavement design supplement is provided in Figure 2.4.

Figure 2.4: Reproduction of TMR TAS with unbound granular pavement configuration

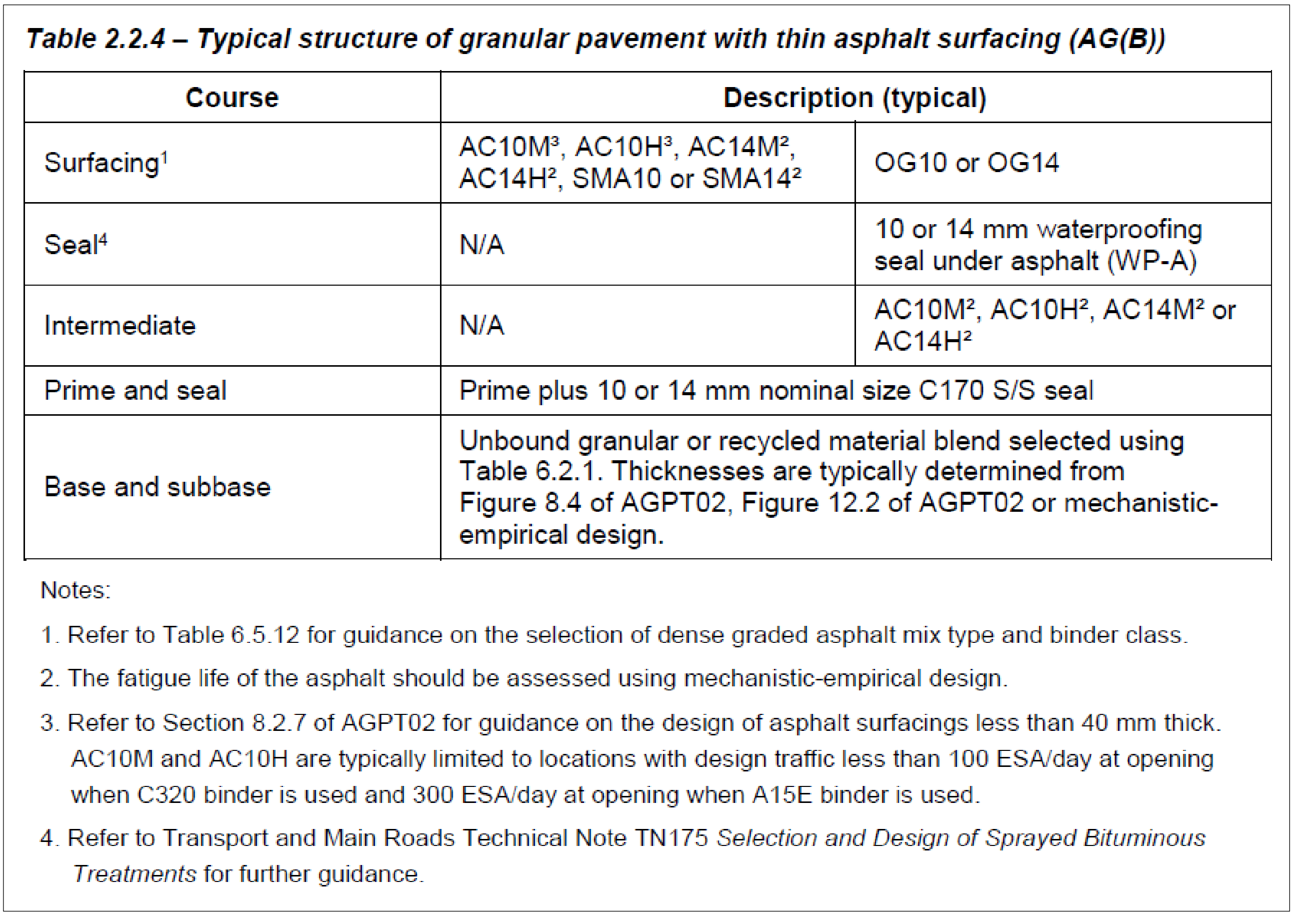


Table 2.2.4 – Typical structure of granular pavement with thin asphalt surfacing (AG(B))

Course	Description (typical)	
Surfacing[1]	AC10M[3], AC10H[3], AC14M[2], AC14H[2], SMA10 or SMA14[2]	OG10 or OG14
Seal[4]	N/A	10 or 14 mm waterproofing seal under asphalt (WP-A)
Intermediate	N/A	AC10M[2], AC10H[2], AC14M[2] or AC14H[2]
Prime and seal	Prime plus 10 or 14 mm nominal size C170 S/S seal	
Base and subbase	Unbound granular or recycled material blend selected using Table 6.2.1. Thicknesses are typically determined from Figure 8.4 of AGPT02, Figure 12.2 of AGPT02 or mechanistic-empirical design.	

Notes:

1. Refer to Table 6.5.12 for guidance on the selection of dense graded asphalt mix type and binder class.
2. The fatigue life of the asphalt should be assessed using mechanistic-empirical design.
3. Refer to Section 8.2.7 of AGPT02 for guidance on the design of asphalt surfacings less than 40 mm thick. AC10M and AC10H are typically limited to locations with design traffic less than 100 ESA/day at opening when C320 binder is used and 300 ESA/day at opening when A15E binder is used.
4. Refer to Transport and Main Roads Technical Note TN175 *Selection and Design of Sprayed Bituminous Treatments* for further guidance.

Bonding between asphalt and the granular base layer is ensured and specified as part of the typical pavement composition for thin asphalt surfacing on granular pavement.

The quality of the unbound material, compaction requirements, suggested binder selection are specified to tailor to Queensland’s needs.

For a TAS to perform adequately, it needs to have a sound base constructed with good quality unbound materials. A high standard granular material is specified for a base layer with high level of traffic expected in year of opening, in the area where high level of rainfall is expected recognising the potential impact of moisture on pavement and subgrade. A typical base material for thin asphalt surfacing in this case is material type 1.1, 2.1 or 2.2 and for sub base type 1.2, 2.3 or 2.4 (TMR 2017). Presumptive value of unbound granular modulus ranges from 300, 350 and 500 MPa. The highest 500 MPa is reserved for a project-specific TMR’s High Standard Granular (HSG) material.

Where a thin asphalt layer is specified, and the average daily ESA exceeds 100, a minimum compaction of 102 % (standard Proctor) in the unbound base course should be considered to minimise the potential of failure due to asphalt fatigue.

Other practices commonly adopted on TMR projects to reduce the risk of early asphalt fatigue include the use of lightly bound materials (to provide a higher level of support to the overlying asphalt) and use of asphalt incorporating SBS polymer modified binder.

2.3 Main Roads Western Australia

Main Roads Western Australian (MRWA) developed the Engineering Road Note 9 (ERN09) (MRWA 2013), as the supplement to Austroads AGPT02. For MRWA a thin asphalt is defined as surfacing of 60 mm or less.

The ERN09 is provisioned with both empirical and mechanistic design procedures for thin asphalt surfacing.

MRWA has experienced some success with the in-service performance of thin asphalt surfacing application on granular materials within the Perth Metro region. A series of known parameters to ensure the successful application have been incorporated in the supplement are listed below (with an asphalt fatigue design life of 5 years):

- traffic limit of 40-year design traffic of less than or equal to 3×10^7 ESA
- the pavement is well drained
- the subgrade is Perth sand
- the sub-base is crushed limestone
- the basecourse material is either rock base or bitumen stabilised limestone.

If all the above are satisfied, the asphalt fatigue life requirement for thin asphalt can be reduced from 15 to 5 years.

MRWA also specify 99% modified compaction, a maximum dry back moisture content of 70%, and include a curvature function requirement for crushed rock base below thin asphalt surfacing (MRWA 2017). A maximum 700 kPa FWD curvature of 0.13 mm is typically specified after placement of asphalt wearing courses for granular pavements in the project Scope of Work and Technical Criteria (SWTC), but this may be varied for different circumstances.

A recent study conducted by ARRB under the WARRIP program (Rice & Jameson 2018), reviewed the performance of several trial sites with a known thin asphalt configuration. The observed trial sites, mostly located on Perth’s major highways, have been performing satisfactorily without major rehabilitation or overlay, some for 20 to greater than 30 years, with traffic loadings of between 1.0×10^7 to 2.75×10^7 ESAs. The study concludes that refinement of the presumptive values assigned to the unbound granular and the subgrade is needed to reduce the amount of conservativeness in the ERN09.

The results of another study done for MRWA, which looked at validating the design assumption by laboratory testing and finite element modelling of one of the trial sites, demonstrates that in order to get a better match between the predicted and measured deflection, the sand subgrade modulus should be at around 150 MPa instead of currently being constrained by ERN09 at 120 MPa (Jameson et al. 2017).The same study also concludes that the predictions with linear elastic model could be improved by reflecting the high degree of support provided by the subbase, the crushed limestone layer, in the Austroads sub-layering method.

2.4 VicRoads

VicRoads provides the code of practice in selection and design of pavement as supplements to AGPT02 (VicRoads 2013). The code does not consider asphalt surfacings which are less than 40 mm thick to provide any structural contribution to the pavement. It specifies the use of thin asphalt of 30mm or 35mm in thickness for design traffic of less than 1×10^6 ESA and between $1\text{-}3 \times 10^6$ ESA respectively.

The pavement type selection and thickness of the unbound pavements materials follow that of the AGPT02.

To ensure that the expected life of TAS-UB pavement is achieved, VicRoads has also concentrated on a non-design aspect of preparing the granular pavements for surfacings

(VicRoads 2010). The focus is on achieving pavement dry-back. A dry-back is the state of allowing the pavement to dry prior to surfacings after water is used to achieve specified density during compaction. VicRoads (2016) require pavement dryback to achieve a value of less than 60% of OMC based on modified compactive effort, where no individual result may exceed 70%.

2.5 Roads and Maritime Services

The Roads and Maritime Services (RMS) Austroads guide supplement does not provide any specific advice on TAS-UB pavements other than where traffic levels exceed 10^6 ESA's, the pavement must be designed using the mechanistic design method as detailed in Austroads AGPT02 (RMS 2015).

However further detail is provided in Specification R123 (RMS 2009) which stipulates the requirements for thin open graded asphalt surfacings (TOGAS) typically 15 mm to 40 mm thick. The specification considers TOGAS as a surfacing with a much shorter design life than structural dense graded asphalt. Thus, the service life is expected to be 5 to 7 years and it is not considered a structural layer of the pavement nor is it intended to bridge areas of defective pavement. A high binder emulsion tack coat is required and typically will be applied at a rate of 0.5 to 1.0 L per m^2. Pavements with even surface texture and low deflections values are most likely to succeed with a TOGAS. Due to the rapid placement and compaction of a TOGAS, the specification also stipulates a placement trial of minimum length 300 m and one lane width.

2.6 Brisbane City Council

Brisbane City Council (BCC) developed their own empirical design chart for thin asphalt surfacings, less than 50 mm thick, on granular pavements (BCC web access). For pavement design BCC considered roads with estimated traffic over a 20-year period of no more than 10^6 ESA as lightly trafficked roads. This type of pavement configuration is preferable for BCC as it provides the lowest whole of life costs, enables easy installation and maintenance of utilities, provides acceptable ride quality and the best opportunity for rehabilitation in urban environments. The empirical design chart is reproduced below in Figure 2.5.

Figure 2.5: BCC Empirical Pavement Design Chart

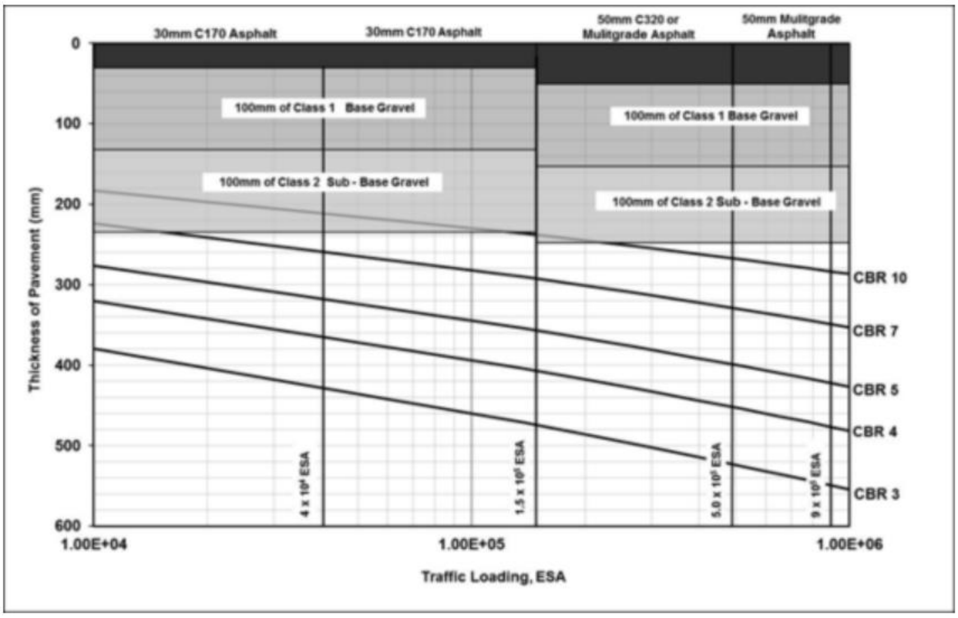


Figure 3.5.5.1.1a—Design chart for roads subject to light traffic

For a higher design traffic loading, a TAS is assumed to have significantly less fatigue life than the life of the other structural layers within the pavement. As a result, the surfacing will require more frequent overlay and thus is deemed unsuitable.

Asphalt thicknesses of either 30 mm or 50 mm are specified with a minimum thickness of granular of 200 mm. BCC specifies minimum design traffic for functional road class of 4.0 x 10^4 ESA for local cul-de-sac road, 1.5 x 10^5 ESA for local roads and 9.0 x 10^5 ESA for neighbourhood roads without bus services.

All granular pavements are required to be sealed with prime coat or prime seal prior to surfacing with asphalt.

The relevant Council personnel were contacted late in the year to get a confirmation on limit of the traffic band deemed as the upper limit for TAS-UB application. The upper limit was confirmed to be 1.0 x 10^6 ESA.

2.7 Logan City Council

Like BCC, Logan City Council (LoCC) also developed their own empirical design charts for roads with TAS in their design and construction manual (LoCC web access). Three charts are provided, one for roads with kerbing and DESA < 5 x 10^5, a second for roads without kerbing and DESA < 5 x 10^5 and another for roads with DESA > 5 x 10^5. The minimum total pavement thickness of 200 mm and 250mm for roads with cumulative ESA of less than 1.0 x 10^6 ESA and greater than 1.0 x 10^6 ESA respectively, is specified. The total thickness does not include the asphalt layer in the case of the TAS application. It should be noted that the charts were derived from the superseded Austroads guide (Austroads 1992).

The manual also provides more detailed pavement thickness requirements by road classification as shown in Figure 2.6, which can be of use to this project when assessing pavement configuration of the performing sites later discussed in Section 3.

Figure 2.6: Reproduction of LoCC Total Pavement Thickness Table

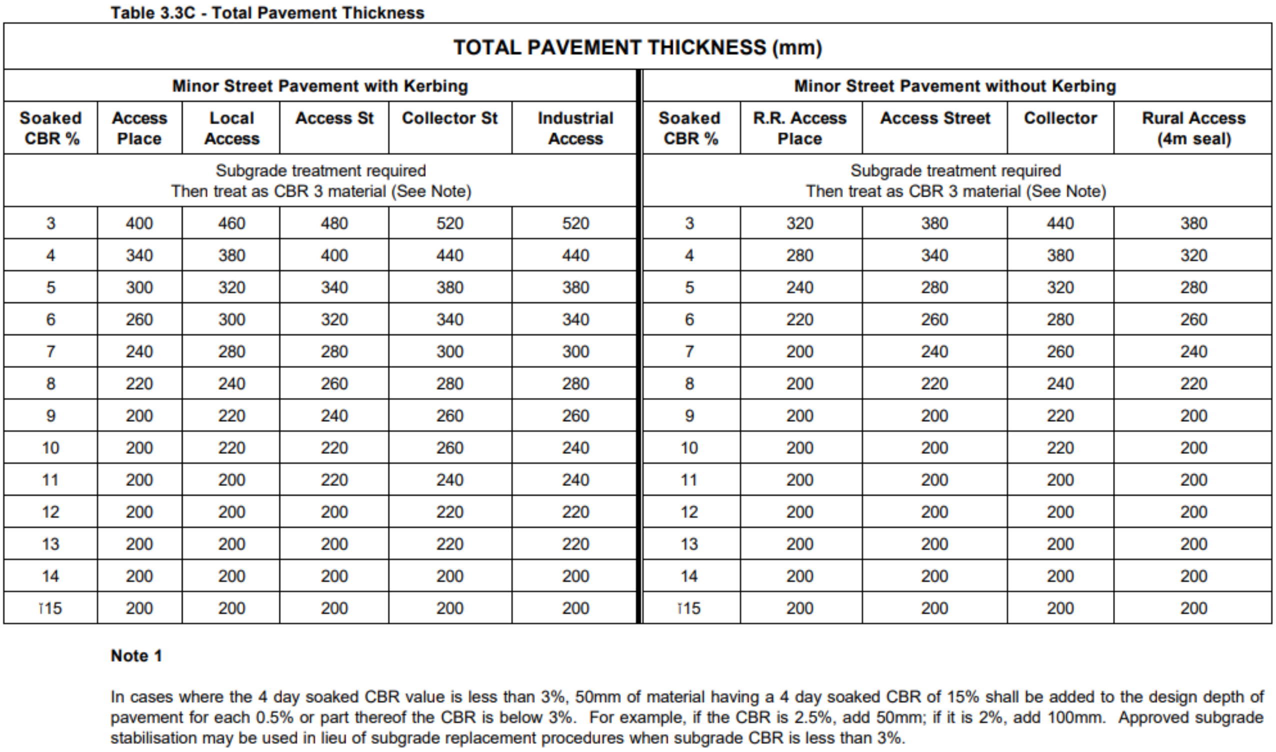


Table 3.3C - Total Pavement Thickness

TOTAL PAVEMENT THICKNESS (mm)

Minor Street Pavement with Kerbing						**Minor Street Pavement without Kerbing**				
Soaked CBR %	**Access Place**	**Local Access**	**Access St**	**Collector St**	**Industrial Access**	**Soaked CBR %**	**R.R. Access Place**	**Access Street**	**Collector**	**Rural Access (4m seal)**
Subgrade treatment required Then treat as CBR 3 material (See Note)						Subgrade treatment required Then treat as CBR 3 material (See Note)				
3	400	460	480	520	520	3	320	380	440	380
4	340	380	400	440	440	4	280	340	380	320
5	300	320	340	380	380	5	240	280	320	280
6	260	300	320	340	340	6	220	260	280	260
7	240	280	280	300	300	7	200	240	260	240
8	220	240	260	280	280	8	200	220	240	220
9	200	220	240	260	260	9	200	200	220	200
10	200	220	220	260	240	10	200	200	220	200
11	200	200	220	240	240	11	200	200	200	200
12	200	200	200	220	220	12	200	200	200	200
13	200	200	200	220	220	13	200	200	200	200
14	200	200	200	200	200	14	200	200	200	200
Ĭ15	200	200	200	200	200	Ĭ15	200	200	200	200

Note 1

In cases where the 4 day soaked CBR value is less than 3%, 50mm of material having a 4 day soaked CBR of 15% shall be added to the design depth of pavement for each 0.5% or part thereof the CBR is below 3%. For example, if the CBR is 2.5%, add 50mm; if it is 2%, add 100mm. Approved subgrade stabilisation may be used in lieu of subgrade replacement procedures when subgrade CBR is less than 3%.

In addition to literature review, LoCC have been involved in the early stage of the project. The Council have provided the team with a list of potential TAS-UB within their jurisdiction. Their view on application of TAS was also shared with the project team including assisting with field investigation by providing two examples of TAS-UB.

From the discussion with LoCC pavement and asset managers, a thin asphalt surfacing is often adopted as the initial treatment for low order residential roads when traffic was relatively low. If need be, the Council will consider an overlay option should the traffic demand increase.

2.8 International Practices

2.8.1 South Africa

A thin asphalt layer is defined as those with less than 50 mm thickness in South Africa. At the time of writing, South Africa is in the process of updating their transfer functions for Hot Mix Asphalt fatigue. The current functions based on the South African Mechanistic-Empirical Design Method (SAMDM), which have been used since 1996, are acknowledged to be not reliable (SANRA 2013). The revised SAMDM will include the updated models for asphalt layers for both fatigue and permanent deformation.

Furthermore, thin asphalt layer is considered as a functional layer and not a structural layer.

Failure in asphalt layer is not considered as a terminal condition and the road can continue to serve the traffic requirements with the application of effective maintenance such as crack sealing.

The use of thin asphalt with inverted (upside-down) pavement is also prescribed in the manual. The inverted pavement is when the strength of the pavement does not decrease with increase in pavement depth. A typical composition of the pavement type comprises of thin surfacing, granular base and cement treated sub-base.

The South African guideline for thin layer hot mix asphalt wearing courses on residential streets (Sabita 2008) recommends asphalt mixes with a sandy skeleton for application on roads with low traffic volume. This is done to achieve workability, resistance to fatigue and durability.

2.8.2 Indonesia

Thin asphalt layers over granular pavements are the most common sealing practice on the Indonesian road network. For lightly trafficked roads, an empirical design method based on the Austroads design method was developed (DGH 2016). For roads with cumulative ESA for 20 years of less than 0.5 MESA, a 50 mm asphalt surfacing on two 150 mm crushed rock base layers is specified as the minimum pavement configuration.

The granular material was specified to be well graded and achieve a minimum modulus of 350 MPa.

2.8.3 Texas Department of Transport (US)

The Texas Department of Transportation (TxDOT) has four different grades of granular base material, each with a different application. In terms of selecting the correct base for a granular pavement, TxDOT considers factors including availability and cost, surface thickness, subgrade strength, traffic loading and lateral confinement. These factors are used to create a material selection matrix. Grade 1-2 is the principal base granular material to be used as a structural layer when considering a thin hot mix asphalt surfacing (< 75 mm) (TxDOT 2018).

TxDOT utilises the program Flexible Pavement Design System (FPS 21) to conduct flexible pavement designs. It is a mechanistic empirical program that uses a performance model based on the degradation of the serviceability index. The program has provision to design for 7 pavement design types including asphalt layers as thin as 25 mm on granular bases (TxDOT 2011).

2.8.4 New Zealand

Unbound pavements with chip seal or thin asphalt surfacing have been used extensively in New Zealand, generally with great success (NZTA 2017). It was recommended to be used on roads with 25-year DESA of less than 5×10^6.

When designing for TAS, the guide only provides stiffness limit criteria for OGPA and SMA moduli, which is no more than 500 MPa and 1250 MPa respectively. The guide also provides some example of good practice and adaptation of lessons learnt when using granular base material such as:

- learning from failures from other road projects and using different aggregate source or modified aggregates
- ensure the unbound base aggregate passes the Repeated Load Triaxial test
- increase and audit quality control
- sealing in summer
- reduce the degree of saturation of the basecourse to below 60% prior to sealing.

One important take away point that might be applicable to TAS-UB is the prevention of surface crack because of the rutting due to the initial compaction. The guide suggests delaying the application of the OGPA layer until after the phase of this initial rutting and instead use sprayed seal surfacing.

2.8.5 Europe

The use of TAS in Europe has been used extensively and has seen an increase in use as reported in the study completed by Danish Road Institute on behalf of ERA-NET Road, a consortium comprising national European road administrations (DRI 2011). The main reasons of the popularity are the cost effectiveness of the treatment and the lower noise level (compared to Dense Graded Asphalt or Stone Mastic Asphalt) which is ideal for application in residential areas. A major disadvantage of using the treatment was identified as construction sensitivity to climate especially in areas where construction during cold weather cannot be avoided.

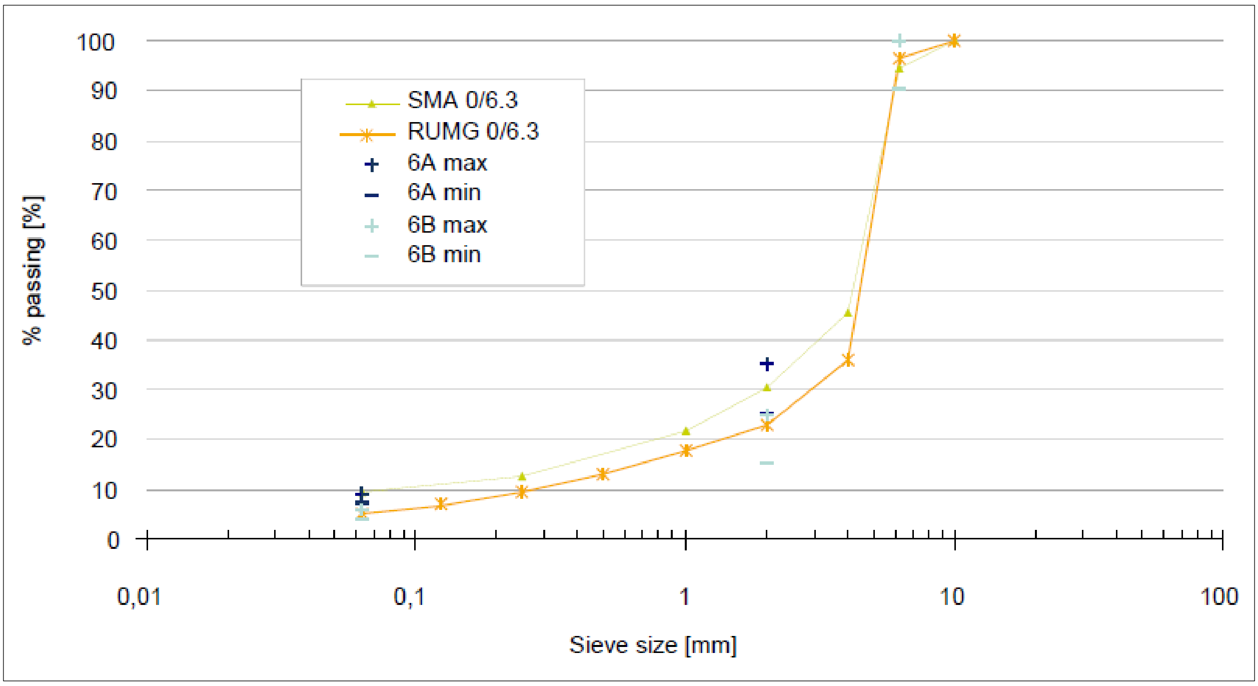
The scope was limited to reporting the performance of 10 – 30 mm thick asphalt surface layer using different hot mix asphalt design.

A more accurate life-cycle cost analysis to assess the economic benefit of using TAS over the conventional treatment was noted as the next step in the report.

The report provides guidance on where the application of TAS is appropriate and where it is not based on the observed practices within the participating countries. It also provides commentary on the design aspect that may impact durability or functional performance of the TAS.

Mix design of TAS used in Europe considers; the choice of aggregate, in particular those with high resistance to wear (abrasion from studded tyres), PMB as the binder of choice with asphalt rubber also presented as an alternative. It was noted that getting the grading right for TAS is critical. The mix is characterised by very high large-sized aggregate content and gap in the grading curve (stony skeleton). An example of grading limit from Belgium practice of mixes using SMA and RUMG (ultra-thin asphalt on granular) is provided in Figure 2.7.

Figure 2.7: Example of grading from two mixes from Belgian practice

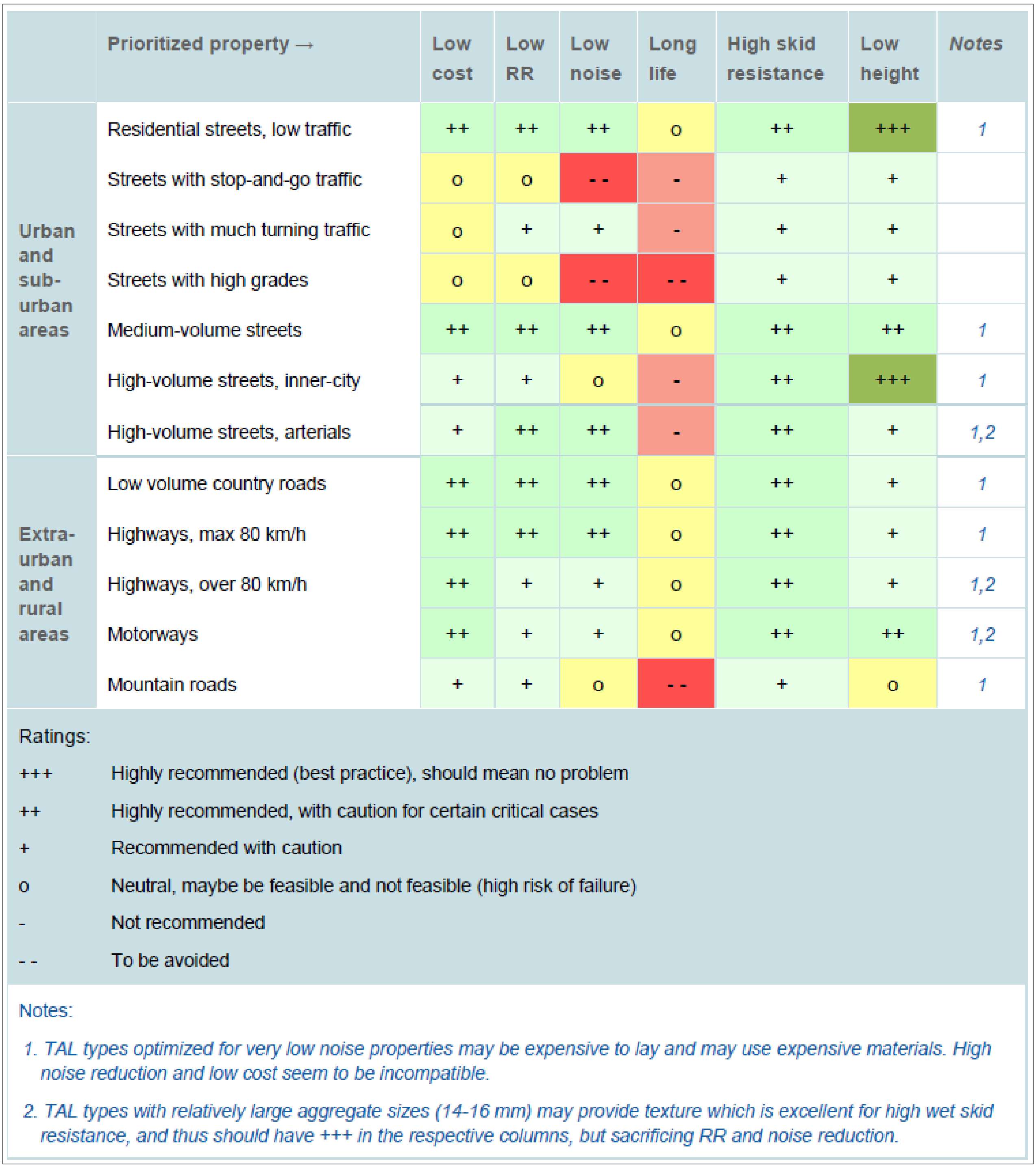


One of the important points made in the report relevant to this project is that it is often difficult to achieve both functionality and durability target. The asphalt surfacing designed for noise reduction for example is not always going to be durable. Some compromises are needed and the decision to adopt thin asphalt surfacing should focus on sustainability issues and economic consideration relating to the life-cycle cost.

The report produced a table of appropriateness of TAS application on different road type and class which can be of use to this project and is reproduced in Figure 2.8.

Similar to South Africa, the decision to adopt TAS in Europe is mostly based on maximising its functional and cost effectiveness benefits rather than durability. A wholistic approach of considering the treatment life cycle cost (LCC), to include maintenance cost consideration, is preferred with efforts being made on research to; provide more accurate LCC, fine tuning the asphalt mix design and improving constructability with warm-mix design among others.

Figure 2.8: Reproduction of TAS applicability for different road type and class



	Prioritized property →	Low cost	Low RR	Low noise	Long life	High skid resistance	Low height	*Notes*
Urban and sub-urban areas	Residential streets, low traffic	++	++	++	o	++	+++	*1*
	Streets with stop-and-go traffic	o	o	- -	-	+	+	
	Streets with much turning traffic	o	+	+	-	+	+	
	Streets with high grades	o	o	- -	- -	+	+	
	Medium-volume streets	++	++	++	o	++	++	*1*
	High-volume streets, inner-city	+	+	o	-	++	+++	*1*
	High-volume streets, arterials	+	++	++	-	++	+	*1,2*
Extra-urban and rural areas	Low volume country roads	++	++	++	o	++	+	*1*
	Highways, max 80 km/h	++	++	++	o	++	+	*1*
	Highways, over 80 km/h	++	+	+	o	++	+	*1,2*
	Motorways	++	+	+	o	++	++	*1,2*
	Mountain roads	+	+	o	- -	+	o	*1*

Ratings:

+++	Highly recommended (best practice), should mean no problem
++	Highly recommended, with caution for certain critical cases
+	Recommended with caution
o	Neutral, maybe be feasible and not feasible (high risk of failure)
-	Not recommended
- -	To be avoided

Notes:

1. *TAL types optimized for very low noise properties may be expensive to lay and may use expensive materials. High noise reduction and low cost seem to be incompatible.*
2. *TAL types with relatively large aggregate sizes (14-16 mm) may provide texture which is excellent for high wet skid resistance, and thus should have +++ in the respective columns, but sacrificing RR and noise reduction.*

France

Thin asphalt layers on unbound granular materials typically have a wearing course between 40 mm and 60 mm thick in accordance with the *French Design Manual for Pavement Structures* (LCPC 1997). These structures are commonly utilised for low traffic pavements (approx 1 x 10^6 ESAs) where the subgrade modulus is typically in the range of 20 – 50 MPa (LCPC 1997).

The required strength of the unbound granular basecourse layers falls into three categories and shall be at least 200 MPa (Category 3), 400 MPa (Category 2) and 600 MPa (Category 1) with design traffic volumes of approximately 2.5 x 10^5 ESAs, 4.0 x 10^5 ESAs and 1.0 x 10^6 ESAs, respectively (LCPC 1997). Additionally, the stiffness modulus of the asphalt layer used for TAS according to the *French Design Manual* is 5400 MPa at 15 °C and 10 Hz, determined using the two-point bending test in accordance with EN 12697-26.

Pavements consisting of TAS over a layer of unbound granular material subjected to design traffic volumes of less than 1.0 x 10^5 ESAs consider the wearing course a non-structural layer, and the thickness is selected using empirical design charts. TAS-UB pavements with a design traffic greater than 1.0 x 10^5 ESAs is determined using the French mechanistic design method to find failure due to fatigue at the base of the asphalt layers and the rutting of the subgrade (LCPC 1997).

It is important to note that the standard axle in French pavement design methodology is an axle of 130 kN whereas the Austroads methodology uses an axle 82 kN. As such, care must be taken when directly comparing design methodologies. Similarly, the Australian and French pavement design methods cannot be directly compared. Although they both utilise the mechanistic procedure, the amplitude of traffic loadings, shift factors, reliability factors and the fatigue properties are determined using separate methods.

2.9 Relevant Studies

This section highlights relevant studies done over the years in trying to get a better understanding of the thin asphalt surfacing pavement responses. The results of these studies are as important to the project as the methods employed. The latter helps in providing the clarity of the next step as the project continues into the second year.

2.9.1 Non-linear Model Granular Layer Modelling

One of the limitations of the current model used in pavement design is the linear elastic assumption in modelling the mechanistic responses of the granular layer. For TAS, having only granular material as the structural layer, getting a more accurate representation of granular layer responses can be equated to getting a more accurate prediction of the asphalt life.

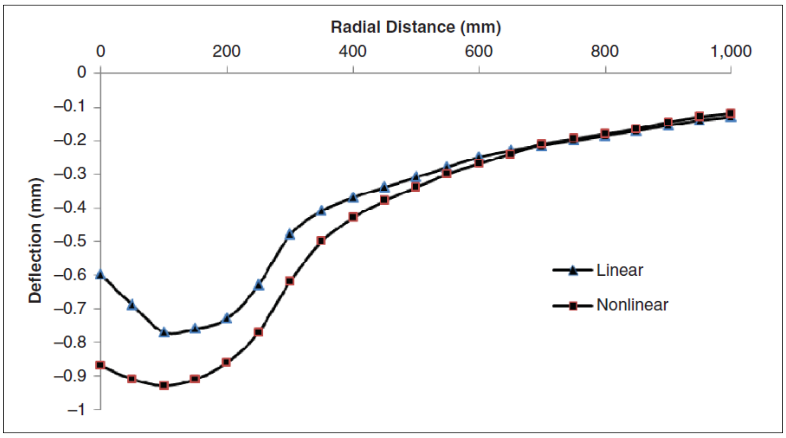
The linear elastic model is simpler to use. Software packages such as KENPAVE (Huang 2004) and CIRCLY are examples of computer packages commonly used in designing pavement with this approach. It provisioned for sub-layered design where the pavement system is divided into several horizontal layers (Vokas & Stoll 1985), each layer however is assumed to be homogeneous and linearly elastic.

A Finite Element (FE) packages are often referred to for non-linear method as they are capable of both methods. FE allows for simulation of the non-linear material as well as load combination.

Studies have been done over the years to point out the degree of refinement needed in design to capture a more accurate pavement response by comparing the linear and non-linear analysis results. These studies can be summarised by the way the two methods are compared such as:

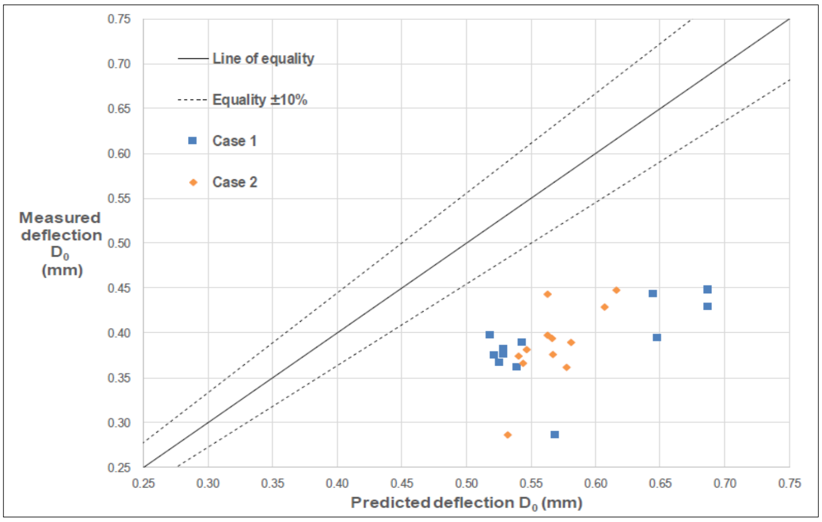
- Direct comparison of the results of linear with the non-linear FE analysis. The result varies in magnitude but in general agreed on a noticeable increased in surface deflection and vertical subgrade strain when analysing with the non-linear model. Some of the comparison results of surface deflection ranges from 10% to 15% (Kim 2001) to a more significant difference of 7% to 59% (Gupta et al 2015) as shown in Figure 2.9. In general, the linear analysis tends to underestimate the responses of the granular layer by predicting less surface deflection and vertical subgrade strain compared to the non-linear analysis.

Figure 2.9: Effect on non-linearity of granular layer on surface deflection



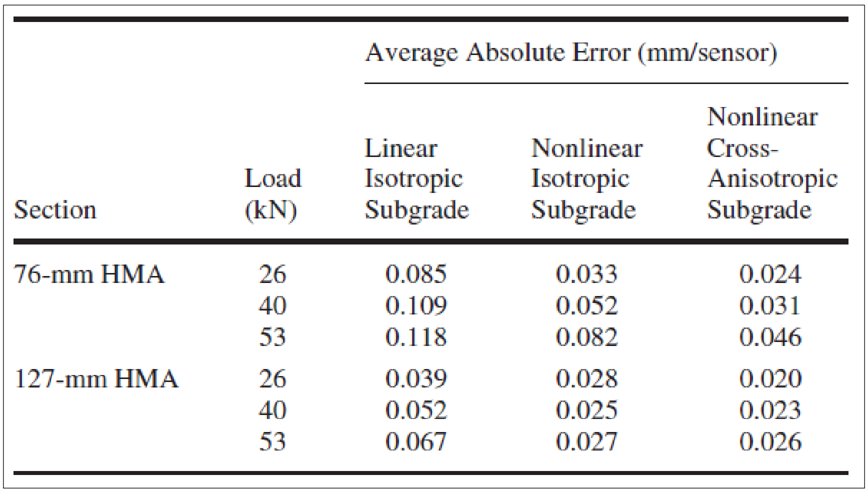
- Comparing the linear and non-linear analysis with the responses from instrumented track. The result shows that the non-linear model is in much better agreement with the measured responses compared to the linear analysis (Gonzales 2007).
- Comparing the linear and non-linear analysis with measured FWD deflection (Jameson 2017). This study explored the responses of several granular bases and sub-bases in known TAS-UB in Western Australia. The comparison shows that the non-linear analysis provides a closer prediction to the measured deflection and curvature. It also highlights that the linear analysis model provides some conservativeness in the current design. In other words, the predicted deflection from the linear analysis is at least 30% higher compared to the measured deflections as shown in Figure 2.10. This contradicts the previous findings because of the unusually high subgrade strength specific to those sites in Western Australia as noted in the report.

Figure 2.10: Comparison of predicted deflection (Austroads) with measured value (FWD)



- Comparing the measured FWD with FE analysis result that models; non-linearity in both base and subgrade layers and accounts for the anisotropic nature of the unbound layer where higher stiffness is expected in the vertical rather than the horizontal direction (Masad et al 2006). A study conducted in 2010 compared the result of FE modelling of non-linear isotropic subgrade and non-linear anisotropic subgrade as well as linear isotropic subgrade a shown in Figure 2.11. The non-linear anisotropic subgrade model provides the closest prediction to the measured deflections (Al-Qadi et al 2010).

Figure 2.11: Comparison of predicted deflection (FE) with measured value (FWD)



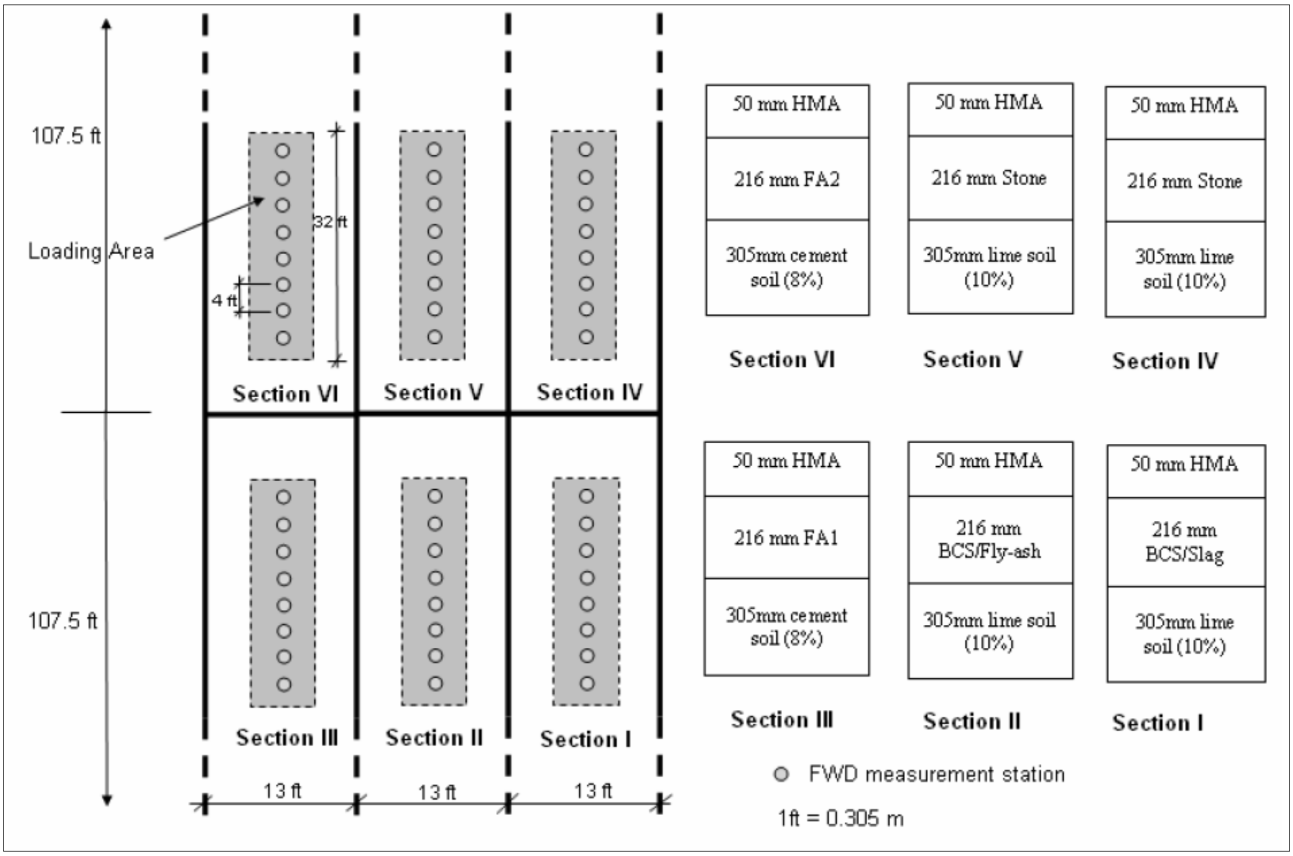
		Average Absolute Error (mm/sensor)		
Section	Load (kN)	Linear Isotropic Subgrade	Nonlinear Isotropic Subgrade	Nonlinear Cross-Anisotropic Subgrade
76-mm HMA	26	0.085	0.033	0.024
	40	0.109	0.052	0.031
	53	0.118	0.082	0.046
127-mm HMA	26	0.039	0.028	0.020
	40	0.052	0.025	0.023
	53	0.067	0.027	0.026

2.9.2 Accelerated Pavement Test - Full-scale Pavement Testing

A full-scale pavement test, employing the Accelerated Pavement Testing (APT) facility, involved construction of multiple pavement configurations in a longitudinal test bed. The test beds were subject to accelerated wheel loading whilst monitoring the response of the different layer through instrumentation.

An example of APT bed configuration for thin asphalt pavement where six different combination of bases and cement or lime treated sub-bases with 50mm TAS were tested is shown below in Figure 2.12 (Wu et. al. 2008).

Figure 2.12: Layout and type of thin asphalt pavement tested (Wu 2008)



The testing with an APT facility is often used as the ultimate validation method complemented by the FE methods. One of the more comprehensive studies of TAS behaviour was done by Erlingson and Ingason (2004) which employed most of the methods previously discussed above including:

- Conducting and comparing linear and non-linear analysis including FE model.
- Determining material properties of the layers either from back-calculation or from conducting repeated load triaxial test.
- Full-scale simulation with APT with embedded instrumentation to measure pavement responses.

The study compares the performance of two typical TAS pavement compositions, one with unbound base the other with cement stabilised base over an unbound sub-base. Both with the same total thickness of 200 mm. As expected, a longer pavement life was observed for the pavement with stabilised base. However, this study only considered rutting as a failure mode. It was noted that increased rutting on the pavement with only unbound base was attributed to lateral movement of material in the horizontal direction as the pavement was loaded. To minimise this Iceland has since moved away from specifying a single 200 mm unbound layer to two layers of unbound with coarser material at the bottom.

Like other studies, the non-linear analysis of the unbound layer gives a better agreement with the measured responses.

2.9.3 TAS with the Upside-down Pavement

A study to investigate the behaviour of TAS with the upside-down pavement configuration was conducted by Papadopoulus and Santamarina (2014) and included in this project as an alternative.

An upside-down pavement is a configuration where a good quality well-compacted unbound layer is constructed between TAS and a stabilised layer.

The study suggests that the use of this configuration, so long as the TAS is limited to 25 to 50 mm range, can benefit from low tensile stress at the bottom of the TAS layer hence increased the fatigue life.

2.9.4 Crack Initiation and Tyre Load

Mun et al. (2004), used FE analysis with the viscoelastic continuum damage model for asphalt layers and non-linear analysis model for the unbound layers to investigate the crack initiation of various pavement structures under different loading conditions. The study demonstrates that the non-uniform pressure distribution does in fact result in greater damage rather than the traditional uniform tire pressure assumption. It also confirms for TAS, the likelihood of top-down cracking increases as the thickness of the asphalt layer increases, the contact pressure is nonuniform, base and subgrade are not stiff and stiffness of the asphalt layer increases.

Further study which considers load nonuniformity as well as the shape of the contact surface was conducted by de Beer et al. (2018). The study investigated the use of rectangular contact shape on TAS compared to the traditional circular shape. It was found that the contact shape is more rectangular than circular, and that rectangular shape model produced a lower response compared to the circular ones.

2.9.5 Correlating Deflection to Pavement Life

Another approach in addition to the layered-elastic models is to predict the pavement remaining life through empirical equations based on deflection data for different sets of loads.

A number of studies in the area with different statistical approach started with Jung (1988) which developed a relationship to calculate the strain at the bottom of the asphalt layer as a result of load applied from FWD. The predicted strain is greater than those computed with the linear elastic model. The same finding was later corroborated by Bilodeau and Dore (2012).

3 INVESTIGATING THE IN-SERVICE PERFORMANCE

This section summarises the observations of the in-service performance of the thin asphalt surfacing on unbound granular (TAS-UB) pavement conducted over the years by TMR and under this project.

3.1 Selection of Performing TAS-UB Sections

The initial scope of the project is to provide an evidence-based case of TAS-UB sites with good performance on TMR’s network. Data from ARMIS, TMR’s data repository system, was used to conduct the initial screening. The pavement layer and historical condition data was obtained and filtered for asphalt layers less than 70 mm in thickness on top of granular base and subbase layers only. These sites were further filtered for sections greater than 500 m in length and by age. For selection, the performing sites are defined as sites which are at least 5 years old with little or no sign of cracking.

This year, the site selection was limited to roads within the Brisbane and Gold Coast regions to enable easy access for inspection. It is the intention of the project to expand the search to include sites from regions outside of greater Brisbane in year 2.

Data presented in ARMIS is generally accurate, however, not all data is entered into the database immediately and condition data can be two to three years old. As such, it was prudent to conduct a field inspection of the selected sites to confirm the actual site condition and if they comprised of thin asphalt layers.

3.2 Field Visual Inspection of Performing TAS-UB

The following summarises the result of the site inspection conducted jointly between ARRB and TMR. The sites visited are those which have been identified as TAS-UB sites with good performance.

A detailed condition information with photos and construction information is available in Appendix A.

Table 3.1: Visual Inspection summary

Site No.	Road Name	Road Number	Chainage (km)	Carriageway AADT (2015)	% HV	Asphalt Depth (mm)	Surfacing Age (Year)	Est. daily ESA at the year of opening	Cracking Condition (ARMIS)	Rutting Condition (ARMIS)	Inspection Notes
Site 1	Nerang – Broadbeach Road	105	7.97 – 8.70	21060	6	35	26 – 28	437	Fair (up to 25 %)	Good (< 6 mm)	Fair to good condition. Aged surface with longitudinal cracks along the construction joint. Some ravelling in the wheel-paths.
Site 2	Birkdale Road	1122	5.00 – 5.86	15842	4.7	35	14	420	Fair (up to 30 %)	Good (< 5 mm)	Good condition. Some patching works with isolated instances of alligator cracking and potholes. Possibly overlaid with another thin asphalt layer.
Site 3	Cleveland – Redland Bay Road	109	1.10 – 2.70	8786	N/A	30 – 40	12 – 13	215	Good (up to 10 %)	Good (< 5 mm)	Good condition. Some longitudinal/ meandering cracks present in wheel-paths – filled in with sealant. Isolated patching work. Wide shoulder for parking and intersects several residential streets.
Site 4	Cleveland – Redland Bay Road	109	7.40 – 10.90	25003 (CH 7.4 – 9.4) 13627 (CH 9.5 – 10.9)	3.9 % (7.4 – 9.4) 5.6 % (9.5 – 10.9)	45 – 60	5 – 6	795 (CH 7.4 – 9.4) 622 (CH 9.5 – 10.9)	Fair (up to 30 %)	Moderate (< 15 mm)	Good condition. Some longitudinal/ meandering cracks present in wheel-paths (sealed). Isolated patching work. Wide shoulder for parking and intersects several residential streets. Long section that intersects several residential streets and urban collectors.
Site 5	Plantain Road (LoCC)	-	-	-	-	30 – 50	-	-	Data not available	Data not available	Very good condition. Some longitudinal cracks in wheel-paths. Part of a bus route – Isolated crocodile cracking present at the bus stop. Wide shoulder for parking and intersects several residential streets.

Site No.	Road Name	Road Number	Chainage (km)	Carriageway AADT (2015)	% HV	Asphalt Depth (mm)	Surfacing Age (Year)	Est. daily ESA at the year of opening	Cracking Condition (ARMIS)	Rutting Condition (ARMIS)	Inspection Notes
Site 6	Beutel Street (LoCC)	-	-	-	-	30 – 50 mm	-	-	Data not available	Data not available	Fair to good condition. Rutting and longitudinal cracks (sealed) observed in the wheel-paths. Forms part of a bus route – Shoving observed at bus stop. Wide shoulder for parking and intersects several residential streets.

A total of seven sites were visited although only six of those appear to be thin asphalt surfacing pavement. One site, at Helensvale - Southport Road, was inspected from the vehicle however it was clear that the surface had recently been replaced or overlaid and thus excluded from the study.

3.3 Previous Investigations of Thin Asphalt Surfacing Roads by TMR

TMR conducted performance inspections on 17 sites of thin asphalt surfaced on granular pavements (TMR 2012). The purpose of the investigation was to visually inspect the pavement for structural inadequacies with a specific focus on fatigue cracking of the surface. The 17 sites investigated had traffic volumes between 3000 to 10000 vehicles/lane/day. Lanes with approximately 3000 vehicles/lane/day had heavy vehicle counts between 8.3 % and 23.5 %. Lanes with between 7000 and 10000 vehicles/lane/day had lower heavy vehicle counts between 5% and 9%.

Details of the site information and inspection results are summarised in Table 3.2.

Of the 17 sites, eight were constructed with dense graded asphalt, eight with stone mastic asphalt and one with open graded asphalt. The investigation generally found that the dense graded asphalts do not perform well on granular bases for the traffic loadings at these sites, with fatigue cracking and overall pavement failure present in all eight sites within four to five years of construction. The eight sites constructed with stone mastic asphalt performed significantly better than those with dense graded asphalt. Four of the eight sites are in good condition, three are in fair condition and one site is in poor condition.

To enable the translation of the observations to development of pavement selection guidelines, the traffic loadings and estimated ages at the time of fatigue cracking were normalised into the parameters of ‘MESA to fatigue cracking’ and ‘Allowable ESA/day (at opening) to achieve fatigue life of 12 years (dense graded) and 15 years (stone mastic)’ (assuming 4% per annum growth). Results are shown in Table 3.2. To estimate these parameters a number of assumptions needed to be made, in particular the actual age at the time of fatigue cracking was estimated from the inspection notes. While it is recognised that there is little precision in this process as it does not use a clear definition of fatigue failure (for example, after a certain area of fatigue cracking occurs), it does provide a general indication of the performance observed.

The results indicate that the fatigue life for dense graded asphalt was typically within the range of 0.6 to 2.4 MESA, with 5.8 MESA the highest achieved life. The lower tenth percentile life was 0.7 MESA which equates to 130 ESA/day at opening to achieve a 12 year surfacing life. This result is about 1.9 times greater than the typical theoretical fatigue lives given in Table 2.1 for dense graded asphalt with C320 bitumen.

For SMA, the life was 5.5 and 5.8 MESA for the two sections that had shown signs of fatigue. This equates to about 750 ESA/day at opening to achieve a 15 year surfacing life. This result is approximately 2.6 times greater than the typical theoretical fatigue lives in Table 2.1. It is also noted that some sections in Table 3.2 had lower traffic but had not exhibited fatigue at the time of the inspections.

The factors of 1.9 and 2.6 between the actual fatigue lives and theoretical fatigue lives are likely to be conservative estimates as the theoretical fatigue lives were calculated based on a conservative pavement structure (as detailed in Section 2.1).

Table 3.2: Summary of thin asphalt surfacing investigation undertaken by TMR

Site No.	Road Name	Road No.	Chainage	Carriageway AADT	% HV	Growth Rate %	Construction Date	Surfacing Age (year)	Est. daily ESA at the year of opening	Est. MESA to fatigue cracking*	Est. Allowable ESA/day (at opening) to achieve fatigue life of 12 years (dense graded) and 15 years (stone mastic)*	Inspection Notes
1a	Kawana Way	152	CH 0.15 - 4.48	14400	5.2	8.0	2004	7	509	0.8	191	DG14 45 mm to 70 mm – fatigue cracking after 4 years – investigated in 2008/9
1b	Kawana Way	152	CH 4.61 - 6.52	13900	5.8	4.0	2005	8	377	0.6	133	DG14 45 mm to 75 mm – visible fatigue cracking after 4 years
2	Maroochydore Road	136	CH 5.24 - 6.90 and 7.4 - 8.9 km	28000	5.7	4.0	2000	11	996	2.0	449	50 mm to 110 mm DG14 on granular base, fatigue cracking after 5 years. It now has extensive cracking throughout.
3	Caboolture Connection Road	9905	CH 2.94 - 8.20	21000	4.6	3.0	2001	10	603	0.9	210	90 mm to 130 mm DG14 on granular base, fatigue cracking after 4 years
4	D’Aguilar Highway	40A	CH 3.30 - 7.40	14000	15	14.0	2003	8	1,318	2.4	540	50 mm to 75 mm DG 14 on granular base, fatigue cracking after 4 years.
5	Cunningham Highway	17B	CH 20.20 - 23.063	5700	23.5	11.5	2004	7	841	< 3.0	< 417	50 mm SMA - Patches on patches. 2011 patch - 150 mm OK, flood rehab patches as well, generally failed.
6	Warrego Highway	18A	CH 24.36 - 27.781	25000	18.3	4.0	2001	10	2,877	< 12.6	< 1725	40 mm SMA14 surfacing, failed, poor condition, many patches, seal over failures

Site No.	Road Name	Road No.	Chainage	Carriageway AADT	% HV	Growth Rate %	Construction Date	Surfacing Age (year)	Est. daily ESA at the year of opening	Est. MESA to fatigue cracking*	Est. Allowable ESA/day (at opening) to achieve fatigue life of 12 years (dense graded) and 15 years (stone mastic)*	Inspection Notes
7	Mt Lindesay Highway	25A	CH 0.0 - 3.93	40000	9.0	4.0	2000/ 2005	6	2,260	5.5	749	40 mm SMA10 surfacing built 2000 + 2005 (no inspection), 2000 section extensive crocodile cracking in wheel paths, no treatments yet
8	Brisbane Valley Highway	42A	CH 5.20 - 7.30	9000	11.0	6.5	2006	5	630	1.3	299	Thin OG over granular base, asphalt surface, some ravelling, transverse cracking and flushing.
9	South Strathpine Road	900	CH 3.10 - 7.40	33000	5.0	2.7	1998	13	1,043	5.8	1332	DG14 35 mm - OWP asphalt fatigue failures.
10	Linkfield Road	902	Whole Length	24500	11	7.2	2006	5	1,671	< 3.5	< 482	2005/06 OG over SMA 50 mm over 150 mm modified granular base (Was asphalt replaced due to bitumen bleeding early in life?)
11	Port of Brisbane Road	904	CH 1.15	14600	19	4.0	2003	8	1,712	5.8	788	SMA14 50 mm - Some small patches otherwise appear OK.
12	Redland Bay Road	1102	CH 2.00 - 3.60	22000	5.8	2.7	2005	6	799	> 1.9	> 256	SMA14 surface mostly, SMA10 @ intersection @ 3.9 km, OK condition, testing required.
13	Mt Gravatt-Capalaba Road	U91	CH 8.03 km	15500	8.3	2.3	2004	7	802	< 2.2	< 501	DG14 40 mm - Pavement has failed, numerous cracks and patches, temporary seal not working.

Site No.	**Road Name**	**Road No.**	**Chainage**	**Carriageway AADT**	**% HV**	**Growth Rate %**	**Construction Date**	**Surfacing Age (year)**	**Est. daily ESA at the year of opening**	**Est. MESA to fatigue cracking***	**Est. Allowable ESA/day (at opening) to achieve fatigue life of 12 years (dense graded) and 15 years (stone mastic)***	**Inspection Notes**
14	Mt Gravatt-Capalaba Road	U91	CH 4.21 - 5.072	31000	7.5	1.1	2004	7	1,448	> 3.8	> 523	Some ruts less than 5 mm, surface is SMA 14 – Why it is performing well? Testing required.
15	Strathpine Road	U93	CH 0.5	35200	7.45	0.9	2001	10	1,644	> 6.2	> 855	Good condition – overlaid with 35 mm SMA in 2002.
16	Samford Road	U95	CH 5.35 - 6.893	23000	4.5	4.5	2006	5	658	> 1.3	> 180	40 mm SMA14 surface in 2006, good condition however flushed.

Notes: * Where < or > is indicated there was insufficient information to provide a reasonable estimate of the actual fatigue life. However, the values provide either an upper bound life (<) or lower bound life (>).

4 SUMMARY OF FINDINGS AND RECOMMENDATIONS

It is expected that the outcome of Year 1 will provide a better picture for the team to determine the direction of the project from Year 2 onwards. Two tasks were carried out in Year 1. The first, a literature review to scan for design methods available in Australia and internationally that can provide more clarity when designing for TAS-UB pavement. The second, selection of performing TAS sites within TMR's network. This section provides comments and recommendations relating to potential design methods for TMR and relevant methods of refining the design as observed from the above tasks.

The initial performance data analysed in Year 1 indicated that dense graded asphalt surfacing (with C320 bitumen) over unbound granular pavement would be suitable for roads with traffic up to about 130 ESA/day (at opening) to achieve a 12 year surfacing life. Similarly, the data indicated stone mastic asphalt surfacing would be suitable for roads with traffic up to about 750 ESA/day (at opening) to achieve a 15 year surfacing life.

Comparisons of the initial performance data with current design procedures found that the actual in-service fatigue life for dense graded asphalt surfacing over unbound granular pavements was conservatively estimated to be 1.9 times greater than the theoretical fatigue life for a typical pavement structure. Similarly, for stone mastic asphalt surfacing the in-service fatigue life was conservatively estimated to be 2.6 times greater than the theoretical base case.

Further sites are needed to provide greater confidence in the above findings.

4.1 Literature Review Summary

The definition of thin asphalt surfacing from almost all the road authorities reviewed is consistent with a single application of asphalt layer between 35 to 50 mm apart from the Texas Department of Transport where TAS is at least 75 mm.

In Australia, most of the design practices from the state road agencies and those from the local governments reviewed, provides a supplementary design manual to Austroads AGPT-02 when designing for TAS. It is done by providing designers with empirically derived design charts, notably based on the Austroads design chart for lightly-trafficked roads. The upper limit of these charts is sometimes more than that specified by Austroads but no more than 1.0 MESA in the case of that for Logan City Council. For a higher traffic demand, all state road authorities and council reviewed recommend the Austroads mechanistic design method.

Studies have been done over the years in the application of TAS on bound an unbound granular material with focus on addressing the inadequacy of the current multi-layer linear elastic model in representing the behaviour of the unbound layer. A more accurate representation was often demonstrated by utilising the non-linear FE model with or without validation by a full-scale pavement simulation. The project team also reviewed literature from other relevant studies such as the impact of tyre loading, using TAS-UB on upside-down pavement and statistical approach of predicting pavement remaining life through empirical equations based on deflection data.

From the above practices and studies, the following comments are made for consideration or application by TMR:

- In some countries (South Africa and parts of Europe), TAS is not designed for fatigue but only for rutting. Fatigue cracking is tolerable provided that a sufficient maintenance regime is in place. A study around the life cycle cost of TAS in Australia is required to check the viability of this option. This project can provide the initial step in that direction by identifying in-service TAS and include them in NACOE's long-term pavement performance (LTPP) project.

- For application in an urban area, Europe is more concerned about the safety and amenity than surface cracking. Thus, their research was focused more on optimising skid resistance and noise reduction properties in the asphalt mix.
- Only studies in WA provide a clear evidence of in-service performing section that outlast the estimated fatigue life. It validated the expectation that TAS on unbound pavement can work given a high subgrade strength of more than CBR 10.
- A good quality, stiff unbound pavement is important to ensure adequate support the TAS. Ensuring adequate compaction have been addressed by TMR. An anecdotal comment from a study in Iceland suggests that a better unbound performance can be achieved by splitting the layer into two different grading, with a coarser grading as a sub-base. More investigation is needed in this area before potentially including it as one of the test configurations when setting up an APT test bed in a later stage of the project.
- An initial boundary condition of when a TAS on unbound pavement can be used has been established based on the practices reviewed as summarised in Table 4.1.

Table 4.1: Summary of TAS on unbound pavement practices

Institution/ Country	TAS Thickness	Design for Fatigue for TAS	Design Fatigue Life for TAS	Asphalt Mixes	Upper Level Traffic Loading (DESA)	Unbound selection criteria	Unbound Quality
Austroads	< 40 mm	Empirical Design Charts (< 40 mm) & Mechanistic-Empirical Design (Austroads ME) (≥ 40 mm)	20 years typical	DG, SMA	Not specified	Traffic loading, climate	
TMR	< 40 mm	Empirical Design Charts (< 40 mm) and Austroads ME (≥ 40 mm)	10 years typical	DG with SMA and OG also considered	Not specified	ESA at year of opening	Type 1.1, 2.1
BCC	30 – 50 mm	Empirical Design Charts	20 years typical	DG	10^6	Traffic loading	Min 200 mm (100mm Class 1 and 100mm Class 2)
LCC	30 – 50 mm	Empirical Design Charts	20 years typical		10^5	Traffic loading	
MRWA	< 60 mm	Empirical Design Charts (< 40 mm) and Austroads ME (≥ 40 mm)	15 years (5 years with exception)		3×10^7	Traffic loading, subgrade	Crushed rock over crushed limestone over Perth sand
VicRoads	30 mm	Empirical Design Charts	20 years	DG-PMB	10^6	Traffic loading	Class 1
	35 mm	Empirical Design Charts	20 years	SMA	3×10^6	Traffic loading	Class 1

Institution/ Country	TAS Thickness	Design for Fatigue for TAS	Design Fatigue Life for TAS	Asphalt Mixes	Upper Level Traffic Loading (DESA)	Unbound selection criteria	Unbound Quality
RMS	< 40 mm	Empirical Design Charts (< 40 mm) and Austroads ME (≥ 40 mm)	5 – 7	OGPA	Not specified	AGPT02	
South Africa	< 50 mm	Transfer function derived from ME design	20 years typical	Hot Mix Asphalt	Not specified	SANRA	Transfer function
New Zealand	< 50 mm	Mechanistic	25	OGPA, SMA	5 x 10^6	AGPT02	Class 1/2
Indonesia	< 50 mm	E	20	OGPA	5 x 10^5	-	Class 1
France	40 – 60 mm	Empirical Design Charts (< 1 x 10^5 ESAs) and Mechanistic Method	Varies	GGA, DGA	10^6	Traffic loading	Category 1-3
TxDOT (US)	< 75 mm	E & M	12	SMA, PFC		Traffic loading, surface thickness	Grade 1-2

4.2 Recommended Tasks

This section highlights the follow up action from Year 1 tasks of selecting of the performing TAS sections, the subsequent field investigation conducted and some recommended task to be undertaken by the project:

- Expand the selected sections further to include; performing and non-performing sections, variety of asphalt mix types and those located in different climatic zone.
- In addition, the project team would like to include a relatively new TAS on unbound pavement sections. Those which have been completed recently (e.g. in the last three years). These sections should have a more accessible and complete design and material test information that are useful to the project.
- Provide TMR with an understanding of the current use of TAS on unbound pavement on their network by providing a state-wide view of where they are located utilising the ARMIS data. This should include review of:
  - The relevancy of the current limit to use TAS between 100 – 1000 daily ESA against the actual performing sections.
  - Likelihood of getting good quality granular material for the identified area.
  - Maintenance cost where cracking exists (this may well be treated as a building block to a separate project to investigate the life-cycle cost of TAS).
  - Potential adoption of deflection and curvature limit when considering TAS application by various traffic band.
- Establish a limited number of sections for further geotechnical test by coring to confirm the make-up material and the back-calculated unbound layer strength. The number of selected sites is dependent on the available project funding.

- Follow up on the condition monitoring of the 17 previously monitored sites by TMR focusing on relatively successful use of SMA mix.
- To supplement the full-scale testing with APT, the project should consider including validation with FE analysis following the methods adopted in WA study. As it involves determining the unbound material moduli from lab testing to be used later in FE analysis, the project team and TMR should consider the above and plan the lab test to accommodate.
- Continue to get the LGA involvement – the team have been working with Logan City Council and now looking to get involvement from Brisbane City Council (BCC). BCC has been contacted and shared some anecdotal comments on the use of TAS in the last 20 years.

The above tasks will be refined as the project progresses and be delivered in the next two to three years. The ultimate practical objective of the project is to eventually update the current provision in the TMR's pavement design supplement for TAS. A draft matrix of the guide was provided to the project team in June 2018 as shown in Appendix B. The limits and boundary condition used will be confirmed and investigated as part of the project.

REFERENCES

Austroads 1992, Pavement Design: A Guide to the Structural Design of Road Pavements, Austroads, Sydney, NSW.

Al-Qadi et al, 2010 'Dynamic Analysis of Thin Asphalt Pavements by Using Cross-Anisotropic Stress Dependent Properties for Granular Layer', Transport Research Record: Journal of the Transportation Research Board, Volume 2154, pp. 156 – 163

Austroads 2012, Guide to pavement technology part 2: pavement structural design, AGPT02-12, Austroads, Sydney, NSW.

Austroads 2017, Guide to pavement technology part 2: pavement structural design, AGPT02-17, Austroads, Sydney, NSW.

Bilodeau, JO & Dore, G 2012, Estimation of tensile strains at the bottom of asphalt concrete layers under wheel loading. Canadian Journal of Civil Engineering, 39, 771–778.

Brisbane City Council n. d., *Chapter 3 Road Corridor Design*, webpage, Brisbane City Council, Brisbane, Queensland, viewed 10 October 2017, <http://eplan.brisbane.qld.gov.au/CP/Ch3RoadCorridorDesign>

Comite Europeen de Normalisation 2019, *Bituminous mixtures – test methods for hot mix asphalt – part 26: stiffness,* EN 12697-26, CEN, Brussels, Belgium.

Danish Road Institute 2011, Optimization of Thin Asphalt Layers – Report 190 - 2011, DRI, Copenhagen, Denmark.

Department of Transport and Main Roads 2012, Granular pavements with thin asphalt surfacings – performance inspections, by P. Wellauer, TMR, Brisbane, QLD.

Department of Transport and Main Roads 2013, Supplement to 'part 2: pavement structural design of the Austroads guide to pavement technology, TMR, Brisbane, QLD.

Department of Transport and Main Roads 2017, Technical Specification MRTS05 – Unbound Pavements, TMR, Brisbane, QLD.

Erlingsson, S & Ingason, T 2004. Performance of two thin pavement structures during accelerated pavement testing using a heavy vehicle simulator. In: Proceeding of the second international conference on accelerated pavement testing, 26–29 September 2004 Minneapolis, MN.

Gonzalez, A., M. F. Saleh, and A. Ali. Evaluating Nonlinear Elastic Models for Unbound Granular Materials in Accelerated Testing Facility. In Transportation Research Record: Journal of the Transportation Research Board, No. 1990, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 141–149

Gupta et al, 2015, 'Critical Pavement Response Analysis of Low-Volume Pavements Considering Non-Linear Behavior of Materials', Transport Research Record: Journal of the Transportation Research Board, Volume 2154, pp. 3 – 11

Huang, Y. H. 2004, Pavement Analysis and Design. Prentice Hall Publications, Englewood Cliffs, N.J.

Directorate General of Highway of Indonesia, Indonesian Pavement Engineering Manual, 2016. The Ministry of Public Works and Housing, DGH, Jakarta, Indonesia.

Jameson, G, Bodin, D, Tseng, E, Latter, L, 2017, Validation of proposed Austroads Finite Element Pavement Design Model: Analysis of Kwinana Freeway Trial Sections, Australian Road Research Board Contract Report, Perth, WA.

Jung, F., 1988. Direct calculation of maximum curvature and strain in asphalt concrete layers of pavements from load deflection basin measurements. Washington, DC: Transportation Research Board of the National Academies, Transportation Research Record: Journal of the Transportation Research Board, No. 1196 125–132.

Kim, Y. R. Assessing Pavement Layer Condition Using Deflection Data. NCHRP Research Results Digest 254, Transportation Research Board of the National Academies, Washington, D.C., 2001.

Logan City Council Web Access - http://www.logan.qld.gov.au/planning-and-building/planning-and-development/superseded-planning-schemes/beaudesert-planning-schemes/design-and-construction-manual

Main Roads Western Australia, 2013, Engineering Road Note 9: Procedure for the design of road pavements, MRWA, Perth, WA.

Main Roads Western Australia 2017, *Pavements,* Specification 501, MRWA, Perth, WA.

Main Roads Western Australia, 2018, Investigation of Tonkin Highway, Reid Highway & Kwinana Freeway Trial Sections, WARRIP 1611, 16/5005, MRWA, Perth, WA.

Mun, S., Guddati, M.N., and Kim, Y.R., 2004. Fatigue cracking mechanism in asphalt pavements with viscoelastic continuum damage finite-element program. Washington, DC: Transportation Research Board of the National Academies, Transportation Research Record: Journal of the Transportation Research Board, No. 1896 96–106. NCHRP 1-37 (2004)

New Zealand Transport Agency, 2012, Asphalt Surfacing Treatment Selection Guidelines, NZTA, Wellington, New Zealand.

New Zealand Transport Agency, 2017, New Zealand Guide to Pavement Structural Design, by M. Gribble, NZTA, Wellington, New Zealand.

Rice, Z & Jameson, G 2018, *Investigation of Tonkin highway, Reid highway & Kwinana freeway trial sections,* Report no. WARRIP 1611, 16/5005, Western Australian Road Research and Innovation Program (WARRIP), Perth, WA.

Roads and Maritime Services, 2009, Thin open graded asphalt surfacing, QA Specification R123, RMS, Sydney, NSW.

Roads and Maritime Services, 2015, Roads and maritime Austroads guide, Publication 11.050, RMS, Sydney, NSW.

Sabita Guideline (2008): “Guideline for thin layer hot mix asphalt wearing courses on residential streets”, Manual 27, May 2008, ISBN 978-1-874968-33-7, published by Sabita, Howard Place 7450, South-Africa.

South African National Roads Agency, 2013, Pavement engineering manual: chapter 10, pavement design, SANRA, Republic of South Africa.

South African National Roads Agency, 1996. South African Mechanistic-Empirical Design Method, SANRA, Republic of South Africa

Texas Department of Transportation, 2018, Pavement Manual, TxDOT, Austin, United States of America

Texas Department of Transportation, 2011, Flexible Pavement Design System FPS 21: User Manual, TxDOT, Austin, United States of America

Vokas, C. A., and R. D. Stoll. Reinforced Elastic Layered System. In Transportation Research Record 1153, TRB, National Research Council, Washington, D.C., 1985, pp. 1–7.

Vicroads, 2010, Best Practice for the Preparation of New Granular Pavements for Thin Bituminous Surfacing, Vicroads, Melbourne, Victoria.

Vicroads, 2013, Selection and Design of Pavements and Surfacings – RC 500.22, Vicroads, Melbourne, Victoria.

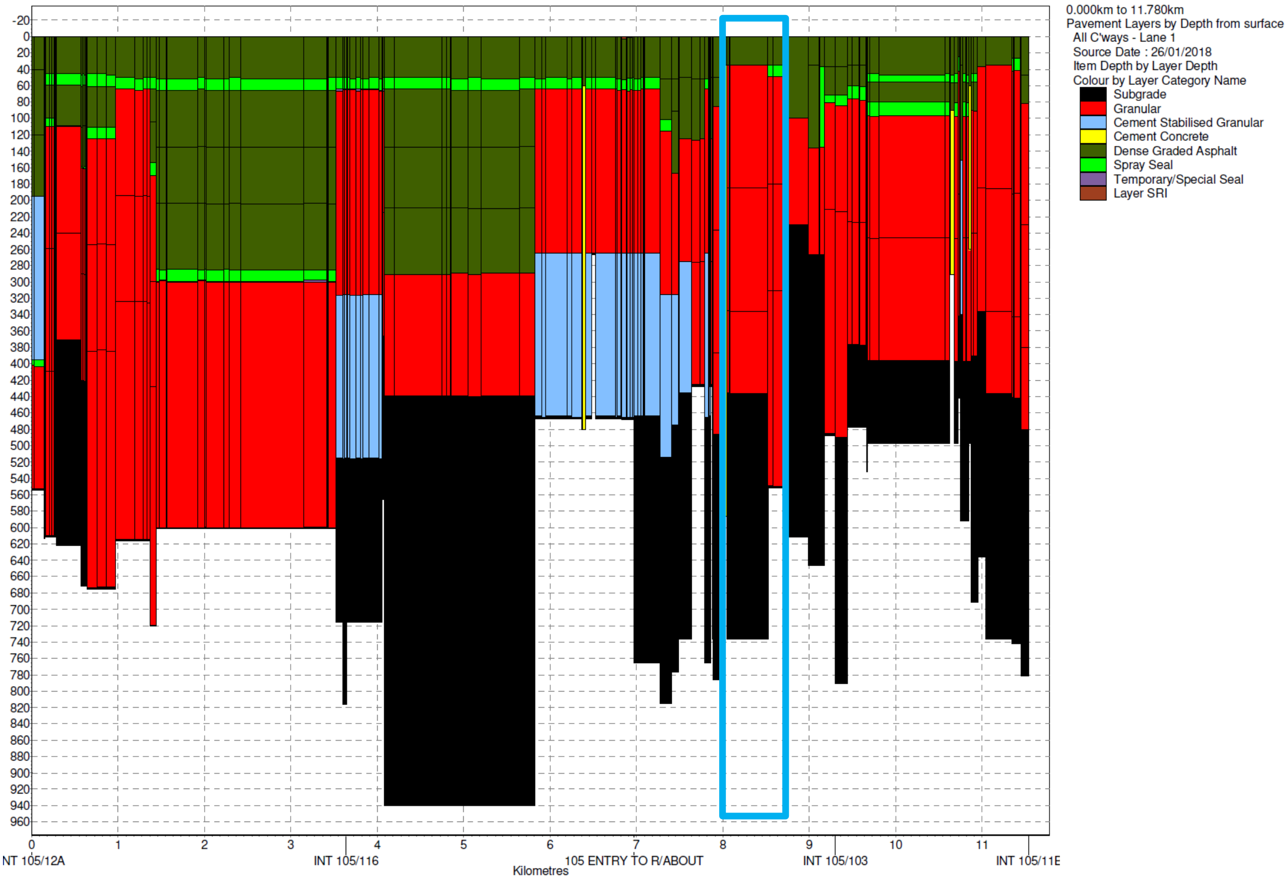
VicRoads 2016, *Preparation of granular pavements for bituminous surfacing,* Section 310, VicRoads, Melbourne, Vic.

APPENDIX A FIELD INSPECTION RECORD

A.1 TMR Roads

A.1.1 105 Nerang Broadbeach Road CH 7.97 – 8.7 km

Nerang Broadbeach Road was visually inspected and appeared to match the construction and condition data obtained from ARMIS. The relevant section is highlighted in blue square below in an extract from TMR's Chartview. The surface appeared aged and longitudinal cracks were observed along the construction joint. Some ravelling of the asphalt was present in wheel-paths. The road is a 6 lane, dual carriageway with kerb and channel drainage in place.

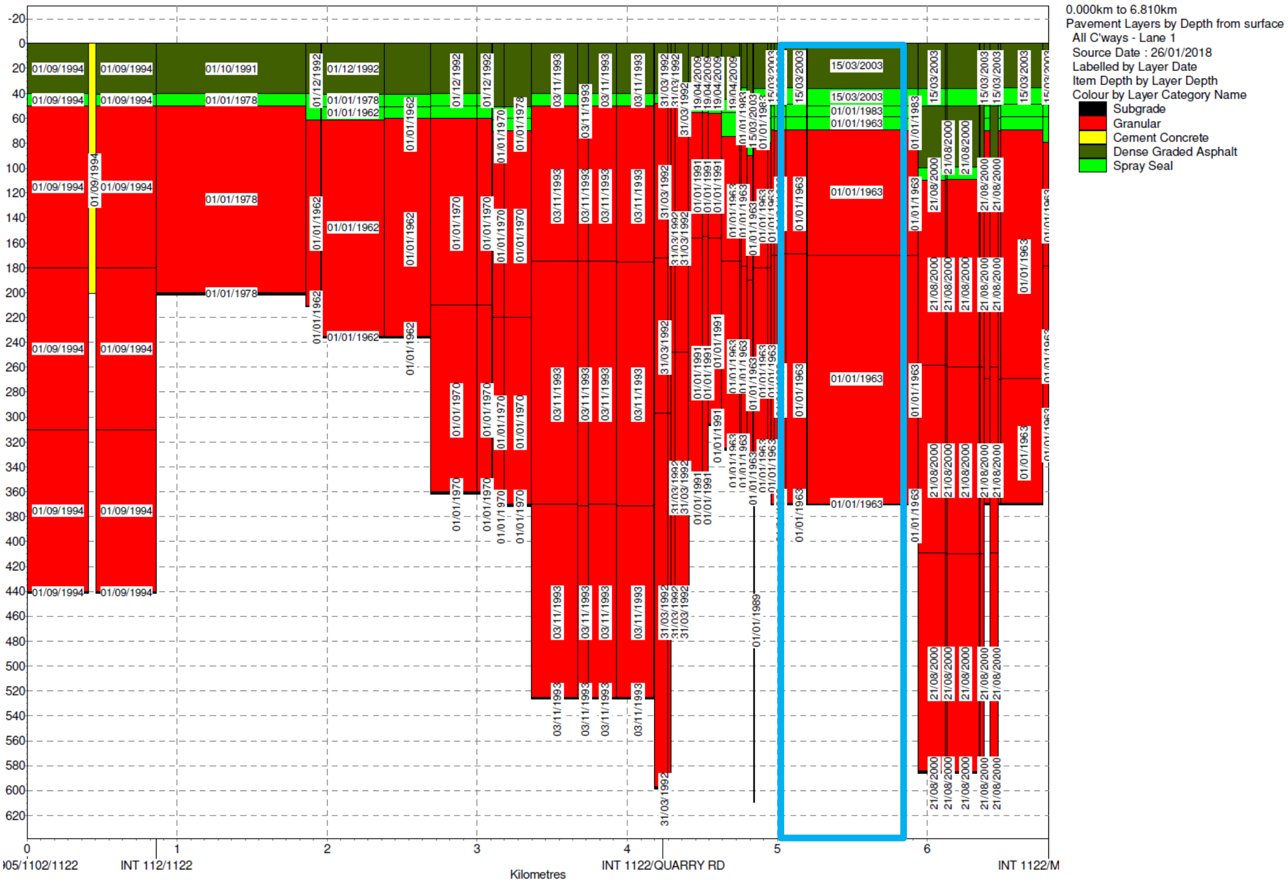


A.1.2 11A Helensvale - Southport Road CH 1.0 - 2.6 km and CH 4.0 – 5.6 km

11A Helensvale - Southport Road was inspected from the vehicle however it was clear that the surface had recently been replaced or overlaid as no ageing of the asphalt was present at all. As such, no other information was gathered.

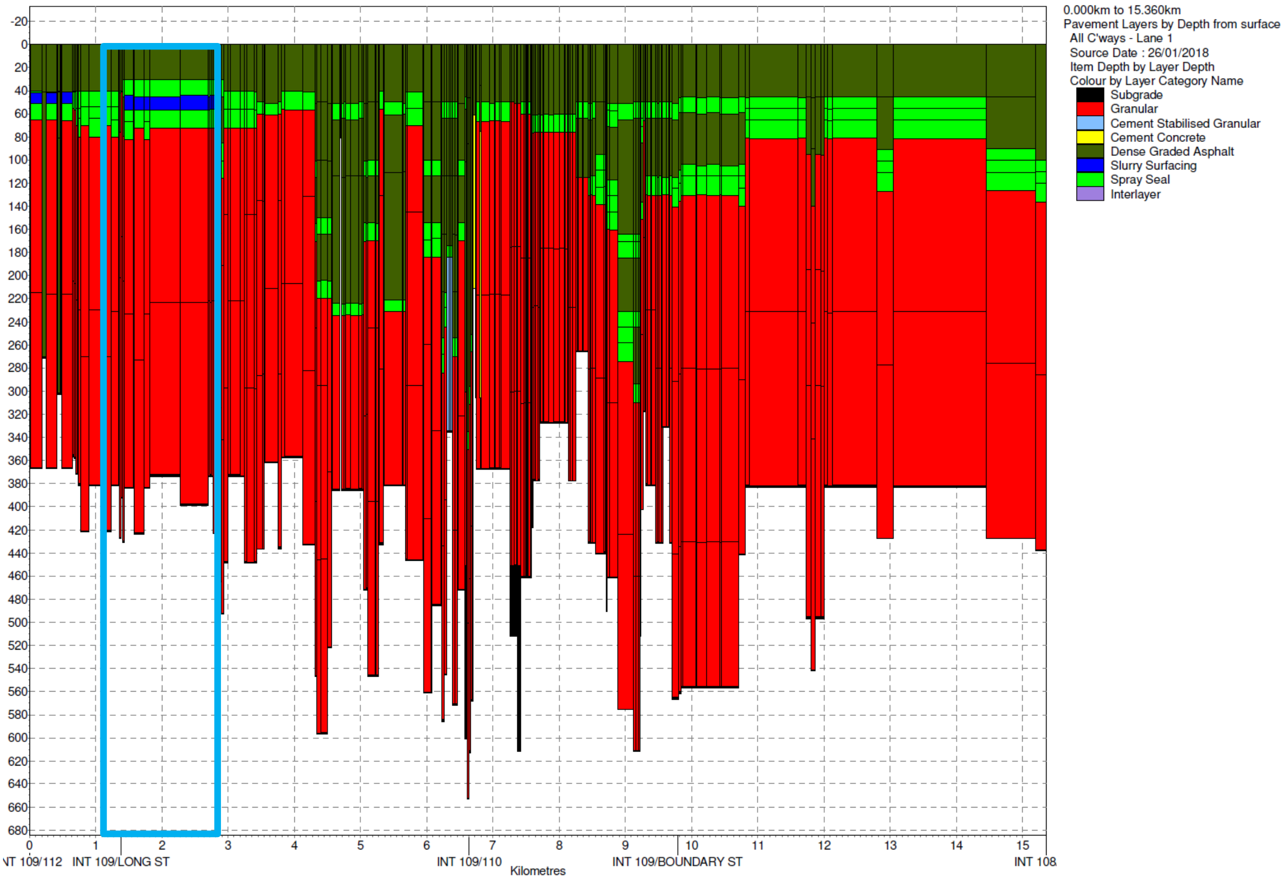
A.1.3 1122 Birkdale Road CH 5.0 – 5.86 km

Birkdale Road was typically found in good condition which matches the ARMIS data. Some patching works and isolated instances of alligator cracking and potholes were present. The section is a two-lane road separated by a median with kerb and channel drainage in place. A wide shoulder is in place for residential parking and a number of residential streets intersect the section. The asphalt surfacing was typically found in good condition with some ageing obvious, however it appears this section may have been overlaid with another thin asphalt layer, due to the construction join at the intersection with Makaha Drive.



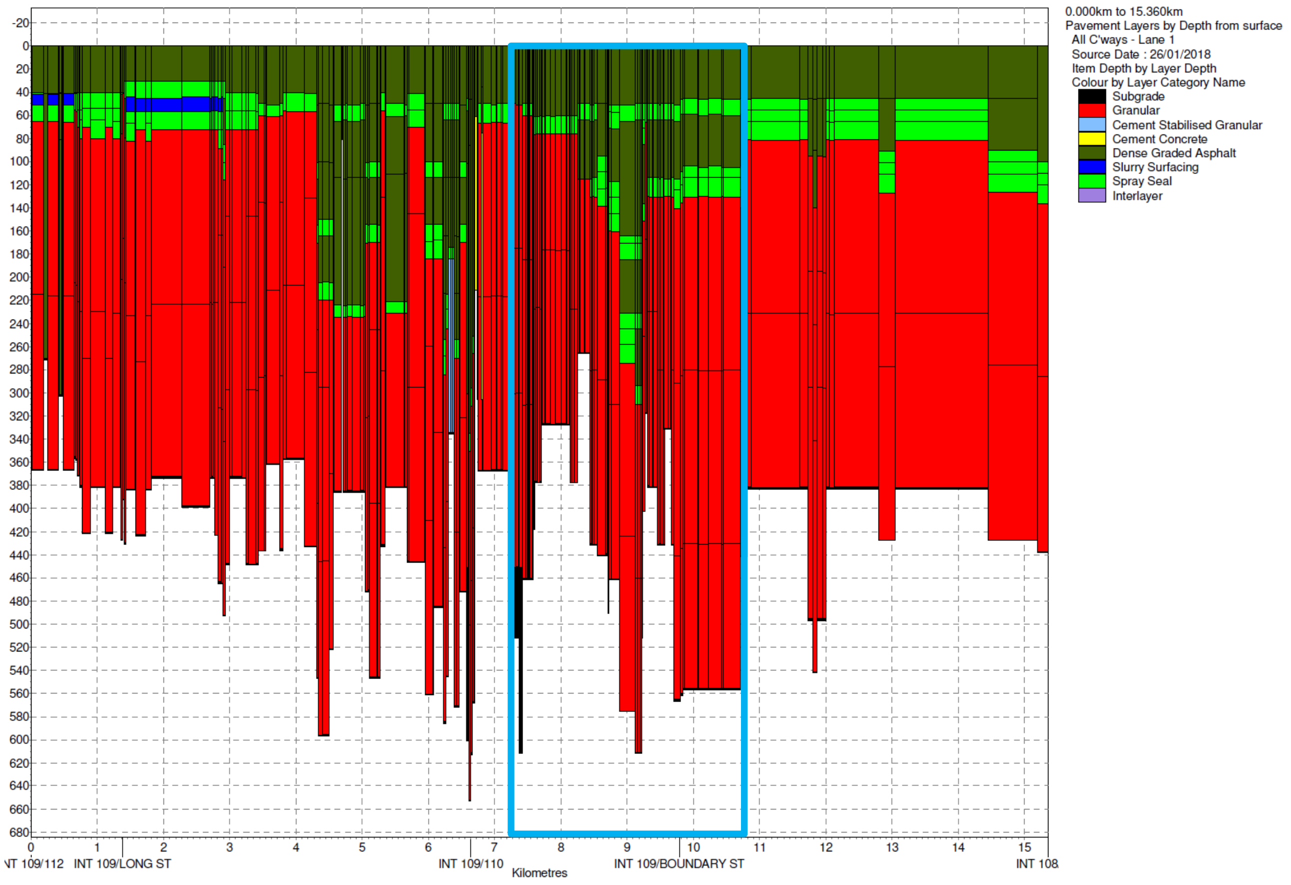
A.1.4 109 Cleveland – Redland Bay Road CH 1.1 – 2.7

This section of Cleveland – Redland Bay Road was typically found in good condition which matches the ARMIS data. Some longitudinal and meandering cracks were present in the wheel paths however these had been filled with sealant. There was also evidence of isolated minor patching works. The section is a four-lane road separated by a median with kerb and channel drainage in place. A wide shoulder is in place for residential parking and the section intersects several residential streets and a major intersection at South Street. Overall the asphalt appears in good condition and no evidence that suggests this is not a thin asphalt layer.



A.1.5 109 Cleveland – Redland Bay Road CH 7.4 – 10.9

This section of Cleveland – Redland Bay Road was typically found in good condition which confirms the ARMIS findings. Some longitudinal and meandering cracks were present in the wheel-paths however these had been filled with sealant. There was also evidence of isolated minor patching works. The section varies between a four-lane road separated by a median and two-lane-two-way road. Kerb and channel drainage is present along part of the length where-as others simply have table drains. As this section is 3.5 km long, it intersects several residential streets and major urban collector roads. Overall the asphalt appears in good condition and there is no evidence that suggests this is not a thin asphalt layer.



A.2 Logan City Council Local Road Inspection

Delegates from ARRB and TMR were invited to inspect two roads under Logan City Council's (LCC) management. Thin asphalt layers on granular pavements make up a majority of LCC's road network as they are easy to construct and maintain on low budgets and are appropriate for low traffic environments. No measured condition data is available for these sections.

A.2.1 Plantain Road

Plantain Road is a residential street that appeared in a good condition. This street forms part of a bus route and some longitudinal cracking was present in the outer wheel paths and isolated alligator cracking was present at the bus stop most likely due to acceleration and breaking movements of the bus. Kerb and channel drainage was present and a number of residential streets also intersected with Plantain Road.

A.2.2 Beutel Street

Beutel Street is a residential street that is in poorer condition than Plantain Road. There was evidence of rutting in the wheel paths as well as longitudinal cracks that had been sealed. Beutel Street forms part of a bus route and shoving was observed at the bus stop. Kerb and channel drainage was present. Several residential streets intersect with Beutel Street.

APPENDIX B EXAMPLE FORMAT OF THE GUIDE TO TAS-UB COMPOSITION

Table B 1: Draft guide to TAS-UB composition

ESA/day at opening	Base options	Surfacing options[1,2,3]
< 50	Type 2.1 Type 3.1	AC10M(C320) AC14M(C320) SMA10, SMA14 Crumb rubber gap graded[4]
50 to 100	Type 2.1* Type 3.1* *And, minimum compaction standard of 102.0%[5]	AC10M(C320) AC14M(C320) SMA10, SMA14 Crumb rubber gap graded[4]
100 to 300	Type 1 (HSG) Type 2.1* Type 3.1* Lightly bound base *And, minimum compaction standard of 102.0%[5]	AC10M(A15E), AC10H(A15E) AC14M(A15E), AC14H(A15E) SMA10, SMA14 Crumb rubber gap graded[4]
300 to 1000	Type 1 (HSG) Lightly bound base	AC10M(A15E), AC10H(A15E) AC14M(A15E), AC14H(A15E) SMA10, SMA14 Crumb rubber gap graded[4]
1000 to 3000	Lightly bound base	AC14M(A15E), AC14H(A15E) SMA14 Crumb rubber gap graded[4]
>3000	Pavement type not typically suitable	

Notes

1. An OG10 or OG14 surfacing can be placed above the dense graded asphalt options when required.
2. For high shear areas with 500 ESA/day or greater, the minimum thickness of asphalt (excluding open graded asphalt) is 100 mm.
3. Requirements for sealing the base and bonding the asphalt to the base are not part of this guide.
4. Option is only suitable if an impermeable gap graded asphalt mix is developed.
5. NACOE P69 project to consider whether any additional requirements are needed, such as additional dry-back requirement and/or maximum curvature requirement, particularly at higher traffic load categories.
6. Where the traffic exceeds 1000 ESA/day at opening, a project specific assessment should be undertaken to consider performance risks and maintenance expectations prior to selection of an asphalt surfaced granular pavement.